# Civil engineering applications of Ground Penetrating Radar: research activities in COST Action TU1208

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Ground Penetrating Radar (GPR) is a non-destructive imaging technique that can be effectively used for advanced inspection of composite structures and for diagnostics affecting the whole life-cycle of civil engineering works. GPR provides high-resolution images of the investigated structures through wide-band electromagnetic waves. It is possible to identify four main areas that have to be addressed in order to promote a wider use of this technology in civil engineering: a) design of innovative systems; b) development of data-processing algorithms and analysis tools, for the interpretation of experimental data; c) integration of GPR with other non-destructive methods; d) development of guidelines and training of end users. The COST Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" is running since 2013 and this paper will present its main activities and objectives, as well as the results achieved until now.

## 1. Introduction

Ground Penetrating Radar (GPR) is a safe, advanced, non-destructive and non-invasive sensing technique that can be successfully employed for sub-surface investigation, inspection of natural or manmade complex structures, and diagnostics affecting the whole life-cycle of civil engineering works [1-3]. In particular, it can be effectively used for the surveying of roads, bridges, tunnels, railways, dams, the detection of underground cavities, and the inspection of modern and historical buildings. It can also be used to map the buried utilities in a region, enabling rapid installation of a new plant with minimum disruption and damage to the existing one; gas, water, sewage, electricity, telephone, and cable utilities can be localised. Furthermore, with GPR it is possible to perform detailed inspection of reinforced concrete, to locate steel reinforcing bars and pre/post-tensioned stressing ducts. Quality control of pre-cast concrete structures, such as deck beams, can be carried out. Deterioration and delamination on bridge decks can be mapped; zones of termite attack or fungal decay in wooden bridge beams can be found. An analysis of geological structures can be made with GPR, for the mapping of soil, rock or fill layers, in geotechnical investigations and for foundation design.

GPR provides high-resolution images of the investigated structures through wide-band electromagnetic waves. Penetration and resolution depend primarily on the transmitting frequency of the equipment, the antenna characteristics, the electrical properties of the ground or surveyed material, and the contrasting electrical properties of the targets with respect to the surrounding medium. The centre frequency of GPR antennas typically ranges from 25 MHz to 4 GHz. Generally, there is a direct relationship between the chosen frequency and the resolution that can be obtained; conversely, there is an inverse relationship between frequency and penetration depth. High frequencies can therefore be used to detect small and shallow targets, whereas low frequencies allow the sensing of larger and deeper targets. GPR works best in dry ground environments, but can also give good results in wet, saturated materials; it does not work well in saline conditions, in high-conductivity media and through dense clays limiting the signal penetration.

Different approaches can be employed in the processing of collected GPR data, aiming at transforming radar data into user-usable images of the subsurface. The procedures depend on the site and equipment characteristics, how data were collected and the aims of the survey. The classical strategy usually includes band-pass filtering to remove unwanted high or low frequency noise, stacking to improve the signal-to-noise ratio, moving-average filtering to smooth out jitter between wave fronts, background-noise removal to remove clutter bands parallel to the air-soil interface, de-convolution filtering to remove multiple echoes or signal ringing, and the application of a migration algorithm to focus the diffractions from buried objects to their true positions. By means of gain adjustment algorithms, signal strengths in different regions are often balanced and corrections are applied for variations in surface topographic elevation.

Once data have been processed, they still have to be analysed. This is a challenging problem, since interpretation of GPR radargrams is typically non-intuitive and considerable expertise is needed. In the presence of a complex scenario, accurate electromagnetic-modelling software is a fundamental tool for the validation of data interpretation. It can be employed for the characterisation of scenarios, as a preliminary step that precedes a survey, or to gain 'a posteriori' a better understanding of measured data. Moreover, it can help to identify signatures generated by uncommon or composite targets. A forward electromagnetic solver can be used to perform repeated evaluations of the scattered field due to known targets, in combination with optimization techniques, in order to estimate – through comparison with measured data – the physics and geometry of the region investigated by the GPR.

It is possible to identify four main areas, in GPR field, that have to be addressed in order to promote the use of this technology in the civil engineering. These are: a) design of novel systems; b) development of electromagnetic modelling, imaging, inversion and data-processing tools for the interpretation of GPR results; c) integrate GPR with other non-destructive testing (NDT) methods; d) contribute to the development of new standards and guidelines and to training of end users, that will help to increase the awareness of operators.

In this framework, the COST (European COoperation in Science and Technology) Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar" is carrying out its activities. The main objective of the Action is to exchange and increase scientific-technical knowledge and experience of GPR techniques in civil engineering, whilst promoting a more effective use of this safe and non-destructive technique. The Action involves 27 COST Countries (Austria, Belgium, Croatia, Czech Republic, Denmark, Estonia, Finland, France, former Yugoslav Republic of Macedonia, Germany, Greece, Ireland, Latvia, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Switzerland, Turkey, United Kingdom), a COST Cooperating State (Israel), 3 COST Near Neighbour Countries (Armenia, Egypt, Ukraine), and 4 COST International Partner Countries (Australia, Hong Kong Special Administrative Region of the People's Republic of China, Rwanda, U.S.A.). University researchers, software developers, civil and electronic engineers, archaeologists, geophysics experts, non-destructive testing equipment designers and producers, end users from private companies and stakeholders from public agencies, are participating to the Action.

In Section 2, COST and the Action TU1208 are presented. The Action's ongoing activities are resumed, as well as the results achieved by now within the four Working Groups composing the scientific pattern of the Action. Information concerning the meetings, workshop and conferences organised by the Action is provided.

In Section 3 importance and interest of Armenian group to cooperate with European colleagues under COST 1208 Action umbrella is presented.

In Appendix, the list of Universities, research centres, private companies and public agencies currently participating to the COST Action TU1208 is reported.

## 2. COST and the Action TU1208 "Civil Engineering Applications of Ground Penetrating Radar"

COST is the longest-running European (EU) framework supporting cooperation among scientists and researchers across Europe; founded in 1971, it has been confirmed in Horizon 2020. It contributes to reducing the fragmentation in EU research investments, building the European Research Area (ERA) and opening it to cooperation worldwide. It also aims at constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe, and fostering the establishment of excellence in various key scientific domains. Gender balance, early-stage researchers and inclusiveness are strategic priorities of COST.

COST does not fund research itself, but provides support for activities carried out within Actions: these are bottom-up science and technology networks, centred around nationally funded research projects, with a four-year duration and a minimum participation of five COST Countries. The Actions are active through a range of networking tools, such as meetings, workshops, conferences, training schools, short-term scientific missions, and dissemination activities; they are open to researchers and experts from universities, public and private research institutions, non-governmental organisations, industry, and small and medium-sized enterprises.

COST Actions are funded within nine key science and technology fields: biomedicine and molecular biosciences; food and agriculture; forests, their products and services; materials, physics and nanosciences; chemistry and molecular sciences and technologies; earth system science and environmental management; information and communication technologies; transport and urban development; individuals, societies, cultures and health. In addition, Trans-Domain Actions deal with broad, multidisciplinary topics and Targeted Networks target specific policy strategies.

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

The COST Action TU1208 is running in the "Transport and Urban Development" COST domain; it was launched in April 2013 and will end in April 2017. The scientific structure of the Action includes four Working Groups (WGs). The WG1 focuses on the design of novel GPR instrumentation (more details are given in Subsection 2.1). The WG2 deals with the development of guidelines for the surveying of transport infrastructures and buildings, and for the sensing of underground utilities and voids (see Subsection 2.2). The WG3 studies electromagnetic forward and inverse methods for the solution of near-field scattering problems by buried structures and data-processing techniques (further information can be found in Subsection 2.3). The WG4 is concerned with applications of GPR outside from the civil-engineering field and integration of GPR with other NDT technologies (see Subsection 2.4).

Several events were organised by the Action, during the first 18 months of its lifetime. A kick-off meeting was held, to launch the activities (Brussels, Belgium, April 2013). The first general meeting was mainly devoted to address the state of the art, advancement, ongoing studies and open problems, in the topics of interest for the Action (Rome, Italy, July 2013) [4, 5]. A workshop on finite-difference time-domain (FDTD) modelling was held, along with WG 2 and 3 meetings (Nantes, France, February 2014) [6]. A second general meeting was organised jointly with the European Geosciences Union General Assembly, to present and discuss the results achieved during the first year of the Action (Vienna, Austria, April-May 2014) [7]. A Working Group Meeting focusing on the organisation of dissemination and training initiatives took place (Barcelona, Spain, May 2014). In June-July 2014, the Action co-organised with the Université Catholique de Louvain the 15$^{th}$ International Conference on Ground Penetrating Radar (GPR 2014), held in Brussels, Belgium [3].

The Action TU1208 is also active in offering Training Schools (TSs) [8] for PhD Students and early-stage researchers. A TS on "Microwave Imaging and Diagnostics: Theory, Techniques, Applications" was co-organised with the COST Action TD1301 "Development of a European-based Collaborative Network to Accelerate Technological, Clinical and Commercialisation Progress in the Area of Medical Microwave Imaging" and the European School of Antennas (Madonna di Campiglio, Italy, March 2014). A TS on "Future Radar Systems: Radar 2020" was co-organised with the European School of Antennas and the European Microwave Association (Karlsruhe, Germany, May 2014), it covered the state of the art and new trends on radar technologies. Finally, a Training School on "Civil Engineering Applications of GPR" was held in the University of Pisa (Pisa, Italy, September 2014), covering topics as GPR basics and history, how to conduct a survey, the main applications of GPR in civil engineering, design of GPR systems, radar interferometry, electromagnetic techniques for the modelling of GPR scenarios, imaging and inversion techniques for the interpretation of GPR data.

In Subsection 2.5, the next meetings and training activities are announced.

The COST Action TU1208 is constantly promoting its activities in prestigious international conferences related to the Ground Penetrating Radar [9]-[13].

It is still possible to join the Action TU1208, in order to contribute to its scientific activities and participate to its events; interested researchers and experts are welcome to take contact with the Authors of this paper. Information on the Action can be found at www.cost.eu/COST_Actions/tud/Actions/TU1208 and www.GPRadar.eu.

### 2.1. Novel GPR instrumentation

The **WG1 of the COST Action TU1208** focuses on the development of innovative GPR equipment dedicated for civil engineering applications. It includes three Projects. Project 1.1 deals with the "Design, realisation and optimisation of innovative GPR equipment for the monitoring of critical transport infrastructures and buildings, and for the sensing of underground utilities and voids." Project 1.2 is concerned with the "Development and definition of advanced testing, calibration and stability procedures and protocols, for GPR equipment." Project 1.3 focuses on the "Design, modelling and optimisation of GPR antennas."

During the first year of the Action, the Members coordinated between themselves to address the state of the art and open problems in the scientific fields identified by these Projects [4, 14]. In carrying out this review work, the WG1 benefited from the contribution of Dr. David J. Daniels, participating to the First

General Meeting as an external expert and giving a plenary talk on GPR design challenges; he also prepared for the Action a special paper that is included in [4], resuming the characteristics of GPR systems, with particular reference to the various modulation techniques, highlighting the issues related to the design of GPR antennas, suggesting what improvements in subsystems - such as antennas, receivers and transmitters - are needed to increase overall GPR performance, and giving ideas for further research and developments. The WG also benefited from the contribution of Dr. Erica Utsi, participating to the First General Meeting as an external expert and sharing with the Members her wide experience on GPR technology and methodology. The synergy with WG2 and WG4 was useful for a deep understanding of the problems, merits and limits of available GPR equipment, as well as to discuss how to quantify the reliability of GPR results.

An innovative reconfigurable ground-coupled stepped-frequency GPR is being studied and optimised by the Members; it was designed in Italy and is equipped with two bow-tie antennas with a series of switches along their arms, so that their size can be varied. The system was tested in several sites, both indoor and outdoor, in comparison with a commercial ground-coupled pulsed system [3, 4, 7]. Subsequently, within a Short-Term Scientific Mission (STSM), the prototype device was sent to Norway and compared with commercial ground-coupled stepped-frequency radar [15]. These experimental activities were fundamental to gain a deepen knowledge of the reconfigurable GPR prototype and to plan its improvement.

Another innovative system being designed within the Action and proposed by Italian Members, will allow investigating the mechanical properties of pavement, in addition to its geometrical and electromagnetic properties [3, 4].

Cooperation with the COST Action IC1102 "Versatile, Integrated, and Signal-aware Technologies for Antennas (VISTA)" has been established, concerning the design of GPR antennas.

At least two more WG1 activities need to be mentioned, as they are very interesting and promising. The first one, coordinated by Italy and involving Members and external experts from Germany, United Kingdom, Japan and United States, is the development of a protocol providing recommendations for the safety of people and instruments in near surface geophysical prospecting, with a particular focus to the use of GPR.

The second initiative is called GPR4Everyone, it was proposed by Italy and consists in creating a virtual store of GPR equipment at the disposal of Members from inclusiveness Countries: some Institutes have GPR systems and complementary NDT equipment no longer used, while there are Institutes who cannot afford to buy a GPR; thus, the idea is to cense the unused equipment and make it available to be given for free to researchers from less research-intensive countries, as a small step to counterbalance research communities' unequal access to funding and resources distribution.

### 2.2. GPR surveying of pavements, bridges, tunnels, and buildings; underground utility and void sensing

The **WG2 of the COST Action TU1208** deals with the development of guidelines and protocols for the surveying, through the use of a GPR system, of transport infrastructure and buildings, as well as for the sensing of utilities and voids. It includes five Projects. Project 2.1 focuses on outlining "Innovative inspection procedures for effective GPR surveying of critical transport infrastructures (pavements, bridges and tunnels)." Project 2.2 is concerned with the development of "Innovative inspection procedures for effective GPR surveying of buildings." Project 2.3 deals with identifying "Innovative inspection procedures for effective GPR sensing and mapping of underground utilities and voids, with a focus to urban areas." Project 2.4 focuses on the development of "Innovative procedures for effective GPR inspection of construction materials and structures." The WG2 also includes Project 2.5 on the "Determination, by using GPR, of the volumetric water content in structures, sub-structures, foundations and soil," this is a topic of great interest in civil engineering, as water infiltration is often a relevant cause of degradation of structures, such as roads of bridges, and of rebar corrosion.

During the first year of the Action, information was collected and shared about state-of-the-art, ongoing studies, problems and future research needs, in the topics covered by the five above-mentioned Projects [4, 14, 16]. In carrying out this review work, the WG2 benefited from the contribution of Dr. Janne Poikajarvi who participated to the WG Meeting in Nantes as an external expert and presented the Mara Nord Project, recently carried out in Finland, Sweden and Norway, aiming at demonstrating the potential of GPR in road-condition measurement and rehabilitation planning, and at creating and harmonising Scandinavian recommendations; he prepared for the Action a special paper as well, that is included in [6], where the achieved results are presented and how the project was carried out is explained step by step.

Based on the experience and knowledge gained from the in-depth review work carried out by WG2, several case studies were conducted; they were presented during the Second General Meeting and the GPR 2014 conference [3, 7] and are not resumed here for brevity reasons. Furthermore, the extension of GPR application to railways track ballast assessment was demonstrated [17].

The Action identified some reference test-sites, for an advanced comparison of available inspection procedures to be carried out in the next years of activity (taking advantages of the interaction with WG4), as well as to test GPR equipment (interacting with WG1), electromagnetic simulators, and data-processing algorithms (thanks to the cooperation with WG3). In particular, the Action chose the IFSTTAR geophysical test site and the accelerated pavement testing (APT) facility. 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 [6]. 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 [6].

Another interesting and promising WG2 initiative that has to be mentioned is the development of a Catalogue of European test sites and laboratories for the testing of GPR equipment, methodology and procedures that is being coordinated by France and Italy. The catalogue will represent a useful tool for the GPR community and it will contribute to identifying new cooperation possibilities among research groups, to clarifying which are the missing testing facilities in the various European regions, and to addressing current or future research needs.

### 2.3. Electromagnetic methods for near-field scattering problems by buried structures; data-processing techniques

The **WG3 of the COST Action TU1208** focuses on the development of accurate, versatile and fast electromagnetic scattering methods for the characterisation of GPR scenarios and on the improvement of inversion, imaging and data-processing algorithms for the elaboration of GPR data collected during civil engineering surveys. It includes four Projects. Project 3.1 deals with the development of advanced "Electromagnetic modelling for GPR applications." Project 3.2 is concerned with the development of advanced "Inversion and imaging techniques for GPR applications." The topic of Project 3.3 is the "Development of intrinsic models for describing near-field antenna effects, including antenna-medium coupling, for improved radar data processing using full-wave inversion." The Project 3.4 focuses on the "Development of advanced GPR data-processing algorithms."

During the first year of the Action, information was collected and shared about state-of-the-art of the available electromagnetic-scattering, imaging and inversion data-processing methods [4, 14]. In carrying out this review work, the Members of Project 3.1 could benefit from the special workshop on FDTD organized in Nantes [6]. The Members of Project 3.4 could benefit from the contribution of Prof. Andreas Tzanis, who participated to the WG Meeting in Nantes as an external expert and presented the well-known matGPR software that he developed, providing a broad and functional range of tools for the analysis of GPR data; he also prepared for the Action a special paper giving an overview on GPR data processing, suggesting open issues and possible future developments in this area, that is included in [6].

Reference test scenarios were defined by the WG3 Members, in cooperation with WG2, to test the modelling/inversion/imaging/data-processing techniques during the next years of activity [7, 8].

For what concerns electromagnetic-scattering methods, particular attention is being paid to the FDTD technique and the spectral domain Cylindrical-Wave Approach (CWA). In the FDTD technique, the Maxwell's equations are solved through space and time discretization; GprMax is a freeware and versatile FDTD simulator, very well-known in the GPR community. This tool is being further tested and improved by WG3 Members. In particular, the possibility to adopt a more realistic representation of the soil/material hosting the sought structures and of the GPR antennas is being introduced in the software; moreover, input/output procedures to ease the definition of scenarios and the visualisation of numerical results were developed [3, 7]. Part of this work was carried out during two STSMs involving Members from Italy and United Kingdom [8].

In the CWA, the field scattered by subsurface two-dimensional targets with arbitrary cross-section is expressed as a sum of cylindrical waves; use is made of the plane-wave spectrum of such waves to take into account the interaction of the scattered field with the interfaces between different materials that constitute the medium hosting the sought targets. The method was extended to deal with through-the-wall scenarios [18].

Advancements of inversion/imaging/data-processing algorithms achieved by Action Members were presented during the Second General Meeting and the GPR 2014 conference [3, 7], as well as in [19, 20]. They are not resumed here for brevity reasons.

### 2.4. Different applications of GPR and other NDT technologies in civil engineering

The **WG4 of the COST Action TU1208** focuses on applications of GPR outside from the civil engineering field. It also deals with the integration of GPR with other NDT techniques, in order to improve the potential of the combined methods. Among such techniques there are ultrasonic testing, radiographic testing, methods employing surface waves, approaches involving the using of an open coaxial probe combined with a vector network analyser, liquid-penetrate testing, magnetic-particle testing, acoustic-emission testing, eddy-current testing, self-potential methods and DC methods; the coupling of GPR with infrared thermography or with Falling Weight Deflectometer (FWD) and its Light version (LFWD) is promising, too. In civil engineering, several methods that are commonly used in solid-earth geophysics have their counterparts in non-destructive testing. In fact, the most used construction materials are mineral aggregates, such as concrete (mineral aggregates, cement, additives) or asphalt (mineral aggregates, bitumen, additives), and also soils and rocks are mineral aggregates; thus, it is possible to effectively use earth-monitoring methods for civil engineering applications, of course the scale of structures and infrastructures is much smaller rather than the one of the earth and an adaption of the methods is recommended and required.

The WG4 includes six Projects. Project 4.1 deals with the "Application of GPR and other non-destructive testing methods in archaeological prospecting and cultural heritage diagnostics." Project 4.2 is concerned with the innovative "Application of GPR to the localisation and vital signs detection of buried and trapped people." Project 4.3 focuses on the "Application of GPR in association with other non-destructive testing methods in surveying of transport infrastructures." Project 4.4 regards "Applications of GPR in association with other non-destructive testing methods in building assessment and in geological/geotechnical tasks." Project 4.5 is about the "Development of other advanced electric and electromagnetic methods for the characterisation of construction materials and structures." Project 4.6 focuses on the "Application of GPR in association with other non-destructive testing methods in the management and protection of water resources." During the first year of the Action, information was collected and shared about state-of-the-art, ongoing studies, problems and future research needs, in the topics covered by these Projects [4, 7, 14, 21].

Based on the experience and knowledge gained from the in-depth review work carried out by WG4, several new case studies were conducted, mainly relevant to archaeological prospecting; some of them were carried out through STSMs in Greece and Austria, involving Members from Spain and Belgium [8]. The results of these studies were presented during the Second General Meeting and the GPR 2014 conference [3, 7], as well as in [22, 23]; they are not resumed here for brevity reasons.

Within the WG4 activities, the cooperation with the COST Action TU1206 "Sub-Urban - A European network to improve understanding and use of the ground beneath our cities" has to be mentioned. This Action focuses on highlighting the importance of the ground beneath cities, which is often under-recognised and overlooked, with the main aim of transforming the relationship between experts who develop urban subsurface knowledge and those who can benefit most from it – as urban decision makers, practitioners as well as the wider research community.

### 2.5. Next events and training activities

The Third General Meeting of the COST Action TU1208 is going to be held in London, United Kingdom, on March 4-6, 2015. It will include a half-day training for PhD Students and early-stage researchers, the Management Committee meeting, and the meetings of the four WGs. Special sessions will take place, focusing on the condition assessment of transport infrastructure and the mapping of urban subsoil with GPR: the main challenges of these tasks will be discussed, the view-points of stakeholders, private and academic GPR end-users will be presented and compared, with the aim of making a significant step forward in the development of GPR European guidelines and protocols.

The Action is organising a Session on "Civil Engineering Applications of Ground Penetrating Radar," within the 2015 EGU General Assembly, to be held in Vienna, Austria, on April 12-17, 2015.

Furthermore, the Action is co-organising, jointly with the European School of Antennas and the European Association on Antennas and Propagation, a Training School on "Ultra-Wide Band Antennas, Technologies and Applications," to be held in the Karlsruhe Institute of Technology, in Karlsruhe, Germany, on April 20-24, 2015. The course will present an insight into the design, evaluation and measurement procedures for ultra wideband (UWB) antennas, as well as the characteristics of the UWB radio channel. The theoretical lectures will be complemented with laboratory tutorials on antenna design, experimental techniques including measurements in anechoic chamber, detection of hidden objects and wave propagation simulations.

Finally, the Action is organising a workshop on "Advanced GPR surveys using multichannel antenna arrays," to be held in May 2015, in the archaeological site of Carnuntum, Austria. The scope of the workshop is to inform about the potential of multichannel GPR systems, to educate on exact data positioning using motorized array GPR systems in combination with GPS and robotic total stations, and to familiarize the participants with common systems and workflows in regard to data acquisition, processing and efficient interpretation. Carnuntum was a Roman army camp on the Danube in the Noricum province and after the 1st century the capital of the Pannonia Superior province, with 50,000 people; its remains are situated in Lower Austria, halfway between Vienna and Bratislava, and the "Archaeological Park Carnuntum" extends over an area of 10 km² near today's villages Petronell-Carnuntum and Bad Deutsch-Altenburg. The whole area is being mapped with GPR by the Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology.

## 3. GPR activities in Armenia and Participation to TU1208

In July 2013 Fiber Optics Communication Laboratory at State Engineering University of Armenia joined the COST 1208 Action as a representative from COST Near Neighbour Countries. In the end of April 2014 it was the first COST TU1208 meeting where participated Armenian group [24]. The following information has been presented on this meeting.

Armenia is a country located in a very complicated region from geophysical point of view. It is situated on a cross of several tectonic plates and a lot of dormant volcanoes. The main danger is earthquakes and the last big disaster was in 1988 in the northwest part of contemporary Armenia. As a consequence, the main direction of geophysical research is directed towards monitoring and data analysis of seismic activity. National Academy of Sciences of Armenia is conducting these activities in the Institute of Geological Sciences and in the Institute of Geophysics and Engineering Seismology.

Research in the field of ground penetrating radars is considered in Armenia as an advanced and perspective complement to the already exploiting research tools. The previous achievements of Armenia in the fields of radiophysics, antenna measurements, laser physics and existing relevant research would permit to initiate new promising area of research in the direction of theory and experiments of ground penetrating radars.

One of the key problems in the operation of ground penetrating radars is correct analysis of peculiarities of electromagnetic wave interaction with different layers of the earth. For this, the well-known methods of electromagnetic boundary problem solutions are applied. In addition to the existing methods our research group of Fiber Optics Communication Laboratory at the State Engineering University of Armenia declares its interest in exploring the possibilities of new non-traditional method of boundary problems solution for electromagnetic wave interaction with the ground. This new method for solving boundary problems of electrodynamics is called the method of single expression (MSE) [25-27]. The distinctive feature of this method is denial from the presentation of wave equation's solution in the form of counter-propagating waves, i.e. denial from the superposition principal application. This permits to solve linear and nonlinear (field intensity-dependent) problems with the same exactness, without any approximations. It is favourable also since in solution of boundary problems in the MSE there is no necessity in applying absorbing boundary conditions at the model edges by terminating the computational domain. In the MSE the computational process starts from the rear side of any multilayer structure that ensures the uniqueness of problem solution without application of any artificial absorbing boundary conditions.

Previous success of the MSE application in optical domain gives us confidence in successful extension of this method's use for solution of different problems related to electromagnetic wave interaction with the layers of the earth and buried objects in the ground.

Armenian group involved mainly in COST TU1208 activities carrying out in WG3, where other methods of electromagnetic modelling are in use by European colleagues. It is expected to perform comparison of the MSE with other existing modelling methods in frame of COST cooperation.

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**Appendix - Universities, research institutes, private companies and public agencies, participating to the COST Action TU1208.**

**COST Countries**

**AUSTRIA**: Ludwig Boltzmann Institute for Archaeological Prospection and Virtual Archaeology, Vienna; Zentralanstalt für Meteorologie und Geodynamik, Vienna. **BELGIUM**: Université Catholique de Louvain, Louvain-la-Neuve; Belgian Road Research Centre, Brussels; Ghent University, Ghent; University of Liège, Liège; Vrije Universiteit, Brussels. **CROATIA**: University of Zagreb, Zagreb; University of Split, Split. **CZECH REPUBLIC**: Transport Research Centre, Brno; Arcadis Geotechnika, Prague; Inset, LtD, Prague; Brno University of Technology, Brno; Czech Technical University in Prague, Prague. **DENMARK**: Ramboll Denmark, Department of Geophysics and Geohydrology, Copenhagen. **ESTONIA**: Institute of Ecology, Tallinn. **FINLAND**: Aalto University, Espoo, Helsinki; Geological Survey of Finland, Espoo, Helsinki. The **FORMER YUGOSLAV REPUBLIC of MACEDONIA**: Ss. Cyril and Methodius University, Skopje. **FRANCE**: Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux (IFSTTAR), Bouguenais Cedex; Alyotech Technologies, Nantes; Université Bordeaux, Bordeaux; Centres d'Etudes Techniques de l'Equipement (CETE), Angers – Blois – Les Ponts de Cé; Clermont-Ferrand University - Blaise Pascal Institute, Clermont-Ferrand cedex; École supérieure d'électricité (SUPELEC), Gif sur Yvette; Institut Fresnel, Marseille; Institut National des Sciences Appliquées (INSA), Toulouse; Strasbourg University, Strasbourg; University of Nantes, Nantes; University Nice Sophia Antipolis, Sophia Antipolis; Laboratoire d'Etudes et de Recherches sur les Matériaux (LERM), Arles Cedex. **GERMANY**: Federal Institute for Material Research and Testing (BAM), Berlin; DMT GmbH & Co. KG, Exploration & Geosurvey, Hamburg; Karlsruhe Institute of Technology (KIT), Karlsruhe; Institute of Bio and Geosciences, Forschungszentrum Jülich, Jülich; Technische Universität Ilmenau, Ilmenau; Ruhr-Universität Bochum, Bochum; Fraunhofer Institute for High Frequency Physics and Radar Techniques, Wachtberg. **GREECE**: National Technical University of Athens, Athens; Aristotle University of Thessaloniki, Thessaloniki; Geoservice, Athens; Technical University of Crete, Crete; Geoterra, Athens. **IRELAND**: National Transport Authority, Dublin. **ITALY**: "Roma Tre" University, Rome; ELEDIA Research Center, Trento; IDS Ingegneria dei Sistemi SpA, Pisa; Consiglio Nazionale delle Ricerche (CNR), Istituto per i Beni Archeologici e Monumentali (IBAM), Lecce and Potenza; Consiglio Nazionale delle Ricerche (CNR), Istituto per il Rilevamento Elettromagnetico dell'Ambiente (IREA), Naples; "La Sapienza" University, Rome; Seconda Università di Napoli, Napoli; Università Mediterranea di Reggio Calabria, Reggio Calabria; University of Genoa, Genoa; INFN & University of Naples "Federico II", Naples; Provincia di Roma, Rome; Provincia di Rieti, Rieti; University of Napoli "Parthenope"; Politecnico di Torino, Torino; Università di Firenze, Firenze; Università di Perugia, Perugia; Università di Catania, Catania. **LATVIA**: Transport and Telecommunication Institute, Riga. **MALTA**: University of Malta, Msida. **NETHERLAND**: Technical University of Delft, Delft. **NORWAY**: Norwegian University of Science and Technology, Trondheim; SINTEF, Trondheim; 3d-Radar AS, Trondheim. **POLAND**: National Institute of Telecommunications, Warsaw; Road and Bridge Research Institute, Warsaw; University of Science and Technology - Akademia Górniczo-Hutnicza im. Stanisława Staszica, Kraków; Kielce University of Technology, Kielce. **PORTUGAL**: Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Leiria, Leiria; University of Minho, Guimarães; National Laboratory for Civil Engineering (LNEC), Lisbon. **ROMANIA**: Ion Mincu University of Architecture and Urbanism, Bucharest; National Institute of R&D for Optoelectronics (INOE 2000). **SERBIA**: Faculty of Technical Science, Novi Sad. **SLOVAKIA**: Technical University of Kosice, Kosice. **SLOVENIA**: University of Ljubljana, Ljubljana. **SPAIN**: Geofisica Consultores, Madrid; Universidade de Vigo, Pontevedra; Universidad Politécnica de Catalunya, Barcelona; Polytechnic University of Valencia, Valencia; Public University of Navarra, Pamplona. **SWITZERLAND**: Hochschule Rapperswil, Rapperswil; Scuola Universitaria Professionale della Svizzera Italiana, Lugano-Manno; Smartec, Lugano-Manno; Meet Electronic Engineering, Coldrerio. **TURKEY**: Ankara University, Ankara; Suleyman Demirel University, Isparta. **UNITED KINGDOM**: The University of Edinburgh, Edinburgh; The University of Greenwich, Chatham Maritime; Atlas Geophysical Limited, Powys; British Geological Survey, Edinburgh; Edinburgh Napier University, Edinburgh; GM RADAR Solutions, London; Infrastructure Services - Mouchel, Glasgow; Queen Mary University of London, London; The University of Nottingham, Nottingham; Keele University, Keele; TRL Ltd – Infrastructure Division, Wokingham. **ISRAEL** (COST Cooperating State): Holon Institute of Technology (HIT).

**COST "Near Neighbour Countries"**

**ARMENIA**: State Engineering University of Armenia, Yerevan. **EGYPT**: National Research Institute of Astronomy and Geophysics (NRIAG). **UKRAINE**: Usikov Institute for Radiophysics and Electronics of the National Academy of Sciences of Ukraine.

**COST "International Partner Countries"**

**AUSTRALIA**: Department of Transport and Main Roads. **RWANDA**: National University of Rwanda. **HONG KONG**: The Hong Kong Polytechnic University, Hong Kong. **UNITED STATES OF AMERICA**: University of Mississippi, Oxford, Mississippi; University of New Mexico, Albuquerque, New Mexico; University of Texas, Austin, Texas; Washington State Department of Transportation, Olympia, Washington.