Optimised Radar to Find Every Utility in the Street

Brief Guide for Radar Measurement

Pavel Pospíšil, Lumír Miča, Evert Slob, Howard Scott

Contract n° FP6-2005-Global-4-036856

CONTENTS

1. Executive Summary

Report describes the necessary steps, comprising of a desk study and subsequent site investigation, to ensure successful GPR use in the field:

- **Desk study**
  - Rock/Soil type
  - Water saturation
  - Ground water table level
  - Determination of hydrometeorological conditions of measurement
  - Determination of terrain surface
  - Vegetation influence on measurement
  - Electric line influence on measurement

- **Site investigation**
  - Location of investigation points
  - Verification of rock/soil types in the ground
  - Verification of water saturation
  - Verification of material and microrelief of the surface
  - Verification of the surface moisture conditions
  - Verification of vegetation close to measurement profiles and its moisture
  - Verification of type of electric lines and their orientation to measurement profiles

It is concluded that use of the proposed methodology will guarantee the quality of GPR measurements results so that assets buried in the streets of developed European cities and industrial areas may be located on a more consistent basis than has hitherto been possible.

2. Theoretical consideratons

2.1. Ground

Ground can be natural, anthropogenic, or mixed. A natural ground occurs in shallow depths (up to 2m) and is formed mostly of younger sediments or rocks. There are mostly Quaternary or Tertiary sediments but in some areas neovolcanic rocks such as basalt, andesite or rhyolite can be found together with their tuffs. Only exceptionally do the older rocks (Mesozoic or Palaeozoic), which can be limestones, shales, slates, sandstones, conglomerates or granites and gneisses, rise up close to the surface.

Anthropogenic and mixed grounds are formed mainly in urban areas and cover the natural soil. Anthropogenic and mixed soils are composed of mixed natural soils and/or from artificial material (etc. recycled materials, artificial surface).

Outside urban areas the typical ground surface consists, in descending order, of following horizons: topsoil, subsoil, soil and bedrock (Fig. 1). These vary in thickness from centimetres to metres. They can be different in colour, texture, structure and other properties. The topsoil is usually formed from organic soil (humus). The thickness is usually about 0.5 m.

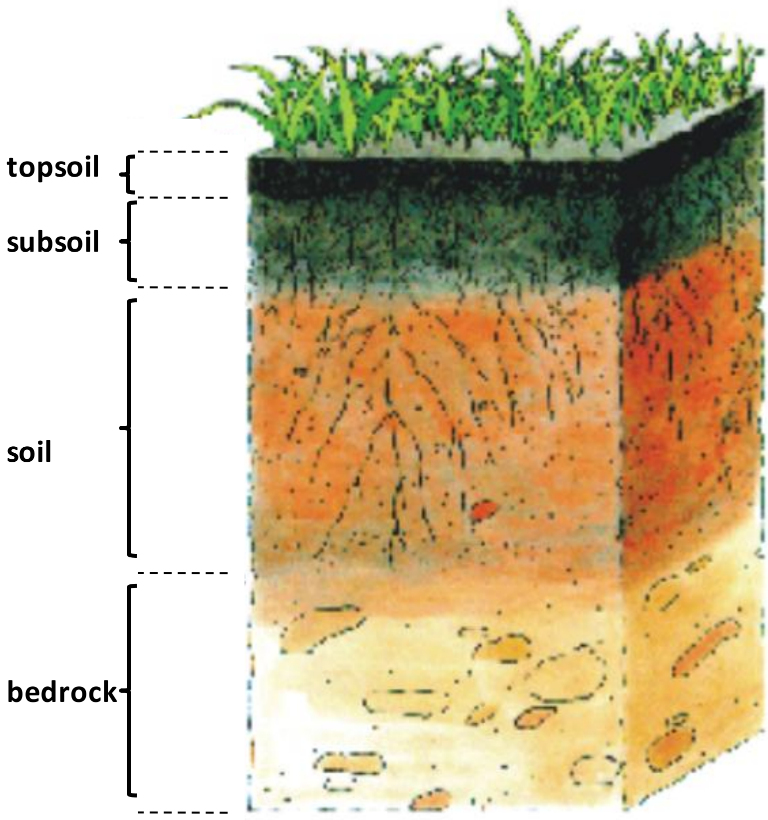


Fig.1 Typical profile of the ground.

As **soils** are **composite materials**, where the components are: air, water and/or ice, mineral, aggregates and their weathering products, clays, colloidal particles, salts and organic compounds, and therefore their **dielectric values depends on**:

- **individual dielectric constants of the components,**
- **volume fractions of components,**
- **geometrics of components,**
- **electrochemical interactions between the components.**

Ground water (GW) is also a very important factor to be taken into account when using GPR. GW is in the soil layer in many cases and can also fill the pores, or joints in the rock mass. The saturation of voids is variable and depends on the surrounding conditions (infiltration of rain/surface water or level of GW table). In special cases the GW table can be very close to surface. This is usually the case where a GPR measurement site is near to a source of water such as a river, lake or sea.

Other effects can also be important such as the

- chemical composition of the soil, which can exhibit different behaviour depending upon the proximity of sea (salt water) or rivers (fresh water).
- capillarity of the soil, which depends upon the size of voids, can lead to the soil being fully saturated above the ground water table. This level, where there is 100% saturation, is called the “capillary saturation level”.

Anthropogenic layers can be formed from:

- redeposited and mixed natural soils

- recycled materials (crushed concrete, bricks etc.)
- asphalt concrete, normally known simply as asphalt, is a composite material commonly used for construction of pavement, highways and car parks. It consists of asphalt binder and mineral aggregate mixed together then layed in layers and compacted.
- concrete pavement

2.2. Risk parameters of the radar measurement

There are several important factors that affect GPR measurement, such as mineral composition and structures of the ground, presence of water, in all its forms, surrounding the measurement site, temperature and artificially induced EM fields.

The most important are:

1) Water
   a) In voids in the soil (partially saturated or fully saturated)
   b) On the surface of ground
   c) Absorbed in vegetation roots surrounding the measurement site
2) Clay-fraction and mineral composition of the clays.
3) Ferromagnetic materials in the mineral composition of the rocks/soils – typically basalt in the form of hard rock or completely weathered into a form of basaltic gravel or sand.
4) Electric lines oriented parallel to the measurement profile, which can affect EM waves transmitted and received by GPR antenna. The electromagnetic field surrounding overhead and buried power lines may also produce significant noise that could potentially mask the presence of buried pipes or cables.

2.3. Archive material study of the ground

The goal of this phase of search the goal is to obtain such information from the archives that, has already been gathered about the given location (or its adjacent surroundings) in the past. There are a number of options. We recommend especially:

2.3.1. Studying existing maps

- Geologic
- Geomorphologic
- Engineering geologic
- Hydrogeologic
- Raw materials
- Soil etc.

The study should also include noting any detailed explanatory notes published together with these maps.

The first step is to select the proper type of map/maps and map scales.

2.3.2. Searching data stored in the archives

There are maintained by national governments (e.g. Czech Republic – Czech Geological Survey – Geofond, http://www.geofond.cz),

A new web portal (eEarth http://fraga.nitg.tno.nl/dinoLks/eEarth.jsp) has been created where borehole data from several EU countries are stored/linked.

e Earth: Electronic Access to the Earth Through Boreholes

eContent programme of the European Commission.

Contract No. EDC11142 eEARTH / 28771

What is eEarth?

The eEarth system allows the user to browse borehole data held by six European geological surveys, representing the United Kingdom, Netherlands, Germany, Poland, Czech Republic and Lithuania. The system incorporates a multilingual web-GIS interface, and borehole information can be displayed in seven European languages: English, Dutch, German, Polish, Czech, Lithuanian and Italian.

2.3.3. Using data and information stored in archives of existing and/or dissolved research and survey companies and organizations.

Some information is not accessible in the centralized archive. In some cases the investigators may also access the information stored in private archives of local companies or survey institutions.

2.4. Detailed assessment of soil and rock environment quality

Before conducting GPR testing, it is necessary to assess the soil/rock environment in the area to be surveyed. Due to the fact that, usually, it will be a very heterogeneous environment, not only vertically (in depth) but also horizontally (distribution networks – linear constructions), it is a very difficult task. It is, therefore, necessary to carry out several steps to obtain optimal results:

2.4.1. Empirical knowledge

Empirical knowledge is very important consideration in preparing to carry out GPR survey that can accelerate the process. Experienced operators will ensure that they determine the type of ground, including parameters such as bedding (with thickness), type of rock or soil, approximate groundwater table level etc prior to carrying out a survey. They will also estimate soil moisture content relative to weather development in the recent past. In addition, they should also be aware of the potential hazards that may be encountered during the survey process.

2.4.2. Excavation Work and soil sample assessment

The very basic assessment of geologic composition and study of physico-mechanical features of rocks, prior to any excavation activity, consists of observing the actual situation of the rock mass (colour, stratification, granularity, humidity and behaviour). We distinguish between the following categories:

- **Direct observation**:
  - ***Drilling works (portable sampler or incision; round-turning holes; vibration holes; rotation core holes and core-less holes)***
  - ***Digging and mining works (deeper)***

- **Indirect** observation as a special category; mostly **field test**, consists of:
  - ***Penetration exploration (dynamic penetration – DP; static penetration – CPT; standard penetration test – SPT; weight penetration test - WST***

An objective of the ORFEUS project was to identify an instrument that would enable the subsoil to be explored within the depth range accessible by radar (1.0 to 2.0 m). The criteria were that the device should be mobile/portable, provide immediate access to the results, and be affordable for companies not routinely involved in geotechnical research. After evaluating all relevant facts, we selected a combination of dynamic penetration sampling, and manual sampling.

Manual Sampling

This method allows the collection of small samples of rock mass, which may be semi-disturbed (with natural moisture) or disturbed. The sample is documented by means of a macroscopic description and, where there is sufficient time, it may be analyzed in a soil mechanics laboratory. Within ORFEUS a manual sampler DGSI Hand Auger (Fig. 2) was chosen for indirect - in-situ assessment of the rock mass features.

Fig. 2 DGSI Hand Auger

The manual sampler DGSI hand auger consists of a sampling chamber Ø 83 mm, tubes (drilling tubes 1 m long) and capstan. The sampling chamber including tubes, penetrates the subsoil by a rotation action applied by the capstan. When the sampling chamber is full, the tubes are withdrawn and the sample is inspected and documented. This process is repeated until a depth is reached that correspond to the length of one tube set. Additional tubes are connected and the process repeated to reach the required depth. Ideally, it is necessary to examine the subsoil down to a depth of 4 metres, but experience indicates that the maximum depths will be in range 2 to 3 metres. Success depends upon determining the features of the subsoil.

Alternatively, classifying soils for GPR survey purposes may be carried out by means of visual inspection. This is an indirect, but convenient, method of classifying the soil into fine grained or coarse grained categories. The field identification is only suitable for particle size up to 60 mm, because it is not possible to excavate coarser grains from subsoil by means of the DGSI hand auger. The filed identification and description of soils is summarized in Chapter 5.

Dynamic Penetration Testing

Dynamic penetration testing serves for the determination of subsoil composition. Compared to manual sampling, here **the sampler is pushed into the subsoil in a defined way, while the resistance is measured (as a function of penetration).** This method can be used in soil and

soft rocks (= eluvium). It is used for identification of lithology and for relative comparison of features or classifications obtained by other field sampling (e.g. manual direct sampling).

Dynamic penetration (DCP) is caused by of a hammer of a specified weight falling through a defined distance (manually as sown in fig. 10 or mechanically, see fig. 11). During the action, the penetration resistance is measured (e.g. by number of hits or time needed for a certain penetration depth – usually 10 or 20 cm). The evaluation itself depends upon the geometry of the penetration point and the weight of the hammer.

The validity of the choice for DCP is reinforced by an extensive study (Saarenketo, T., 2006), where DCP was also used for the identification of the dielectric features in relation to firmness and/or solidity of the soil. In this research work, carried out by the Texas Transportation Institute in a series of laboratory tests in 1995, the correlation between dielectric parameters and strength and deformation properties of materials was first studied. Dielectric values and California Bearing Ratio (CBR) values were measured.

Dynamic Cone Penetrometer - DCP

DCP (Fig. 3) has been developed in South Africa under the name of "Portable Pavement Dynamic Cone Penetrometer" for research and quality check of the subsoil layers and subsoil of the paved roads (http://www.dot.state.il.us/materials/research/pdf/ptat4.pdf). This method gained popularity in the USA (field identification of CBR or non-drained shear strength of c_u). Within the test, depth and number of hits is recorded (Fig. 4a). It is possible to define so called DCP penetration index (DPI – mm/blow) – Fig. 4b or arithmetic average, which is defined by equation (16).

$$DPI_{avg} = \frac{\sum_{i}^{N} (DPI)_i}{N}$$

where N is the total number of DPI recorded in a given penetration depth of interest.

In ORFEUS the equipment used was DCP K-100 Deluxe DCP Kit (Fig. 5).

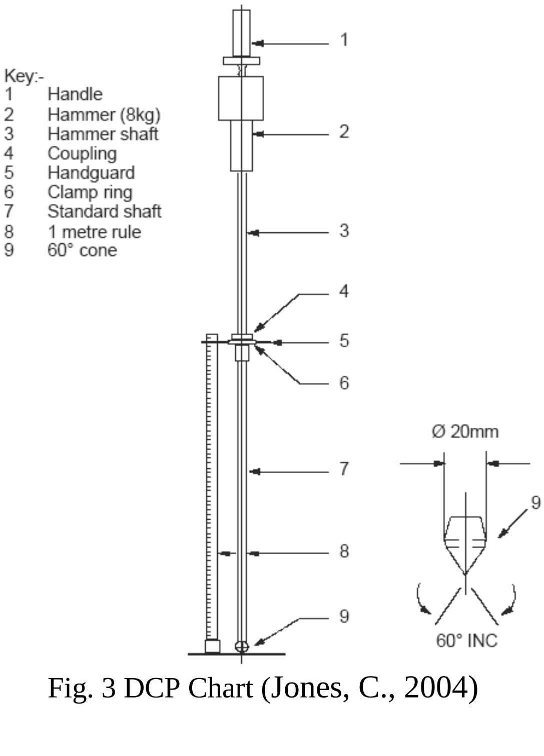
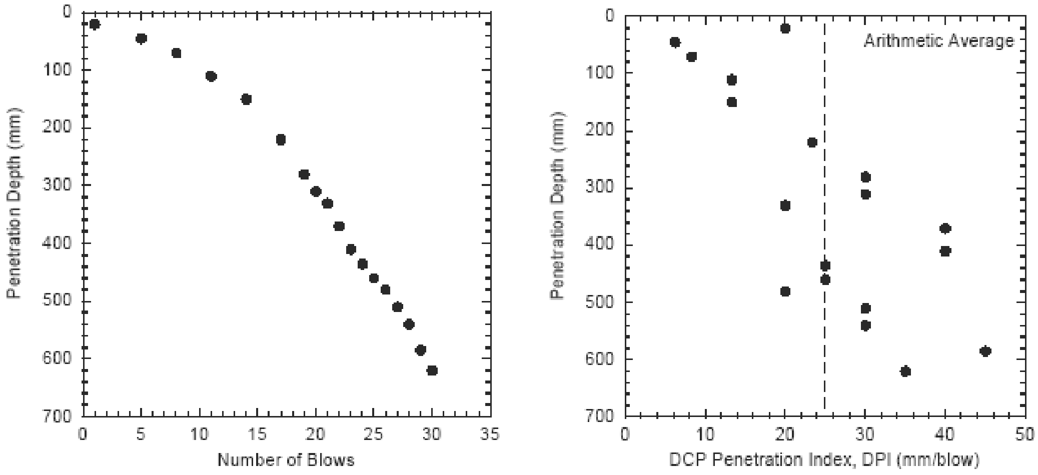


Fig. 3 DCP Chart (Jones, C., 2004)



(a) (b)

Fig. 4 DCP Evaluation Possibilities (Tuncer B. E. and Craig H. B., 2005)

Fig. 5 DCP Evaluation Possibilities

Practical use f DCP when using GPR

How can DCP be used in practice when searching for distribution networks using GPR? DCP can be used to monitor changes in solidity of the materials comprising the subsoil (Fig.6). Change in solidity is then defined by the slope of the curve obtained. Lines with small dips indicate more solid layers, whereas steeper dipping lines indicate softer layers. Within single-sized soils (clay, loam), changes in solidity explicitly indicate changes in consistence. With steeper dipping lines we find solid to soft consistence, which means that the soil shall prove to be fully saturated. Lines with small dip indicate solid consistence. Side values then indicate mush-like consistence (in fact zero hits needed – DCP just by its weight penetrates the subsoil) and very solid consistence when the penetration stops. Within powdery soils (and, gravel), the lines with small dips indicate fully sedimented soils and steeper dipping lines indicate less sedimented soil. Side values then indicate conditioned soil (analogy with mush-like soils) and cemented soil (analogy with solid soil).

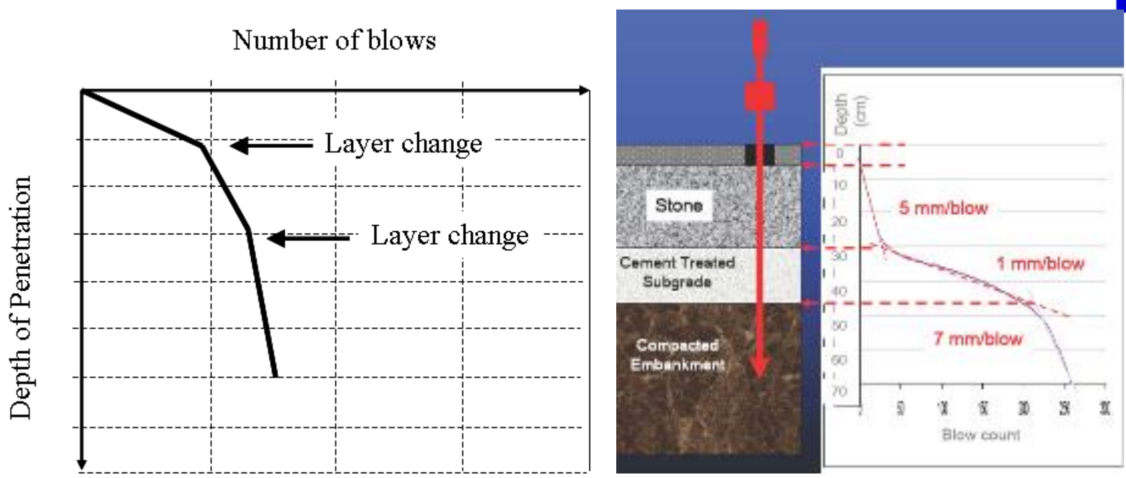


Fig. 6 Determines of stiffness (Louay, M., 2006)

Furthermore, DCP can help to identify the type of the given soil. According to (Webster et al, 1992), after identifying DPI, it is possible to conclude that the values of DPI between 15 to 127 implies clay, 6 to 15 show sand and 2.7 to 5 gravel. Other classifications can be found in the relevant literature (Munnir, D. N., 2003). Here we find classification done according to the number of hits “n” needed for the penetration of 100 mm (Table 1), instead of according to DPI.

Table 1 Classification of granular and fine grained (cohesive) soils based on DCP results (Huntley, 1990).

Granular soils			
Classification	n Value Range		
	Loamy sand	Sand	Gravelly sand
Very loose	< 1	< 1	< 3
Loose	1 – 2	2- 3	3 - 7
Medium dense	3 – 7	4 - 10	8 – 20
Dense	8 - 11	11 – 17	21 – 33
Very dense	> 11	> 17	> 33

Fine grained soils	
Classification	n Value Range
Very soft	< 1
Soft	1 – 2
Firm	3 – 4
Stiff	5 - 8
Very stiff to hard	> 8

In the literature (Tuncer and Craig, 2005) can be found the relationship between DPI and other properties of soil. The example is the relationship of DPI to water content and dry unit weight of soil. For the purpose from this equation can be derived the relationship of water content for sandy soils including SC, SC-SM, and SP-SM (17) or for Clayey soils (CL):

$$w = \frac{338.5 - DPI - 15.28\gamma_d}{0.86}$$

$$w = \frac{DPI - 242.96 - 12.12\gamma_d}{2.62}$$

For easier usage of DCP, it is possible to use an automatic system for measuring the depth of penetration and number of hits. The data is displayed on a data acquisition box and recorded electronically. The new name of DCP is DCP Data Acquisition System (Fig. 7).

Fig. 7 Connection of DCPDAS and DCP

Measurement of moisture content

Since there are relationships between soil moisture content and the other important physical characteristics, it is an advantage to be able to measure this parameter. This can be achieved by using a special probe that uses the relationship between the soil dielectric constant and moisture. This system was developed by Vertek and is known as the Vertek SMR Probe (Figure 8). Equipment cost is about 5400 EUR.

Figure 8 Vertek SMR Probe.

2.5. Methodology of Subsoil Testing for GPR Setting

On the basis of the methods of sampling described above and assessment of the subsoil for GPR, the following methodology is recommended:

The portable sampler should be used for the visual evaluation of the soil character (macrostructure). On the basis of this description, in step one, it should be possible to determine whether the soil is fine-grained (clay, loam), coarse-grained (sand, gravel) or combination (sandy clay or clayey sand). Electric permittivity and conductivity are the most important parameters for assessing the successful use of GPR. Both parameters are significantly influenced particularly by the presence of water, and the saturation of the soil can be identified indirectly from the consistency of the soil using a sensory test - see section 6.2.3.

Rapid estimates of soil consistency, which relates to moisture, can be obtained from hand samples using simple criteria. These criteria can be found in many textbooks on soil – e.g. Atkinson 2007, Withlow, 2001. Examples of consistency estimation is in Table 2

Tab. 2 Estimation of consistency

Domain for soil consistency DESCRIPTION of RESULT entity				
AS 1726-1993 1993, *Geotechnical site investigations*. Standard Australia				
Qualifier 1: minimum undrained shear stress, kPa				
Qualifier 2: maximum undrained shear stress, kPa				
Code	Category	Description	Qualifier 1	Qualifier 2
SFTV	very soft	undrained shear strength <=12 kPa, soil exudes between the fingers when squeezed in hand		12
SFT	soft	undrained shear strength 12-25 kPa, soil can be moulded by light finger pressure	12	25
FRM	firm	undrained shear strength 25-50 kPa, soil can be moulded by strong finger pressure	25	50
STF	stiff	undrained shear strength 50-100 kPa, soil cannot be moulded by fingers, can be indented by thumb	50	100
STFV	very stiff	undrained shear strength 100-200 kPa, can be indented by thumb nail	100	200
HRD	hard	undrained shear strength >200 kPa, can be indented with difficulty by thumb nail	200	

Eventually, just the rough fraction can be identified, then the sediment of the soil plays an important role:
→ calculated by conversion from the DCP test

However, in nature, it is more usually to find mixed soils. These must be assessed on an individual basis:
→ representation of soft as well as rough fraction – in case when rough fraction dominates, the soil sediment plays an important role. However, there is no simple direct method of identifying it. In this case it is necessary to use penetration testing.

Correlation between DCP and GPR – location of DCP testing points close to the measured GPR profile and setting mutual distance of DCP must always be determined by a qualified person who is aware of local rock composition including its evolution and development in time (backfills). In case of unknown conditions, it is possible to optimise the accuracy of measurements of the soil/rock quality by shortening the distance between the DCP testing points.

3. Step by step Approaches to Radar Measurement

3.1. Desk study

3.1.1. Rock/Soil type

Estimation of rock/soil type on the basis of geological maps, final reports of geological surveys and borehole data.

3.1.2. Water saturation

Estimation of moisture content from the data published in final reports of geological or geotechnical surveys in the area or from borehole sample analyses. Inspect seasonal and weather conditions to determine wether there is a satisfactory comparison between the historical data and the present situation.

3.1.3. Ground water table level

Estimation of moisture content from the data published in final reports of geological or geotechnical surveys in the area or from borehole sample analyses. Inspect seasonal and weather conditions to determine whether there is a satisfactory correlation between the known data and the present situation.

3.1.4. Determination of hydrometeorological conditions of measurement

Obtain precipitation data from hydrometeorological institutes. It should be the most recent to the day of measurement. Take into account the effect of long time evaporation and associated decreases in moisture content, especially in clays.

3.1.5. Determination of terrain surface

Material characteristics

Profile measurement should be carried out in a location where the surface material will not complicate the process of measurement. Maps, aerial images or archive study can make clear the nature of the surface.

Microrelief

Determine whether the microrelief at the measurement site is described in archive reports. Rough surface and the presence of free space (air) between antenna and the ground can disturb EM waves.

3.1.6. Vegetation influence on measurement

Grass, bushes or trees in the place or close to measurement site may significantly disturb EM waves especially shortly after a period of rain.

3.1.7. Electrical power transmission line influence on measurement

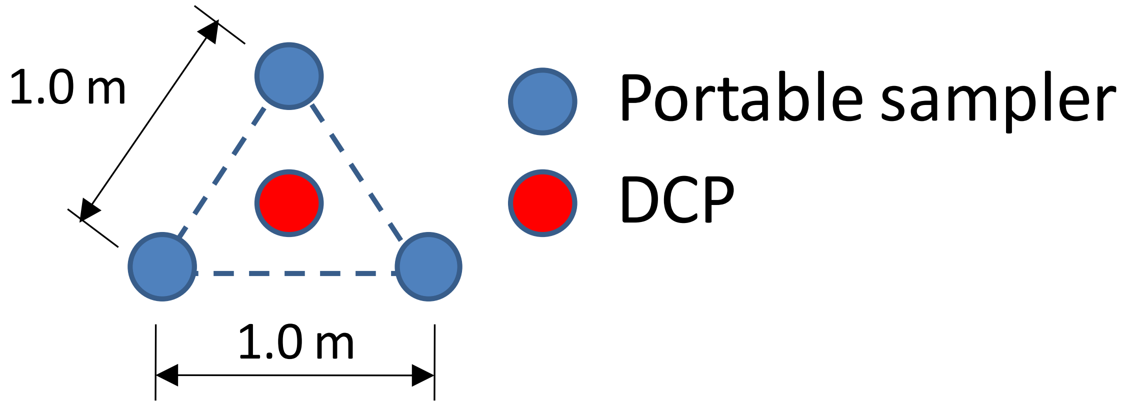
Electric lines, especially those carrying higher voltages, above the surface or in the ground can influence the measurement by induced EM field which is surrounding the line.

3.2. Site investigation

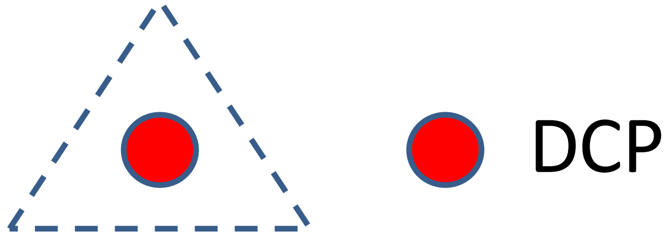
3.2.1. Location of investigation points

Investigations are carried out by using a portable sampler and DCP (a 'TYPE I' sample), with each point being sampled in the geometric configuration shown below, or by a DCP only (TYPE II). Usually, the spacings are 100 metres for TYPE I, and 25 metres for TYPE II measurements. It is preferable to use the TYPE I method for initial investigations.

TYPE I.



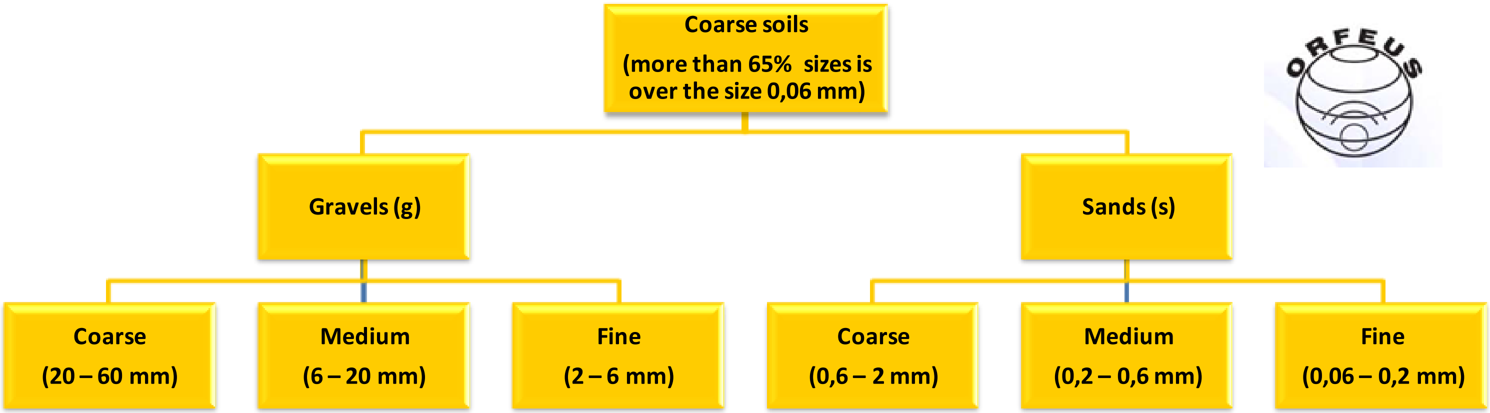
TYPE II.



3.2.2. Verification of rock/soil types in the ground

Use portable sampler and visual evaluation of the soil character (macrostructure) – On the basis of this description, in characterization (diagrams below) it would be possible to determine whether the soil is fine-grained (clay, loam), coarse-grained (sand, gravel) or combination of both (e.g. sandy clay or clay sand).

Hard rock material is easily identifiable by hammer. It should be jointed or compact.



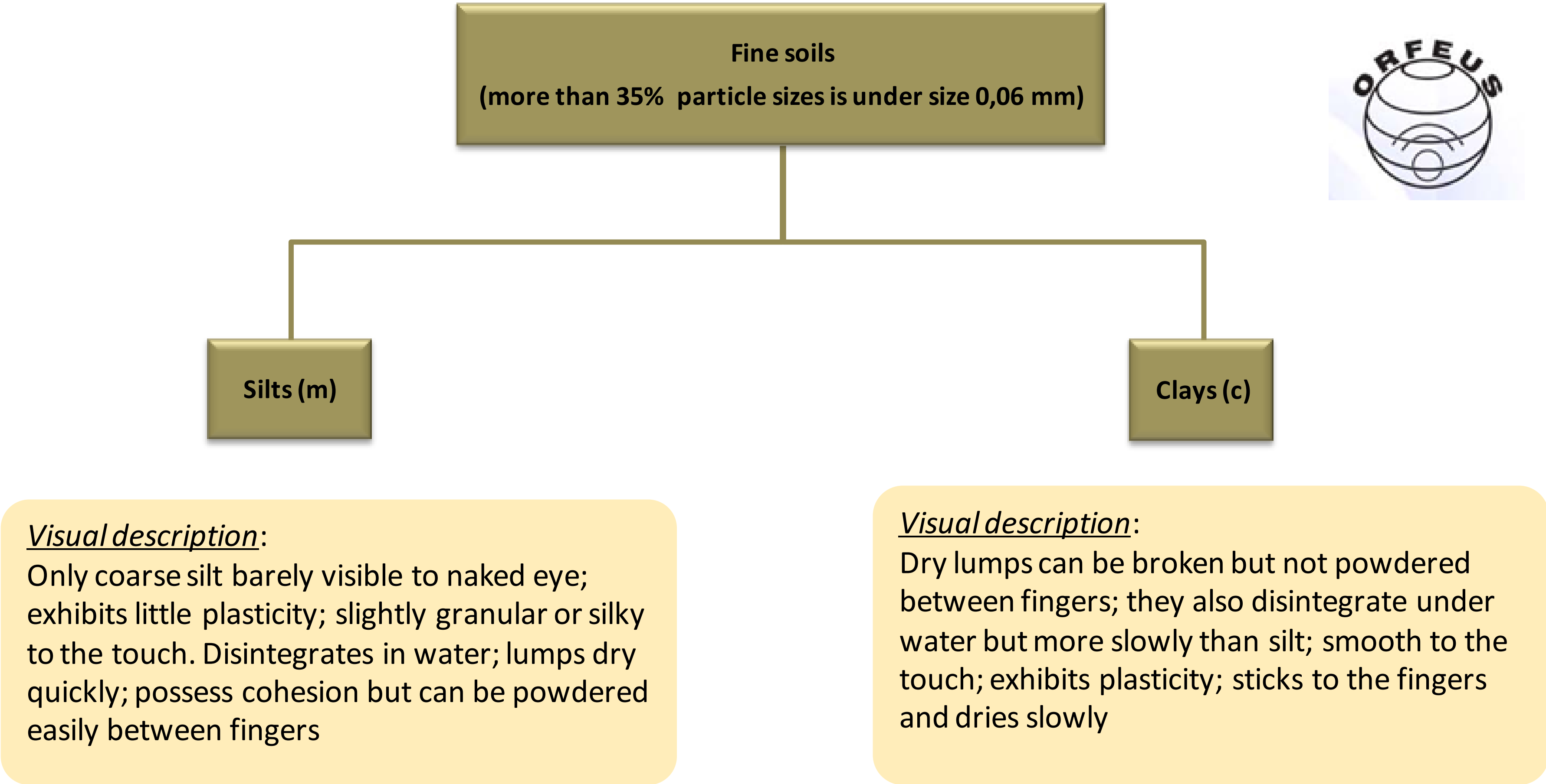
Visual description:
Easily visiable to naked eye; particle shape can be described; grading can be described:
well graded = wide range of grain sizes
Poorly graded = dominant one size → higher porosity than well graded.

Description mixture with other soil basic soil type:
Clayey or silty sand:
– % of „c“ or„m“ is from 5 to 15 → the same behaviour as clean sands (high permeability, the porosity is affected by soil density – determination by DCP)
– % of „c“ or„m“ is from 15 to 35 → for lower % the soil is the behavoiur as coarse soil (the permeability is lower than clean sand; for GPR is important information about soil density - determination by DCP) and for higher % the behaviour is as fine grained soil (the permeability is more lower than clean sand; for GPR is important information about consistency - determination by DCP or if you have sample of soil, use field test (handy))

Visual description:
Easily visiable to naked eye; particle shape can be described; grading can be described:
well graded = wide range of grain sizes
Poorly graded = dominant one size → higher porosity than well graded.

Description mixture with other soil basic soil type:
Clayey or silty gravel:
– % of „c“ or„m“ is from 5 to 15 → the same behaviour as clean gravels (very high permeability, the porosity is affected by soil density – determination by DCP)
– % of „c“ or „m“ is from 15 to 35 → for lower % the soil is the behavoiur as coarse soil (the permeability is lower than clean gravel; for GPR is important information about soil density - determination by DCP) and for higher % the behaviour is as fine grained soil (the permeability is more lower than clean gravel; for GPR is important information about consistency - determination by DCP or if you have sample of soil, use field test (handy))

Characterization of granular soils



Characterization of fine grained soils

3.2.3. Verification of water saturation

As the relative permittivity or electric conductivity (very important parameters for GPR measurement) relate to water content in soil it is useful quickly to evaluate the water content.

The saturation of the soil can be indirectly identified from its consistency by using the following sensory tests:

In case of soft fraction the consistency, which is significant for the setting of GPR parameters, can further identified because it is influenced by water held in the skeleton of the soil. For GPR purposes, it is necessary to determine the value as quickly as possible, which is determined by a touch test. It needs experience and basic knowledge about soil identification and description. Using this simple test, we can determine consistency pursuant to the below-listed criteria:

Very soft state – soil pressed in the first runs out between the fingers
$\rightarrow$ saturation degree = 1 $\rightarrow$ all pores are filled with water

Soft state – the soil can be kneaded easily
$\rightarrow$ saturation degree = 1 $\rightarrow$ all pores are filled with water

Firm state – it is possible to form rolls of a diameter of 3 mm
$\rightarrow$ saturation degree = 1

Stiff state – when trying to form rolls of a diameter of 3 mm they crumble
→ saturation degree < 1


Very stiff state – the soil can be crushed to compact pieces, can be indented by thumb nail
→ saturation degree << 1 → less than 80% pores are filled with water.

Hard state – the soil can be crushed to compact pieces, can be indented with difficulty by thumb nail – only small amount of water in pores.


Calibration of DCP

Dynamic Cone Penetration can be used for indirect assessment of soil type and in case of fine grained soils for assessment of consistency directly in the place of measurement.

Use DCP → measure the penetration depth versus number of blows (Fig. a) and then define the average index DPI_{avg} (Fig. b) defined by equation $DPI_{avg} = \frac{\sum_{i}^{N}(DPI)_i}{N}$, where N is the total number of DPI recorded in a given penetration depth 10 cm. The result from this 1st step is definition of average DPI_{avg} for 10 cm.

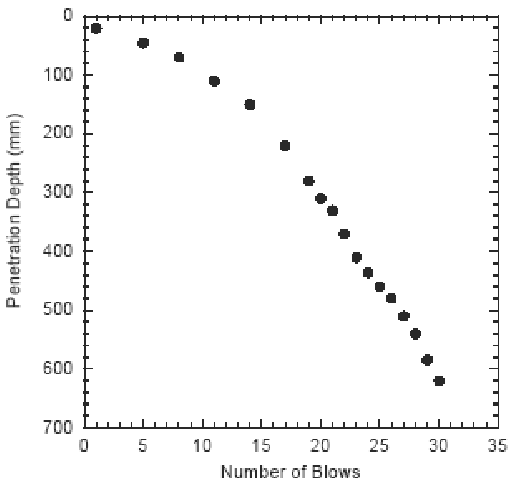


Fig. a)

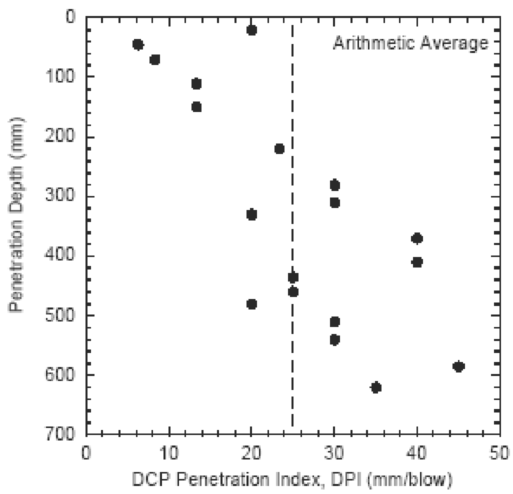


Fig. b)

Table Typical DPI ranges for various soils (Webster et al, 1992).

Soil Type	DPI Range
Clay (CL)	127-15
Sand (S-W)	15-6
Gravel (G-W)	5-2,7

It is also possible to estimate the soil type by the correlation between DPI (results of DCP measurements) and CBR (California Bearing Ratio). This is used widely for classification of soils is according to the equation:

$$\log \text{CBR} = 2.46 - 1.12 \log \text{DPI} \qquad (17)$$

The relationship was defined by US Army Engineers Waterways experiment Station (Webster et al, 1992) and type of soil for different values of CBR (Fernando, E. G. and Oh J., 2004) you can find in Tables.

Table Typical CBR ranges for various soils (Fernando, E. G. and Oh J., 2004).

Major division	Subdivision	Unified soil Classification	CBR range (%)
Coarse grained soils	Gravel and gravelly soils	GW	40 ÷ 80
		GP	30 ÷ 60
		GM (LL < 25 and PI < 5)	40 ÷ 60
		GM (LL > 25 and PI > 5)	20 ÷ 30
		GC	20 ÷ 40
	Sand and sandy soils	SW	20 ÷ 40
		SP	10 ÷ 40
		SM (LL < 25 and PI < 5)	15 ÷ 40
		SM (LL > 25 and PI > 5)	10 ÷ 20
		SC	5 ÷ 20
Fined grained soils	Silts and clays with LL < 50	ML	≤ 15
		CL	≤ 15
		OL	≤ 5
	Silts and clays with LL > 50	MH	≤ 10
		CH	≤ 15
		OH	≤ 5

3.2.4. Verification of material and microrelief of the surface

The material on the surface of a site, where the measurement is planned, has to be verified directly before the starting of measurement.

The type of microrelief can only be predicted (if it is possible) by means of desk study. It is, however, necessary to verify the study in detail and place the measurement profile on an optimal surface. This means that it is necessary to walk the profile, and carefully inspect the surface, to determine whether an adjustment to its location is required.

3.2.5. Verification of the surface moisture conditions

The GPR measurement cannot be performed on visibly wet surfaces (visible pools of water in the line of measurement) or in places where the surface comprises wet grass. Only the operator’s experience will allow a correct judgement to be made. See Figure 4.

3.2.6. Verification of vegetation close to measurement profiles and its moisture

Bushes and large trees close to the planned measurement profiles can significantly influence the measurement because of the presence of water in leaves and roots. The worst effort occurs after a periods of rain when the water adsorbed on the surface of leaves significantly increases their moisture content. This condition can persist for several hours after rain, depending on temperature and wind.

3.2.7. Verification of electric line types and orientations relative to planned measurement profiles

After documenting all power lines (beneath and above ground) the information on type, actual location and orientation should be verified by an on-site physical inspection. All providers of electricity, or their representatives should be contacted to assist directly in marking the position of lines.

4. Conclusion

The landscape of EU countries is very variable, not only from the point of view of geomorphology and vegetation but also because of the quality of the ground. The various countries contain many types of rocks/soils in different conditions of weathering, water saturation etc. Therefore a single map classifying the ground for GPR measurement in the detail needed for practical use would be extremely complex and difficult to interpret.

The cost effective solution achievable in reasonable time is to educate the workers in the measurement process. Workers who understand the measurement process will be able to adapt the parameters by, for example, delaying the measurement after heavy rain, and/or slightly changing the profile and/or optimising the setting of the GPR apparatus so that higher quality data for final analysis may be obtained.

The measurement results depend upon a complex methodology of measurement. Discipline is essential to avoid missing any important disturbing factors that may compromise the integrity of the whole process of measurement and analysis of the data. Those data may then become unreliable. Adhering strictly to the proposed methodology will increase the quality of final results of analysis.

5. References

Publications:

Atkinson, J. (2007): The Mechanics of Soils and Foundations. Taylor and Francis. Second Edition. Abingdon.

Daniels, D. ed., (2004): Ground Penetrating Radar. The Institution of Engineering and Technology; 2nd edition.

Fernando, E. G. and Oh J. (2004): Guidelines for evaluating routine overweight truck routes, FHWA/TX-04/0-4184-P2, Texas Transportation Institute

Jones, C. (2004): Improved Measurement of Pavement Strength by Dynamic Cone Penetrometer, R8157, TRL Limited

Louay, M. (2006): Application of DCP in Prediciton of Resiliant modulus of subgrade soils, 2006 Pavement Performance Seminar,

Munnir, D. N. (2003): Field evaluation of in-situ test technology for QC/QA during construction of pavement layers and embankments, MSc Thesis, Birzeit University, USA

Myslivec, A., Eichler, J., Jesenák, J. (1970): Soil Mechanics. SNTL. Praha (in Czech).

Saarenketo, T. (2006): Electrical properties of road materials and subgrade soils and the use of ground penetrating radar in traffic infrastructure surveys, Dissertation A 471, Oulun Yliopisto, Oulu, Finland

Tuncer B. E. and Craig H. B. (2005): Investigation of the DCP and the SSG as Alternative Methods to Determine Subgrade Stabilit, Department of Civil and Environmental Engineering University of Wisconsin-Madison, USA

Webster, S., Grau, R. and Wiliams, T. (1992): Description and application of dual mass dynamic cone penetrometer, Department of Army Waterways equipment station, Instruction report GL-92-3

Whitlow, R. (2001): Basic soil mechanics, Pearson Education Limited, Prentice Hall, 4th edition, Harlow, England

Web sites:

http://www.dot.state.il.us/materials/research/pdf/ptat4.pdf

http://www.eurogeosurveys.org/.

http://www.geofond.cz

http://fraga.nitg.tno.nl/dinoLks/eEarth.jsp