Recommendations for guidelines for the use of GPR in asphalt air voids content measurement

Mara Nord Project in cooperation with:

European Commission, Finnish Transport Agency, Swedish Transport Administration, Norwegian Road Administration, ELY center, Lapin Liitto, North Calotte Council, Rovaniemi University of Applied Sciences, Oulu University of Applied Sciences, Roadscanners, Road Consulting, Carement, Ramböll Sweden, Malå Geoscience, Swedish National Road and Transport Research Institute, SINTEF, 3D Radar, NCC Roads

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PREFACE

Ground Penetrating Radar (GPR) is a non-destructive ground survey method that can be used in assessing roads, railways, bridges, airports, tunnels and environmental objects. Its main advantage is the continuous profile it provides of the road structure and subgrade soil. The GPR technique is becoming an increasingly important tool especially for structural evaluation of roads in the design phase but recently it has also been used more frequently in quality control and quality assurance of paving and construction projects.

The Nordic countries have reached a good level of skill and accumulated knowhow of GPR applications on roads over the last 15 years. However Finland, Sweden and Norway have slightly different practices in the use of GPR and, as such, that is why there is a need for common procedures when companies are increasingly operating across the borders. The level of knowledge, awareness and experience regarding the use of GPR in the Road Administrations vary in all three countries and there is a need to share the knowledge and develop procedures to ensure better quality of GPR services. To respond to these recognized needs, Mara Nord, an international cooperative project financed by Interreg IV A Nord, has been initiated among Finland, Sweden and Norway. In this project, one goal was to produce common guidelines that can be used as a reference in procurement processes in all three countries. Another reason is that, in quality control / quality assurance projects major economic sanctions can be implemented based on the GPR results and that is why the survey procedure has to be flawless and fair for all interested parties.

Johan Ullberg from Swedish the Transport Administration has been in charge of the guidelines. Mara Nord project lead partner has been the Rovaniemi University of Applied Sciences and experts participating have been Anita Narbro and Janne Poikajärvi. Other key experts have been Katri Eskola from the Finnish Transport Agency, Kalevi Luiro from the ELY-centre of Lapland, Finland, Per Otto Aursand and Leif Bakløkk from Norwegian Public Roads Administration, Rauno Turunen from Oulu University of Applied Sciences, Finland. This report on recommendations for the guidelines has been written by Timo Saarenketo from Roadscanners Oy, Finland.

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1. Introduction

Nordic countries have been pioneers in ground penetrating radar (GPR) applications on roads. The first applications were reported in the early 1980´s from Denmark and Sweden. In Finland subgrade soil and road structures have been analysed with GPR for almost thirty years and it is a tool routinely used in the Finnish Traffic Agency's rehabilitation projects.

This GPR method description guideline for asphalt air voids content measurement projects has been produced, because it is essential that current practice is described precisely so that new entrepreneurs will know how the ground penetrating radar surveys should be done and what the basic quality level for the results should be.

The results of a quality control survey can lead to, in the worst cases, major economic sanctions against the contractors and therefore the reliability requirements for the results are extremely high. Results have to be repeatable and outputs must be made in a way that eliminates all forms of speculation and/or manipulation of the results. In other words, results have to be indisputable and fair to all interested parties.

This method description guideline should be followed when doing survey design, data collection, analysis and reporting with a 2D GPR system prior to an asphalt air voids content measurement. In this publication, there is also an exact description of how the project results should be linked to road registry data bases or other GIS systems used in Nordic Road Administrations. Pertaining to the parts and methods not described in this publication, the other national publications and guidelines related to road construction quality control / quality assurance projects must be followed.

This publication also presents a short introduction to GPR theory and principles. The guidelines were written to meet the general guidelines and practices in the Nordic region but this document can also be used elsewhere in the world.

2. Ground penetrating radar (GPR) technology

2.1 General

Ground penetrating radar method is based on the use of radiofrequency electromagnetic (EM-) waves. The frequency range utilised is from 30 to 3000 MHz. Inside of this frequency range, it is said that EM- waves can propagate in a low electrical conductivity medium. Physical parameters affecting the wave are the medium's conductivity, dielectricity and magnetic susceptibility. In Nordic countries, magnetic susceptibility does not have a significant effect on a ground penetrating radar signal's behaviour.

2.2 Electrical Properties affecting GPR wave propagation

2.2.1 Dielectric value

Dielectric value describes a substance's ability to charge or polarize due to the influence of an electric field. After the electric field's effect ends, the substance returns to its' initial state. If the material's structure is such that its' initial state does not return completely, its polarization is partly lost. In such cases, dielectric value can be considered as a complex quantity, where the real part describes reversible polarization and loss is in the imaginary part. The most important element in molecular polarization in road materials and subgrade soil is the water molecule. The extent of dielectric value depends most on how much free water there is in the material because the dielectric value of water is more than 10 times higher than the dielectric value of other road materials. Therefore, increasing water content increases the dielectric value of the material. However in hot mix pavements there is no water present and its components are aggregate and bitumen and air. That is why dielectric value of asphalt depends on the volumetric proportions of asphalt´s components and the compaction degree. Dielectric value of bitumen is normally 2.8, dry and hot aggregate 5-7 and air 1.

2.2.2 Electrical conductivity

A medium's electrical conductivity describes the ability of free charges to move in the medium. External electric fields move charges from place to place. The more free charges, ions and electrons there are, the higher the conductivity of the material and ground penetrating radar attenuation. Salt causes problems with GPR signals but it is not normally present in newly paved asphalt pavements. A special material that has proven to cause significant GPR signal attenuation and decrease the reliability of asphalt air voids content measurements is steel slag.

2.3 Principles of different GPR systems

Ground penetrating radar hardware systems used on roads can be divided into two categories; impulse radars and stepped frequency radars. The principles of these systems are described in the following sections.

2.3.1 Impulse radar

Impulse radar is the most commonly used ground penetrating radar type. The working principle is described hereafter. A pulse, generated in a transmitter antenna, is sent into the medium. The length of the pulse is from under a nanosecond up to tens of nanoseconds, depending on the frequency. When propagating in road structures and subgrade soil a part of the pulse energy is reflected from surfaces of different electrical properties; some of them are propagated through the interface and are reflected back from the interfaces that follow. How the signal attenuates is a result of geometric attenuation, signal scattering, reflections and thermal losses. A GPR system records the two way travel time and amplitudes of signal reflections as a function of travel time are presented. When measurements are made rapidly between sequential survey points, it can be compiled as a GPR profile (radar image).

In the Nordic ground penetrating radar projects, the grey scale tone and a reflector polarity in the printouts should appear as in Figure 1.

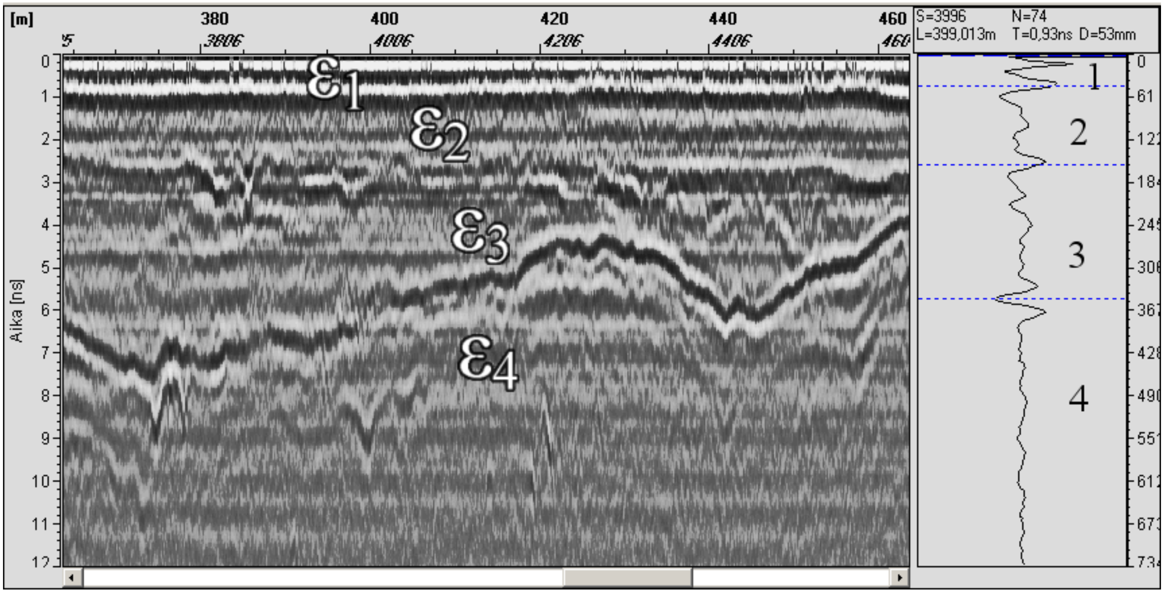

Figure 1. Ground penetrating radar profile, measured with an air coupled antenna and its individual pulse. The profile has reflections from interfaces of two mediums with different dielectric properties (ε). Image structure's layer 1 describes the pavement, layer 2 describes base course, layer 3 sub-base and layer 4 filter course. The figure shows that the dielectric value of materials (moisture) increases proceeding downwards from the road surface with the exception of the dielectric value of the filter course (ε4), which is less than that of the sub-base and, as such, the polarity of the reflection is inverted (black line in the middle of two white lines).

2.3.2 Stepped frequency radar principles

With a stepped-frequency radar, the radar waveform consists of a series of sine waves with stepwise increasing frequency. The radar measures the phase and amplitude of the reflected signal at each frequency and uses an inverse Fourier Transform of this data to build a time domain profile. Thus, the step-frequency radar collects data in the frequency domain and converts the data to time-domain data through computer processing. The resulting radargram is similar to impulse radar data, and it can be processed and interpreted the same way as impulse radar data. However, since stepped-frequency data are collected in the frequency domain, they allow advanced filtering and signal processing to be applied directly to the raw frequency domain data.

2.4 Principles of GPR image

2.4.1 Reflection and polarity

When a GPR signal propagates from medium 1 to medium 2 and medium dielectric values are E_1 and E_2, the reflection coefficient will be:

$$R = \frac{\sqrt{\varepsilon_1} - \sqrt{\varepsilon_2}}{\sqrt{\varepsilon_1} + \sqrt{\varepsilon_2}}$$

On the basis of the formula, the polarity of the reflection changes if E_1 is smaller than E_2, which is usually the basic situation in road and soil structures (water content increases when proceeding deeper). If E_1 is bigger than E_2, then the polarity of the reflected wave remains the same as the progressive wave's polarity at the interface. In road radar measurements, however, it is common practice that the surface reflection is recorded as positive, even though the reflection coefficient is negative. Similarly, the other layers, where $\varepsilon_{(upper)} < \varepsilon_{(lower)}$, are recorded as positive reflections. In the grey scale they should be presented in such a way that the white reflection is in the middle (see Figure 1. $\varepsilon_1 < \varepsilon_2$). Correspondingly, if the dielectric value of the lower layer is smaller than the upper, for instance in the structure of Figure 1 $\varepsilon 3 > \varepsilon 4$, the reflection is a so-called negative reflection and then the black reflection is in the middle. The GPR signal polarity, as it leaves the antenna and progresses into the medium, can be changed by 180 degrees by changing the positions of the transmitter- and receiver antenna or when doing GPR data post processing by multiplying the signal with a factor -1.

2.4.2 Depth penetration, resolution and interface depth

Achievable depth penetration with ground penetrating radar depends on what antenna frequency is used and therefore the wave length of the signal. The attenuation increases as GPR central frequency increases. A highly conductive medium results in an increase in the amount of energy scattering objects, as the length of wave gets shorter. Similarly, the penetration depth becomes smaller as the frequency gets higher. On the other hand the resolution improves at the same time. The resolution also improves as dielectric value increases.

Resolution refers to how close interfaces can be to one another and can still be identified as separate interfaces. This applies to both directions, horizontal and vertical. The vertical dimension's resolution of the pulse can be calculated from the following formula (1):

$$h = \frac{\tau \cdot c}{2 \cdot \sqrt{\varepsilon_r}}$$, where (1)

c	=	the speed of light in vacuum (0.3 m/ns)
τ	=	the pulse length (ns)
ε_r	=	medium's relative dielectricity

The depth to an observed interface can be calculated from the formula (2) (for monostatic antennas):

$$s = v \cdot t = \frac{0.5 \cdot twt \cdot c}{\sqrt{\varepsilon_r}}$$, where (2)

twt	=	two way travel time of the wave.

2.5 Ground Penetrating Radar in pavement air void content measurements

Since the late 1990´s GPR has increased in popularity in quality control surveys of new road structures. In the early years, GPR was used in quality control surveys only for road structure thickness verification (Al-Qadi 2003, Saarenketo 2008). Later, new GPR quality control applications included measuring the air voids content of asphalt and detecting segregation in asphalt were developed (Saarenketo 1998, 2008, Roimela 1998). The greatest advantages of GPR methods are that they are not destructive in comparison to the traditional drill core methods, costs are low and GPR surveys can be performed from a moving vehicle reducing safety hazards for highway personnel. The GPR method also presents the possibility of continuous linear data collection and thus 100 % coverage of a new road structure under inspection can be achieved. Drill core methods only provide point specific information and thus they cannot reliably be used to find defective areas in new pavements.

Ground penetrating radar (GPR) technology is used to measure the dielectric value of the asphalt pavement, which is then used to calculate the air void content of the pavement. The method is suitable for measurement of air void content of **new bituminous pavements only**, regardless of the quality of the base course.

The term "air void content" is used to represent the ratio between pore volume and the total volume of pavement and is presented as percentage.

The term dielectric value or “relative dielectric permitivity" refers to the capacity of a material to store, and then allow the passage of, electromagnetic energy when an electrical field is imposed upon it. It can also be described as a measure of the ability of a material within an electromagnetic field to become polarized, and therefore respond to, propagated electromagnetic waves. The dielectric value of a material is a function of volumetric proportions of its material components and the dielectric properties of these components.

3. GPR equipment in pavement voids content measurements

3.1 General

Most of the GPR equipment used in road surveys utilise pulse radar principles as previously described. Equipment for road investigations consists of several components (Figure 2). Antennas consist of a transmitter, which transmits the pulse into the medium and a receiver that receives the reflected signals. The antennas are controlled by a control unit, where the wavelength and strength of pulse are regulated. In digitizers, the received pulses are converted into digital format. A digitizer can be located in the antenna or in the control or central processing unit. The data collection setup is controlled with data collection software. Some setup parameters include scans per time or distance unit (for instance scan/sec, scan/m), measuring time window (ns), the number of the samples per scan (for instance 512, 1024 samples/scan) and the data format (for instance 8, 16, 32 bit). Calibrated optical encoders (distance measuring instruments) are used to trigger the control unit as the systems moves over a distance. Nowadays, GPS is also an essential part of GPR data collection and this also applies with digital video and still image capture process. A power supply is of course necessary for operation of the equipment.

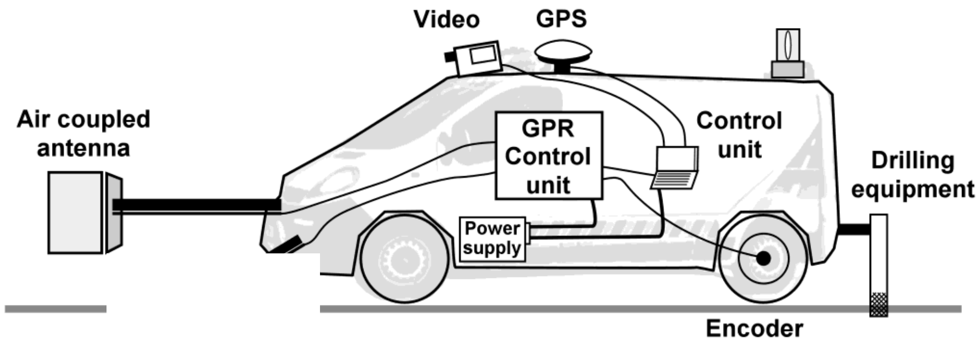

Figure 2. Typical instrument configuration of a ground penetrating radar van used in road surveys.

Air coupled antennas are mainly horn antennas, but lately other antenna types have also been developed. Frequencies vary from 400 MHz to 2.5 GHz, but the most commonly used central frequency is 1.0 GHz. Air coupled 2.0 - 2.2 GHz antennas are also available on the market. These antennas have proven to be effective, for instance, in detecting individual layers in bitumen bound layers, in gravel road wearing course thickness surveys and in locating steel nets. Normally the depth penetration of air coupled antennas is 0.5 – 0.9 m and that is why they are mainly used in pavement structure surveys. During the measurements, air coupled antennas are typically 0.3 – 0.5 m above the pavement surface. Since pulse radar air coupled antennas are suspended in the air, the antenna’s coupling does not change when electrical properties of the road surface change. That is why these antennas can also be used in repetitive measurements, where the ground penetrating radar data quality should not change if and when the properties of the road surface are changing. This makes it possible to calculate quality parameters on the basis of reflection amplitude and frequency response. In addition, air coupled antenna data collection can be done using survey speeds up to 80-100 km/h and thus without interruption to the other traffic.

Currently, there are several device manufacturers, which produce GPR equipment suitable for road surveys. The biggest ones are Geophysical Survey Systems, Inc. (U.S.A.), IDS (Italy), Mala Geoscience (Sweden), 3d-Radar A/S (Norway), Sensors&Software (Canada), Utsi Electronics (U.K.), Penetradar (U.S.A.), Radarteam Sweden Ab (Sweden), Geoscanners AB (Sweden). In addition, there are also several smaller companies involved in the business.

3.2. Theory of the test method

In the method, air void content and pavement thickness measurement is based on the measurement of dielectric value and GPR signal two-way travel time through the pavement. The dielectric value of a pavement is a function of the dielectric values and volumetric proportions of its individual components rock, bitumen and air. Compaction decreases the air void content in the pavement, which leads to a decrease in the volume of low-dielectric value component, air, and an increase in the proportional content of bitumen and rock. Thus, compaction leads to an increase in the dielectric value of the pavement.

A "surface reflection method", which can only be done with air-coupled antenna GPR systems, is used to determine the dielectric value of the asphalt surface. The dielectric value of pavement is obtained based on calculations of reflection amplitudes from electrical interfaces, such as the air/pavement interface. The air coupled antenna transmits electromagnetic pulses and their reflections from electrical interfaces are registered by a receiver antenna. When the EM pulses transmitted by the antenna meet an electrical interface, for example the pavement surface, a part of the energy is reflected and this reflection is registered by a receiver antenna. The GPR unit measures the respective peak-to-peak amplitude A1 for pavement surface reflection. Figure 3 illustrates the operational principle of a bi-static horn antenna system: the transmitter antenna (T) and receiver antenna (R) and numbers 1, 2, and 3 represent layer interfaces in the pavement structure.

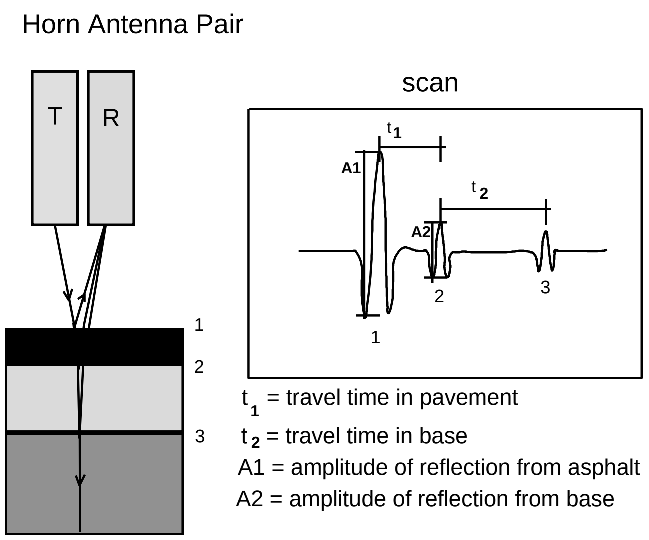

Figure 3. Operational principle of horn antenna.

The relative dielectric value of the pavement can be calculated by using the following formula 3:

$$\varepsilon_a = \left(\frac{1 + A_a / A_m}{1 - A_a / A_m} \right)^2 \quad \text{(3), where}$$

A_a is the reflection amplitude from pavement surface, and A_m is the reflection amplitude from a metal plate (complete reflection).

3.3. GPR system specification and calibration of the equipment

The Pavement GPR equipment includes:

- 1.0 – 2.5 GHz horn antenna (or other air coupled antenna) and antenna cable
- Transmitter / receiver electronics (if not already built into the antenna)
- Central unit with display containing data storage system
- Survey vehicle
- Computer (pc) for processing of measurement data

The equipment used in surveys should pass annual antenna specification tests (Scullion, Lau & Saarenketo 1996). Equipment should be calibrated after each survey using air pulse and metal plate tests. Optional calibration can be done using a rubber plate with a known dielectric value.

4. Survey planning and performance

4.1 Measurement timing, planning and information

Because paving projects are mainly finished in summer or early fall, this is also the time when quality control surveys with GPR are normally done.

In pavement and top part of the pavement structure quality control surveys it is recommended that air coupled antennas be used especially when the interest is bituminous pavement and unbound base thickness and their quality.

Before the final quality control survey order is agreed upon, the following checklist should be gone through with the client.

I. Construction quality:

   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

II. Antenna central frequency

   Based on the central frequency, there are, in general, two categories of air coupled antenna: a) 1,0 GHz horn antennas and b) 2,0 – 2,5 GHz horn antennas. When using antennas with lower central frequency and longer wavelengths the surface reflection info comes from a thicker slice, which starts from the asphalt surface, compared to that from a higher frequency antenna. That is why, in normal cases, it is recommended that a 1,0 GHz antenna be used in asphalt air voids content surveys, but if the amount of new asphalt is 60 kg/m2 or less then it is recommended that a 2,0 Ghz antenna be used.

III. Location of survey lines, density of measurement grid, cross sections

   The number and location of survey lines need to be defined with the client before the surveys and there are different practices. Finland has required data collection only from the outer wheelpath and Swedish guidelines require the survey to be done from the outer wheelpath and between wheelpaths. Swedish guidelines can eliminate the effect of traffic compaction from the results. That is why these guidelines recommend that, if only one survey line is measusured, it should be measured between the wheelpaths. However recent test results have shown that in addition to the two lines per lane it is also recommended that one line be measured along the pavement joint in lane centre.

IV. Positioning of a survey

One thing that has caused considerable confusion in evaluating a GPR quality control survey is the positioning of the survey. Before the survey is done one of the following options should be selected:

a. Positioning based on the construction/paving plan

   This means that survey starting point is normally 0 m and it ends at the end of the construction/paving project. This is a good and recommendable system. The designed structures can easily be compared with the GPR data. The only problem area is if thickness data should be transferred afterwards to road data bases. Though this can usually be done with many GPR software packages

b. Positioning based on road data base address

   This is recommended for use especially if a road construction project is not one continuous section but consists of separate sections, as is the case in many road rehabilitation projects. The advantage of this system is that structure information can be transferred directly to road data bases. Potential problems will occur in this system if the geometry of the road has been improved and thus the length of the new road does not match with the old road data base.

Positioning should always be based on the GPS coordinates.

V. Output formats for quality control documents

GPR surveys results in road construction quality control can be presented in numerous ways and the output formats have to be agreed upon beforehand. Descriptions of different output formats are given in chapter 6.2.

VI. Time table of the survey and delays

The time tables for pavement quality control works are normally quite tight and hectic because the final meetings between the contractor and client are, in most cases, arranged quite soon after the construction work is done. That is why any delays in planned time schedules can cause problems for the GPR service provider.

In addition, weather, like continuous heavy rain, present an unpleasant problem for the GPR data collection crew and may cause delays.

Before the surveys, a final plan should be sent to the client´s contact person, describing when and how the measurements are to be done, measurement equipment and personnel. The note can be sent via mail, e-mail, or fax or if this is not possible, then communicated over the phone. Safety considerations for the ground penetrating radar measurements are described in a road works safety plan required by each Nordic road agency. In general, survey crews must have the required national road work safety course documents and each country also require traffic safety plans and advance notice of GPR work especially on high volume roads.

Nordic government authorities may also require a radio license for the use of each GPR device in the country. These national guidelines may also define special geographical areas, such as airports, astronomical survey stations, hospitals, prisons or defence force areas, where the use of GPR is prohibited or a special license is required. Ground penetrating radar equipment, if working properly, will not cause interference but broken equipment can possibly cause false alarms.

4.2 Implementation of measurements

A minimum amount of four measurements (scans) per meter are recorded but currently the recommended density is 10 scan/m. The measurement time (range) used is 20 nanoseconds. Maximum measurement velocity is 50-60 kmph. One measurement covers an area of approximately 300 mm x 300 mm. Data collection is conducted as a continuous profile from the beginning to the end of the survey section. The position where the measurement is conducted has to be predefined with the client. The different surveys options have been described earlier in chapter 4.1. When needed, the contractor and the client of the paving project can agree on the amount, length and location of survey lines. If measurements are done on the wheel path the survey should be done within 3 weeks after the paving work is completed since traffic compacts the pavement.

Measurements are not allowed during rain or when the pavement surface is wet. Likewise, measurements are not to be conducted when the pavement is frozen. Survey speed should be constant and stopping minimized.

During the data collection, the GPR hardware must be safely and securely mounted on the survey vehicle and the measurements should be conducted in such a way as not to endanger the workers, road users or anyone in the close vicinity of the road. The survey vehicle must be equipped with nationally accepted warning lights and safety signs. To ensure GPR data quality and for traffic safety reasons it is recommended that there should always be two persons in the survey car, one focusing on driving and the other running and controlling the measurement devices. But the client can make the decision concerning the number of personnel. The measurement staff should have completed the necessary local road safety courses (Finland: Tieturva I, Sweden: Säkerhet på Väg, Norway: Kurs i arbeidsvarsling).

Road number, road section or distance, direction and the survey personnel should be marked into the header file. In addition, there should be a logbook in the survey vehicle in which time of the survey, survey equipment, weather, possible problems and other possible notes are documented. In addition, in Finland, Ficora requires that the following survey information is documented: the location, date, time, unit serial number, antenna types and serial numbers used in each survey. In practice each central unit has a logbook, where all the surveys are documented with the required information.

Before starting a survey, the correct location must be ensured. Usually the surveys start and end in road registry's start and end points or nodes or at the start and end of the new pavement. If the survey does not follow the road registry, the start and end point should be marked with paint on the road, unless they are simple and unmistakable locations such as culverts or bridge joints. As described in chapter 4.1, when surveying new roads and pavements it is sometimes easier to follow project distance and chainage.

The GPR operator can add markers at locations of intersections, bridges, culverts, etc. These markers can be used to link the GPR file and video, unless linking has been done already during the survey. Markers are also used, when two or more lines or lanes are surveyed and there is no GPS from all survey lines.

When using air coupled antennas, after every survey session and before the GPR unit is switched off, a metal pulse reflection should be recorded. It is recommended that a metal reflection is also taken before the start of the measurement. In addition, if a height correction file is not available, a "bouncing file" should be recorded. This is described in the MaraNord rehabilitation guidelines.

When measuring with an air coupled antenna, the so-called "direct pulse" (from transmitter antenna to receiver antenna) must be completely visible all the time.

4.3. Reference data

Air voids content calculations using GPR technique requires calibration drill cores and at least 2 drill cores have to be taken and analysed. The place of the drill cores should selected first by measuring the whole road section and then by selecting places for the calibration cores from homogenous sections where dielectric value of the asphalt surface is close to the approximate average Er value of the new asphalt. Drill cores should be also taken if paving mixture, materials or technique has been changed. If different dielectric values are measured from different lanes, calibration drill cores should be taken also from these places.

Another option to collect calibration and reference information from a GPR analysis is to make a reference test section at the beginning of each project. This could be done on a section with variations in the number of compaction roller passes as described in figure 4. This procedure would allow an asphalt contractor to receive information about the number of compaction roller passes necessary to obtain proper asphalt density. The problem here is that it can be complicated to arrange for a GPR system to be on-site when paving starts on the new section which is also being used as the reference test site.

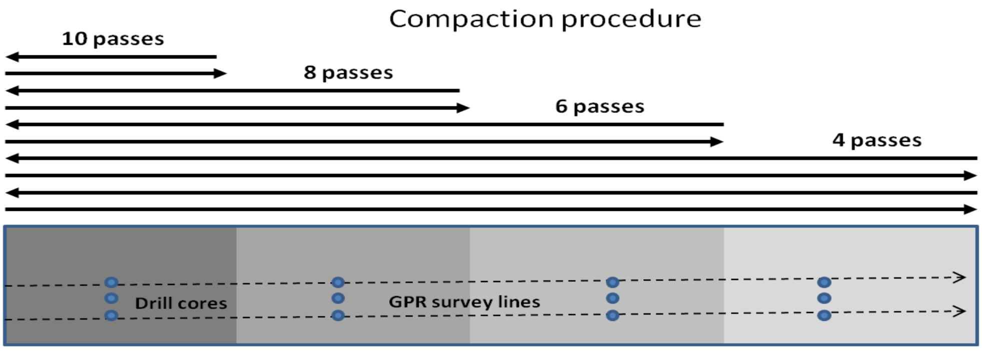

Figure 4. Example of compaction calibration procedure that could be used on a site before the actual compaction work starts.

4.4. Measuring accuracy

The measuring accuracy for air void content measurement using GPR surface reflection technique is +/- 0,9 percent (Roimela 1998). This statistical analysis result has been achieved through comparison of core sample results and GPR measurements conducted as static shots over each individual measurement point (R=0,9223).

4.5. Other survey data

Other survey techniques that can be used together with GPR in asphalt quality control surveys are digital videos, thermal cameras, 3d accelometers and laser scanner techniques. Digital video and thermal camera data provide supporting data and help with the analyses of the causes for problematic sections, such as segregation, found in the GPR surveys. A 3d accelometer provides information about the evenness of the asphalt surface and laser scanner emission data can be used to calculate the paved area.

5. GPR Data Processing and Calculation of air voids content

5.1 General

A primary goal of the GPR surveys in pavement air voids content control is to provide information about the pavement quality for the road owner or for the contractor. If the data collection has been carried out properly with the appropriate equipment, the quality control documents can be produced with careful and professional processing and interpretation. The following chapters describe the general guidelines for data processing and interpretation.

5.2 Preprocessing

In this case, preprocessing means GPR data editing and combining road design data and other data collected during the quality control process. Data editing includes operations which do not change the original information content of the data. This means distance scaling, joining and splitting of different lines and reversing directions.

Frequently the coordinates at certain points on a survey line are known and these points should be linked to the data such that their z-coordinates are also stored. Recently, in most cases, coordinates are collected simultaneously during the surveys, using real time GPS systems.

5.3 Data processing and calculation of air void content

Processing of air coupled antenna data is described in Mara Nord GPR guidelines for road rehabilitation projects and detailed descriptions can also be found in GPR text books and software manuals made by different GPR manufacturers.

The calculation of air void values is based on the use of mean dielectric values. The method applies the results of laboratory tests conducted to define the function between the dielectric value and air void content (Roimela 1998). The method includes taking 1-2 calibration core samples from the pavement under survey, representing sections of mean dielectric value calculated after GPR data collection. Air void content of the calibration cores are defined using laboratory methods approved by national asphalt standards and guidelines. Using the air void content value obtained from the calibration samples, and their respective dielectric values, a calibration coefficient is determined for the calculation of air void contents of the pavement. The formula for calculation of air void content (y) is presented as formula (5):

$y = 272{,}93 e^{-1{,}3012 k \varepsilon_x}$, x between $1<x<n$ (5), where

k is the calibration coefficient

ε_x is the measured dielectric value using GPR surface reflection method

There is a more detailed description of the method in the publication “Päällystetutkatutkimukset 1996-1997” (Roimela 1998).

When calculating dielectric value of asphalt surface temperature drif correction should be made from the air coupled antenna data.

6. Reporting and Delivery of Results

6.1 General

When delivering Ground Penetrating Surveys in Nordic Countries, the results and collected data should always be delivered as scaled GPR data (data that has been used in interpretations), a bitmap of the GPR profile is not enough. The ownership of the data also stays with the client if not otherwise agreed.

The ground penetrating radar results (and printouts) are given in digital format copied or zipped to a memory stick, DVD or external hard disk drive. There are many ways to report and deliver the data and the client can request one or several of them.

6.2. Reporting formats

The results are presented in diagrams (longitudinal profiles) or tables as mean values for one, three or five meters. In the longitudinal profile diagrams, the measured dielectric value and location of sample drillings with the results should also be presented.

The results can additionally be presented on a GIS map. This requires obtaining location information of the object consistent with the road register.

The survey results include mean value, standard deviation, as well as meters and percentages above and under the limiting values of air void ratio. The results are calculated for the whole survey object and individually for each measurement line. The results calculated for the whole object, as a basis for eventual compensations, are decisive.

In the report, at least the following results should be presented:

- Measurement organization
- Client organization
- Survey method, used equipment and used software
- Used void content limits, based on for example:
  PANK ry 2000 Pavement norms
  0 – 5 % for a single sample
  0 – 4% for the average
- Proportional class with its additional information, for example why higher limits are being used compared to norms
- Type of asphalt mixture
- Object number
- Measurement date
- General information regarding the object
- Total length of the object
- Measurement length
- Measurement interval, if it differs from the measurement length

The final output table presents the results of the calculations, average, standard deviation, lengths (m) exceeding the upper limit or less than lower limit and the average dielectric value of the measurement line. Results can be presented separately for each measurement line and for the whole object.

Whether the interrelationship between the dielectric value and the void content is exceptional, the reasons have to be clarified in the report. As an example, one form of delivering the outcomes is presented in Appendix 1.

A GPR survey consultant should also release a brief report to the client, where the surveys are described.

6.3 Printing to an image file

The image files should be delivered in png-format. An A4-sized horizontal page should be the minimum of width=1096 x height=756 pixel. The client determines how long a distance should be printed on a single page. If the size is not specified, 500 meters on one page in 20cm/m scale. The image files should be named so that the road number, section (if road sections are used) and distance are in the title and also numbered. For instance: 21_216.001 PNG, 21_216.002 PNG.

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Saarenketo, T. 2008. NDT Transportation. Chapter 13 in text book “Ground Penetrating Radar: Theory and Applications” Ed- Harry M. Jol. Publisher Elsevier, 524 p.

Sebesta, S. and Scullion, T. 2002. Application of Infrared Imaging and Ground Penetrating Radar for Detecting Segregation in Hot-Mix Asphalt Overlays. Transportation Research Board Paper, 15 p.

Appendix 1

COMPANY OY
Address
00000 Helsinki

Void content report 2012

Client Organization/ Name
Address

Object: HW 007 Place A – Place B, both lanes **Object number:** 212121

Measurement method:GPR *MODEL*, air-couples antenna *FREQUENCY*
Software: N.N.

Void content limits: Norms **Mix:** AB
Asphalt mix class: A
Requirement: 0 - 5 % for single sample **Date:** 1.6.2012
1 - 4 % for average

Lenght of the object: 10 000m
Measurement lenght: 20 000m

Section 1 start:	0m
Section 1 end:	6 000m
Section 2 start:	8 000m
Section 2 end:	10 000m
Analysis length	8 000m

Comparement object: *Comparement object, which has been used for calibration*

Calibration factor: **0.6265**
Average void content –value based on calibration factor 3.25
and related average dielectic value 6.97

Object information	Void content (%) Average	Deviation	Single sample below (%)	Single sample below (m)	Single sample Over (%)	Single sample Over (m)
Lane 11	2.93	0.65	4.48	13.13	3.93	314.40
Lane 12	2.33	0.29	15.06	1204.80	0.00	0.00
Lane 22	2.51	0.39	12.02	23.92	0.49	0.98
Lane 21	2.57	0.34	3.75	300.00	0.48	38.40
Total main lanes	**2.75**	0.50		1541.85		**352.80**

Additional info:

Place 1.6.2012 Tauno Tutka, Päällystetutkaajat Oy

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