Experiences of integrated GPR and Laser Scanner analysis – We should not only look down but also around

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ABSTRACT

The underlying causes of geotechnical problems on roads have traditionally been tackled by drilling and/or taking samples through and under the road structure. These types of investigation are however both expensive and traffic intrusive and, as the latest tests with new non-destructive road survey techniques have shown, can often lead to false diagnostics and rehabilitation solutions that do not work in the long term.

This paper will demonstrate the benefits of the integrated analysis of ground penetrating radar (GPR) and laser scanner (lidar) data in road structural condition surveys. This will include the analysis of drainage condition, the use of GPR in detecting anomalous moisture in road structures and subgrade soils, and how laser scanner data can provide information regarding drainage structures and drainage related deformations on the road surface. Cases will be provided on how GPR can be used to detect ice lenses and unfrozen water in the frozen ground as well as examples of the use of GPR and laser scanner analysis in road embankment stability problem diagnostics. Finally, examples of the integrated analysis of GPR, Laser Scanner and Traffic Speed Deflectometer data, collected in Finland, will be summarised.

Keywords: ground penetrating radar, laser scanner, diagnostics, drainage, permanent deformations

1 INTRODUCTION

The main traditional procedure for engineers working in road problem diagnostics and rehabilitation design has been to look directly under the pavement. This assumes that all of the sources of problems are related to pavement structure thickness and material properties, and the moisture content of road structures and subgrade soil beneath the pavement. This strategy has however often led to imprecise conclusions as to where the root causes of the underlying problems really are. A good example is that of capillary action which is described in almost all figures in civil engineering text books as a vertical force adsorbing moisture from the subgrade under the road.

Such traditional strategies have now started to be challenged thanks to the results obtained by modern road survey techniques and their integrated analysis. When considered together good visualisations can be produced of the relationship between road structures, road geometry and the condition of the road surroundings over different seasons. As an example, the results of these new methods of evaluation have given new valuable information concerning the importance of well functioning road drainage. A good drainage system is not just an issue for summertime, it should be also be maintained during the wintertime.
This paper will present experiences and latest findings of road problem diagnostics made based on the results of GPR, Laser Scanner and Traffic Speed Deflectometer surveys carried out by Roadscanners.

2 SURVEY METHODS

2.1 Ground Penetrating Radar

Ground Penetrating Radar systems use discrete pulses of radar energy with a central frequency varying from 10 MHz up to 2.5GHz to resolve the locations and dimensions of electrically distinctive layers and objects in materials. Pulse radar systems transmit short electromagnetic pulses into a medium and when the pulse reaches an electric interface in the medium, some of the energy will reflected back while the rest will proceed forwards. The reflected energy is collected and displayed as a waveform showing amplitudes and time elapsed between wave transmission and reflection. When the measurements are repeated at herz frequencies (currently up to 1000 scans/second) and the antenna is moving, a continuous profile is obtained across the target (Saarenketo 2006). In addition to pulse radar GPR systems (Figure 1) stepped frequency radar systems are also entering the road survey markets.

The propagation and reflection of the radar pulses is controlled by the electrical properties of the materials, which comprise 1) magnetic susceptibility, i.e. magnetism of the material, 2) relative dielectric permittivity and 3) electrical conductivity. The magnetic susceptibility of a soil or road material is regarded as equal to the value of the vacuum, and thus does not normally affect the GPR pulse propagation. The most important electrical property affecting GPR survey results is dielectric permittivity and its effect on the GPR signal velocity in the material and, as such, it is very important to know precisely how to calculate the correct depth of the target (Hamrouche and Saarenketo 2012).

In road surveys the GPR method has been traditionally used to measure the thickness of the pavement structure layers. Recently however GPR systems have been improved and their data analysis has also enabled material properties such as moisture content and susceptibility to permanent deformations to be calculated (Saarenketo 2006, www.roadex.org).

Figure 1. Road survey system equipped with ground penetrating radar system (in front) and a 2D laser scanner (at the back).

2.2 Laser scanner

Laser scanning is a technique where distance measurement is derived from the travel time of a laser beam from the laser scanner to the target and back. When the laser beam angle is known, and beams are sent to a range of directions from a moving vehicle with a known position, it is possible to make a 3D surface image, or ‘point cloud’, of a road and its surroundings. The point cloud can have millions of points, with every point having x, y & z coordinates and additional reflection or emission characteristics. The accuracy of a laser scanner survey can be affected by factors that reduce visibility, such as dust, rain, fog or snow. High roadside vegetation can also prevent the capture of information from the hidden ground surface.

A laser scanner is composed of three parts: a laser canon, a scanner and a detector. The laser canon produces the laser beam, the scanner circulates the beam and the detector measures the reflected signal and defines the distance to the target. The distance measurement is based on the travel time of light, or phase shift, or a combination of both. Laser scanner systems can be classified into two types of system: 3D laser scanners that can be used for mobile mapping, and 2D laser that is designed to be used in basic pavement engineering projects (Figure 1) (Saarenketo et al. 2012).

The great advantage of laser scanner data compared to, for instance, profilometer data is that data can be collected outside the pavement area. This allows the connections between drainage defects and pavement failures to be shown visually. The greatest benefits of 2D and 3D laser scanning systems are gained when they are used together with other NDT pavement systems.

2.3 Traffic Speed Deflectometer

Deflection measurements have a key role in evaluating the structural condition of a pavement structure and the fatigue level of the asphalt. With the help of deflection surveys, it is possible to locate road sections that are still visually in good condition but which will become distressed very soon if appropriate measures are not taken. Traditionally deflection surveys have been carried out with falling weight deflectometer systems but their limitation is that they are point measurement and are traffic intrusive. The new solution for this problem is the traffic speed deflectometer (TSD) (Figure 2) that measures continuous deflections of a pavement under a moving 10 tonne axle load using Doppler sensors. The normal survey speed with this truck is 80 km/h so it does not require any protection during the survey. Deflection bowls similar to FWD can be calculated from the TSD measurements.

Figure 2. TSD truck used deflection surveys in Finland.

3 INTEGRATED DIAGNOSTICS USING GPR, LASER SCANNER AND TSD DATA – SELECTED CASES

3.1 Damages related to private access road culverts

ROADEX research using modern survey methods has revealed new findings regarding the factors that affect the condition of low volume roads in Northern Europe (www.roadex.org). One of these is the significant amount of road damages that are related to poorly performing private access road culverts. Figure 3 presents examples from Rd 934 in Finland where more than 50% of high frost heaves were located close to private access roads. The culverts at these points were clogged in the early spring when the snow started to melt and the road was still frozen. This caused water to infiltrate into the frozen road structures causing frost heaves. Figure 4 shows the consequence of this infiltration, which can be normally seen as permanent deformations in the road shoulder.

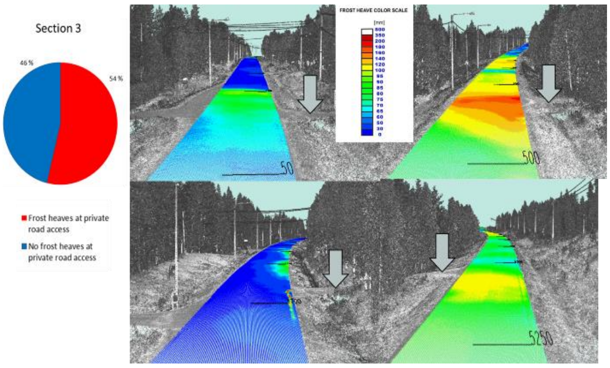

Figure 3. Examples of 3D laser scanner frost heave survey data. Frost heaves are clearly related private access roads and their clogged culverts. Statistics on the left show that more than 50% of the frost damages are linked to private road access.

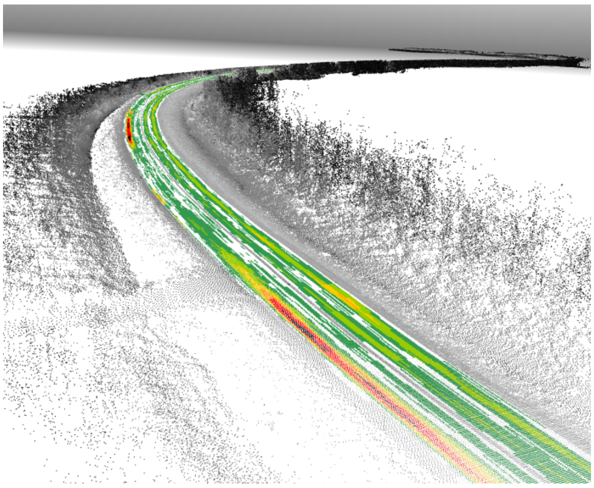

Figure 4. Rutting analysis, based on 2D laser scanner data, shows that shoulder deformation can be related to private access road.

3.2 Main road culverts and slope stability

A new development in GPR analysis is the analysis of the saturation level in the road structure. This is based on the fact that at high saturation levels (>80%) the material attenuates the high frequency components of the signal and thus the relative amount of low frequencies is increased. This can be presented on GPR profiles as Figure 5 from Rd A83 in Scotland shows. In this case a main road culvert was clogged under a road located on sloping ground. Due to this the embankment around the culvert was saturated with water, and this had already caused a shear failure close to road shoulder at the time of the survey.

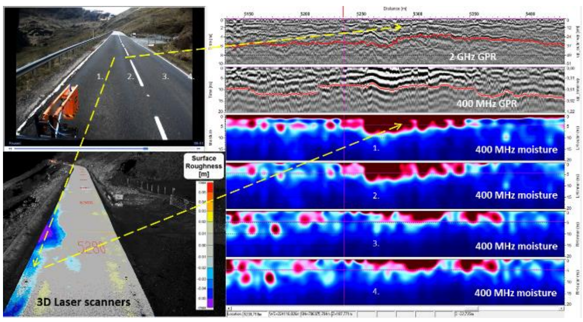

Figure 5. GPR data and moisture analysis and laser scanner profile from Rd A83 in Scotland

3.3 Frozen main road ditches

Frost heave analyses based on laser scanner surveys have shown that the depth of the ditch is not the only critical factor in road drainage management. Figure 6 presents a case from HW4 in Finland where ice has formed in the bottom of a ditch during the winter and has eventually filled it. In springtime the water melting from the snow infiltrates into the frozen road structure causing formation of ice lenses and differential frost heaves. This problem could be detected in 2011 and 2013 as figure 6 shows.

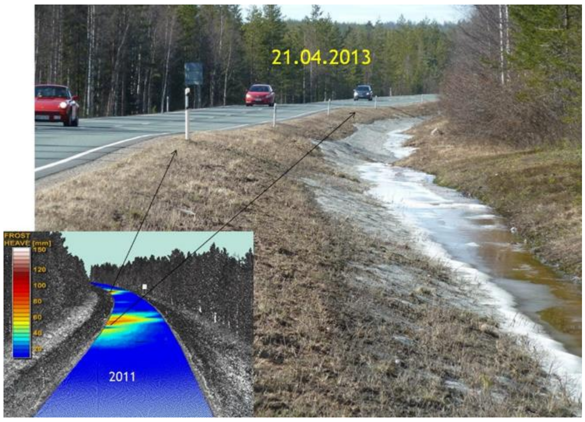

Figure 6. Laser scanner data based frost heave analysis from HW4 in Finland. The ditch is filled with ice and in the summer the bottom of the ditch is 60 cm deeper than the ice surface.

3.4 Detecting unfrozen water in frozen pavement structures

The GPR moisture analysis technique is also sensitive in detecting unfrozen water in frozen material, i.e. the presence of segregation ice. This information, together with laser scanner data analysis, has brought valuable new information regarding the importance of early snow removal from road shoulders. Figure 7 from Rd 3662 in Finland shows that water melting from the road shoulder is infiltrating into the frozen pavement and base course forming ice lenses. Permanent deformations can be seen to take place exactly on these locations later as a result of the excess amounts of water melting from the ice lenses. Rutting analyses reveal 1.5-2 times higher rut depths at these locations.

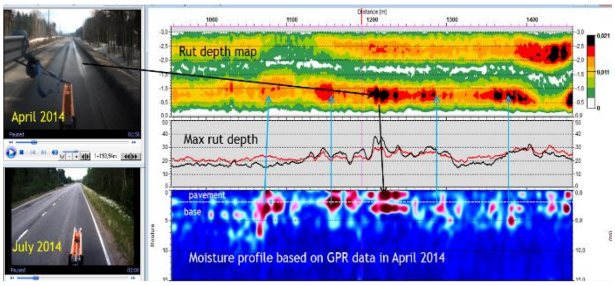

Figure 7. Rut depth maps from right line (top), maximum rutp depths (middle) and GPR moisture analysis (bottom) from 2 GHz data measured in April 2014 (photo left above).

3.5 *TSD and laser scanner data analysis and Mode 2 rutting*

Traffic Speed Deflectometer data and its integrated analysis can also provide new information on the failure mechanism of both highways and low volume roads. A good finding has been the close relationship between the Base Curvature Index (BCI), calculated from the TSD data, and Mode 2 rutting that can be seen as shoulder deformations in laser scanner data. Figure 8 provides a good example from Rd 3662 in Finland where severe road shoulder deformations were found on sections with BCI values higher than 80. Very often these sections with high BCI values also had problems with poor drainage.

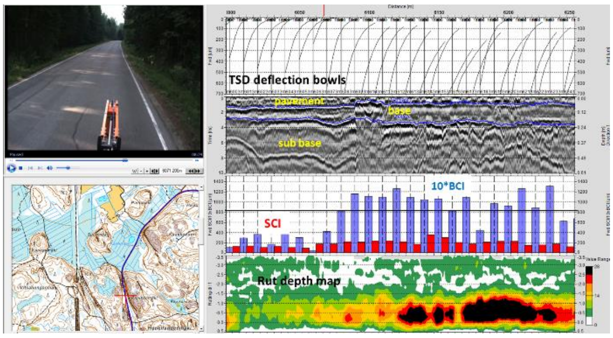

*Figure 8. TSD deflection bowls (top field), 2 GHz GPR data (2nd field), SCI and 10*BCI values (third field) and laser scanner rut depth map from Rd 3662 in Finland.*

4 CONCLUSIONS

The experiences of integrated analysis of GPR, Laser Scanner and TSD data over the last few years have provided greater understanding of the root causes of road problems in cold climate areas. Poor winter maintenance and delayed removal of snow walls, for example, seem to have a great effect on the formation of permanent deformations on road shoulders. This is especially the case on narrow low volume roads. Clogged access road and main road culverts are also often the main reason for early phase pavement damages on roads.

These types of problems can however be easily treated through better maintenance policies and standards. The new technologies presented in the paper will also be a great help in moving towards more proactive maintenance strategies in the future. This will lead to substantially longer pavement lifetimes with the consequential potential for major savings in annual road paving costs.

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