Introduction of Ground Penetrating Radar in Pavement Rehabilitation in Norway

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Abstract

The recent development of Ground Penetrating Radar (GPR) technology has open up a whole range of new possibilities for better planning and performance of road rehabilitation. In Norway this technology has so far been just tested in a limited number of projects. The Norwegian University of Science and Technology in co-operation with the research organisation SINTEF has now purchased a 3-D GPR system that makes it possible to investigate road structures prior to rehabilitation.

It is believed that use of this new technology will significantly increase the benefit from scarce public funding for rehabilitation of roads and reduce the errors or sub-optimal solutions that occurs from time to time as a consequence of not knowing what kind of layering and materials are present.

In addition to be a useful tool to investigate the structures prior to rehabilitation, the GPR is also very well suited for quality control after construction.

1. Introduction

Rehabilitation of roads will be increasingly more important in Norway (Lerfald, Hoff 2004). Many years with insufficient funding for maintenance of pavements have caused a decreased standard of the road network and simple resurfacing will not be sufficient in many cases. Previously the basis for selecting sections for strengthening was falling weight deflectometer tests (FWD) that were performed on a routine basis at network level. From the FWD tests the bearing capacity of the road sections was calculated using an empirical method. However this strategy is no longer considered cost efficient and today the need for strengthening is determined by estimating the pavement life period from annual rut measurements.

The new practice might be efficient to identify weak sections, even if it is necessary to wait until the damage has taken place. However, to be able to choose the optimal method for rehabilitation and design it is necessary to gather more information about the existing structure.

Recent advances, in GPR-technology (Eide 2000) have made it possible to get more information out of this method and make this a practical tool for pavement engineers both for network level surveys and for project level investigations. The GPR-technology has been taken into use in several countries but in Norway only limited testing of this method has been done.
However, as a new system has been bought by the Norwegian University of Technology (NTNU) in co-operation with the research institute SINTEF, this tool is now being taken into more widely use.

2. **Three-dimensional ground penetrating radar (3D-GPR)**

The GeoScope is a three-dimensional step-frequency ground penetrating radar that uses antenna array for precise and rapid data acquisition. The GPR transmits electro-magnetic waves through an antenna array and measures the echo from layers and objects in the subsurface. The depth of the objects is found by measuring the travel time from the signal is transmitted until the echo is received. By multiplying this time with the wave velocity of the signal, a depth estimate is obtained.

The GeoScope can generate waveforms from 100 MHz up to 2 GHz with as much as 1000 frequencies with waveform lengths of 0.5-10 milliseconds (Figure 2). The step-frequency technique has a coherent receiver which means that the whole waveform length in milliseconds is used as 100% efficient integration time. By comparison, impulse GPRs use stroboscopic sampling with significant loss of energy. Figure 1 shows a photo of the GeoScope 31-channel antenna array.

![Figure 1. The 31-channel GPR-antenna array mounted suspended in front of the car.](image)
The step-frequency waveform gives optimum source signature with a uniform frequency spectrum. The computer control allows the user to set the dwell time on each frequency as well as the start and stop frequencies.

The GeoScope sequentially transmits one complete waveform on each transmitting antenna while receiving on the corresponding receiving antenna. The transmission of one complete waveform on one transmitting element is called as scan. The recorded frequency domain data contain one complex value for each frequency in the waveform. The radar system performs real-time time domain conversion through Fast Fourier Transform allowing the user to view B-scans from one antenna at a time. Raw data can be stored in the 3DR data format either as time-domain or frequency-domain for post-processing.

**Figure 2.** Frequency span used for the 3-D GPR.

Figure 3 shows an example of measurements of a road section interpreted for layer thickness variation. As can be seen from the figure the layer variation is quite severe and problems with longitudinal unevenness should be expected.
Figure 3. Measurements with GPR interpreted for layer thickness variation
3. Identifying weak sections by network level surveys

In addition to the annual measurements of rutting and unevenness (IRI) the 3D-GPR could be a very useful tool to identify weak sections prior to severe damages. Williams et al (Williams, Martin 2006) concluded that the use of GPR made it possible to collect large quantities of information about the structures that otherwise would have required very much effort. They also recommend to combine GPR measurements with FWD and cored samples. One of the important benefits from performing GPR is the possibility to identify the sections most suited for additional testing.

The ability to “see” saturated materials and in some cases also ice-ences makes this a very useful tool for the Norwegian low-volume network which experiences severe problems with frost heave and spring thaw weakening almost every year. With the expected climatic change this problem is believed to worsen with more rapid changes between freezing and thawing.

4. Investigations of sections before rehabilitation

After the sections have been selected for rehabilitation based on the network level investigation and priority through some form of Pavement Management System (PMS), the next level is to determine the appropriate action for the selected section and to design the rehabilitation. Today this is done differently from region to region in Norway based on very limited use of information from measurements of the road.

A GPR survey performed before rehabilitation can give information about:

- Layer thickness
- Materials
- Depth to bedrock or weak subground
- Water properties
- Homogeneity of the structure
- Large particles/stones in base layer
- Water pipes and other utilities

All of this information will be very useful in planning the rehabilitation of a road section. The economic benefit from being able to utilise the remaining value of the existing infrastructure is substantial. If one adds the saving from not choosing rehabilitation method that will have little effect, e.g. deep milling/stabilisation in a base layer with a lot of large particles/stones, the use of a GPR prior to rehabilitation will be cost effective and should be used in most cases.

5. Quality control after new construction or rehabilitation

The new standardised system for quality control of asphalt production is believed to improve quality of the asphalt mix itself. However, it is well known that the placing and compaction is of equal importance to the performance of the asphalt pavement. For the road owner it is important
to have a system for quality control that is efficient and reliable. As even bad pavements will perform well in a few years depending of the traffic it is necessary to catch the weak pavements just after construction to be able to complain to the contractor. Traditional quality control of asphalt is a cumbersome process with time consuming sample coring. It is also very difficult to know where to take the cores, and depending on the priorities of the person determining the spots for coring, it is easy to get bias into this system. Coring also punctures the new pavement and even with careful repairs the cored holes might be initiating point for future damages.

One of the most interesting parameters to evaluate for quality control is the actual thickness of the asphalt layer. Al-Qadi and Lahouar (Al-qadi and Lahouar 2005) concluded that GPR gave most accurate results for thick asphalt layers and less good results for thin layers. Saarenketo and Scullion (Saarenketo and Scullion 2000) found an accuracy of about 3 -5 % for new pavements but proposes to also take cores for older pavements to achieve the desired accuracy also for these pavements.

6. Use in research projects

For research projects where test sections are evaluated it is extremely important to be able to determine the variation of layer thickness. Fauchard et al (Fauchard, Dérobert 2003) used the GPR to control test sections performed at the LCPC circular test track with promising results. The new GPR-equipment is planned used for the field verification test sections in the NordFoU-project on “Pavement Performance Models”.

It is well known that the use of salt for ice removal dampens the signal significantly. This might be considered a limitation for use of the GPR. However, SINTEF/NTNU plans to utilize this effect to measure the residual salt concentration on the road after preventive salting. This would be an effective instrument to help optimize the salt use to secure good friction with minimal environmental impact.

7. Conclusions

Use of Ground Penetrating Radar is going to be increase quality of planning and performance of rehabilitation of roads in Norway through measurement of:

- Layer thickness
- Materials
- Depth to bedrock or weak subground
- Water properties
- Homogeneity of the structure
- Large particles/stones in base layer
- Water pipes and other utilities

It will also be very useful for quality control and a lot of other applications.
8. References


