

Subsurface Sensing Technologies and Applications (AM101)

Using Ground Penetrating Radar for Assessing Highway Pavement Thickness

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ABSTRACT

Surface distress is a fairly good indicator of rehabilitation needs but it does not directly relate to remaining life estimates. Mechanistic pavement design requires that strains be calculated utilizing more or less complex modeling. Over the years many devices measuring surface deflections under a given load have been developed. The device by choice for assessing strains due to load is the falling weight deflectometer (FWD). It creates an impulse load on the pavement surface. The data are commonly used in models for backcalculation of elastic moduli and strains. More complex modeling would involve finite element or dynamic element methods. The FWD method has proven to be an excellent tool for overlay design. For this purpose its simplicity and straightforwardness are well documented. However, to successfully backcalculate layer stiffness adequate layer thickness is needed. Thus there is a strong need for assessing layer data at testing points. Using Ground Penetrating Radar (GPR) it is possible to achieve data without coring. The present paper is a part of an ongoing bearing capacity study carried out by a regional road administration in central Sweden. Its objective is to optimize testing for equipment and methods used and presently available. In addition to evaluate the results from the study, the present paper discusses some other applications for GPR that may evolve from it.

Keywords: GPR, high-speed non-destructive testing, highway overlay design.

1. INTRODUCTION

The Swedish National Road Administration (SNRA) manages about 100 000 km (centerline) of roads. Pavement management input data are primarily based on surface characteristics. These data are assessed at an adequate sampling rate by several surveying vehicles operating up to 90 km per hour.

Pavement management systems (PMS) is a methodology for optimizing the use, repair and maintenance of roads, streets and highways for road authorities like cities, states or nations. The principles of PMS are amply described by Haas and Hudson¹. In short a PMS will let administrators model long-term consequences of restricted budgeting on the entire road network. Also, it assists pavement engineers in ranking projects most needed for repairs and maintenance concerning such aspects as traffic safety, travelling times and transportation quality in general. Further, it should advise not only that maintenance and repair should be done, but also when, what and how to do it.

Like in any modeling there is a way of describing the status of the system. By tradition, the highway community likes to categorize pavement properties as either functional or structural ones. The former properties are important as they describe how the motoring customers value their trips. Typically one would associate roughness as a very fundamental property. There are a few others like friction, drainage and perhaps rutting contributing to the comfort of the trip, the traveling time and safety of the passengers. Evidently, the surface of the road will largely influence these functional properties and indeed quite

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a few devices are used for assessing such data. Gathering surface characteristic data is done travelling at traffic speeds. However, the data will only provide information of the present state and at best the rate of deterioration if a series of measurements over time is available.

When major maintenance or repair such as an overlay is needed more data are needed for the structural modeling. Such information lets the pavement engineer calculate the need for and the design of extra layers. Unfortunately, traditional means of gathering data are slow, and in some case not non-destructive. The present paper is addressing how Ground Penetrating Radar as a Non-Destructive Testing (NDT) method can be utilized in existing PMS practices. The intention is not only to demonstrate what can be done, but also to give a background of the needs of pavement engineers so that GPR manufacturers and practitioners will have a better understanding of what is wanted. An example case from a regional road administration is also included in the paper.

2. CURRENT PROCEDURES FOR STRUCTURAL EVALUATION

As mentioned above pavement management input data are primarily based on surface characteristics. Even if the surface distress is a fairly good indicator of rehabilitation needs it does not directly relate to remaining life estimates. Mechanistic pavement design requires strain calculation utilizing more or less complex modeling.

Over the years many devices measuring surface deflections under a given load have been developed. E.g. the Benkelmann Beam, the LaCroix Deflectograph and the Dynaflect vibrator. A common device for assessing strains as a function of load is the falling weight deflectometer (FWD). It creates an impulse load on the pavement surface. The load, mimicking the one from a passing truck axle and typically seven deflections at various points from the load are recorded. The data are commonly used in models for backcalculation of elastic moduli and strains. The FWD method has proven to be an excellent tool for overlay design. For this purpose its simplicity and straightforwardness are well documented.

In some smaller countries the FWD is also used for assessing bearing capacity on a road network level. However, the relatively low capacity per unit makes it less attractive for this purpose on large networks. In addition the FWD stationary operation mode requires lane closures and high user costs for reduced capacity on high volume roads. The need for a device that will assess deflections without stopping and with a much better capacity than current procedures is undoubtedly high, and currently there are systems being developed for that purpose^{2 3}.

The FWD (or by other means) gathered deflection data are used to calculate stresses and strains in the structure on which overlay designs are decided. A typical pavement model is shown in Figure 1 below. The load is corresponding to a standard axle truck tire. The E stands for E-modulus and the mu for Poisson's ratio. The d:s represent the thickness of the pavement layers. The white arrows are critical points in the structure. More complex modeling would involve finite element or dynamic element methods. Naturally, the pavement model must reflect the structure. This requires a good knowledge of the construction history, such as layer thickness. However, these may not always be readily available and also roads may be patched and repaired so that little is known about the actual structure. So typically, coring has to be done in order to assess the correct thickness. It is in this context that GPR techniques could be used replacing the rather expensive coring. Besides, pavement thickness often varies to a high degree, so that a continuous record is of much benefit for the evaluation.

A GPR contact device was demonstrated at the First International Conference on Backcalculation of Pavement Stiffness in Baltimore, MD in 1988. With the development of the horn antenna non-contact devices soon made it possible to collect data at higher speeds. Devices were used for bridge health monitoring in Sweden starting in 1991. It was typically used for detecting delaminating layers. The evaluation techniques had to evolve somewhat as some layer interfaces are hard to interpret⁴. In the early 1990:ies one usually had to rely on a few experts, but presently there is commercial software available. However, one has to bear in mind that the thickness of the asphalt concrete layer is the most important for the backcalculation of layer stiffness and overlay design procedures. Fortunately, the interface between bound and unbound layer is typically rather easy to detect by GPR as the dielectric constants do differ.

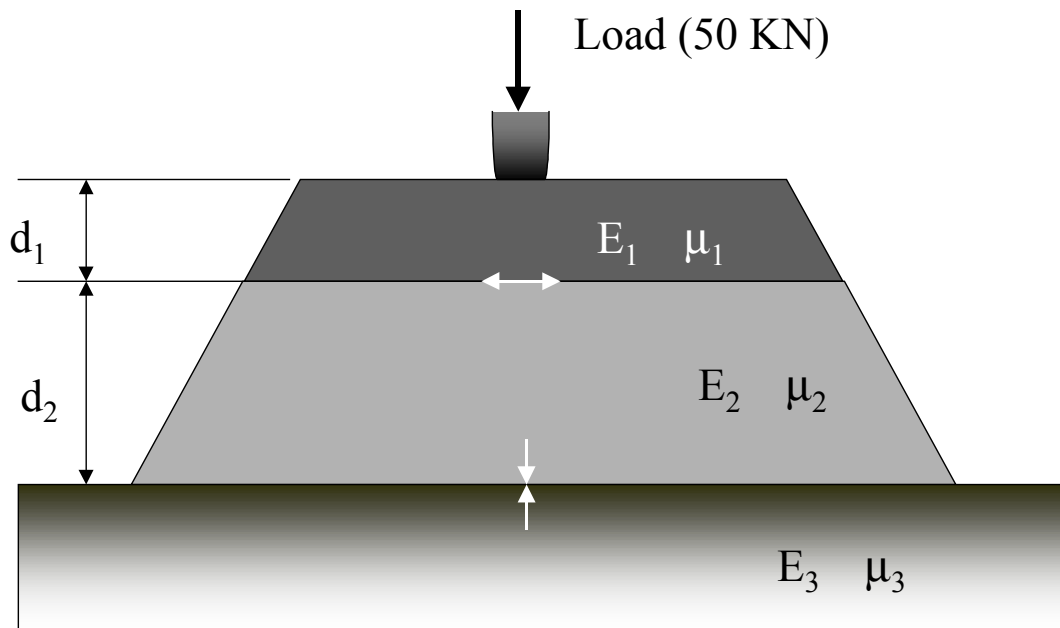


Figure 1. Structural Pavement Model

3. GROUND PENETRATING RADAR USED FOR PAVEMENT EVALUATION

The Swedish National Road Administration (SNRA) manages over 100,000 km of roads. The need of maintenance varies mainly depending on manufacturing practices, age, underlying soil conditions and climate. Maintenance and rehabilitation of roads is not only an economical concern but also a safety concern and there is a need for identifying areas where rehabilitation is needed or will be needed in the near future. The SNRA has pointed out that the thickness of the pavement is the single most important parameters in quality control of roads. Other important parameters of interest are the water content in the roadbed and its variation with depth, grain size distributions in different parts of the engineered road structure and detection of rocks larger than 20 cm in diameter. This makes Ground Penetrating Radar a vital part of the inspection program. By combining visual inspection, surface inspection, GPR and Falling Weight Deflectometer, SNRA aims at locating areas of interest before the problems evolve and rehabilitation costs soar. Moreover, the continuously assessment of data of the GPR contributes in steering stationary FWD testing in frequency and location modes.

GPR is a non-destructive method used for high-resolution images of subsurface conditions. GPR works similarly to a fish finder or sonar on a boat. The difference is that the GPR uses electromagnetic pulses instead of sound. The system receives reflections from buried objects and changes in electrical properties of materials, which are displayed as a continuous profile on a PC monitor. The data are displayed in real time for immediate analysis on the job site. With the advent of the high-frequency GPR systems, highway examination became one of the most important uses for GPR. The high data acquisition speed and resolution capabilities make the method well suited for road applications. The system measures the time it takes for the pulse to propagate down to the reflecting interface and back up again, the so-called two-way travel time. The measured time is depending on the depth to the layer interface and the velocity of which the wave propagates. Hence, in order to conduct accurate depth determinations from radargram, it is necessary to calibrate the ordinary GPR measurements with velocity measurements or coring.

GPR has evolved as the most promising NDT method for assessing layer thickness in road structures. The measuring speed and high-resolution capabilities of the GPR method makes it well suited for road monitoring. However, GPR is less suited for determining stiffness parameters. Therefore, other non-destructive methods or coring are necessary compliments to GPR. One such non-destructive method is FWD. An effective approach of combining GPR and FWD is to conduct the GPR measurement first and use that information to determine appropriate locations and station distance for the FWD measurements.

Other than assessing layer thickness on existing pavements there are a lot of different uses for GPR in relation to pavement property assessment. During construction the contractor can ascertain layer thickness to avoid penalties. Likewise the road authorities can use it for construction control. Other applications involve identifying large stones and boulders that may become a frost heave problem. Soils that contain much water affects pavement deterioration. Therefore, moisture susceptibility is another property that can be assessed by using GPR.

4. BEARING CAPACITY ASSESSMENT IN SWEDEN'S CENTRAL REGION

The road network in Sweden's Central Region has constantly been improved over the last decades by reconstruction or overlays. Still many parts are worn down. The maximum allowable load has been increased over the years without increasing the actual bearing capacity of the roads. Lack of bearing capacity leads to a higher deterioration rate, or imposing restrictions at certain times of the year, particularly the spring thaw. This hurts local businesses and may impede future economic development. In the summer of 1997 a decision was made by the Central Regional Road Administration (CRRA) to address the issue by initiating a major study. It is aiming at mapping the needs for improvements of the secondary road network by employing the best technology available. The project includes actual testing in various forms and advanced analyses of the material tested. After three seasons about 3000 km have been investigated and the Administration hopes to further investigate about 1000 km a year by contracting consultants. By the testing and analyses, lack of bearing capacity is not limited to identifying the problem but can also lead to suggestions for improvement that may be highly cost-effective. The objectives are:

- To assess the location and extent of lacking bearing capacity
- To suggest a working solution
- To assess the economical needs
- To estimate/calculate the costs and benefits

The high-volume roads usually are constructed in such a way that the bearing capacity is adequate. The types of roads in the present study are thus limited to low-volume local trunk roads with an annual daily traffic of 1000 or less. However, they are designated as important for local businesses. Other roads included are those that are designated as important for tourism or public transportation et cetera. The intention of the study is to investigate about 1000 km per year for five years starting in 1997. Methods used include:

- Ground Penetrating Radar (GPR)
- Falling Weight Deflectometer (FWD)
- Visual Surveying
- Roughness measurements (IRI) summer as well as winter conditions
- Rutting

Note that this is the first major bearing capacity inventory in Sweden that mandates GPR and winter roughness measurements as well.

Cost/Benefit-Analysis

Results will be used for long-term planning and short-term action as well. Results are useful for the investment process. New ways of testing and measuring is a valuable way of increasing the regional administration in house own competence as well as the competence of consultants.

Working Concept

The regional road administration decided on the following working concept:

- The bidding is divided into four counties with each about 250 km per year
- Bidding process done by February each year
- The consultants hand over results by December each year

Summary after three years

By utilizing the right technology and highly competent consultants the ambition of covering 1000 km per year has been achieved. The Non-destructive evaluation techniques used have proved to be valuable tools in localizing bearing capacity deficient sections and also in predicting what means and methods should be used in the reconstruction process. In conclusion the goals have been fulfilled. It is important to say here that fast and reliable methods for the evaluation were preferred for use on the road network level. The most valuable method have been the use of ground penetrating radar as this technique has evolved during the three years of the project. Up until 1999 four different consultants have been involved with GPR measurements. The consultants have refined the analysis and equipment has been modified and renewed, especially the antennae, which are now more powerful. However, there are only a few consultants today that have the competence of road GPR measurements, so the Central Regional Road Administration would welcome other actors on the scene.

The CRRA foresees a great increase of GPR in Sweden. One reason being that this technology is not yet well known by regional and local administrators. The advantage over traditional methods is getting continuous measurement covering the entire project, whereas coring is merely intermittent sampling. The former method thus enhances quality control aspects of the overlay design remarkably. The present author representing the road authorities (Ersson) does not see GPR as a compliment to other means of data gathering, but rather the other data gathering as a compliment to the GPR measurements.

A typical GPR-profile with a layered road structure is shown in Figure 2 below. This section shows a till subgrade covered by sand and asphalt layers. The interface between sand and till is particularly easy to distinguish as the characteristic of the GPR-signal changes dramatically when it encounters the large numbers of rocks in the till. In the Figure, the travel time is shown to the left and the calculated thickness is shown to the right. Figure 3 shows the GPR-profile is an interpreted section by the Reflex software. This information can be used as a pre-screening tool for guiding FWD-measurements as a more frequent sampling rate is desired where there is a large variability.

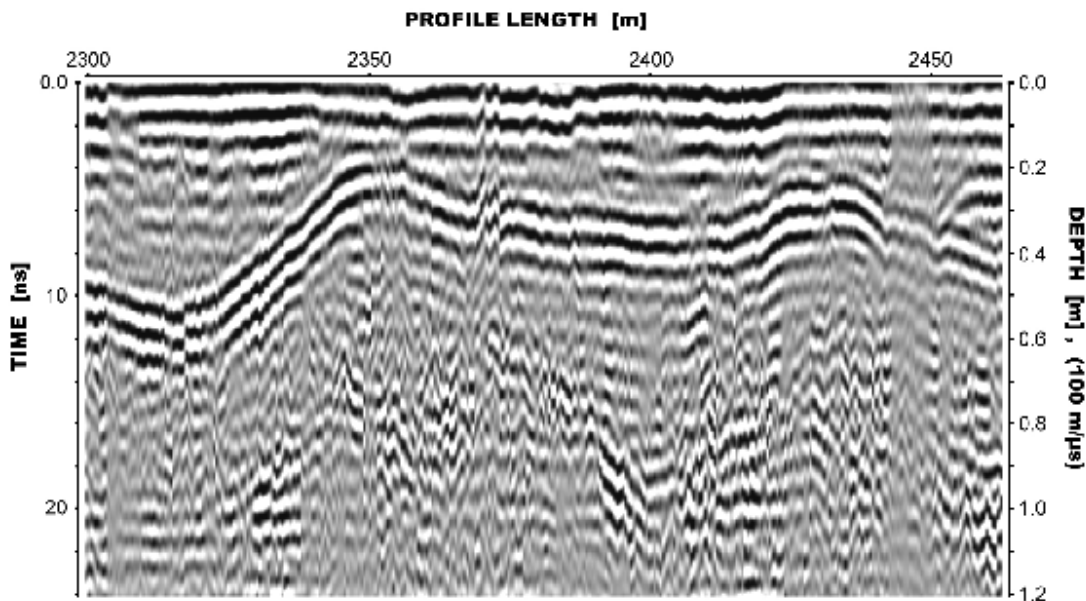


Figure 2 Radargram

The GPR-measurements presented in this paper were conducted using the RAMAC/GPR 1GHz antenna. The antenna is mounted behind a van and is towed along the road surface. A video camera is used for continuously monitoring the road and allows the operator to make comments. Typical objects to comment are intersections, commonly used as reference points, drainage pipes and culverts across the road and areas with visible defects on the road surface.

An important aspect is presenting the data so that the pavement engineer could easily compare various parameters. As seen in Figure 2 an untrained person would have a difficult time in trying to interpret the various interfaces between layers in the Radargram. The interpreted part looks much better for the layman, but nevertheless diagrams presented in color and on large

sheets of paper are easier to grasp. Figure 4 shows such a diagram where the radar and roughness parameters have been cut out from a large A3 size sheet. Other parameters are usually rutting, surface deterioration, amount of asphalt concrete overlay et cetera. They are not shown here for clarity reasons.

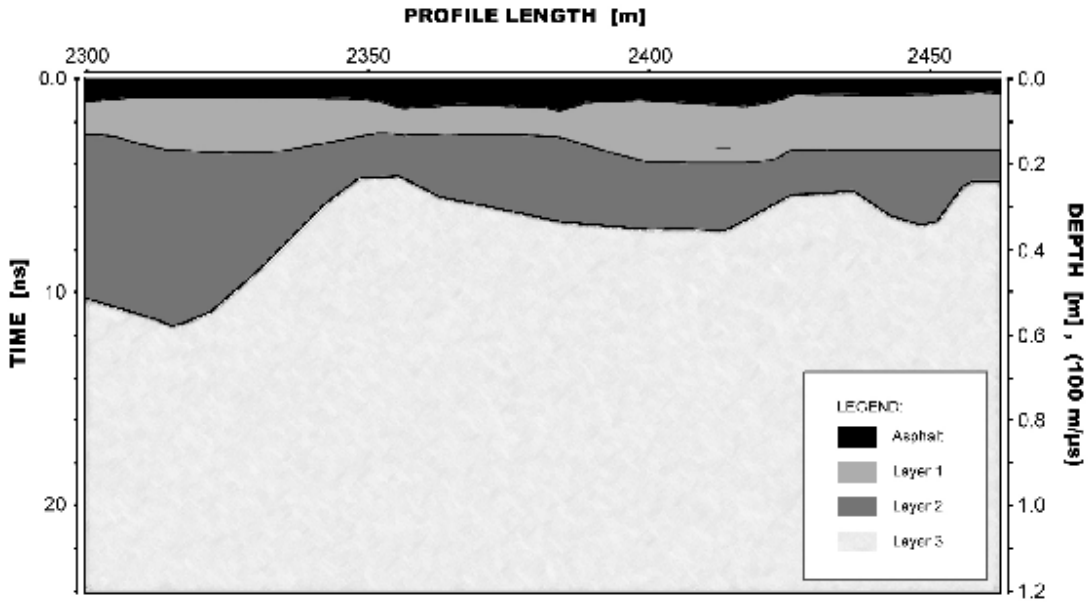


Figure 3. Interpreted radargram showing variations in layer thickness.

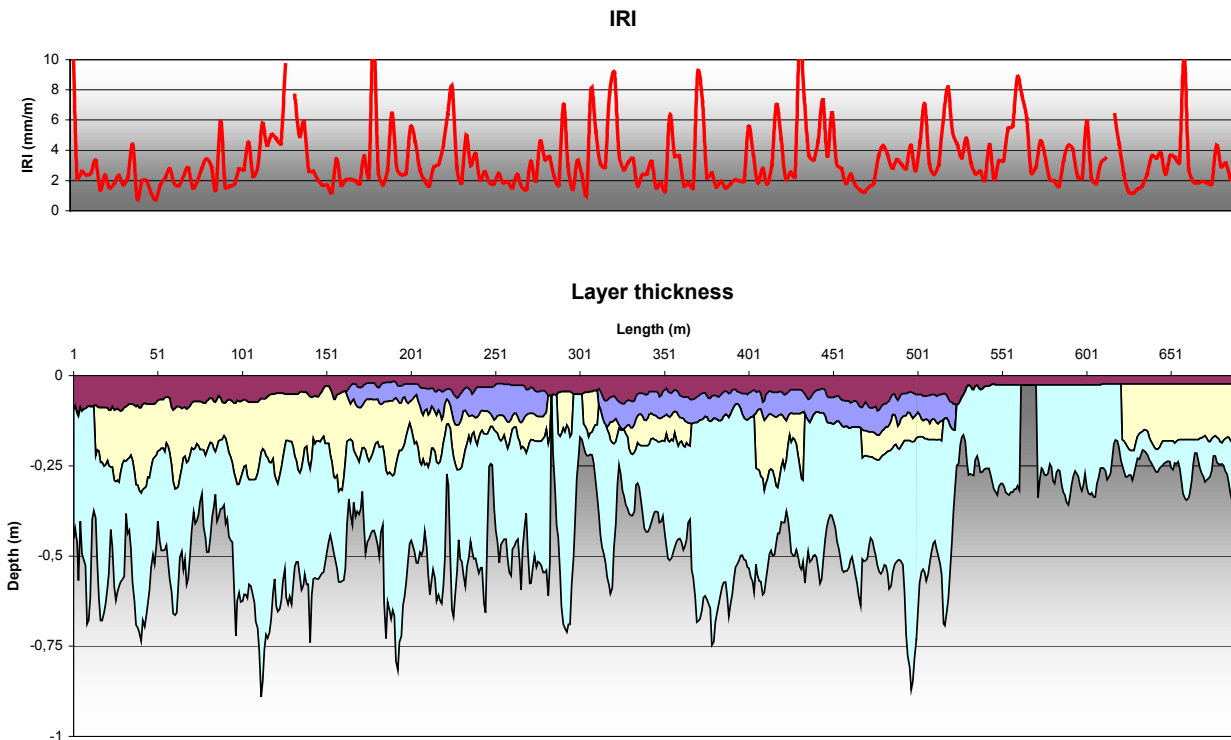


Figure 4. Example of Layer Thickness and IRI (roughness) Diagram from the Study

A study was carried out on how the GPR thickness affected the design vis-à-vis average values. For a four-layer system, i.e. an asphalt layer, a base course, a subbase and subgrade, the overall fit of the backcalculated deflection basin in relation to the measured one was improved from 0.60 to 0.47 % rms-value. The top asphalt layer varying from 50 to 100 mm in thickness was found to have a larger coefficient of variation (cov) of stiffness using the GPR layer thickness data. The other unbound layers varied less and the subgrade was backcalculated the same. The reason for this may be a variation across the road not accounted for in the study. The top layer may vary due to aspects such as adjusting to the cross slope. For a five-layer system the average rms-value was 0.74 % for the average value and 0.67% for the GPR-data. In this case the cov was lower for the top layer and higher for the second layer, however both these layers were thin, so small rounding errors could have attributed. In this comparison one has to bear in mind that the average thickness derived from GPR is most likely much better than any representative datum derived from coring. The moduli were thus backcalculated with thickness data from any of the twenty stations in the present study. It turned out that they all yielded higher rms-values, i.e. the backcalculated deflection basins did not fit as good as those from the average GPR thickness data. Figure 5 illustrates the differences.

When it comes to the design based on the average thickness it is actually slightly underestimating the needed overlay when compared to the GPR derived thickness. In one case the bearing capacity is rated as sufficient, when it is really not. This little study shows that the benefits of assessing layer thickness are worthwhile. Thus, it is recommended that studies like this be carried out for the further evaluation.

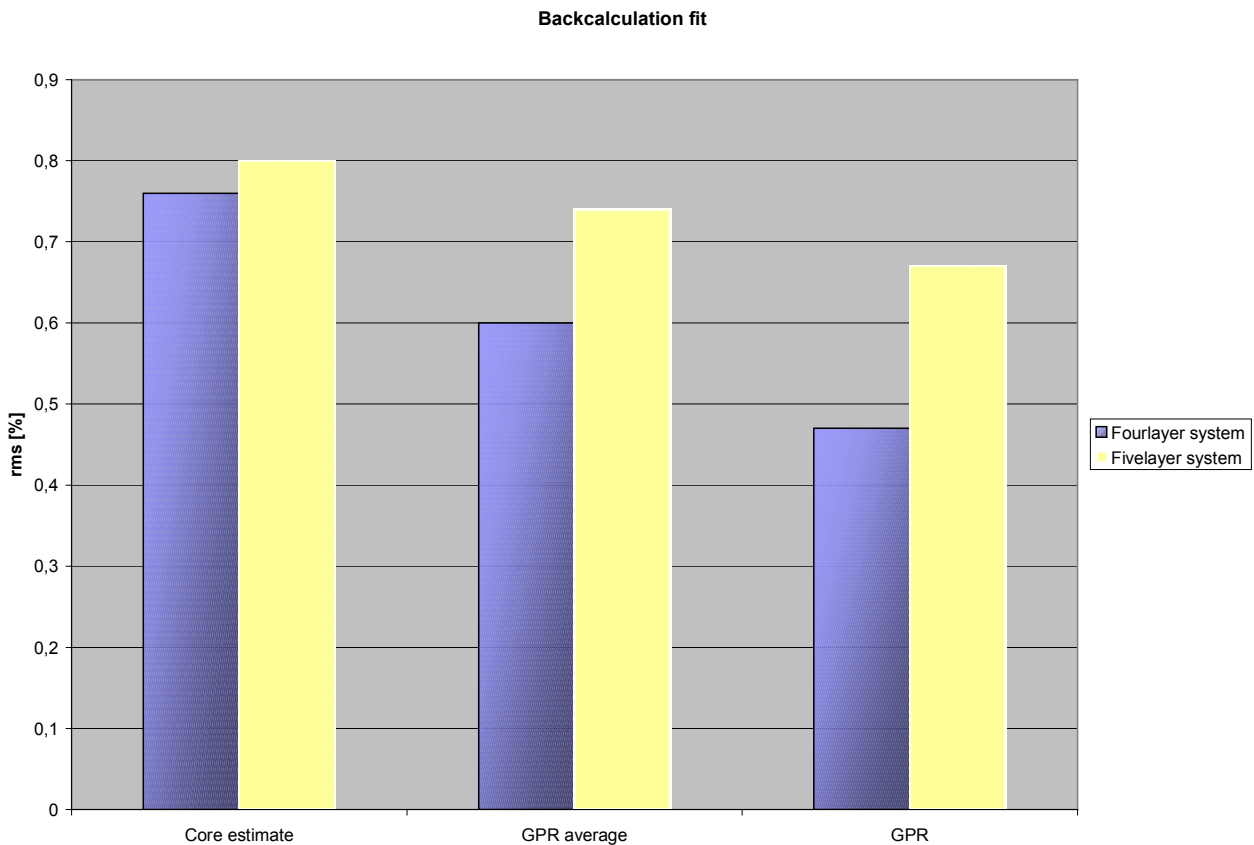


Figure 5. Goodness of backcalculated basins using GPR vs. Data from coring

5. OTHER GPR USES AND FUTURE APPLICATIONS

Construction quality control

A reason for road roughness is often drainage pipes or culverts crossing the road. In order to avoid subsidence over the pipe the construction needs to follow certain procedures. According to the Swedish road construction code, the trench for the pipe should have a certain width and the angle of the trench slope should not exceed a certain value, all depending on the pipe or culvert sizes and the climate zone. GPR can be used as a tool for investigating that the trench has been constructed up to code. Below are two examples where GPR has been used for quality control of trenches. Figure 6 shows an example where the trenching was made too narrow and Figure 7 one where the trenching was made wide enough and the sides of the trench with adequate slopes.

Moisture content

A 3-D radar image of the road, where the moisture and saturation level could be mapped too, would yield lots of information about the current status. In an international study it was found that the dielectric properties of aggregates actually correlated better with strength than the moisture content per se⁵.

Combined equipment

As there is some variability in pavement thickness across the road it would be worthwhile combining the FWD with GPR equipment. This would ensure that layer thickness would be sampled exactly where the intermittent FWD tests are done. Also, a high-speed rolling deflectometer (RDT) is currently being developed. The RDT is a truck-based system. By comparing two transverse profiles under two different load conditions, surface deflections are assessed. The vehicle is equipped with forty sensors and a measuring width of 5.0 meters. With a GPR technique it might be possible to actually look at the deformation of layers as it happens.

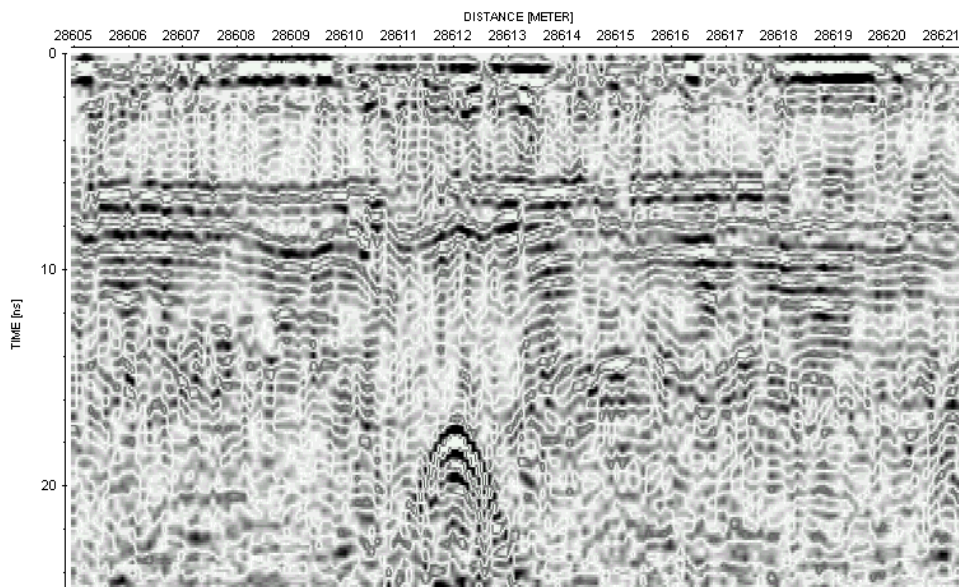


Figure 6. Trench too steep and too narrow!

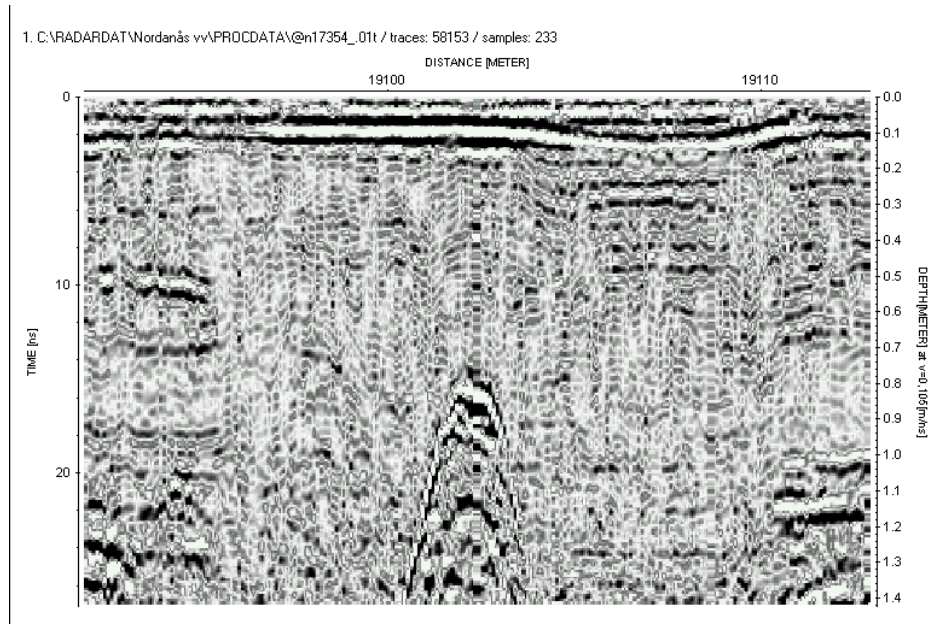


Figure 7. Trench constructed according to code

6. CONCLUSIONS

In the on-going bearing capacity inventory by Sweden's Central Regional Road Administration, GPR was included as a mandatory test for primarily assessing layer thickness. The method has improved the backcalculation of elastic moduli procedures and it has contributed not only to less coring, but also to improve the core sampling where needed. It is recommended that a thorough evaluation be made on exactly how large the improvement is over conventional methods.

Efforts should be made to sample FWD and GPR data simultaneously. This could improve the backcalculation even more as there is now some uncertainty about layer thickness variation across the road.

For research reasons, the high-speed deflection tester should be enhanced with GPR. The results could contribute to a better understanding of the non-linear dynamic effects that occur in asphalt-bound materials.

The next step in GPR road surveying will be to make full use of multi-channel GPR. This will make it possible not only to measure a full section across the road in one measurement but also to acquire velocity information in every single measuring point. As the porosity and the water content in the road structure affect the velocity of the GPR-wave, deviations in GPR-velocity might be a useful tool for locating deteriorated areas. In addition, velocity information can be used for calibrating the GPR data so that exact layer thickness can be determined without coring.

Multi-channel GPR can also facilitate simultaneous measurements with more than one antenna frequency. In this way, high frequency antennas can be used for the near surface objects (asphalt thickness and water content) while antennas with lower frequency can be used for deeper objects (thickness of sand layers and water content).

ACKNOWLEDGEMENTS

Håkan Andersson, Raycon and Jesper Emilsson, Malå Geoscience contributed the Radargrams. Sonia Larrivé and Bengt Ehnberg, Vägverket Konsult also contributed with data and diagrams. Peter André, VTI assisted with graphics. Their help is greatly appreciated.

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