# Bearing capacity of airfield pavements – In situ survey, measurements and calculations using GPR and FWD

A. Lalagüe
*Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway*

D. Gryteselv
*SINTEF Road and Railway Engineering, Trondheim, Norway*

I. Hoff
*Department of Civil and Transport Engineering, Norwegian University of Science and Technology (NTNU), Trondheim, Norway*

ABSTRACT: Runways, taxiways and aprons must have documented their bearing capacity with PCN value (Pavement Classification Number), preferably by a technical evaluation. On new structures this is normally relatively simple to accomplish. On older parts with unknown layer structure and material properties this can be a challenging task. SINTEF/NTNU has been using data from FWD (Falling Weight Deflectometer) in combination with GPR (Ground Penetration Radar) to estimate the PCN value both of asphalt and concrete pavements. GPR is used to estimate layer structures, layer thickness and to a certain extent the type and characteristics of material in each layer. Backcalculation of FWD data is used to estimate the modulus of elasticity of each material layer. By using GPR data, FWD data and aircraft traffic data as input in a suitable calculation program system the PCN value can be estimated. Despite several challenges and many uncertain factors this could be a cost-effective way to estimate PCN values compared to other extensive destructive investigations and material testing.

KEY WORDS: Bearing Capacity, in-situ survey, GPR, FWD.

## 1 INTRODUCTION

Airfields owners must document the bearing capacity giving a PCN value (Pavement Classification Number). The PCN value must be assessed for each main section of the airfield, preferably by a technical calculation or evaluation. This means that each runway, taxiway and apron should be evaluated separately if the structure and/or the traffic/load vary. With new structures and known materials and layer thicknesses, this is relatively simple to accomplish. A structural design based on equivalent traffic and load is normally also done prior to construction.

Old structures are usually far more difficult to evaluate. Construction data are commonly unknown. To obtain layer thicknesses and material properties, an extensive destructive examination together with time consuming laboratory and/or field tests is necessary.

By combining two nondestructive technologies such as Ground Penetrating Radar (GPR) and Falling Weight Deflectometer (FWD), it is possible to reduce the time to collect data about existing structure. GPR is used to measure layer thickness and identify the main type of material (i.e. bituminous, non-bituminous, and concrete). To a certain extent also some material properties can be detected. Nevertheless a few destructive investigations like core drilling or excavating to calibrate GPR data is still indispensable.

This paper presents experiences from investigating some Norwegian airfields with emphasis on the use of GPR to examine the existing structure and the use of FWD to estimate the structure stiffness with the purpose of assessing the PCN value.

## 2 USING 3D-GPR

### 2.1 Principle

Ground Penetrating Radar (GPR) is a nondestructive method used to map the subsurface. It sends electromagnetic waves to the ground and registers the reflected signals induced by the dielectric properties differences between two materials. An image is then created when moving along the surface. Depth range and resolution depend mainly on the operating frequency and the electrical conductivity of the ground. High frequencies penetrate less into the soil than lower frequencies but give a better resolution. Exploration depth is very limited in highly-conductive soils such as clay and saline soils, but sand, gravel, ballast and bedrock are easily penetrated.

GPR can detect all kinds of objects, as long as they are of substantial size (5 – 10 cm) and have dissimilar dielectric properties from the host environment. Cables, pipes, drains, waterways, groundwork, iron framework, anchorage are thus usually easily detected. In road engineering, GPR is used in quality control to determine the layout and the thickness of the different layers. Non reinforced concretes, found in most Norwegian airfields, usually give good response as well.

If appropriately used, the GPR technology is time-saving, cost effective and provides more valuable information than any other ground exploration methods.

### 2.2 Case study from Norwegian airports

The GPR technique has successfully been used in Norway to identify the airfield structure. Airfield structures usually fall into two categories: flexible (asphalt) and rigid (concrete) pavements. Concrete can be reinforced or not, and may sometimes be covered by an asphalt layer. The thickness of the design is directly correlated to the bearing capacity of the structure and is a key parameter in quality control investigations.

The Figures below show typical airfield structures that can be found in Norway, along with the corresponding radar profile:

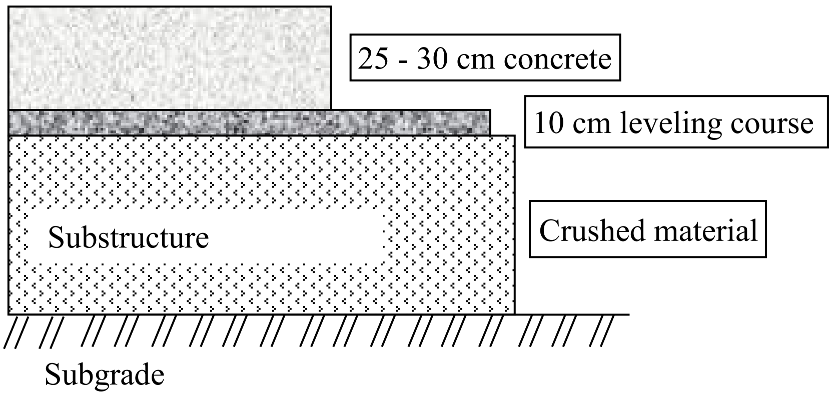


Figure 1: Typical Norwegian rigid pavement structure

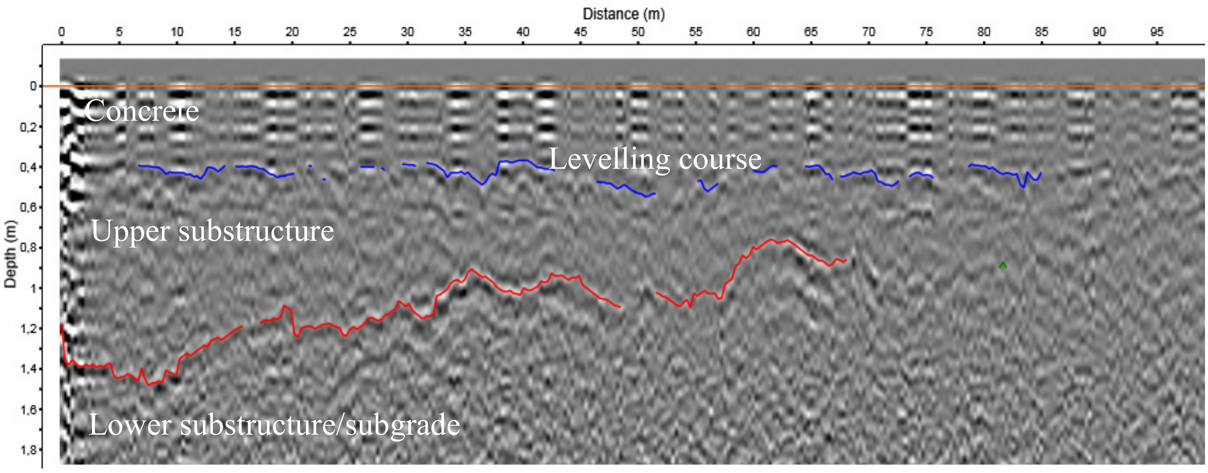


Figure 2: Non-reinforced concrete pavement - GPR profile (inline view)

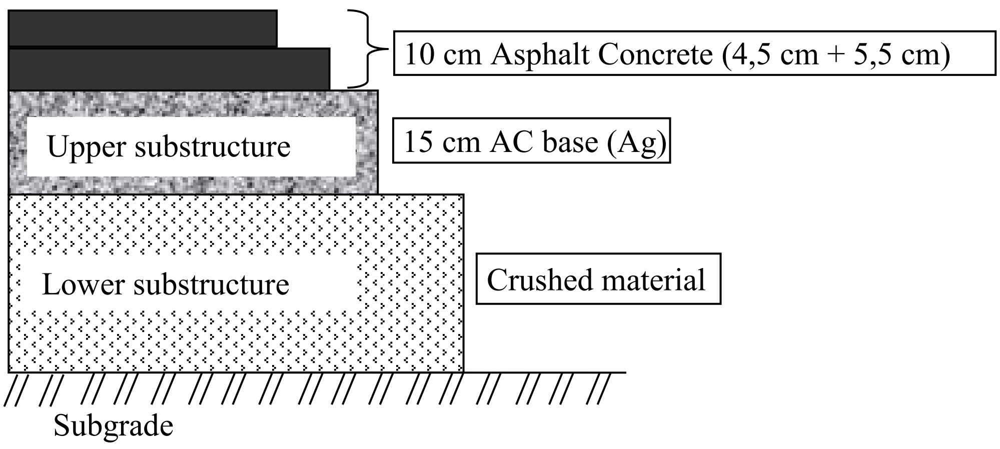


Figure 3: Typical Norwegian flexible pavement structure

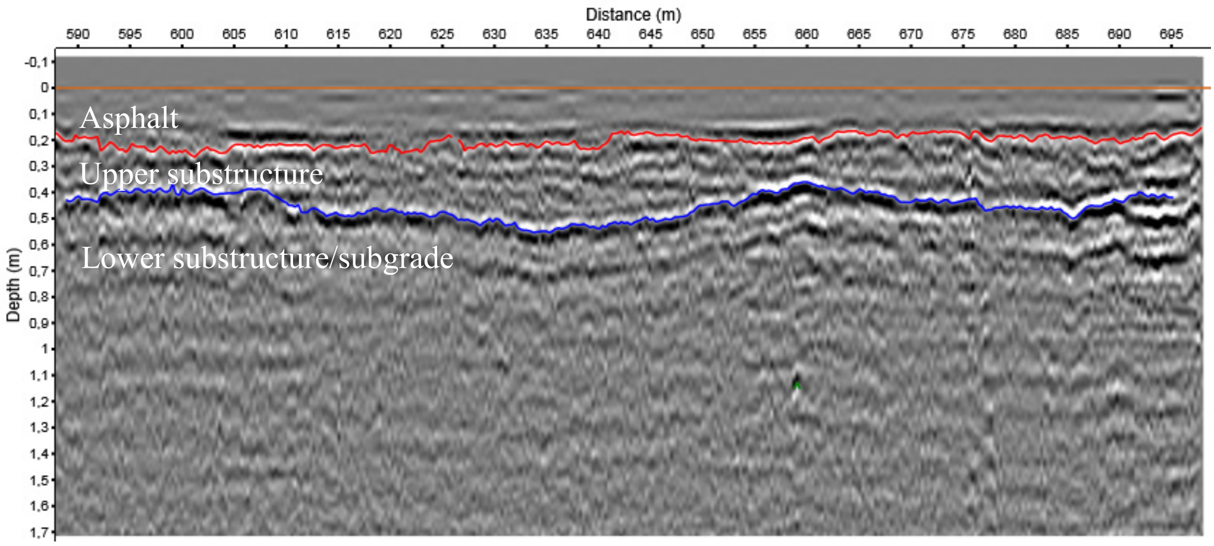


Figure 4: Asphalt pavement – GPR profile (inline view)

As can be seen in Figures 2 and 4, layers are not always homogenously defined and thicknesses may vary greatly. In the absence of documentation, an application of GPR would be to locate abrupt changes in layers thicknesses (Figure 5) or subsurface defects (settlements par example).

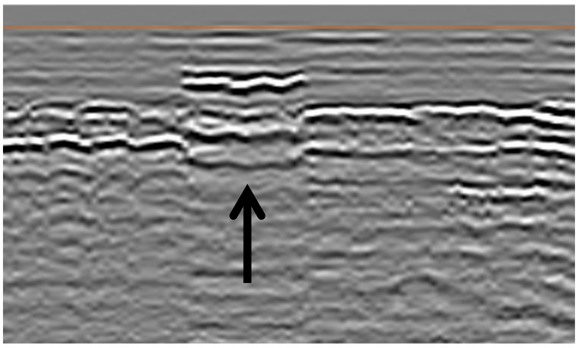

Figure 5: Change in the pavement structure resulting from rehabilitation works (GPR profile - inline view)

Sometimes, asphalt overlays are laid over concrete slabs to rehabilitate runways. Again, when works are not sufficiently documented or if information is missing, GPR can successfully be used to map asphalt and concrete areas. The total pavement thickness is usually different and can be plotted on a color depth map (top view, Figure 7). However, the depth of penetration depends greatly on the surveyed material and may be limited in concrete pavements. Uncertainties (poor signal strength) are therefore not interpreted or sometimes indicated by a dashed line.

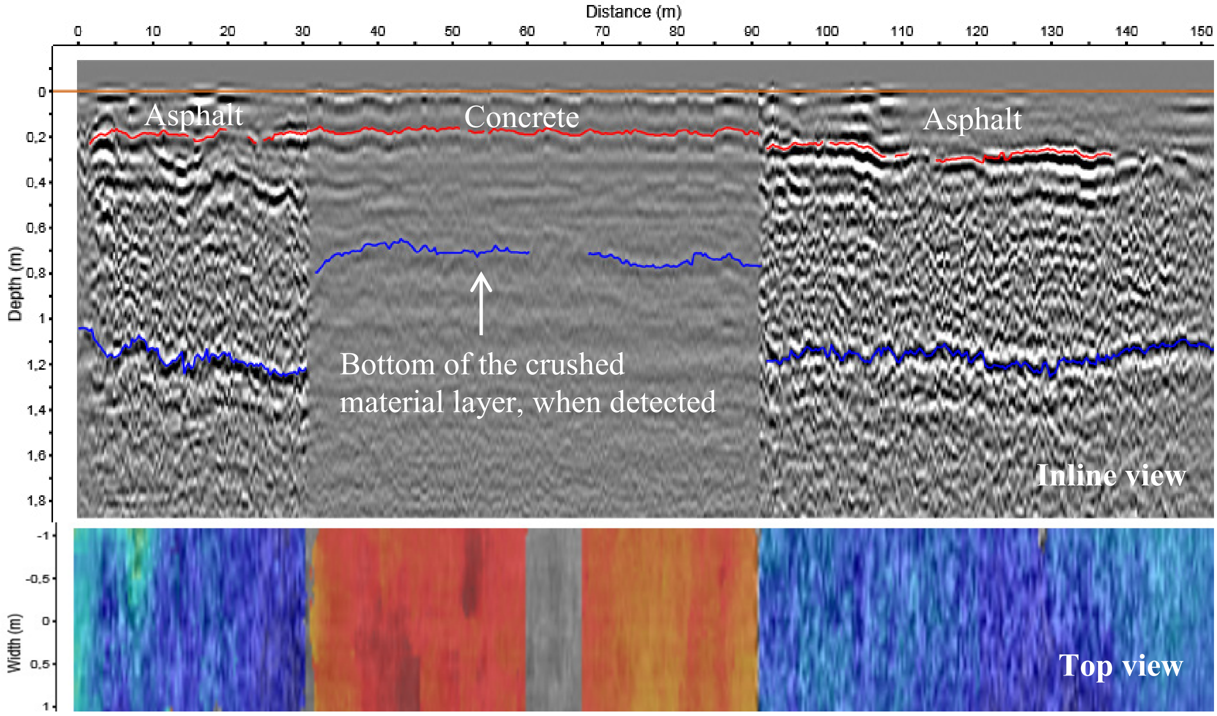


Figure 6: Asphalt and concrete structures

GPR is also commonly used to locate any anomaly or buried object in the ground. The Figure below shows an asphalt pavement GPR profile taken from a Norwegian airfield. In asphalt/base course materials the depth of penetration is usually very good and objects are easily detected. The anomaly number 1 has a size of about 1 m x 0,5 m and is 1,25 m deep. GPR detects changes in dielectric properties but does not provide much information about the nature or type of the surveyed material. Object number 1 can for example be a cavity, a plate or another buried structure. Object number 2 is about 0,70 m wide and minimum 2 m long. Thanks to the cross profile and top views that display the shape of the object, it can be assumed that it is a pipe.

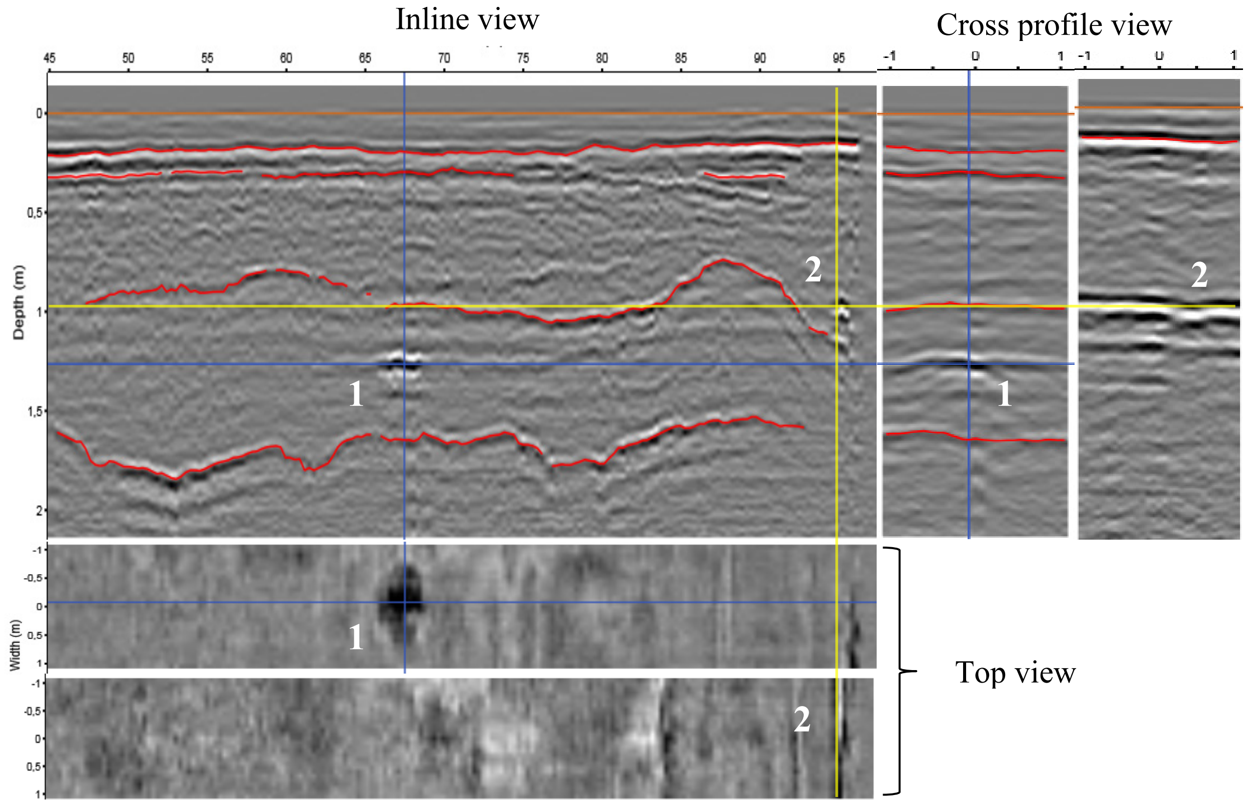


Figure 7: Located objects in the ground

GPR is a reliable geophysical method used to map the subsurface, detect anomalies in the pavement structure and locate buried objects. It has some performance limitations caused mostly by the environment. Highly-conductive soils (clay, peat) and brine from winter maintenance should be avoided to ensure effective results. The method becomes more powerful when used in combination with conventional site investigations such as drilling; soil surveys are consequently more comprehensive and thorough, cost-effective and time-saving.

## 3 USING FWD

FWD - Falling Weight Deflectometer is used to estimate the structural capacity of the overall pavement structure; surface deflections are then an input for the backcalculation of the individual layers stiffness (E-moduli). Layer thicknesses and main material types (i.e. concrete, bituminous, non-bituminous) can be found from GPR measurements and analysis. In this example a Dynatest 8000 FWD (Figure 8) is used. Normally the load will be approximately 130 kN with a contact stress of 1.8 MPa. This is somewhat less than the load of most design aircrafts. Since the materials involved normally show a non-linear stiffness, an insufficient load will underestimate the layer moduli.


Figure 8: FWD operated by the Norwegian Public Road Administration (NPRA), Region North

The measured stiffness can vary a lot along a section. Figure 9 shows this quite clearly where deflection basins for three locations on the same section are illustrated.

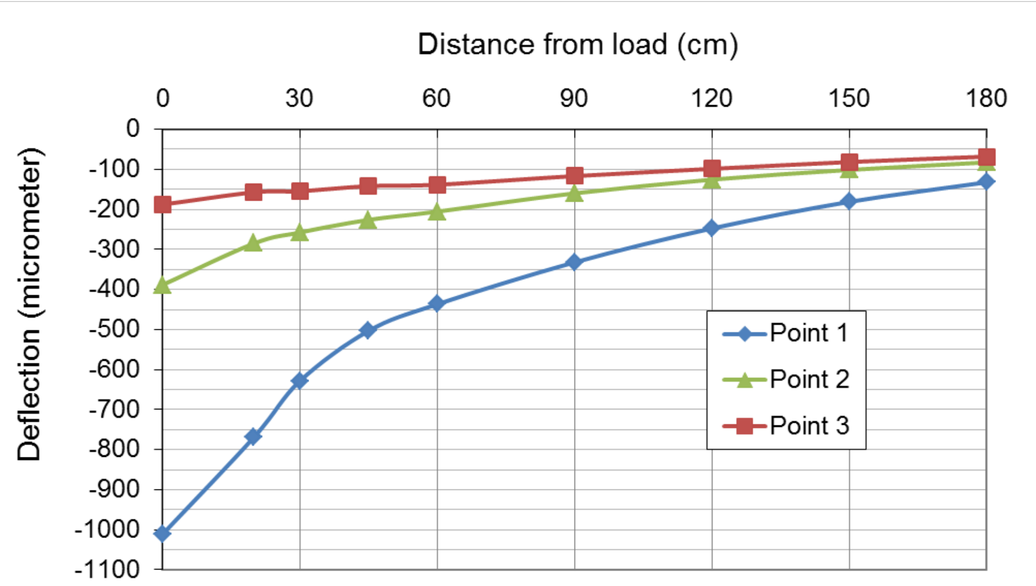


Figure 9: Example of deflection basin for three different locations on the same section

Obviously the structure could be expected to be different in the three locations shown in Figure 9. This is not always true. Thus local weaknesses or strengths can be discovered in this way. Even with only 30 – 50 meters between the drops it will not be possible to locate every weakness. By using the continuous GPR scanning profile it is possible to become aware of local suspicious variations along the sections that could need closer examinations.

Figure 10 shows variations along a taxiway. The tests have been done in two lines, 5 m from the centerline. The spacing between points is 50 m. Stiffness is here simply defined as maximum stress divided by maximum deflection. Even if local variations may be important, it is easy to see the change in response at about 1400 m when the structural response is completely different.

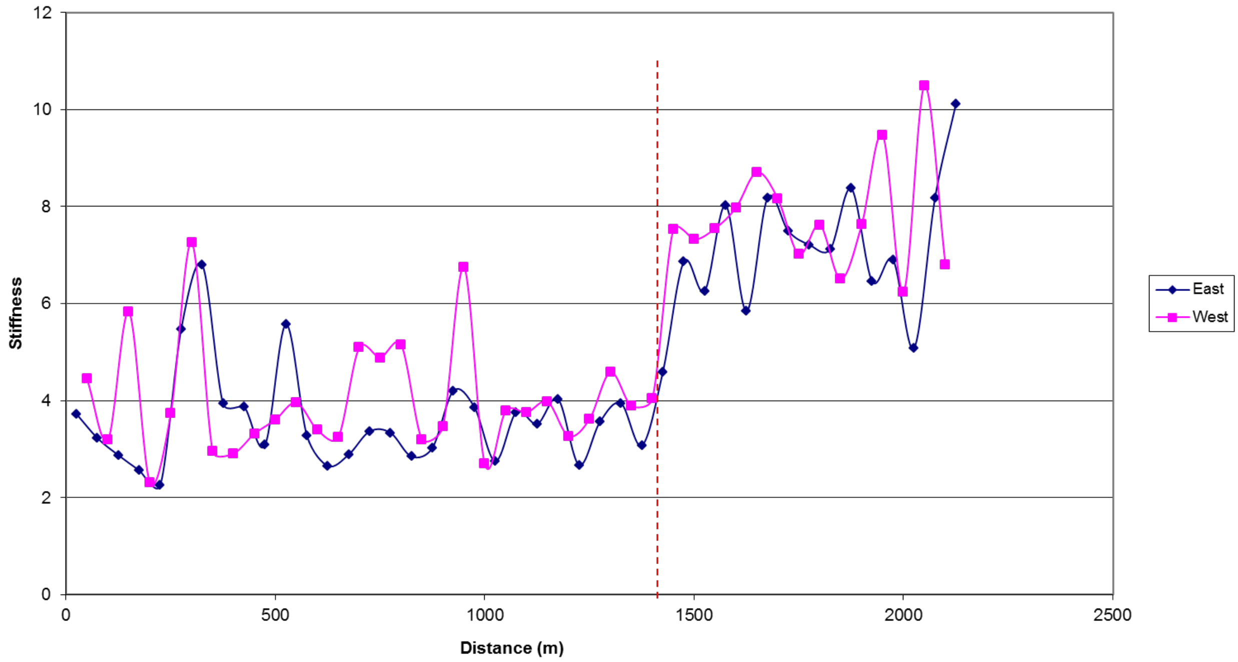


Figure 10: Variation of the structure stiffness along one of the taxiways.

In our work we used the 90-percentile value of measured stiffness from FWD as an input to backcalculation analysis to avoid using the extreme high values you always will find. Even with good knowledge of layer thickness and good FWD data available it will be necessary to apply engineering judgment to secure useful results. Backcalculation will often place too high stiffness in one layer and too low in the next.

Table 1: Backcalculated values and values used for resilient modulus (MPa)

| Layer | Thickness | 5 m east | 5 m west | Average | Value used in analyses |
|---|---|---|---|---|---|
| Asphalt | 100 mm | 12618 | 20811 | 16715 | 4 000 |
| Asphalt base course | 150 mm | 706 | 100 | 403 | 1 100 |
| Glacial gravel | 500 mm | 153 | 2845 | 1499 | 310 |
| Soil | N/A | 416 | 312 | 364 | 250 |

As can be seen from Table 1 the difference between the calculated stiffness and the stiffness based on engineering judgment can vary quite a bit. The values used for analyses give the same total deflection for the FWD-blow, but the distribution of stiffness (and by this the deflection bowl) is quite different. The table above illustrates the problem with inaccurate determination of layer thickness. If the real layer thickness deviates from what is used in modeling the calculated stiffness will be affected quite extensively.

## 4 CALCULATION / ESTIMATION OF PCN

The ACN/PCN (Aircraft/Pavement Classification Number) method is used to calculate the bearing capacity of an airport i.e. the aircraft with the highest ACN number that can drive the airport without causing need for excess maintenance. The PCN does not give any information about the risk for immediate failure of a single especially heavy plane. The Norwegian regulations require the PCN value to be published for all airports, but the regulations do not specify how this should be done.

Two different tools have been used for calculating PCN: Pavers and PCASE. Both can use data from FWD as an input to accomplish backcalculation of layer parameters. Both can use fatigue models for estimating the number of design aircraft passages allowed before permanent damage occur (cracking or deformation). Pavers is as far as we have found out easier to use because of better handling of FWD data and easier use of metric units. PCASE can be faster in estimating PCN value if construction data and material properties are known.

Fatigue modeling of asphalt pavements is not straight forward and several models have been proposed and are in use. The choice of model will greatly influence the resulting estimation of pavement fatigue life. For the analyses of the Norwegian airports the fatigue model called DWW F78 in the Pavers system has been used:

$$\log N = 26{,}676 - 7{,}327 \times \log(E) + 0{,}769 \times \log2(E) - 5{,}851 \times \log(\varepsilon)$$

Where:
N = Number of load repetitions until fatigue
E = Young's modulus
$\varepsilon$ = Horizontal strain at the bottom of the asphalt layer.

For soil another «fatigue»-model was used:

$$\text{Log } N = 25{,}305 - 7{,}14 \times \log(\varepsilon(z))$$

Where $\varepsilon(z)$ is vertical strain in the soil layer.

The Pavers system does not consider other distress modes like permanent deformations in the layers above the soil. The method is also quite sensitive for small changes in input parameters. Nevertheless, used together with good input data and sound engineering judgment the method gives reasonable results for typical structures and common traffic situations. For more untypical structures or traffic, more advanced analyses should be considered.

## 5 CONCLUSIONS

SINTEF/NTNU has been using data from FWD in combination with GPR (Ground Penetration Radar) to estimate the PCN value both of asphalt and concrete pavements. GPR is used to estimate layer structures, layer thickness and to a certain extent the type and characteristics of material in each layer. Backcalculation of FWD data is used to estimate the modulus of elasticity of each material layer. By using GPR data, FWD data and aircraft traffic data as input in a suitable calculation program system, the PCN value can be estimated. Despite several challenges and uncertain factors this could be a cost-effective way to estimate PCN values compared to other extensive destructive investigations and material testing.

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