# Utilizing GPR and FWD for Pavement Structural Assessment and Moisture Detection

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**Abstract.** Asphalt pavement performance is profoundly impacted by the presence of water and moisture in the road, resulting in substantial costs to society. Research showed that significant portion of the road sections need early maintenance measures regardless of traffic volume due to moisture-related damages. Monitoring moisture conditions, preferably using a non-destructive continuous method, is thus vital to the decision-making and selecting appropriate maintenance intervention. Furthermore, understanding moisture conditions is critical for accurately interpreting automatic road condition measurements, especially during the spring (thawing) when the roads exhibit the lowest load bearing capacity due to increased levels of moisture.

This study employed a multi-receiver Ground penetrating radar (GPR) and a Falling weight deflectometer (FWD) measurements to assess moisture levels and structural condition of an indoor full-scale test road. The groundwater level of the test road was varied by introducing water to the system.

The results revealed a good correlation between the FWD and the average GPR velocity measurements. The GPR measurements provided a relative water content of the test roads. Further exploration of other GPR parameters, such as frequency, magnitude, and amplitude of the GPR signal is recommended, as these may offer an even better correlation to moisture content.

**Keywords:** GPR · FWD · Moisture content · Moisture damage

## 1 Introduction

The performance and durability of asphalt pavements are adversely impacted by the presence water and moisture in the road, ultimately incurring substantial cost to the society. Previous research has revealed that, 10% of roads necessitate paving measures within 5 years after construction regardless of traffic volume [3]. Such early maintenance needs are often attributed to damage due to repeated traffic loading coupled with potential shortcomings in the execution of paving work. The presence of moisture and water in the roads also play a pivotal role in affecting the performance of asphalt mixtures. Thus, obtaining information regarding the moisture condition is key for the pavement design processes.

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Previous investigations of road structures at the Swedish Road and Transport Research Institute (VTI) full-scale test facility and field sections, conducted using the falling weight deflectometer test (FWD) clearly indicated the adverse effects of water in the road structure. FWD deflections on the pavement surface increased significantly in the presence of water and have a significant impact on service life [5]. Thus, knowledge of moisture and water conditions during deflection measurements using FWD/TSD (Traffic speed deflectometer) is vital for the analysis/interpretation of the measurement data as well as for selecting appropriate maintenance measures.

The water/moisture content of road materials can be measured using different methods. The methods can be either stationary (or point measurement) or continuous. The stationary moisture measurement methods include laboratory tests of drilled specimens, capacitance-based methods, resistivity-based methods, and Time domain reflectometry (TDR). The continuous moisture monitoring techniques collect continuous moisture data along the length of the road. These methods include thermal camera method and Ground penetrating radar (GPR). GPR-based methods are the most commonly used for continuous road moisture survey. The GPR antenna can be either air coupled, or ground coupled, depending on the way the antennas are mounted with respect to the ground surface. The air coupled GPR permits surveying at a higher traffic speed. Furthermore, depending on the number of receivers in the GPR unit, different analysis methods are adopted, i.e., the surface reflection method (one receiver only) or coreless GPR (multi-receiver). The measurements from the surface reflection method are limited to thicknesses of roughly 25–40 mm depending on the antenna's frequency [1]. In coreless GPR, the travel time shift recorded at each receiver of the electromagnetic wave reflected from a specific boundary is determined. This time shift leads to calculation of the layer thicknesses and the average wave velocity (average dielectric value). Relatively accurate values of layer thickness and average dielectric constants can be found using the coreless GPR [7]. However, a high resolution GPR unit is required to achieve the accuracy and a skilled GPR operator is needed to process the data [1]. The present study evaluated the coreless GPR method (utilizing two receivers) to detect the moisture level of test road constructed within an indoor test facility.

## 2 Method

### 2.1 Test Facility

An indoor full-scale test facility at the Swedish Road and Transport Research Institute, VTI, was employed for this work. The test pit is 3 m deep, 5 m wide and 15 m long [6]. The sides and the bottom of the test pit are made of concrete. The groundwater level in the test pit can be varied by adding water to the pavement structure through an installation at the bottom of the pavement structure. The pavement structure was instrumented with asphalt strain gauges (ASG) at the bottom of the asphalt layers. The structural condition of the pavement was evaluated using FWD. In the FWD tests, impact loads of 30, 50 or 65 kN were applied, and the resulting pavement surface deflections at 7 sensor locations were measured. The GPR measurements were conducted to detect the moisture levels in the pavement structure. The GPR and FWD measurements were simultaneously carried out at different ground water levels. The strain responses of the strain gauges under the

FWD loading were also recorded. The indoor full-scale test facility and the cross-section of the test pavement are shown in Fig. 1. The FWD/GPR tests were conducted under the following conditions:

- Dry state - when no water was present in the structure.
- Low moist state - when the groundwater level is 20 cm below the top surface of the subgrade (wet-1).
- High moisture state - when the groundwater level is 20 cm above the subgrade, or in the middle of the subbase layer (wet-2).
- Drained state – the water stored in the pavement was allowed to completely drain.

**Fig. 1.** Indoor full-scale test facility at VTI (left). Cross-section of the pavement structure (right), the numbers in the layers indicate the thickness mm.

## 2.2 GPR

GPR is a non-destructive test method used to survey subsurface materials/conditions. GPR involves sending a small electromagnetic pulse via a transmitting antenna and registering the reflected signal via a receiving antenna. The travel time of the pulse from the transmitter to the receiver and the properties of the received signal are used to determine the type and/or the composition of the material. The propagation velocity of electromagnetic waves in soils is strongly influenced by water content ([2, 4]). This is because the dielectric constant increases as the water content in the soil increases. The GPR multi-channel WARR (Wide Angle Reflection) method takes advantage of this property for detecting the relative water content. In this project, multi-channel GPR (having 500 MHz antennas) measurements were conducted to measure GPR velocity. In this setup, the travel times of an electromagnetic pulse from a transmitter (Tx) to the receivers (Rx) are registered in all receivers. Two different antenna configurations were tested to investigate the appropriate distance between transmitter Tx and receiver Rx. A calibration measurement was also made to record the different travel times for the "direct wave" between transmitter and receiver.

# 3 Results

## 3.1 FWD and ASG Measurements

Figure 2 presents the FWD deflection basins and the measured strains for dry, wet, and drained conditions. The deflection at 1200 mm reflects the influence of the groundwater within the subgrade or lower pavement layers, i.e., the deflection $D_{1200}$ increases as the groundwater level rises. The deflection reverted to its initial dry state value once the structure was nearly fully drained. Note that, the center deflection $D_0$ decreased for drained condition. This was due to the temperature drop during the drained test, i.e., the temperature dropped from 12 °C to 3 °C. The effect of temperature on the measured asphalt strain was removed using the FWD back-calculated asphalt moduli. The asphalt modulus-temperature relationship was employed to adjust the strains to 10 °C. The strain increased as the groundwater level rose. The strain for the drained condition is marginally higher than for the dry condition. This difference could be attributed to residual moisture in the base or subgrade layers or potential errors arising from temperature corrections.

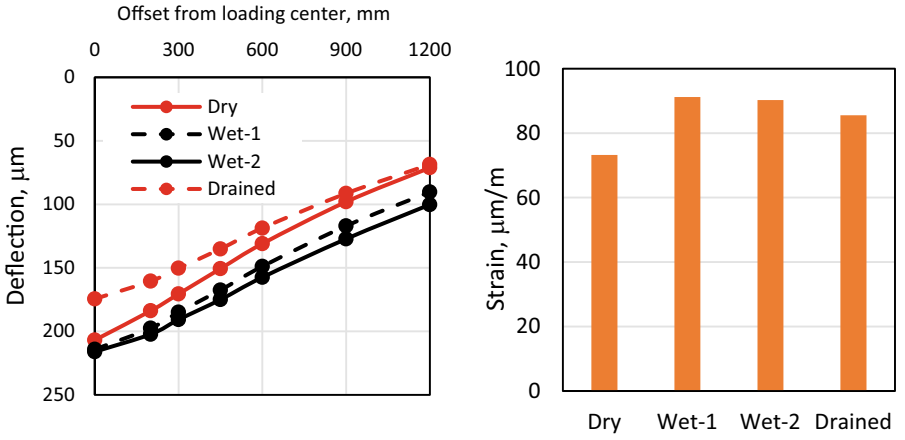


**Fig. 2.** FWD deflection basin for dry, drained and two levels of raised groundwater levels (left). Measured ASG strain adjusted to 10 °C (right).

## 3.2 GPR Velocity Measurements

The GPR WARR velocity measurements were determined for depths of 0 to 0.7 m (over the subgrade) and for depth of 0 to 2.7 m (over the whole structure including the subgrade). This approach was employed to explore the most effective means of distinguishing between varying groundwater levels. Figure 3 (left) shows the velocity variation over the depth of 0 to 0.7 m. In this case, the velocity for dry, wet-1 and drained cases produce very similar values of the GPR velocity. This is because the moisture has not reached or migrated to the depth of 0 to 0.7 m, and consequently, it does not impact the velocity. However, for the wet-2 condition, where the groundwater level was in the middle of the subbase layer, the velocity was significantly lower since the moisture reached the depth 0 to 0.7 m. On the other hand, as shown in Fig. 3 (right), both wet-1

and wet-2 conditions produced lower average velocity for the depth 0 to 2.7 m compared to the dry and the drained conditions. In this case, the velocity for the wet-2 conditions was relatively lower than the velocity at the wet-1 condition where the groundwater level was below the top of the subgrade. The dry and drained condition produced very similar values as indicated in the figures. These results aligned with the ranking derived from FWD deflection measurements. However, when examining the average velocity for a depth of 0 to 0.7 m, the wet-1 condition did not correspond to the FWD results.

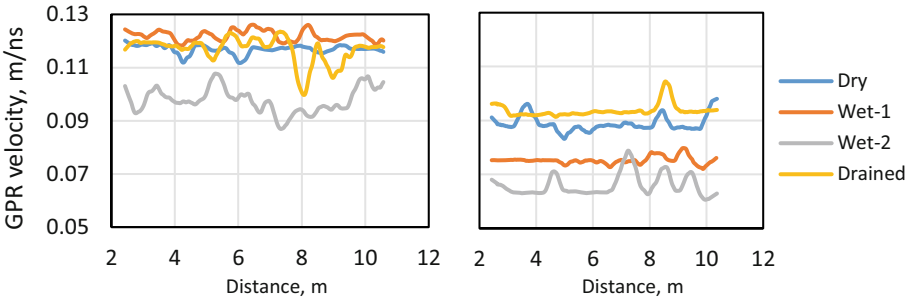


**Fig. 3.** GPR Velocity variation for depth 0 to 0.7 m (left) and for depth 0 to 2.7 m (right).

In addition to velocity measurements an average frequency spectrum has been performed, Fig. 4. The GPR data samples where truncated so that the remaining data only contained 52 samples, which approximately describes the depth of 0.25 m to 0.70 m.

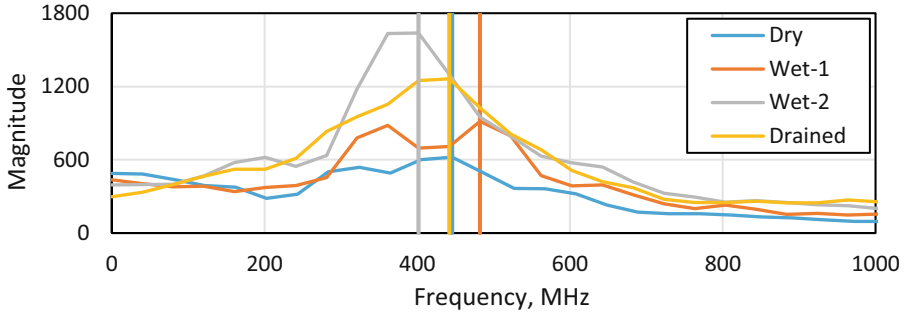


**Fig. 4.** Average frequency spectrum.

As expected, the result shows that the peak frequency tends to decrease when the material contains more moisture and at the same time the magnitude tends to increase. The peak frequency for dry and drained conditions shows very similar values. The magnitude differs that could indicate that there is still some impact. Important to add is that the groundwater level in wet-1 is still below 0.7 m and it is assumed that there is no impact on the material.

## 4 Conclusions

GPR and FWD measurements were conducted on indoor pavement structure under both dry and wet conditions. The ground water level was varied by introducing water into the pavement system. A GPR configuration having two receivers, each with 500 MHz antennas, was employed for collecting the GPR data.

The results demonstrated a good agreement between the measured FWD deflections and GPR velocity measurements concerning moisture levels. Elevated groundwater levels led to increased FWD deflections, reduced GPR velocity, reduced GPR frequency, and higher asphalt strain, affirming findings from previous research that this method effectively discriminates road sections with varying moisture conditions. However, it's important to note that the method produced relative water content based on GPR velocity variations rather than providing precise volumetric or gravimetric moisture content data. This distinction was evident in the indoor full-scale facility measurements.

A 500 MHz antenna was chosen for this project to penetrate deeper into the pavement structure. Combining FWD or other automatic road monitoring techniques with GPR having high and low frequency antennas could offer valuable insight into layer thickness and moisture conditions, enhancing the quality of road performance data collection.

While the GPR WARR velocity measurements is proved to be a useful indicator of moisture presence in the subsurface materials, further investigation into other GPR parameters such as frequency, magnitude, or the amplitude of the GPR signal is recommended. These parameters are easier to obtain and may add valuable information when analyzing moisture content.

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