Bearing Capacity Assessment on low Volume Roads

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Abstract. A large part of Latvian road network consists of low traffic volume roads and in particular of roads without hard pavement. Unbounded pavements shows serious problems in the form of rutting and other deformations, which finally lead to weak serviceability and damage of the road structure after intensive exploitation periods. Traditionally, these problems have been associated with heavy goods transport, overloaded vehicles and their impact. To find the specific damaging factors causing road pavement deformations and evaluate their prevention possibilities, and establish conditions that will allow doing it, the study was carried out. The tire pressure has been set as the main factor of load. Two different tire pressures have been used in tests and their impacts were compared. The comparison was done using deflection measurements with LWD together with dielectric constant measurements in a road structure using percometer. Measurements were taken in the upper pavement structure layers at different depths during full-scale loading and in different moisture/temperature conditions. Advisable load intensity and load factors for heavy traffic according to road conditions were set based on the study results.

1. Introduction
The most important road efficiency factor is the guaranteed road serviceability, which closely depends on the adequacy of actual traffic loads on particular road structure. Latvian road operation experience shows a number of problems associated with heavy transport and its impact on the road pavements. A large part of the paved road network has experienced strong rutting. It is mainly explained by overloaded cargo traffic loads. This leads to reducing of road capacity and shortens road service life. Regarding the roads with unbound pavement, they suffer from heavy loads during weak capability periods – winter and spring slush and during and after strong rainfall periods.

It is therefore important to find efficient possibilities to prevent road damage, while keeping necessary transportation volume.

The research is focused on low volume roads, typically with unbound pavement. Bearing capacity of such roads usually significantly decreases in slush seasons. Therefore responsible authorities close them for heavy transport during these periods. This results in economic disruption in the service area of the closed road.
To establish conditions that will allow using the road without interruptions and without damaging it, the study is carried out. The research methodology is based on road surface deflection measurements with low weight deflectometer (LWD) together with dielectric constant, temperature and moisture measurements in the road structure using percometer during full scale loading with maximum allowed axle load.

2. Comparative studies
According to Treube et al. [10], rutting in pavement surface layer decreases using lowered tire pressure, however, this phenomenon was less marked than expected. It has also been pointed out that low compaction and poor drainage contribute to significantly more rutting. Bradley [1] reviewed research and user experience using variable tire pressures in the forest industry. In this review it is indicated that effect of reducing tire pressures on roads with thin pavements and low bearing capacity is essential in terms of road maintenance costs as well as construction costs and serviceability.

Studies of road structure using dielectric characteristics of pavement material in road structure are available from 1995 when percometer was used in tube suction test by Saarenketo and Scullion [8], [9]. Further, there were several studies with regard to the road pavement operational characteristics and dielectric properties of the road materials and soils: Saarenketo et al. [6] and [7]. All the studies mentioned were conducted under laboratory conditions.

Research on the road operating parameters considering their impact on the frost heave, during which dielectric properties of the medium are studied, is described by Saarenketo et al. [6] and Saarenketo and Aho [4]. The possibility to use the dielectric value of the medium under load as a parameter and characteristic of the loading impact on the road structure was also considered.

In the study of George [2], the elastic modulus calculations employing forward calculation equations (assuming an elastic half-space) obtained with deflectometer were regressed against laboratory resilient modulus. Among other it was concluded that the first sensor deflection exhibits a large variability. It was also detected that the first sensor modulus tends to be lower than each of the offset sensor modules when the surface material is softer than the underlying soil.

The research of Korkiala-Tanttu et al. [3] concentrates on the behavior of pavement with low bearing capacity under spring conditions and overload. Measurements were made in laboratory simulated conditions. The results led to conclusions that the majority of permanent deformations in all structures occurred in the subgrade sand, as well as that when the ground water was at the top of the subgrade (-0.5 m from the asphalt), a relatively larger share of permanent deformations occurred in the subbase gravel and the subgrade. When the ground water was lower (1.0 m), a greater share of displacements occurred higher up in the base course.

Zariņš [11] examined the feasibility to evaluate road pavement response under full scale loading in situ using the dielectric conductivity parameters of the road material. It was identified that evaluating change of dielectric parameters in unbound road material under loading it is possible to detect the structure condition and serviceability.

3. Dielectric behaviour of the road material
The dielectric permittivity of the granular material describes the degree of resistance of the media to the electric field. Dielectric permittivity of the subsoil material is determined by intensity of various processes in the subsoil structure. They include 1) the ionic and 2) dipolar polarisation and relaxation of the water molecules and 3) the atomic and 4) electronic resonances in the material media due to the
voltage applied to it. Dielectric permittivity $E_r(\omega)$ for soil or road material can be expressed with relationship:

$$E_r(\omega) = \frac{E(\omega)}{E_0}$$

(1)

Where, $E(\omega)$ – absolute dielectric permittivity of material, which depends on frequency and is a complex value.

$E_0$ – dielectric constant of material, or the relative permittivity of a material for a frequency of zero.

The character of each of these processes can be determined using different measurement frequency. The most important ones for the road structure are the first two values mentioned. The measurements to detect them must be carried out using the frequencies of about 2 kHz for detecting the ionic and domain polarization processes and of about 40-50 MHz for the molecular level polarization processes. However, the whole spectrum of the frequencies or at least both mentioned together can possibly raise interest in the subsoil material studies. The parameter measured with the percometer is the real part of the complex relative dielectric permittivity value $E_r$. Measurement $E_r$ for the natural materials, including subsoil materials and other granular building materials, is relatively complicated. In order to avoid the impact of environmental heterogeneity on the conductivity parameters, it is important to choose the adequate frequency of measurement and the location of sensors. Also it is important to establish correct understanding about the water influence on the physical and chemical processes in the road material depending on actual chemical composition of the water. The conductivity of the granular material largely depends on its moisture, but much more – on the electrochemical properties of the water solution, i.e. salt content in the water as well as on the electrochemical properties of the medium particles. It is possible to use empirical relationships between conductivity $E_r$ and the proportion of the water in the material – moisture W. In general, relation $E_r = f(W)$ at different moisture conditions and water electrical properties is non-linear and depends on water and material particle interactions. Most of the typical materials have fixed inherent values of W and $E_r$.

The main process, which can be analysed with respect to the road material response to the pressure, is the change of polarisation in the water solution in interaction with the soil particles and voids during the loading and consecutive volume change. Polarization reduces the electric field in the dielectric media because of the increase of polarization charge density on the particle surface. Consequently, the surface parameters of the media constituent material and their molecular structure must be taken into account while evaluating the measured dielectric data. The latter applies especially to the quantity of the water solution, density and its chemical structure. In order to compare the measurements made in different media, influence of all of the parameters must be precisely identified and evaluated. However, two different measurements taken at the same media in sufficiently similar conditions can be assumed as comparable, even without knowing those parameters, assuming that they are the same in both measurements compared.

The losses of material conductivity under pressure results from the inherent heat loss, the loss from the process of polarization of water molecules, and from the loss in the electrochemical processes between clay mineral particles. This phenomenon is the result of a complex frequency dependent dielectric permittivity. The real part of the dielectric permittivity for natural environments changes in the range of 1 for the air up to 81 for the water. Water is the component of the natural environment, including the unbound road materials, which to a great degree affect both the dielectric permeability and material mechanical properties, for example, the bearing capacity of the pavement structure. Note
however that this effect also depends on other factors, for example, grading composition, etc. Road structure can contain several forms of water: adsorption (hygroscopic) water, capillary (matrix) water, and free water. Dielectric permeability of the water within soil or road material depends on the total soil particle surface area available for water molecules, on the polarization of the water molecules, as well as on the density of the soil. Thus, change of the material conductivity and hence the dielectric permittivity resulting from load or compression can be explained with the release of the colloidal particles and ions from the clay particle surface and their suspension in the free and matrix water. Others factors causing this effect are due to 1) suction and 2) pumping phenomenon in capillary material, as a result of cyclic loading. Loss of the dielectric capacity of the soil and the road material can also be explained with suction, when the free water from the upper layers is temporarily withdrawn to the lower layer as a result of the compression and subsequent release of the pavement structure.

![Test Vehicle](image)

**Figure 1.** The test vehicle.

### 4. Methodology and test site

The methodology of the research was based on the road bearing capacity evaluation using LWD together with dielectric permittivity measurements in the selected road structure using percometer. Measurements were made during full scale loading in different pavement structure layers at different depths and in different moisture/temperature conditions. The road structure performance was tested in two loading conditions while loading with standard six axle timber haulage vehicle (see figure 1): 1) with common tire pressure 0.8 MPa and 2) with the reduced tire pressure 0.35 MPa using CTI system installed on the same test car.
Special infinity sign shape test site was prepared (see figure 2) in a way to simulate definite road conditions. Structure of the test road was made similar to most low volume roads under consideration. The structure of the road and sensor configuration is shown in figure 3. Water table during the first test session appeared at 0.65m below road surface. In the later sessions it was at the depth 0.70-0.80m.

![Configuration of sensors in the test station.](image)

Loading was performed until direct and clear visible indications of pavement collapsing appeared. After each test session road structure was restored by profiling and compacting. Each test session contains test of road structure in the same conditions with both 0.35 and 0.8 MPa tire pressures in exactly that sequence.

Test equipment consists of the percometer equipped with two sensors, data logger, LWD and the portable weighting-machine for fixing determined axle loads in the particular test session.

The research methodology is based on the road structure dielectric constant measurements using a percometer during loading and LWD measurements before and after loading. Continuous $E_r$ measurements were carried out at the depth of 0.25 and 0.50 m of the pavement structure during the test.
Project consists of four test sessions held in as different as possible road and moisture conditions – in late spring, before summer rain period, during and after summer rain period, during and after autumn rain period.

![Installation of upper sensor.](image)

**Figure 4.** Installation of upper sensor.

The $E_r$ evaluation of road pavement response is based on the consideration that the dielectric permittivity change of an unbound pavement material under the load correlates with the amount of the applied impact [11]. So the measurements of $E_r$ in equal media conditions for different loads can be used for impact evaluation. Therefore it can be assumed that the induced parameter changes within a single measurement session (in equal conditions) are comparable.

Assuming that load impact influences the change of the dielectric parameters of the road material, and that to a great extent this change depends on matrix water, the measurements in the tests for detecting $E_r$ were carried out using frequency 2 kHz. Samples of $E_r$ were taken using sampling rate 100 Hz.

Duration between consecutive vehicle passes was set to approximately 60 seconds considering the speed of 20 km/h. Vehicle crosses the test section of the road in approx. 8-10 seconds. Dielectric permittivity measurements were taken using two sensors at 25 and 50 cm depth. These sensors were also used to determine the temperature and moisture in the structure.

Bearing capacity of road structure was tested using LWD equipped with set of three geophones. Deformation modulus $E$ from the measured displacement was backcalculated according to Boussinesq equation. LWD measurements were done before, after and between all test sessions as well as few days prior and after. Measurements were located in wheel track and between wheel tracks. According to George [2], deflectometer measurements were done using 300 mm plate and interpreted considering displaced (second and third) geophones for road bearing capacity evaluation. The first geophone was located in the center of the loading plate (modulus signed as $E(0)$), the second and the third, respectively, at a distance 0.3 and 0.6 m from center of the loading plate (signed as $E(0.3)$ and $E(0.6)$).
5. Test results

Overview of moisture dynamics during the research period is shown in figure 5. As shown, two of the performed test sessions were made in relatively dry conditions, while the other two – in wet. It was fixed that in all cases moisture level drops during the test, and to a higher degree it happens after passes using standard pressure – 8 bar tires. It can be also pointed out that higher drop appears at higher initial moisture. Such moisture drop can be explained by pumping action during load pass, which withdraws water from road structure to the surface. Higher tire pressure leads to deeper and more intensive action.

![Figure 5. Moisture dynamics over test period (%).](image)

Analysis of the correlation of bearing capacity with moisture does not show sufficiently reliable relationship (see figure 6). It can be explained by insufficient amount of data. However, it reflects the expected hypothesis that capacity is inversely proportional to moisture content. It is confirmed by measurements from all three geophones, and most strongly it appears in the upper part of pavement (see trendlines E0/W<sub>up</sub> and E0.3/W<sub>up</sub> in figure 6).

![Figure 6. Relationship of moisture content to the bearing capacity.](image)
The data obtained after test sessions indicate that using tires with lowered pressure can significantly increase service life of a road. The number of test vehicle passes with each type of tire pressure, until clear indications of pavement collapse was fixed, are collected in table 1. The indications of pavement collapsing are:

- Increasing dielectric permittivity under pavement (sensor 2). As shown in figure 5, until the 17th pass \( E_r \) in the lower sensor did not show any obvious response to the load. The 17th pass indicated clear response. This can be explained by loosening of the pavement bonds. The pavement does not adequately spread the load from wheels and this reflects on the deeper parts of road structure;

- After collapsing dielectric permittivity of the upper layer (sensor 1) decreases due to loosening of the pavement bonds and pavement material cracking in lateral displacement zone (see figure 7). It reflects as rising of dielectric resistance.

- Appearing of visible lateral cracks in the surface of pavement and rapid growth of lateral displacements along wheel tracks (see figure 8).

Table 1. Comparison of test vehicle passes until pavement collapse.

| No of Test session | 0.35 MPa (with CTI) | 0.8MPa (standard pressure) |
|--------------------|---------------------|---------------------------|
| 1                  | >22                 | 17                        |
| 2                  | >23                 | 18                        |
| 3                  | >26                 | 17                        |
| 4                  | =75                 | -                         |

Figure 7. \( E_r \) response diagram during test drive with tire pressure 0.8 MPa.

Using lowered pressure (0.35 MPa) tires, collapsing conditions of the road structure were not observed after the designated count of passes.

Dielectric permittivity to a great extent depends on matrix water movement. In the first test session during regular test vehicle passes the pumping effect appears and it reflects in dielectric permittivity as from the lower sensor. \( E_r \) rises significantly when water reaches the sensor. In the upper sensor it appears after approximately 40 passes of the test vehicle in 3 hours. In this case it conforms to appearing of typical pavement collapse indications. However, in general any reasonable correlation between pavement moisture and bearing capacity during the observation period was not fixed, if considering those moisture levels typical for a particular structure. In some cases rising of moisture is
followed by rising of the bearing capacity. That can be explained by consolidation of matrix water or release of some molecular bound (hygroscopic) water during compaction of pavement material under load. This can also be justified by rising of temperature by 1-2 degrees C in the upper sensor.

From the analysis of backcalculated modulus of deformation from all three LWD geophones (see figure 7) it can be concluded that the upper part or the layer of payment was compacted during loading while the lower part loses bearing either due to water pumping, or due to shear strain induced deformations in the base ground, or both together. It follows from the fact that during all test sessions bearing capacity backcalculated from the first geophone E(0) rose during loading with the lowered pressure tires, while other two E(0.3) and E(0.6) geophones gave falling capacities.

![Figure 8](image_url)

**Figure 8.** Dynamics of modulus of deformation during the test session.

The rising of bearing capacity E(0) during the use of lowered pressure tires once again points at the main advantage of CTI system – the upper layer compaction phenomenon.

![Figure 9](image_url)

**Figure 9.** Visible indications of pavement collapse.
After loading with full pressure tires, backcalculated capacities from all geophones showed falling bearing capacity. This to a greater extent relates to \( E(0) \), and confirms actual physical condition of the road after pavement collapse.

LWD measurements were performed in two zones of carriageway – in the wheel track and between the wheel tracks. Backcalculated modulus between wheel tracks typically was significantly lower and did not change during loading (see figure 6). This happens due to lower degree of compaction.

6. Conclusions
If managed in improper way, heavy traffic can seriously damage an unpaved road. If loading is intense, pavement material bonds are breaking down, shear stress in unbound pavement material and subsoil exceeds the threshold values and pavement collapses. As demonstrated in the current research, the structure of a typical low volume road can be destroyed by passing of less than twenty closely following full loaded timber haulage vehicles. To prevent this, considering of traffic intensity margins is necessary. These margins define the boundaries of pavement workability. Most of low volume roads with unbound pavement can sustain some ordinary heavy vehicle passes. Each of them breaks the pavement structure to some extent. Current research establishes that reasonable number of closely following heavy vehicle daily passes on a typical low volume road should not exceed 15-20. The exact number of close passes varies depending on subsoil, pavement, and drainage conditions. That number can be increased up to 50% by using lowered tire pressure. This prevents upper layer damage and supports pavement compaction. It was concluded that the reduced pressure in tires significantly reduces the impact on the upper layer of the pavement. However, in the depth of the base layer and subsoil this effect disappears. After intensive use, road structure must be profiled or repaired, if necessary, to reestablish loosened pavement bonds which to a great extent have hydraulic nature. Self recovering time after marginal loading lasts minimum 1-2 days.

It was also detected that pavement collapse is the function of passing frequency. Optimum frequency allows recovery of the pavement structure between consecutive passes. If pavement recovery is not complete, the next pass increases the previous damage. It is possible to put forward the hypothesis that optimum passing frequency is not a linear function. It depends on previous degree of damage and provided recovery time.

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