Heavy load impact on low volume road pavement

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ABSTRACT: Latvian low volume roads and particular – their pavements shows serious problems in form of cracking, rutting, other deformations and which finally leads to weak serviceability and short lifetime of the road structure. In many cases these problems has been associated with overloaded vehicles and their impact. To find how heavy traffic loads impact road structure and evaluate their prevention possibilities, as well as to investigate the efficiency of freight transport, and establish conditions that will allow to optimize it, a study is carried out in Riga Technical university in cooperation with Latvian State Forests SC. As option for load impact reducing, the Central Tire Inflate system (CTI), installed on the test vehicle, is being checked. The research methodology is based on deflection measurements with LWD together with dielectric constant measurements in the road structure using percometer. Measurements are taken in the various pavement structure layers in different depths, during full-scale loading and in different moisture/temperature conditions. Increase of the contact surface is established using the CTI system, which was installed on the test vehicle. The advisable intensity and load for heavy traffic considering road conditions were established during the study.

KEY WORDS: road pavement, bearing capacity, dielectric permittivity, CTI, LWD

1 INTRODUCTION

One of the most essential descriptors of road efficiency is the guaranteed road bearing capacity. It mostly depends on adequacy of actual traffic loads on particular road structure. Latvian road operation experience show several problems associated with heavy loads and their impact on the road pavements. A large part of the road network has experienced strong rutting. The overloaded traffic loads are mentioned as the main reason. This leads to reducing of road capacity and shortens their service life.

It is therefore important to find efficient possibilities to prevent road damaging while keeping necessary transportation amounts.

The research is focused on low volume roads, typically with unbound pavement. Bearing capacity of such roads usually significantly decreases in slush seasons. Therefore authorities are closing them for heavy transport during these periods. This results in economy interruption in the service area of the closed road.

To establish conditions that will allow to use the road for an entire year without damaging it, the study is carried out in Riga Technical University in cooperation with Latvian State Forests SC. As option, for load impact reducing, the central tire inflate (CTI) system, installed on the test vehicle, were being checked. 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.

According to Treube et all, (1995) using of CTI system decreases rutting in pavement surface layer, however this improvement was less than expected. There is also pointed, that low compaction and poor drainage contribute to significantly more rutting.

Bradley (1997) reviewed research and employing experience of variable tire pressures in forest road design. This review fixes 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 usage efficiency.

First studies of road structure using percometer are available from the 1995th when percometer was used in tube suction test by Saarenketo and Scullion (1995) and Scullion and Saarenketo (1997).

There are several studies about the dielectric properties of the road materials and soils, with regard to the operational characteristics: Saarenketo et al. (1998), Saarenketo et al. (2000). These studies were conducted under laboratory conditions. Research on the road operating parameters, considering their impact to the frost heave, during which dielectric properties of the medium are studied, is described by Saarenketo et al. (2000) and Saarenketo and Aho (2005). There was also considered the possibility to use the dielectric value of medium under load, as parameter and characteristic of the loading impact on the road structure. Zariņš (2010) examined the feasibility to evaluate road pavement response under full scale loading in situ of using the dielectric conductivity parameters of the road material.

2 DIELECTRIC PROPERTIES OF THE ROAD MATERIAL

The dielectric permittivity $E_r(\omega)$ of the subsoil or road material can be expressed with relationship:

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

where: E(ω) – the absolute dielectric permittivity of the material, which depends on the frequency and is a complex value, E0 – the dielectric constant of the material, or the relative permittivity of the material for a frequency of zero.

Permittivity describes degree of the resistance of a medium to the electric field. Dielectric permittivity of the soil material is determined by intensity of the various processes in the material structure. They are: 1) the ionic and 2) dipolar polarisation and relaxation of the water solution molecules and 3) the atomic and 4) electronic resonances in the material due to the voltage applied to it. The character for each of those processes is possible to determined using different measurement frequency. The most important ones for to the road structure are the first two of mentioned. The measurements must be carried out using the frequencies: – about 2 kHz for detecting the ionic and domain polarisation processes, and about 40-50 MHz for the molecular level polarisation processes. However, possibly, the whole spectrum of the frequencies or at least both mentioned together can make an interest in the soil material studies.

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 natural soil materials and other granular building materials, is relatively complicated. In order to avoid the impact of environmental heterogeneity on the conductivity parameters, there is an importance to choose the adequate frequency of measurement and proper location of sensors. Also it is important to establish a correct understanding about the water influence to 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 electrochemical properties of the medium particles. It is possible to use empirical relationships between the 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 depend on water and material particle interactions. Most of the typical materials have fixed inherent values of the W_v 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 medium, because of the increase of polarization charge density on the particle surface. Consequently, the surface parameters of the soil constituent material and their molecular structure must be taken into account while evaluating the measured dielectric parameters. The latter applies especially to the quantity, density and chemical structure of the water solution. In order to compare the measurements made in different materials, influence of all of the parameters must be precisely identified and evaluated. However, two different measurements taken at the same soil material 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 change of material conductivity under pressure results from: - the inherent heat transfer, - the process of polarization of water molecules, and, - the electrochemical processes between clay mineral particles. So this phenomenon is the result of a complex, – frequency dependent dielectric permittivity. The real part of the dielectric permittivity value for natural media changes in the range from 1 for the air, up to 81 for the water. Water is that component of the natural environment, including the unbound road materials, which in great degree affect both the dielectric permeability as well as its mechanical properties, for instance – bearing capacity of the pavement structure. Note however that this effect also depend on other factors, such as grading composition, etc. Road structure can contain 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, as well as from the polarization of the water molecules, as well as 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 releasing 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 the 1) suction and 2) pumping phenomenons in capillary material, resulting from cyclic loading.

3 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 a road structure using percometer. Measurements were made during full scale loading in the different pavement structure layers in 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 fig. 1.) with common tire pressure – 0.8 MPa and with reduced tire pressure 0.35

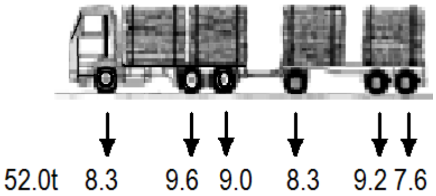

Figure1: The test vehicle and load distribution scheme

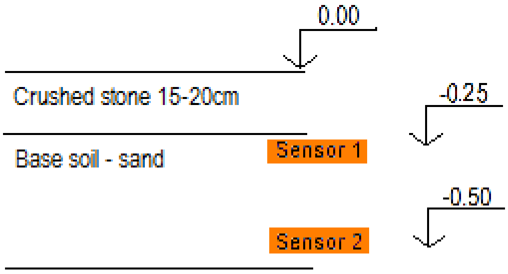

Figure 2: Configuration of sensors in the test station

MPa. The necessary tire pressure was adjusted using CTI system, installed on the same test vehicle. Special test site was constructed for mentioned purposes. Test road was made with structure similar to most low volume roads under consideration. Structure of the road and sensor configuration in it is shown in fig. 2. Groundwater level during first test session appears 0.65m below road surface. In later sessions it was in depth 0.70-0.80m.

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 loading of road structure with booth 0.35 and 0.8 MPa tire pressures.

Test equipment consists of the percometer equipped with two sensors, data logger, LWD and the portable weighting-machine for fixing determined, equal for each test session, axle loads. The test procedure consists of dielectric constant measurements using a percometer during loading and LWD measurements before and after loading. Er measurements were carried out in depth of 0.25 and 0.50 m of the pavement structure during loading with the test vehicle.

The paper represents test sessions held in late spring, before and during autumn rain period. 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 (Zariņš 2010). So measurements of E_r in similar soil conditions can be used for the impact evaluation for different loading conditions. Therefore it can be assumed, that the induced dielectric permeability parameter changes within a single measurement session and similar material conditions are comparable.

Assuming, that pressure from load change the dielectric permittivity of the road material, and that in greater extent this change depend on matrix water, the measurements in the tests for detecting E_r was 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 speed of 20 km/h. Vehicle crosses the test section of the road in approx. 8-10 seconds.

Figure 3: Location of upper sensor

Bearing capacity of road structure was evaluated using LWD, equipped with set of three geophones. Deformation modulus E from 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 (2003) deflectometer measurements was done using 300 mm plate and considering displaced (second and third) geophones for road bearing capacity evaluation. First geophone located in center of loading plate (modulus signed as E(0)), second and third respectively at distance 0.3

and 0.6 m from center of loading plate (signed as E(0.3) and E(0.6)).

4 TEST RESULTS

Overview of backcalculated deformation modulus from all three geophones in test section of the road during research period is shown in fig.4.

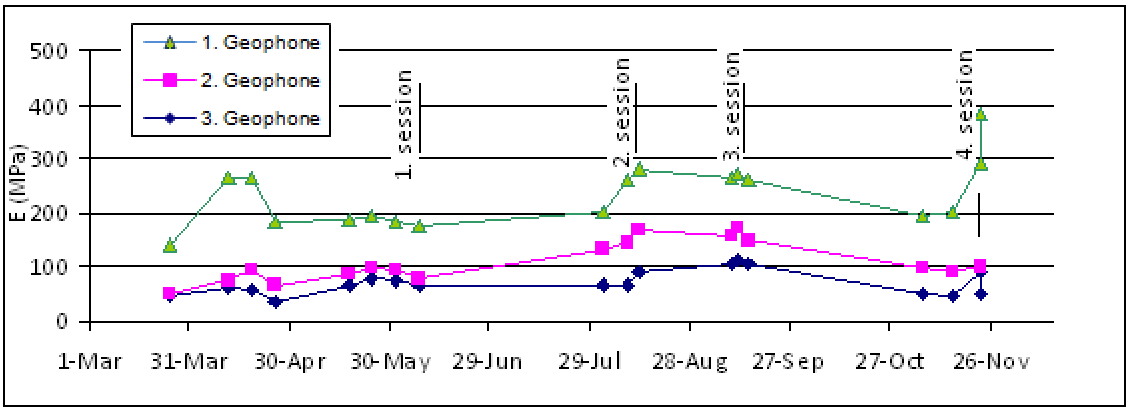

Figure 4: Backcalculated deformation modulus E (MPa) over the test period.

The number of test vehicle passes with each type of tire pressure, until clear indications of pavement collapse are recorded in the Table 1. Data obtained after four test sessions indicates that using tires with lowered pressure, service life of a road can be significantly increased. The indications of pavement collapsing were:

- Increasing dielectric permittivity under pavement. As shown in fig. 5.: until 17th. pass E_r in lower sensor (sensor 2.) didn't show an obvious response to load. The 17th. pass indicate clear response. This can be explained by loosening of pavement bounds. This provides that the impact from wheels reach deeper parts of road structure.
- After collapsing decreases dielectric permitivity of upper layer (sensor 1) due to loosening of pavement bounds and pavement material cracking in lateral displacement zone (see fig. 5.) It reflects as rising of dielectric resistance.
- Appearing of visible lateral cracks in surface of pavement and rapid growing of lateral displacements along wheeltracks (see fig. 7.)

Using lowered pressure (0.35 MPa) tires collapsing condition of the road structure in first three sessions were not observed after designated count of passes. In last session loading was performed with only this pressure and indications of collapsing was fixed after 75 passes.

Dielectric permittivity in great extent depends on matrix water movement. In the first test session the pumping effect appears during regular test vehicle passes. It reflects in dielectric permittivity starting from the lower sensor. Er rose significantly when water reached

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	-

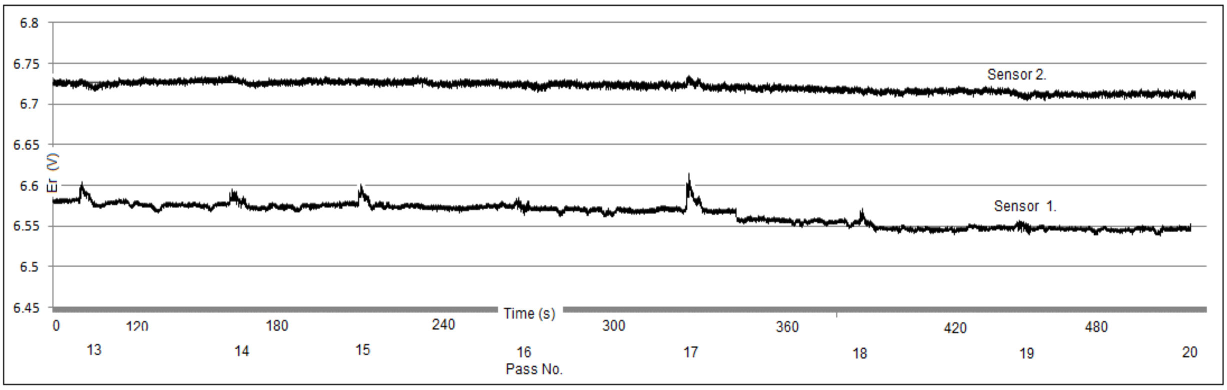

Figure 5: E_r response diagram during test drive with tire pressure 0.8 MPa.

the sensor. It reached the upper sensor after approximately 40 passes of test vehicle in 3 hours. In this case it conforms to the appearing of typical pavement collapsing indications. However in generally there wasn't fixed any reasonable correlation between pavement moisture and bearing capacity during observation period, if considering those moisture levels, typical for particular structure. In some cases rising of moisture follows by rising of bearing capacity. That can be explained by consolidation of matrix water, or releasing of some molecular bound (hygroscopic) water, during compaction of pavement material under load. This can be justify also by fixed rise of temperature for 1- 2 degrees C in the upper sensor.

From analysis of backcalculated modulus of deformation (see fig.6.) it can be conclude, that upper part or layer of pavement, was compacted during loading, while lower part lose bearing. It happens either due to water pumping, either due to shear strain induced deformations in base ground, or due to both together. It follows from fact that during all test sessions bearing capacity backcalculated from first geophone E(0) rises during loading with lowered pressure tires, while other two E(0.3) and E(0.6) geophones gave descending capacities.

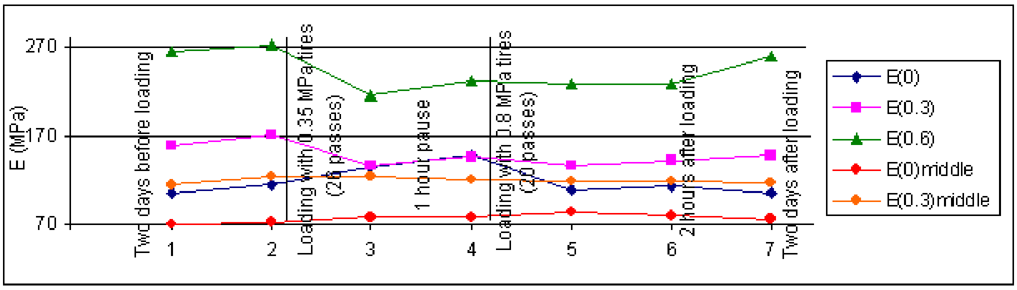

Figure 6: Dynamics of modulus of deformation during test session

The rising of bearing capacity E(0) during use of lowered pressure tires once more time points to the main advantage of CTI system – the upper layer compaction phenomenon. After loading with full pressure tires, backcalculated capacities from all geophones showed descending bearing capacity. This in greater extent relates to the E(0), and confirms actual physical condition of the road after pavement collapsing.

LWD measurements were performed in two zones of carriageway - in wheel track and between wheel tracks. Backcalculated modulus between wheeltracks (E(0and0.3)middle) typically was significantly lower and did not changing during loading (see fig 6.). This happens due to less degree of compaction here.

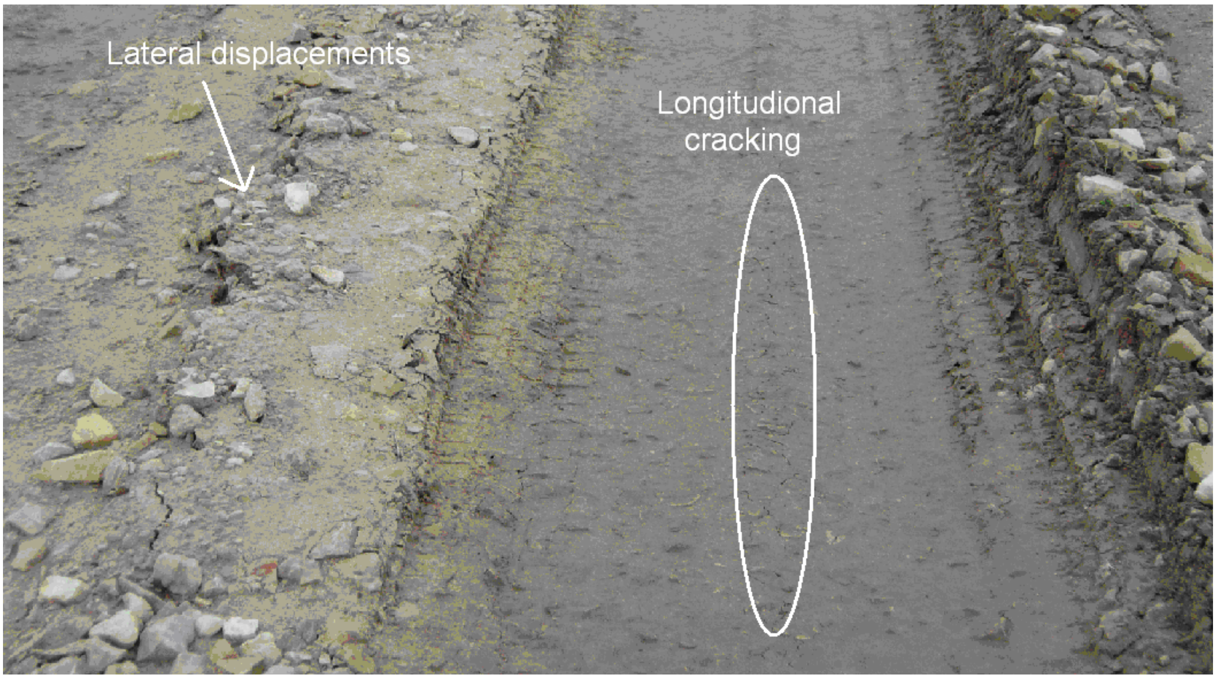

Figure 7: Visible indications of pavement collapse

5 CONCLUSIONS

If managed in improper way, the heavy traffic can seriously damage a road. If such road loading is intense, pavement material bonds are breaking down, shear stress in pavement and subsoil exceeds allowable and pavement collapse. As fixed in current research, structure of typical low volume road can be collapsed by passing of less than twenty close following heavy vehicles. To prevent this, considering of traffic intensity margins is necessary. These margins define boundaries of pavement workability. Most of low volume roads with unbound pavement can carry few ordinary heavy vehicle passes. Each of them breaks pavement structure in some extent. Current research establish that reasonable number of close following heavy vehicle daily passes on typical low volume road not exceed 15-20. Exact number of close passes varies depending on subsoil, pavement, and drainage condition. That number can be increased significantly by using lowered tire pressure. This prevents from 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 loosen pavement bounds which in great extent have hydraulic nature. Pavement recovering time after marginal loading lasts at least 1-2 days.

The condition of road structure can be monitored and analysed in terms of soil or material dielectric parameters such as dielectric permittivity. In general these parameters depend on character of water movement and condition in the road material and the subsoil. Dielectric parameters of road material can be measured within two frequency intervals –about 2 kHz for detecting of the ionic and domain polarisation processes, and about 40-50 MHz for the molecular level processes. This study was carried out in the lowest frequency interval. However, the results show that some of the response parameters, i.e. – the recovery time, can be researched in the higher frequency interval, because of its more ionic level character.

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