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Permanent deformations of unbound materials of road pavement in accelerated pavement tests

Les déformations permanentes des matériaux non liés du chaussee en essai accéléré

L. Korkiala-Tanttu & R. Laaksonen,
VTT Building and Transport, Espoo, Finland; leena.korkiala-tanttu@vtt.fi

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ABSTRACT: The permanent deformations in different kinds of road structures have been studied at VTT with an accelerated pavement tests. The tested road constructions consist of different structural solutions (embankment with or without slope), heavy overloads, rehabilitated structures and layers with different water contents and material properties. The common objective for all of the tests was to find out where permanent deformations happen and what is their relation to the dynamic response.

1 INTRODUCTION

VTT (Technical Research Centre of Finland) jointly owns with the Finnish Road Administration and VTI from Sweden an accelerated pavement testing machine called HVS-Nordic. HVS is a linear, mobile testing machine with full temperature control. The loading wheels are dual or single and wheel load can vary from 20 to 110 kN. VTT has a test site in Otaniemi with two water proof test basins where test structures were constructed. During the second Finnish testing period from 2000 to 2002 VTT has done four test series. Each test series consisted of three different test structures. The first test series were part of the EU Reflex research programme with reinforced structures. The second test series were part of the national 'Low-volume road research' -project. The third series were 'Spring - overload' tests where the effect of overload was studied under spring conditions. The last series - 'Rehabilitated steep slope' - compared different rehabilitation methods together. The other tests, besides the European Reflex programme, were national. This paper focuses on the last three test series.

2 TEST OBJECTIVES

All four research projects studied structures of low-volume roads. In a low-volume road, the permanent deformations of structural layers and subgrade play a significant role in deterioration and service life of the road. So the common objective for all of these tests was to determine where permanent deformations happen and what is their relation to the dynamic response. Tests were also done in order to verify laboratory test results in a full-scale environment. Furthermore, the objective was to determine suitable modelling parameters for a computer based design system.

The objective of the HVS 'Low-volume' road research tests was to study the effect of the cross section and edge effects to the structural strength of pavement. The third research project concentrated on the effects of the overloads to the behaviour of pavement with low bearing capacity under spring circumstances. The second objective of this research was to study the validity of the 'fourth power rule' under spring conditions. In the fourth test series the rutted low-volume road structures with steep side slopes were rehabilitated with a new asphalt layer and different kinds of reinforcements. The objectives of these tests were to define the influence of the reinforcement: what is the rutting rate of the improved structure when comparing it to the rutting rate before rehabilitation. The other aim was to define how much different reinforcements decelerate rutting.

3 TESTED STRUCTURES AND METHODS

The 'Low-volume' test included three different cross sections: one with a steep slope (1:1,5), one with a gentle slope (1:3) and one without slope (figure 1). The total thickness of the pavement layers was 640 mm, which consisted of the 40 mm asphalt layer, 400 mm crushed rock and 200 mm gravel on the subgrade of dry crust clay. All test sections were instrumented to measure the changes in stresses, water contents, temperatures and deformations during construction and testing in both the horizontal and vertical directions. The testing wheel was a Super Single wheel, which had the load raised in 10 kN steps from 30 kN to 50 kN. The test basin was water - proof so the level of the water could be raised from W1 to W3 during the test. The response measurements were both dynamic and static. The length of each test section was eight metres and they were tested separately. The testing programme was the same for all test sections.

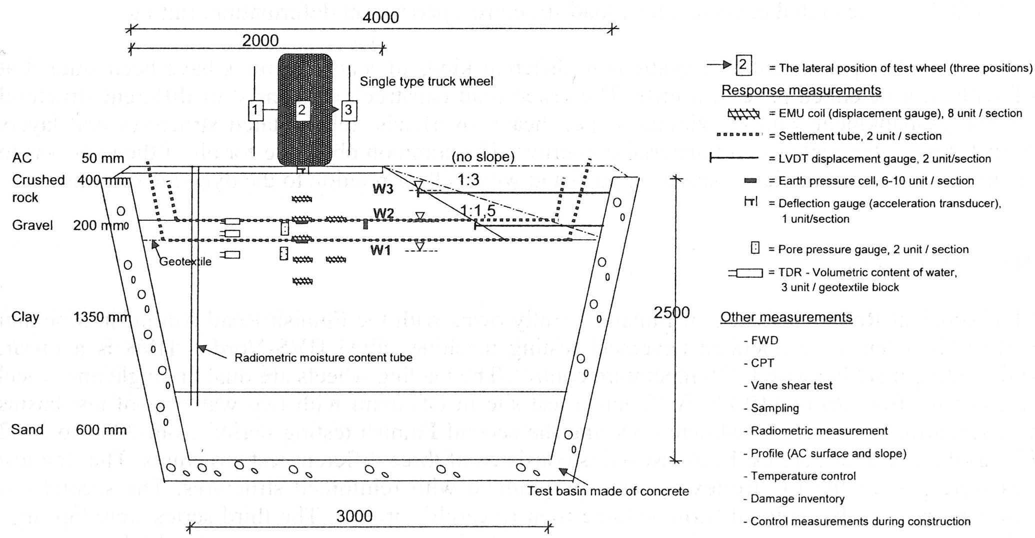

Figure 1. The cross section of the 'Low-volume' road tests.

In the 'Spring - overload' test program the structures were all similar. The subgrade was sand, which was covered with 250 mm layer of crushed gravel as subbase, 200 mm layer of crushed rock as base course and 50 mm asphalt on the top (figure 2). The used test wheel was a dual wheel. The tested structures differed from each other in respect of the applied load (50 kN and 70 kN) and water table levels (W1 and W2). The instrumentation was designed to measure the deformations with many different methods so that also the accuracy of different measuring systems could be evaluated.

All 'Low-volume' test sections were rutted after the testing. The structure with a steep 1:1,5 slope was deteriorated most. Its rut depth varied from 60 to 80 mm and there was a wide longitudinal crack in the left edge of the rut. These test structures were rehabilitated in the 'Rehabilitated steep slope' test and there they were tested again.

In the 'Rehabilitated steep slope' test the originally eight metre long test sections were divided into two to get six four metre long sections. The damaged structures were first levelled with adjustment mass. Then different kinds of reinforcements were installed on the surface. All structures were covered with a 40 mm asphalt layer. The tested reinforcements included two different steel nets and one glass fibre geotextile. Also two reference structures without reinforcements were tested. The side slopes in all these structures were steep (1:1,5). The loading programme in the 'Steep slope' tests resembled that of the 'Low-volume' tests with the same load and water level steps. Only the number of the passes was double in the 'Steep slope' test.

The classification, deformation and strength properties of the unbound pavement materials were determined in the laboratory. The properties of the asphalt layer were not tested in the laboratory.

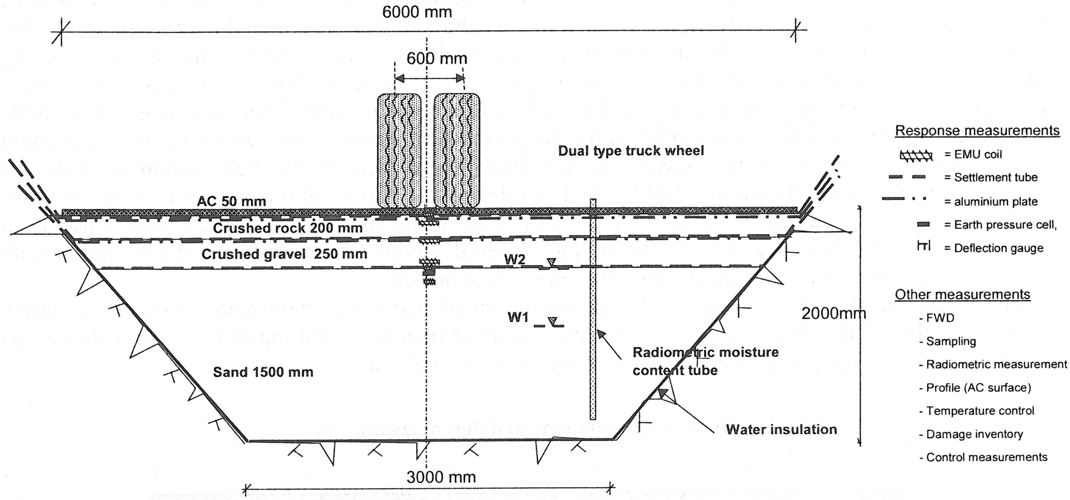

Figure 2. The cross section of 'Spring - overload' tests.

4 TEST RESULTS AND ANALYSIS

The construction of the test structures inside basins was done very carefully to get as even constructions as possible. The quality of the construction was followed with levelling, density and bearing (FWD, Loadman) tests. Despite this the quality measurements showed that there was large scattering in some properties. The biggest problem was the thickness of the asphalt layer and hence the bearing capacity of the structures. The average thickness of the asphalt layer in the 'Low-volume' test series changed between 37 - 47 mm. The calculations by multilayer programme showed that a 10 mm decrease in asphalt thickness increases stresses with about 11 - 29 % in the base layer and 5 - 11 % in the subbase. This problem was common to all test structures.

The rutting of the structural layers was documented with Emu-Coil sensors. Other measurements - like levelling and settlement profile measurements - were also made to supplement and to compare the reliability of the measurements. The relative proportions of rut were calculated from the total rutting at the surface of the asphalt layer. Figures 3 and 4 show the proportions of vertical displacements in the 'Low-volume' and 'Spring-Overload' tests.

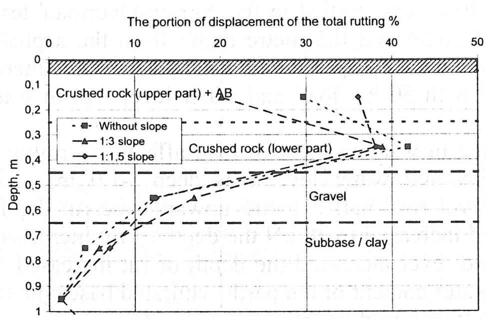

Figure 3. The proportions of deformations in 'Low-volume' tests.

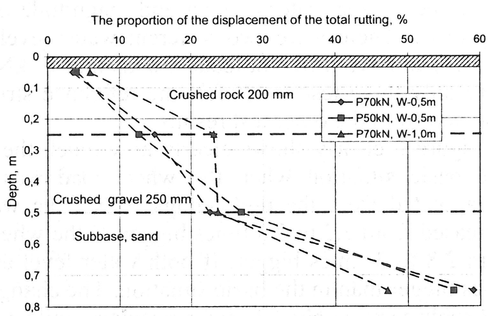

Figure 4. The proportions of deformations in 'Spring-Overload' test.

There are two opposite views regarding where the permanent deformations happen. One argument is that the most significant part of the permanent deformations happens in the base course. According to the other argument, it is the subgrade that deforms. The HVS test results show that both arguments are correct and depend on the structure. In the 'Low-volume' test it was the base course that deformed (figure 3) and in the 'Spring - Overload' test it was the subgrade that deformed the most (figure 4). So, from the surface of a moderately rutted road it is impossible to know where in the structure rutting really will happen and how deep the ruts will be. The only possible method is to calculate permanent deformations in different pavement layers. The calculation of permanent deformations is not a simple task. There are only a few material models for the permanent deformations, which takes into account the capacity, the amount of the passes and the stress state. One of the best available models is presented by Huurman /Huurman 1997/. VTT modelled the 'Low-volume' test structures with an element program called Flac. The calculation was made using material properties, which had been determined in the laboratory. Even with simple material models a relatively good correlation with calculations and real behaviour of the test structure was achieved.

Rehabilitation also affects a lot to the accumulation of permanent deformations of the structure. The total rutting of the 'Steep slope' test was much smaller than in the rutting of the 'Low-volume' test (figure 5) although the passes were doubled in the 'Steep slope' test.

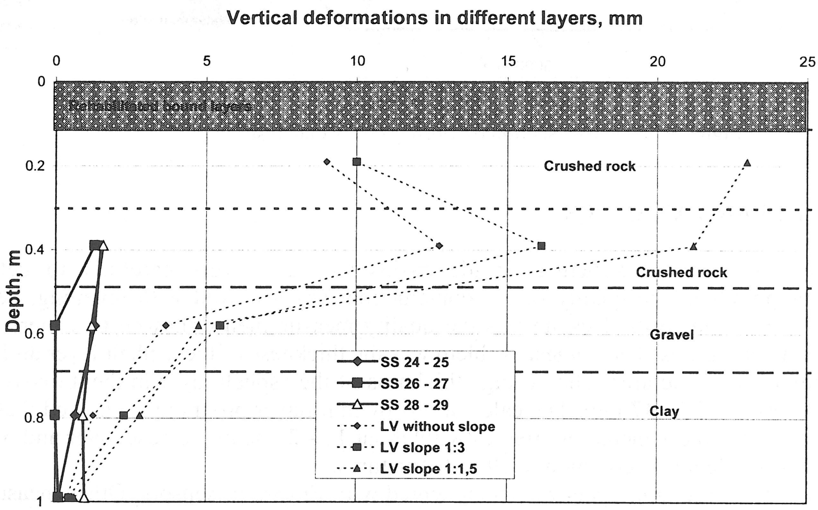

Figure 5. The deformations in different layers in 'Low-volume' (LV) and 'Steep slope' (SS) tests.

The effect of the water content and magnitude of the load was studied in the 'Spring-Overload' test (figure 6). There were two different water levels (1,0 metre and 0,5 metre depth from the asphalt surface) and two different loads (50 kN and 70 kN) which were compared with each other. While there were only three test structures, the reference structure with 50 kN load and water level -1,0 m was assessed from the other test results.

Figure 6 clearly shows clearly how much the change in water content or load affects the rutting. The basic situation when the wheel load was 50 kN and water level was deep (-1,0 m) was extrapolated from the preloadings. When the water level rose half a metre upwards the rut depth increased from 2,2 to 2,5 times bigger. If the wheel load increased to 70 kN the depth of rut increased from 2,8 to 3 times bigger. If both water level and load level increased the depth of rut increased 6 times bigger than in the basic situation. The change in water content of the partly saturated base course and subbase was only 0,3...0,4 percentage units, yet its effect was drastic.

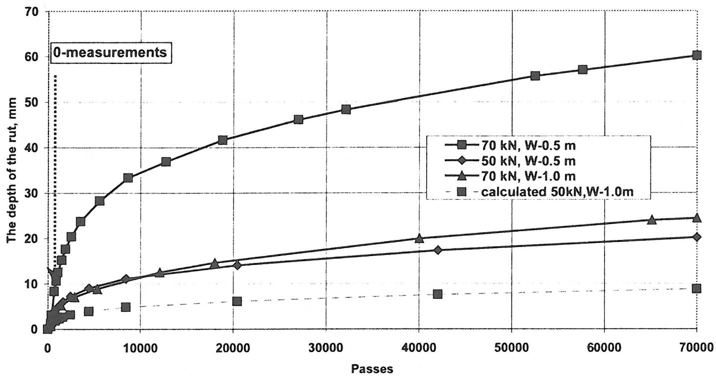

Figure 6. The depth of the rut in 'Spring-Overload' test as the function of passes.

5 DISCUSSION

One objective in the 'Spring - Overload' test was to find out the validity of the 'Fourth power law' in spring conditions. The fourth power law dates back to the AASHTO research project in the sixties. The researched roads were mainly roads with thick asphalt layers (more than 80 mm). The fourth power law is a simple empirical way to estimate the deterioration speed of a pavement, where the proportion of the passes with same depth of the rut grows on the fourth power of the proportion of the applied wheel loads to the standard wheel load. Hence this proportion should be independent of rut depth. According to the HVS tests descriped in this VTT research, the proportion is actually very dependent on the depth of the rut (figure 7) and hence the fourth power law is not valid for low-volume roads with thin pavement layers.

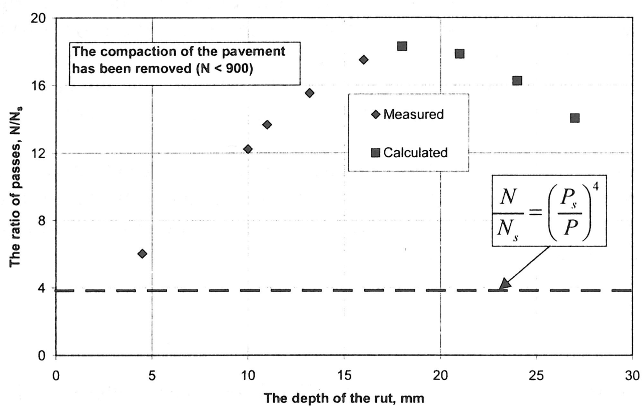

Figure 7. The validity of 'Fourth power' law in 'Spring -overload' test.

It is well-known that the deformation behaviour of granular materials is highly non-linear. Many studies have shown that there is some limit value of transient load after which the permanent deformations will grow quickly. This limit value is usually called the 'shakedown' limit in highway engineering. This phenomenon corresponds to the yielding in geotechnics. The 'shakedown' limit can be clearly seen when both resilient and permanent deformations are compared with each other (figure 8). The amount of the 'shakedown' limit depends on many things, the most important of which are the material, water content, stress state and density. In the 'Steep slope' test the ' shakedown' limit was not exceeded so the permanent deformations were quite moderate.

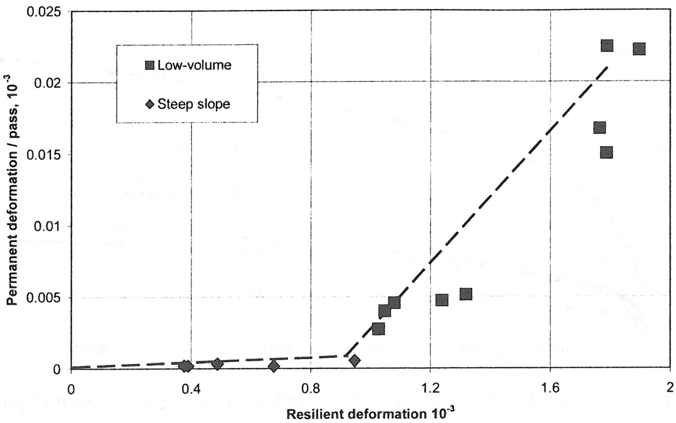

Figure 8. The ratio of resilient and permanent deformations in the 'Low-volume' and the 'Steep slope' tests in base course's crushed rock.

6 CONCLUSIONS

The place or structural layer where deformation occured varied in different tests – in the 'Low-volume' test program the base course was the most deforming layer and in the 'Spring - Overload' test program it was the subgrade that deformed most. Thus it is not possible to define the deformation in various layers of a moderately rutted road based on surface measurements.

The response of unbound granular materials is highly non-linear and this behaviour must be taken into consideration while modelling the structure. Also the deformation behaviour of granular materials is non-linear and a limit value of permanent deformations called a 'shakedown' limit can be noticed. The behaviour/response of unbound material is defined in excess to its mineralogy by several other state variables like stress, density, moisture and temperature. From the point-of-view of deformation the crucial factor is the moisture content, where a slight change may a cause drastic change in rutting.

The empirical Fourth power law is commonly used to estimate the pavement's deterioration. The HVS tests descriped here clearly showed that this simple relation is not valid for thinly coated pavements.

During the test programs a suitable, efficient and cost-effective testing procedure and instrumentation arrangement was developed, which provided enough information for the analysis and decision-making. In future this optimized research process is available for similar projects and also for the acceptance tests of materials or structures.

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