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Accelerated load tests with a heavy vehicle simulator

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Preliminary report

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Accelerated load tests with a heavy vehicle simulator

A full-scale accelerated structural load test was performed in the scope of field trials conducted to investigate the effect of various strengthening actions on weak pavements. The asphalt layer thickness varied from 6.5 cm to 13.6 cm. The results of deformations applied on test structures are presented in the paper. The loading of each test structure lasted for approximately 2 weeks. Clear dependence between the depth of permanent deformation and thickness of asphalt layers was established on thin pavement structures only.

Key words:
pavement deformations, field test, accelerated load test, heavy vehicle simulator

Prethodno priopćenje

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Ubrzani test opterećenja pomoću simulatora teških vozila

Pokus ubrzanog nanošenja opterećenja na konstrukcije u naravnoj veličini proveden je u okviru terenskih ispitivanja obavljenih u svrhu istraživanja učinkovitosti raznih mjera za pojačanje kolničkih konstrukcija slabe nosivosti. Debljina asfaltnog sloja varirala je od 6,5 cm do 13,6 cm. U radu su prikazani rezultati deformacijskog djelovanja na ispitivane konstrukcije. Na svaku konstrukciju nanosilo se opterećenje tijekom otprilike dva tjedna. Ustanovljeno je da naglašena ovisnost između dubine trajne deformacije i debljine asfaltnih slojeva postoji samo kod tankih kolničkih konstrukcija.

Ključne riječi:
deformacije kolnika, terensko ispitivanje, ispitivanje ubrzanim opterećivanjem, simulator teških vozila

Vorherige Mitteilung

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Beschleunigter Belastungstest mittels Simulierung von Schwerfahrzeugen

Im Rahmen von Feldversuchen an Konstruktionen in Originalgröße ist eine beschleunigte Lastauftragung durchgeführt worden, um die Wirksamkeit verschiedener Maßnahmen zur Verstärkung von Straßenkonstruktionen schwacher Tragfähigkeit zu erforschen. Die Asphaltschicht war zwischen 6,5 cm und 13,6 cm stark. In der Arbeit sind Resultate zum Verformungsverhalten der untersuchten Konstruktionen dargestellt. Die Lasten wurden bei jedem Versuch während ca. zwei Wochen aufgetragen. Eine deutliche Abhängigkeit der verbleibenden Verformungen und der Stärke von Asphaltschichten ist nur bei dünnen Fahrbahndecken festgestellt worden.

Schlüsselwörter:
Fahrbahnverformung, Feldversuche, Versuche mittels beschleunigter Lastauftragung, Simulierung von Schwerfahrzeugen

1. Introduction

An accelerated load test (ALT) was performed using the Heavy Vehicle Simulator, HVS-Nordic. This device was chosen to investigate the effect of different strengthening treatments on existing pavements. Six different road structures were selected for field trials, and four of these test structures are presented in the paper. New road sections were built for the purposes of this test. Sub-base and base layers made of uncrushed gravel with grain size 0 to 32 mm were constructed on the initial ground composed of silt and clay. Unbound layers were up to 60 cm in thickness. The planned thickness of the asphalt layers was 6.0 cm at test structure I, 8.0 cm at test structure II, 10.0 cm at test structure III, and 13.0 cm at test structure IV. The asphalt thickness was controlled at three profiles for each test structure, and it was established that the actual pavement thickness varied from 5.7 cm to 14.4 cm, which is probably due to the uneven surface of the base layer.

A full-scale accelerated load testing was performed on four different road structures in April and May 2008. The test wheel was moving in a 8 m section, but the speed of the wheel was constant at the distance of 6 m. The test structures were well instrumented with strain gauges and inductive coils for vertical displacement (deformation) measurement. The readings also provided the response data at different load conditions, e.g. wheel load, tire pressure, etc. Two different road structures were tested at the same time. Thus, the wheel was running for the first 4 m on one road structure, and the second 4 m on the other one. One test lasted for two weeks and the machine was running day and night for seven days a week, with interruptions for daily maintenance/servicing only. During the main test, cross-section measurements were carried out to calculate the propagation of rut depth. It was decided that the pavement temperature should be kept constant at 20°C and that the wheel load should be 60 kN at the beginning of the tests, after which it can be increased if necessary. The load was applied in both directions, and the lateral wander shift of wheel was used in transverse direction.

2. Construction

2.1. Ground conditions and unbound layers

After the ALT, five boreholes were drilled in March 2009 to determine the actual road structure and subgrade conditions. The boreholes were drilled at the end of March 2009 within the area of the ALT testing performed. The drilling was conducted after five days of heavy rain, and the soil under the test structures I to IV was investigated. The boreholes were made next to the location where the deformations occurred due to the ALT wheel loads. Intact samples of gravel and silty clay were taken for laboratory testing. Static penetration tests (SPT) were performed in the clayey silt. They clearly showed that the subgrade beneath the gravel fill was very soft. The boreholes were dry, except at the test structure II, where the deepest (two meters deep) borehole was drilled and soon afterwards the water table rose to the level of 110 cm beneath the road surface. It can be assumed that the ground water table is at

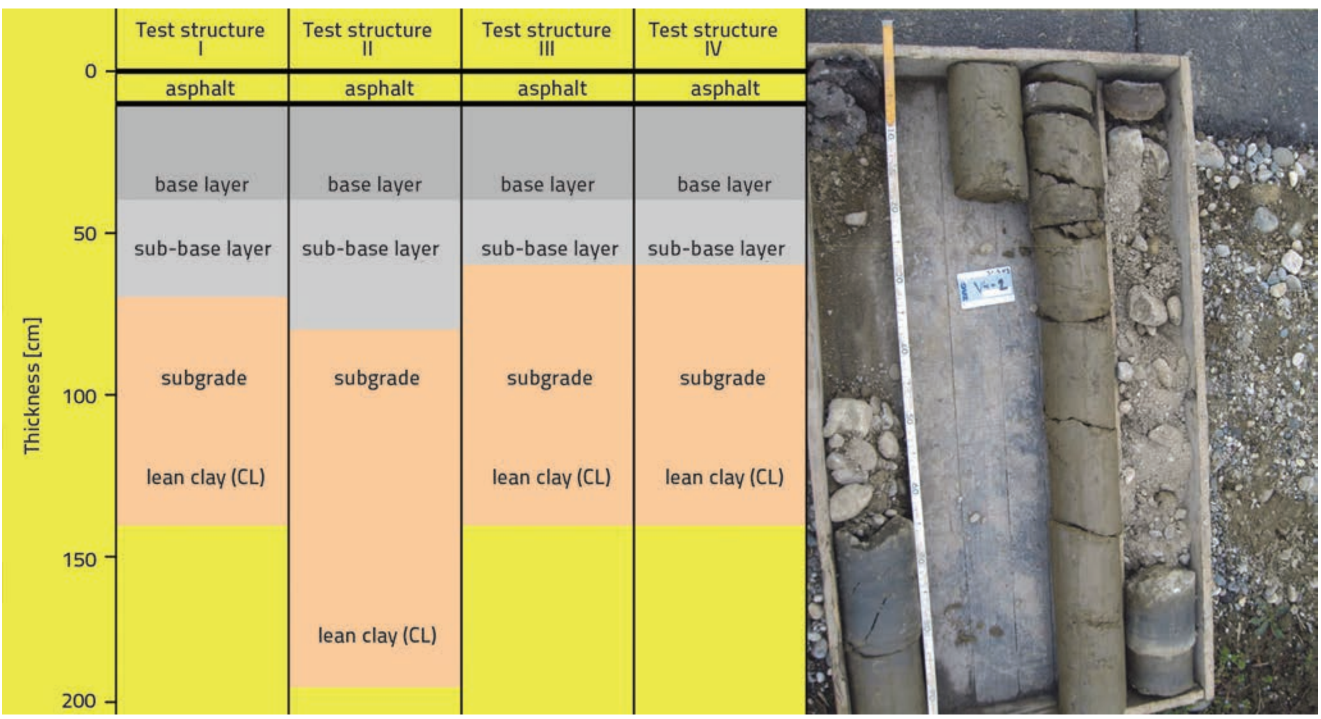

Figure 1. Ground and road structure conditions

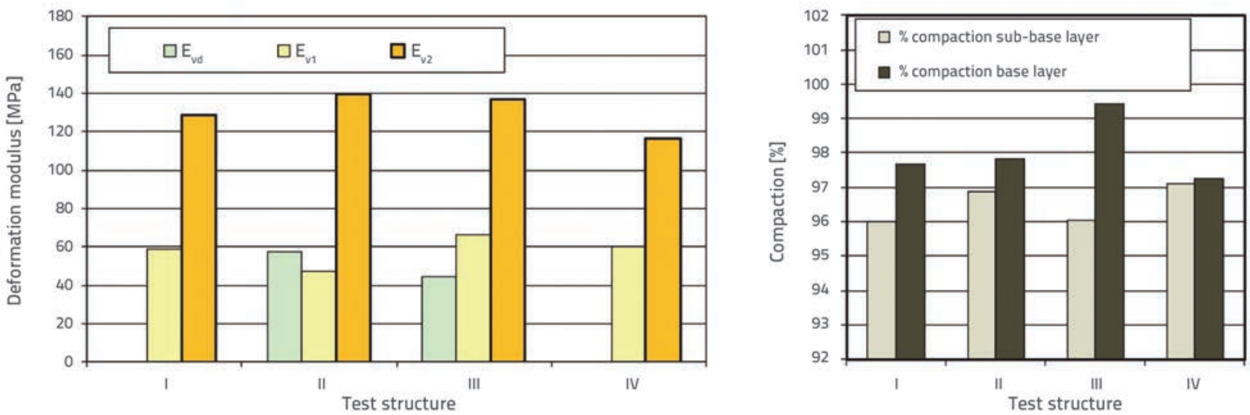

Figure 2. Results of field tests (I to IV) on unbound layers - deformation moduli and compaction

the depth of more than 100 cm below the road surface. The established ground conditions are shown in Figure 1. The subgrade consisted of lean clay (classified as CL according to the Unified Soil Classification System).

Unbound sub-base and base layers, each 20-25 cm in thickness, were constructed on top of the subgrade. Uncrushed poorly graded 0-32 mm gravel (classified as GP-GM), taken from the Mura River, was used for these two layers. The thickness of the fill differed over the overall length of the test section due to changes in the original ground level. The grain size analysis revealed that there was not much difference between the characteristics of the sub-base and base layers. The overall gravel fill thickness was 60 cm on average, but varied between 50 cm and 70 cm.

Several field control tests, aimed at defining the compaction and deformation moduli, were performed on top of the sub-base and base layers during the construction activity in November 2007. A non-destructive method relying on radioactive isotopes (nuclear method) was used for the density and water content testing. Representative samples of the unbound layer were taken and the percentage of compaction was calculated based on Proctor tests performed in laboratory. Static deformation modulus tests (E_{v1} and E_{v2}) and dynamic deformation modulus tests (E_{vd}) were performed according to Slovenian national regulations [1] and [2]. One measurement of the static deformation modulus was performed at every test field. Dynamic and static deformation moduli measured for the unbound base layer, and compaction values for the sub-base and base layers, are presented in Figure 2. Static deformation moduli E_{v1} and E_{v2} of the base layer were measured at all four test structures. E_{vd} was measured at test structures II and III only, as shown in Figure 2. E_{v1} and E_{v2} were also measured at test structure III for the sub-base layer. It was established that the deformation moduli measured on the sub-base layer were much lower than those corresponding to the base layer, which is probably due to the very soft subgrade.

The moisture content of the sub-base and base layers was determined during the road construction in November 2007. The material of the base and sub-base layers (four samples of gravel) was extracted from the boreholes in 2009, and the water content measurement was repeated. There was no increase in water content compared to initial conditions, although the drilling was conducted after a rainy period.

It was assumed for the accelerated load test analyses that the actual thickness of the unbound layer varies from 50 cm to 70 cm, since no significant difference was established between the deformation moduli and material characteristics of the sub-base and base layers.

Table 1. Characteristics of asphalt layers

Test structure	Designed asphalt surface layer	Average compaction and void content [V.-%] in surface layer	Designed asphalt base layer	Average compaction and void content [V.-%] in base layer	Designed thickness of asphalt pavement [cm]	Actual thickness of asphalt pavement [cm]
I	6 cm AC16 surf B50/70	95,1 % comp. 6,8 % void	Only one asphalt layer was built	N/A	6,0	6,5
II	4 cm AC11 surf B50/70	103,2 % comp. 2,8 % void	4 cm AC16 base B50/70	95,3 % comp. 6,6 % void	8,0	10,5
III	4 cm AC11 surf B50/70	101,9 % comp. 4,0 % void	6 cm AC22 base B50/70	98,5 % comp. 9,1 % void	10,0	9,3
IV	4 cm AC11 surf B50/70	102,4 % comp. 3,6 % void	9 cm AC22 base B50/70	98,5 % comp. 9,2 % void	13,0	13,6

2.2. Asphalt layers

Asphalt mixtures of different thicknesses were designed on top of the unbound base layer, as shown in Figure 3 and Table 1. Three different asphalt mixtures were designed, with the overall pavement thickness varying from 6 cm (test structure I) to 13 cm (test structure IV). After the testing, three cores were drilled for each test structure through the asphalt layers, and several laboratory tests were performed including measurements of the actual thicknesses of asphalt layers. An average measured core thickness ranged from 6.5 cm to 13.6 cm (cf. Table 1). It can also be concluded from Table 1 that the compaction level of surface layers was very good.
The asphalt thickness was controlled at three profiles for each test structure, and it was established that the actual pavement thickness varied from 5.7 cm to 14.4 cm, which is probably due to the uneven surface of the base layer (see Table 2). On the same profile, the surface rutting depth was measured during the ALT test. Surprisingly, it was revealed that the test structure II is thicker than the test structure III, although the design data would point to the contrary.
The B50/70 bitumen was used for the AC asphalt mixtures. The conditions B50/70 and B70/100 are usually used in Slovenian climate. It can be assumed from the data on void content in asphalt layers that only the AC surf 16 (test structure I) is permeable to surface water, while the asphalt layer can be assumed to be almost impermeable to water on all other test structures.
Wheel tracking tests at 60°C according to EN 12697-22 (with the small device) were performed on asphalt cores drilled from test fields (cf. Table 3). The asphalt mixture AC base 22 showed an excellent resistance to permanent deformation, while the resistance of the mixture AC surf 11 is still good for low-traffic roads. Only the AC surf 16 can be assumed to be typical for low traffic roads as to its resistance to permanent deformation.

Table 2. Actual thickness of all asphalt layers

Test structure / core number	Measured thickness [mm]	Designed asphalt thickness [mm]	Average thickness [mm]
I/1	62		
I/2	57	60	65
I/3	71		
II/1	96		
II/2	106	80	105
II/3	111		
III/1	92		
III/2	93	100	93
III/3	94		
IV/1	129		
IV/2	138	130	136
IV/3	144		

Figure 3. Tested pavement structures, incorporation of sensors in base layer

Table 3. Wheel tracking test results

Mixture	Average compaction and void content % and V.-%	Rut depth			PRD Average [%]	WTS Average [mm/1000]
		Sample 1 [mm]	Sample 2 [mm]	Average [mm]		
AC 16 surf	93,3 % comp., 8,6 % void	5,80	4,04	4,92	7,6	0,22
AC 11 surf	100,8 % comp., 5,1 % void	1,79	1,54	1,67	3,9	0,10
AC 22 base	99,0 % comp., 8,.7 % void	1,42	1,53	1,48	2,7	0,05
PRD - relative rut depth, WTS - rate of rut development						

2.3. Sensors

During construction of test structures, sensors were installed in the pavement to obtain response data following the HVS loading [3, 4] (COST 347, 2005; Format, 2005). Inductive coils (EMU-coils) were placed at the bottom and top of unbound base layers to measure vertical deformations of the base layers. Asphalt strain gauges (ASG) were placed at the bottom of the asphalt layers to measure horizontal strains in asphalt in the longitudinal direction.

Three sets of these sensors were installed for each structure at the centre line of the HVS loading. The exact location of all sensors was established by topographic survey measurements. The ASG and EMU coils are shown in Figure 4.

The HVS tests in Slovenia [5-8] were carried out with the dual wheel load at the pavement temperature of +20 °C (see Figure 5). The following test parameters were used in the tests:

- Dual wheel load 60 kN and 80 kN (Table 4),
- Tire pressure 800 kPa, tire size 295/80 R22.5,

Figure 4. Sensors - ASG and EMU coils

Figure 5. HVS at test site – April 2008

- Wheel speed 12 km/h, loading in both directions, with the lateral shift of 15 cm from centreline.

Table 4. Wheel loads and number of passes

Test structure	Wheel passes at load 60kN	Wheel passes at load 80kN
I i II	0 – 293 000	/
III i IV	0 – 49 760	49 760 – 208 135

Pavement deformations (settlements) were documented each day during the accelerated load test. Cross profiles were measured and the rutting depth was determined based on these profiles. At the same time, the readings were taken from the EMU coils, and these data were used to determine permanent deformations in the unbound gravel layer. The average vertical distance between the EMU plates was 15 cm. 5 cm of gravel was placed between the top EMU coil and the base asphalt layer, and hence it was assumed in further analyses that the distance between that asphalt and the lower EMU coil amounts to approximately 20 cm.

3. Results and analysis

3.1. Test structures I and II

The loading was not increased from 60 kN to 80 kN on test structures I and II, because the road structure was weak. About 300000 passes were performed in 12 days. The rutting depth on the surface, and permanent deformation in 15 cm of the unbound gravel layer, were measured every day at three profiles for every test structure. The results of these measurements are shown in Figure 6. The profiles are numbered P1-1, P1-2, and P1-3 for test structure I, and P2-1, P 2-2, and P2-3 for test structure II. It can be seen that permanent deformation on the asphalt surface has a similar propagation trend depending on the number of load passes as the deformation in the unbound gravel layer. The deformations on the surface were considerably bigger, especially at test structure I. The profile 1-3 was located next to the profile P2-1 at test structure II, and the influence of the thicker and stiffer asphalt layer is clearly shown. As expected, it can be seen that the deformation of asphalt and unbound layer is greater at test section I where the asphalt thickness is 6.5 cm only. It is also obvious that the deformation (settlement) of the base layer is much bigger at test structure I, where only 6.5 cm of asphalt was placed.

Attempts were made to evaluate correlation between the rutting depth on the surface and the permanent deformation in 15 cm of the unbound gravel layer. The deformation (settlement) on the surface of the asphalt layer at test structures I and II is shown in Figure 7 as related to the deformation measured in 15 cm of the unbound layer.

It was assumed from linear model given in Figure 7 that the intercept (2.57 mm) in the linear equation represents a pure initial deformation of the pavement structure. It can be seen

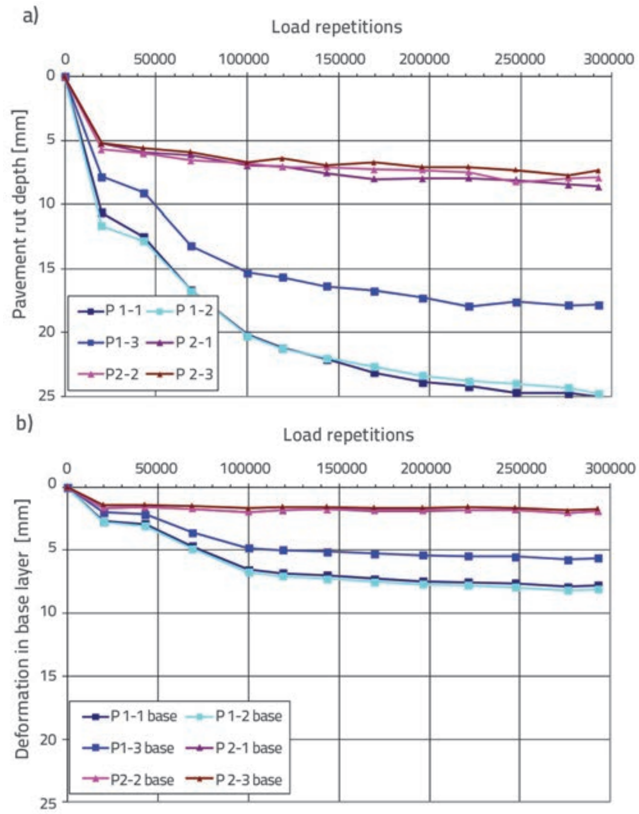

Figure 6. Test structures I and II: a) surface rutting; b) deformation in the unbound base layer

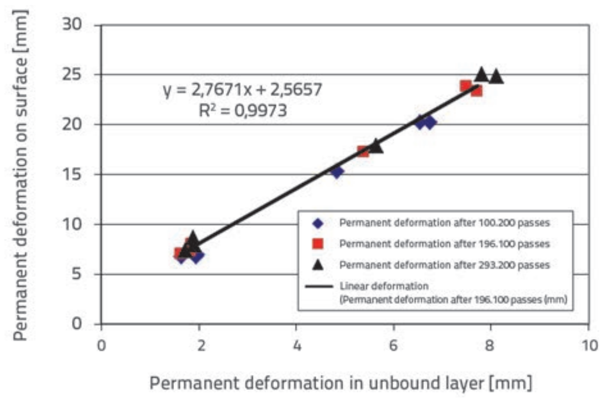

Figure 7. Correlation between rutting depth on surface and permanent deformation in 15 cm of unbound gravel layer at test structures I and II

from the slope of the curve that more than one third of the deformation (2.77) is in the 15 cm of the unbound base layer after initial deformation.

Figure 8 shows interdependency between the permanent deformation on the surface and asphalt thickness. It can be seen that the rate of permanent deformation is highly dependent on the asphalt thickness in the case of small asphalt thicknesses (e.g. 6.5 cm). It can be seen From Figure 8 that the correlation coefficient is good (0.95), and the slope of the curve increases with the number of passes.

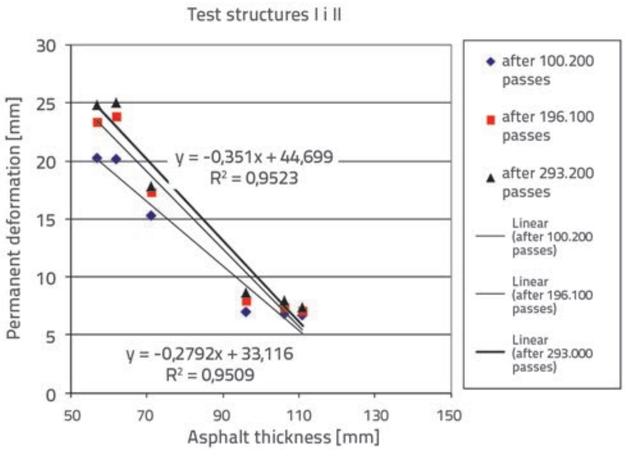

Figure 8. Interdependency between permanent deformation measured on surface and asphalt thickness

3.2. Test structures III and IV

The main difference between test structures III and IV was the asphalt thickness (9.3 cm and 13.6 cm, respectively). After 50000 passes the wheel load was increased from 60 kN to 80 kN. Figure 9 shows the propagation of permanent deformation on the asphalt surface of test structures III and IV (Figure 9.a) and permanent deformation in 15 cm

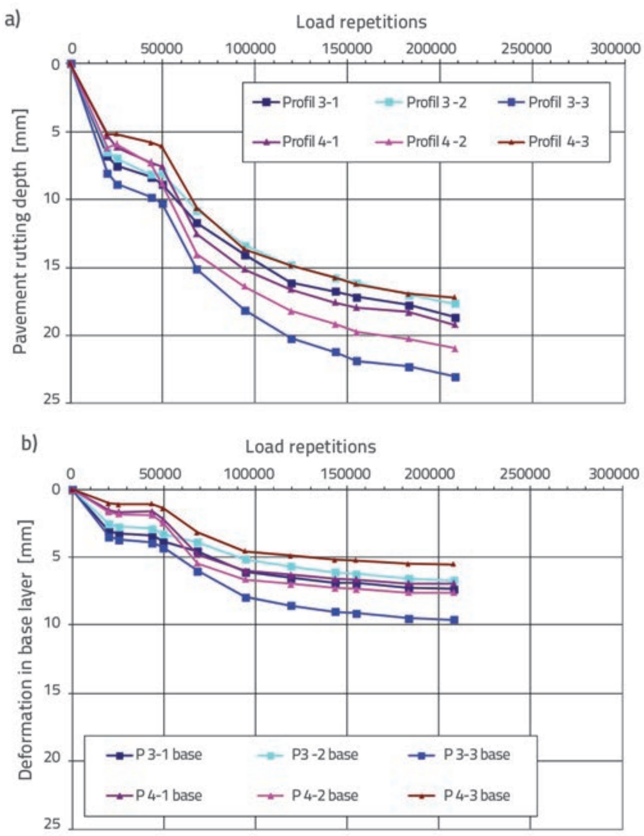

Figure 9. Test structures III and IV: a) permanent rutting; b) deformations in base layer

of the unbound base layer (Figure 9.b). It can be seen that the line of propagation of permanent deformation on the surface has the same shape as the deformation in the unbound gravel layer. As expected, deformations in the unbound layer are much smaller compared to those on the surface.

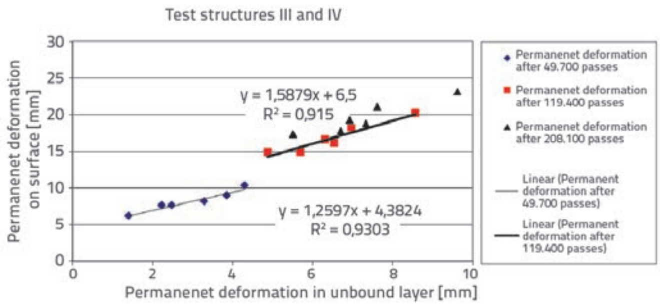

Figure 10. Test structures I to IV – average pavement deformation

The deformation (settlement) on the asphalt layer surface of test structures III and IV, as dependent on the deformation measured in 15 cm of the unbound layer, is shown in Figure 10. It was established that this dependence can be described by two linear models. The first linear model was determined for the 60 kN load, and the second one for the 80 kN load. It was assumed from linear models given in Figure 10 that the intercepts (4.38 mm and 6.5 mm) in the linear equation represent a pure initial deformation of the pavement structure. It can be seen from the slopes of the curves that more than one half of the deformation (1.26 and 1.69) is in the 15 cm of the unbound base layer after initial deformation. Figure 11 shows interdependency between the permanent.

deformation on the surface and asphalt thickness. If the asphalt layer is more than 9 cm in thickness, the measured permanent deformation is almost independent of the asphalt thickness.

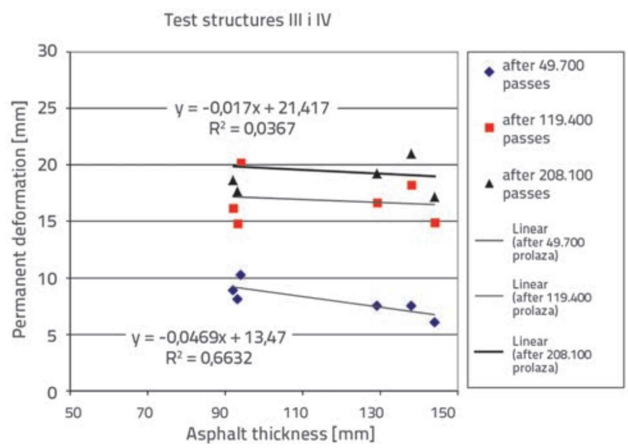

Figure 11. Test structures III and IV – interdependency between permanent deformation and asphalt thickness

4.3. Analyses of testing results

It can be seen in Figure 12 that average deformations on the surface of test structures II, III and IV were similar to one another when the 60 kN load was applied. The 80 kN load was applied after 50 000 passes on the surface of test structures III and IV, and the curve describing average deformations as related to the number of passes became steeper.

If linear models in Figure 7 and Figure 11 are compared, it can be seen that, with a thicker asphalt layer, most of the deformation on the surface is due to deformation in the unbound base layer situated beneath the asphalt layers.

It was also proven for test structures III and IV that the permanent deformation is almost independent of asphalt thickness in case of asphalt layers of more than 9 cm in thickness. A small correlation coefficient was established after approx. 50000 load passes (0.66), but there is no correlation between the asphalt layer thickness and permanent deformation after approximately 200000 passes (0.04).

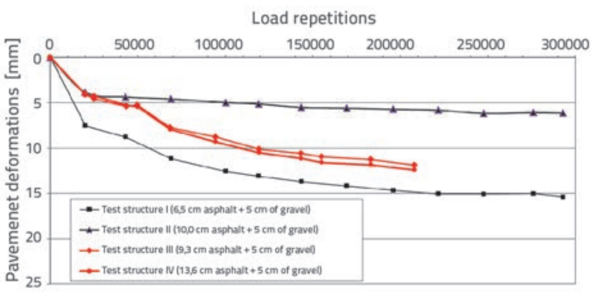

Figure 12. Test structures I to IV – average pavement deformation

4. Conclusions

Accelerated load tests (ALT) were performed on selected pavement structures with the Heavy Vehicle Simulator, HVS-Nordic. The structure of pavements was selected to simulate upgrading of weak roads to heavy traffic.

The unbound sandy gravel layer was placed on a weak clayey subgrade and compacted in the thickness of 60 cm. Investigations showed that the average thickness of pavement actually varied from 6.5 cm at test structure I, to 10.5 cm at test structure II, to 9.3 cm at test structure III, and to 13.6 cm at test structure IV. The full-scale accelerated load testing lasted for approximately two weeks on each test structure, and the rut depth and deformation of the unbound layer was monitored every day as a function of the load. Repetition numbers were monitored in each section.

A clear dependence between the depth of permanent deformation and the asphalt layer thickness was established on the thinnest pavement structures (5.7 cm to 7.1 cm). However, all permanent deformations were the same and did not depend on thickness of asphalt at other test structures with the asphalt thickness ranging from 9.3 cm to 13.6 cm. It was also established that most of the deformation on the surface is due to deformation in the unbound base layer beneath the asphalt layers in case of asphalt layers of more than 9 cm in thickness. It can be concluded that it is optimal to construct asphalt layers of about 9 cm in thickness on weak base layers, as was the case at the studied test fields. The optimum performance depends on the deformation moduli of the unbound layers and the asphalt thickness. It has been taken into account that the deformation moduli may depend significantly on the water content or groundwater table.

A good linear correlation was established between the permanent deformation in the unbound gravel layer and the permanent deformation on the surface (rutting). The regression curve was calculated. It was assumed that the intercept in the linear equation represents the pure initial deformation in the asphalt layers. The ratio between the deformation at the surface and the deformation in 15 cm of the unbound base layer can be seen from the slope of the regression curve.

All our conclusions are based on the observed pavement deformation only. It is however known that the asphalt pavement deformation is just one of possible forms of deterioration; the other main type of failure, i.e. disintegration of structure (cracking, potholing etc.), should also be taken into account in the final evaluation of a candidate structure alternative. Therefore, further studies are needed to be completely certain that thicker asphalt pavements are not cost effective to prevent premature disintegration of the pavement.

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