High Stable Asphalt for Heavy loaded Bus Test Lane Sections

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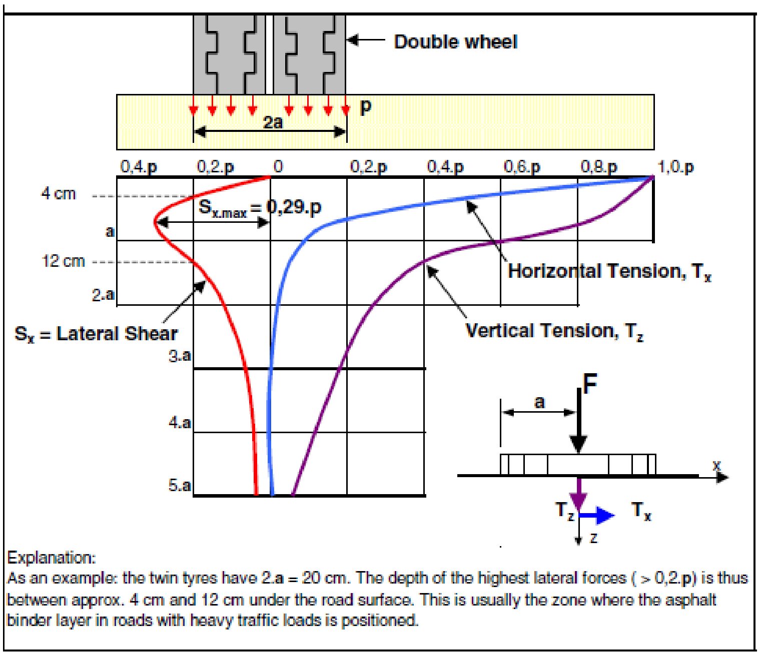
ABSTRACT: High stable asphalt for a heavy loaded bus test track in the city of Wuppertal, Germany, has been designed in the Pavement Research Centre of the University Wuppertal by means of analytical calculation models in combination with laboratory tests. Rutting is the major problem of heavy loaded asphalt bus lanes, especially at bus stops or traffic lights where bus speed decreases to zero. Rutting increases with decreasing lateral load distribution, unfavourable material selection and/or mix composition, and inadequate layer thicknesses. According to this, stable asphalt with high resistance against permanent deformation has to be designed. Therefore, eight different asphalt mixes with polymer modified and conventional binder have been produced for extended mix design tests. By means of analysing the laboratory test results, stable asphalt with high rutting has been selected. Following, the selected high stable asphalt has been paved compared to conventional asphalt in the scope of rehabilitation of a bus track. Since reconstruction in 2005, the rutting has been annually measured after every summer period. After three observation periods in 2008 the section with innovative asphalt pointed out much lower rut depth (9 mm) compared to the conventional asphalt (27.5 mm). This development of measured rut depth in situ confirms the laboratory test results as well as the analytical calculation.

KEY WORDS: bus test track, rutting, resilient modulus, polymer modified stable asphalt

1 INTRODUCTION

It is well known, that the performance of asphalt pavement depends on temperature, load type and time. With increasing temperature and decreasing loading time, the stiffness of asphalt layers as well as the bearing capacity of asphalt pavements significantly decreases. Asphalt pavements are stressed by traffic and climate, which have a main impact on the pavement performance. The construction materials used, the asphalt mix design and the quality of construction mainly influence the asphalt pavement quality. The main asphalt properties with respect to the pavement performance are the resistance against permanent deformation, resistance against fatigue, adhesion between binder and aggregate and ageing. The criterion of pavement design has to be selected in relation to deterioration mechanisms and the requirements in situ, so that low life cycle costs occur. The classical pavement design criteria are the fatigue at the bottom of the asphalt base layer, and the structural rutting originating in the granular layer and/or subgrade. But permanent deformations are most important for flexible pavements, because this mainly influence the maintenance of the asphalt pavement.



Explanation:
As an example: the twin tyres have 2.a = 20 cm. The depth of the highest lateral forces (> 0,2.p) is thus between approx. 4 cm and 12 cm under the road surface. This is usually the zone where the asphalt binder layer in roads with heavy traffic loads is positioned.

Figure 1: Lateral force diagram of a heavy vehicle tyre from test measurements (Wirtgen, 2002)

2 ASPHALT BUS LANE

After the definition of German Design Guidelines (RStO 01, 2001) the bus lanes and the bus traffic areas are described as heavy loaded pavement areas, especially at bus stops or traffic lights because of decelerating, stopping and accelerating. Furthermore the number and the capacity of buses increase due to city development and higher-order needs of public transportation, because most public transport journey within the city are made by bus. This development leads to increasing total weight and axle loads of buses. In addition the load of pavement construction will be increased by reduced tire dimension and higher tire pressure. To resist these high stresses of heavy loaded buses adequate pavements shall be used. The common paving methods for bus tracks and bus stops areas are block-, rigid-, semi rigid and asphalt paving (MB B BV, 2000). Every paving method has positive as well as negative aspects. The adequate pavement construction method should balance pros and cons taking of local conditions into consideration.

The authorities of Wuppertal selected a bus track for initiating a pilot project with two test sections, see figure 2. One section should be paved with innovative and the other one with conventional asphalt. Thereby the surface (40 mm thickness) and binder (60 mm thickness) course have been reconstructed. The rigid base layer has not been touched, but to avoid the reflection of cracks from rigid layer into the asphalt layer geo grids have been laid down. The design traffic volume was calculated after the German Design Guidelines (RStO 01, 2001) for a 30-year lifetime to 37 Mio (10 t) ESAL for the innovative section and to 31 Mio. ESAL for the conventional section. Such heavy traffic volume cause rutting on asphalt pavements. Hence asphalt layers with high resistance against permanent deformation should be paved on the test lane during the maintenance procedure. Thus, innovative asphalt mixtures with high resistance against permanent deformation have been designed in the asphalt laboratory of the University of Wuppertal. To compare the improvement of innovative asphalt mixes against conventional asphalt mixes, both variants were selected for paving.

Figure 2: Bus lane test section with innovative asphalt mixes

3 OUTLINES OF ASPHALT TESTS

Such heavy traffic volume, as above calculated cause rutting on asphalt pavements. Thus, by means of extended laboratory tests in the asphalt laboratory of the University of Wuppertal BESTLAB, high stable asphalt with a long lifetime and low life-cycle costs has been designed. Therefore stone mastics asphalt (SMA 0/11 S) with eight polymer modified / high polymer modified binders and with a conventional binder have been produced and tested to determine the influence of binder used by means of several asphalt tests. In the asphalt test laboratory BESTLAB following tests have been conducted:

- Conventional and performance related binder tests
- Temperature dependent resilient modules and,
- Wheel tracking tests.

The tests have been conducted with both polymer modified and conventional asphalt mixtures respectively. The asphalt mixes used differed only in the binders used while aggregate and gradation were kept constant. The polymer modified and high polymer modified Bitumen was delivered as ready mixed modified bitumen. The high polymer modified bitumen is an innovative product with a higher content of polymers compared to conventional polymer modified bitumen. The authors are unaware of the exact composition of the polymers used for modification. For each asphalt mix the same types of aggregate were used, as they are listed below:

- Limestone filler (0/0.09 mm),
- High quality diabase sand (0/2 mm) and
- High quality diabase chippings (2/5, 5/8, 8/11 and 11/16).

The following asphalt mix-types were selected:

- Stone mastic asphalt, surface course (SMA 0/11 S, Binder content 6.8 %, void content: about 3.5 %). Fibres had been added to provide adequate stability of bitumen and to prevent drainage of binder during transport and placement of SMA.
- Asphalt concrete, binder course (ABI 0/16 S, binder content 4.5 %, void content: 6.0 %) ABI 0/16 S have been produced for selected innovative and conventional asphalt.

4 ANALYSIS OF LABORATORY TESTS

4.1 Binder Properties

The binder properties have been tested by means of conventional binder tests: needle penetration (EN 1426, 2007) and softening point ring and ball (SP R&B) (EN 1427, 2007) with respect to European Standards. The test results are listed in table 1. The measured values of conventional bitumen are in the permissible range of EN 12591 (EN 12591, 2000). The determined SP R&B of the variants with polymer modified bitumen stand out significantly compared to the conventional variant with penetration grade 50/70. Particularly, the high polymer modified binder PmB 25H, PmB 7 and PmB 8 indicate with high SP R&B a high viscosity. Thus, asphalt produced with these binders will show high stability in high temperature compared to other polymer modified and conventional binder. In addition, the variants PmB 1, PmB 2, PmB 3 and PmB 25H show very low penetration values compared to the other variants. These variants can be classified as hard binders.

A high softening point R&B indicates a good performance against permanent deformation. Asphalt mixtures with a soft binder (low softening point R&B and a high needle penetration value) will cause a relatively high rutting compared to asphalt mixtures with a stiff binder, if identical aggregate structures were used. Furthermore asphalt with a high elastic recovery will affect the rutting resistance positively. The elastic properties of binders can reform the displacements after load removal.

Table 1: Binder properties

		PmB 1	**PmB 2**	**PmB 3**	**PmB 25H**	**PmB 5**	**PmB 6**	**PmB 7**	**PmB 8**	**50/70**
Softening Point Ring & Balls	°C	76.0	79.0	85.0	91.3	62.8	72.3	91.9	96.0	49.0
Needle Penetration, 25 °C	1/10 mm	24	26	30	22	43	49	47	58	54

4.2 Temperature dependent resilient modulus

The service temperatures and the temperatures in asphalt have significant influence on the lifetime and maintenance costs, particularly on rutting resistance of asphalt pavement. Thus, in practice an asphalt mixture with low temperature sensitivity will be preferred so that it causes low permanent deformation at higher temperatures, as well as less thermal cracking at low temperatures.

The temperature dependent resilient modulus characterizes mechanical properties of asphalt mixes and indirectly, also performance properties. The resistance against permanent deformation at high temperatures can be estimated by means of the temperature dependent resilient modulus as follows: The higher the modulus at high temperatures the higher the resistance against permanent deformation. To characterize the temperature sensitivity, resilient modules were determined at different temperatures between 10 °C and 35 °C by means of the dynamic indirect tensile test on drill cores produced with SMA 0/11 S (EN 12697–26, 2004). Drill cores have been gained out of the slabs, which have been produced by means of roller compactor (EN 12697-33, 2007).

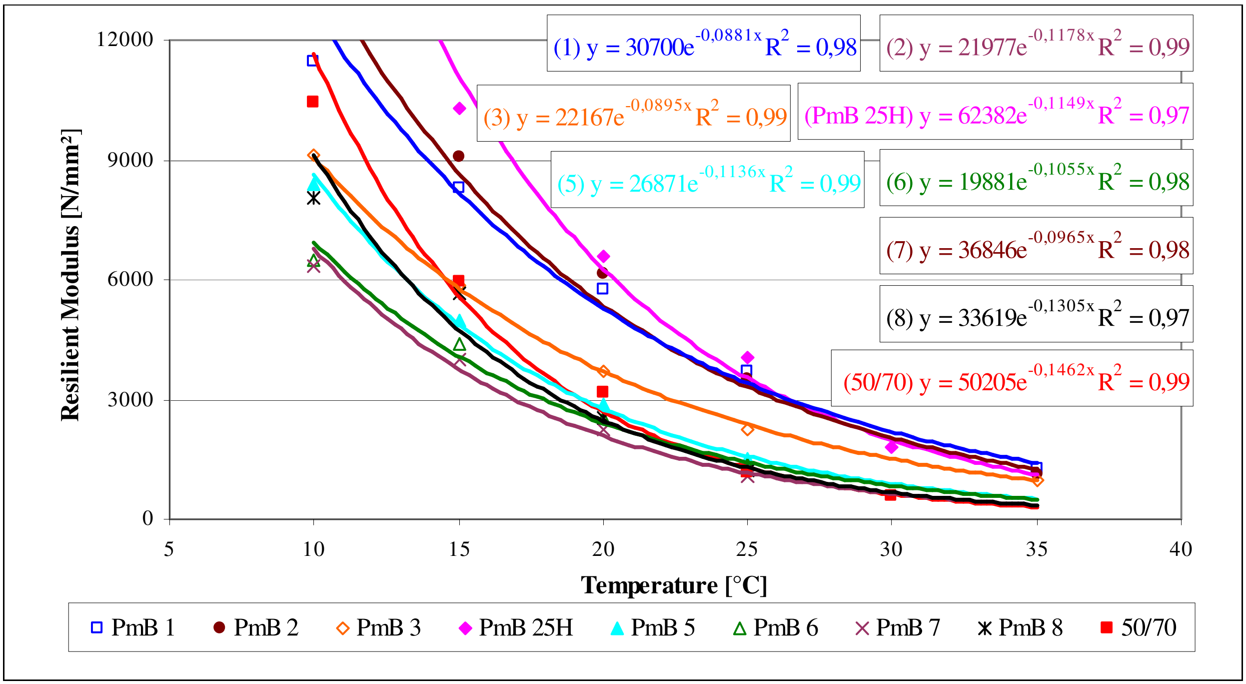


Figure 3: Temperature dependent resilient modulus for Stone Mastic Asphalt (SMA)

For the resilient modules temperature master curves were developed, see figure 3. As expected, resilient modulus decreases with increasing temperature. The variants (PmB 1, PmB 2, PmB 3 and PmB 25H) show higher resilient modules at temperatures above +30 °C. The high resilient modules of these asphalt variants at high temperatures are the result of the low pen value. The asphalt variant produced with PmB 25H let expect high resistance against rutting because of high value of softening point ring & balls compared to the variant PmB 1, PmB 2 and PmB 3. Conventional asphalt mixtures 50/70 and the polymer modified binders PmB 5, PmB 6, PmB 7 and PmB 8 show low resilient modules at temperatures above +30 °C and will tend to rutting in high gear.

4.3 Wheel Tracking Test (WTT)

Worldwide there exist numerous test methods and mixture response parameters to characterize rutting. In this work the resistance against rutting was determined by means of the wheel-tracking test after the German Standards (TP A-StB SBV, 1997). This method has been widely adopted Hamburger Wheel rutting test. It is a straightforward method to evaluate rutting. The stone mastic asphalt slabs were tested with steel wheels in a water-controlled device at 50 °C. The slabs have been produced by means of a roller compactor (EN 12697-33, 2007). The slabs are loaded for 20,000 passes and the rut depth is the result of two simultaneously tested slabs. The gained test results are displayed in figure 4.

The determined test results of polymer modified asphalt point out with significant low rut depth after 20.000 load cycle compared to conventional asphalt 50/70. The gained rut depths of polymer modified binders are about 30 – 50 % of the rut depth of conventional variants. The polymer modified variants PmB 3, 5 and 6 shows a high rut depth compared to the other polymer modified binders. The variant PmB 7 highlights with the lowest rut depth. As expected the variant PmB 25H show also a low rut depth and range close to the rut depth of the variants PmB 7.

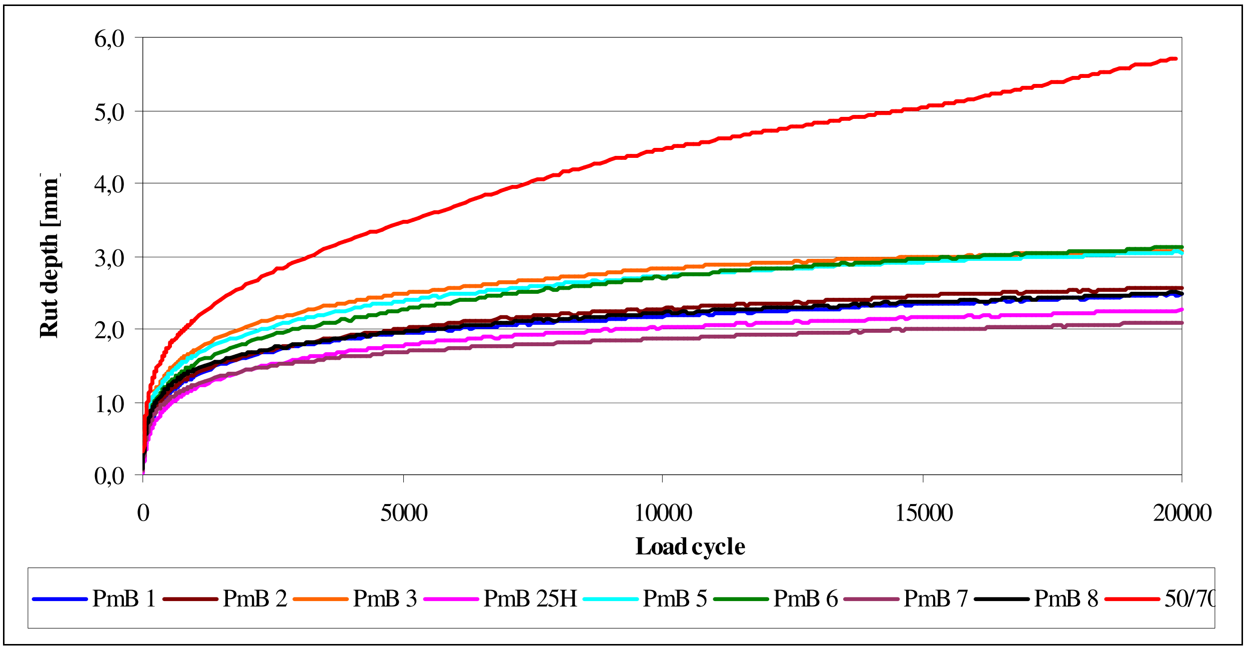


Figure 4: Test Results of Wheel Rutting Test (SMA, Water, 50 °C, Steel wheel)

4.4 Selection of Adequate Binder

The results of binder and asphalt tests are abstracted in the table 2. The variant PmB 7 has the lowest rut depth of 2.08 mm compared to other variants and a resilient modulus of 61 MPa at a temperature of 50 °C. The variant PmB 25H has a rut depth of 2.26 mm and a resilient modulus of 200 MPa. But the variant PmB 1 has the highest resilient modulus of 375 MPa compared to the other variant and rut depth of 2.47 mm. Thus, the variant PmB 1 has the highest stiffness and the conventional asphalt 50/70 has the lowest stiffness at a temperature of 50 °C compared to the other variants. But the resistance against permanent deformation of the variant 1 is lower compared to the variants PmB 25H and PmB 7. The variant PmB 7 has the highest resistance against permanent deformation, but a very low stiffness at a temperature of 50 °C. The variant PmB 25H has a 3-times higher stiffness at a temperature of 50 °C and about 8 % lower rut depth compared to the variant PmB 7. Furthermore, the variants PmB 25H and PmB 7 show high softening points R&B compared to the variant PmB 1. The resilient modulus at 50 °C have been calculated by means of the Master Curve equation, see figure 3. In addition, the asphalt binder course and stone mastic asphalt will be placed on a rigid pavement. With respect to the site condition, asphalt with high stiffness at high temperature has to be selected to keep the rutting lower.

Table 2: Results of Binder Tests and Asphalt Tests

		PmB 1	**PmB 2**	**PmB 3**	**PmB 25H**	**PmB 5**	**PmB 6**	**PmB 7**	**PmB 8**	**50/70**
Softening Point R&B	°C	76.0	79.0	85.0	91.3	62.8	72.3	91.9	96.0	49.0
Resilient Modulus (at 50 °C)	MPa	375	296	252	200	92	102	61	49	34
Rut depth after 20.000 Load cycle	mm	2.47	2.57	3.08	2.26	3.05	3.12	2.08	2.48	5.72

By means of appreciation of test results and site condition, the high viscosity variant PmB 25H has been selected as high stable asphalt variant. The achieved test results reveal that the rutting can be kept much smaller by using innovative asphalt PmB 25 H with the prediction of a long lifetime and low maintenance costs.

5 CALCULATION OF PERMANENT DEFORMATION

By means of analytical pavement calculation the development of asphalt performance behaviour can be estimated over lifetime. The calculations have been carried out with respect to the performance related asphalt test results of mechanical characteristics and material parameters of the asphalt mixes used. Most of asphalt pavement damages occur if stress, strain and/or deformation caused by traffic load and climate exceed permissible values within lifetime. The damages can be calculated versus load cycles or time by means of several models at critical locations of asphalt pavement structures. The development of damages can be kept much lower by a pavement construction with adequate layer thickness, optimized mix composition und paving quality (Cost 333, 1999).

Many different models have been suggested, to predict permanent deformation. In this study permanent deformation calculations are based on the VESYS (Visco Elastic System) method. The basic assumption of this method is that accumulated permanent deformation $w_{pZ,k}(N)$, is a function of the load repetition number N. The relation is described in equation 1. The elastic deformation $w_{rZ,k}$ is calculated dependent on layer stiffness by means of multi layer theory. The material constants μ_k and α_k are derived from wheel tracking test curves. The α_k is the exponent of the regression equations of wheel tracking curves.

$$w_{pZ,k}(N) = w_{rZ,k} \cdot \mu_k \cdot N^{\alpha_k} \tag{1}$$

To calculate the material parameters μ_k, the equation 1 has been converted after μ_k (equation 2). By substitution of parameters $w_{pZ,k}$ (rut depth of wheel tracking test), $w_{rZ,k}$ (elastic deformation calculated with resilient modulus at 50 °C), load cycle N (N=20000) and α_k, the material parameter μ_k has been calculated [Beckedahl]. The resilient modules at 50 °C were extrapolated by means of the temperature master curve shown in figure 1.

$$\mu_k = \frac{w_{pZ,k}(N)}{w_{rZ,k}\ N^{\alpha}} \tag{2}$$

Only the heavy vehicle or corresponding number of axle loads applied to the pavement contributes permanent deformation at high temperature. Thus, the relevant traffic loading or number of axle loads at decisive temperatures has to be known. In this framework the number of load cycles has been determined according to static distribution contingent of asphalt surface temperature after RDO Asphalt 09 (RDO Asphalt 09, 2009). As decisive asphalt surface temperature, in which the permanent deformation contributes, higher temperatures than 42.5 °C were assumed. Thus 1.2 % of total design axle loads have been considered as relevant traffic load. As design temperature for surface layer the median value of 47.5 °C has been taken into account. For the asphalt binder course the design temperature has been calculated after the temperature gradient according to RDO Asphalt 09.. To calculate adequate permanent deformation, resilient modules of decisive layers have been calculated for surface layers (47.5 °C) and binder layers (43.5 °C). For the rigid layer a resilient modulus of 20,000 (MPa) has been considered. Taking into account all the factors mentioned above, the elastic deformation could be calculated for various asphalts.

By means of calculated elastic deformation $w_{rZ,k}$ and determined material parameter μ_k and $\alpha_{k,}$ the permanent deformation has been calculated after equation 1 for different load cycles separate for SMA and ABI as well as the accumulation of SMA and ABI. The calculation results are listed in table 3. Hence the calculated rutting was displayed versus lifetime, see figure 5**.** By means of curve progression, significant influences of binder used on the calculated rut depth can be determined, but without a possible plastic flow. The rutting curve of innovative asphalt runs very flat compared to that of conventional asphalt. Thus the innovative asphalt will cause very low rutting and as a further result low maintenance costs.

Table 3: Calculation of permanent deformation

Life time (Year)	1	2	3	3,5	4	6	8	10	12	16	20	24	28	30
Conventional Asphalt 50/70														
ESAL of 10 t (Mio)	0.8	1.6	2.4	2.8	3.2	4.8	6.4	8.0	9.6	12.8	16.0	19.2	22.4	24.0
$w_{pZ,k}$ (SMA)	11.1	14.0	16.0	16.9	17.7	20.2	22.3	24.0	25.5	28.1	30.3	32.2	34.0	34.8
$w_{pZ,k}$ (ABI)	6.7	8.1	9.1	9.5	9.8	11.0	12.0	12.7	13.4	14.5	15.5	16.3	17.0	17.3
$w_{pZ,k}$ (SMA+ABI)	17.8	22.1	25.1	26.4	27.5	31.3	34.2	36.8	38.9	42.7	45.8	48.5	50.9	52.1
PmB 25H														
ESAL of 10 t (Mio)	1.3	2.6	3.9	4.6	5.2	7.8	10.4	13.0	15.6	20.8	26.0	31.2	36.4	39.0
$w_{pZ,k}$ (SMA)	3.1	3.5	3.8	3.9	4.0	4.3	4.5	4.7	4.8	5.1	5.3	5.5	5.6	5.7
$w_{pZ,k}$ (ABI)	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6
$w_{pZ,k}$ (SMA+ABI)	4.0	4.5	4.9	5.0	5.1	5.5	5.8	6.0	6.2	6.5	6.8	7.0	7.2	7.3

According to the pavement management system guidelines (AP Nr. 9/A1, 2001) a rut depth over 30 mm can be classified as a maximum allowed rut depth for such bus lanes. A rut depth of 25 mm is deemed to be a critical value. According to experience a rut depth of 30 mm will lead to a reconstruction of the damaged layer. Hence the lifetime of pavement construction with rut depth of 30 mm will be exploited. By means of calculated rut depth the conventional asphalt will reach this marginal value after lifetime of 5 years. The innovative asphalt will not exceed a rut depth of 8 mm, even after a design period of a 30-year lifetime. Hence a reconstruction of surface and binder layer will not be necessary during the design period. The calculated rut depths indicate that the permanent deformation can be kept much smaller by using innovative asphalt instead of conventional asphalt.

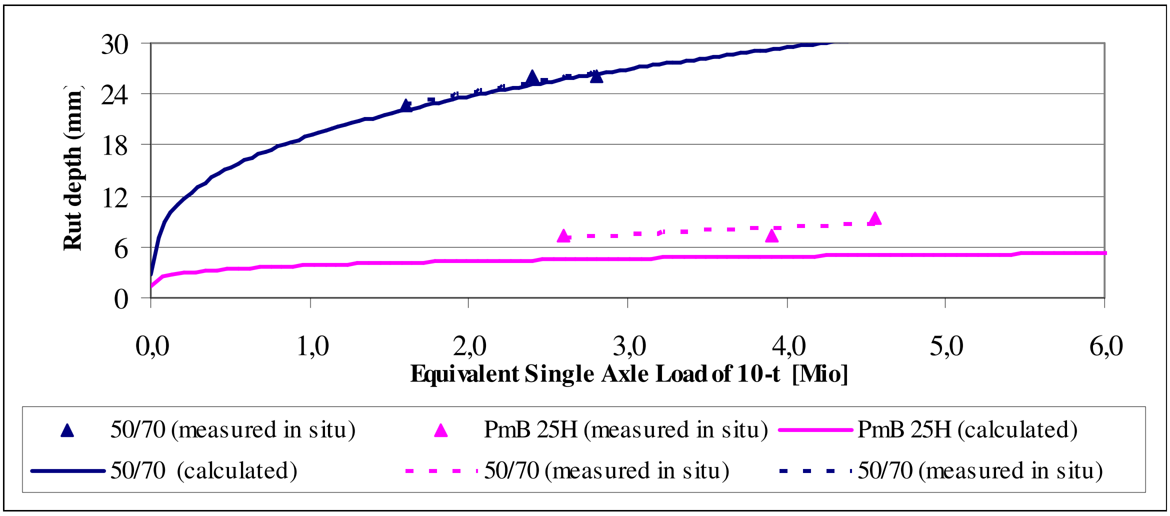


Figure 5: Development of calculated rut depth (SMA+ABI)

6 COMPARISON OF CALCULATED AND MEASURED RUT DEPTH

The permanent deformation on the surface of the test sections has been measured annually. The measured rut depths in situ are plotted in figure 6 and show clearly differences in measured rut depth both test sections. In addition, also profile of double tires can be seen in the surface of the section with conventional asphalt mixes. Maximum rut depths of 27.5 mm on the test lane with conventional and 9.0 mm on the test lane with innovative asphalt have been measured. The maximum rut depth is the difference between the highest and the lowest points of the transverse profile. Furthermore, permanent deformation basins of innovative sections cannot be determined, although this test section bears 20 % more axle loads compared to the conventional test section.

For a lifetime of three years a rut depth of 25.1 mm on the test section with conventional asphalt and a rut depth of 5.0 mm on the test section with innovative asphalt have been calculated by means of the calculation model used. In common, the calculated rut depths are lower than the measured rut depth in situ. As well, the measured rut depths in situ confirm the prediction of lifetime on the basis of calculated rut depths. Taking into account this development the test lane with innovative asphalt will have a long lifetime with low maintenance costs.

To note, the section with conventional asphalt 50/70 has been reconstructed with the innovative asphalt PmB 25H in the years 2009, because of deficiency rutting.

7 CONCLUSIONS

To increase the lifetime of heavy loaded bus lanes with low maintenance costs a high stable asphalt with innovative high polymer modified binder has been designed. The mix design of innovative asphalt has been carried out by means of extended laboratory binder and asphalt tests. The determined tests results of innovative asphalt show very high resistance against rutting and a high stiffness modulus at high temperatures compared to conventional asphalt. To find out the improvement of innovative asphalt compared to conventional asphalt in situ, two test sections of the bus lane have been paved and annually the rutting development have been observed. After a lifetime of three years rut depths of 27.5 mm on the conventional section and 9 mm on the innovative section have been measured. These measured values quite clearly confirm the prediction based on calculation model. Hence, lifetime of heavy loaded bus lanes paved with high polymer modified asphalt can be increased much more compared to heavy loaded bus lane paved with conventional asphalt mixes. Thus, life cycle costs of heavy loaded bus lanes can be significantly reduced.

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