Case studies & non-highway applications; Success and failure from real practice

Renewal of the pavement of a very heavily trafficked German highway on the basis of an availability model

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Abstract

The public-private partnership project “BAB6 AS Wiesloch/Rauenberg - AK Weinsberg” comprises a 48km section of the German highway BAB 6 in Baden-Württemberg, which ranks among the most heavily stressed highways nationwide, counting about 273 million equivalent 10t-axle passages over 30 years. This project was placed as an availability model and contains the partial six-laning and the operation for 30 years. In 2017, the contract has been awarded to the project company “ViA6 West”, who will operate and maintain the entire section. However, “Via6 West” subcontracted the execution planning and constructional implementation of the required construction activities to the consortium “A6 West”. To ensure high quality and performance, “ViA6 West” supervises “A6 West” and the execution planning occurred in close coordination. The pavement is optimized by computational dimensioning, the selection and enhancement of the material, and appropriate construction methods to assure bearing capacity and performance of the pavement over and also beyond the operation period. Because of topographical reasons, the section contains only 5 overpasses, but 31 bridges, including the 1.35km long crossing of the Neckar Valley. The highway is extended from 4 to 6 lanes on 25km length in total by basically renewing the pavement, thereof 16km with porous asphalt surface course for noise protection. The remaining renewed parts get a stone mastic asphalt surface course. The asphalt mixtures contain the reclaimed asphalt of the previous pavement, so that 100% of the reclaimed asphalt will be recycled. As an innovation, the sealing below the porous asphalt surface course consists of very dense asphalt concrete, paved as upper layer with the compact asphalt method. The sections with stone mastic asphalt surface course are paved hot on hot with compact asphalt method as well. The renewal of the pavement started in 2018 and is planned to be completed in mid-2020.

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1. INTRODUCTION

The German motorway BAB 6 between the interchange Wiesloch/Rauenberg and the motorway junction Weinsberg is 48km long and was awarded as a PPP-project in 2016 by the state of Baden-Württemberg. The PPP-project was configured as availability model and comprised both the renewal and widening of altogether 25.5km motorway and the operation and maintenance of the complete 48km section. Because of topographical reasons, the section contains only 5 overpasses, but 31 bridges, including the 1.35km long crossing of the Neckar Valley.

The widening of the motorway from 4 to 6 driving lanes was required with regard to the high traffic volume of more than 100,000 vehicles/day. Concurrently, there was a very high traffic load due to 20.7% heavy traffic. For this reason, the pavement was designed and optimised by means of computational dimensioning according to the corresponding German guideline RDO Asphalt 09 [1] in order to ensure the bearing capacity and performance of the pavement over and also beyond the operation period.

16.3km of the 25.5km renewed pavement (64%) had to be built with porous asphalt surface course for noise reduction of −5dB(A). The remaining parts of the renewed sections plus all bridges got a stone mastic asphalt surface course, which must provide −2dB(A) noise reduction. While the renewal had to be completed within 5.5 years, the operation and maintenance of the complete section has to be carried out during the 30-year concession term. For the realisation of the project, the complete section was separated into 4 construction sections and 5 maintenance sections.

The availability model was awarded to the project company "ViA6 West", who sub-contracted the design and construction works to the engineering, procurement and construction (EPC) contractor "Bau-ARGE A6 West", a consortium of two German infrastructure construction companies, Hochtief Infrastructure GmbH and Johann Bunte Bauunternehmung GmbH & Co. KG.

The tender documents required the majority of the six-lane carriageway to be constructed according to the standard cross section RQ 36 (Figure 1), which is usually used for new-build motorways in Germany. However, some sections had to be built even broader with a 1.0m wider hard shoulder on each side. The width of the hard shoulder adds up to 3.5m then and enables the temporary release of the hard shoulder.

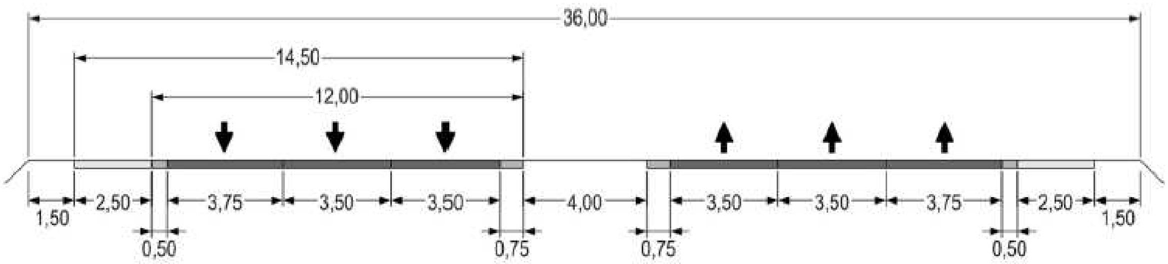


Figure 1: Standard cross section RQ 36 for a six-lane motorway

The calculated optimised pavement design to be realised in the construction sections combines a fully bound pavement structure with a hydraulic stabilised layer, irrespective of whether the surface course is made of porous asphalt or stone mastic asphalt. However, since the design varies from a typical fully bound pavement structure, it will be herein after referred to as completely bound pavement.

2. DESIGN AND COMPUTATIONAL DIMENSIONING

2.1. General

The computational dimensioning of the revised and optimised pavement design for the BAB 6 PPP-project was conducted with the software PaDesTo 2008-15 [2], which is conform to RDO Asphalt 09 [1].

The analytical approach described in RDO Asphalt 09 enables to design the pavement structure and the layers' thickness with regard to their composition, which needs to satisfy the performance criteria (i.e. resistance to fatigue and deformation) over the design life. The design of the pavement is done with the objective of avoiding fatigue-related cracking in the pavement during the given period.

The calculation of the pavement bearing capacity and deterioration in line with the computational dimensioning according to RDO Asphalt is done on a layer by layer basis with focus on several damage criteria, including plastic deformation (unbound layer, upper bituminous bound layers) and fatigue (bottom up cracking in asphalt base course).

It is influenced by the design parameters thickness, stiffness (elastic modulus) and fatigue function, Poisson's ratio, and bonding between layers. Therefore, these parameters have to be adequate determined or adapted in order to generate an appropriate pavement design.

2.2. Input data for the optimised pavement design

The **relevant design traffic** was specified by the project company "Via6 West" and was given for the 30-year operation period with 272.6 million equivalent 10-tons-standard-axles (ESAL).

The **thickness of the frost-resistant pavement** was calculated with regard to the geographical position, geometric conditions of the carriageway, the construction of the boarders and edges, and the local water conditions according to German guidelines [3]. It amounted to 70cm, but was increased to 75cm for the entire section in consideration of possible individual local conditions and influences.

Regarding the porous asphalt, the thickness of the (porous) surface course must not be included in the frost-resistant pavement thickness; the unbound subbase layer thickness has to be raised by the surface course's thickness, instead.

However, the completely bound pavement structure does not require any frost-resistant pavement thickness. The reason for this is that the frost resistance of the layers of the completely bound pavement structure is given by the total stiffness of the bound layers. The in-situ soil has to meet the required bearing capacity or modulus of deformation, though [3].

In the framework of computational dimensioning, the **climatic conditions** are important and part of the influencing parameters as they affect the temperature of the pavement surface and accordingly the subjacent layers. Germany is divided into 4 zones, whereby the project is located in zone 2, possessing a statistical distribution of the asphalt surface temperatures during the year as shown in Figure 2.

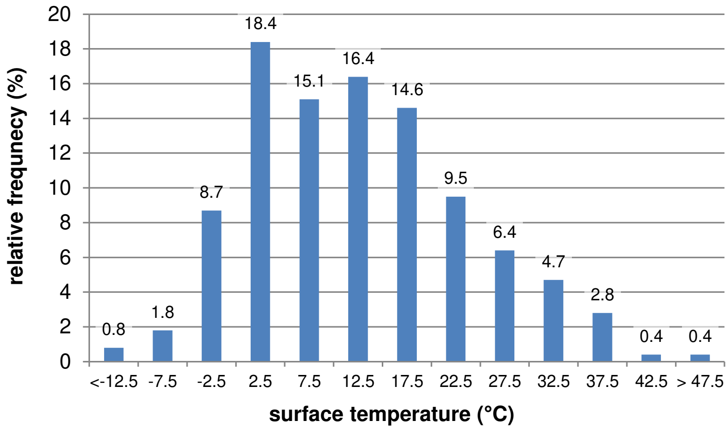


Figure 2: Statistical distribution of the asphalt surface temperatures in zone 2 during the year [1]

RDO Asphalt [1] provides the **material parameters** for so-called calibration asphalts of base course, binder, and surface asphalt mixtures. However, it is also possible to calculate the pavement performance based on the material properties of the asphalt actually used.

In line with the project, the computational dimensioning of the optimised pavement was executed on the basis of material parameter of asphalt used in practice. At first and for the determination of the pavement structure, the parameters originate from asphalt of other projects, but which are comparable to the asphalts intended for use. In the course of initial type testing, the parameters have been determined on asphalts mixed in laboratory with locally available suitable aggregates and reclaimed asphalt, as will be used in the pavement to ensure the designed performance. After laying, the parameters were redetermined on specimens taken from the asphalt pavement for quality control.

Figure 3 shows the elastic moduli and Figure 4 shows the fatigue functions, which, mainly, derive from asphalt pavement. As an exception, the results for the porous asphalt are available for test specimen from the asphalt mixture only; this is marked with a star (*). The material parameters of the calibration asphalts (AC T, AC B, and AC D) are given additionally for comparison only. It is to be seen that the asphalt courses have a very good performance, which even often exceeds the performance of the calibration asphalts. This particularly applies to the relevant temperature range and the relevant elastic initial strain respectively, which are indicated by the red box.

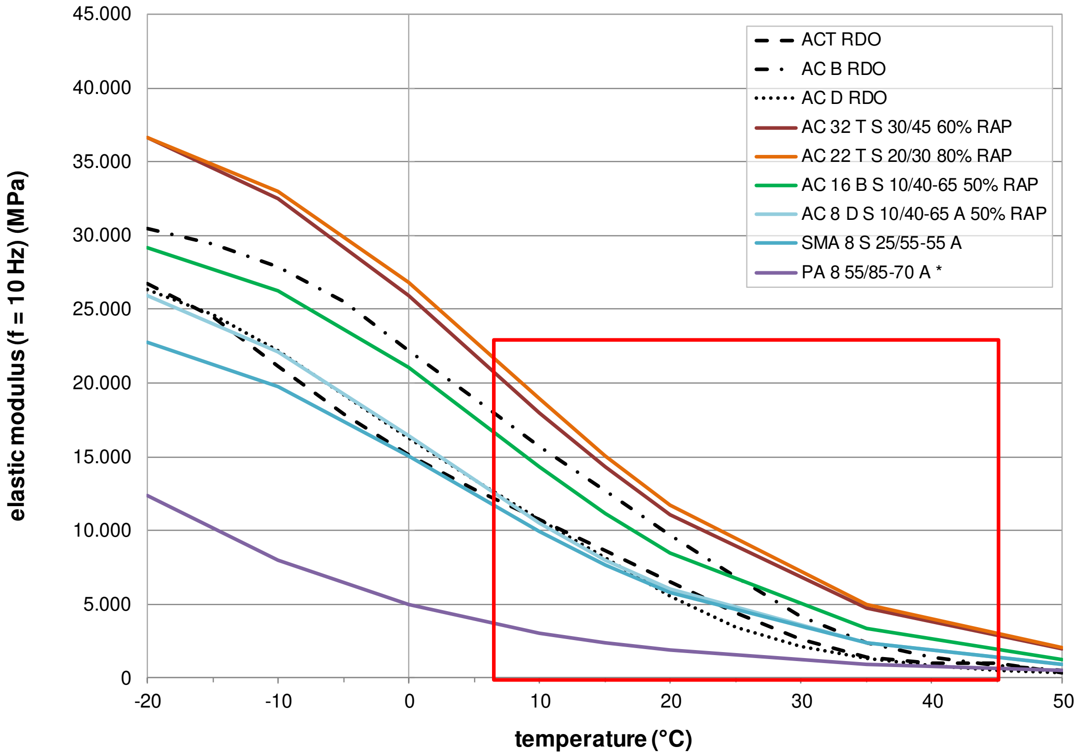


Figure 3: Temperature-dependent elastic moduli of the asphalt courses

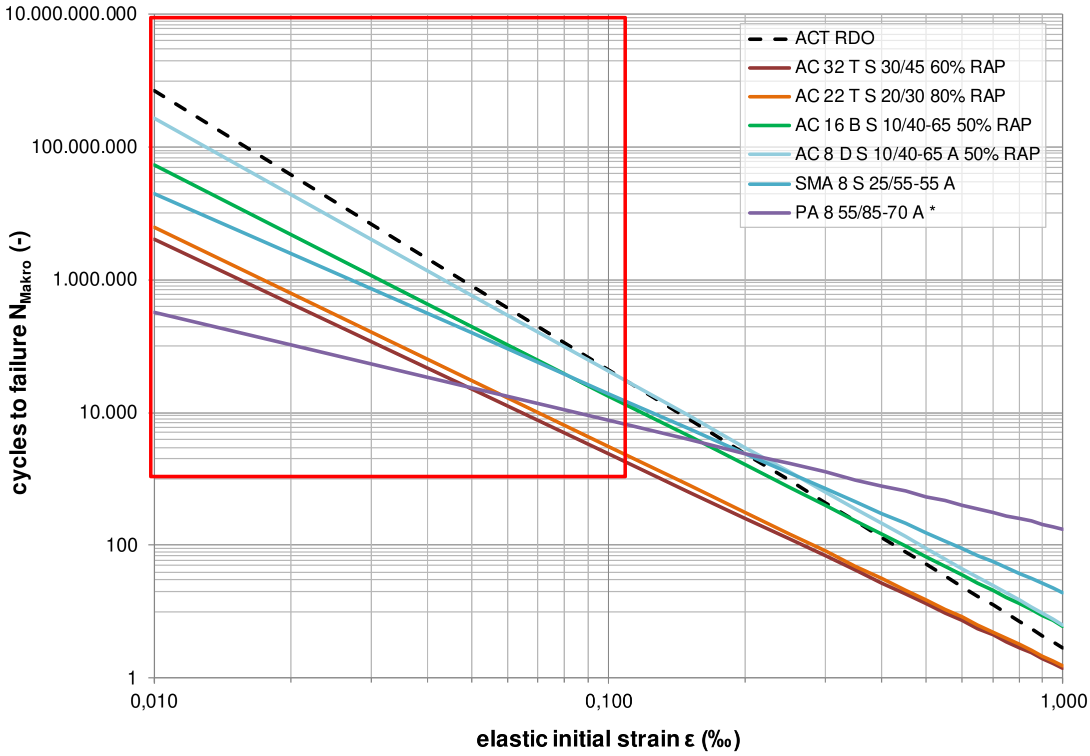


Figure 4: Fatigue functions of the asphalt courses

The modulus of the stabilised layer was assumed to be 2,000MPa, which represents the state of a cracked stabilised layer.

The suitability of the subgrade or subsoil was treated as given in principal in the calculation model for the duration of the pavement life. The modulus of deformation (E_{V2}) on the formation level was initially set to 70MPa, which corresponds to the requirements, and was adapted to the realised modulus later on.

2.3. Porous asphalt surface course

Porous asphalt surface courses are used for noise reduction. The thickness of the porous asphalt surface course depends on the speed and percentage of the heavy traffic, but not on the traffic load. This results from the fact that the traffic noise is a mix of the high-frequency rolling noise of passenger cars and low-frequency rolling noise of heavy goods vehicles. The higher the percentage of heavy goods vehicles, the thicker the porous asphalt surface course must be in order to optimally absorb the entire noise collective. Therefore, the acoustically effective layer thickness of the porous asphalt surface course must be determined with the highest expected percentage of heavy goods vehicles, usually occurring at night.

In this PPP-project, the acoustically effective layer thickness was determined on the basis of 45% heavy goods vehicles at night and a speed limit of 120km/h. Thus, the layer thickness resulted in 5.0cm, but is also effective for a speed range from 80km/h (speed of heavy goods vehicles) with a constant or smaller percentage of heavy goods vehicles.

The porous asphalt is laid on a waterproofing layer made of dense asphalt concrete. Therefore, an extra thickness of 0.5cm had have only to be added to allow for clogging of the voids by dirt and fouling, but not for technical reasons (e.g. clogging because of ascending bitumen). So, the technical necessary layer thickness of the porous asphalt surface course amounted to 5.5cm.

2.4. Optimised pavement design

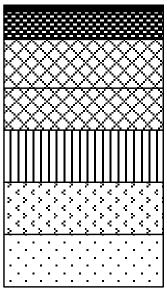
The optimised pavement design was calculated on the basis of the assumptions mentioned above and the idea of a completely bound pavement structure. Compared to a fully bound pavement according to RStO 12 [3], which is actually a full-depth bituminous pavement or a full-depth cementitious pavement down to the formation level, the planned completely bound pavement combined a bituminous pavement in the upper part with a cementitious layer (stabilised layer) on the formation level. Additionally, the zone under the formation level was treated with cement as well to raise the bearing capacity of the formation level.

In line with the widening, the new pavement or rather the new carriageways are wider than before. This enabled to reuse 100% of the old asphalt pavement in the new asphalt layers. The percentage of reclaimed asphalt used in the new asphalt layers averaged 60%, which is considerable and exceeded the current common practice, where the average use of reclaimed asphalt amounts to 40% to 45%. However, not only reclaimed asphalt but also the old unbound pavement building material has been reused.

The calculations of computational dimensioning resulted in the pavement structures as shown in Figure 5 with a stone mastic asphalt surface course (pavement concept V1) and Figure 6 with a porous asphalt surface course (pavement concept V2). The pavement structure of the concepts is equal from the asphalt base course downward, only the asphalt surface course and the thickness of the asphalt binder course differs.

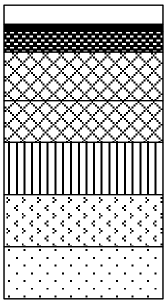
The stone mastic asphalt surface course and the asphalt binder course of V1 as well as the waterproofing layer and the asphalt binder course of V2 were each laid using the compact asphalt technique. With the compact asphalt technique two layers are placed “hot on hot”, which are finally compacted together. The advantages of the compact asphalt technique are amongst others an intensive bonding owing to adhesion and interlocking, the possibility to reduce the upper layer’s thickness to save high quality resources, and to enhance performance devoid of deficits in processability by using the heat of the lower layer and higher compacted asphalt layers, which thus are more dense and stable. For this reason, it was also possible to ensure that the voids content of the waterproofing layer does not exceed 3Vol.-%, which was postulated in order to be accepted as waterproof and dense.

A main characteristic of the completely bound pavement is the two-layer asphalt base course on a stabilised layer. The 15cm thick stabilised layer consists of building material mixture 0/45 with cement CEM I 32,5 R. The total thickness of the asphalt base course is 26.0cm, which was split into two layers. The layers’ asphalts were adapted with regard to the usage and stresses: The upper layer of the asphalt base course consisted of asphalt concrete AC 22 T S with resulting paving bitumen 20/30 and contained up to 80% reclaimed asphalt, whereas the lower layer consisted of asphalt concrete AC 32 T S with resulting paving bitumen 30/45 and contained only up to 60% reclaimed asphalt. (Note that the bitumen grades mentioned are those which result with the addition of reclaimed asphalt and thus the proportionally contained harder bitumen.) While the upper layer is quite stiff and offers a great bearing capacity, the lower layer is more elastic and fulfils a function like a reinforcement that absorbs and resists higher strains. Hence, the lower layer has an important share in the fatigue resistance of the asphalt pavement.



2.0 cm	asphalt surface course, SMA 8 S 25/55-55 A, upper layer of compact asphalt pavement
8.0 cm	asphalt binder course, AC 16 B S 10/40-65 A (result.), lower layer of compact asphalt pavement
14.0 cm	asphalt base course, upper layer, AC 32 T S 20/30 (result.)
12.0 cm	asphalt base course, lower layer, AC 22 T S 30/45 (result.)
15.0 cm	stabilised layer, building material mixture 0/45
51.0 cm	**total thickness of the completely bound pavement structure**
15.0 cm	soil consolidation
15.0 cm	soil improvement

Figure 5: Computationally dimensioned optimised pavement structure V1 with stone mastic asphalt surface course



5.5 cm	asphalt surface course, PA 8 55/85-70 A
2.0 cm	waterproofing layer, AC 8 D S 10/40-65 A (result.), upper layer of compact asphalt pavement
6.0 cm	asphalt binder course, AC 16 B S 10/40-65 A (result.), lower layer of compact asphalt pavement
14.0 cm	asphalt base course, upper layer, AC 32 T S 20/30 (result.)
12.0 cm	asphalt base course, lower layer, AC 22 T S 30/45 (result.)
15.0 cm	stabilised layer, building material mixture 0/45
54.5 cm	**total thickness of the completely bound pavement structure**
15.0 cm	soil consolidation
15.0 cm	soil improvement

Figure 6: Computationally dimensioned optimised pavement structure V2 with porous asphalt surface course

3. IMPLEMENTATION

3.1. General

The designed optimised pavement structure bases on the calculation with specified material properties and characteristics. In order to achieve the designed and calculated performance and to meet the assumed material parameters, special requirements were made amongst others for the asphalt mix design, the layer properties as well as their quality control.

It is hence stressed that comprehensive testing and quality control during the construction phase was executed to ensure that these theoretical, assumed parameters have had been met as minimum criteria.

Also, the designed courses thicknesses constitute minimum thicknesses. The tolerance for the total thickness of the asphalt pavement was maximum −2cm.

3.2. Initial type testing and mix design

The asphalt mixtures were designed with the locally available aggregates and reclaimed asphalt intended for use. No reclaimed asphalt or any other recycling material has been used in the stone mastic asphalt and porous asphalt to ensure highest quality.

In addition to the common regulations given in the technical specifications ([4], [5]), further requirements were made to ensure the asphalt properties assumed in the framework of the computational dimensioning. These additional requirements concerned for example the voids content of the mixture (Marshall specimen) as well as the compacted layer, the minimum binder content, narrowed tolerances in mix production, and increased demands on the evenness, which implies also a more uniform thickness of the layers. Furthermore, extended initial type testing of the asphalt for each layer was required; this implied additional testing to analyse and to assess the performance and properties for each asphalt (compactibility, low-temperature performance, resistance to fatigue, resistance to deformation, stiffness, and fatigue function).

3.3. Construction works

The stabilised layer was mixed in place and had to be notched in fresh state. The unevenness on the surface of both, the soil consolidation (formation level) and the stabilised layer was limited to 10mm over 4m measuring length.

All asphalt layers had to be laid using a feeder and, as far as possible, in only two strips. Furthermore, the asphalt binder course and the waterproofing layer or the stone mastic asphalt surface course, which were paved with compact asphalt technique, had to be laid with staggered moving paving sets “hot on hot”, so that the first strip was still hot when the second strip was laid. The used compact asphalt technique is called “InlinePave”. The paving set consists of two pavers, one paver for the upper layer and one paver for the lower layer, running at a constant distance behind each other, and one feeder (see Figure 7). Figure 8 shows staggered moving pavers and feeders for the seamless paving of the porous asphalt course with 19.0m paving width. The unevenness on the surface of the stone mastic asphalt surface courses was limited to 4mm over 4m measuring length, for porous asphalt surface course to 3mm over 4m measuring length.

Figure 7: Paving of waterproofing layer and asphalt binder course with compact asphalt technique

Figure 8: Paving of the 19m wide porous asphalt course with staggered moving pavers and feeders and 6+0-traffic-routing on the old and provisionally widened carriageway at the construction site

3.4. Quality control

The enhanced construction requirements and the complete reuse of the existing asphalt amongst other things led to the installation of a comprehensive, three-stage quality management and monitoring system. The first stage of the quality control had been the extended initial type testing as described above. The second stage demanded the conventional self-monitoring and factory production control of the EPC contractor as well as external third-party checks by independent engineers, concessionaire, and road authority with regard to the diverse requirements during production, construction, and once each layer had been placed. The third stage was taking cores per construction section and carriageway once they were completed to validate the performance properties of the built pavement (elastic modulus and fatigue function) and their compliance with the calculated performance. In addition, further performance test has been stipulated in case of deficiencies of the total thickness, the binder content of the asphalt base course, or the voids content of the asphalt base course. Figure 9 shows a core taken from a construction section with a porous asphalt surface course.

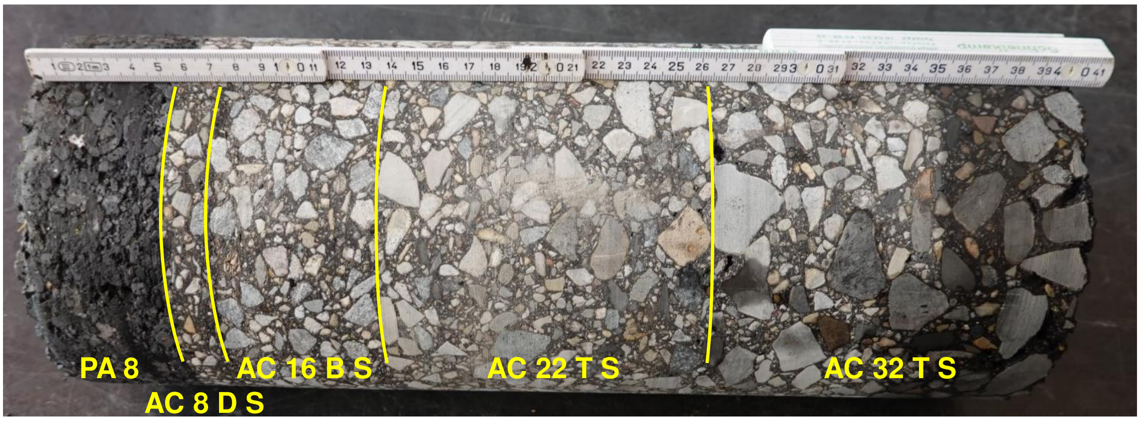


Figure 9: Core taken from a construction section, pavement concept V2 with porous asphalt surface course, waterproofing layer, asphalt binder course, upper and lower asphalt base course

3.5. Results

On the formation level of the construction sections, the modulus of deformation averaged about 130 MPa to 190MPa and exceeded the minimum requirement of 70MPa predominantly clearly.

The compaction of the stabilized layer averaged 100.4% to 103.2%, which clearly exceeded the minimum requirement of 98.0%. The average compression strength was about 7MPa, lying at the upper end of the permissible range between 4.2MPa and 8.0MPa.

The asphalt showed a good and uniform composition; also, the upper asphalt base course with up to 80% reclaimed asphalt exhibited a very steady composition according to the requirements. The different asphalt layers largely met the compaction as well as layer bonding requirements.

For the upper and lower asphalt base course of the different construction sections, the rate of compaction was about 100% to 103% in average and never underruns the minimum limit. For a small number of samples, the voids content counted in minimum 0.7Vol.-%, which falls short of the lower limit of 1.0Vol.-%. However, additional analyses and calculations regarding the possible temperature-related volume increase showed that this will not impair performance.

The stone mastic asphalt, the asphalt binder and in some sections the porous asphalt contained coarse aggregate from moraine (with percentage of crushed grain surface complying with category $C_{95/1}$) instead of rock. Related research has shown a similar and, in some cases, even better performance of the asphalts with moraine. In addition, the moraine in the surface courses serves as lightening aggregate to reduce the course's heating.

In matters of thickness, the sections always met the target total thickness in average, but fell occasionally below the target total thickness with the individual value.

Based on the material parameters gathered on the placed pavement, the performance of the pavement was recalculated for the finished construction sections. Figure 10 shows a comparison of the fatigue index calculated at the beginning with data from other projects (RDO (basis)), after initial type testing with data from the project-related asphalt mixed in laboratory (RDO (project)), and of the finished construction sections (CS) 6,1c.2, 5, and 2.1. Here, the target or average layer thicknesses as well as the corresponding minimum total thickness or the total thickness less the tolerance (−2cm) has been analysed separated according to the pavement concept.

As to be seen in Figure 10, these recalculations confirm that the realised pavements will resist the given traffic load (272.6 million ESALs) during the 30-year operation period and no fatigue cracking is to be expected. The tested pavement layers do not only comply with the requirements and assumed properties of the computational dimensioning, but – with the exception of construction section 2.1 – also exceed the performance assumed at the beginning with the asphalt performance from other projects (RDO (basis)). However, over all sections, the asphalt pavement provides important performance reserves in respect of fatigue, even in the case of the minimum total thicknesses.

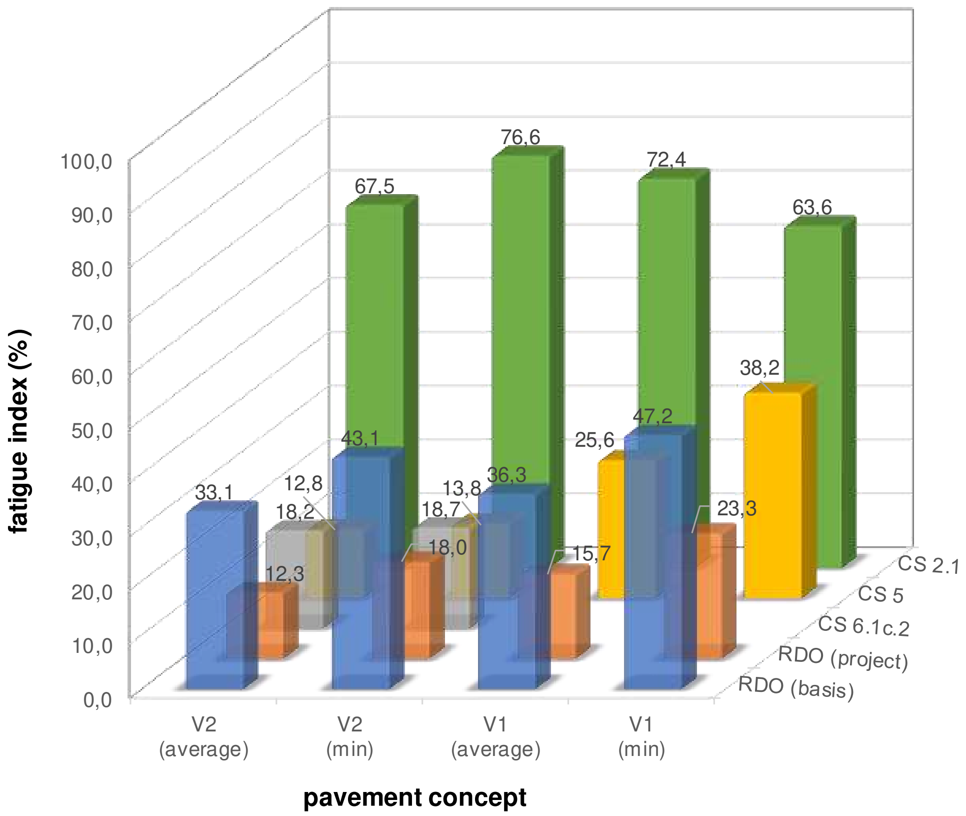


Figure 10: Fatigue index calculated by computational dimensioning with different material parameters and for different pavement structures

Measurements with the CPX-method yielded that noise reduction requirements of −5dB(A) for porous asphalt surface course and −2dB(A) for stone mastic asphalt course have been fully met.

4. SUMMARY

The placing of the partial six-laning and operation for 30 years of the BAB 6 section as availability model enables the project company or rather the EPC contractor to optimise the pavement structure for the construction sections within the framework of the given loading and other requirements as for example noise reduction.

The pavement structure was optimised in consideration of amongst others the use of natural resources and, associated therewith, the 100% reuse of reclaimed asphalt, the fatigue performance for the traffic load of 272.6 million ESALs, the use of appropriate advanced construction techniques, and of course the maintenance. The design of the pavement structure was done by means of computational dimensioning using PaDesTo, where the pavement material and material properties initially corresponded to asphalts, which were comparable to the asphalt intended for use but originated from other construction projects. In the course of the project, the performance was regularly recalculated on the basis of the material parameters determined on asphalts designed in the context of initial type testing and, at last, gather on the placed pavement.

The designed optimised pavement structure is a completely bound pavement structure with a 51.0cm or 54.5cm thick asphalt pavement on a 15cm thick stabilised layer. The zone under the formation level was treated with cement (soil improvement and soil consolidation) as well to raise bearing capacity of the formation level. The asphalt surface course consists of porous asphalt or stone mastic asphalt depending on the noise reduction requirements specified in the official approval of the plans.

For the realisation of the construction works, a three-stage quality control was implemented and a quality manual was compiled that provided amongst others detailed method statements for crucial steps as well as for testing and ongoing monitoring.

The performance and requirements have been met – and partly exceeded – by the implemented optimised pavement design as far as it has been constructed and tested to date. In addition, tests on the already constructed pavements prove a good compliance with the strived performance values and parameters.

Indeed, this specific pavement design has never been built before, so that there is no long-term data available for actual performance to prove that the analytical design assumptions will de facto be met over the lifecycle of the pavement. But since the single layers comply with standard construction methods used for years and reflect established and proven practices, it can be inferred that the concept of the optimised pavement design is reliable, too. Besides, a similar pavement structure — the fully bound pavement structure — is described in guidelines as well.

The recalculation of the computational dimensioning with the material or layer properties of the placed pavement proved that the pavements are suited for the purpose and will resist the given loading during the 30-year operation period and no fatigue cracking is to be expected; this is also valid for the determined minimum total thickness. In addition, the pavements structures do not only stand the traffic load and climate conditions but also offer important reserves in respect of fatigue. At the same time, this means that the pavement structure's performance and usability exist also beyond the concession term. Irrespective of this, maintenance has to be executed professionally and a renewal of the surface courses must be planned.

Figure 11: 6+0-traffic-routing on the new porous asphalt course, left construction site

The use during the operation period will reveal the performance and properties of the designed optimised pavement concepts in practice. However, on the basis of the calculations, the numerous measurements and test as well as the previous, up to one year use of the already renewed sections, a good performance that withstands the stress is to be highly expected. In particular, during the two phases with temperatures up to 40°C this summer, there were no deformations in the form of rutting on these sections. This also applies to the eastern section, where a 6+0-traffic-routing took place on the porous asphalt surface course (Fig. 11).

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