Performance of a stress-absorbing asphalt layer in joint-less bridge ends: Laboratory and Numerical Analysis

M. Woldekidan, M.Huurman, M.M.J. Jacobs
（Research and Development, BAM Infra Asfalt, Culumborg, Netherlands)
Milliyon.woldekidan@bam.com (Corresponding author)
Rien.huurman@bam.com
Maarten.Jacobs@bam.com

ABSTRACT

Joints at bridge ends have always been a subject of discussion in relation to traffic-related noise and driving comforts. To overcome such issues joint-less pavement structure at bridge-ends was developed by Ooms.bv in 1999. In this structure, the approach slab is connected to the bridge in such a way that movements of the bridge are transferred to the lower end of the approach slab. This is to provide sufficient construction height for placing a durable joint that can accommodate the temperature movements. In this structure a special stress absorbing layer, called Thermifalt is used. BAM has recently developed an alternative stress absorbing mixture. Applications of this mixture in joint-less bridge end structure require validation. As part of this process, the performance of the mixture is thoroughly investigated in the laboratory. Then extensive finite element simulations have been performed to analyse mixture performance in a joint-less bridge end construction. Laboratory results show that the mixture outperforms the strength requirement specified for Thermifalt. Numerical results corresponding to daily and seasonal joint movements were analysed for all possible scenarios of the bridge end construction geometries. Numerical results also confirmed that the mixture meets all the performance criteria specified for Thermifalt layer as used in the joint-less bridge end construction.

Keywords: Joint-less bridge ends, stress absorbing layers, finite element modelling, bride end joints.

1. INTRODUCTION

Seasonal and daily temperature variations result in expansion and shrinkage of bridge decks. This leads to movements at locations where the embankment and the bridge connect to each other. These movements have to be accommodated without damaging the bridge or the pavement structure placed over the bridge-ends. For this purpose joints or openings are commonly provided. These joints however have always been a subject of discussion in relation to traffic-related noise and driving comfort. Damages to asphalt layers also initiate often at this locations. To overcome such issues an innovative joint-less pavement structure was developed in the Netherlands by Ooms.bv in the years 1999 to 2001 [1]. In this pavement structure the approach slab is directly connected to the bridge deck in such a way that the temperature related movements of the bridge deck are transferred to the lower end of the approach slab. The opening to allow the bridge to move is provided at the end of the approach slab. This is to provide sufficient construction height for construction of a durable asphalt layer over the joint that can accommodate temperature related movements. Within the available construction height, several layers of stress absorbing asphalt mixtures are placed. These stress absorbing layers consist of high-performance flexible asphalt, called Thermifalt. In between these layers reinforcements are placed. The performance of Thermifalt asphalt in this joint-less bridge end construction is validated based on extensive numerical and laboratory analysis [1, 2]. This asphalt construction has excellent durability with performance guarantee up to 25 years. The approach is accepted by the Dutch ministry of infrastructure and design charts are readily available. The design charts are applicable for seasonal and daily temperature variations that lead to expected joint movements within the range of 5mm to 25 mm per each side of a bridge [2].

BAM Infra has recently developed an alternative stress absorbing asphalt mixture which can absorb very large strains. Application of this mixture for the jointless asphalt construction requires validation. As part of the validation process, laboratory and numerical analysis works have been done. In this process, the performance of the mixture is first investigated in the laboratory. As a bench mark the performance data of the Thermifalt have been used. Then after, extensive Finite Element (FE) simulations have been performed to analyse the mixture performance applied in the jointless asphalt pavement construction. In the simulations, all possible scenarios specified in the design chart [2] are considered. In this design chart the expected seasonal and daily joint movements are placed in five categories. For each category the details of the asphalt construction varies. For all categories, FE simulations have been performed. Results show that in all cases the performance of the stress absorbing asphalt mixture sufficiently meet the performance requirements specified for the Thermifalt layer. For field validation, this stress mixture is applied on a full scale joint-less asphalt pavement construction on bridge-ends on a major Dutch motorway A4, near the city of Leiden. The performance of the site is being monitored. In this paper, overview of the numerical work and some key laboratory performance data of the stress absorbing layer are presented.

2. NUMERICAL AND LABORATORY WORKS

2.1 Finite Element model

Based on expected joint movements, five types of jointless asphalt constructions are specified in the design document. These details, given in Table 1, are used as a basis for the FE model geometries.

TABLE 1 Pavement construction details for jointless bridge ends.

Categories	Expected joint movements per each side of bridge [mm]	Min thickness total asphalt layers [mm]	Min number of Thermifalt layers	Min number of polymer modified asphalt layers	Min number of reinforcement layers	Anchor L [m]
Catagory-1	7-9	200	1	2	1	-
Catagory -2	9-14	250	2	2	2	-
Catagory -3	14-19	300	2	3	3	5
Catagory -4	19-22	350	3	3	4	10
Catagory -5	22-25	350	3	3	5	15

Based on the details given in Table 1, five different FE models were made. An illustration on the geometry of the asphalt construction is given in Figure 1. The legend in Figure 1 describes the different components of the bridge-end construction. Items from Figure-1 which are not described in the legend are not relevant for this paper, for brevity these details are not given in this paper. The description for these items can be found in the literature [1,2].

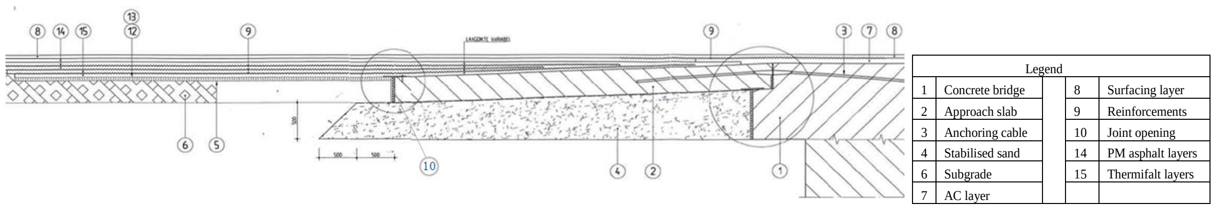

FIGURE 1 Geometry of the jointless brigde-end construction [1,2].

As shown in Table 1, the geometrical details for the asphalt construction vary depending on the expected seasonal and daily joint movements. For each geometrical details corresponding to the various joint movement category, separate finite element models were prepared. An illustration on the FE element models is given in Figure 2. This geometry corresponds to the model prepared for joint movements corresponding to category-3 in Table 1, the geometry of which consists of two stress absorbing Thermifalt layers, three layers of polymer modified (PM) asphalt layers and a surface layer. In total 300 mm thick asphalt construction is placed above the joint opening as shown in Figure 2.

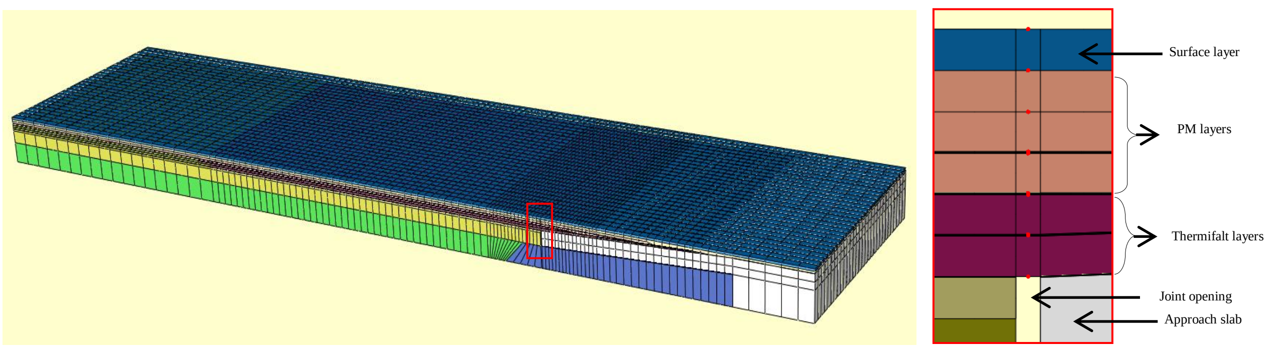

FIGURE 2 FE model for jointless brigde end construction.

In Figure 2, the different colours depict different material properties. In between the thermifalt layers and on the top of the first PM asphalt layer, reinforcement grids have been placed. These reinforcements are embedded with sufficient embedment length on both sides of the joint opening. For detailed information on embedment length for reinforcements, reference is made to available design documents [1-4]. Interfaces between different layers are modelled as cohesive layer. Wherever reinforcement is to be provided between layers, double layer of cohesive layers are used, where by the nodes in the middle layer are used to model the reinforcement layer. Arbitrary section showing the interface and reinforcement details are shown in Figure 3.

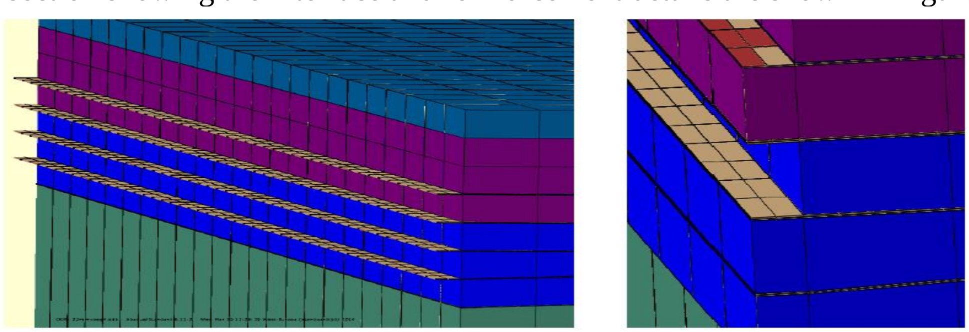

FIGURE 3 Sections showing interface and reinforcement details (left: general overiew, right: close up view for the interface layer)

Other than the interface layers, all other materials are meshed using three dimensional, 20 node quadratic element with reduced integration (C3D20R). The typical model in general comprises 73322 nodes, 12815 C3D20R elements, 11840 COH3D8 elements. The load applied to the models corresponds to the expected joint movements due to seasonal and daily temperature variations. These displacements are applied as boundary conditions on the bridge, i.e., at the concrete surface on the right end of the model (Figure 2).

Material properties

The material properties for the various parts of the construction have been adopted from literature. These values remain the same as the values used in the original numerical analysis performed in the development of the bridge-end construction [1,2,4]. In this simulation, only the properties of the stress absorbing layer have been changed. The strength and stiffness properties of the special stress absorbing asphalt mixture, developed as a substitute of Thermifalt layer, have been determined in the laboratory. The critical strain is determined based on uniaxial tension tests performed on cylindrical asphalt specimens. The cylindrical specimens have a diameter of 50 mm and height of 100 mm. The tests were carried out at four temperatures varying from -10°C to 30°C. At each temperature the critical strains are determined at five different strain rate levels varying from 0.5%/hour to 5%/hour. Based on the obtained data is a master curve constructed using Time-Temperature superposition principle for the critical strain at a reference temperature of 10°C. Figure 4 shows the strength characteristics of this mixture compared with the specification given for the Thermifalt layer [3,5].

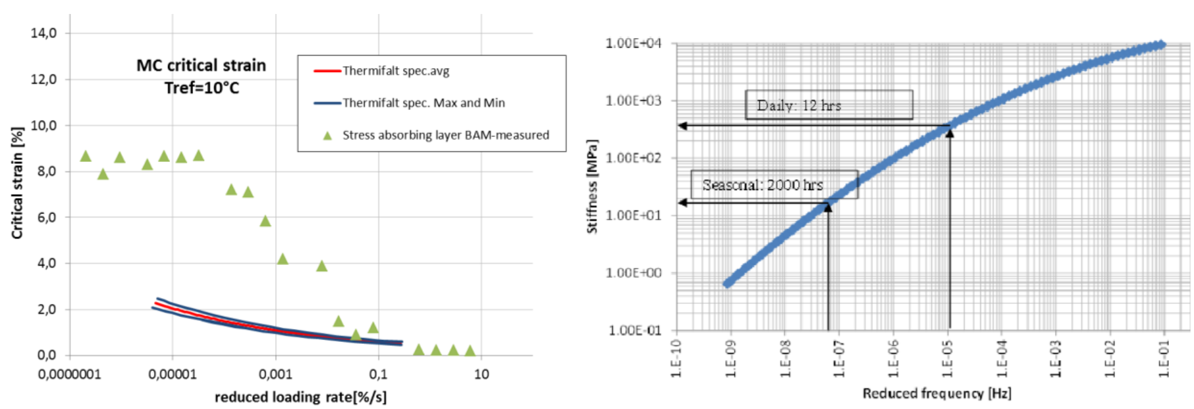

FIGURE 4 Mastercurves for properties of the stress absorbing asphalt mixture: strength at 10°C (left) and stiffness properties at reference temperature of -10°C (right).

As shown in Figure 4 (left), the critical strength of the stress absorbing layer from BAM outperforms the specifications given for Thermifalt. Figure 4 on the right also presents the stiffness properties of this mixture. The frequencies corresponding to the daily and seasonal joint movements are obtained based on a loading cycle with periods of 24 and 4000 hours respectively following the procedures used in the literature [1]. With this input, the stiffness of the stress absorbing layer corresponding to the seasonal and daily joint movements can be obtained from the master curve. These stiffness values were then used in the relevant FE simulations. To meet the design requirements, the computed strain in all Thermifalt layers, except the lower layer, should remain below 50% of the critical strain given in Figure 4.

Model accuracy and Mesh sensitivity analysis

Before applying the newly developed stress absorbing layer in the model, the accuracy of the model have been thoroughly checked. First the model output has been checked based on mesh sensitive analysis. Then after, exact simulations that have been performed during the development of the joint-less bridge end construction have been repeated. Obtained results were then compared with values reported from literature. After the model accuracy has been thoroughly checked, further simulations have been performed to analyse the occurring strain and strain rates within the stress absorbing layer as applied in the joint-less bridge end structure.

2.1 Results

FE simulations have been made for all possible scenarios given in the design chart. For Brevity all results are not be discussed in this paper. Illustration is given using the simulation results obtained from the FE model corresponding to the jointless asphalt construction construction of category-3 in Table 1. The FE model for this construction is also shown in Figure 2. At the location of the opening, the occurring strains in the stress absorbing layers and the overlaying PM asphalt layers were analysed. Overview of the tensile strain distribution in the layers above the joint opening is shown in Figure 5 and Figure 6.

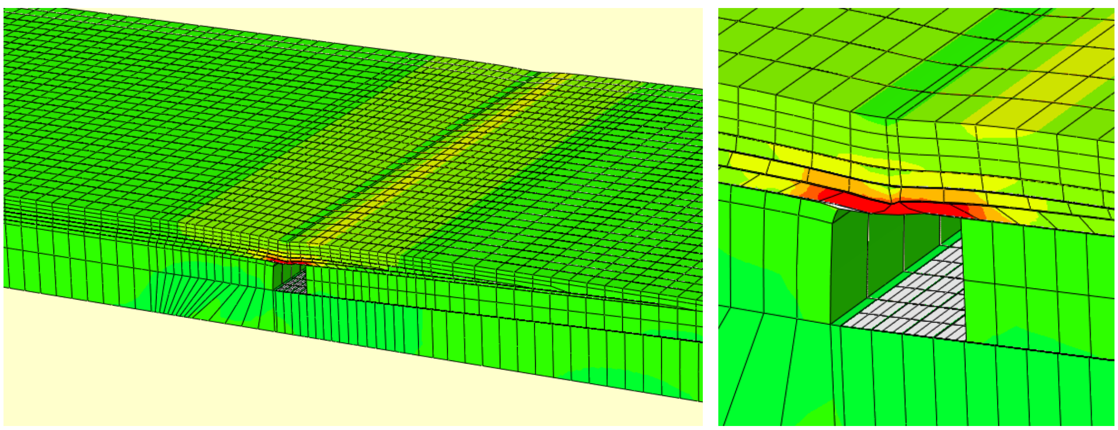

FIGURE 5 Tensile strain distributions at the location of the joint (deformation scale 20X)

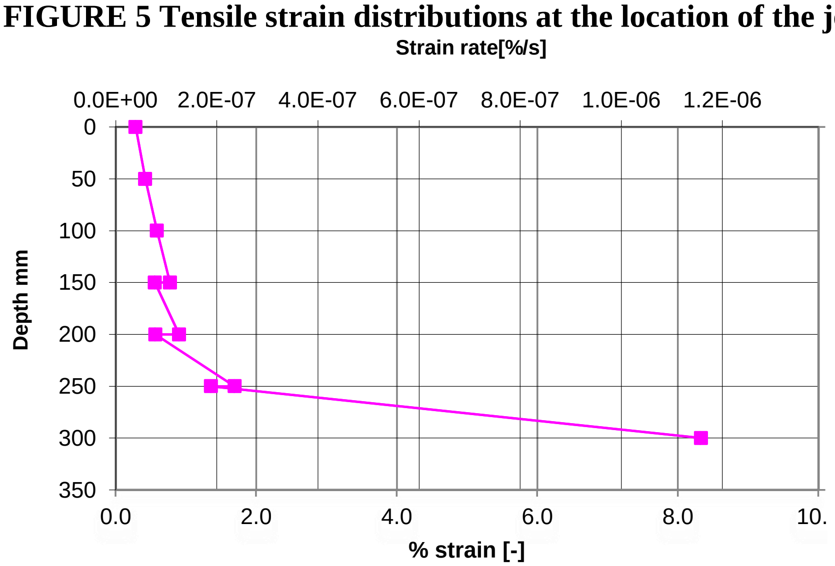

FIGURE 6 strain distribution in the pavement layers above the joint opening (seasonal joint movements).

Similar analysis has also been performed for joint movements corresponding to the daily temperature variations. As illustrated in Figure 6 above, the effect of reinforcement layers on the strain distribution at the depth of 150 mm, 200 mm and 250 mm can be seen. The computed strain and strain rates were used to evaluate whether or not the stress absorbing layer can absorb these movements without cracking. Criteria used in the development of the joint-less bridge end construction stipulate that the utilized strength of the Thermifalt layers should remain within 50% of the critical strength. According to these criteria, the occurring strains in the stress absorbing layers were used divided with the available strength. The obtained performance for the stress absorbing layers is summarized in Table 2.

TABLE 2 Performance of the stress absorbing layers.

	Stress absorbing Layer	locations	Occurring Strain[%]	Occuring Strain-rate [%/s]	Available strength Critical strain[%]	Utilized strength (occurring/ avail.strength)	Cracking
Daily variation	1st layer	bottom	0.26	5.99E-6	1.53	<50%	No
		top	0.15	3.47E-6	2.02	<50%	No
	2nd layer	bottom	0.09	2.04E-6	2.60	<50%	No
		top	0.06	1.39E-6	3.07	<50%	No
Seasonal variation	1st layer	bottom	8.33	1.16E-6	3.30	>50%	Yes
		top	1.36	1.88E-7	5.71	<50%	No
	2nd layer	bottom	1.69	2.35E-7	5.43	<50%	No
		top	0.56	7.82E-8	6.65	<50%	No

As shown in Table 2, the seasonal joint movements lead to a strain of 8.33 % in the first stress absorbing layer. This is beyond the 3.3% critical strain the stress absorbing layer can sustain. Hence cracking will occur in this layer. However, all the other stress absorbing layers can sufficiently sustain the joint movements without cracking both for the daily and seasonal movements. The first Thermifalt layer, which is placed just above the joint opening, experience the maximum strain and is originally meant to be cracked according to the design documents [1, 2]. This has also been the case with simulations using the properties of the Thermifalt layer. This implies that the alternative stress absorbing layer developed by BAM fulfils the design specification for use in the jointless bridge constructions. In all simulations performed for the various scenarios, similar results have been obtained.

CONCLUSIONS AND RECOMMENDATIONS

To evaluate the performance of the stress absorbing layer developed by BAM for use in joint-less bridge end constructions, various finite element models were made. The models differ in the number of Thermifalt layers, reinforcement layers and polymer modified asphalt layers. The geometrical details were prepared based on relevant design documents. This has resulted in a total of five finite element models corresponding to joint movements summarized in category 1 to category 5 in Table 1.

In performing the FE simulations, the properties of the various materials used in the structure were obtained from literatures. For the Thermifalt layer, the property relevant to the newly developed stress absorbing layer from BAM has been used. On the models, seasonal and daily joint movements were applied. The resulting tensile strain and strain-rates within the stress absorbing layers were then obtained. For the computed strain-rates, the corresponding material strength (critical-strain) for the stress absorbing layers were then obtained based on the performance curve obtained from the laboratory. Comparison between the computed strain and the material strength provided expected performance of the stress absorbing layers.

Simulation results have shown that the bottom (first) layer of the stress absorbing layer will in all cases crack as a result of seasonal joint movements. The cracking of the first Thermifalt layer for seasonal loadings has also been stated in relevant literature [2]. For all other stress absorbing layers in all models, it was found that the stress absorbing asphalt mixture have the ability to absorb significant joint movements both for seasonal and daily conditions without cracking.

In relation to material properties, the simulations performed in this work were all linear elastic. This has been performed in conformity with the numerical works performed during the development of the jointless bridge end construction. The availability of the 3D FE models implies, future simulations can also be performed for visco-elastic cases and it also provides a possibility for evaluating any other alternative materials deemed suitable for this kind of joint-less bridge end structures.

References

[1] A.H. de Bondt, J.G.F.Schrader. Jointless Asphalt Pavements at Bridge Ends, 3D Finite Element Modeling of Pavement Sturctures, Amsterdam, The Netherlands, 2002.

[2] P.Spencer, Standard details for concrete bridges (in Dutch), Dutch Ministry of Infrastructure (Rijkswaterstaat Dienst Infrastructuur), Document NBD 00730, 2009.

[3] Ooms bv. (2005), performance requirements for joint-less bridge ends, appendix D, in dutch “Prestatie-eisen componenten voegloze overgang, bijlage D”

[4] W.J. Anemaat (2009), “Standard Details for concrete Bridges”, Rijkswaterstaat Dienst Infrastructuur, Document NBD 00730.

[5] R.C. van Rooijen, A.H. de Bondt (2003), Development and Use of Functional Asphalt Tender specifications, The 6th international RILEM symposium on performance testing and evaluation of bituminous materials, PTEBM’03, Zurich, Switzerland