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ALTERNATIVES FOR BRIDGE SURFACINGS WITH ORTHOTROPIC PLATED DECK: A FATIGUE POINT OF VIEW

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Steel orthotropic decks are sensitive to stiffener-to-deckplate fatigue. Larger traffic volumes and concentrated wheel loads contribute to this phenomenon. Traditionally, the effect of the wearing courses is taken into account through load dispersal under 45° reducing the stress at the deck plate surface. However for asphalt surfacings this effect is small. A more reliable solution could be present if a structural cooperation were present between the deck and the surfacing. In this paper, the results are presented from a study of various alternatives for a lightweight bridge surfacing contributing to fatigue reduction at the stiffener-to-deckplate intersection. Asphalt, neoprene and composite layers are considered as well as honeycomb sandwich panels. The effect of the solutions is measured by strain gauges on an orthotropic bridge prior to the final surfacing installation. The results are compared with conclusions derived from a finite element model and indicate that depending on the type of layer, a 20 to 30 % reduction of stresses is possible, resulting in a 3 to 5 times longer fatigue life, without increasing the deck weight.

Key words: orthotropic bridge deck, fatigue, surfacings, asphalt, stiffener-to-deckplate detail, honeycomb pannel

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1. THE ORTHOTROPIC STEEL BRIDGE DECK CONCEPT

1.1. Introduction

Due to their contribution to the general resistance of the structure, by significantly reducing the total weight of the construction, orthotropic steel deck plates are one of the most commonly used deck systems for larger span bridges. This contribution also allows the design of tied arch bridges of a more moderate span but with an extremely low structural depth, e.g. a structural depth of only 1 m for a double track railway bridge with a length just over 110 m. The recent design practice in Belgium has used this advantage for about 10 arch bridges, most of them a part of the development of the European network of High Speed Lines where a considerable number of short to medium span bridges for the high-speed railway lines have been designed. However, orthotropic deck plates are also highly sensitive to fatigue damage, requiring an in-depth fatigue analysis, ensuring the fulfillment of all fatigue criterions. This problem is mainly caused by many stress concentrations and large amplitudes of stress variations caused by road traffic in particular. Recent international research has extensively studied this phenomenon [1].

1.2. Stress field in an orthotropic deck

The complex stress field in an orthotropic road bridge can be attributed to three different actions working in a union. The first of these actions is caused by the membrane stresses occurring because of the bending of the lateral main girders of the bridge, with the bridge deck itself acting as their upper flanges. This action, in fact, represents the main action of the overall bridge concept.

The orthogonal anisotropy (i.e. orthotropic behavior) of the deck with the distribution of the load working on the deck corresponding to different rigidities of the ribs and the crossbeams is responsible for the second action existing in the deck plate.

Finally, the local bending along longitudinal or transverse axis of the deck plate elements under direct wheel loading causes the third action existing in an orthotropic road bridge. The largest stress concentrations for this deck concept are found at the ribs where longitudinal stiffeners are connected to the deck plate and both hogging and sagging bending effects are found, as well as at the intersection of both longitudinal and cross stiffeners (see Fig. 1).

1.3. Influence of wearing courses

Road pavements on the deck plate may contribute to the dispersal of concentrated wheel loads from road traffic. This has also been observed for railway loading, where the ballast may disperse the track loads. However, wearing courses and pavements are not always available or sufficient to reduce the heavy traffic loads, for instance in the case of movable bridges. An example of this is the Calandbridge in Rotterdam, which was examined more closely and where severe damage due to cracking and fatigue has been found. In Belgium, large span bridges with orthotropic plated deck (for instance the Vilvoorde viaduct) do not suffer from this cracking, but smaller movable bridges also show this sensitivity. This situation has to be considered in view of the ever increasing axle loads and more compact wheel loads introduced by road traffic. The design and fatigue loads as mentioned by prEN 1997-2 [2], that were intended as higher bond values of European traffic may well be circulating frequently at present. In view of these considerations, the conclusion must be to find systems to decrease the aggressive effects of concentrated wheel loads on orthotropic plated decks or to eliminate these effects.

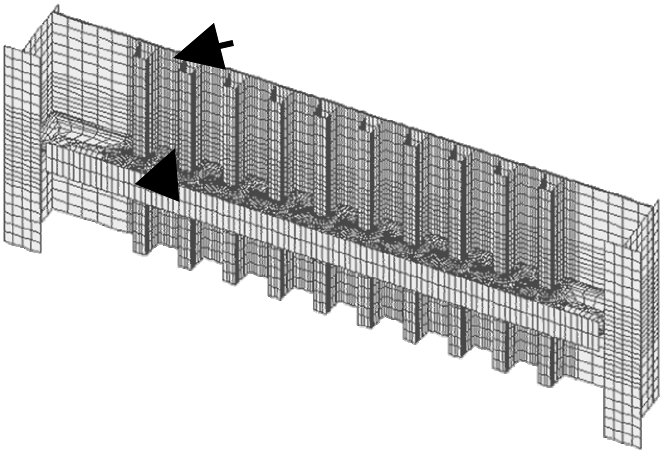


Fig. 1. Finite element model, showing the different groups of fatigue sensitive locations

1.4. Objective of the research program

When trying to improve the fatigue behavior of a certain bridge type, one has only two possibilities. The first one is to reduce the number of stress cycles, the second one is to reduce the stress ranges in all fatigue sensitive details.

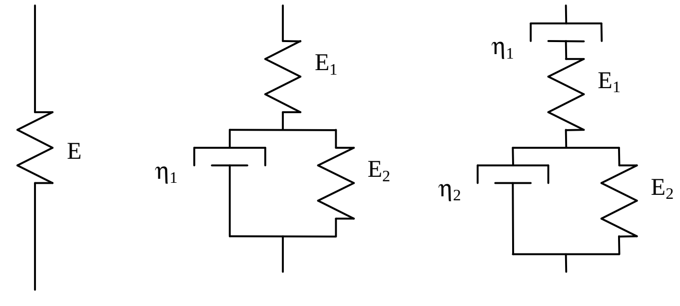
Since it is not the objective of this study to make radical changes to the orthotropic deck concept, this paper tries to find solutions by installing an extra layer on top of the steel deck plate, thus improving the load dispersal before it reaches the deck surface. Several possibilities, such as asphalt layers, independent rubber, synthetic or even FRP mats as well as aluminum or FRP sandwich panels are considered and were studied initially using finite element modeling [3], [4] and laboratory testing [5],[6] to prepare for the full scale field testing.

2. THE INSTALLATION OF ASPHALT LAYERS ON THE ORTHOTROPIC DECK

One of the most logical solutions for the above mentioned fatigue problems is the use of an asphalt layer as a dispersion layer. Since most road bridges are equipped with asphalt layers anyhow, any positive influence of this layer would be greatly beneficial in improving the fatigue behavior.

To study, the influence of an asphalt layer on an orthotropic bridge deck, a finite element model was developed. For most previous finite element models for asphalt calculations, linear elastic material models were used, however to model the asphalt layer as correctly as possible, a visco-elastic material model was developed

The best material behavior law for bituminous materials is the Burgers model, incorporating not only the loading frequency, but also the phase distortion which exists in the stress-strain relationship for a visco-elastic material, thus enabling the study of the degradation of the material over longer time periods. However, since the Burgers model cannot be used in the available finite element software, i.e. SAMCEF, the closest approximation was used. The Zener material model uses a Young’s modulus E*, incorporating the dependency of asphalt on the ambient temperature as well as on the loading frequency. This simplification should not radically interfere with the calculation of the maximum occurring stress range in the considered welding detail.



a) Linear Elastic Material Model

b) Zener Material Model

c) Burgers Material Model

Fig. 2. Different possible material models for asphalt layers

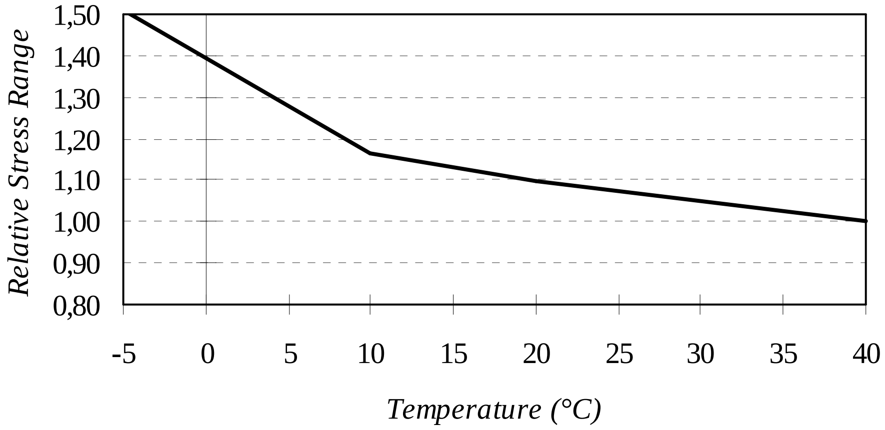


Fig. 3. Variation of relative stress range as a function of temperature for asphalt

To make the material model even more accurate, the calculations for this paper were performed using a behavior law that is temperature dependent, to allow the study of the influence of the asphalt layer at different temperatures. The initial results, as shown in Fig. 3, clearly point at a positive effect for the asphalt layer. Generalizing, asphalt clearly allows a reduction of the stress range in the longitudinal stiffener connection; however the size of this reduction is highly dependent on the asphalt temperature. Only at lower temperatures can this reduction be called significant.

3. FIELD TESTING PROGRAM

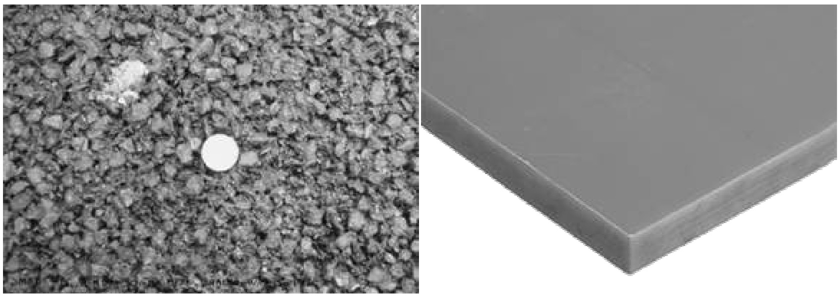
3.1. The Albert Channel bridge

During the spring and summer months of 2004, an extensive number of tests were carried out at a tied arch bridge with an orthotropic deck. The bridge, which is being built as a part of the High Speed Railway link between Antwerp and the Netherlands, crosses the Albert Channel, one of Belgium's most important waterways, a little north of the city of Antwerp.

The orthotropic deck is made up of a 15 mm thick deck plate with a width of 10 m between the main side beams, longitudinally stiffened by 10 trapezoidal stiffeners passing continuously through 1 m high transverse crossbeams which are distanced at 3,9 m from each other. To reduce the fatigue stresses at the longitudinal stiffener to crossbeam intersection, large cope holes are cut out of the crossbeams. The photograph in Fig. 4 shows the test bridge days before its installation, as well as the crossbeams and trapezoidal stiffeners of the orthotropic deck.

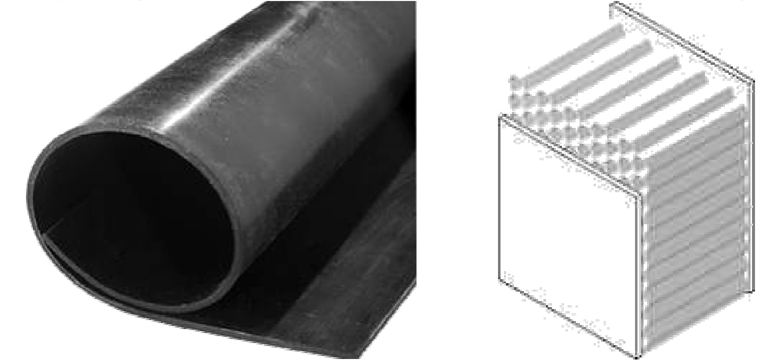
Fig. 4. Bridge over the Albert Channel before installation - Photograph of orthotropic deck of the Albert Channel Bridge, showing a crossbeam, trapezoidal longitudinal stiffeners and the cope holes

The bridge is fully equipped with more than 200 strain gauges. The majority of these gauges are located on the deck plate and the joint between the deck plate and the web of the longitudinal stiffeners. The testing program does not only include local testing of the orthotropic deck plate, but also testing of the global bridge action of the tied-arch itself.



a) Asphalt layer

b) Glass fiber reinforced epoxy slab



c) Neoprene layer with polyamide inlays

d) Aluminum honeycomb sandwich panel

Fig. 5. Dispersion layers installed on the Albert Channel Bridge

3.2. Test layers

Before the installation of the ballast and the tracks, a number of bridge sections is equipped with various dispersion layers as diverse as asphalt, rubber with and without polyamide inlays, glass fiber reinforced epoxy plates, aluminum honeycomb sandwich panels, e.a., some of which are shown in Fig. 5

Some more detailed information, such as dimensions and thickness values, about these layers is summarized in table 1. This table also illustrates a wide variation between the different layers being studied. Most layers, but the asphalt one, were glued onto the steel deck plate, using special neoprene-based glue. The asphalt layer was installed using classic installation techniques for cold asphalt.

The use of neoprene-based glue ensured that the connection between dispersion layer and deck plate was as sound as possible, keeping in mind that the tests were performed on a railway bridge, implying that all layers and strain gauges needed to be removed at the end of the strictly limited testing period. This factor also implied that the used glue had to be a quick-bonding one.

The attachment of layers to the deck plate proved to be optimal in most layers. Only the gluing of the glass fiber reinforced epoxy layer proved to be less than ideal, when examined during the removal of the layers. As previous finite element studies prove, a good connection of the dispersion layer is of the utmost importance for optimal dispersion. This might imply that the results found for the epoxy layer aren’t as positive as they would be under ideal conditions.

Table 1: Characteristics of the dispersion layers

	Area [m²]	Thickness [mm]
NR/SBR Rubber layer	7	20
CR/SBR Neoprene layer, with 2 PA inlays	7	8
Polyurethane plate, PUR90	4	15
Epoxy plate, HGW 2372.4 with glass fiber inlays	2,2	20
Asphalt layer, particle fraction 2-5mm	3	55
Aluminum sandwich panel - skin - core, cell size 6,3mm	4,5	25 0,8 23,1

3.3. Strain gauge locations

During the passage of fully loaded 45 ton trucks, strain measurements were carried out, to allow a comparison of the effects of the different dispersion layers on the stress range in the connection of the longitudinal stiffener to the deck. This off course implies that an extra section of the bridge deck is equipped with strain gauges, to allow the recording of reference values.

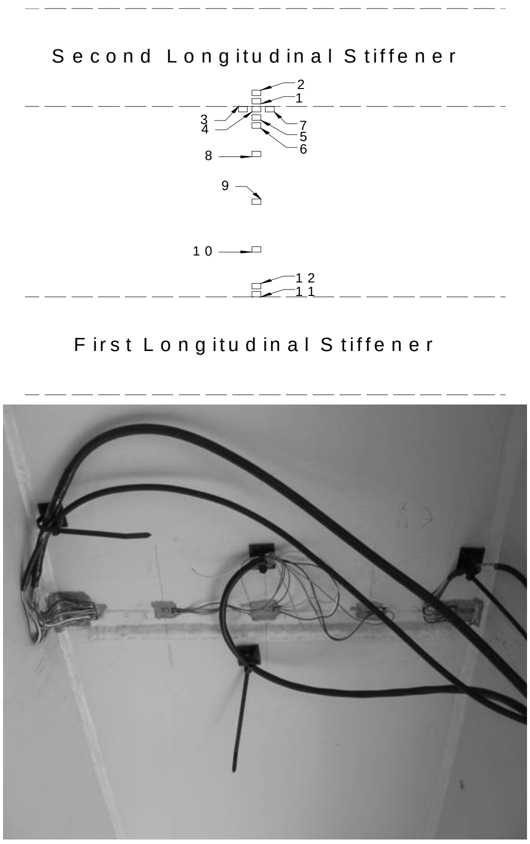


Fig. 6. Location of the strain gauges on the deck of the Albert Channel Bridge

Each section for local measurements is equipped with 12 strain gauges, all of them located between the first and second longitudinal stiffener and halfway between consecutive crossbeams. The placement of these strain gauges is shown in Fig. 6. This number is chosen for practical reasons in connecting the strain gauges to the measuring device, as well as because this placement and number of gauges is enough to allow a study of the critical location as well as the strain field around this specific detail.

3.4. Testing procedure

The lorry is to drive over the deck at a slow and constant pace and with the front wheel on the driver's side along the following lines, from the side of the bridge going inwards:

- the wheel exactly above the first stiffener;
- the middle of the wheel above the side of the first stiffener;
- the side of the wheel next to the first stiffener;
- the middle of the wheel exactly between the first two stiffeners;
- the side of the wheel next to the second stiffener;
- the middle of the wheel above the side of the second stiffener;
- the wheel exactly above the second stiffener;
- the middle of the wheel above the second side of the second stiffener;
- the side of the wheel after the second stiffener.

This creates a total of 9 different loading positions.

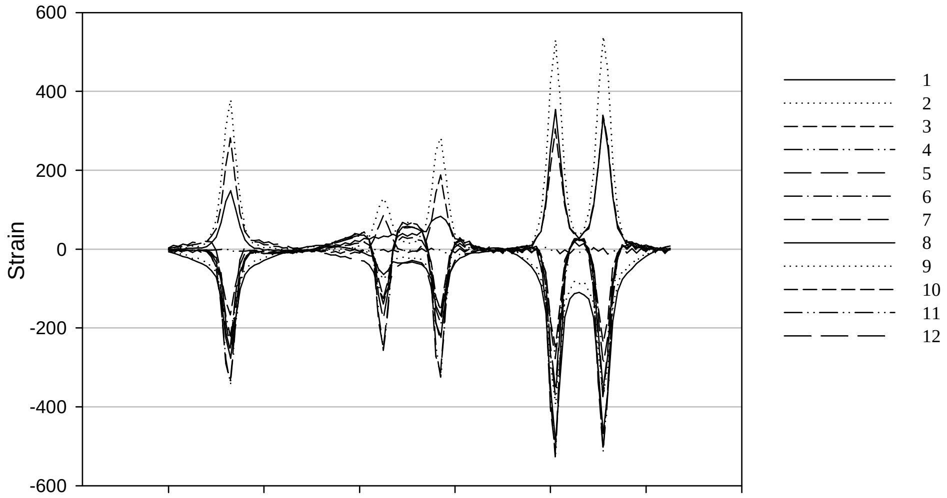


Fig. 7. Example of measurement output for a set of 12 strain gauges
(Strain [10^{-6} m/m] vs Time)

Meanwhile, the strain in all concerning strain gauges is recorded at a sampling frequency sufficiently high to allow the measurement of the strain peaks that sometimes happened to be very steep. A frequency of 200 Hz, combined with a slowly driving lorry, proved to be accurate enough for the measurements, while still keeping the noise problems within acceptable limits. In Fig. 7, the strain variations of all 12 strain gauges under the passage of the lorry, with its front left wheel in the middle between the first two stiffeners, has been displayed. All five axles of the lorry are easily distinguishable, as well as the two equally heavy axles of the trailer.

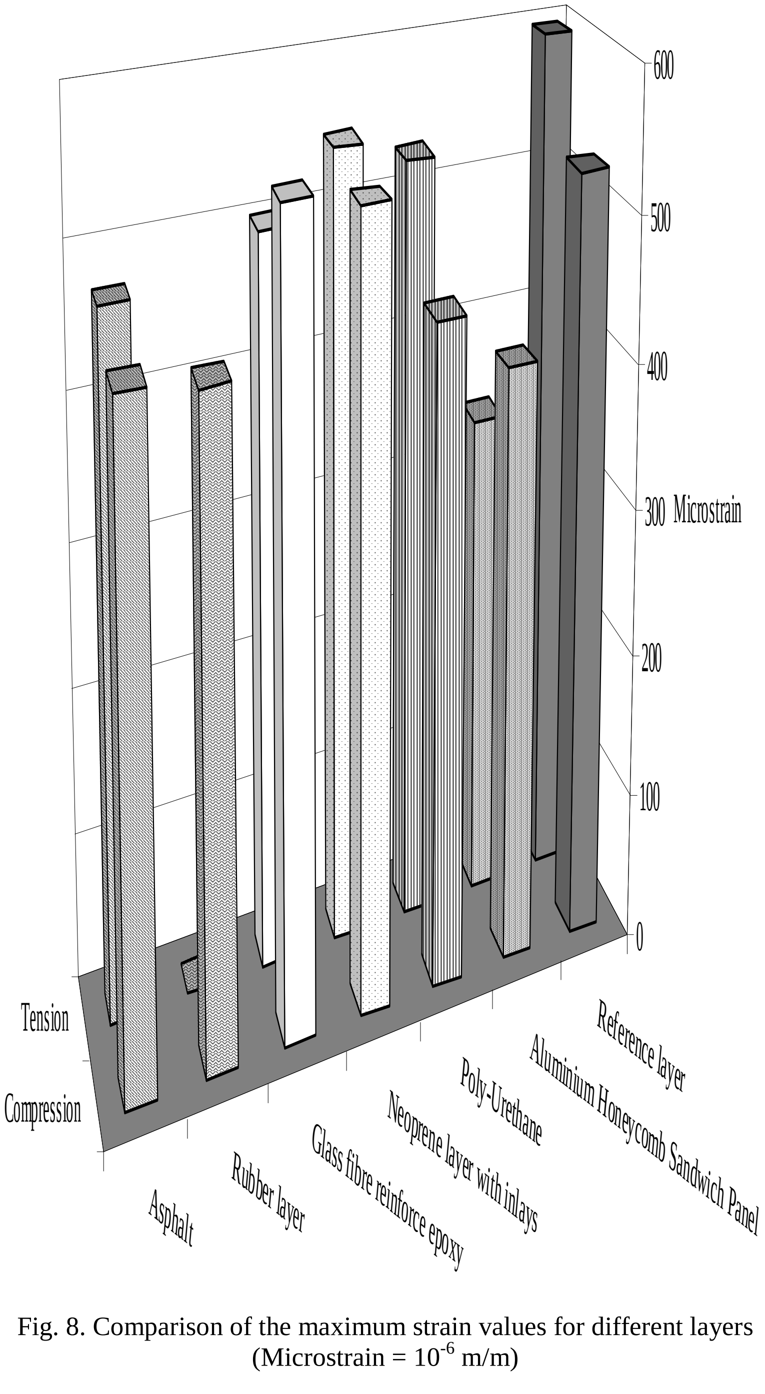


Fig. 8. Comparison of the maximum strain values for different layers (Microstrain = 10^{-6} m/m)

3.5. Testing results

After filtering through the measurement data for all strain gauges and all 9 load positions, it was possible to make a provisional comparison between the efficiency of the six different layers in reducing the stress ranges in the orthotropic deck. These values are shown in the three-dimensional chart in Fig. 8. One of the values for the rubber layer is omitted, since the concerning strain gauge gave an unreliable signal for the considered loading position.

Looking at this diagram, it becomes quite apparent that the variety, found in the layer characteristics of paragraph 3.2, can also be found in the degree of strain reduction that can be achieved.

While some of the proposed layers offer low reduction values, this could be expected based on FEM [4] and due to practical problems with the testing on real bridges. The glass fiber reinforced epoxy layer offers a real reduction only for loading positions resulting in tension in the deck plate, which could be expected, bearing in mind the unsatisfactory connection between the layer and the deck plate because of bad gluing. The other layer offering only a slight reduction is the neoprene layer with inlays, which was only 8 mm thick, being the thinnest layer of the test.

By comparison, the classic rubber layer, without inlays making it more susceptible to deformations, offers a considerable reduction on the stress peak of about 15%, with its higher thickness of 20 mm. Other layers offering comparable reductions are the polyurethane and asphalt layers. However, when looking at the asphalt layer, it is always wise to maintain a reserved position. The characteristics of asphalt layers are highly temperature dependent. While it was not possible to repeat the field tests at different temperatures, this was studied previously in a laboratory test [5], as well as using finite element calculations [4]. Any reduction found here, can thus only be counted upon depending on the climate of the construction region. Another important factor is that this was the thickest layer, 55mm, also making it the heaviest solution. A point in favor is that on most road bridges asphalt layers are installed in the form of wearing courses anyway. Any contribution is thus an extra bonus.

However, the layer that delivers the most satisfying results is, without a doubt, the aluminum honeycomb sandwich panel. Not only does it allow a reduction of about 25% on the peak value of the stress range, it is also the layer with the lowest weight, i.e. only 6,4 kg/m² in this test series.

4. CONCLUSIONS

The field tests performed during the making of this paper clearly follow the trends postulated in previous papers [4]. Installing a layer on top of an orthotropic deck with a sole purpose of the reduction of the stress peaks in the deck itself seems to be a possible pathway to a complete eradication of the fatigue sensitivity, which is so typical for a bridge with an orthotropic steel deck.

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