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Development of a 3D-FEM for Surfacings on Steel Deck Bridges

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Summary

The life span of surfacings for orthotropic steel deck bridges is often limited. There is no universally accepted method for the design of surfacings. However, some theories to estimate the stresses/strains in the different layers are available. These theories are almost all based on one or both of the following assumptions:

1. Linear strain gradient in the asphalt and the steel.
2. The gradient of strain through the depth of the asphalt and steel are equal.

Measurements disagree with both assumptions. More realistic theories are thus required to enable the design of steel deck surfacings. In this paper the development of such models are discussed. These models agree with the measurements and as such will help to design surfacing with a longer life span.

Introduction

Modern steel deck bridges consist of a 10-14 mm thick steel plate stiffened by longitudinal stiffeners spanning in the direction of the traffic flow, transverse girders support these stiffeners. Usually, the deck plate is surfaced with a 30-70 mm thick surfacing material e.g. mastic asphalt (1).

To the best of the authors' knowledge there is no universally accepted model for the design of surfacings on orthotropic steel deck bridges. However, some theories to estimate the stresses/strains in the different layers are available. These theories are almost all based on one or both of the following assumptions:

1. Linear strain gradient in the asphalt and the steel.
2. The gradient of strain through the depth of the asphalt and steel are equal.

Hameau et al. (2) have executed measurements on a two-span beam model. The measured strain over the height of the asphalt and the steel is shown in Figure 1 and shows that the strain gradient in the surfacing is not linear.

This non-linearity may be a result of the non-linear response of the asphalt and/or the geometry of the tested model. However, this work indicates that the assumptions upon which most composite theories are based might not be true. This indicates the need for a better understanding of the behaviour of orthotropic steel deck bridge surfacings. For this reason a research program that concentrates on material testing, full scale testing, and FE modelling is being conducted at the

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Delft University of Technology. In this paper the development of a 3D-FEM (Finite Element Model) of the bridge deck and the surfacing is presented.

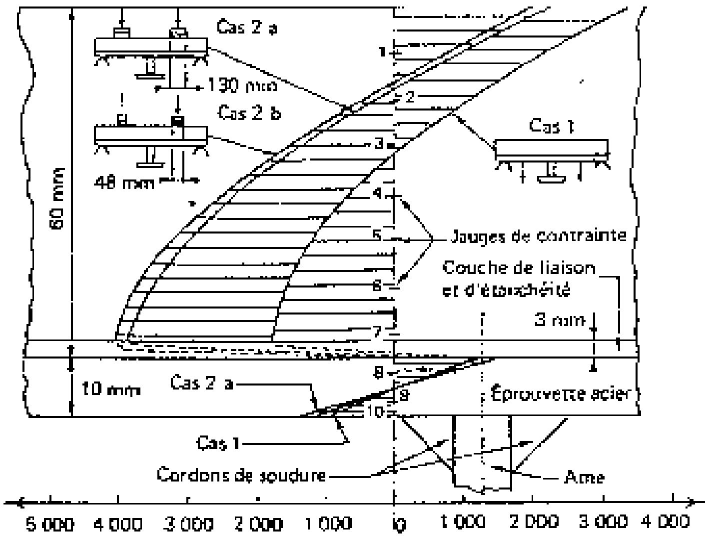

Figure 1 Strain distribution (Hameau, 2)

Model Geometry

The basic geometry of the bridge that is considered in the research program is presented in Figure 2. The model is based on the full-scale test sections that will be tested in the LINTRACK accelerated pavement testing facility of the Delft University of technology.

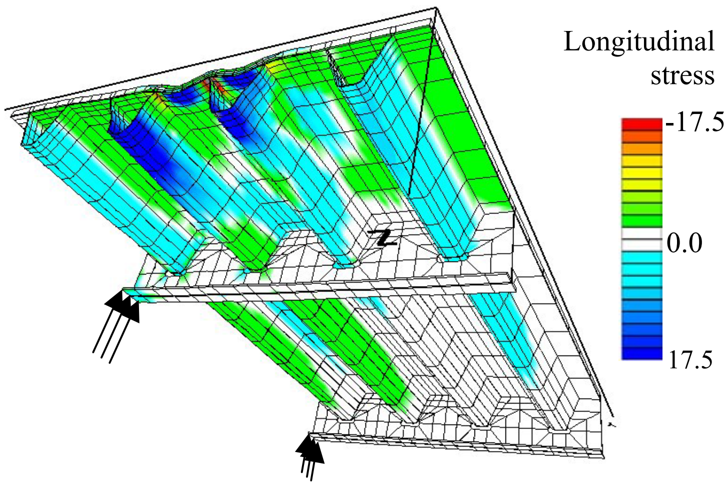

Figure 2 Deformed mesh (250x) with indication of longitudinal stress σ_{yy}.

Since the bond between steel deck and surfacing is expected to be a determining factor in surfacing behaviour an interface element layer is present between the surfacing and the steel bridge deck. In the area of interest the surfacing is modelled by three elements over the surfacing height. In the larger part of the model only one layer of elements is used to represent the surfacing.

In the calculations discussed in this paper the bridge deck is only supported at the outer bottom edges of the girders. This is indicated in figure 2, which gives the longitudinal stress in the complete structural model under a 14.5 ton dual wheel axle with 0.707 MPa contact pressure. In this particular case the membrane interface has a low shear stiffness (1 N/mm^3) and the 5000 MPa surfacing is only 50 mm thick.

The model shown in Figure 2 makes use of symmetry in the two front faces of the plot and may thus only be used to simulate the bridge reactions to a wheel load placed exactly between girders. A similar model is available for loads placed on a girder.

Linear Bridge Deck Behaviour

To validate the principal behaviour of the models, numerous linear computations were made. Within these computations the stiffness of the membrane interface, the thickness of the surfacing and the stiffness of the surfacing were varied. The geometry of the steel part of the bridge deck was kept constant.

Figure 3 gives the transversal strain in a 50 mm 5000 MPa surfacing under a dual wheel 14.5 tons axle load placed on a girder. One of the wheels of the dual wheel is placed over the centre of a stiffener, the other is placed between stiffeners and thus supported by the girder. As is shown by Figure 3, deformations mainly occur in the area that is not supported by the girder.

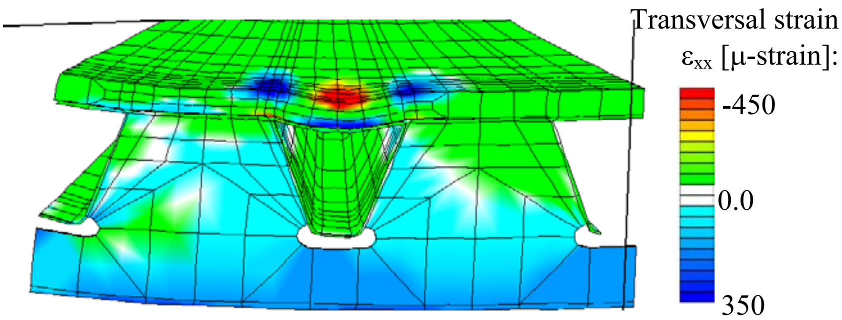

Figure 3 Deformed bridge deck (250x) with transversal strain ε_{xx}.

Design charts of the strain in the surfacing can be made. These charts give the strain over the height of the surfacing in five cross-sections as a function of: load condition, surfacing thickness, surfacing stiffness, membrane stiffness and girder spacing. Hereafter an example of such a chart for a 50 mm surfacing is presented. The chart refers to the situation that the load is placed between girders and gives the transversal strain, ε_{xx}.

Figure 4 shows that the gradient of strain in the surfacing is not linear, even when the applied materials show linear behaviour. The figure furthermore shows that the gradient of strain in the steel and the surfacing are not necessarily equal. Both observations are in agreement with the measurements of Hameau et al. (2).

ε_{xx} under a 14.5 tons dual wheel single axle between girders
50 mm surfacing, surfacing stiffness = 3000 MPa, Girder spacing = 3000

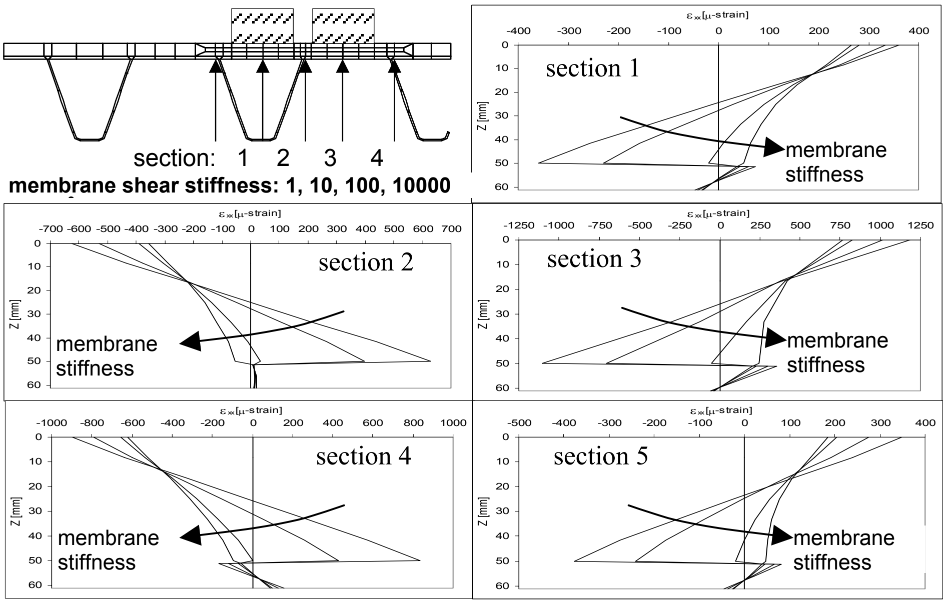

Figure 4 Design chart example.

Since surfacing strains depend on surfacing stiffness, surfacing thickness and the membrane interface stiffness it is possible to design a surfacing in such a way that it will withstand repeated loading over the desired design life.

Non-Linear Behaviour

In the previous section it was shown that the two structural models that were developed do describe the phenomenon measured by Hameau et al. It is, however, not possible to further validate the models since it is shown that geometry is a determining factor and the measurements refer to a layered beam and not a real bridge deck. For this reason it was decided to make a third structural model that represents the larger part of the full-size test sections tested in the LINTRACK machine. For verification of the models on the basis of LINTRACK measurements the third model should be able to cope with moving loads combined with bridge deck dynamics.

For the problem under consideration, in-elasticity is the primary cause of damage when repeated traffic loads are applied. To investigate the influence of the bond between the surfacing and the steel deck on the development and propagation of damage, a series of analyses were performed in which the inelastic response of the surfacing was simulated by means of the ACRe asphaltic material constitutive model available in CAPA-3D. Details of the constitutive model can be found in (3).

With the ACRe material model included in the third structural model a fully dynamic, non-linear analysis was made. In this analysis a 14.5 tons dual wheel axle travels over the bridge at a speed of almost 60 km/h.

In figure 4 the deformation of the bridge deck is shown under the third passage of the 14.5 tons dual wheel axle. In this figure an indication of transversal stress, σ_{xx}, is given. The 50 mm surfacing is placed over a membrane interface with a 10 N/mm^3 shear stiffness. The figure corresponds to the moment in time that the dual wheel axle is exactly between girders.

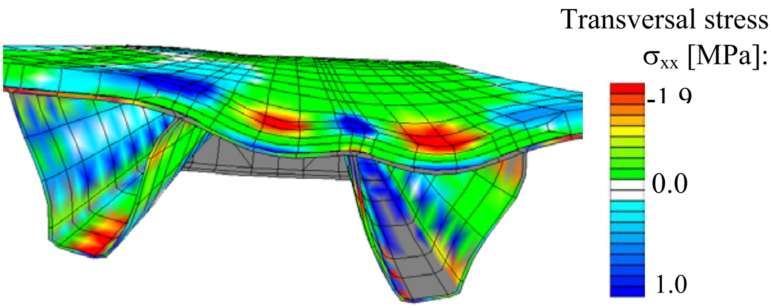

Figure 4 Deformed bridge deck (250x) with transversal stress σ_{xx} under 3rd passage of 14.5 tons dual wheel axle.

A global impression of the moving load is given in Figure 5. The figure gives the development of total damage during the first three load repetitions. The figures refer to the situation that the load has just passed half the distance between two girders, as can best be seen by considering the first (left) plot in figure 5.

The damage in the surfacing gives a clear indication of the wheel paths of the two wheels at one end of the axle. It is shown that damage accumulation under the wheel that travels over a stiffener is much larger than is the case under the wheel that passes between two stiffeners. This can be understood by considering the fact that the girder supports the steel plate between two stiffeners and does not support the plate within a stiffener. Figure 5 furthermore shows that the highest levels of total damage develop between two girders, where stresses and strains are highest due to a lack of girder support.

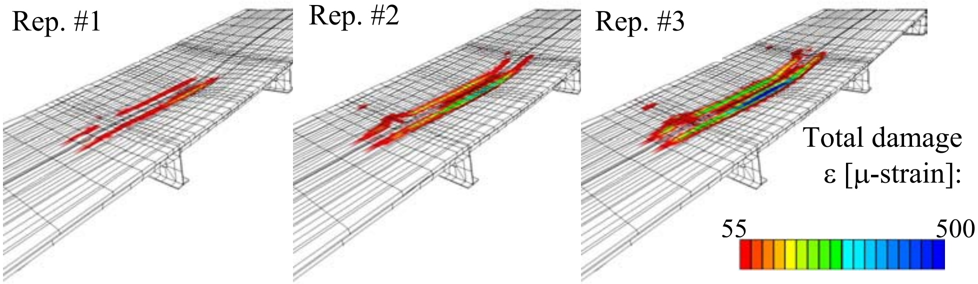

Figure 5 Development of total damage.

Conclusions

The conclusions of this paper can be summarised as follows:

- The models give results that are in agreement with measurements.
- Non-linear development of strain is at least for a large part dependent on bridge deck geometry.
- The ACRe material model is capable of describing the different aspects of the response of surfacing materials on orthotropic steel deck bridges.
- The levels of strain in the surfacing depend on the surfacing stiffness, the surfacing thickness and the membrane stiffness, implying that surfacings can be designed when one or more of these parameters are controlled.
- Both assumptions that form the basis of current design methods are not realistic.

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