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Influence of temperature effects in steel box girders

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***Abstract*— A number of recent monitoring project of steel box girders in Belgium have indicated that daily temperature variations can be an important load condition. The resulting behavior is not always included in the design loads according to the codes.**

As part of a large-scale project in order to improve the accessibility of the Belgian capital by train, the existing railway line between Brussels and Ghent is expanded from 2 to 4 tracks over a length of 25 km. This line crosses the valley of the river Pede by a 523 m long historic viaduct, built in the 1930‟s. In those days the viaduct was chosen over large backfills in the valley due to poor soil conditions. With respect to the protected work of art, two additional lateral fly-overs consisting of steel box girders with variable hollow section are integrated in the existing viaduct. This paper shows the results of the detailed monitoring program verifying the design and behavior of the newly built superstructure. Extensive strain measurements were performed during a two-day load test, together with acceleration measurements in order to evaluate the dynamic response of the structure. In addition long term strain monitoring was carried out in order to study the effects of temperature gradients on the closed steel box girders of the fly-overs.

The measured temperatures are introduced into a finite element model. Stresses resulting from this model are compared with measured stresses and stresses based on calculation using the same model but based on Eurocode load combinations. While the size of temperature variations is more or less as was expected the resulting behavior is more complex and less homogeneous than is generally assumed.

***Keywords*—Steel box girders, temperature load, temperature effects, monitoring.**

I. Introduction

As part of a large-scale project in order to improve the accessibility of the Belgian capital by train, the existing railway line between Brussels and Ghent is expanded from 2 to 4 railway tracks over a length of more than 25 km. This line crosses the valley of the river Pede by a 523 m long historic viaduct, built in the 1930's, as is shown in *Fig. 1*. In those days the large viaduct was chosen over large backfills in the valley due to very poor soil conditions. With respect to the protected work of art, two additional lateral fly-overs consisting of steel box girders with variable hollow section are integrated in the existing viaduct. These additional steel box girders are shown in *Fig. 2*.

This paper shows the results of the detailed monitoring program verifying the design and behavior of the newly built steel superstructure. Extensive strain gauge measurements were performed during a two-day load test, together with acceleration measurements in order to evaluate the dynamic response of the structure. In addition long term strain monitoring was carried out in order to study the effects of temperature gradients on the closed steel box girders of the fly-overs. Thermal sensors were installed on the steel bridge deck to analyze the temperature during long-term strain gauge monitoring in order to study the effects of temperature gradients on the closed steel box girders of the steel fly-overs.

The 523 m long historic viaduct crossing the Pede valley in Belgium consists of 16 three-hinged reinforced concrete arches with a span of 32 m each and a maximum height of 20 m. This paper shows the monitoring results of the temperature variations and strains of the newly built superstructure.

The background of the monitoring project is a number of recent measurement projects on steel box girders in Belgium, which have indicated that daily temperature variations and their uneven distribution over the bridge can be an important load condition. The resulting behavior is not always included in the design loads according to the codes.

The measured temperatures are introduced into a detailed finite element model. Stresses resulting from this model are compared with measured stresses and stresses based on calculation using the same model but based on design load combinations. While the size of the temperature variations is more or less as was expected the resulting behaviour is more complex and less homogeneous than is generally assumed.

Figure 1. Front view of the historic Pede viaduct.

Figure 2. Front view of the new steel super structure

II. Strain gauge and temperature monitoring

A. Setup of the measurement projects

The strain and temperature data discussed here are the results of the long-term temperature monitoring during the time period from July 7th, 2012 to July 10th, 2013. The strain gauges were installed in three cross-sections of the steel bridge deck in fixed points. Looking at one of these measurement sections, the gauge sensors which are measuring the thermal variations are the ones in the center of the lateral sides of the box section, indicated with number 8215 and 8216 in *Fig.4*. The other 5 "classic" strain gauges are measuring the actual strain in longitudinal and transversal directions of the bridge deck, as indicated in *Fig. 4*.

The strain gauges, which are part of a more extensive monitoring project, are numbered as logically and straightforward as possible, linked to their position in the steel deck, as shown in the diagrams in *Fig. 4*. All the measured temperatures are absolute values, which are expressed in degrees Celsius (°C).

All the strain values are relative to their respective baseline which was zeroed at the start of the monitoring period and are expressed in micro strain such as: (μS): 1 μS = 10-6 m / m

The installed strain sensors were applied following a strict procedure. The first step consists of the preparation of the steel surface by grinding to remove traces of corrosion and to make the surface smooth and even, but with just enough roughness to result in a good attachment of the gauges later on. This also includes ensuring that the surface is fat-free and pH neutral. The second step, the attachment of the actual sensors with epoxy resin based glue, includes applying pressure on the sensors during a short period to ensure a perfect contact between the surfaces. Afterwards, protection of the sensor from the radiation of the sun and rain, moisture and environmental conditions is provided using a type of waterproof rubber.

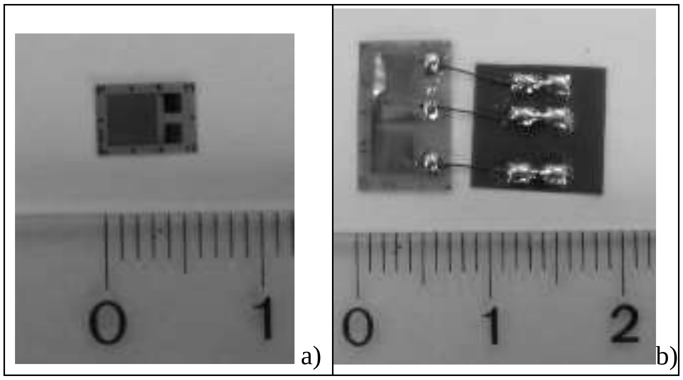

Figure 3 a) Temperature sensor; b) Strain gauges

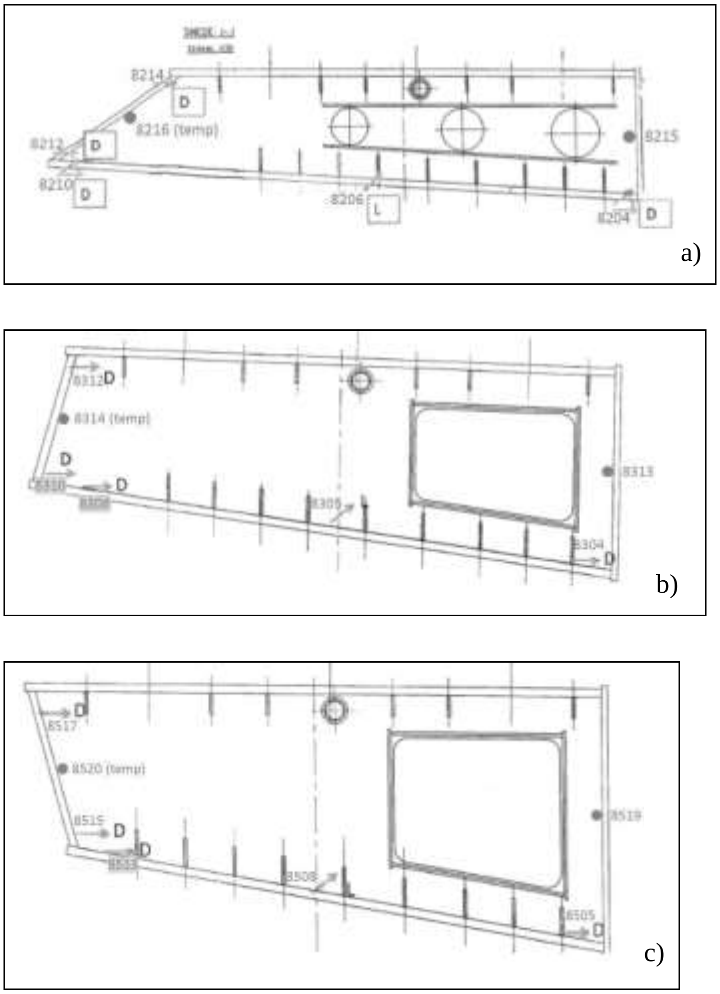

Figure 4. Positions of temperature sensors and strain gauges: a) at the middle of the span;
b) at one fourth of the span; c) at the supports

B. Results of the monitoring

The results of temperature as well as strain variations during the entire monitoring period are shown in Fig. 5. Analysis of the monitoring data indicates that substantial temperature variations exist. Measured temperature values of more than 30 degrees and below 0 degrees are quite common at all locations. The temperatures are measured at both sides of the steel box sections and monitoring shows different values, because of variations of the normal daily cycle of the sun and resulting partial exposure.

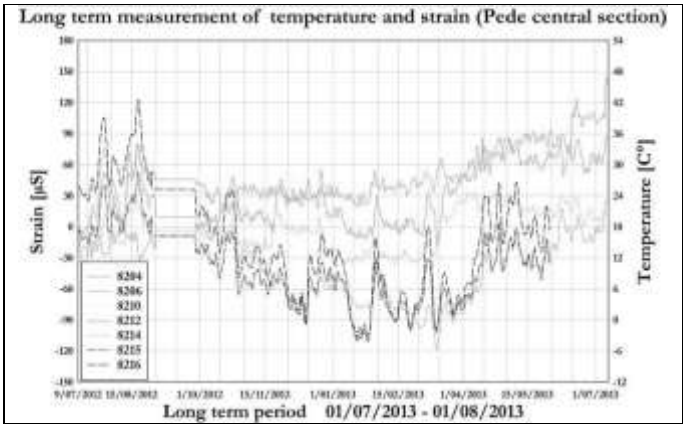

Figure 5. Long-term measurement graph of temperature and strain

A positive sign corresponds to an action resulting in traction, a negative sign of the strains to an action resulting in compression.

Looking at the synthesis of the monitoring, as shown in the chart in *Fig. 5*, focusing on the central cross-section of the bridge (i.e. the cross-section pictured in *Fig. 4* a), the variations of the strains are shown in lighter colors, while the temperatures are shown in darker dashed colors. Both variations are shown in their appropriate scale on different vertical axis. There are some imperfections when looking at the normal measurements, caused by problems with power supply. Nevertheless the graph in *Fig. 5* gives a suitable idea of the quality of the monitoring. Two additional vertical lines in *Fig. 5* are marking the location of the maximal and minimal temperature values recorded during the monitoring period. The values at these two moments in time are used for the construction of the sinusoidal functions of the finite element model which is described in the next paragraph and shown in *Fig. 6*. Overall, temperatures values are varying between -5.6 °C and 47.3 °C. The collected measurement data is quite substantial and allows for calibration of the finite element model.

Thermal loads are often not considered during the first design step of steel box girders; although their influence can be quite substantial. When the thermal loads and more specifically the thermal gradients reach considerable values a number of other effects are influenced, therefore the quantification of the thermal loads working on steel box girders becomes quite important.

III. Finite element modeling of the temperature variations

A. *Introduction*

A finite element model has been developed for the modelling of the added lateral steel box girders with variable sections of the bridge. The height of the box section is about 1.985 m, while the width of the upper surface is about 4.140 m. The longitudinal open stiffeners which are present in the real bridge are not represented in the finite element model but they have been taken in account by modifying the thickness of the corresponding steel plates accordingly. This ensures that the thermal behavior in terms of conduction and thermal capacity of the model is comparable to the real bridge. The steel plates are modelled as shell elements with different thicknesses and material proprieties, and the concrete as volume elements with linear elastic proprieties. The thicknesses vary between 45 mm for the sides, 35 mm for the diaphragms, 95 mm for the bottom plate and 65 mm for the top plate. The span length is 32.100 m. Nineteen variable cross-sections are used to give the bridge its peculiar shape. On the top of the steel box, a concrete structure is installed which is not contributing significantly to the thermal behavior. The two different materials are assumed to be perfectly connected over their entire connection area.

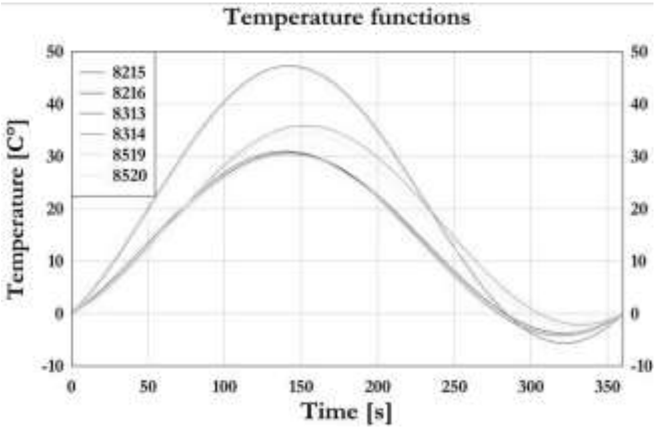

Figure 6. Thermal functions used in the model

B. *Description of the finite element model*

Two different types of finite element analyses were performed: a steady state thermal analysis, followed by a structural implicitly non-linear analyses.

The thermal analysis is used to determine the actual the surface temperatures on all points of the steel box during a fictional 24h day. To do this, 8 different sinusoidal temperature functions were applied on the faces of the steel model, shown in *Fig. 6*. These functions are based on the real temperatures which are registered using the sensors applied in the long term monitoring described in the previous paragraphs. The temperatures in the thermal analysis vary over time and is simulating simulate the real solar irradiation during a longer period. For this thermal analysis, the thermal functions are actually acting the constraints of the steel box girder.

The structural implicit non-linear analysis leads to a static structural behaviour along the same time used on the thermal analysis using the thermal loads obtained on the previous analysis as structural load; the time steps is of 1 second the thermal conductivity has been assigned to the model so it can deform under the thermal load applied, a reference temperature of zero degrees is also assigned to the model; in the 4 bottom sides of model 4 supports are used as fixed points for apply constraints.

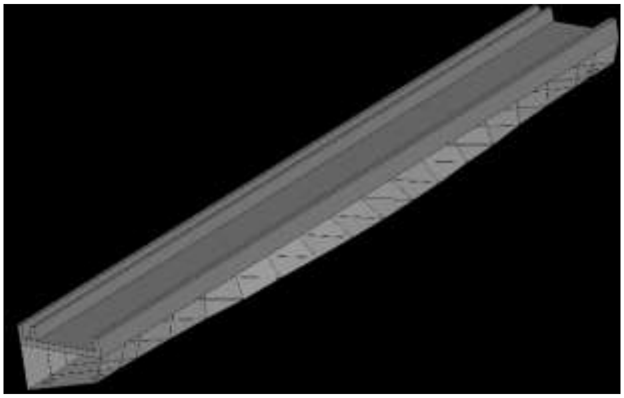

Figure7. General overview of the finite element model

The overall appearance of the finite element model is shown in *Fig. 7*. The concrete structure on top, supporting the ballast layers of the train, is clearly visible at the top, as well as the steel parts at the bottom with their variable cross-section. In the corners it is possible to see the 4 supports where the constraints are applied during the non-linear structural calculation.

C. *Finite element results*

The results of the central cross-section of the bridge are summarized in the *Fig.* 8. The maximal displacements are about 0.84 cm and are occurring along in the longitudinal axis in correspondence with the moment when the highest temperature values are working in the middle section as was expected. Looking more in detail, it can be seen that the irregular cross-section combined with temperature variations will result in a slight torsional effect. The variation of the strains in time, also shown in F*ig. 8*, is closely linked to the overall temperature variations.

Measured strain values					
Location	8204	8206	8210	8212	8214
Min.	20	-78	-	-16	-32
Max.	-27	83	-	72	26

Calculated strain values					
Location	8204	8206	8210	8212	8214
Min.	57	-17	-	-16	-19
Max.	-18	60	-	81	92

Table 1. Strain values [*10e-6] based on measurements and finite element modelling at the moments of maximal and minimal temperature

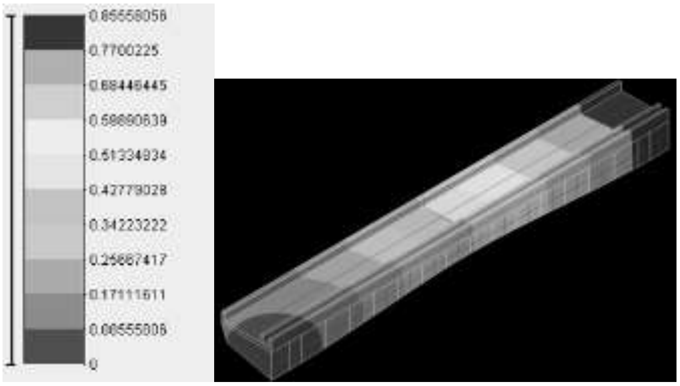

Figure 8a) Results of the finite element model: overall nodal displacements;

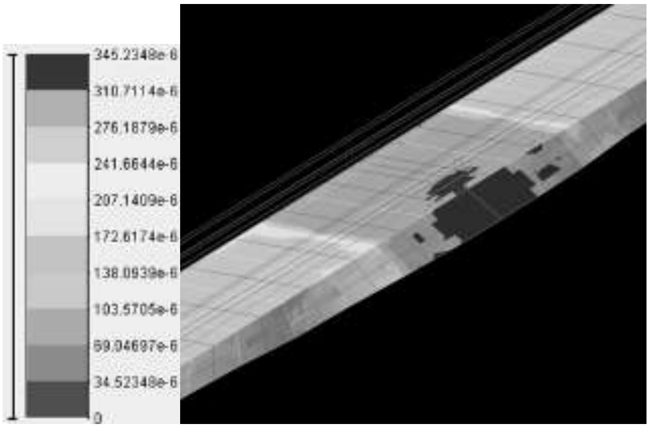

Figure 8b) Results of the finite element model: first principal strain at the moment of the maximal temperature

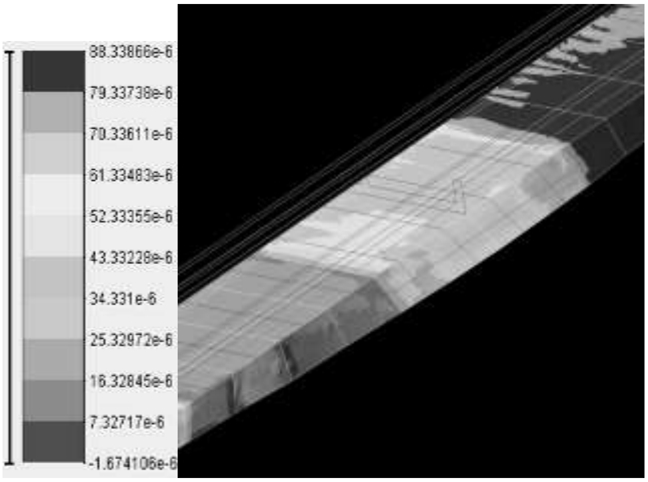

Figure 8c) Results of the finite element model: first principal strain at the moment of the minimal temperature

In *Table 1* the comparison between the real and the finite element model strains is illustrated. These results are for the central cross-section and the strain values are measured as nodal strains in point of the finite element model as close as possible to the actual locations where the strain gauges were installed. Results of all the other cross-sections has been computed but not treated in the paper, since the results are quite similar. Comparing both measured and calculated values shows that it is quite possible to predict the size of the strain and stress variation using finite element modeling.

D. Conclusions

A number of recent monitoring projects of steel box girders in Belgium have indicated that daily temperature variations can be an important load condition. The resulting behavior is not always included in the design loads according to the codes. While the size of temperature variations is more or less as can be expected, the resulting behavior is more complex and less homogeneous than is generally assumed.

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