Conformity assessment of two orthotropic steel deck bridges in Bulgaria according to present requirements

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Abstract. Two orthotropic steel deck (OSD) bridges along “Hemus” highway in Republic of Bulgaria are discussed in the paper. They are built at 1985 and are in exploitation over 30 years up to present times. The first of the bridge superstructures is with closed section trapezoidal longitudinal ribs of the OSD and steel plated main girders with 72,45 m span. The second bridge superstructure is with open type section longitudinal ribs of the OSD and steel box main girder with 162m span. Visual inspection and some measurements are performed for evaluation of the overall condition of these bridges. It must be mention that the traffic has considerably increased. Some checks for fatigue for the second bridge are performed in accordance with Eurocode. The condition in respect to fatigue behaviour in accordance with the used structural details in the OSD and the prescriptions of the present design standards is analysed and discussed.

1. Introduction

In the focus of this article fall two steel road viaducts built in 1985 in Bulgaria. They are situated at km 35+144 (Viaduct 1) and km 35+760 (Viaduct 2) of the “Hemus” highway, which is envisaged to connect Sofia with Varna town, the second biggest Bulgarian harbour on the Black sea.

The superstructure of Viaduct 1 is continuous beam over six spans 60m+4x72,45m+60m. It consists of two steel plate girders with an orthotropic steel deck plate on top (see figure 1). In this section of the highway the alignment falls into horizontal curve with a constant radius of 850m and longitudinal slope of 4,61%.

The superstructure of the Viaduct 2 is continuous steel box girder beam over three spans 100m+162m+100m (see figure 2). It still holds the span record in Bulgaria for road bridge. The road alignment is again falling into horizontal curve with a constant radius of 1467,25m and longitudinal slope of 4,61%.

Both bridges have orthotropic steel deck (OSD) plates and are in exploitation for 35 years. In this period the traffic intensity as well as the traffic volume on the highway has increased considerably. These facts and the reported defects of similar bridges with OSD [1] abroad, trigger research project in the University of Architecture, Civil Engineering and Geodesy, Sofia. Under this project visual inspections of the two viaducts were performed. The analysis of the findings as well as the conformability assessment of the OSD to Eurocode is presented in this article.
Figure 1. General view of Viaduct 1.

Figure 2. General view of Viaduct 2.

2. Visual inspection and conformity analysis
Both Viaducts have orthotropic steel deck plates (see figure 3). The difference is that in Viaduct 1 the longitudinal stiffeners are closed type trapezoidal, while in Viaduct 2 they are open type single plate stiffeners.

Figure 3. OSD cross section of Viaduct 1 (a) and Viaduct 2 (b), according to [5].
The main findings during the visual inspections of the viaducts are as follows:

Misalignment between the adjacent assembly elements of the steel structure in Viaduct 1. In order to compensate it the connecting splices were produced with considerable initial deformations. Usually, prescribed misalignment tolerances for welded details, in the standards, are in the range of a few millimetres. In this case they are obviously larger.

![Figure 4. Misalignment between adjacent assembly elements in the connection of the stiffeners of the OSD of Viaduct 1.](image)

Fatigue crack is found into the zone of the connection of the longitudinal stiffeners close to the backing strip (see figure 5) in Viaduct 1. In [2] this detail is prescribed with backing strip from the inside of the trapezoidal stiffener and tack weld falling into the place of the future butt weld. Moreover, the sequence of the welding in this detail is very important. It should be such that the residual stresses are as small as possible and resulting in compression at the bottom flange of the stiffener (see figure 5 (c)).

![Figure 5. Crack noticed into the zone of the backing strip of the longitudinal stiffener (a) and detail of the connection according to [2] (b) and (c).](image)

The connection detail between the trapezoidal longitudinal stiffeners of Viaduct 1 and the web of the cross beams is realized without holes in the web. In [2] it is recommended that stiffeners are continuous, passing through cut outs in the webs of the cross beams. Discontinuous stiffeners are allowed only for light weight traffic (pedestrian bridges and under footpaths) and for distances between cross girders smaller than 2,75m. As far as the cope hole at the bottom is concerned, both options are allowed in [2], with and without it (see figure 6 (b)). In any case, one should bear in mind, that the reduced plasticity in cold formed trapezoidal stiffener in the bended zone, combined with high tension residual stresses from welding leads to low fatigue strength detail – category 36, according to [3].
Fatigue crack is also found at welded connection between closed trapezoidal longitudinal stiffener and 12mm thick deck plate in the zone of the first intermediate support of the main girders. In order to prevent such cracks, following prescriptions are given in [2] - minimum plate thickness 14mm(16mm) and minimum stiffness of the longitudinal stiffeners should be provided as well. In addition, the weld could be either automatic or manual, according to figure 7 (b and c), but its thickness should not be smaller than the thickness of the stiffener. In this case, as seen from the picture, the weld quality is poor, and the weld thickness is smaller at the location of the crack.

Open flat stiffeners in Viaduct 2 are passing through the web of the cross beams, welded only from one side. In this case the load is transferred eccentrically. According to [2] open flat stiffeners should be welded to the web of the cross beam from both sides. Single sided welding is not allowed.
3. Fatigue check of specific OSD details according to EN 1993-1-9

In addition to the conformity assessment, fatigue checks of some of the details of the OSD plates are performed, according to [3]. The selected method for the verification, according to БДС EN 1993-2:2007/NA:2011, is the Safe Life Concept. According to this method an acceptable reliability should be provided during the whole design life of the structure without the need for regular inspections and maintenance. The fatigue checks are performed according to the damage equivalent factor concept, using fatigue load model FLM3, according to [4]. The partial safety factor for fatigue strength of the OSD elements is chosen as 1,15.

The internal forces and moments are determined from elastic analysis of FE model of the OSD plate segment of Viaduct 2. In longitudinal direction the segment is 14m (7 spans between cross beams) and in transversal 6,50m (the distance between the webs of the box girder). More information on the FE model is given in [6]. The additional stresses from global bending of the box girder are not considered.

Four details are verified, summary of the results is presented below.

![Figure 9. Longitudinal stiffener effective cross sections, over support (a), mid-span (b).](image)

Deck plate connection with cross beam web – Detail category 71.

\[
\Delta \sigma_{FLM3} = \frac{\max M_{FLM3} - \min M_{FLM3}}{W_y}
\]

\[
\Delta \sigma_{FLM3} = \left[1.0 - (-8.8)\right] \frac{100}{300.6} = 3.3kN/cm^2 = 33MPa
\]

\[
\Delta \sigma_{E,2} = \lambda_{r} \lambda_{E} \lambda_{s} \Delta \sigma_{FLM3} = 1.77 \Delta \sigma_{FLM3} = 58MPa
\]

\[
\gamma_{f,y} \Delta \sigma_{E,2} = 58 < \frac{\Delta \sigma_{E}}{\gamma_{Mf}} = \frac{71}{1.15} \approx 62
\]

Deck plate connection with longitudinal stiffener – Detail category 100.

\[
\Delta \sigma_{FLM3} = \left[10.5 - (-2.5)\right] \frac{100}{540.2} = 2.4kN/cm^2 = 24MPa
\]

\[
\Delta \sigma_{E,2} = \lambda_{r} \lambda_{E} \lambda_{s} \Delta \sigma_{FLM3} = 2.19 \Delta \sigma_{FLM3} = 53MPa
\]

\[
\gamma_{f,y} \Delta \sigma_{E,2} = 53 < \frac{\Delta \sigma_{E}}{\gamma_{Mf}} = \frac{100}{1.15} \approx 87
\]
Stiffener connection to the web of the cross beam – Detail category 80.

\[ \Delta \sigma_{\text{FLM3}} = \frac{[1.0 - (-8.8)]100}{177.1} = 5.5kN / cm^2 = 55MPa \]  

(8)

\[ \Delta \sigma_{e,2} = \lambda_1 \lambda_2 \lambda_3 \lambda_4 \Delta \sigma_{\text{FLM3}} = 1.77 \Delta \sigma_{\text{FLM3}} = 97MPa \]  

(9)

\[ \gamma_{eff} \Delta \sigma_{e,2} = 97 > \frac{\Delta \sigma_c}{\gamma_{Mf}} = \frac{80}{1.15} \approx 70 \]  

(10)

Web of the cross beam – Detail category 112.

Figure 10. Stresses in the web of the cross beam.

\[ M = 0.20v_L0.203 = 10kNm \]  

(11)

\[ \sigma = \frac{M}{W} = 8.1kN / cm^2 = 81MPa \]  

(12)

\[ \Delta \sigma_{\text{FLM3}} = \sigma - 0 = 81MPa \]  

(13)

\[ \Delta \sigma_{e,2} = \lambda_1 \lambda_2 \lambda_3 \lambda_4 \Delta \sigma_{\text{FLM3}} = 2.18 \Delta \sigma_{\text{FLM3}} = 177MPa \]  

(14)

\[ \gamma_{eff} \Delta \sigma_{e,2} = 177 > \frac{\Delta \sigma_c}{\gamma_{Mf}} = \frac{112}{1.15} \approx 97 \]  

(15)

4. Summary and conclusions

Two steel road bridges with OSD on “Hemus” highway in Bulgaria have been inspected after 35 years of exploitation. Their general condition, based on visual inspections, looks satisfactory.

Problems with fatigue cracks in steel bridges with OSD plates, having the same age, have been reported worldwide. On European level this has led to specific recommendations for their structural detailing, published as Annex C in [2]. The two bridges under consideration were designed and detailed according to the best bridge practice and standards in force at the time of their construction. Nevertheless, conformity analysis with recent recommendations has shown that some of their details are inappropriate in terms of fatigue.

Fatigue verification of the OSD plate of Viaduct 2, in accordance with Eurocode, were performed. Damage equivalent factor concept and FLM3 were used. The results show that the check is not fulfilled for two of the four details. It is important to state that the stresses from global bending of the steel box girder are not considered into these verifications. They should be added in cumulative way to the local stresses: , and are of importance to all details subjected to longitudinal normal stresses. One of the critical details is the one-sided connection detail of open flat stiffener, which could be the reason for removing this option from the contemporary standards. For Viaduct 1 verifications were not performed, but fatigue cracks were detected during the visual inspection.
Inappropriate detailing, together with the increased traffic on the highways since the time of their construction as well as the execution quality 35 years ago, are all factors that might lead to crack initiations at different locations of the OSD plates. In order to prevent future accidents more thorough investigation of the two viaducts is recommended. The relevant managing authorities should take the appropriate measures such as regular inspections in order to control and prevent any crack propagation. Since these viaducts have passed only one third of their design life, different advanced strengthening methods could also be an option for prolonging their life.

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