Extending the fatigue life of welded tubular bridge joints thanks to internal diaphragm stiffening

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Summary

Tubular arch bridges comprise many welded tubular nodes, which are the most critical parts, since they reduce the fatigue strength of the bridge. Due to geometric discontinuity and the welding process, various stress concentrations are introduced at the nodes, making this type of bridge prone to fatigue damage caused by the varying traffic loads. High peak values of stresses, so-called hot spot stresses, are reached near the weld toe of the nodes. The objective of the present research is to increase the fatigue strength of these nodes or to reduce the hot spot stresses. A possible solution is to provide diaphragms inside the main tube. These diaphragms will reinforce the main tube thus reducing the in-plane deformation of this tube. Calculations show that the diaphragms have a positive influence on the hot spot stresses near the weld toe. The fatigue life of the whole bridge increases considerably due to this reduction of the weld stresses.

Keywords: Tubular arch bridges; welded tubular nodes; fatigue damage; diaphragm stiffening; hot spot stress; FE-models; strain measurements.

1. Introduction

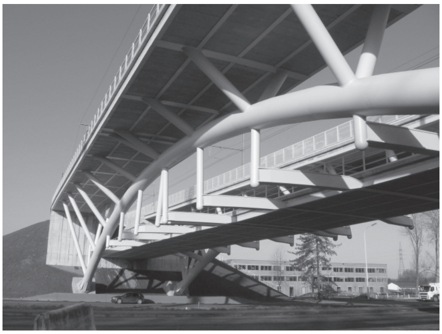
Fig. 1: Woluwe Lane Bridge

Circular hollow sections are being used in various modern bridges. Although these bridges are highly appreciated because of their aesthetic value, they are considered to be costly, mainly due to the use of welded nodes. The fatigue strength of these structures is an important aspect because high stresses, so called hot spot stresses, are reached near the weld toe of the nodes. Due to geometric discontinuity and the welding process, various stress concentrations are introduced at the nodes, making this type of bridge prone to fatigue damage due to the varying traffic loads. In tubular bridges, the braces, connected to the main tube also introduce local bending of the arch tube, according to the ratio of the tube diameters. Consequently these welded nodes are the weakest parts and determine the global strength of the structure. If the hot spot stresses can be decreased, then the fatigue strength of the arch bridge will increase.

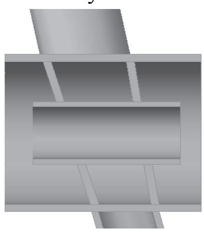
Fig. 2: Diaphragm stiffening

The objective of the present research is to increase the fatigue strength of the nodes by reducing the hot spot stresses near the weld toe. A possible solution is to provide diaphragms exactly at the location of the weld toe, inside the main tube. These diaphragms will

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reinforce the main tube thus reducing the in-plane deformation of this tube. The Woluwe Lane tubular arch bridge (*Fig. 1*) is equipped with diaphragm stiffening. Each node contains two internal diaphragms to reinforce the main tube (*Fig. 2*).

2. Calculating the fatigue life of a node of the Woluwe Lane Bridge

To calculate the fatigue life of a node, the calculated hot spot stress range must be used in conjunction with a $S_{R,hs}$-N design curve. Once all the stress concentration factors (SCFs) of node ALK09 are calculated with the proposed alternative method, the hot spot stresses for various load conditions can be easily calculated. Moving train loads are placed on the bridge deck of the wireframe model of the Woluwe Lane Bridge. Train types 1 to 4 will be considered because only passenger trains cross the Woluwe Lane Bridge. In *Fig. 3* the highest hot spot stress variation of node ALK09 with and without diaphragm stiffening is plotted for train type 1. It becomes clear that the variation in hot spot stress is significantly lower due to the internal diaphragm stiffening.

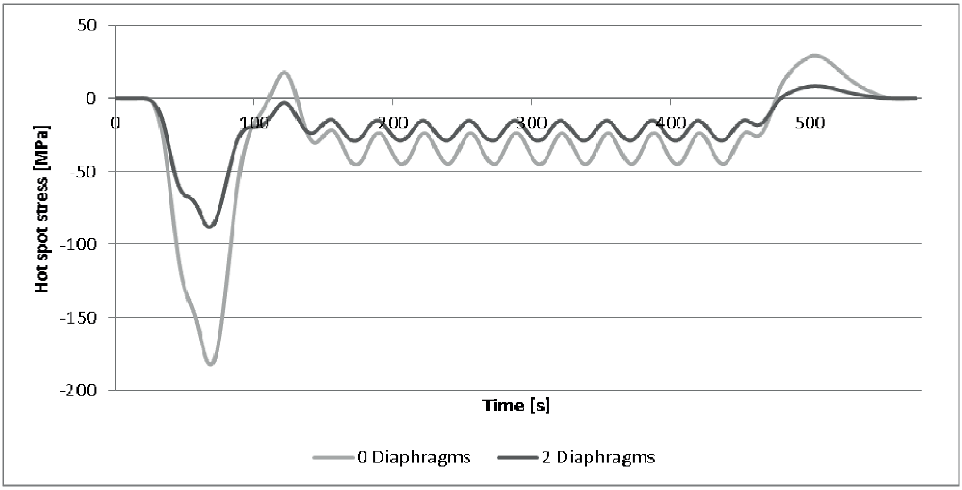

Fig. 3: Hot spot stress variation of node ALK09 with 0 and 2 diaphragms caused by train type 1

The fatigue damage due to the four train types equals:

- Node without diaphragms: total D_i for one year = 9,50E-02 => fatigue life = 10,53 years
- Node with 2 diaphragms: total D_i for one year = 8,67E-03 => fatigue life = 115,30 years

The fatigue life of node ALK09 with diaphragm stiffening is extended with 104,77 years or is 10,95 times longer than the fatigue life of the same node without diaphragm stiffening for this loading condition.

3. Conclusions

It has been verified that the diaphragms have a positive influence on the fatigue strength of the bridge. The internal diaphragms reinforce the chord and lower the hot spot stresses at the weld toe. The diaphragms allow for a slender and more aesthetic bridge with a longer fatigue life. In addition, the proposed alternative method to calculate the SCFs allows to calculate more accurately the hot spot stresses of existing tubular bridge structures. With these stresses, a more accurate indication of the remaining fatigue life of the structure can be determined, based on the condition that the appropriate S-N curve is known. The purpose of further research is to determine the optimal location of the diaphragms for various nodes. Furthermore, the influence of different parameters of the diaphragms and the tubes will be researched. In the near future, all calculations will also be validated experimentally by fatigue tests on representative samples of welded tubular nodes. Small nodes with and without diaphragm stiffening are being made in order to carry out laboratory tests.