Strengthening orthotropic steel decks with Fiber Reinforced Polymers

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Summary

The paper describes a method to strengthen orthotropic steel bridge decks who suffer from fatigue (cracks) due to increased heavy traffic load. It explains for which reasons and in what way a solution with Fiber Reinforced Polymer (FRP) has been chosen and what the advantages are in relation to other possible solutions. Extensive testing at Delft University of Technology is explained and testing results are given. Further testing and results of a full scale bridge model are described. It is made clear that the proposed solution is a very interesting solution for strengthening fatigued orthotropic bridge decks. Further scheduled improvements are pointed out.

Keywords: Bridge strengthening; orthotropic steel bridge deck; fibre reinforced polymers; FRP; fatigue damage; heavy traffic; asphalt, surfacing.

1. Introduction

In the Netherlands fatigue in orthotropic steel bridge decks is a severe problem due to increased traffic by lorries and changed wheel configurations. This problem is more severe in the Netherlands than in any other country in the world. The fatigue problem occurs mainly in the traffic lane for heavy transport. To deal with this problem a solution had to be chosen of which the weight does not transcend the weight of the existing asphalt layer. It must strengthen the deck plate and keep the functions of this asphalt layer such as coating, roughness and noise reduction. In the past years many solutions with these characteristics have been investigated. In the end the Dutch Government chose for a High Strength Concrete layer of ca 75 mm for the full bridge deck surface. Due to problems with the start of this solution the writers proposed a solution with FRP which in their opinion is more suitable. In the sixties and seventies many of these steel bridges with orthotropic decks have been built worldwide. In the future it is expected that many of these bridges will run into similar fatigue problems as described dependent on the traffic growth on that particular bridge.

2. Problem and analyses

The problem with the orthotropic steel bridges are fatigue cracks occurring in the steel deck plates. These cracks occur mainly in the wheel tracks of the slow lane, more in particular in the weld region between through leg and the deck plate. This is the case in many of the Dutch orthotropic bridge decks and even concrete bridge decks suffer from increased traffic. In the Van Brienenoord bridge in Rotterdam the first fatigue cracks in the movable part of the bridge, showed up only seven years after the opening of the bridge in 1997. After ten years it had to be replaced completely.

Analyses of the problem made clear that under increased traffic the asphalt layer gives insufficient support to the deck, especially in the summer time because of higher atmospheric temperatures. Higher temperatures make the asphalt weaker and less stiff. As result of this it spreads the wheel contact pressure loading insufficiently. To stop the fatigue crack growth a stress reduction in the steel deck of approximately a factor 7 was necessary.

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The solution to the problem should be a better alternative for the asphalt layer. A solution which provides a better spread of the load, which gives strength to the steel deck under all temperatures and which is not heavier than the weight of the asphalt layer. In case a solution can be found which is not heavier than the asphalt layer needing replacement, it is not necessary to additionally strengthen the main structure of the bridge.

3. FRP Solution

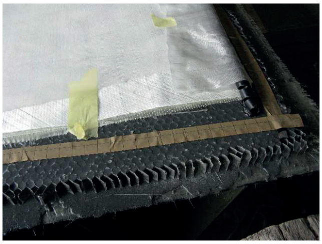

Fig. 1: FRP Solution

A solution which meets the criteria described is a solution with Fiber Reinforced Polymer. The FRP will be built up from three different layers to get the right adhesive quality, resistance against bending shear and effective outer fibres. The base layer consists of glass fibre and adhesive epoxy, the second layer is a 25 mm high honeycomb filled with epoxy mortar and the third layer consists of a number of glass fibres, placed in different directions. Investigations today are focused on an even stronger top layer which must reduce the steel stresses with a factor 15 instead of 7. After removal of the asphalt layer, the subsequent layers can be placed under conditioned weather circumstances one by one directly on the bridge deck needing repair and after removal of the asphalt layer.

4. Testing

Fig. 2: 4-point bending tests

Different tests have been carried out at the Stevin laboratory of Delft University of Technology [1] to prove the characteristics of the described solution. After the good results of the first fatigue tests of the solution, the stress reduction has been tested and optimized more in detail. A large number of 4-point bending tests have been performed on stress reduction, on bonding behavior, on several types of static and fatigue failure mode mechanisms and on time dependency effects like creep. After the laboratory tests the stress reduction has also been tested on a full scale orthotropic bridge deck section of 8 x 3,6 m² [2].

The tests showed that this particular layer configuration can give a stress reduction of a factor 7.

5. Discussion and conclusions

By reducing the stresses in the steel deck of orthotropic steel bridges, the Fibre Reinforced Polymers layer lowers the stresses significantly and stops the growth of existing small fatigue cracks. It increases the remaining lifetime of the existing bridges with more than the required 30 years. An even higher stress reduction factor can be obtained by using carbon, instead of glass fibers for the top layer. Because of the low weight of the FRP layer, a bridge can be strengthened without strengthening the main structure. It is pre-eminently suitable for movable bridges, because weight is an even bigger issue there. With the FRP layer the traffic disturbance during execution can be reduced with a factor 2 to 3, compared to the solution, which has been chosen.

6. References

[1] ROMEIJN A., "Bridge deck strengthening – Laboratory research", Delft University of Technology, Rep. nr. 25.5-10-03, 2010.

[2] ROMEIJN A., "Bridge deck strengthening", Delft University of Technology, Rep. nr. 25.5-10-01, 2010.