Strengthening of high volume steel bridge with a thin SFR-HSC

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Abstract

The Galacopperbridge is part of the Highway A12 and exits of two parallel placed steel bridges, one for each direction, and was built in the 70s. Each bridge has a in total 5 lanes and 2 emergency lanes. The bridge is damaged by the enormous amount of (heavy) traffic and this is much more as foreseen in the design. The result is cracks in the steel plates. The huge amount of intermediate repairs should be a thing of the past. It was decided to strengthen the steel bridge with a Steel Fibre Reinforced High Strength Concrete (SFR-HSC). The starting point of the design is to place a 90 mm thin layer concrete layer directly on an intermediate layer of epoxy with gritted bauxite 3/6. This intermediate layer is the only connection between the steel bridge and the concrete pavement. No other anchoring by means of dowels or anchors is used, that means the concrete pavement sticks at the steel bridge by bond! The pavement was conventionally placed by means of a slipformpaver. Unfortunate sized slabs were placed manually and due to the very stiff fresh concrete, this is a point of attention.

Introduction

The Galecopper-bridge is the 5th of eight bridges in the Project Renovation Bridges (PRB). The bridge is located in the centre of the highway network of The Netherlands and close to the cities Utrecht and Nieuwegein. To this the bridge crosses the Chanel between Amsterdam and the Rhine. So this location makes the renovation to a crucial project. The flow and safety on the road network around Utrecht as well as the shipping on the Amsterdam-Rhine Canal do have the highest priority and this all does make the project technically very challenging. The bridge should not only be renovated but also strengthened and increased.

Principles of the design of the steel bridge

Orthotropic steel bridge decks have as the name says orthotropic properties. This means that differences in the mechanical properties of the plate on each other orthogonal lying main directions (longitudinal and transverse). Almost all orthotropic steel bridge decks have a similar configuration. The deck has a running surface consisting of a deck plate. The stiffness is extracted from the longitudinal girders under the cover plate are welded, see figure 1. The cover plate's goal is to " the taxes on the transfer to the longitudinal girders, in addition, the flange plate as contributions to the bending stiffness of the total

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system. The running surface consisting of the cover plate and the longitudinal girders are located on cross carriers and main beams which run around the span. An axle load is transferred to the cover plate to the longitudinal girders, from the longitudinal girders to the cross carriers and of the cross carriers towards the main beams.

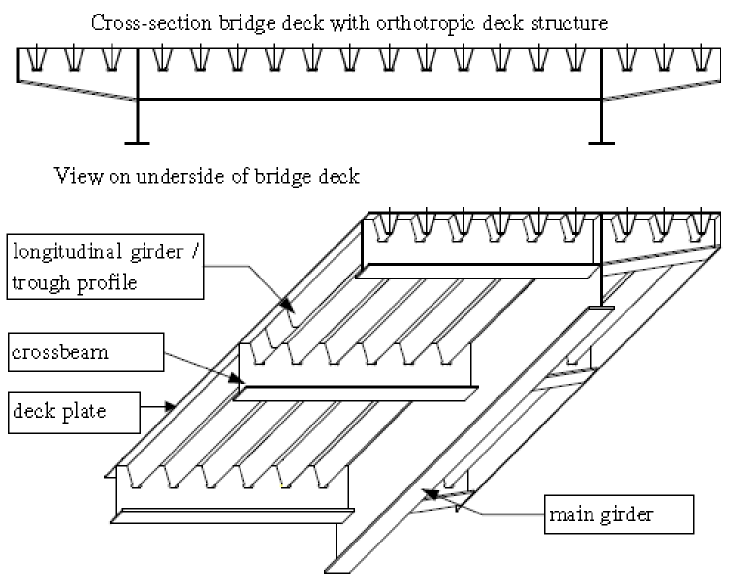

Figure 1 Typical layout of a steel bridge (de Jong, F.B.P.)

Problems caused by fatigue and the possible solutions

Problems caused by fatigue

The development from 1960 to now can be summarized as follows:

- Between the 60's and 70's there has been an increase in both axle loads (from 8 to 10 ton) and a total weight of the heavy traffic from 32 to 36 ton. Heavy traffic with a maximum weight of 50 ton are rare in this period.
- During the next two decades the increase of the total weight continued caused by the technical development (air suspension and super singles).
- Between 1990 and 2000 the number of heavy "single "trucks" (trucks without trailer or semi-trailer) with 3, 4 or 5 axles did grow explosive. That means that not only the heavy trucks became heavier but at the same time shorter.
- Nowadays the heavy trucks, including the ones with trailer or semi-trailer, with a total weight of 46 ton is quite common. The weight of 4 axle trucks is nearly 50 ton and 5 axle axle trucks is 50 ton.

In addition, in the period 1962 – 2002 the traffic taxes in accordance with the VOSB ' 63 (requirements for the design of steel bridges) are used. Since 2002, the European European standard for the traffic load. Each country is free to choose a main category (with a so-called National Application Document). In Netherlands is the heaviest category. The standard is based on load of the entire bridge deck by traffic, regardless of the current roadway layout. Recent measurements have shown that applying the heaviest category in accordance with the traffic in Netherlands. A direct translation of numbers and categories of vehicles to load of works of art may not be possible. This is a historical overview of the taxes not really occurred. In the current practice, the traffic volume on a large part of the main road network and is measured on a site the axle loads and weights of the six passing trucks measured. For these measurements distinguish the configurations are shown in Appendix a. the first measurements of road tax in the Netherlands date back to 1998. The picture that emerges from these measurements is that over 7% of the axle loads higher than 11.5 tons and a quarter of the trucks in the heaviest category of 50 tons and above. The values that are larger than what is generally allowed by law, be caused by overloaded vehicles or vehicles for which a waiver has been issued (special transports). Works of art designed with the European standard for traffic loads of 2002 are calculated.

Locations of the fatigue cracks

It is quite logical that the first cracks do occur where the loads of the heavy traffic are located. That means the right lane as one can see in figure 2. But also on other lanes fatigue cracks can occur.

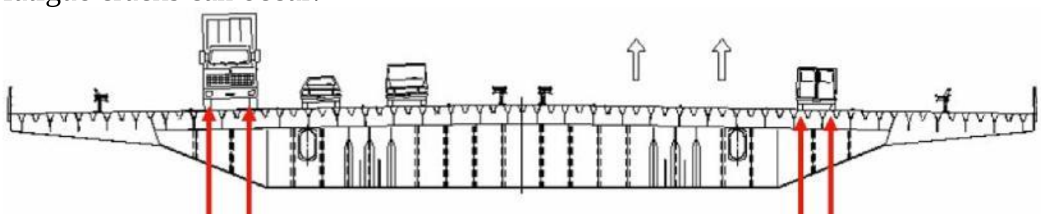

Figure 2 Fatigue cracks on locations of a typical layout of lanes on a steel bridge (Dooren, F. van)

Van Dooren distinguished the following four types of cracks (see Figure3a-d):

- type 1: connecting element in trough element;
- type 2: connection trough element to cross beam;
- type 3: connection trough element to deck plate;
- type 4: deck plate crack.

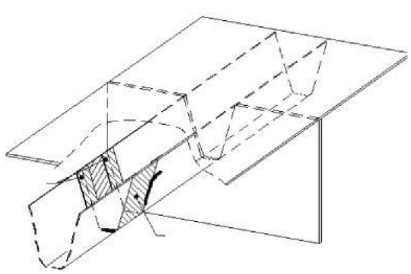

Figure 3a Type 1: connecting element in trough element (Dooren, F. van)

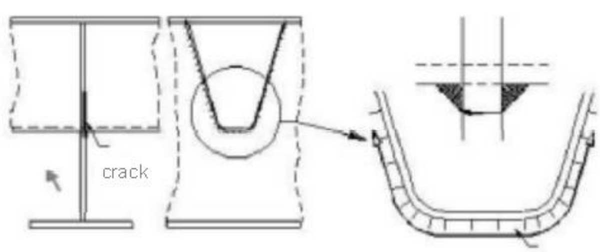

Figure 3b Type 2: Connection trough element to cross beam (Dooren, F. van)

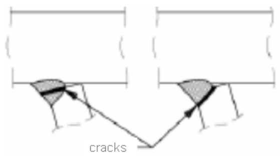

Figure 3c Type 3: connecting trough element to deck plate (Dooren, F. van)

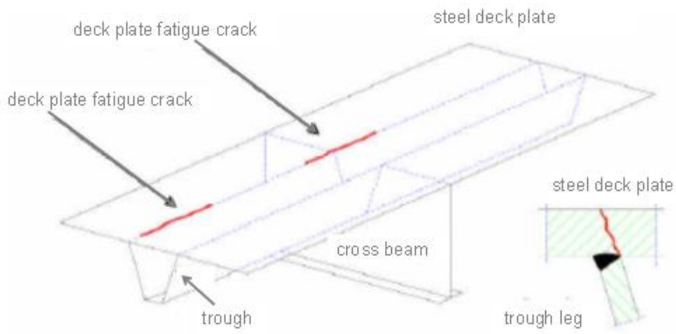

Figure 3d Type 4: Deck plate crack (Dooren, F. van)

The most critical fatigue cracks are located in the steel deck plate directly above the trough profile (figures 3c and 3d).

Options approach fatigue problems

Based on current insights there are generally only two solutions conceivable for the approach of the fatigue problem of steel bridges:

- to strengthen the steel deck with high strength concrete (HSC)
- replacement new construction.

The solutions are limited, because the extra weight on these bridges has to be as low as possible.

Principle of the overlay with HSC

Theoretical design

The main purpose of the overlay of HSC is to reduce the tensions in the deck plate in order to get the remaining life of the bridge (related to fatigue). The stress reduction in the deck plate is generally defined by the thickness of the concrete, the quality of the concrete and the extent to which the concrete and steel work together. The bonded overlay to the deck plate leads to a reduction of the tension in the steel deck plate.

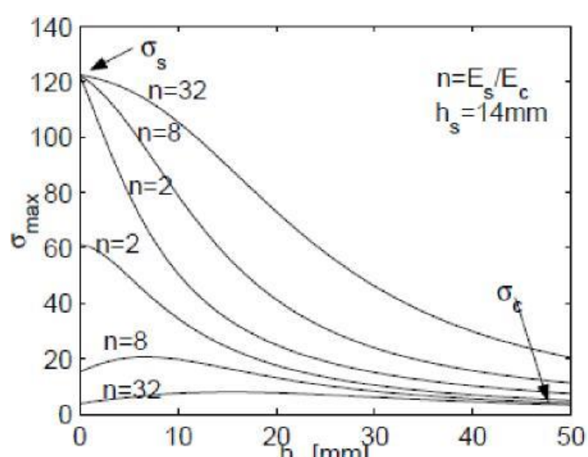

Figure 4 Relationship stress reduction in the deck plate and the thickness of the HSC (Walter, R.)

In figure 4 is the stress reduction for a 14 mm thick deck plate given as a function of the thickness of the overlay and the stiffness. It can be seen that there is a critical thickness for all overlays where applying a thicker overlay has little effect. At a realistic relative stiffness ($E_c \approx$ 26 GPa) one can see that up to 30 mm most stress reduction is achieved. A less rigid overlay ($E_c \approx$ 6.5 GPa) would only achieve this stress reduction at 50 mm.

The Caland bridge was the first bridge where a similar application is running. The results of tensile stress measurements on the Caland bridge are given in figure 5. It is shown that a reduction ($\Delta\sigma_s$) of 80% is observed.

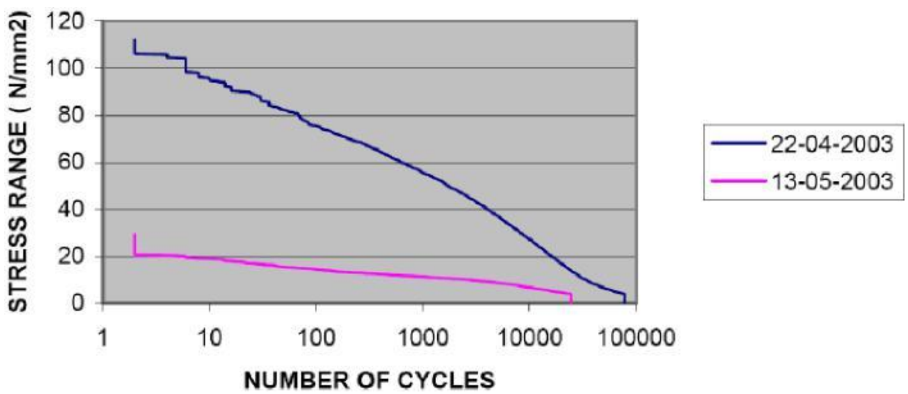

Figure 5 Number stress wings on the Caland bridge as a function of the stress ripple, as measured in the deck plate before the removal of the asphalt (22-04-2003) and after application of the HSB-overlay (13-05-2003) (Hageman, J.G.).

The main arguments for the chosen solution (HSB-overlay attached to the steel plate by an epoxy bauxite layer) are:

- Largest reduction in peak tensions;
- Relatively easy to apply;
- Disparities plate well;
- No stress concentrations in the connection between anchors and deck plate.

Design of "Galecopper"

The application on the Galecopper bridge consists of a HSC with a strength class of C90/105. The HSC mix design results in a thixotropic mixture, which means that behavior of the HSC without compaction energy it rather stiff. However under the influence of vibrations it is well workable. The compaction class of the concrete in accordance to the Standard NEN-EN 12350-4, measured at work, is typically between 1,04 and 1,13. The applied concrete composition of the HSC did meet the specifications of table 1.

The interlayer between the deck plate and the HSC overlay is, as mentioned before, an epoxy bauxite layer.

Properties	Requirement	Tolerance	Standard / Method
Compressive strenght	C 90/105	-	NEN-EN 206-1 / NEN 8005
Environment class	XF4 / XD3	-	NEN-EN 206-1 / NEN 8005
Compressive str. developement	250 MPa/24h	-	NEN 5970
E-modulus	50 GPa	± 10%	NT-Build 205
Bending strenght	10 MPa	± 25%	NEN EN 14651 / CUR-Aanbeveling 35
Autogenous shrinkage	< 0,3 ‰	-	Method TU-Delft
Total long term shrinkage	< 0,45 ‰	-	Method TU-Delft
Thermal expansion coefficient	$10*10^{-6}$/ºC	± 10%	CRD-C 39-81
Frost thaw resistance	< 10 g *	-	CEN/TS 12390-7 H7 CF/CDF
Density	< 2700 kg/m^3	-	NEN-EN 206-1 / NEN 8005
D_{RCM}	$2*10^{-12}$m2 /s	-	NT-Build 492
D_{max}	2/5 mm	-	NEN-EN 12620 / NEN 5905

* = Requirement now set at max. 100 g

Table 1 Specifications of HSC (Tender Documents)

The target value of the mean thickness of the HSC is 80 mm (Figure 6), with a maximum average value is 90 mm. The individual tolerances are down to 70 mm and up to 110 mm. The last value should be limited as much as possible because this leads to an extra load on the bridge construction.

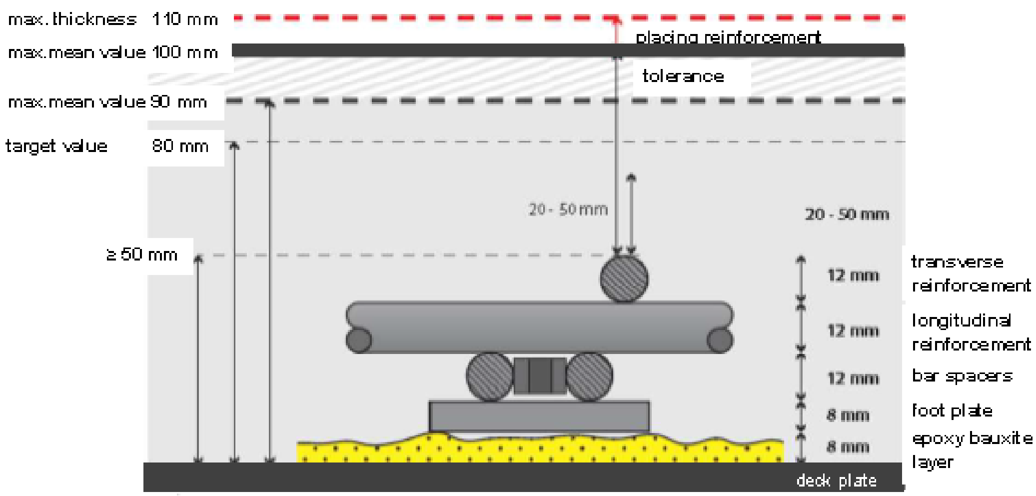

Figure 6 Chosen HSC overlay on the Galecopperbridge (Combinatie VWG)

Implementation of the HSC on the Galecopperbridge

Introduction

In general the implementation of the HSB on the Galecopperbridge consists of the following implementing parts:

- Removal of the asphalt layer;
- Cleaning of the steel bridge deck;
- Cracks repairs/inserts;
- All-weather supply (tent);

- Blasting of the bridgedeck (SA2);
- Placing of the edge profiles (f.i. Figure 7);
- Applying of an intermediate layer (between the steel deck and HSC-layer);
- Placing of the reinforcement;
- Application of the HSC;
- After treatment of the concrete layer.

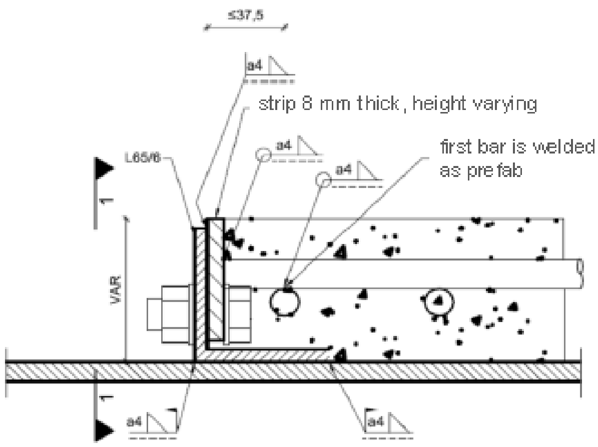

Figure 7 An example of the 3 different used edge profiles. (Combinatie VWG)

After the removal of the asphalt the bridge deck is cleaned by means of water jets and examined for cracking in the steel bridge deck plate by means of "TOFD". TOFD is a reliable nondestructive test method and stands for Time-of-Flight Diffraction. All cracks have been properly welded before the bridge deck good be released for the next step in the process.

Figure 8 Overview of the Galecopperbridge incl. the all-weather facility (Snowwhite commissioned by Ministry of Transport, Public Works and Water Management)

An all-weather facility is required in order to create conditioned circumstances, so the intermediate and concrete layer can take place without to be disturbed by the weather conditions. It was decided on this jobsite to place a tent over the complete working width for each phase of the bridge. The detected cracks are welded. Larger cracks are repaired by a deck plate repair (insertion). The works are carried out in 4 phases. The site width in phase 1 and 4 are 5.75m1 and 7.15 m1, and in phase 2 and 3 each time 7.05m1 and 7.15 m1 as one can see in figure 9.

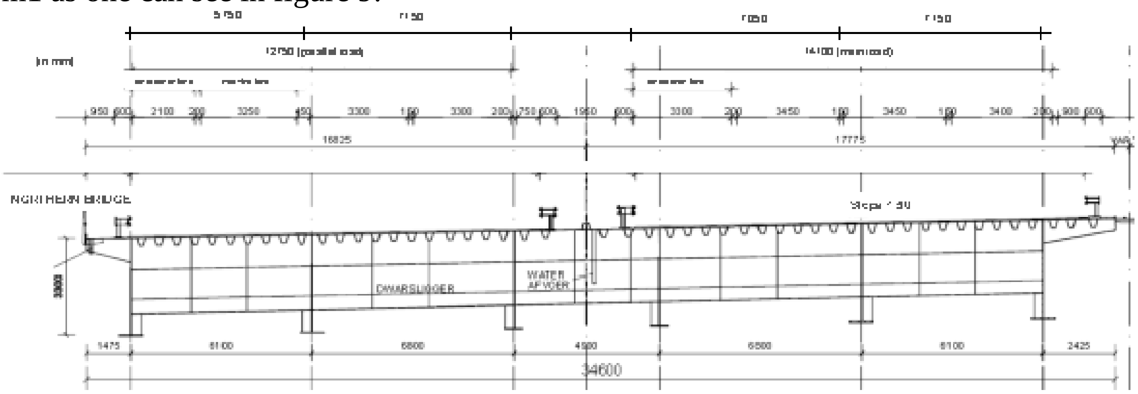

Figure 9 Overview of the layout of the HSC paved lanes of the northern bridge. The southern bridge is mirrored (Tender Documents).

After giving the deck be free the edge set profiles welded on deck. It collapses seam profile is glued to the deck. The cover plate is SA 2 blasted. The primer is placed within 4 hours after blasting. The epoxy adhesive layer is filled in with a bauxite granulate 3-6 mm. This is made for the benefit of the adhesion (bond) between this layer and HSB layer. After testing the tensile strength of the adhesive epoxy layer starts with the adjustable edge formwork. This edge formwork is adjustable to achieve a new longitudinal-alignment. This alignment is designed so that on average up to 85 mm concrete is allowed. This is a part of the maximum new construction weight. The minimum layer thickness is set at 70 mm. After this the reinforcement. The reinforcement consists of diameter 12 Space 75 mm Center to Center, both longitudinal and transversal.

Figure 10 Front of the slipformpaver and in the front the reinforcement and the special developed ultrasoon measurement system (Vissers, H.W.A.)

The spacers do include 2 combined bars of 12 mm. Every 2.5 m the spacers are glued on the bauxite. The intermediate supporters are laying on the deck without a any connection to the bauxite. The reinforcement is delivered as so-called roll-reinforcement. After checking the minimum height of the top transversal reinforcement to the deck (50 mm) and the cover to the top (at least 20 mm) the work is released to the HSB. For this inspection a special developed ultrasoon measurement system is used (fig.10).

The concrete composition has already been described and is rotated in a forced mixer in batches of 1.7 m3, due to the stiff mix and mixing time. During production of the HSC the concrete-plant is only running for the Galecopperbridge, concerning capacity, logistics and to pollution of other mixtures. The concrete transport is done with concrete mixers with a load of 5.1 m3 per transport. If doing so, the job site always get really fresh concrete. On arrival at work the mixture has been controlled for consistency and concrete temperature.

Figure 11 The electronic sensor for the driving direction of the slipformpaver (Vissers, H.W.A.).

The equipment used during the execution on this job site, is a Wirtgen SP slipformpaver 1600 and a curing and plastic sheet machine of Gomaco TM 600. The paver is specially modified for this work. This modification consists of a conveyor with distribution hopper. This leads to the concrete compaction room at the top of the trench. In this room the concrete is rotating/moving by means of an auger, so no demixing can take place. The compaction is achieved by horizontal high frequency vibrating pokers. The height and direction of the paver by means of 5 electronic sensors is retrieved in the automatic system of the paver, see figure 11. These sensors do follow the edge set profiles. As a result, the new alignment exact achieved with an excellent longitudinal and transversal evenness. The progress speed is approx. 0.5 m1/minute. The desired cross-section is formed by the slipform pan. The surface is slightly covered by spraying Compacta. Compacta make the finishing easier. Finally, a so-called super-smoother used to the last-surface treatment followed by some manual works. After finishing the concrete surface sprayed with a curing compound on paraffin – basic and then covered with a plastic sheet. During the paving process continuously before the slipformpaver once again the top cover of the reinforcement has been checked. This is done with the same ultrasoon measurement system as mentioned before.

To investigate whether the movement of the bridge deck affects the processing process of the HSC vibration monitoring systems are placed on the steel deck. If exceeds a certain value follows an automatic message to the implementation team. During application of reinforcement are also per deposit maturity sensors. Upon reaching a maturity of 1100 °Ch (degrees x hours) follows a release for work travel and at a maturity of 2200°Ch should be a start made for putting a surface wear layer. The concrete surface is for the adhesion to the epoxy bauxite surface first blasted. So one can be sure that the curing compound and the upper mm concrete removed.

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