Reinforced High Performance Concrete Overlay System for Rehabilitation and Strengthening of Orthotropic Steel bridge decks.

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Abstract

After serious damage of the bascule of the Van Brienenoord Bridge in one of the main highways in the Netherlands and its replacement a special Task Force was formed within the Civil Engineering Division of the Dutch Ministry of Transport, Public Works and Water Management. The aim was to investigate the cause, to understand and control the fatigue mechanism for the 80 steel fixed and movable bridges in the Netherlands and to develop practical solutions for cost effective rehabilitation and renovation. This project including the research is described in detail in papers presented earlier in different conferences and in this conference [Boersma P.D. and de Jong F.B.P. 2003, De Jong F.B.P. and Boersma P.D. 2003, De Jong F.B.P. *et al* 2004, M. H. Kolstein 2004]. A large research project including a pilot project in 2003 is executed during the last 6 years to develop a new revolutionary high strength concrete wearing course on orthotropic steel bridges which is also extending the service life of the total construction by solving fatigue problems in specific deck details. This is a very promising solution since it turns the deck plate in a much more rigid construction with a higher "plate factor" due the monolithic composite interaction between the RHPC (Reinforced High Performance Concrete) overlay and the steel deck plate. The RHPC overlay with a thickness of minimum 5 cm will result in a stress reduction with a factor of 4 – 5 in the deck plate and a factor 3 – 4 in the trough wall and thus extend the service life of the orthotropic bridge deck with some extra decades without additional maintenance. Project initiator is the Civil Engineering Division of the Dutch Ministry of Transport, Public

Works and Water Management in close co-operation with Contec ApS, inventor of the Ultra Thin Heavy Reinforced High Performance Concrete Overlay, the Delft University of Technology and TNO Building Materials. This paper will describe the development of the RHPC overlay, the properties of the RHPC overlay and the first application on an orthotropic bridge deck in the Netherlands.

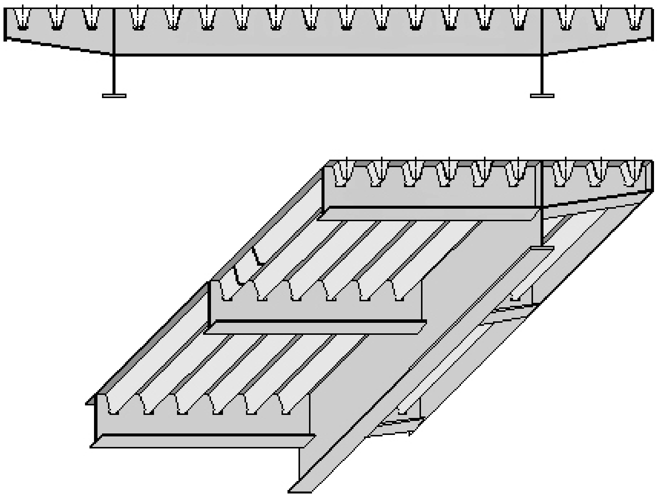


Figure 1: Typical orthotropic bridge deck in the Netherlands.

Introduction

During the last 26 years exciting new developments have been taking place in the development of cementitious materials. The compressive strength rose from circa 60 MPa to more than 300 MPa [Bache 1981, Buitelaar 1992, 1995].

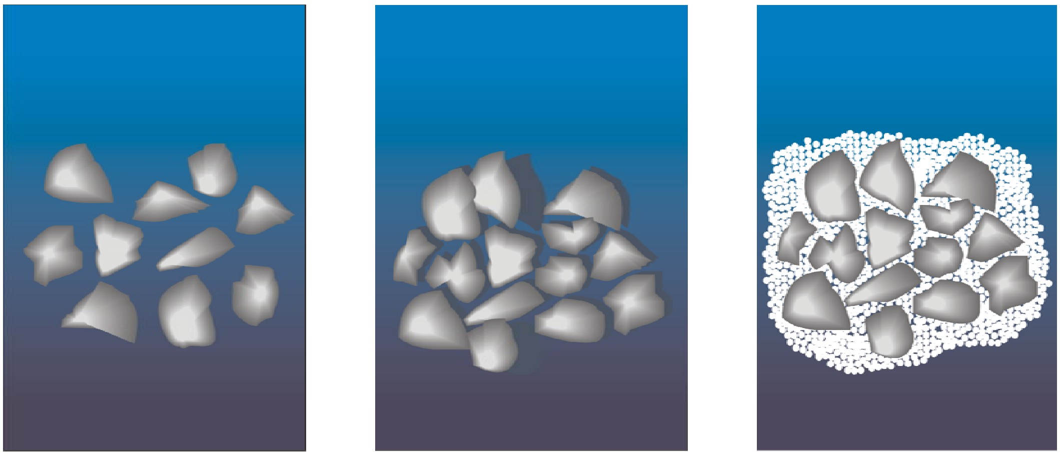


Figure 2: The structure of cementpaste in fresh concrete based on: A Portland cement; B Portland cement with a superplasticizer and C Portland cement with a superplasticizer and well dispersed micro silica and additives.

This is made possible by techniques for the densification of the microstructure of the fresh cement paste. The reduction of the porosity and/or a reduction in pore size and pore distribution in the cement matrix, will change different parameters of the hardened matrix and will thus result in a much higher strength, -durability, impermability and wear resistance. HPC (f_c 100 -155 MPa) and especially UHPC (Ultra High Performance Concrete, f_c 165 - > 400 MPa, cast and cured at 20°C) are used for special applications like in the security industry (ATM's, bank vaults and protective structures), wear protection (pipe bends, linings and equipment in pneumatic and hydraulic transport systems with abrasive materials), offshore (strengthening platforms, windmills, etc.), industrial floors (toppings, semi-flexible wearing course, heavy reinforced ultra thin overlay, etc.), concrete repair (shotcrete, handpatch) and prefab elements (stairs, balconies, panels, etc.). Much higher strengths (f_c > 600 MPa) are possible by a further densification of the cement matrix combined with an additional pressure and heat treatment during setting and hardening.

Heavy reinforced HPC and UHPC

A HPC and an UHPC are very strong materials and thus also very brittle materials. Therefore it is necessary to use in the matrix a large amount of aggregates and, if possible, reinforcement (fibers and rebars) to reduce the brittleness number. Very large amounts (v/v >20%) of main reinforcement (traditional rebars, high strength rebars, carbon rebars, wire, etc.) in combination with a HPC or an UHPC including a large amount (v/v 10%) of fibers are transforming the very brittle matrix in a very ductile composite [Bache 1986, Buitelaar 2004]. This composite or hybride material is known under the acronym CRC (Compact Reinforced Composite).

Photo 1: HRUHPC.

Photo 2: Placing 45 mm thick panels on a bascule bridge.

The CRC principle makes it possible to predict the behaviour of small, medium and large sized constructions under different loadings very accurate, especially when scaling up from small models are used for modelling the actual construction. This makes it thus also possible to deal with high local stresses in constructions, accidental overloading and impact resistancy on any level. The HRUHPC (Heavy

Reinforced Ultra High Performance Concrete) seems to have extremely good fatigue resistance even under continuous high loads. Various research projects and applications are executed during especially the last 5 years for different applications of HRUHPC [Kaptijn 2004].

Table 1: Properties of HPC, UHPC, HRUHPC and ductile high quality steel [Bache 1992]

Properties	**HPC**	**UHPC** **0 - 2% fibers**	**4 – 12% fibers**	**HRUHPC**	**High quality steel**
Compressive strength MPa	80	120 – 270	160 - 400	160 - 400	
Tensile strength MPa	5	6 - 15	10 - 30	100 - 300	500
Flexural strength MPa				100 - 400	600
Shear strength MPa				15 - 150	
Density kg/m^3	2.500	2.500 2.800	2.600 3.200	3.000 4.000	7.800
E-modules GPa	50	60 - 100	60 - 100	60 - 100	210
Fracture energy N/m	150	150 – 1.500	4.000 – 5.000	$2 \cdot 10^5$ – $4 \cdot 10^6$	$2 \cdot 10^5$
Strength/ weight ratio m^2/s^2				$3 \cdot 10^4$-10^5	$7.7 \cdot 10^4$
Stiffness/ weight ratio m^2/s^2				$2 \cdot 10^7$-$3 \cdot 10^7$	$2.7 \cdot 10^7$
Frost resistance	Moderate/ good	Excellent	Excellent	Excellent	
Corrosion resistance	Moderate/ good	Excellent even with 5-10mm cover	Excellent even with 5-10mm cover	Excellent even with 5-10mm cover	Poor

The ultra thin heavy reinforced high performance concrete overlay

One of the first large applications of the RHPC overlay is as a white topping on damaged pavements and industrial floors and in cargo ships [Buitelaar 1999, 2002]. The unique properties of the RHPC makes it possible to place the overlay as an "independent" topping (industrial floors) or wearing course (ultra thin white topping) on a cracked and/ or polluted sub base or even on an under dimensioned sub base made from different materials like asphalt concrete, concrete, wood, ceramics or steel. The concrete overlay contains one or more layers of welded mesh reinforcement (bar diameter 6 – 20 mm and bar spacing 15 – 50 mm). The concrete mixture contains both steel fibers and acrylic fibers and is based on a special composite of pre-blended materials. The HPC can be mixed at the building site or in a batching plant and can be transported with dumpers or truck mixers. The flow and workability are such that the material is easy to compact with the use of a laser screed or a double vibration screed. Research is done to investigate whether traditional asphalt pavers, traditional concrete slipform pavers and other specialized concrete placing equipment as used for large concrete pavements can be used to resurface large areas within a certain time limit. Immediately after compacting it is possible to float the overlay with a mechanical finishing machine with a closed disc (power float).

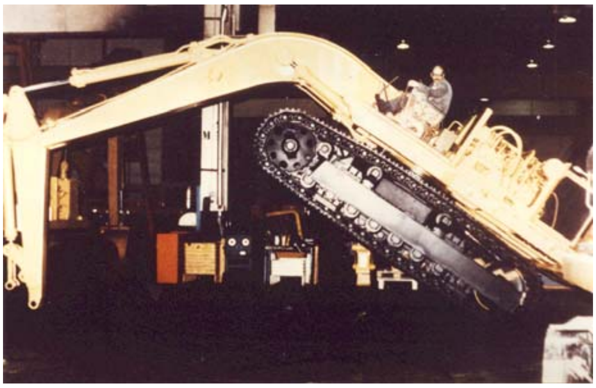


Photo 3: UHPC topping in the heavy industry.

Photo 4: RHPC topping in the food industry.

The standard setting time of the mixture is more or less equal of that of a traditional concrete mixture and depends on temperature and relative humidity. A shorter setting time is possible by using special accelerators. During several hours after casting the surface is finished with mechanical finishing machines. Afterwards, the overlay must be protected against further evaporation of the mixing water. After curing for approx. 24 hours (at 20°C), the very high quality overlay is ready for use. Due to the large amount of welded mesh reinforcement and steel fibers, the hardened HPC overlay is able to withstand a certain amount of restrained deformations from the base without the occurrence of surface cracks.

The RHPC overlay for orthotropic steel decks

The RHPC overlay is a combination of a HPC strength class C110 (based on special pre-blended materials and reinforced with both steel fibers and acrylic fibers) and welded mesh reinforcement (consisting of two specially produced mats Ø 8 mm # 50 x 100 mm positioned on top of each other such that a total of three layers of Ø 8 mm rebars spaced at 50 mm is obtained) [Buitelaar, 2002]. The mesh reinforcement is placed on a Ø 8 mm rebar used as a spacer. Thus, the total amount of reinforcement is approx. 24 kg/m^2 traditional reinforcement and approx. 5 kg/m^2 steel fibers. The total thickness of the RHPC overlay is in this specific case 50 mm. The concrete cover on the reinforcement is thus only 18 mm. If the thickness of the layer should be increased, the reinforcement can be adjusted if necessary. To replace the existing wearing course with a RHPC overlay, the bonding between the steel deck plate (thickness 10 - 12 mm) and the overlay is of crucial importance to secure total deck rigidity and a uniform "monolithic" behaviour under all circumstances. For that

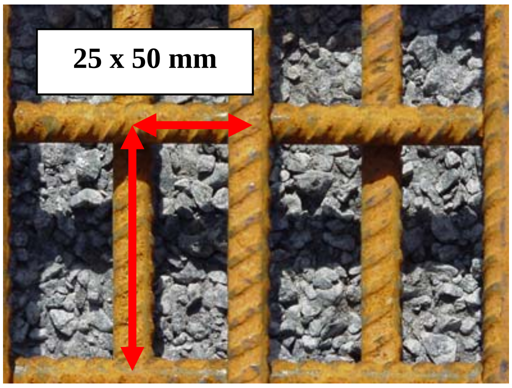


Photo 5: Reinforcement principle.

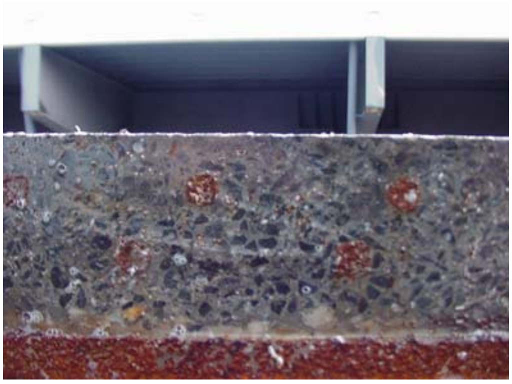


Photo 6: RHPC overlay on deck plate.

reason the first investigations were focused on creating a bonding zone that met all requirements. A bonding zone can easily be created by connecting the mesh reinforcement and the steel deck plate by welds, but this might result in undesirable local peak stresses. Therefore research was carried out to find the optimal bonding agent. The best method turned out to be the use of a two-component epoxy based adhesive with sprinkled-in bauxite aggregates. After hardening of the epoxy, the overlay is cast. The surface will be shot blasted. No additional wearing course will be applied.

Research programs

Before it is possible to make a design for a rehabilitation of such an important infrastructural structure like a highway bridge, it is necessary to know the material properties to be able to check and/or to develop calculation methods. Furthermore it is important to have information about the durability of the material and the behaviour under traffic loads to be able to predict the total extension of service life. Beside research on relatively small samples it was also necessary to perform tests on full-scale structural elements under different loading conditions. In several sub projects and at different institutes (Civil Engineering Division, Contec ApS, Delft University of Technology and TNO Building and Construction Research) these properties were investigated and documented [Braam *et al.* 2003-2004, Braam, C.R., Kaptijn, N., Buitelaar, P., 2003 and Buitelaar, P., Kaptijn, N., Braam, C.R., 2004].

This research is far from finished, at this moment and also for the next years various tests are executed and planned to obtain much more information about the qualities and the effect of the RHPC overlay placed on orthotropic bridge decks. The behaviour of the orthotropic bridge deck with the bonded RHPC overlay is completely different from a traditional surfaced orthotropic bridge deck due to the much higher stiffness and therefore more investigation will be necessary including detailed FEM calculations.

Table 2: Different research made with the RHPC for orthotropic bridge decks

Description test - research	**Test made by parties involved**	**Period of testing - research**
Adhesion tests on small Samples	Adhesion Institute Delft University of Technology Contec ApS	November 1999 – May 2000
Fatigue tests on small Samples	Adhesion Institute Delft University of Technology Contec ApS	November 1999 – May 2000
Placing 60 m^2 RHPC overlay on removed bascule	Civil Engineering Division Contec ApS	October 2000
Placing 20 m^2 RHPC overlay on removed bascule	Civil Engineering Division Contec ApS	July 2001
Removeability RHPC Overlay	Civil Engineering Division Contec ApS	August 2001
Skid resistance RHPC overlay after shotblasting	DWW	August 2001
Compressive strength and modules of elasticity HPC	Stevin Lab. Delft University of Technology	April – May 2002
Flexural strength HPC	Stevin Lab. Delft University of Technology	May – June 2002
Short term shrinkage and creep HPC and RHPC	Stevin Lab. Delft University of Technology	April – May 2002
Long term shrinkage HPC and RHPC	Stevin Lab. Delft University of Technology	August – September 2002
Effect curing and power floating RHPC	Stevin Lab. Delft University of Technology	August – September 2002
Adhession HPC on steel	Stevin Lab. Delft University of Technology	August – September 2002

Frost/ thaw resistance HPC CDF method	Stevin Lab. Delft University of Technology	November – December 2002
Adhesion RHPC overlay on steel (-20°C - +20°C)	Stevin Lab. Delft University of Technology	November – December 2002
Chloride penetration Nordtest	Stevin Lab. Delft University of Technology	April 2002 – April 2004
Fatigue test RHPC overlay on part orthotropic bridge deck	TNO Building and Construction Research	June – July 2002
FEM calculations RHPC overlay on orthotropic bridge deck	Civil Engineering Division	May – April 2002
Extension of service life calculations on various orthotropic bridge decks	Civil Engineering Division	May – April 2002
Pilot project Caland bridge approx. 540 m^2	Civil Engineering Division Contec ApS Bruil-Ede B.V.	30 April – 3 May 2003
Stress reduction on Caland bridge after RHPC overlay	Civil Engineering Division	22 April 2003 (before placing) – 13 May 2003
Influence traffic on adhesion RHPC overlay on 2 orthotropic steel bridge decks	Civil Engineering Division Stevin Lab. Delft University of Technology	April – May 2004
Stress reduction RHPC overlay on part orthotropic bridge deck with un-repaired fatigue cracks	Civil Engineering Division Stevin Lab. Delft University of Technology	May - September 2004
FEM calculations RHPC overlay on different details orthotropic bridge deck	Civil Engineering Division	April – May 2004

Placing 300 m^2 RHPC overlay with asphalt paver	Contec ApS Kirchhoff-Heine Strassenbau GmbH & Co. KG	May 2004
Placing 250 m^2 RHPC overlay with slipform paver.	Civil Engineering Division Contec ApS Bruil-Ede B.V.	October 2004

Properties of the RHPC Overlay

The different research made for the rehabilitation of orthotropic steel bridge decks resulted in a large amount of information, some of the most important are described hereafter.

Static and fatigue loads on small samples
The first tests were performed at the Adhesion Institute of the Delft University of Technology. Four types of samples were tested:

- prefab panels glued in-situ on the steel deck using a two-component epoxy paste adhesive;
- casting the mortar on a wet two-component epoxy paste adhesive;
- casting the mortar on a hardened two-component epoxy paste adhesive provided with granite using both reinforced and non-reinforced samples.

Tests were done as follows: 10^6 cycles with wheel load from 35 kN (contact pressure 2.2 MPa), followed by 10^6 cycles at both 4 MPa, 7 MPa and 8 MPa. It was concluded that no damage due to fatigue had occurred after the $2{\cdot}10^6$ “normal” wheel loads and the additional overloads. When compared with the results from non-reinforced samples, the welded mesh reinforcement resulted in additional strength and coherence of the HPC matrix. This rehabilitation method was regarded as being the most practical one when compared with the other methods tested.

Large scale testing
After the first tests a 60 m^2 overlay was placed in October 1999 on a part from the old bascule from the Van Brienenoord Bridge. The area was divided in two sections: one with an epoxy adhesive which was sprinkled with 1 – 3 mm aggregates (silica) and one section immediately placed on the steel deck by using welds to fixate the welded mesh reinforcement. Placing went very well and neither cracks nor micro cracks where observed during the first months. The bond strength at the location where the relatively smooth and weak aggregates were used was 3 MPa. Fracture occurred in the aggregates. After cutting out larger samples poor compaction at the interface was observed. This was probably due to poor action of the hammers from the vibration screed. A second test area of 12 m^2 was placed in July 2001

(conditions: high temperature, high wind speed and direct sun radiation. The aggregates sprinkled in the bonding zone were now Hyperit (a very dense and hard Norwegian granite) 2 – 4 mm. An air powered high frequency vibration screed was used this time to compact the RHPC.

Photo 7: Placing HPC testarea.

Photo 8: Finishing surface RHPC overlay.

Despite the weather conditions, it was still possible to float the mortar for several hours to obtain a very dense, hard and shiny surface. Several drill cores were taken out later and they all showed a good compaction around the dense reinforcement and their overlaps.

A part of the surface from the first test area was shot blasted to test the skid resistance according to the Dutch Standard: The skid resistance was very good: 71 SRT units compared with 55 SRT units for an open graded asphalt concrete wearing course and 65 SRT units for a dense asphalt concrete wearing course surface. Also a test was made to investigate the possibilities to remove a part of the RHPC overlay. By using the right equipment it was possible to cut through the RHPC overlay and to break out large plates without damaging the steel deck.

Compressive strength
The compressive strength of the HPC including the steel fibers was measured on 100 mm cubes and 100x100x400 mm^3 prisms. The 28-day cube compressive strength was 117 MPa. This was 84 MPa for the prisms. The prism tests were also used to determine the modulus of elasticity: 47.2 GPa at 28 days. The development of the cube compressive strength was 0.44 (1 day), 0.59 (2 days), 0.68 (3 days) and 0.79 (7 days) when related to the 28-day strength. At all ages, prism compressive strength was about 0.68 times the cube compressive strength. Much higher strengths, up to 180 MPa, are possible by replacing the aggregates with calcinated bauxite.

Bending tensile strength
Small beams with a height h of 50, 100 and 150 mm were loaded in three-point bending (500 mm span). Also in this case, only the steel fibers were added to the mix. The bending tensile strength was 9.8 MPa, 11.9 MPa and 9.6 MPa for, respectively, h = 50 mm, 100 mm and 150 mm. These results indicate that, in this

range of element depth, the bending tensile strength is not size-dependent. Much higher strengths are possible by replacing the aggregates with calcinated bauxite.

Time-dependent behaviour of hardening concrete
The early-age deformation of the mixture was investigated using an autogenous deformation testing machine (ADTM) (Koenders, 1997). Both reinforced and non-reinforced specimens were cast in a temperature-controlled steel mould. The temperature of the hardening specimen was kept constant at 20ºC. The specimens were covered such that there was no water or air exchange with the environment. The relatively high amount of reinforcing steel reduces the deformations by about 40%.

Time-dependent behaviour (shrinkage) of hardened concrete
Six prisms (dimensions 100x100x400 mm^3; no steel bar reinforcement) were de-moulded after one day and sealed to prevent drying. Then, shrinkage measurements started. Because of the sealing, only autogenous shrinkage was measured. The specimens were stored at 20ºC and 50% RH until an age of 28 days was reached. Then, the sealing was removed from three of the prisms; the other three prisms were kept sealed. The three unsealed specimens now also started to develop drying shrinkage. Measurements continued until an age of 91 days was reached. After t = 61 days, the deformation of the sealed prisms remained almost unchanged. The unsealed specimens (i.e. the prisms also subjected to drying shrinkage) demonstrated even after t = 97 days a considerable increase of the deformation.

In practice drying shrinkage will be less and develop slower: drying is prevented at the contact surface with the steel bridge deck and the relative humidity will be higher (75-80%). The surface will also often be wetted by rain. The monitoring of strips (a steel deck plate with a RHPC layer) in a ‘natural’ environment (rain, sun and wind) confirmed this. More tests will also involve shrinkage free HPC.

Adhesion capacity concrete – steel deck plate
The adhesion was measured on 77 mm diameter steel discs provided with an epoxy layer and a HPC layer. Two types of aggregates sprinkled in the epoxy were used: Norwegian granite and bauxite. The specimens were load displacement controlled in pure tension. Average bonding strength was 2.96 MPa (s.d. 0.29 MPa) for the specimens with granite. This was 4.81 MPa (s.d. 0.45 MPa) for the specimens with bauxite. Also adhesion tests were measured by bending tests of steel deck plates with an sprinkled in epoxy layer and a HPC overlay of 50 mm, in this case the average bonding strength was 11,2 MPa with the Norwegian granite and 12,5 MPa with the bauxite.

Frost/thaw resistance in combination with de-icing chemicals
One side face of cubes, age 28 days, was exposed to a 3% (m/m) NaCl-solution and subsequently subjected to 12 hour cycles during which the temperature of a water bath varied from –20ºC to +20ºC (RILEM, 1996). After 14 cycles a weight loss of 0.9-8.4 g/m^2 was found (average 3.6 g/m^2). The loss is small when compared with

ordinary Portland cement mixtures, for which a loss of several kg per m^2 is found (Visser, 2002).

Chloride ion penetration
Cubes were placed in a NaCl solution (165 g/l). After core-drilling, slices were sawn and tested according to a standardized procedure (Nordtest, 1995). After 1, 6, 12 and 24 months of exposure, chemical analyses demonstrated that when the amount of natural available chloride was taken in account no chloride penetration could be detected.

Fatigue and load distribution on a large sample
A large sample was sawn and burned from the second test area including the orthotropic steel deck, stiffeners and a crossbeam to be tested at TNO. The mesh presented in figure 3 is almost identical to this sample. Fatigue tests were performed with simulated actual traffic loads.

A wheel load of 105 kN was applied $4.2{\cdot}10^6$ times, thus simulating 25 years of actual use. Since neither fatigue failure nor cracks were observed, the load was increased to 136.5 kN ($1.4{\cdot}10^6$ cycles), followed by the same number of cycles at both 168 kN and 210 kN. Afterwards, a static load of 400 kN was applied.

Photo 9: Testing in TNO.

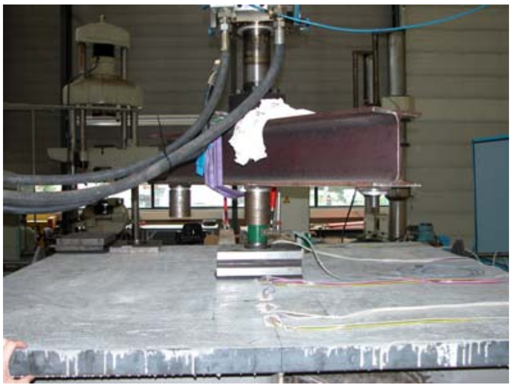
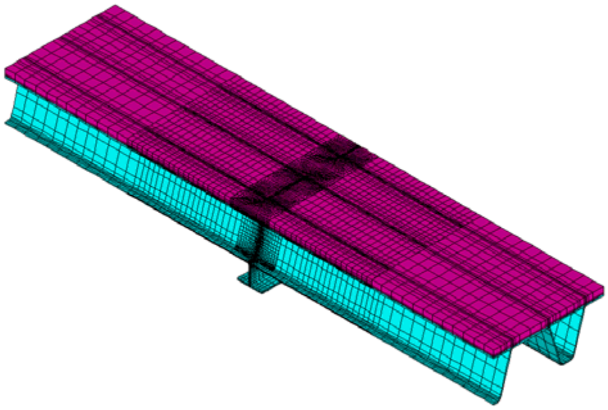


Photo 10: Testing RUHPC overlay on deckplate with fatigue cracks in TU Delft.

The total wheel loads where thus simulating 75 years of the actual traffic load spectrum on the Moerdijk Bridge. Still neither damage, de-bonding nor micro-cracking of neither the RHPC overlay nor the deck plate occurred. According to FE-calculations, a large crack with a width of 8 mm should be visible in the steel deck plate at that time.

Finite Element research
For several years the Ministry of Transport is investigating the various structural components, the connections and their effects on stresses by means of finite element calculations. In order to get a good understanding of peak stresses that develop due to traffic loads, very fine meshes were used (Pover, 2002).



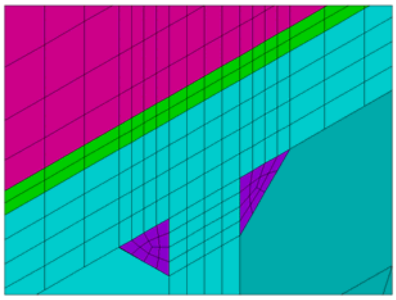


Figure 3: FEM calculations part bridge deck. Figure 4: Detailed mesh.

In the areas where peak stresses develop, mesh refinement was used (near trough stiffener/ deck plate connection, in and near transverse girders). To obtain a realistic stress pattern, brick elements were used; 4 layers over the thickness of the steel plates. Even the welds were modeled with brick elements (figure 4). This gave the structural engineers a good tool to study the influence of various (steel) design improvements. Also alternatives for overall stress reducing measures were computed with the model: a 50 mm RHPC layer, steel plates glued on top of the deck plates and filling the trough stiffeners with cork filled Polyurethane. The concrete layer gave the largest stress reduction in the steel deck plates. The reductions for the maximum stresses in the deck plate in the trough stiffener/ deck plate connection ranged from 4.4 – 21.0 (Table 3), depending on the location considered.

Table 3: In-plane stresses and stress reduction factors for various stress reducing alternatives; max/ min stresses in the deck plate near the trough stiffeners.

	Standard steel design	RHPC overlay	Glued steel plates	PU filled trough stiffeners
	Top deck plate			
Sx (MPa)	121	6	28	36
Sz (MPa)	63	14	27	33
	Bottom deck plate			
Sx (MPa)	-124	-27	-59	-66
Sz (MPa)	-43	-7	-19	-19
	Stress reduction			
For Sx/Sz top	1 / 1	21 / 4.4	4.4 / 2.3	1.9 / 1.5
For Sx/Sz bottom	1 / 1	4.7 / 5.8	2.1 / 2.2	1.3 / 1.4

Pilot project Calandbrug

All the tests proved that the intended application of a RHPC overlay is a very promising solution to rehabilitate orthotropic steel bridge decks to elongate the service life of the total construction. Both durability and strength of the RHPC overlay are adequate.

In the period from 29 April until 4 May 2003 a pilot project on the Caland Bridge was executed to test the logistics on an actual small sized project before other more complex and much larger projects will be executed. The area concerning the pilot project was two traffic lanes with a width of 6.7 meter and a length over 80 meters in

Photo 11: Caland bridge in the Netherlands.

Photo 12: Placing tent.

one traffic direction. In this period the whole project had to be executed including rerouting the traffic, removal of the asphalt wearing course, inspection and repair of the deck plate and the application, hardening, curing and shot blasting of the RHPC overlay. Due a selection procedure four contractors were invited to make a quotation for the whole project, after this one contractor was selected. Before that the selected contractor had to make a trial area and a detailed project description and quality plan. In a very strict time schedule of only a few days the whole job had to be executed, every delay in one of the disciplines would have resulted in a delay of the other disciplines and therefore a team of skilled site managers and engineers where on site during the whole job. After the removal of the asphalt wearing course a tent was placed to protect the whole area against influences from the weather. Here after TOFD (Time Of Flight Diffraction) inspections were made to investigate if there were critical cracks in the deck plate to be repaired. This is a very reliable but time demanding technique and what must be done on a blank steel deck. Several times shot blasting was here fore necessary and made it difficult for other disciplines to start with their work.

When the inspection was finished at the edges pre-fabricated steel L-profiles with welded on dowels were placed (to avoid peak stresses in the deck plate) in a two-component epoxy paste adhesive with fillers. These L-profiles were necessary to avoid the bending (curling) of the RHPC due to traffic loads, shrinkage, temperature loading or local debonding. When TOFD inspection and some repairs and replacement of earlier emergency repairs were finished the whole deck plate had to be shot blasted again to remove the corrosion film. The two - component epoxy paste adhesive was placed on the deck plate and calcinated bauxite 3 -6 mm was sprinkled-in. Due to the very low temperature and the fact that no fillers were used in the two-

Photo 13: Placing the interface layer.

Photo 14: Reinforcement principle.

component epoxy paste adhesive there was an un-even distribution of the layer thickness of the two- component epoxy paste adhesive and thus also of the calcinated bauxite. Despite detailed information the welded mesh reinforcement was not placed well and instead of welded connections between the rebars a steel wire was used to connect the rebars. This resulted in a upwards bending of the reinforcement in the middle of the two traffic lanes due to the building traffic and this couldn't be compensated later. Decided was, mainly due to the strict time schedule, to leave this and to compensate the higher middle part with a slope in the RHPC. Therefore it was necessary to apply an additional 20 – 30 mm of the HPC in the middle, thus the thickness of the concrete cover at some locations was approx. 40 – 50 mm instead of the maximum allowed 20 mm.

Photo 15: Casting HPC.

Photo 16: In use again.

A mobile concrete batching plant which was placed close to the building site was used to mix the pre-blended and weighed materials. Concrete mixing trucks and wheel shovels where used to transport the material as close as possible to the double vibration screed where a small crane was used to spread the HPC. An accelerator was added to speed up the reaction of the HPC and thus making both the finishing - and the shot blasting procedure earlier possible. The HPC surface was floated with single power floats almost directly after compacting the mortar, a few hours later power trowels were used to obtain a smooth, dense and shiny surface. Hereafter the whole surface was covered with burlap sheets and wetted with water. A compressive strength of minimum 30 MPa was reached in less than 24 hours after casting, the burlap sheets were removed and the surface was shot blasted to obtain the required skid resistance of at least 64 SRT. Immediately after the shot blasting procedure details like the joints with the adjacent lanes were finished, special trucks were used to remove the tent and the barriers were placed and connected. A special perforated water hose system was placed under the barrier to cure the HPC overlay during a period of 7 days independently and without disturbing the traffic streams. The whole execution of the pilot project from the first step until re-use of the new wearing course took less than 120 hours!

Conclusions

Fatigue cracks are a large problem for orthotropic steel bridge decks, especially cracks in the steel deck plate are of great concern due to their effect on traffic safety. Much is learned from the pilot project and this experience and know-how will be very useful for larger projects which will be executed in the following years. Strain measurements on the re-surfaced Caland Bridge show a stress reduction with a factor 4 - 5 in the fatigue critical structural details. This equals the reduction factor measured on the small test samples in the Adhesion Institute of the Delft University of Technology and the computer simulations. Further investigations (De Jong, F.B.P. 2004) on a part of an orthotropic steel deck plate with fatigue cracks and a RHPC overlay show also a significant stress reduction in the trough wall (stiffeners). It could be thus be possible to leave certain fatigue cracks un-repaired when the RHPC overlay will be placed what will result in a shorter shutdown time and additional savings on repair costs. The pilot project demonstrated that it is also practically possible to place the RHPC overlay on a orthotropic steel bridge deck even when traffic, including heavy loaded freight trains, are allowed to use a part of the bridge deck. Much more detailed specifications can now be made to based on information obtained during the execution and evaluation of the pilot project.

The problems with the reinforcement resulted at several places in a thicker and un-reinforced cover (40 – 50 mm) on the reinforcement near the dividing line of the two traffic lanes of the bridge deck. Very fine transversal cracks (at the surface 0.05 – 0.1 mm), concentrated in the thicker applied middle part, are visible each 30 – 100 cm, maximum crack dept is the thickness of the concrete cover. There is no shrinkage visible along the steel profiles at the edges in the longitudinal direction. Modelling and more investigation will be made but possible reason is a combination of the following: thicker concrete cover, less reinforcement in the longitudinal direction (only 50% compared to the transversal direction), partially restrained shrinkage in longitudinal direction (by deck plate and troughs), insufficient curing during the first 7 days, movements and stresses due to traffic in the orthotropic steel deck plate and the complete different behaviour of the resurfaced deck compared to both a traditional surfaced steel deck or the RHPC overlay. Small cracks are in principal accepted and will not have influence on the durability of the RHPC overlay but crack distance, crack width and crack depth must be minimized. Therefore more investigation will be made to increase the tensile strength of the HPC with the use of stronger aggregates and blends of different fibers and to detail the reinforcement much more efficient. Stresses during the setting and hardening of the RHPC overlay must be reduced as much as possible by using adequate curing starting directly after the compaction of the HPC. The use of special internal working curing compounds mixed with the pre-blended materials will be more investigated. More investigation and research will be made in the possibilities for the placement of the HPC with traditional slipform pavers to be able to resurface large area's with in a certain time limit. Much confidence is vested in the HRHPC overlay as an wearing course on orthotropic steel bridge decks to reduce fatigue problems in the deck plate and specific deck details.

Preparations are started for the restrengthening of large orthotropic steel bridge decks. The planning is to resurface the Moerdijk bridges (32,000 m^2) and the Hagestein bridge (7,500 m^2) in the summer of 2005. Other orthotropic steel bridge decks will follow soon after. Fatigue problems in with orthotropic steel bridge decks are not an unique problem for the Netherlands alone, several similar problems are known in other countries and therefore a lot of international attention and interest have been received for the RHPC overlay as a rehabilitation and restrengthening method.

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