Heavy Reinforced Ultra Thin White Topping of High Performance Concrete for Re-strengthening and Rehabilitation of Structures and Pavements

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ABSTRACT:
During the last 15 years new applications are developed for a so-called heavily reinforced ultra thin white topping (HRUTWT) of high performance concrete to re-strengthen, rehabilitate and/or repair structures like orthotropic steel bridge decks, concrete viaducts and industrial floors and pavements. This paper describes various applications in the Netherlands during the last decade with focus on the rehabilitation and re-strengthening of industrial floors, orthotropic bridge decks and viaducts.
Keywords: high performance concrete, ultra high performance concrete, compact reinforced composite, rehabilitation, re-strengthening, orthotropic steel bridge decks, bridges, viaducts, pavements, industrial floors

1. INTRODUCTION

Compact Reinforced Concrete (CRC) has been developed by Hans Henrik Bache [1-3] and co-workers in 1986 to cope with the extreme brittleness of so-called Densified Systems containing homogeneously arranged ultra fine Particles (DSP) materials as originally developed in 1978 [4,5]. This CRC concept, used mainly in combination with (Ultra) High Performance Concrete ((U)HPC), is only used for the security industry (e.g. vaults, safes), the military industry (panels to protect people and valuables) and the prefab industry (balconies, stairs, panels, bridges, etc.). For on-site applications in civil engineering, like for instance industrial floors, industrial pavements and white toppings, the original system has several disadvantages, mostly related to the very low water/binder ratio, like workability, finishability and autogenous shrinkage. By adjusting the (U)HPC mixture, a new system has been developed and marketed under the name Contec Ferroplan System by Contec ApS, using the principles as originally developed by Bache. The mixture was widely applied over the last 15 years.

2. HEAVILY REINFORCED HPC

2.1. Compact Reinforced Composite

CRC is a very strong and stiff composite material with exceptionally high ductility. CRC is build up of densely arranged main steel bar reinforcement embedded in a strong, rigid and ductile UHPC matrix. The three basic principles of CRC are:

1. Provide the brittle matrix materials (HPC/UHPC) with a high strain capacity and fracture energy under tensile loading. This is achieved by reinforcing the matrix with a high volume of small and strong steel fibers.
2. To further increase the tensile strain capacity of the material provide it with steel bar reinforcement, acting as a stiff frame to ensure the formation of a multiple crack system with very high tensile strain capacity.
3. Provide dense and homogeneous particle and fiber packing at both the micro and macro level by effective use of geometrical and kinematical principles; the UHPC should exhibit viscous behavior during the whole process (mixing, transport, casting and compaction), even when provided with very dense main reinforcement, assisted by well designed mechanical vibration.

CRC consists of the following materials:

- HPC/UHPC with aggregates having a diameter up to 1/3 of the space between the main reinforcement rebars.
- Water and binder at an extremely low water/binder ratio (UHPC: 0.13 – 0.18).
- 5 – 20% main bar reinforcement (high strength steel, traditional reinforcement, carbon rebars, etc.).
- 5 – 10% steel fibers.

The properties of the CRCs constructed are as follows:

- compressive strength: 150 – 400 MPa;
- bending strength: 100 – 350 MPa;
- shear strength: 15 – 150 MPa.

It is noted that CRC is in fact a reinforced concrete, but deviates fundamentally from it in several ways. This is reflected in a load capacity that is more like that of structural steel. The design principles, the composition and production are also differing from those of traditionally reinforced concrete.

2.2. Heavily Reinforced HPC

The heavily reinforced HPC is based on the same principles as CRC, but is adjusted such that workability, finishability, set time and autogenous and total shrinkage are more like a traditional concrete than a (U)HPC. This is obtained by:

- reduced volume of binder;
- increased volume of aggregates;
- increased water/binder ratio (typical 0.28 – 0.32).
- the use of special additives.

The HRUTWT is especially developed to meet all the technical standards and practical requirements for industrial floors and white toppings placed with standard equipment and by traditional labour. It was originally developed to be used when a traditional topping or overlay cannot be placed and/or used, e.g. in case of not sound or cracked concrete, sub-bases from diverged materials, weak foundations or heavy mechanical, chemical and/or thermal loads. Particularly in these cases the combination of a (U)HPC combined with steel bar reinforcement can produce a strong and ductile "floating" overlay. The HRUTWT consists of a special pre-blended micro silica containing high performance binder, acrylic fibers, steel fibers and one or more layers of welded mesh reinforcement. The (U)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, despite the large amount of aggregates and fibers present, is easy to compact with the use of a laser screed, a double vibration screed or a slipform paver. Immediately after compacting it is possible to float the overlay with a finishing machine with a closed disc (power float). The set time of the concrete equals that of traditional concrete and depends on the temperature and humidity. Several hours after casting it is possible to finish the concrete with mechanical finishing machines to obtain the desired surface structure. After finishing the concrete must be protected against further evaporation of the mixing water. Already after curing for approx. 24 hours, the high quality overlay, having a high bending tensile, compressive and impact strength, is ready for use. Thanks to the mesh reinforcement and steel fibers the hardened concrete is able to resist a certain amount of displacement of the base without transmitting damaging cracking to the surface.

The technical explanation for the success of the HRUTWT is that the mixture contains just enough mixing water and has a well balanced composition of fine and larger aggregates what makes it relatively easy to place and compact during which the reinforcement is completely encapsulated in the matrix. During the long process of finishing for several hours, the concrete becomes gradually more compacted and air is pressed out; the longer the finishing process, the better the result. It also seems that this finishing process has a positive influence on the chemical shrinkage of the mortar, despite the fact that a considerable part of the mixing water evaporates during placing and finishing. By compressing the mortar during several hours with mechanical finishing machines the chemical shrinkage is partly compensated for.

3. RESEARCH

Before it is possible to make a design for a rehabilitation of such an important infrastructural structure like a motorway 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 behavior under traffic loads to be able to predict the total extension of the service life. Besides 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 these properties were investigated and documented [6]. Table 1 gives an overview of the results obtained.

Table 1: Properties of the HRUTWT

Description	HPC and UHPC
compressive strength concrete [MPa]: 24 h/ 2 d/ 3 d/ 7 d/ 28 d	50/ 70/ 80/ 90/ 120 75/ 100/ 120/ 150/ 180
flexural strength concrete [MPa]: 24 h/ 7 d/ 28 d	7/ 9/ 11 9/ 12/ 15
flexural tensile strength HRUTWT [MPa]: 24 h/ 2 d/ 3 d/ 7 d/ 28 d *	60/ 70/ 74/ 77/ 80 70/ 80/ 84/ 87/ 90
density of concrete [kg/m]	2,600 / 2,700
E- modulus concrete [MPa]	48,000 / 55,000
wear resistance DIN 52108 Böhme-value [cm /50 cm]	< 6 / < 4
impact resistance	very high / extremely high
frost/thaw resistance SS 13 72 44A-IV	very good
frost/thaw resistance CDF	average 4 gr/m^2, i.e. 100 times less than reference 58 MPa concrete
chemical resistance compared to high quality concrete (45MPa)	very good
water penetration according to DIN/ISO 7031	< 1.5 mm
chloride penetration after 24 months according to Nordtest	not measurable (< 1.5 mm in concrete skin)
steel fibers [% Vol.]	1 – 2%
steel fibers per m^2 of layer	2 – 4 kg/m^2
reinforcement [% Vol.]	4 – 10%
reinforcement per m^2 of layer	8 – 45 kg/m^2
thickness of HRUTWT	30 – 70 mm
shrinkage of HRUTWT *	< 0.3 ‰

* depending on the amount of steel bar reinforcement and thickness of the HRUTWT.

4. APPLICATIONS OF THE HRUTWT

4.1. Industrial Floors and Pavements

An industrial floor or pavement is of crucial importance for a company as soon as a building and/or area is in use. If, however, a building is designed the floors are often not a priority at all. Surface damage, cracks, broken joint edges, dust, etc. can result in uncomfortable use, health problems for the users and damage to transportation equipment. In the food industry and in case of so-called fluid tight structures, not only the requirements of the user are of importance but the requirements from the authorities as well. In the rehabilitation or renovation of industrial floors or pavements the factor time is often the key factor. Shutdown time must be minimized since every stagnation in the complex process of production, transport and storage has considerable financial consequences. The choice for a resurfacing system for the floors is mainly based on two factors: the necessary shut down time and the expected service life of the new topping or overlay. Esthetical and financial factors are of less importance as long as the new topping meets the standards and specifications defined by the user and the related industry. The shut down time can become a problem when the floors are not sound anymore, contaminated, damaged or even under-dimensioned. To remove a reinforced concrete floor including removal of all products stored is not often preferred. Since the HRUTWT can be placed on sub bases made of various materials and with different properties, it is especially used in the industry. Also some characteristics of the HRUTWT like: no joints (it looks like a monolithic concrete floor), extreme durability, short curing time (in many cases re-use of the floor in 24 – 48 h) and not sensitive to a humid or wet sub base (food industry) are important arguments for a client to choose for the HRUTWT alternative.

Examples of applications during the last 15 years are:

- Food- and food processing industry. The HRUTWT is applied on tiles, epoxies, asphalt and under-dimensioned floors. Most of the time a complete re-surfing of an area of 500 – 1,500 m^2 is carried out in 2-3 d.
- Heavy industry: Steel industry, workshops, shipyards, scrap yards, etc.
- A lot of tailor-made solutions are developed for extreme low temperatures (cold stores, freezing rooms, freezing tunnels, etc.), under-dimensioned floors and heavy damaged floors.
- For new pavements to store and handle steel to prepare for recycling, a special structure is developed in Germany with the HRUTWT placed on a roller compacted concrete. This made it possible to resurface large outdoor area's very fast, economic and with the approval of a complete fluid tight construction with a very high wear- and impact resistancy.
- A large research program was started in South Africa in 2003 [7]. Project initiators are the South African National Roads Agency, Contec ApS and local contractors. Their aim is to rehabilitate and re-strengthen an asphalt concrete highway by applying a HRUTWT. It is foreseen to place a HRUTWT directly on top of the deteriorated asphalt course instead of placing a relatively thick thin white topping or thick asphalt wearing course. Lifting and/or rebuilding (since the drive through height might become too small when a thick layer is applied) of several viaducts crossing the road can be avoided.

4.2. Orthotropic Steel Bridge Decks

Heavily and intensely loaded orthotropic steel bridges suffer from fatigue cracks in the deck plate. Periodical repair inspection and, if necessary, repair is a costly measure that doesn't solve the basic structural problems. After serious damage due to fatigue 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 fixed and movable orthotropic bridges in the Netherlands and to develop practical solutions for cost effective rehabilitation and renovation [8-10]. Various methods for renovation and a reduction in stress with each specific method were investigated in cooperation with the Delft University of Technology and TNO Building and Construction Research. First research focused on the re-strengthening of the deck plate since the fatigue cracks which occurred in the deck plate have the highest priority to be repaired because of their effect on the traffic security [11,12]. One of the idea's was to place a steel fiber reinforced HPC overlay as was done earlier on a orthotropic bridge deck in Canada and later used on various orthotropic bridge decks in Japan. Contec ApS was consulted because of their specific knowledge of (U)HPC overlays in combination with large amounts of main reinforcement. Different tests and calculations showed that an un-reinforced HPC overlay will deteriorate very fast due to the high tensile stresses introduced by the traffic loads. This supported the idea as original proposed by Contec ApS to use an HRUTWT. Results from tests and applications demonstrated that the intended application of the HRUTWT is a very promising solution to rehabilitate orthotropic steel bridge decks to elongate the service life of the total structure since it increase the "plate factor" by monolithic composite interaction [13-21]. Both durability and strength of the HRUTWT are adequate.

4.2.1. Pilot Project Caland bridge

In the period from the 29th of April until the 4th of May 2003 a pilot project on the Caland bridge was executed to make it possible to test the logistic aspects on a relatively small project before other more complex and much larger projects would be executed. The area concerning the pilot project were two traffic lanes with a total width of 6.70 m and a length of 80 m in one traffic direction. During this period the entire project had to be executed, including re-routing 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 HRUTWT. Time to re-use (re-opening to traffic) of the new wearing course was less than 120 h.

The pilot project provided know-how useful in the larger projects executed in 2005 - 2006. Steel strain measurements on the re-surfaced Caland bridge showed a stress reduction with a factor 4 - 5 in the fatigue critical structural details. This equals the reduction factor as measured on the small test samples tested by the Adhesion Institute of the Delft University of Technology and as predicted using computer simulations.

4.2.2. Hagenstein Bridges

A total area of 8,400 m^2 (two bridges each 340 m long and approx. 12 m wide) of the two Hagenstein bridges on the A27 (direction Breda – Almere) had to be resurfaced with the HRUTWT. The first phase had to be placed within a strict time schedule of maximum 14 d in July 2005. The thickness of the HRUTWT was 60 mm so the standard configuration of 3 layers of reinforcement of ø 8 mm was used. This enabled transport over the reinforcement using wooden underlayment plates in the driving route of the mixer trucks. The specific HPC was mixed in a concrete batching plant located at approximately 45 min driving from the building site. The HRUTWT was cast in two days and each casting was over the full width of the bridge. The original idea was to place the HRUTWT with a slipform paver but the contract sum for the traditional method with the vibration screed was, for this relatively small job, lower. Also in this project the application of the intermediate epoxy layer with sprinkled in aggregates and the HRUTWT took place in a large tent placed over the whole area to be able to work independent of the weather conditions. As soon as the required strength of minimum 50 MPa was reached (within 24 h after casting) the bridge was re-opened for traffic again. A special water tube was positioned under the barrier to cure the HPC overlay with water sprayed during a period of 7 d independent of and without disturbing the traffic streams.

In the summer of 2006 the second bridge of Hagenstein was resurfaced in 3 days. Since other operations had to take place, a longer shutdown period was foreseen. During placing of the HPC the temperature was 37°C; in the tent temperature was even up to 47°C. Some the reinforcement details were changed to be able to place the reinforcement faster and to guaranty the flatness with regards to the concrete cover. The working method was adjusted and a special spreader was used to level the HPC in front of the vibration screed. Casting was successful despite the hot weather and up to 120 m^3 were cast in 8 h. In a small area some shrinkage cracks were visible because a ventilator, used to lower the temperature for the workers, was directed towards the concrete surface. Up to today and after 3 years of heavy use, the HRUTWT functions as expected and steel stress reductions are as foreseen.

4.2.3. The Moerdijk Bridge

In May 2005 the first phase (direction Breda – Rotterdam, 2 times 2 driving lanes each approx. 1,000 m long - 10 spans of about 100 m each) of the rehabilitation of the largest orthotropic bridge in the Netherlands, the Moerdijk bridge (total area to resurface 32,000 m^2), started. This bridge in the motorway A16 is part of the major connection between the ports of Rotterdam (NL) and Antwerp (B) and is believed to have the most intense traffic spectrum of Western Europe. Major rehabilitation was necessary since previous measures taken (repair of cracks in the steel deck plate) resulted in repair every 4 – 6 years. These repairs not only had considerable financial impact due to the high direct costs of the repairs as such (welding several thousands of meters of cracks, applying a new asphalt wearing course) but also a high environmental impact by creating large streams of wasted materials and air pollution caused by large traffic jams (partly closure for traffic of two lanes over a long period of time). Since the deck plate was uneven the thickness of the HRUTWT was between 47 – 100 mm, thus improving the comfort for the traffic. The dense reinforcement had to be placed very accurately to provide a concrete cover of 20 – 25 mm on the rebars. At the locations where the HPC layer thickness was over 60 mm extra reinforcement was applied. Placing was very complicated, not only because of the varying layer thickness but also because no transport over the reinforcement was possible. Two specially constructed traverses (one for the transport of the HPC and one for spreading the HPC by a small crane placed on the traverse) were used. The traverses were moved over a rail positioned in the longitudinal direction (100 – 150 m) of the working area, between the barriers on both sides of the driving lanes. In repeated cycles 20 elements each 100 m long (joint to joint) were prepared (removing asphalt, inspection, steel cracks repair, shot blasting) and cast. The HPC was mixed in a batching plant located close to the actual job. Application of the intermediate epoxy layer and the HRUTWT took place in a large tent to enable working independent of the weather conditions.

In the first phase of the Moerdijk bridge it was not possible for the contractor (using the prescribed vibration screed placing) to obtain the flatness of maximum 3 mm over 3 m . Also the skid resistance was lower than expected. This was caused by the fine fraction of the large aggregates used (2-4 mm) and the hardness of these hyperit aggregates that creates wear of tires, thus leaving rubber particles on the concrete surface. The complexity of the job (bridge in use with movements/vibrations) in combination with the relatively new method of rehabilitation made placing more difficult than foreseen. Additional tests performed at the Delft University of Technology with attention to the placebility, shrinkage and use of internal curing compounds have shown promising results for placing with slipform pavers on new rehabilitation projects [15, 16].

In 2006 some damage occurred at two locations, caused by a locally poor connection between the concrete and the interface; the concrete poorly passed the dense steel mesh, especially at laps of welded fabric. After research carried out and checking at other locations the decision was taken to replace the HRUTWT on 2.5 elements (1,500m^2). The concrete was removed by high pressure water, which demonstrated to be a difficult and time consuming operation. In 2007 the HRUTWT was replaced after some adjustments were made to the reinforcement lay-out (increased bar spacing; reduced number of layers in the thicker parts; increased bar diameter) to make casting and compacting easier. The method of casting was also adjusted to improve spreading and compacting. The HPC surface was not power floated since an additional calcinated bauxite sprinkled-in epoxy wearing course was applied later. Instead of the traverses a large conveyor belt placed on a truck was used to transport the HPC to the site. In the second phase of the project a conveyor belt was placed on a traverse while the HPC was unloaded at one side from the truck mixer on to the conveyor belt. Part of the casting took place at night to avoid warm weather and to use an emergency lane. A special mobile mixing plant was placed close to the building site during casting to avoid long delivery times for the concrete.

4.2.4. Movable Steel Bridges

Movable steel bridges (bascule bridges) with an orthotropic deck plate are provided with such a relatively lightweight wearing course that the concrete overlay is only an option when its thickness is considerably reduced, down to 20-25 mm. Traditional steel bar reinforcement will then have a too small concrete cover to prevent the steel from corroding. Alternatives might be the use of carbon fiber (5.4 mm) or stainless steel (6 mm) bars.

In 2 projects at the Delft University of Technology the possibility of applying a HPC or an UHPC on the deck plate is investigated [22]. In a first test series the static bar-concrete bond strength was investigated. Also the bending stiffness of the combined 12 mm steel deck and 20-25 mm reinforced composite structure was tested. The results provided information on how to calculate the stresses in the reinforcement bar in a cracked cross-section. In a second test series the 20 mm overlay was tested in fatigue. The centre-to-centre distance of the rebars was 12mm at a 6 mm concrete cover on the rebars. The stresses occurring due to the fatigue loading were based on the Eurocode (load model 3) and simulated in four-point bending tests. The calculation model developed from the static test results was used to calculate stresses. The fatigue lifetime of each material was defined. Life-time predictions were carried out using actual loading schemes and distributions.

4.3. Concrete Viaducts

Most of the concrete and steel bridges and viaducts in the Netherlands have been build in the period 1960 – 1980. They were build with the material and knowledge of that period and were designed using the standards of that time, including traffic prognoses and loads. Since then both traffic intensity and loads have increased much more than predicted. Several concrete viaducts in The Netherlands are under-dimensioned for the present traffic intensity. Some of these viaducts are also partly deteriorated because of chloride penetration and/or poor quality of the concrete.

4.3.1. Viaduct Wilp

Since the results of the research and the pilot project Caland bridge were very promising, the engineering division of the Ministry of Transport decided to place the HRUTWT as a rehabilitation and re-strengthening method on Viaduct Wilp in the motorway A1 between Apeldoorn and Deventer as a pilot project in 2003. Another important reason for this rehabilitation and re-strengthening was that the Dutch Government had decided to construct a rush hour lane in this part of the A1 to reduce traffic jams. Therefore, it was necessary to increase the capacity of the viaduct from two times 2 driving lanes to two times 3 lanes; the emergency lane is used as a rush hour lane. Although the viaducts in this part of the A1 had originally been designed in the 1960's for 3 traffic lanes in each direction, traffic intensity and wheel loads had increased such that the shoulders (outside lanes) and had to be re-strengthened to resist these loads. According to new codes like the Eurocode 1 the viaduct should at present be able to be loaded over its total width (shoulder to shoulder), whereas in the original design this had not been accounted for.

Viaduct Wilp was build in the 1970's and is constructed as follows:

- longitudinal prefabricated pre-stressed concrete ⊥ beams as girders (T beams turned 180 degrees);
- wooden formwork between the girders as working structure, support for the reinforcement and permanent formwork for the deck slab.
- 160 mm thick concrete deck cast in-situ.

Besides some deterioration of the T beams positioned at the shoulder and some not well compacted concrete in the deck slab, there were no mayor concerns regarding the concrete quality. The load spreading capacity of the deck slab was, however, insufficient to upgrade the capacity of the viaduct. Due to the intense traffic it was not an option to completely demolish the viaduct and construct a new viaduct that meets the requirements of present codes. A new viaduct consisting of prefabricated concrete girders and a relatively slim reinforced prefab UHPC deck could have been a relatively fast solution but was not further investigated. To remove the old and to cast a new deck slab in a higher quality concrete and to apply more reinforcement was also not an option since this could damage the pre-stressed concrete girders. A traditional reinforced overlay increases the dead weight and, as a result, decreases the load capacity of the viaduct. A HRUTWT of approx. 70 mm, fully bonded to the deck slab was found to be able to resist the high stresses and to also spread the loads over a larger area. The surface of the deck slab has to be prepared, for instance by shot blasting, to provide a clean and open concrete surface. Since the quality of the concrete used for the deck slab was not uniform and the bonding properly too low, it was also necessary to create a mechanical anchoring. This extra anchoring was done by applying on average steel 7 anchors per m^2 (studs with a plate were found to provide the best anchoring). Extra bars (both U- and L-bars) fixed with epoxy in holes at the four sides of the deck (at shoulders' working joints and expansion joints) were provided to avoid curling (delamination) of the HRUTWT. The studs with plates also enabled accurate positioning of the reinforcement and provided extra fixation points. In this pilot project the traditional concrete placing method was used.

4.3.2. Viaduct Voorst

In 2005 the HRUTWT was placed on a similar viaduct as viaduct Wilp, also in the motorway A1. This resulted in a more efficient placing and a better quality of the HPC overlay with regard to speed, compaction, strength, shrinkage and flatness. The total viaduct had to be resurfaced in four parts to interrupt the traffic streams as less as possible. Due to the width of the viaduct and the maximum working width of the slipform paver used, the two outside lanes at the shoulders, approximately 2.5 m wide and 80 m long, were cast using a double vibration screed. Four lanes of approximately 8.50 m each were cast by slipform paver. The concrete was mixed in a mobile mixing plant located within 30 minutes driving form the building site. It was transported to the building site with truck mixers. At the building site a mobile crane transported the HPC by bucket to the front of the slipform paver. In the first trial at Voorst viaduct where the concrete was placed with a slipform paver, it was decided to position the high frequency poker vibrators horizontally instead of vertically. The poker vibrators were also close to the front metering screed. The concrete was found to stick between the vibrators and the screed. This not only resulted in bad cooling of the vibrators and less efficient vibrating but also a faster setting of the concrete around the vibrators due to the heat development. Adjusting the distance between the vibrators and the front metering screed made it easier to remove the clumps of concrete but didn't result in a better and easier placing. Placing was not only a problem, but, as concluded later, also compaction was poor in an area of about 50 m^2. Therefore, the vibrators were positioned vertically again. Also the method of finishing was adapted. Finishing with both the super smoother and the trowel plate functioned well and resulted in a smooth surface. Despite some problems related to the lack of experience of the personnel involved and to the quality control at the concrete batching plants, placing by slipform paver was found to be a very promising alternative for large areas. Since demolishing and replacing of the HRUTWT is extremely difficult and costly it should be avoided. Preparing a very detailed planning before starting to execute the job as well as quality control during placing are essential to reach this goal.

4.3.3. Reconstruction 6 Viaducts in the N37/A37

In 2007 the N37 in the North East of the Netherlands, an important road connection with the North West of Germany, was reconstructed from a two lane road to a four lane motorway. Research demonstrated that it was possible to upgrade 6 of the existing concrete viaducts close to Emmen with the HRUTHPC overlay, thus avoiding construction of new viaducts. Before starting the actual job a trial area of several hundred m^2 was placed on a concrete slab nearby a viaduct. A small concrete mixing plant with a drum mixer at a driving distance of 45 minutes was used for the trial area, as well as later for the 6 viaducts. Special attention was given to the location and configuration of the laps in the reinforcement. Long rebars were used to reduce the number of laps. Because of the location of the viaducts, tower cranes were used to transport the HPC in buckets from the concrete mixing truck to the area in front of the slipform paver. The width of the large slipform paver (12.5 m) enabled placing of the entire width of a viaduct in one jointless run.

5. CONCLUSIONS

The market for industrial floors is growing; old industrial buildings and – pavements need a new topping or wearing course to meet new demands. The so-called liquid-tight structures used to avoid any spillage of dangerous and/or polluting liquids will be prescribed more by the stricter environmental rules the industry has to face. The HRUTWT is a very promising alternative especially when spillages are combined with impact, wear and heavy loads.

The projects on the orthotropic steel decks of the Caland, Hagenstein and Moerdijk bridges have shown that it is an effective and practicable solution, which can be applied within a period of a few days on an area of 1,000 – 2,000 m^2. Replacement of the surfacing of mastic asphalt with a HRUTWT is successful in reaching its major goal: reducing the stresses in the deck plate to improve the fatigue life of the bridge. Reduction percentages of approximately 80% of the stresses in the deck plate itself and of 60% in the longitudinal weld between deck plate and trough web were theoretically predicted. Measurements in practice confirmed these results. Therefore, it might be concluded that the use of the HRUTHPC overlay is a very effective and economical solution with regard to improving the fatigue behavior of the bridge deck structure.

The HRUTWT has a several strong points:

- spreading loads over a large area, partly by

membrane action;
- relatively small increase of height and self weight;
- short shut down periods;
- suitable not only to re-strengthen but also to repair concrete damage in the concrete deck;

It must be noted that special attention must be paid to the, preferably dry, storage of the aggregates used and the measurement of its water content: rather small variations can result in a considerable change in the consistency of the mixture: a 1 percent point (by mass) change in water content of the large aggregates results in a change of the water-binder ratio from 0.27 to 0.30 for the slipform paver mixture. During some of the projects even a 3% change was not taken into account. This might result in problems during placing, especially when the HPC is placed in relatively thick layers (like on the Moerdijk bridge) and when a slipform paver is used. On the other hand, the mixture has demonstrated to be relatively "fool proof" or "contractor proof" since problems with the water-binder ratio, weather conditions, not planned shutdowns due to problems with equipment (sometimes several hours delay!) did not result in problems with the HRUTWT: No cracks at the production overlap after a shutdown were observed, nor de-bonding of the top layer.

Even when it is necessary to place a thin wearing course on top of the HRUTWT to cope with skid resistance, it is until now the only fast method available to considerably reduce the stresses in the fatigue critical structural details in an orthotropic steel bridge deck. Despite several other problems encountered, partly related to the lack of experience with this kind of projects in particular and thin HPC overlays in general, there is a great interest in using this technique in following re-strengthening orthotropic steel bridge deck projects. Today, it is also regarded as being the only effective and efficient alternative for full reconstruction of bridges.

More than 15 orthotropic steel bridge decks in the Netherlands have to be re-strengthened in the next 10 years; 10 of them within the next 5 years. The use of the HRUTWT might grow more drastically since worldwide several thousands of bridges and viaducts designed and build in the seventies of the last century must be rehabilitated during the next 10 years due to the more intense and higher traffic loads and deterioration of the concrete deck.

Countries coping with these fatigue problems show great interest in this rehabilitation method developed in a unique cooperation between the civil engineering division of the Ministry of Transport, a technical university, the supplier of the HRUTHPC overlay and contractors.

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REFERENCES

1. Bache, H.H. (1986), "Compact Reinforced Composite". CBL Report no. 39. Cement- and Concrete lab. Aalborg Portland.
2. Bache, H.H. (1987), "Compact Reinforced Composite Basic Principles". CBL Report No. 41. Cement- and Concrete lab. Aalborg Portland. May 1987.
3. Buitelaar, P. (2002), "Ultra Thin Heavy Reinforced High Performance Concrete Overlays". 6th International Symposium on Utilization of High Strength / High Performance Concrete, Leipzig, Germany.
4. Bache, H.H. (1981), "Densified cement/ ultra fine particle based materials". The second International conference on superplasticizers in Concrete. Ottawa, Ontario, Canada June 10 – 12, 1981.
5. Buitelaar, P. (2004), "Ultra High Performance Concrete: Developments and Applications during 25 years". Plenary session International Symposium on Ultra High Performance Concrete. Kassel, September 2004.
6. Braam, C.R. et al (2002 – 2005), "Research Contec Ferroplan". Various test reports Delft University of Technology. 2002 – 2005 Delft, The Netherlands.
7. Kannemeyer, L., Perrie, B.D., Strauss, P.J., du Plessis, L. (2006), "Ultra-Thin CRCP: Modelling, Testing under Accelerated Pavement T and Field Application for Roads". 6th International DUT – Workshop on Fundamental Modelling of Design and Performance of Concrete Pavements. September 15 – 16, 2006, Priorij Corsendonk, Old-Turnhout, Belgium.
8. Boersma, P. and P. de Jong (2003), "Techniques and solutions for rehabilitation of orthotropic steel bridge decks in the Netherlands". Proceedings Structural Faults and Repair. United Kingdom 2003.
9. Pover, J. (2002), "Draft Internal report Ministry of Transport; Analyses various solutions for life time extension PSR-project" (in Dutch). April 2002.
10. Straalen, IJ. and R. Vis (2002), "Tests on orthotropic steel bridge decks - Life time extending solution with a 5 cm thick layer concrete on the deckplate: supplementary test". Report 2002-BC-R0030 for the Ministry of Transport. August 14th 2002.

11. De Jong, P. and P. Boersma (2003), "Lifetime calculations for Orthotropic steel bridge decks". Proceedings Structural Faults and Repair. United Kingdom 2003.
12. De Jong, P. and H. Kolstein (2004), "Strengthening a bridge deck with high performance concrete". Proceedings ASCE/ SEI. Orthotropic Bridge Conference. Sacramento, CA. USA 2004.
13. Buitelaar, P.. Kaptijn, N. and C.R, Braam (2004), "Reinforced high performance concrete overlay system for steel bridges". 5th. CROW workshop Istanbul, Turkey.
14. Buitelaar, P. (2004), "Heavy Reinforced Ultra High Performance Concrete". International Symposium on Ultra High Performance Concrete. Kassel, September 2004.
15. Buitelaar, P.; Braam, R. and N. Kaptijn (2004), "Reinforced High Performance Concrete Overlay System for Rehabilitation and Strengthening of Orthotropic Steel bridge decks. Proceedings ASCE/ SEI Orthotropic Bridge Conference. Sacramento, CA. USA.
16. Buitelaar, P.; Braam, R.; Kaptijn, N. and H. Sliedrecht (2006), "High Performance Concrete for rehabilitation and strengthening of orthotropic steel bridge decks". 7th International conference on short & medium span bridges. August 23 – 25, 2006, Montréal, Québec, Canada.
17. Buitelaar, P.; Braam, C.R.; Kolstein, H. and P. de Jong (2006), "Reinforced High Performance Concrete for rehabilitation of orthotropic steel bridge decks". Proceedings Structural Faults and Repair. United Kingdom.
18. Buitelaar, P.; Braam, C.R. and M. de Wit (2006), "Heavily Reinforced Ultra Thin White Topping to re-strengthen infrastructural structures." 10th International Symposium on Concrete Roads. September 18 – 22 2006, Brussels, Belgium.
19. Buitelaar, P. and Braam, C.R. (2006), "Ultra Thin White Topping to re-strengthen infrastructural structures and pavements", 6th International DUT – Workshop on Fundamental Modelling of Design and Performance of Concrete Pavements. September 15 – 16, 2006, Priorij Corsendonk, Old-Turnhout, Belgium.
20. Buitelaar, P. and Braam, C.R. (2008), "Application of the Reinforced High Performance Concrete Overlay on orthotropic steel bridge decks", Orthotropic Bridge Conference. August 25 – 29, 2008. Sacramento, CA. USA.
21. Kolstein, M.H. and Sliedrecht, H. (2008), "Reduction of traffic induced stress using reinforced high strength concrete, Orthotropic Bridge Conference. August 25 – 29, 2008. Sacramento, CA. USA.
22. Braam, C.R, Kolstein, M.H., Romeijn, A. and Buitelaar, P. (2008), "Concrete overlays to improve the fatigue life of movable orthotropic steel bridges", Orthotropic Bridge Conference. August 25 – 29, 2008. Sacramento, CA. USA.