

UHPFRC ANCHOR PLATES AND FIRST APPLICATION FOR STRENGTHENING A RHINE LOCK

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Abstract

Concrete / UHPFRC anchor plates (“Hybridanker”) are designed for the use with post tensioning systems or ground anchors. High performance fibre reinforced concrete in combination with a high tensile strength material like steel or carbon fibres is used to absorb and transfer high forces from the tensile element to the structure. Composite anchor plates can therefore replace ordinary steel plates to anchor strands, bars or wires. Many advantages like low specific weight, flexible moulding in the manufacturing process, or durability against corrosion can be easily realized.

First application of the composite anchor plates has been realized at the Rhine lock in Iffezheim, where permanent multi-strand ground anchors had been installed. For the application, tests were performed according to the requirements of the ETAG 013 guideline to proof the resistance of the composite anchor plate and to secure a load transfer to the structure without damaging the existing concrete.

Résumé

Des plaques d'ancrage en BFUP ("Hybridanker") sont conçues pour l'utilisation avec les systèmes de post-tension ou de tirants d'ancrage. Des bétons à haute performance, renforcés par des fibres à haute résistance à la traction, comme l'acier ou le carbone, sont utilisés pour absorber et transmettre des forces élevées de traction à la structure. Ces plaques d'ancrage composites peuvent alors remplacer les plaques en acier ordinaire avec torons d'ancrage, barres ou fils. De nombreux gains, comme un poids spécifiquement faible, la facilité de moulage dans le procédé de fabrication, ou la durabilité contre la corrosion, peuvent facilement être réalisés.

La première application des plaques d'ancrage composites a été réalisée à l'écluse du Rhin à Iffezheim, où des tirants d'ancrage multi-torons permanents ont été installés. Pour l'application, des tests ont été effectués selon les exigences de la directive ETAG 013 pour vérifier la résistance des plaques d'ancrage composites et garantir un transfert des charges à la structure sans endommager le béton existant.

1. INTRODUCTION

In geotechnics and post-tensioning the tensile elements need to be anchored to transfer the load to the structure or the ground. The most common tendon types are bars and strands. The load transfer usually is realized with steel anchor plates. The anchoring of the tensile elements is done with domed or flat anchor nuts when using bars and wedge plates when using strands.

The plates are used to reduce the pressure in the contact surface between the anchorage of the tensile element and the concrete of the structure. Another requirement is bridging the force over the opening of duct or borehole. The development of concrete anchor plates pursue the goal to provide a load transfer system that is lighter and less steel consuming than ordinary steel solutions. Therefore ultra high performance fiber reinforced concrete is used that is lighter and cheaper than steel and non-corrosive. The integration of special features within a casing can be realized less energy intensive than by machining bare steel plates, [3], [4].

2. DESIGN

2.1 Model

The design of concrete anchor plates depends on the used tensile element and the used anchoring method. First the force of the tensile element needs to be applied to the anchor plate. The contact surface between nut or wedge plate and the ultra high performance fiber reinforced concrete must be large enough to reduce the pressure to an acceptable amount. The load distribution inside the UHPFRC is described by struts. The vertical force is transferred directly to the structure while the horizontal force creates tensile forces that need to be absorbed by a material with high tensile strength. The assumed model for load application with domed nuts and with flat nuts or wedge plates and the load distribution inside the UHPFRC are shown in Figure 1, [3].

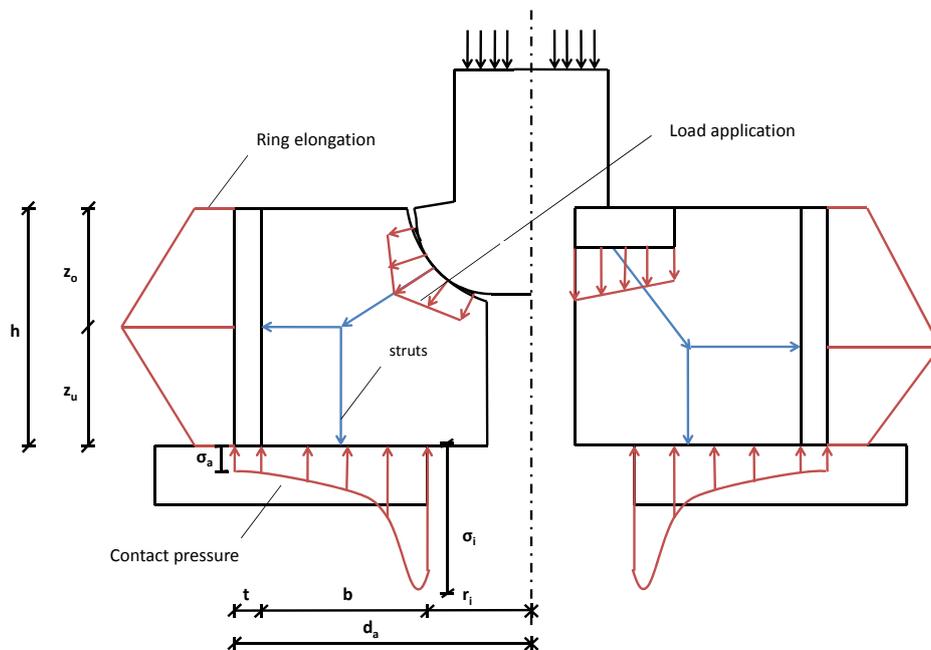


Figure 1: Design model for concrete anchor plates ([3], modified)

If a flat nut or wedge plate is used an additional washer plate can be necessary to reduce the pressure between the anchor element and the UHPFRC surface. With the model shown in Figure 1 the dimensions of the concrete anchor plates could be determined for prototype and verification testing. The results were used to refine the assumptions. After all it is possible to define the dimensions of the concrete anchor plate depending on the used tensile element (strand, bar, wire), the corresponding anchor element (wedge plate, flat and domed anchor nut, anchor body) and the characteristics of the structure (bore hole diameter, duct diameter, concrete strength, reinforcement).

However, the determination of the dimensions is a complicated procedure as there are many parameters that need to be taken into account. The thickness of the used reinforcement (steel ring, carbon fiber ring) is for example influenced by the height of the concrete plate which is influenced by the load application and opening diameter of the structure (borehole, duct). The opening has a high influence on the mechanical behavior of the concrete anchor plate. With an increasing diameter of the opening the tensile forces at the bottom of the concrete plate increase and result in a lower ultimate breaking load compared to the same plate on a small opening in the structure.

1.2 Materials and variations

The design of the concrete anchor plate was first modeled for the use of UHPFRC and steel rings. Tests with other filler materials like high strength mortar with fibers and basalt, that have a lower compressive strength than 180 MPa showed extensively lower ultimate breaking loads which is why there were no more considerations replacing the UHPFRC by another material. With the actual mixture usual compressive strengths are higher than 200 MPa, for special applications the compressive strength can be increased by particular methods like tempering up to 300 MPa. The use of steel fibers avoids single cracks and guarantees a more ductile behavior.

The steel ring can be replaced by other materials like a composite carbon fiber ring. During a case study for the use of anchor plates in highly corrosive conditions (sea water) an anchor plate was designed and manufactured. For its design, the described model was used to define the dimensions of the ring. Therefore it is necessary to know the exact characteristics of the carbon fiber composite. The prototype is shown in Figure 2. The tests showed almost the same mechanical behavior as the equivalent solution with a steel ring.

Moreover the possibility of inner reinforcement using stirrups and helixes was considered to protect it from corrosive conditions by the surrounding UHPFRC. Another advantage of inner reinforcement is the free practicable outer shape of the concrete anchor plate so that also a rectangular shape can be easily realized. The arrangement of the stirrups has to be considered according to the intended use and the boundary conditions like borehole diameter or type of anchorage (domed nut, flat nut, wedge plate, etc.) During a case study for the strengthening of a deck slab with bars and flat anchor nuts this type of concrete anchor plate was produced with integrated injection pipes and a washer plate for anchoring the flat nut (see Figure 2). The function (maximum breaking load) and serviceability (crack widths, strain) was proofed in several tests.

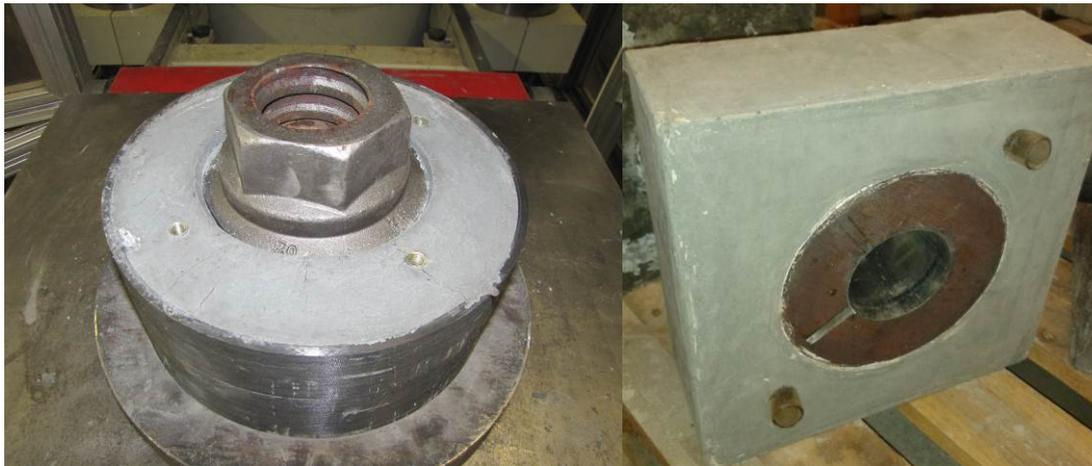


Figure 2: Prototype with carbon fibre ring (left) and concrete anchor plate with inner reinforcement, washer plate and injection pipes

3. FIRST APPLICATION

3.1 Project

The Wasser- und Schifffahrtsamt Freiburg is in charge of the Rhine lock in Iffezheim one of the biggest and effective locks with two chambers in Europe. In one year about 30.000 cargo ships pass the lock with a total number of goods of about 25 Mio. tons. The lock is operating 24 hours a day and seven days a week. It started operating in the year 1977.

During a revision of the lock in the year 2010 a cracked construction joint was found in the sill of the head gate. Spallings were a sign for an excessive load. Divers detected, that the tensile reinforcement was completely damaged on the water side. Further evaluations and research by the Bundesanstalt für Wasserbau (BAW) in Karlsruhe showed an insufficient bond in the construction joint which caused a change of position of the middle sill block, [1].

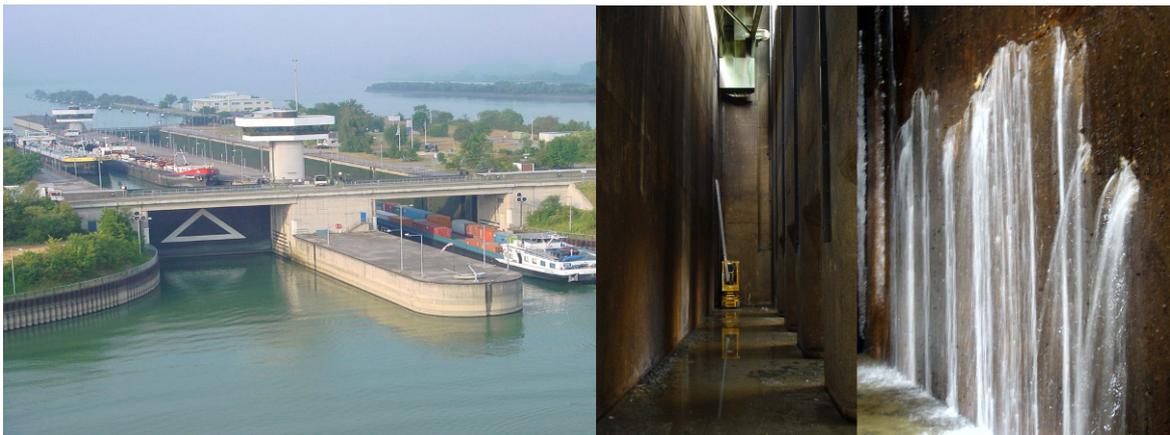


Figure 3: Left: Rhine lock in Iffezheim ([1]), Right: Sill of head gate at revision and cracked construction joint permeable to water ([1])

To reestablish the stability of the construction the BAW worked out a solution together with the technical division of DYWIDAG-Systems International GmbH (DSI). The plan was

to install 14 permanent ground anchors to have horizontal resistance against the water on the upper side. Moreover the construction joint should be filled with mortar to guarantee the water tightness, [1].

3.2 UHPFRC solution

Due to the difficult accessibility and the poor available space DSI suggested to use concrete anchor plates because of its low specific weight and optimized dimensions in comparison to usual steel plates.

The concrete anchor plate consisted of an UHPFRC-filler and a steel ring. The steel ring needed to be corrosion protected as it is done for the usual steel components that are used with the permanent ground anchor system. The UHPFRC itself is non-corrosive. For the assembly of the system a recess and threaded sleeves were integrated in the UHPFRC surface to center two steel half shells. These shells were put between the wedge plate and the anchor plate. The threaded sleeves should be used to connect the cap to the concrete anchor plate. The cap protects according to the approval of the permanent ground anchor system the anchor head of mechanical damage and corrosion. Additionally a non-corrosive PE-pipe should be added as connection between the concrete anchor plate and the corrugated duct inside the borehole in the structure. The sealing between the two ducts should be realized with rubber rings, [1].



Figure 4: Concrete anchor plate solution before and after assembly zone including components for connecting the SUSPA-Kompaktanker ([1])

3.3 Proof of concept

The use of concrete plates in combination with an approved system required an appropriate proof of concept for the plate and the structure. Usually the proof of concept is realized by approval tests according to the European Technical Approval Guideline 013 (ETAG 013). This Guideline provides regulations and test criteria for the use of pre-stressing systems that have to be fulfilled, [1].

In this case the proof of concept should be realized by a load transfer test where the characteristics of the old structure would be taken into account and also the calculated dimensions of the used concrete anchor plate. Furthermore the capacity of the concrete anchor

plate should be proofed in a compression test on a steel plate with an equivalent opening as in the structure, [1].

Regarding the conditions in the existing structure the following assumptions have been taken for the load transfer test:

Table 1: Assumptions for load transfer testing

Compressive strength of end block	25 N/mm ²
Bursting reinforcement	none
other reinforcement	none
Dimensions of the end block	side length 700 mm, height 1400 mm
Hole diameter	150 mm

As there is no reinforcement in the concrete end block, the ultimate breaking load should be 130 % of the ultimate tensile strength of the used ground anchor. During the performed test there were no visible cracks, neither during the 10 performed load cycles nor during increasing the load until 143 % of the ultimate tensile strength of the anchor. The test was aborted and not performed until the failure of the concrete end block. The criteria according to ETAG 013 were fulfilled (Breaking load, cracks, stabilization of the vertical and horizontal elongation). The test setup and the results are shown in Figure 5, [1].

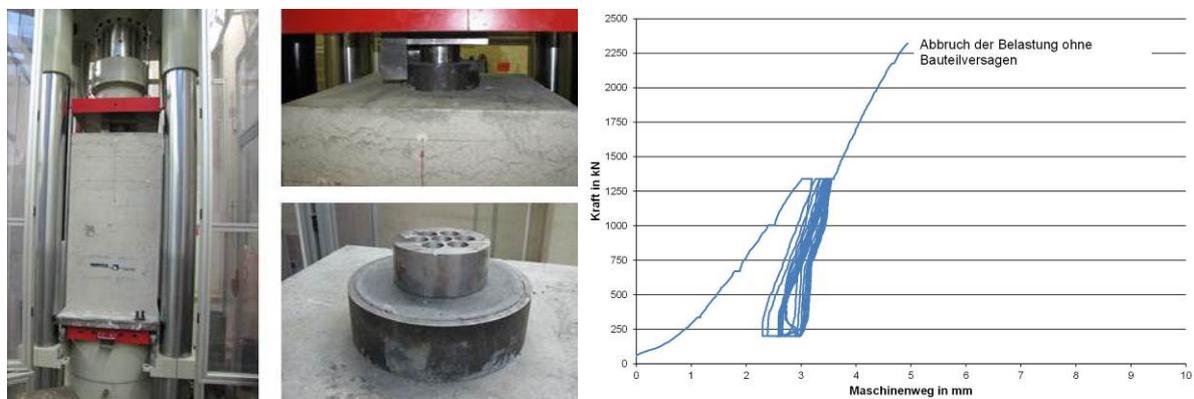


Figure 5: Left: Setup of load transfer test ([1], modified), Right: Load displacement curve ([1], modified)

The capacity testing was performed at the laboratories of the Technische Universität München. The conditions and characteristics for the test as UHPFRC strength, tensile strength of steel ring, dimensions of the wedge plate and opening in the ground should be the minimum requirements for the use on site. The ultimate breaking load that should be reached was calculated regarding to the design loads and the maximum strengths of the used tensile elements and was determined to 110 % of the ultimate tensile strength of the used strands. The compression test was then performed successfully, [1].

3.4 Production

The concrete anchor plates were produced in an upside down position. The steel ring was first galvanized and coated with a three-layer corrosion protection. For pouring the ring was used as casing for the concrete. The later top side was realized with a special wooden casing that allowed the integration of a recess and threaded sleeves. The recess helped to center the steel half shells and therefore to simplify the assembly of the anchor head. Regarding the pouring of the UHPFRC there was no special requirement to the fiber alignment as in this case the task of the fibers is not to increase the tensile strength in a certain direction but to minimize the risk of big single cracks during the use of the concrete anchor plates.

For the production an existing concrete formula was used and adapted. For example the fiber content was reduced by one third as the function and the serviceability of composite anchor plates were proofed with the reduced fiber content in several tests (load transfer to structure, static and dynamic behavior). With the used concrete formula a water cement ratio of 0.24 could be realized. The ingredients are shown in Table 2.

Table 2: Ingredients of filler concrete

Nr.	Resource	Notation
1	Cement	CEM I 52,5 R-HS/NA
2	Water	Water
3	Additives	Silica fume Sika Silicol P
4		Silica dust (QM 1) W12
5		Silica dust (QM 2) W3
6	Admixture	VisoCrete 20 Gold
7	Aggregates	Silica sand H33
8		Basalt 2/8
9	Steel fibers	Weidacon FM 0.15/9

The ingredients were mixed for each batch. For this application three batches with a volume of about 50 liters were concreted. After the hardening time of about 24 hours the concrete plates were tempered to reduce shrinkage and reach an early high concrete strength of more than 185 MPa. To ensure the quality of the produced plates, one plate was taken from the production and a successful capacity test was performed. The compressive strengths of all batches were controlled before sending the plates to the construction site.

3.5 Installation

Due to the conditions on site, the plates had to be carried down the stairs to get them into the lock. After drilling the boreholes the SUSPA-Kompaktanker was inserted. The concrete anchor plates were placed on a mortar bed. Figure 4 shows a fully assembled concrete anchor plate with the half shells and the wedge plate before connecting the cap. After the connection of the cap it was filled with corrosion protection compound to protect the anchor head from

corrosion. After installation every anchor was tested according to DIN 4125 with a testing load of 1330 kN which is 130 % of the final load (= 1020 kN), [1].

4. CONCLUSION

This paper dealt with the concept, experimental studies and mainly the first application of UHPFRC in the field of concrete anchor plates for post-tensioning and geotechnical systems. The high compressive strength and durability of UHPFRC in combination with the tensile strength of steel or composite fiber materials enables a new type of load transfer to the structure. With the calculation and verification of models it is possible to determine the dimensions and constitution of concrete anchor plates for anchoring any tensile element (strands, bars, wires).

For its first application for strengthening the Rhine lock in Iffezheim many advantages of the UHPFRC could be used. The conditions inside the lock required a light weight durable solution. By the use of the UHPFRC it was possible to integrate features like the recess for the half shells as well as threaded sleeves for the connection of the cap. The connection to the structure could be realized by a PE-duct as it could be connected to the concrete plate during the manufacturing process. The functionality of the concrete anchor plate was proofed by load transfer testing according to the European Guideline for Technical Approval ETAG 013 and additionally by capacity testing at the MPA BAU laboratories of the Technische Universität München.

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