Strengthening of 100 year old unreinforced concrete arch bridge

Kuhbrücke/ Hildesheim bridge

The Kuhbrücke/Hildesheim bridge is an unreinforced concrete arch bridge near the city of Hildesheim, dating from 1910. When recalculation showed that the bearing capacity was no longer sufficient, the bridge had to be strengthened.

The Kuhbrücke/Hildesheim bridge has an important function, because it is the single access to an agricultural area owned by the City of Hildesheim. Recalculation has shown that the bearing capacity of the bridge is not sufficient to carry ordinary agricultural machines and traffic loads had been limited to 3 tons maximum for vehicles. Furthermore the bridge and its equipment showed a lot of damage related to ageing.

The City of Hildesheim investigated several alternatives, e.g. building a new bridge at the same place, building a new bridge at an alternative place and strengthening of the existing bridge. Because of limited financial capacities, strengthening was the preferred solution. Structural engineering firm 'matrics engineering' was chosen to search for a technical solution that

- upgrades the bridge for load model 'Brückenklasse 30' according DIN1072 (1985);
- minimizes effort and costs for the structural measures;
- allows use of old bridge during harvest before strengthening is done.

The bridge was strengthened in 2016 to upgrade the capacity for carrying vehicles with maximum weight from 3 ton to 40 ton. The historic arch (fig. 3) and the foundations are further used. New webs were added by horizontal prestressing to the arch (fig. 4). A bar post-tensioning system (50 mm) was used

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with innovative and very durable Ultra High Performance Concrete (UHPC) anchor plates (Hybridanker). Finally a reinforced concrete deck slab was added to create a kind of box section. To reduce thermal stresses in integral bridges it is planned to develop a bridge deck cooling system in a future research project, using the Kuhbrücke/Hildesheim as trial project. To verify the efficiency of the cooling, many temperature sensors were placed. The operation was finished in June 2016.

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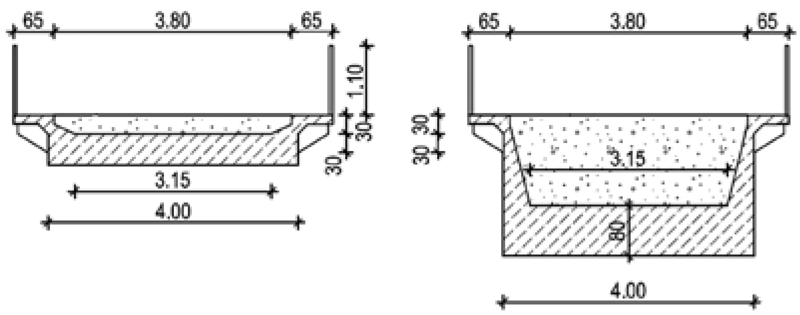
Kuhbrücke – 100 year old structure

The bridge was built as unreinforced concrete arch. The arch is continuous and supported by two massive abutments with a span of nearly 25 m. With a thickness of just 500 mm the bridge is very slender (1:50 ratio of midspan height to span length) and the arch very flat (1:10 ratio of rise of the arch to span). Although more than 100 years in service the bridge showed only minor deficiencies, e.g. a transversal crack of about 50 mm depth at the bottom side of the arch in its centre along total width. This might have come from overloading by traffic, temperature, shrinkage and horizontal movement of abutments. Concrete testing was done to determine the concrete strength. Class C16/20 according to Eurocode 2 (2011) was finally found. Based on that strength calculations



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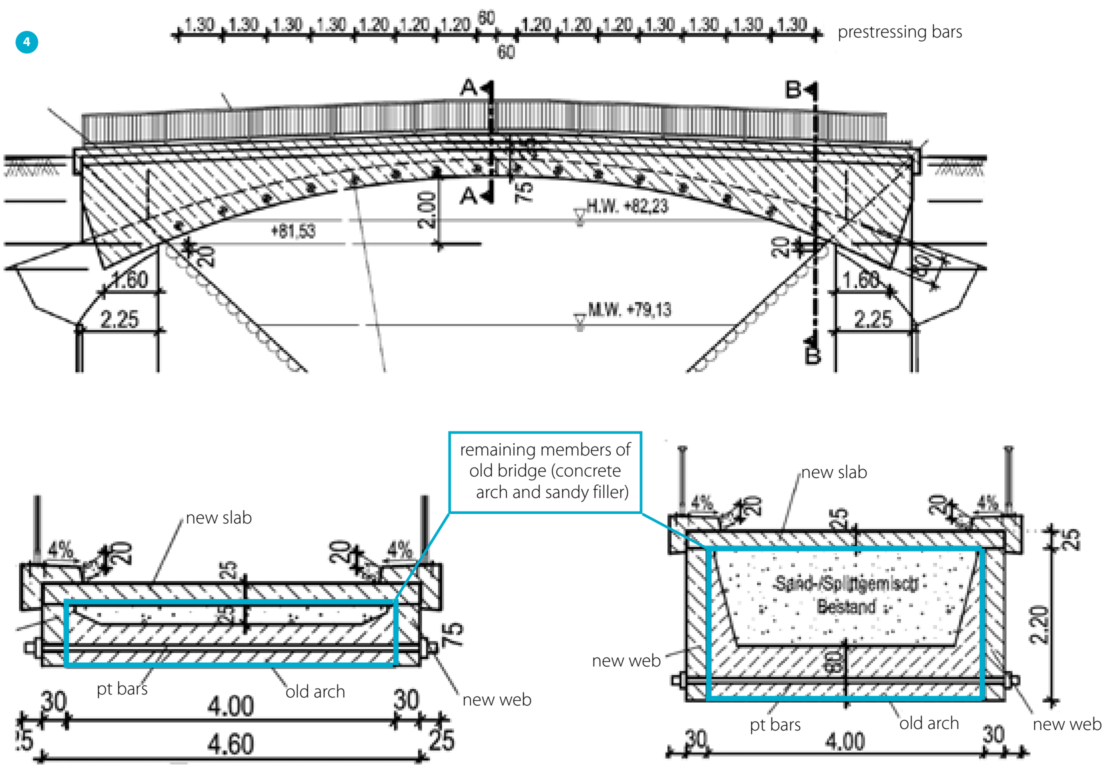

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1 Strengthened bridge, finalized in June 2016
2 Kuhbrücke (1910) before strengthening
3 Sections of the original structure
4 Side view and sections of the strengthened structure

5a

5b

was done and traffic loading finally was limited to vehicle loads of maximum 3 tons. For the upcoming harvest in autumn 2015, when thousands of tons of sugar beet root were expected, an urgent solution was needed. If using this bridge with its limited capacity, only a solution with conveyor belt and small equally distributed loads was allowed. Finally the City of Hildesheim created a temporary access by concrete cylinders thrown into the river and filled up with earth.

Strengthening concept

The main structural deficiency of the arch bridge is the limited bending resistance of the arch both in longitudinal and transversal direction. It must be assumed that the sandy filler above the concrete arch does not act as resistance although it seems that it has some strength.

New cast in-situ webs with height from lower bound of the arch to the traffic lane level are added on both sides of the arch. For monolithically connection to the existing arch, the webs were cast against roughened surface and stressed together by 50 mm prestressing bars (some 1.5 MN for each bar stressing force). Time depending losses were very small because of the age of the existing arch. This prestressing force also solved the deficiencies in transversal direction. Finally a reinforced concrete deck slab was added to further help distributing the loads and to improve durability. The strengthened bridge still needs the high compression resistance of the arch and actively uses it by transferring the forces through the webs into the arch which acts like a bottom slab. Of course dead weight of the bridge is fully transferred by the old arch. The old arch and new members webs and slab act fully together, similar to a box girder/arch.

The bridge is far away from public road network and subsequently de-icing salts are not used. To keep costs small, no sealing was applied. To improve durability, the calculated crack width in the slab was limited to 0.2 mm instead of 0.3 mm.

The arch bridge has no hinges and hence very high stresses can occur due to temperature loading. To avoid massive reinforcing because of the high stiffness of the new box arch girder the concept was to allow cracking and limit the crack width to 0.2 mm in the webs. Further limitation of stresses due to restraint deformation is planned to achieve by actively cooling and heating the bridge deck (see chapter 'Tempering of bridge deck'.)

Construction

Construction works began in February 2016 with installation of scaffolding (photo 5a and 5b). The old bridge deck was completely rebuilt. Only the arch and the filling material

5 Erection of scaffolding
6 Drilling of tendon holes and detailing of webs (from left)

remained and could be used as formwork for the new members. The arch was bored horizontally in transversal direction at the length of 4 m to house the prestressing steel bars (photo 6a and 6b). Vertical and horizontal deflection of borings were very small. After reinforcing the webs and closing the formwork webs were poured with C30/37.

Deck slab was poured in second stage and monolithically connected to the new webs. For transversal prestressing of the arch a bar system of BBV Systems GmbH was applied according to ETA-16/0286 (2016) using Macalloy prestressing bars and 'Hybridanker'-anchorages.

It was the first time that Hybridanker-plates were applied for these prestressing bars. Hybridankers are anchorages made of ultra-high performance concrete (UHPC). Using these anchorages was beneficial from durability point of view (no steel parts exposed outside stainless steel cap, photo 8a and 8b) and also because of very small edge distances. This was proved by special tests which showed that, due to its stiffness (large thickness), when applied on concrete no extra confinement is needed (e.g. spiral).

6a

6b

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The Hybridanker-plates for this project consisted of a force transfer unit made of ductile cast iron, confinement with rebar spiral and precast with Ultra High Strength Concrete with a compressive strength around 200 MPa. Further features were: grouting inlet, threads to connect the cap, trumpet made of polyethylene. The technology is still new; its first application was in 2011. See Weiher et al. (2012) for more details about general principles.

The construction was finished in June 2016 with a fully strengthened arch bridge (photo 1). The position of the arch is still visible by following the anchorages.

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7 Reinforcement of deck slab and installation of prestressing bars
8 Hybridanker-plate for anchoring 50 mm prestressing bar
9 Temperature sensors (a) and plastic hoses (b)

9a

9b

Tempering of bridge deck

The City of Hildesheim was very open-minded for a planned research project. The restraint stresses due to temperature shall be limited by tempering the bridge deck. For that purpose plastic hoses were installed (photo 9a and 9b). The idea is to send tempered liquid in order to cool down in hot periods (e.g. summer) or heat up the concrete deck in cold periods (e.g. winter). By doing so, one may decrease stresses due to temperature significantly. The project shall be used as trial project and permanent use is not foreseen. Therefore, the design was done without considering the benefits of such a tempering. Even higher effects of tempering can be achieved by this method for large continuous girder bridges and integral bridges.

Conclusion

A very old concrete bridge built in 1910 was strengthened at little costs (< 30% of building a new bridge) to meet modern goals. For this purpose it was beneficial that the bridge was unreinforced and furthermore had a static system (arch) that offered hidden resistance.
The strengthening concept was chosen in such a way that the load on the bridge during construction was not large. Innovative aspects were applied, such as the high strength concrete anchorages of prestressing bars and the bridge tempering trial to limit stresses from temperature load. ☒

PROJECT DETAILS

client City of Hildesheim
contractor Hoch- und Industriebau Celle GmbH, Hambühren
PT-system BBV Systems GmbH, Bobenheim-Roxheim
design matrics engineering GmbH, München
tempering matrics engineering GmbH, München; tripleS GmbH, Mülheim an der Ruhr

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