Strengthening of a railway arch bridge from 1854.

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Abstract. This paper presents the inspection of the condition and the design for strengthening of an existing railway arch bridge constructed in 1854. The original arch bridge is constructed with 5 layers of bricks in the arch and granite blocks in the foundation on top of an arrangement of frame made of timber and carried by piles. From the inspection it was concluded that the bricks in the arch was damaged due to freeze-thaw. It was also concluded that the timber structure in the foundation was rotten. The bridge is crossing a small creek. The environment is very sensitive. The access to the construction site is passing through landscape subject to preservation. The strengthening project included the arrangement of a new reinforced concrete arch. The arch was anchored with glued reinforcement bonded to the existing brick arch. The reinforcement and formwork was placed above the creek without disturbing the fauna in the water. The concrete was pumped into a form under the existing arch. After curing of the concrete arch, the strengthening of the foundation was initiated. It was planned to construct a bottom slab under the creek, which was able to carry the new concrete arch. In order to get access for the construction work the creek water was pumped through pipes suspended under the top of the new concrete arch. The procedures to handle the very delicate situation of replacing the foundation, while the bridge was in operation, and also protecting the environment is described in detail in the presentation. The process included high speed concrete curing, working processes under extreme narrow conditions and a very tight schedule.

1. Introduction and background

The arch bridge is carrying the main railroad across Sealand in Deanmark across a small creek – Langvad Creek. The bridge was constructed in 1854 by a British contractor.

The arches are constructed in several layers of burned clay bricks. The supporting structure are made of granite blocks. Also the wings and the façade are made of granite blocks. The foundation is constructed by 7 lines of wood piles. The top of the piles are built into a wood framework carrying the granite walls.

The bridge was original prepared for only one railroad track. In 1899 the embankment was expanded to carry two railroad tracks.

The width of the bridge is 28,5 m. The heights of the embankment is 6 m above the bridge. The clearance under the bridge is 3,2 m.

A condition survey verified that the burned bricks in the arch were deteriorating caused by freezing during the winter. Almost 2 of the 5 layers of bricks were damaged.

An inspection of the top of the wood piles and wood framework under the granite walls showed that the wood was rotten. The biodegradation was initiated caused by lowering of the water level in the area. Farmers wished to increase the use of the land for agriculture, and have drained the area.

Fig. 1. The arch bridge seen from the facade. The bricks in the arch are deteriorated. The deterioration is mainly caused by freezing during the winter.

Parallel cracks in the arch indicate that the facades of the bridge are moving outwards, caused by the pressure from the embankment.

The rehabilitation strategy was to construct a reinforced structure inside the existing bridge. The structure should supply the bearing capacity. The flow in the creek should not be disturbed, and the environment had to be fully protected. The area was preserved and drinking water was drilled out of the ground around the bridge.

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2. Construction procedures

The rehabilitation should be made without restrictions for the traffic on the bridge.

The construction site was established close to the arch in a protected area and in an area where drinking water was drilled out of the ground. Also, fish in the creek were protected. The water level should also be controlled in order not to influence the surrounding farmers.

On that in the light of the construction was planned in two sequences:

1) Construction of the walls and the arch. This part could be done while the creek was protected by a tight platform.
2) Construction of the bottom slab including removing the existing timber structure under the creek. This part had to be done in a very narrow time schedule while the fish in the creek were almost not moving – in the midsummer.

Fig. 2. A platform was constructed above the water in the creek during the construction of the new internal reinforced concrete arch. The platform did also protect the creek.

3. First sequence – the arch and the walls

Initially, the bricks in the arch were covered with a layer of sprayed concrete, and a water tight treatment was applied in order to protect the structure.

Anchors was drilled into the walls.

Reinforcement was arranged along the walls and the arch.

The casting sequence was planned so that the vertical part of walls was established in order to arrange bearing between the existing brick arch and the new concrete structure. The existing arch was not able to carry the new concrete structure. And it was not possible to support the form on the platform above the water. All the load had to be transferred into the existing walls and foundation.

Fig. 3. Binding of reinforcement inside the arch. The surface of the existing arch was covered with sprayed concrete and a water tight surface treatment, before the reinforcement was anchored to the structure.

Fig. 4. First the vertical part of the wall were cast, in order to prepare a load bearing connection. Then the arch was cast.

The formwork for the walls was prepared with standard units. The formwork for the arch was built in 20 mm plywood, cut into shape and supported by every 1,2 m. The arch shape was covered with planks and covered with a 6 mm plywood. The prefabricated formwork was placed on a sledge and moved into position under the bridge.

On top of the form a pipe stub was installed for injection of the concrete. In order to evacuate air entrapped under the arch a pipe was placed on top of the inside of the arch.

Fig. 5. Arrangement of the form for the arch.

In order to avoid cold joints in the façade, the façade was cast in the same operation as the inside arch.

Fig. 6. Reinforcement of the concrete structure for anchoring the existing façade to the new concrete structure. Placement of the formwork for the arches.

The concrete was prepared as "self-compacting" consistence with 16 mm aggregate. The concrete was pumped into the form beginning at the far end until the far façade form was filled. Then the tube was moved from one stub to the next, until the other side was reached. Finally, the second façade formwork was filled from the top of the form.

The casting procedure was succeeded in a continuous process during one day, and without any problems.

4. Second sequence – the foundation and the bottom slab

The second sequence was initiated by construction of a dam across the creek and bypassing the creek through a pump placed in the side of the creek before the dam.

Then the bottom slab of the existing structure was removed, including the rotten timber structure. Only small sections less than 2.5 m wide was done in one operation, in order to maintain sufficient load bearing capacity of the existing structure.

With respect to the environment the construction of the bottom slab had to done between July 14. and September 30. In other words the 11 sections of 2.5 m had to be made in 11 weeks.

The working schedule for the week: Monday removal of the existing bottom structure and geotechnical control. Tuesday to Thursday installation of reinforcement and Friday concrete casting. Following monday start at next section (repeat the above procedure). The strength of the concrete was tested by lok tests, based on the principle of pulling out inserts with a well-defined breaking figure.

Fig. 7. Before construction of the bottom part of the concrete structure inside the bridge, the creek under the bridge was pumped dry. A dam was established on both sides, and a sump was installed in front of the dam.

Before removing the damaged existing bottom slabs a temporary supporting structure was placed at each section with the capacity of 850 kN. The supporting structure had to be as close as possible to the working area and the bottom edge of the walls, thus allowing the crew to work underneath.

In each section the ground water had to be pumped away during demolition of the existing slab, and placing the new reinforcement, and finally filling the concrete into the form. The new high quality concrete was prepared with very high early strength – more than 40 MPa after one week. This was achieved by mixing the concrete with rapid hardening cement and a water cement ratio only 0.35, which means there was only sufficient water in the mix to supply the chemical process for the concrete hardening.

The geometry of the structure under the wall was very narrow, and arrangement of the reinforcement had to be modified during the construction because the situation was quite different from the drawings made in 1850ties.

Fig. 8. Arrangement of reinforcement of the bottom slab inside the bridge. Couplers was used to connect the reinforcement in the wall with the reinforcement in the bottom slab. Couplers was also used to connect the reinforcement between each of the 11 sections of the bottom slabs.

5 Completion

Finally, after completion of the 11 bottom slabs on time, the dam at each end could be removed. The pumping process was stopped and the fish began swimming again. 50 m downstream rocks was placed in the stream in order to regulate and modify the stream to make it more suitable for the fish.

A steel bridge for pedestrians was placed inside the bridge to make the passage accessible for promenades along the creek.

The strengthening of the structure was made, while there was full load from the train traffic above. The strengthening also prepared the structure for the Eurcode EN 1990 and 1991 requirements, quite different from the original requirements in 1850'ties.

The strengthening construction was executed with a minimum impact of the environment, the preserved area and the surrounding farmers. In fact the environment was improved with respect to the fish.

Fig. 9. The new bridge structure after rehabilitation.