Stadsbrug Nijmegen

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Summary

Due to heavy traffic around the city of Nijmegen there is a new city by-pass under construction including a new bridge over the river Waal. The city requested a City Bridge, which will allow a five lane crossing, a two lane-cycle path at the east side of the bridge and a 1.0 m wide inspection lane at the west side of the bridge. In the architectural ambition document from the city, the client also requested a convenient adjournment on and under the bridge. The main bridge over the river had to span at least 240 m, had to fit perfectly within the landscape and join the bridge family of the city. Life cycle and maintenance of infrastructure in this paper shows a different approach on the topic by presenting the design of an integral approach bridge. The structure is a new construction type, built with modern techniques and new materials with a design life time of 100 years and less maintenance costs. Completion of the bridge is scheduled for the end of 2013.

Keywords: Integral bridge, arches, design life time

1. Introduction

The city of Nijmegen decided to build a new bridge across the river Waal, to improve the accessibility to the city and traffic spreading around the city. The bridge will be built at the historical location known as “De Oversteek” (“The Crossing”), where American soldiers crossed the river to secure the existing Waal bridge during the operation Market Garden. The existing Waal bridge, dated from 1936, was at the time of completion the biggest arch bridge in Europe with a span of 244 m.

The contract to design, build and maintain the new bridge crossing the River Waal at Nijmegen has been awarded to a consortium after a design competition in 2009.

The bridge has a total length of 1,400 m. The southern approach bridge at the Nijmegen side, lays in a curvature with a radius of 500 metres. The main span crosses the river Waal in a straight line, while the northern approach bridge is in a horizontal curvature of 2,000 metres.

Fig. 1: Plan view of the bridge

Fig. 2: View of the bridge

The approach bridges consist of a succession of concrete arches. The spans of these arches are 42.5 m. The thickness of the arches at the columns is just under 1.5 m and in the centre of the span 0.5 m. The void above the arches is filled with foam concrete to reduce the weight on the arches and covered with mixed aggregates and asphalt layers.

At the south side the continuous bridge measures a total length of 275 m from the abutment Waalbandijk to the main pier. South of this approach bridge an integral viaduct crosses the Weurtseweg. A dam connects the Weurtseweg with the Waalbandijk.

The main span with a length of 285 m consists of a single tied arch structure. The composite roadway deck is suspended from the arch by inclined stay cables. The bridge rests on bearings at the two main river piers. A moveable expansion joint is foreseen between the single tied arch and the northern approach bridge.

The total continuous length of the side spans at the north side equals 703 m, including the abutment at the Oosterhoutsedijk. The concrete arches of the northern and southern approach bridges are rigidly connected to the bridge columns. The northern approach bridge will be one of the longest integral bridge ever built in the world.

The general width of the total bridge project is 25 m. The bridge is wider at the balconies and at two access points at the northern and southern approach bridge. On the balconies visitors can sit on benches and enjoy the view of the surroundings.

2. Design of the approach bridges

2.1 Super structure

In the tender design, the design team searched together with the architect for the best way to integrate the bridge in the landscape. Since the design life time of the bridge is 100 years, of which the contractor has a maintenance contract for the first 25 years, it is important to think about the maintenance costs. Due to the length of the northern approach bridge which is located over the river foreland and therefore is often flooded, the idea came up to design a bridge without bearings and expansion joints, to save maintenance costs. The shape of the single spans using an arch structure, allows the bridge to breath up and down due to thermal actions, as the whole structure is locked up between the abutment Oosterhoutsedijk and the main river pier. The arch fits very well in the surroundings of the river landscape and the roman style of the city.

Fig. 3: Northern approach bridge under construction

To obstruct the river as less as possible, all the bridge columns and two main piers were lined up parallel to the river axis. The cross section of the columns are shaped as rain drops and measure 2.0 x 6.0 m, are there for hydraulically well shaped, and no floating debris can pile-up in front of them. Each arch is supported by four columns, spaced 21 m in the transverse direction of the bridge and 42.5 m in longitudinal direction. The northern approach bridge consists of 15 arch spans and a half arch at the Oosterhoutsedijk which is connected to a longitudinally prestressed deck monolithically connected to its abutment walls.
Since the load of the arch is transferred to the columns, the concrete deck in transverse direction between the columns is set under tension. To meet the requirements of durability and crack width, the bridge is transversely prestressed using bonding prestressed tendons DSI 27 x 15.7 mm dia. strands – Y 1860. The anchoring points of the tendons are recessed into the concrete structure and covered with grout.

The joint of the arch with the bridge columns is heavily reinforced, since the deck is nearly 1.5 m thick and it was challenging to fit it together with the prestressed tendons at this location.

All intermediate columns are supported by concrete base slabs which are founded on in-situ concrete piles. The base slab at the main piers measure 14.0 x 40.0 x 3.0 m and is founded on 27 bored piles. Due to the heavy thrust from the arches, which enter the main river pier at 20 m height, the pile slab has an offset of 3.0 m from the pier axis, to provide the required counter stability. The main pier consists of two major columns connected at the base and the top by a beam. The tied arch will be supported by the top beam, resting on two main bearings and a centre bearing to transfer the transversal loads from the main span. At the northern main pier, the sliding bearings in longitudinal direction are foreseen, thus a modular expansion joint at this pier is required.

2.2 Design specification

The design and execution of the bridge is classified in the CC3 class according to EN 1990. The possibility of failure of the main structure can lead to:

- Loss of human lives
- Huge economic consequences in the area, e.g. the shipping traffic in the river Waal
- Major financial consequences for the city Nijmegen
- Huge social consequences for the area
- Major environmental impact

According to many international publications, such as [1], it is shown that the failure of a structure is caused for 50% by design mistakes and 25% is caused during the erection. Such human failures are not covered by raising a design load factor or material factor. In compliance with the client a decision was made to fulfil the CC3 requirement by an extra quality control on the design and execution of the bridge. Therefore it was possible to classify the bridge in a CC2 consequence class, which equals a reliability index $\beta = 3.8$. The supervision for the design and engineering level is classified in class DSL3, which will be executed by an external independent organisation.

Besides the above mentioned quality inspection level, the client has chosen an extra inspection level by TIS (Technical Inspection Service). The TIS is hired by the client during the design, engineering and execution phases. The main core for TIS is to minimise the hidden failures after completion of the bridge, and also helps the client to check the design documents on possible risks. Also will TIS check the constructions safety, reliability and durability of the bridge structure.

2.3 Robustness

The bridge structure is designed according to the design loads from the EN 1992-2. Besides the standard and accidental loadings, the bridge has to fulfil the requirements that can lead to progressive collapse of the structure. According to the EN 1990 the structural design must contain enough resistance and redundancy to withstand all the loadings. The choice of a type of construction that can withstand a failure of a structural member is one of the measurements from the EN 1990. Since the failure of one of the structural members will directly lead to progressive collapse, i.e. failure of a pillar or deck section, all accidental loadings have been investigated that can actually lead to progressive collapse. These loadings include, ship impact from the navigation channel on the main piers, ship impact on the columns from the sub channel, extraordinary settlement of the bridge columns, fire caused by traffic under the bridge and explosion under the by-pass at the abutment. To design the bridge on this accidental loadings, it is shown that the robustness of the bridge is well proven and the risk of a progressive collapse during the life time is limited to a minimum.

During the erection of the bridge, special measurements have been applied to prevent progressive collapse.

2.4 Road structure

For the filling of the arches, foam concrete was chosen to be the best suitable. Since foam concrete is generally used for road structures or as a filling material, not much was known about the general behaviour and fatigue.

The foam concrete has to carry the traffic loads downwards to the concrete arches and be able to follow the deflections of the arches caused by traffic loads and thermal effects. Additional material and fatigue tests were independently carried out. With the positive results from these tests, it has been proven that the foam concrete is able to resist the loadings and deflections of the bridge for its 100 year design life time.

Rainwater falling on the road surface is led to swirl units which are positioned next to the road barriers. Drain pipes transport the water under the roadway to drainage units, which are positioned above each bridge column at the east side of the bridge. The first 4 mm flush will be filtered in the unit, before it will be drained by pipes through the columns on to the river and river foreland.

Rainwater that will seep through the water resistant asphalt layer and reach the foam concrete, will be transported sideways to the abutment walls. On these walls a drainage mat will transport the water to the deepest point of the bridge where it will enter a gravel layer at the base of the each arch which is situated in the transverse direction of the bridge. The collected water will than flow to the vertical drainage pipes in the columns.

2.5 Masonry structure

All the outer and inner walls of the concrete bridge structure will be foreseen with brickwork. This prevents gravity painting and gives the bridge a very natural look in the river landscape.

The brickwork has no structural function, other than to resist the wind loading and impact loads from cyclists and pedestrians. Test have been carried out to determine the number off anchors needed to support the brickwork.

Fig. 4: Brickwork at the Oosterhoutsedijk

2.6 Durability

The durability is covered and secured by the right concrete mixture in relation to the normative environmental classes. The quality of the concrete cover ensures the required lifetime of 100 years. The concrete cover on the columns surface requires a higher value, because the surface will be roughened after completion of the columns because of architectural design matters. All anchors that will be drilled in the concrete surfaces are made of stainless steel.

3. Erection of the bridge

The pile caps and the columns are made using a steel form work. The spans between the columns are poured in two phases. The first phase was the erection of the hammerhead spanning the two columns in transverse direction. This was also in advantage to install and prestress the tendon cables, before the deck sections where connected.

Fig. 5: Columns, hammerheads and falsework

The construction of the arches between the hammerheads was carried out on a supporting truss arched falsework structure, covering an area of more than 1,000 m^2 for each span (fig. 5). The falsework consisted of three single sections with a span of 40 m, weighing 100 tons each. The three sections where mounted on the ground to one big unit, weighing 300 tons, and then hoisted by a jack system from the hammerheads into position. Steel columns placed between the falsework arches and the pile caps supported the falsework. Each deck was cast as one concrete unit with a quantity of nearly 650 m^3 in quality C35/45. To keep the bridge stable during the construction stages, three of those falsework sets where needed.

As soon as two arches where cast and the concrete hardened, a prestressed tensioning system of bars and beams, spanning between two arch crests, was set in place to take over the thrust force from the arch, which came into action as the falsework was removed. Each span required ten of those beam structures (Fig. 6).

Fig. 6: Prestressed beams between the crests

Fig. 7: Prestressed tendons at PN7-PN8

Between the axis's PN12 – PN13 and PN7-PN8 temporary diagonal prestressed tendons where installed to act as a stopper and prevent progressive collapse (Fig. 7). Since the cables took over the thrust forces from the arches, it was possible to remove the prestressed tensioning beams and reuse them for the following arches. For the erection phases of the bridge a detailed monitoring plan was introduced with the expected horizontal deformations of the columns caused by the thrust forces of the arches. According to this plan a detailed survey has been carried out, which showed that the horizontal deformations were all within the expected values.

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