Reinforced concrete pylon with cable-stayed tensioning and suspended roadway during the construction phase.

Allplan in practice

THREE CENTURIES OF BRIDGE BUILDING OVER THE FIRTH OF FORTH

The Queensferry Crossing near Edinburgh in Scotland is a cable-stayed bridge with three pylons over 200 m in height. It is one of the largest infrastructure projects in Europe and benefitted from ultra-modern reinforcement planning in 3D thanks to the engineers from Leonhardt, Andrä und Partner (LAP) and Allplan Engineering.

A special kind of infrastructural requirement can be found in central Scotland at the Firth of Forth estuary. Three bridges in the immediate vicinity of each other span an estuary here, which reaches about 80 kilometers inland. The Forth Bridge, a steel bridge from 1890, has served rail traffic at this point. The Forth Road Bridge is a suspension bridge built in 1964 and from the summer of 2017 is to be used exclusively for bus, bicycle and pedestrian traffic. The new Queensferry Crossing bridge now supplements these two bridges. It will be used for road traffic alone, with two lanes and an additional hard-shoulder in each direction. Whilst the Forth Road Bridge was designed and implemented by means of manual drawings on paper, reinforcement and execution plans for the Queensferry Crossing were created three-dimensionally in Allplan Engineering.

The Queensferry Crossing is one of the largest infrastructure projects in Northern Europe.

THE CHALLENGE

Transport Scotland's consultants from the Jacobs Arup joint venture were not given an easy task in developing a concept for the new bridge. The bridge has to be an equal counterpart to the world cultural heritage of the "Forth Bridge." The engineering office Leonhardt, Andrä und Partner took care of the tendering, design planning and assembly calculation (in a joint venture with Rambøll, Gifford und Grontmij). The result of the previous design process was a 2,094.5 meter long cable-stayed bridge with three pylons in the water.

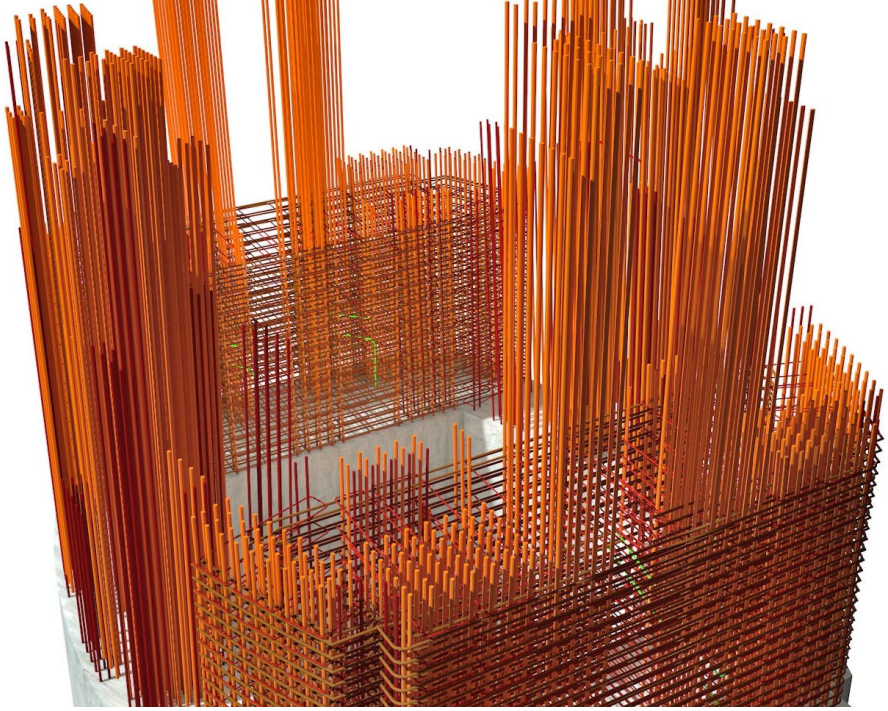
A main span width of 650 meters stretches between each of these up to 210 meter high reinforced concrete towers. These dimensions result from the width of the underlying shipping channels. The spans of the side sections are 223 meters and the foreshore bridges are 104 meters. The middle pylon of the three pylons proved to be structurally particularly challenging. In the case of traditional cable-stayed bridges, the center pylon is back-anchored via rigid side sections located at the edge. However, this approach is not possible with a three-pylon bridge due to the very high bending moments. In addition to this limitation, the bridge should not appear excessively dominant in the context of the two structures that already exist.

THE SOLUTION

The planners achieved the back-anchoring of the central pylon by overlapping the stay cables by 146 meters in the middle of the respective section. This special feature of the structure achieved the necessary stabilization and at the same time allowed for a sophisticated and visually appealing bridge construction.

The three striking reinforced concrete pylons taper from the upper edge of the foundation to the tip from 14 x 16 meters to a slim 7.5 x 5 meters. To plan the pylons, LAP created a complete 3D reinforcement model with Allplan Engineering. This was the first time this working method was used for a bridge of this magnitude and it was extremely challenging. The reinforcement of the individual pylon segments had to be placed precisely in the space due to the upward-tapering cross-section. This method placed high demands on the CAD software used. That is why planners from LAP also relied on Allplan Engineering for the reinforcement and design planning and on the routine of their subcontractor CHP.

Similar to the pylons, the superstructure also has a sophisticated shape, which bears the roadways on each side. The superstructure is in three parts in the areas of the pylons and the cable guying. While



Rendering of one of the 210 meter tall pylons of the Queensferry Crossing.

the superstructure is monolithically integrated in the middle pylon, it is penetrated by the two outer pylons and is supported on them by means of a transverse abutment. This supporting scheme prevents large distortion between the pylons.

Foundation and installation

The middle pylon of the cable-stayed bridge was built into Beamer Rock in the middle of the Firth by means of a sheet pile box. The lateral pylons are installed up to 40 meters deep with wedge boxes. The pylons were concreted in an inner and an outer climbing formwork. A riser with up to 200 bar was required to be able to transport the concrete up to the top of the pylons. Floating cranes and transport pontoons were used since the building site was largely located on the open waters of the Firth of Forth. The largest part of the reinforcement was prefabricated in the nearby port of Rosyth and then had to be lifted on site with the tower crane.

The Queensferry Crossing is the largest bridge for which 3D reinforcement planning was entirely created using Allplan Engineering. It was possible to meet deadlines and costs thanks to accurate and collision-free planning.

The Queensferry Crossing was officially inaugurated by Queen Elizabeth II on September 4, 2017. On September 2-3, 2017, 50,000 guests, who were successful in the ballot, were allowed to cross the bridge on foot.

- **Accurate and collision-free reinforcement planning thanks to Allplan Engineering**
- **Decentralized execution of the project thanks to the exchange capabilities of Allplan Engineering.**
- **Compliance with all planned delivery deadlines thanks to Allplan Engineering**

Client: Transport Scotland
Construction companies: Forth Crossing Bridge Constructors (HOCHTIEF, American Bridge International, Dragados and Morrison Construction)
Planning: Leonhardt, Andrä und Partner, Rambøll, Gifford and Grontmij

"With its 3D reinforcement module, Allplan provided us with excellent support in the construction design so that precise collision-free reinforcement detailing could be provided at the building site while meeting all delivery deadlines."

Andreas Hartung, head of the reinforcement team for the pylons as a subcontractor for LAP-Consult/Germany

THE CUSTOMER

The globally active engineering office Leonhardt, Andrä und Partner (LAP) already specialized in structural engineering during its beginnings under Fritz Leonhardt. This resulted in today's orientation of LAP. Then as now, one of the main focuses of the firm is the construction of bridges and buildings made of steel and reinforced concrete.

This has resulted in many outstanding engineering projects, including the Stuttgart TV tower (1955), the Olympic roof in Munich (1971), the Galata Bridge in Istanbul (1985), the Transparent Factory in Dresden (1999) and now the Queensferry Crossing (2017).

ABOUT ALLPLAN

ALLPLAN is a global provider of BIM design software for the AEC industry. True to our "Design to Build" claim, we cover the entire process from the first concept to final detailed design for the construction site and for prefabrication. Allplan users create deliverables of the highest quality and level of detail thanks to lean workflows. ALLPLAN offers powerful integrated cloud technology to support interdisciplinary collaboration on building and civil engineering projects. Around the world over 500 dedicated employees continue to write the ALLPLAN success story. Headquartered in Munich, Germany, ALLPLAN is part of the Nemetschek Group which is a pioneer for digital transformation in the construction sector.

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