El nuevo puente urbano en Drammen (Noruega)

The new City Bridge of Drammen (Norway)

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RESUMEN

El nuevo Puente de la Ciudad de Drammen es un puente urbano de 259 m de longitud que cruzará sobre la estación de ferrocarril y sobre el río. Esta nueva estructura, que sustituye al puente existente, conectará las principales zonas de la ciudad, Strømsø al sur y Bragernes al norte. El nuevo puente es una estructura mixta, que salva en total ocho vanos sobre las vías de ferrocarril y sobre el río Drammen, y que tiene una luz máxima en su vano central sobre el río de 86 m.

ABSTRACT

The new City Bridge of Drammen, known as Bybrua in Norwegian, is a 259-meter-long urban bridge that will span both the railway station and the river. Replacing the existing bridge, this new structure will serve as a vital connection between the city's main districts—Strømsø to the south and Bragernes to the north. Designed as a composite structure, the bridge features eight spans crossing the railway tracks and the Drammen River, with its longest span measuring 86 meters at the center of the river.

PALABRAS CLAVE: Puente urbano, estructura mixta, puente fluvial, secuencia de montaje, cargas de hielo, BIM.

KEYWORDS: Urban bridge, composite structure, river bridge, erection sequence, ice loads, BIM

1. Introduction

The existing city bridge in Drammen at nearly 90-years old (Figure 1) had exceeded its life expectancy. Retrofitting the structure would have entailed substantial costs and high maintenance expenses.

In addition, the railway station located to the south side below the existing bridge needed to be expanded as part of a major infrastructure renovation scheme led by BaneNOR, the state-owned company responsible for the Norwegian railway infrastructures. As a result, the rail tracks will be raised by 0.50m and larger clearances under the bridge are necessary for new trains, affecting the road alignment.

Due to these factors, the city of Drammen decided to replace the old bridge with a new one connecting the same districts.

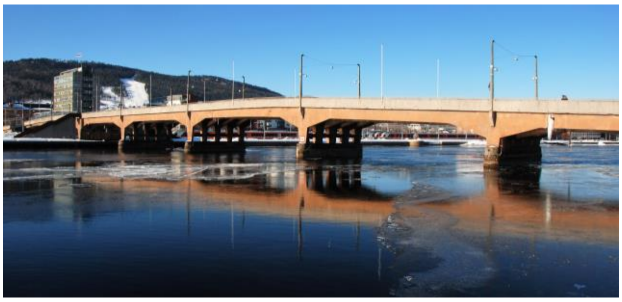

Figure 1. Existing Drammen bridge

2. The winning design

The open competition system proposed by Drammen's Municipality to select a bridge design followed the parallel assignment approach. Several design teams worked simultaneously to present different ideas for the bridge project and the city embankments. The Owner chose the best overall concept from one group and added some ideas from the proposals from other teams to improve the quality of the final design. The team chosen for the detailed design consisted of Degree of Freedom (NO) as the engineering firm, SAAHA (NO) and Knight Architects (UK) as the architectural firms, and Asplan Viak (NO) as the landscape architects.

The final design concept (Figure 3) considered construction constraints related to the soil conditions, the position of the existing bridge piers to be used during the erection sequence, structural efficiency and of course the overall aesthetics and urban integration.

3. Description of the bridge

The new bridge begins at the station square on the south side of the river, in Strømsø, extending 84 meters over the Drammen Rail Station, before spanning the 170 meter wide Drammenselva river and connecting to Bragernes square on the north bank. The first five spans ranging from 14.5 to 19.5 meters in length, cross six railway tracks and four platforms at Drammen's Rail Station in Strømsø. The three spans crossing the Drammen River measure 46, 86 and 42 meters leading to Bragernes (Figure 4). The bridge's horizontal alignment is straight, and the vertical road alignment curves with a maximum slope of 6.7%.

The new bridge features a 19.4-meter-wide deck, an increase from the existing 15-meter deck (Figure 2). It accommodates a 6.98-meter-wide, two-lane roadway, two spacious pedestrian walkways (4.8 meters and 2.8 meters), and two cycle paths, each 2.2 meters wide.

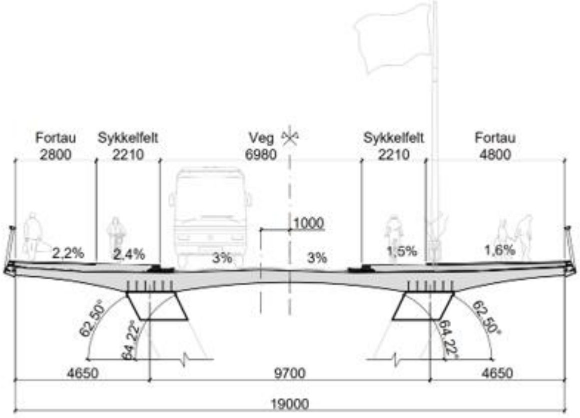

Figure 2. Deck cross section

At axes 1 and 9, on both riverbanks, there are inspectable abutments made of reinforced concrete. They are large enough to house the technical rooms for the numerous services installed along the bridge.

From axis 1 to 6, the bridge's superstructure consists of a 19.4-meter-wide reinforced concrete deck with a vaulted soffit, varying in thickness from 300 mm to 650 mm. It is supported by five transverse V-shaped steel piers, ranging in height from 3.9 to 7.2 meters. These piers also serve as support for the access stairways leading to the railway platforms.

From axis 6 to 9, the bridge transitions into a composite structure**.** The concrete slab remains similar to the reinforced version but is now connected to two longitudinal steel box girders**,** spaced 9.7 meters apart, using headed studs as shear connectors. These girders converge with two steel arcades, inclined at 63°, which connect to piers 7 and 8 in the river. The bridge's steel framework primarily consists of built-up cross-sections with a parallelogram shape.

The piers at axes 7 and 8 (Figure 4) are built within the river and made of reinforced concrete with hydrodynamic round edges. Pier 7 measures 3 meters wide by 6.5 meters long**,** while pier 8 is 3 meters wide by 8 meters long. Both piers stand 8.5 meters high, with their lower sections featuring pyramidal plinths designed to enhance the performance of the piled foundations. At the top, stepped capitals extend above the water surface, contributing to the bridge's aesthetic appeal.

The bridge superstructure is fixed to the pier at axis 7 using a stiffened base plate and anchor bolts, making it the longitudinal fixed point of the bridge, reflected in its large, piled foundation. Axes 1 to 6 and 9 feature pairs of POT bearings, which are guided on the upstream alignment and free on the downstream side. At axis 8, the steel arcades are supported vertically by two free-sliding spherical bearings. Additionally, a shear key at the center of Pier 8 restricts transverse movement and helps resist occasional large drifting ice loads. Spherical bearings were chosen for their proven durability compared to alternative bearing solutions.

The bridge's foundations consist of reinforced concrete pile caps supported by steel piles driven to the bedrock. The piers at axis 7 and 8 in the river will be constructed using cofferdams. There are challenging ground conditions (soft clay), with a great depth to the rock – approximately 45 meters for the northern foundations at Bragernes and 80 meters at axis 7.

Figure 3. Daytime visualization of the new city bridge

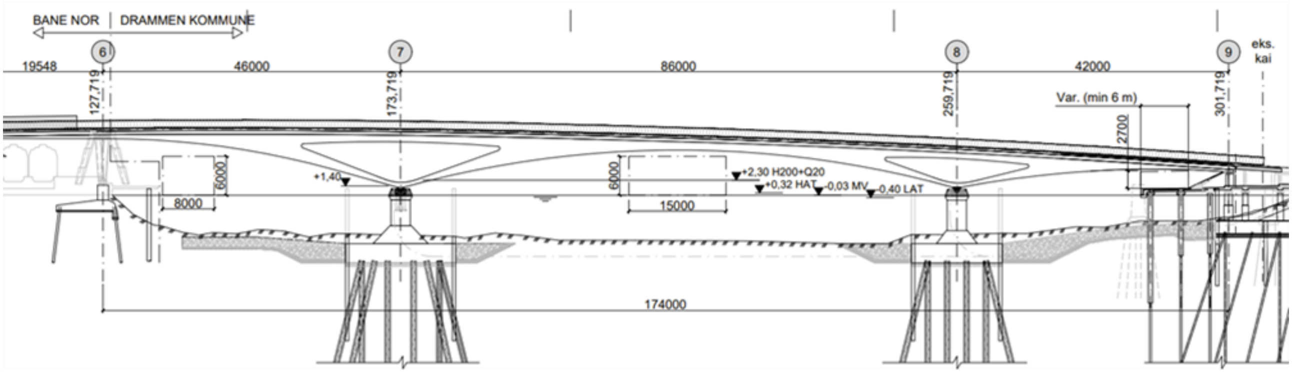

Figure 4. Elevation of the bridge over Drammen River

4. Structural challenges

4.1 One bridge, two administrations

Although the bridge is a single structure, it is divided into two sections, each managed by a different authority. BaneNOR (the Norwegian Railway Authority) was responsible for the section over the railway, while Drammen Kommune oversaw the section spanning the river.

Drammen Kommune will eventually take over the maintenance of the entire bridge. To minimize future maintenance efforts the municipality requested a continuous bridge deck between the two abutments, without any expansion joints between the sections over the railway and over the river. While this decision eliminates maintenance concerns related to expansion joints, it required close coordination between the two engineering teams, particularly regarding the Finite Element Model (FEM) features and analysis results.

4.2 Challenging longitudinal alignment

One of the key challenges the team had to address was to achieve a comfortable road alignment despite the site's constraints. During the optimization phase, the team had to strike a balance between an arch-like structure which naturally aimed to be as tall as permissible, and mobility requirements, which demanded a lower alignment to seamlessly connect with the existing roads at both ends.

The resulting road alignment successfully achieves a smooth geometry that gently ties into both abutments while maintaining a comfortable gradient of less than 5% over more than 80% of the span. This design is advantageous for cyclists and bridge users with limited mobility, as it reduces the effort needed to cross the bridge. Additionally, it helps cut CO_2 emissions by easing the incline for buses.

4.3 Poor ground conditions

The significant depth to bedrock and the poor quality of the soft clays above it were somewhat unexpected results from the ground survey. As a result, the piles had to be driven to depths ranging from 45 meters down to 80 meters. Moreover, since the resistance and stiffness of the piles and pile caps became a key design parameter, the foundations at axes 7 and 8 were determined through an iterative process. This process involved the reactions and displacements from the FE model of the superstructure, the derived foundation dimensions, and the stiffnesses provided by the substructure design based on those dimensions.

4.4 Large Ice Loads

Ice load actions (Figure 5) were applied to the concrete piers and steel columns. Three main effects were considered: drifting ice loads in the longitudinal direction, expansion ice forces in

the transverse direction and vertical forces due to ice.
Ice loads have been estimated according to the Norwegian codes SVV Handbook N400 [1] and Handbook N200 [2].

Figure 5. Floating ice on Drammen River

Based on local conditions, three possible drifting ice load cases were considered, combining different scenarios of ice thickness and water level, in order to maintain a similar overall probability of occurrence. The horizontal forces on the steel columns due to this action were defined as follows:

- A force of 3700 kN, associated with the 100-year ice thickness (0.56 m) combined with the 1-year return water level (+1.50 m).
- A force of 5000 kN, associated with the 10-year ice thickness (0.44 m) combined with the 10-year return water level (+1.80 m).
- A force of 4700 kN, associated with the 1-year ice thickness (0.26 m) combined with the 100-year return water level (+2.10 m).

5. Bridge structural design

5.1 Materials

The following materials were considered in the design:
- Reinforced concrete: Used for the abutments, pile caps, piers, plinths, and deck slab. Concrete class B45 was used in conjunction with B500NC reinforcement steel.
- Structural steel: Used for the deck. Steel type S355ML in accordance with NS-EN 10025-4.
- Headed studs: S235 J2 + C450 steel in accordance with EN 100025.
- Anchor bolts: Type DYWIDAG, quality Y1050H in accordance with NS-EN 10138-4.
- Spherical bearings and shear key at axis 8: Designed according to NS-EN 1337-7:2004 and NS-EN 1337-8:2007.
- POT bearings at axes 6 and 9: Designed according to NS-EN 1337-3:2005.

5.2 Foundations design

The foundation design for the river supports presented a significant technical challenge due to the poor ground conditions, in order to guarantee the stability of the superstructure and to transfer the loads to the soil and the deep bedrock.

The bedrock depth varies from approximately 40 meters to 70 meters, being deeper on the Strømsø side. The ground layers generally consist of clay and silty clay down to the rock. Additionally, there is a thicker layer of moraine above the rock close to the Strømsø side.

To transfer the large vertical and important horizontal forces imposed by the bridge supports, a system of steel core piles, some of which are inclined, was used. These piles are drilled to the rock and connected by a large pile cap cast under the river pier supports. The pile cap has dimensions of 16 by 20 meters and a thickness of 3 meters, and it will be constructed below the riverbed. The pile caps are surrounded by a permanent underground sheet-pile cofferdam, which allows construction within the water flow and improves the lateral resistance and stiffness of the system throughout its service life.

5.3 Structural modelling

Several finite element models (FEM) were developed to account for the complexity of this composite structure, considering factors such as the erection method, composite action and shear connection, slab effective width, long-term properties of the concrete, cracking, boundary conditions of the supports, and the local and global stability of the steel elements. These FEM included both global and local models, created using SAP 2000 software.

Global models were developed to verify global stability, design the steel and concrete elements, assess ultimate limit states (ULS) and serviceability limit states (SLS), and obtain reaction forces for the foundation design.

To account for uncertainty and variability in the soil-structure interaction of foundations, the bridge was analyzed in two different scenarios: soft soil and stiff soil conditions. This led to the creation of a separate FE model for each scenario. As a composite structure, cracked regions are generated in the concrete deck. Cracked and uncracked models were assessed and combined with both soft and stiff soil models. Consequently, four global FE models were developed.

These global FEM were evolutive incorporating the history of forces during the erection sequence, persistent situations in the short-term, the effects of shrinkage and creep in the long-term and the seismic design situation. The steel elements were modelled using frame (beam) elements, with thin-wall box sections (composed of 4 thin plates).

Figure 6. Render of the new bridge over the river Drammen

The concrete deck was modelled using shell elements with torsional stiffness neglected. The deck elements were connected to the steel elements to simulate the composite action.

The global model includes linear springs to model the soil-foundation interaction, support points on the temporary supports during the construction phases, and bearing supports at all axes. For the spherical support, rotations and horizontal movements are released and transverse movement is restrained due to the shear key.

5.4 Local models of the supporting points

The joints between the steel structure and the concrete piers at axes 7 and 8 were designed using a local FE model (Figure 7). The following design verifications were performed:

- ULS verifications: Yielding patterns were obtained using the Von Mises criterion. The plates could yield completely.
- SLS verifications: Yielding was analyzed using the Von Mises criterion. The analysis ensured that the plates do not reach the plastic range.

- Brittle fracture: The maximum tensile stress was limited to $0.75 \cdot f_y$ in accordance with NS-EN 1993-1-10.

Due to limitations on the steel plate thickness imposed by fracture toughness and weldability requirements in accordance with NS-EN 1993-2, longitudinal plates and additional web plates were required.

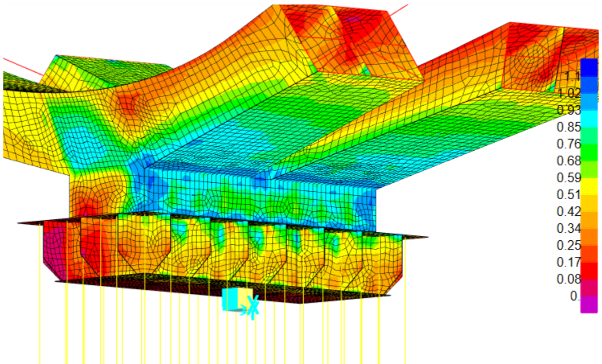

Figure 7. Joint support at axis 7. Plate stress for ULS combinations.

6. Coordination with other disciplines. Use of BIM.

All disciplines, starting from the preliminary design stage, have shared information via a global BIM model (Figure 8). This model was used to perform clash tests and for interdisciplinary coordination. The BIM model goes beyond simple 3D geometry by incorporating metadata, or information, about the structure, enhancing its functionality beyond just geometric and visual aspects. It enables better planning, multidisciplinary collaboration, design, clash detection and construction, thus improving efficiency and reducing risks.

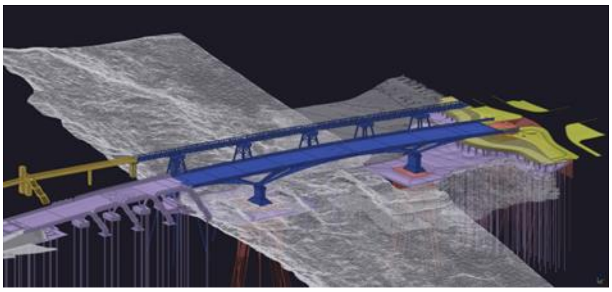

Figure 8. BIM model of the complete project

7. Proposed Erection Method

To overcome the potential problems imposed by the connection with the segment of the bridge over the railway lines (designed in detail by Norconsult engineers, on behalf of BaneNOR) and particularly the limitations due to the poor geotechnical conditions, it was essential to study carefully the construction sequence and the restraint conditions under the steel superstructure. The proposed construction method involved erecting two half-bridges in equilibrium from both riverbanks, without connecting them at the central span until the total self-weight of steel and concrete was in place. This operation was facilitated by using the existing bridge foundations to place temporary supports in the river supporting the large steel elements until they are fully connected. The final bridge segment to be executed is the connection between the bridge over the railway and the bridge over the river, ensuring no permanent load effects between the different sections.

This method helps minimize the horizontal reactions at the river bridge supports, and consequently at the foundations beneath them for permanent loads. To further reduce the horizontal loads at the foundation for variable loads (mainly traffic, temperature, and transverse ice loads) and to reduce the cost and the risk associated with deep foundations under the riverbed, it was decided to place two longitudinal sliding spherical bearings between one of the concrete river piers and the steel superstructure.

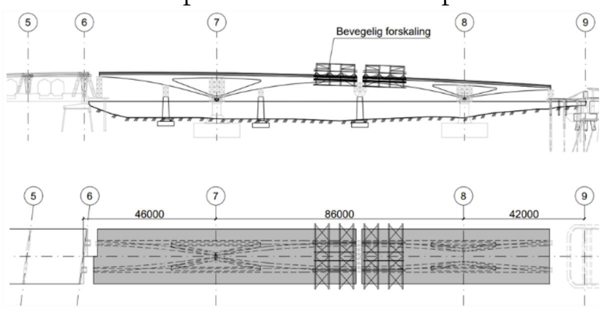

Figure 9. Key stage of the construction sequence

8. Conclusions

Despite the significant technical challenges posed by the location and the initial geometric constraints, the team successfully delivered a safe and elegant structure that is set to become a landmark for Drammen's central city bridge—all within a reasonable cost.

The construction of this type of bridge in the city center offers an opportunity to look toward the future and rethink the relationship between infrastructure and the built environment, emphasizing its positive impact.

To date the construction is well advanced and the bridge is expected to be completed in 2026. The design team has been carefully monitoring the construction process and is eager to document the lessons learned along the way.

Acknowledgements

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