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Advanced layout of a steel bridge - Ullevaalskrysset footbridge

Andri Gunnarsson[1] and Magnús Arason[1]

[1]EFLA Consulting Engineers, Höfðabakki 9, Reykjavík 110, Iceland

E-mail: andri.gunnarsson@efla.is

Abstract. The Ullevaalskrysset Footbridge replaces two temporary and ageing truss girder bridges across a busy road intersection with a single, modern steel structure, shaped to suit the requirements of pedestrians and cyclists. Different layouts and bridge types were examined by EFLA in the conceptual phase, resulting in the client choosing a steel box girder bridge with cantilever ribs stretching out from a continuous spine. The bridge is constructed of four ramps with fairly constant construction height and span lengths. The ramps connect to the main spans of the bridge across the two roads at an intersection. The height of the cross section varies across the main spans. A pair of V-shaped steel columns support the bridge. The four ramps join up in an integration zone with increased width to allow for safe intersection of the flow of cyclists and pedestrians in all four directions. The steel bridge has a total length of 290 m in 18 spans and the total width of the structure is 7,2 m. The longest span is 37,5 m, over the main highway (Ring 3), and 27,5 m, over a side road. Tuned mass dampers are installed in both spans to secure acceptable comfort for pedestrians. Practical aspects of steel as a structural material, are widely integrated in the design, resulting in light structure with seamless flowing aesthetic.

1. Introduction

The bridge site is in Ullevaal, a northeastern district of Oslo, Norway, at the busy road intersection of Ring 3 and Sognsveien. The Ullevaal district is a trafficked area, heavily used by motorist, pedestrians, and cyclists. Various infrastructure landmarks such as the University hospital, University of Oslo, several colleges, and the national football stadium, Ullevaal, are located in the vicinity of the site [1].

The principal aim of the project is to replace the existing bridges at the site, shown in Figure 1, and thereby improve the accessibility, safety and capacity for the pedestrians and cyclists in the area. The project has also been aimed at providing a bridge structure with aesthetic qualities. The existing bridges no longer meet the requirements of pedestrians and cyclist with ramp slope of 1:10 as well as being only 2,5 m wide. The bridges also tend to oscillate when exposed to high traffic load.

The Ullevaalskrysset Footbridge, shown on Figure 2, replaces the ageing truss girders with a single, modern steel structure, shaped to suit the requirements of pedestrians and cyclists.

A preliminary design phase for new bridges was carried out in conjunction with areal planning in 2008. This focused on a post-tensioned concrete bridge. However, the design work was put on hold and was not resumed until January 2015. At that point, EFLA Consulting Engineers, in cooperation with BEaM architects, were engaged by the Norwegian Road Administration to compare steel and concrete based bridge solutions, devise new alignments for the bridges and subsequently to prepare the tender design of the favoured alternative.

The bridge is a steel box girder bridge with cantilever ribs stretching out from a continues spine. The steel bridge has a total length of 290 m in 18 spans and the total width of the structure is 7,2 m (free width 6,0 m). The bridge is constructed of four ramps with fairly constant construction height and span lengths. The ramps connect to the main spans of the bridge across the two roads at an intersection. The longest span is 37,5 m, over the main highway (Ring 3), and 27,5 m, over the Sognsveien secondary road. The height of the cross section varies across these main spans and tuned mass dampers are installed in both spans to secure acceptable comfort for pedestrians. Pairs of V-shaped steel columns support the bridge. In turn, the columns are supported on pile caps founded on composite piles, i.e. steel tubes filled with concrete, extending 20-45 m down to bedrock.

Figure 1. The ageing truss girder bridges of today.

Figure 2. The new Ullevaalskrysset footbridge (rendering by BEaM).

The tender design was finalized in the spring of 2017 and a tender was opened in the summer of 2017, resulting in the appointment of a contractor in October 2017. The construction work started in November 2017 and planned completion of the construction project is in late 2019.

2. Ullevaalskrysset area and background of the project

The bridge, currently situated at the site, were constructed as preliminary structures in 1992 in conjunction with large road and tunnel projects in the area. Work on the revision of the areal planning started in 2007 and completed in 2012, defining the footprint for a new bridge [2].

The existing bridges are heavily used by pedestrians and cyclists, commuting to and from the large infrastructure landmarks in the area and the bus stops at both sides of Ring 3. Furthermore, the cycling routes along Ring 3 and Sognsveien are part of the main cycling network in Oslo [2].

The bridges are narrow, only 2.5 m wide, which results in low capacity and danger of collisions between pedestrians and cyclists. Their ramps slope 1:10 without landings, making them unsuitable for the disabled. The bridges also tend to oscillate when exposed to high traffic associated with events at Ullevaal stadium, making users feel unsafe.

The cycling route across Sognsveien is currently at a zebra crossing, very close to the Ring 3 slip road. This causes danger of collisions between motorists and cyclists crossing the road due to limited visibility and high speed of both parties. In addition, using the existing bridge to cross Ring 3 on a bicycle is currently very tricky, leaving a gap in the defined cycling route along Sognsveien at this point.

3. Design criteria

The main design criteria were to increase the traffic safety, capacity and accessibility for pedestrians and cyclists at the Ring 3 – Sognsveien intersection.

To this end, the bridge has a free width of 6 m width between railings, defined as a 3.5 m wide cycling lane and a 2.5 m wide footway separated by a 20 mm high curb. Maximum longitudinal slope is 7% and the vertical clearance above the road surfaces is to be 4.9 m at minimum.

The design load criteria included the following:

- Pedestrian load according to NS-EN 1991-2.
- Vibrations from pedestrians should be accounted for according to SÉTRA Guidelines
- Wind load according to NS-EN 1991-1-4. Base value of v_b = 22 m/s.
- Temperature load according to NS-EN 1991-1-5
- Collision load according to NS-EN 1991-1-7

The new bridge crosses a busy highway, Ring 3 (60.000 vehicles/day) and Sognsveien (12.000 vehicles/day) in Oslo. High emphasis has therefore been put on defining a structural solution which minimizes the effect on the motorists in the construction phase. This also highlights the need for a structure with a low maintenance demand, especially where the bridge crosses the roads.

There are also various other constraints that affect the choice of solution. Distance to bedrock is 20-45 m and the soil mainly consists of sensitive clay which makes for a challenging foundation design. There is a lot of various technical installations in the ground, including drainage, electrical and telecommunications, leading to a requirement for relocation of cables and/or pipes at all the 19 bridge foundations. The areal planning of the site also entails various challenges as it was developed assuming a narrower bridge of smaller footprint compared to the final design. A time-consuming re-evaluation of the planning process, with new width criteria for the bridge, was not an option within the project framework.

4. Conceptual phase and choice of solution

The conceptual phase took place in the winter of 2015 with the main objectives of defining a solution in terms of plan and profile and bridge type. The main criteria for the choice of solution where cost, feasibility, functionality, traffic safety for the pedestrians and cyclists, effect on infrastructure in the ground, operation and maintenance, environmental impact, aesthetics and effect on the motorists.

Several alternatives were considered for the bridge alignment in plan, resulting in the selected alternative which is shown on Figure 3. The chosen layout has four adjacent ramps which connect in a large integration zone at the centre of the bridge. This is where pedestrians and cyclists coming from all four directions will intersect each other in a safe manner. There are also two stairs which connect two of the main bus stops in the area to the bridge. The chosen plan layout defines the basic geometry for the bridge, i.e. a total width of 7.2 m and a total length of 290 m which is divided to 18 spans. The spans on the ramp sections vary from 14 to 18 m in length while the two main spans above Ring 3 and Sognsveien are 37.5 m and 27.5 m long respectively.

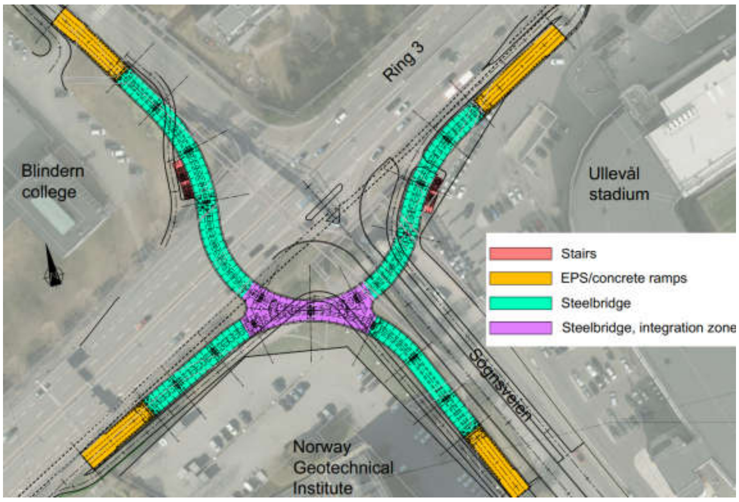

Figure 3. Plan view for the bridge.

A pre-design phase was carried out in 2008, resulting in a proposal for a post-tensioned concrete bridge. However, when the design recommenced in 2015, the client also wanted to explore the alternative of a steel bridge. Both alternatives where considered for the same layout.

For the concrete bridge, a post-tensioned beam with an elliptically shaped underside was considered as shown on Figure 4, while the three following sub-alternatives where considered for the steel bridge:

- A cable stayed bridge where the two main spans are supported by the main cables and the stay cables are attached to two of the ramps. The proposed cross section is shown on Figure 5. A pylon was then planned at the centre of the bridge which would also support the intersection zone of the bridge.
- A girder bridge with a triangular structural edge beams.
- A box girder bridge with a box section forming a narrow spine below the deck with cantilevered ribs extending from it to support the full width of the bridge.

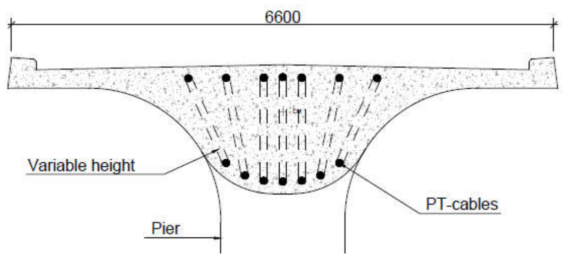

Figure 4. Cross section for the proposed post-tensioned concrete bridge solution.

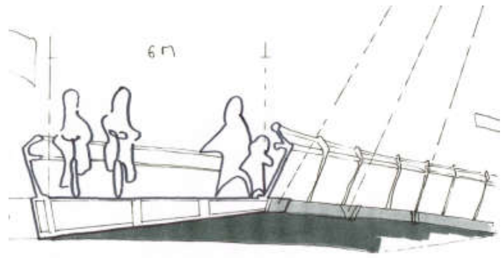

Figure 5. Cross section for the proposed cable stayed bridge solution (Sketch by BEaM).

The client eventually chose the steel box girder bridge mainly with respect to its feasibility and traffic safety during construction, along with the perceived flowing, lightweight and simple aesthetic of this bridge. Figure 6 and Figure 7 show parts of the rendering work done in the conceptual phase, visualizing the planned appearance of the bridge.

Figure 6. The new Ullevaalskrysset footbridge viewed from Ring 3 (Rendering by BEaM).

Figure 7. The new Ullevaalskrysset footbridge view from the bridge deck (Rendering by BEaM).

5. Structural system and design phase

The structural system is a box girder section running along the centreline of the bridge below deck level, see Figure 8. It has a height of 0.6 m at the ramps but varying height above the main spans, 0.9-1.2 m above Ring 3 and 0.7-0.9 m above Sognsveien. The width of the box section is approximately 1/3 of the total width of the bridge and it forms a seamless flowing spine below the bridge deck as shown in Figure 6.

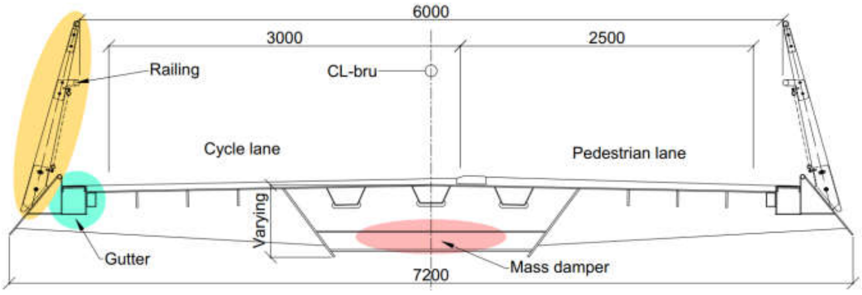

Figure 8. Principal cross section of the bridge deck.

The stiffened box section forms the main bearing element of the bridge, and the use of a stiffened box section is a widely known solution for the span lengths of this project.

Cantilevered V-shaped beams extend out from the spine at 2.3-2.5 m intervals supporting the rest of the bridge deck. At the intersection zone, the beams extend further out and connect with the beams from the adjoining bridge part. These cross beams support the large transition zone between the spines. The weight of the steel deck is varying between 1.4-2.4 tonne/m. The total steel weight is 530 tonnes. At the ends, lightweight ramps of concrete and EPS are constructed to provide connection between the bridge deck and ground level. Longitudinal sections are shown in Figure 9 and Figure 10 below.

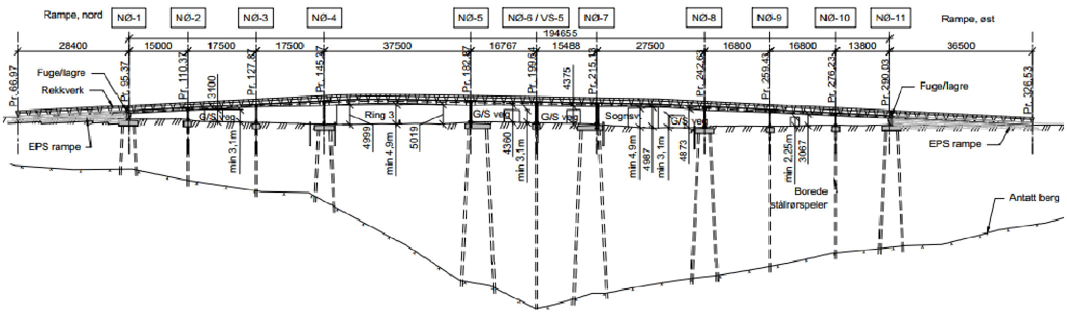

Figure 9. Longitudinal section for the bridge, stretching from the north end to the east end.

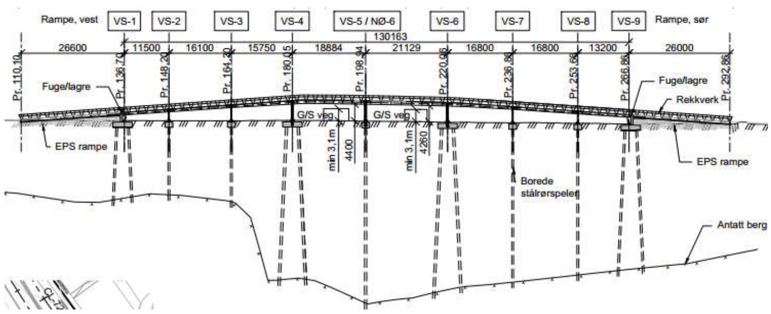

Figure 10. Longitudinal section for the bridge, stretching from the west end to the south end.

The bridge is supported by V-Shaped pairs of columns with circular cross sections. Their deck connections are pinned along the ramps to allow for thermal expansions, see Figure 11. Five pairs of columns supporting the transition zone are welded to the underside of the bridge deck to provide rigidity, see Figure 12. The bridge is supported on bearings at the ramp ends. The bearings sit on concrete abutments. Expansion joints are also integrated in all of the four bridge ends.

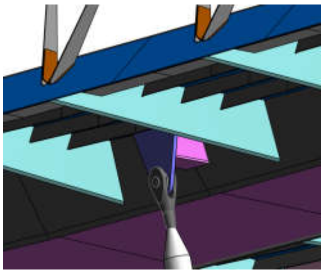

Figure 11. Pinned connection at the ramp sections.

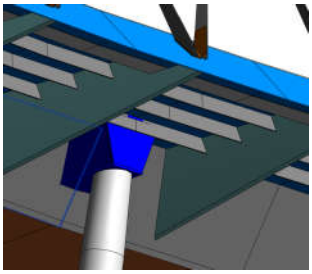

Figure 12. Fixed connection at the transition zone.

The columns are supported on concrete foundations (pile caps) which rest on Ø508-610 mm drilled composite piles (steel tubes filled with reinforced concrete) which extend to bedrock.

Some of the lowest natural frequencies of the bridge are quite close to the frequencies for pedestrians and joggers. The first horizontal mode along with the two first vertical modes for the Ring 3 span (37.5 m) and the first vertical mode for the Sognsveien span (27.5 m) are considered vulnerable for oscillation due to vibration from pedestrians and are considered in the dynamic analysis of the bridge. Models for crowd loading are used to estimate acceleration and comfort criteria. A finite element model for the bridge, constructed of linear elements in SAP 2000 (V17.2.0) and defined with the relevant foundation stiffness as calculated by the advanced pile group program (Geosuite Pilegroup), is used to carry out the dynamic analysis.

The calculated acceleration in the vertical direction, both for the Ring 3 and the Sognsveien spans, exceeds limits. The main reason for this vulnerability regarding the response of the structure in the vertical direction is the relatively slender cross section for the main spans along with the relatively low modal mass, especially on the Sognsveien span. Vulnerability to dynamic loading was not recorded for other spans of the bridge, ranging from 14 to 18 m in length.

Tuned mass dampers will be installed in both the Ring 3 and the Sognsveien spans, 2000 kg and 1000 kg respectively. The effect of the dampers for the Ring 3 span is shown in Figure 13, and this clearly demonstrates how effective they will be in enhancing the comfort of pedestrian and securing a dynamic behaviour which is up to standard.

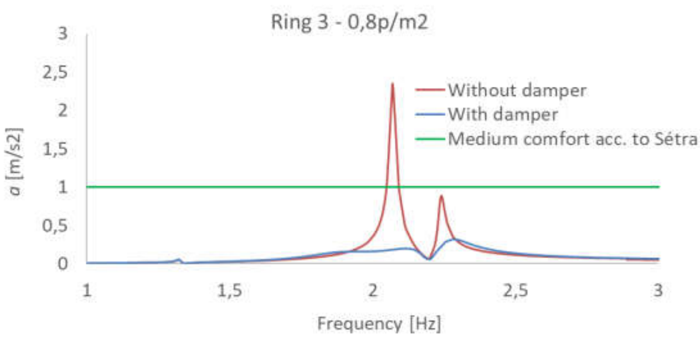

Figure 13. Calculated vertical response of the Ring 3 span of the new Ullevaalskrysset footbridge when loaded with crowds of density 0.8 pers. / m^2, with and without damper.

A gutter is embedded into the edge beam along both sides of the bridge deck. It will be made of stainless steel to minimise the need for maintenance. The railing is also made of stainless steel, designed with V-shaped posts extending from the V-shaped transverse beams. A stainless steel meshing spans between the posts. An LED lighting is integrated into the handrail to provide adequate illumination of the bridge deck.

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6. Construction phase

The construction phase started in November 2017 and planned completion of the construction is in late 2019.

The main contractor is HAG Anlegg AS of Norway but the subcontractor responsible for the fabrication of the steel bridge is Western Construction of Lithuania.

Space is limited at the construction site. It is split in half by the Ring 3 motorway, and Sognsveien also splits the southern site in half. This makes for a challenging planning of the construction works, especially regarding work with piles and mounting of the steel bridge.

The work schedule for the bridge consists of four main aspects, installation of piles, casting of foundations, fabrication of steel and erection of the steel bridge. Work with installation of piles is carried out separately for the three main quarters of the site followed by casting of the foundations. Work with installation of piles, shown on Figure 14, started in February 2018 and planned completion of the concrete foundation and abutments is in August 2018.

Figure 14. Work on pile-drilling in the southwestern quarter of the construction site.

Figure 15. Work on relocating electrical cables in the ground.

Fabrication work for the steel bridge is ongoing during the work with piles and foundations. The steel bridge will be transported to Oslo from Lithuania in relatively small parts. It will then be welded together to larger parts, approximately one span, on site and each span will then be lifted to its final position. The plan is to begin by erecting the transition zone of the bridge to create a rigid base, and then to construct the four ramp sections in all directions. The biggest challenge of the erection phase is the main span over Ring 3. The road must be closed for as little time as possible (approximately 2 days) making it very important to carry out the task in a quick and efficient way. Planned beginning of the erection works is in the fall of 2018 and planned finish is in the spring of 2019.

In addition to the bridge works, a lot of electrical cables, se Figure 15, and drainage and communications infrastructure is relocated or restructured. The Sognsveien road in its entirety will also be relocated and pedestrian- and cycle lanes constructed at ground level. These additional works are integrated into the work schedule for the bridge construction.

7. Discussion

A new footbridge providing separated cycle- and pedestrian lanes, high capacity, a safe and innovative layout and a refined structure has been presented. The bridge will improve considerably the accessibility and traffic safety for the pedestrians and cyclists in the area.

The design team has fulfilled the main objectives defined by the client and provided the means for creating an important link in the infrastructure in Oslo.

The complexity of the project and the construction site makes steel the favourable material selection for the bridge because:

- Steel is appropriate when there is a demand for a lightweight and advanced geometry.
- A steel solution minimizes the effect on the underlying highway due to short construction time of the crossing, i.e. the whole span, crossing Ring 3, can be lifted in over 2-3 days. This is a big advantage compared with a concrete bridge which requires extensive scaffolding and closure of the underlying road during the curing period of the concrete.
- It is possible to transport the bridge to the site in relatively small elements and erect it simultaneously making the most of a tight construction site.
- It shortens the construction time to be able to fabricate the steel parts simultaneously to foundation works.

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