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Building Bridges using Thin-walled Pre-fabricated Elements

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Abstract

An application of a new construction method using thin-walled pre-fabricated concrete elements in a bridge project in Austria is shown. For the erection of the bridge across the river Lafnitz U-shaped bridge girders are produced from thin-walled pre-fabricated concrete elements, moved to their final position and filled with pumped concrete.

To also use thin-walled pre-fabricated concrete elements for the erection of box girder bridges, a new construction method was recently proposed, where segments of a box girder are produced from such elements. These segments are then connected to each other with the aid of post-tensioning tendons forming a bridge girder, which is moved to its final position with a construction method as for example incremental launching or the balanced lift method. In the final position pumped in-situ concrete is added first to the flanges and then to the webs.

It will be shown in the paper, that this approach is advantageous for bridge construction methods, which show a large difference in the bending moment distribution along the bridge girder during the individual construction stages and the final state. Due to this fact, the required amounts of concrete, reinforcement and post-tensioning tendons can be reduced, and more efficient bridge structures can be produced.

Keywords: bridge engineering, lightweight girder, posttensioning, pre-fabrication, thin-walled elements

1 Introduction

Pre-fabricated slab elements are successfully used in concrete construction. These elements can be very economically produced under industrial conditions. Production steps like the fabrication of the reinforcement and its placing as well as that of the formwork at the perimeter of the elements is done by robots. At the construction site the pre-fabricated elements serve as lost formwork. Together with the in-situ concrete layer they form a monolithic concrete slab, which has the same qualities like a slab which is cast in-situ without pre-fabricated elements.

The usage of pre-fabricated slab elements in the production of bridge girders was proposed a few years ago [1], [2]. U-shaped bridge girders with a length of 25 m and a weight of only 8 kN/m have been produced. The walls of the bridge girder shown in Figure 1 consisted of pre-fabricated slab elements with a thickness of 70 mm. The slab elements were positioned on a casting bed with a steel top surface and kept in position with steel beams, which were welded to the casting bed. The pre-fabricated slab elements had a rough surface and were equipped with lattice girders in order to achieve a good bond with the filler concrete. In the lower part of the pre-fabricated slab elements reinforcement was protruding from the elements in order to achieve a rigid connection with the bottom plate, which was cast later between the wall elements. The bottom plate with a thickness of 120 mm was cast without joints over the entire length of 25 m of the U-shaped girder.

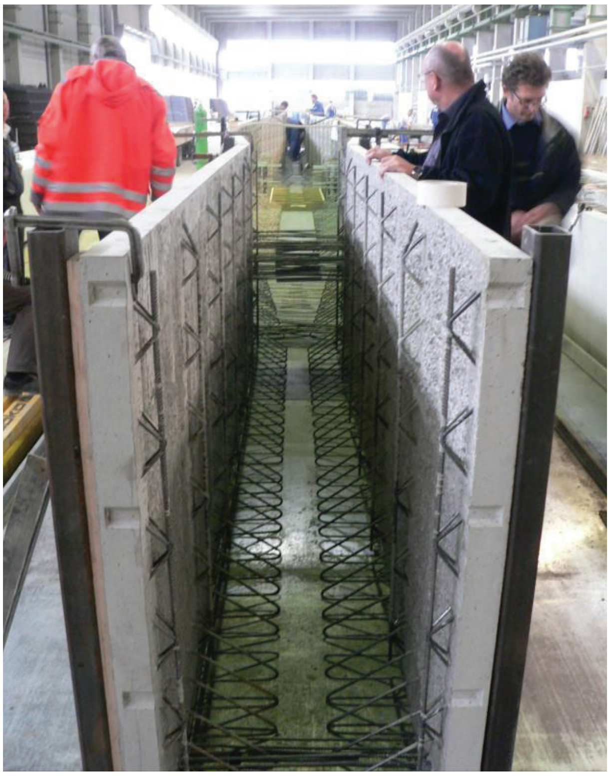

Figure 1. U-shaped bridge girder made with pre-fabricated slab elements

Figure 2 shows the vertical assembly of two compression struts and two U-shaped bridge girders in a large-scale experimental setup. Reinforcement was welded between the lattice girders at the top side to stiffen the open cross-section of the U-shaped girders, as can be seen in Figure 2. The transformation of the bridge girders from the vertical position into the final horizontal position was achieved by lowering the top points of the girders with the aid of mobile cranes and can be seen in Figure 3. The advantage of using lightweight elements during this transformation process is self-explanatory. The lifting equipments and the hinges have to be designed according to the weight of the hollow structural elements. The weight of the two compression struts (150 kN each) and the two bridge girders (210 kN each) resulted in a varying force for the mobile cranes during the lowering process with a maximum of 270 kN.

Figure 2. Vertical assembly of compression struts and bridge girder in a large-scale experiment

Figure 3. Transformation from the vertical position of the bridge girders to the horizontal position

The construction method is currently applied for the erection of two bridges in the south-east of Austria. Figure 4 shows a longitudinal section of the Lafnitz bridge with a length of 120 m. Erection on falsework was not possible for this bridge, because it is located in a natural preserve. The bridge was originally planned as a steel-concrete-composite bridge, whereby an installation of the steel girders with incremental launching was foreseen. However, the owner (ASFINAG Baumanagement GmbH) could be convinced, that a post-tensioned bridge erected according to the balanced lift method [1] would be more efficient, with the building cost at just 75% of the original design. The same construction procedure as in the large-scale experiment (Figure 1 to 3) is applied. The U-shaped girders are shown in dark grey colour in the cross-section displayed in Figure 5. The transformation process shown in Figure 3 will be carried out four times. It turns out that the weight of the four U-shaped girders shown in Figure 5 is only 8% of the weight of the final cross section. Once the girders are filled with in-situ concrete, the deck slab is erected using a formwork carriage.

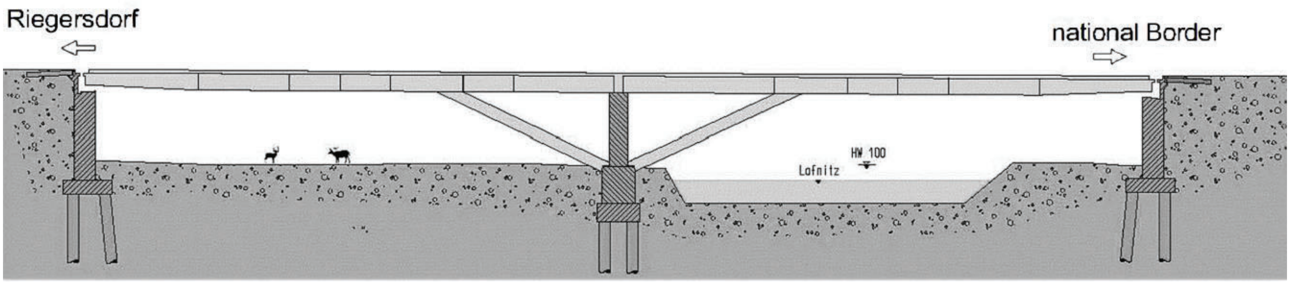

Figure 4. Longitudinal section of Lafnitz-bridge.

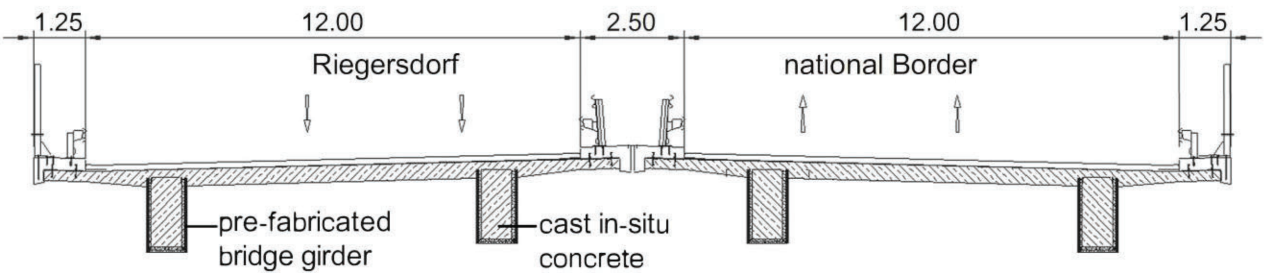

Figure 5. Cross-section of Lafnitz-bridge.

2 Cross-sectional properties of U-shaped girders and box girders

It is possible to build post-tensioned concrete bridges with U-shaped concrete girders at a much lower price than steel-concrete-composite bridges, as has been shown in the previous section with the example of the Lafnitz bridge. However, from a structural viewpoint U-shaped girders are inferior to box girders. This is a known fact and will be demonstrated here with the example of two single span girders loaded by their own weight. The length of the girders is equal to 40 m. The height and the width are equal to 2 m and 1 m, respectively. The cross-sections of the U-shaped girder and the box girder are shown in Figure 6. The webs consist of pre-fabricated slab elements with a thickness of 50 mm. The thickness of the bottom slab is equal to 200 mm for the U-shaped girder. Deck slab and bottom slab have a thickness of 100 mm in the girder with the box section. The cross-sectional area and the weight per unit length are therefore equal for the two different cross-sections. The cross-sectional properties of these two girders are presented in Table 1. The weight per unit length is equal to 9,5 kN/m for both girders.

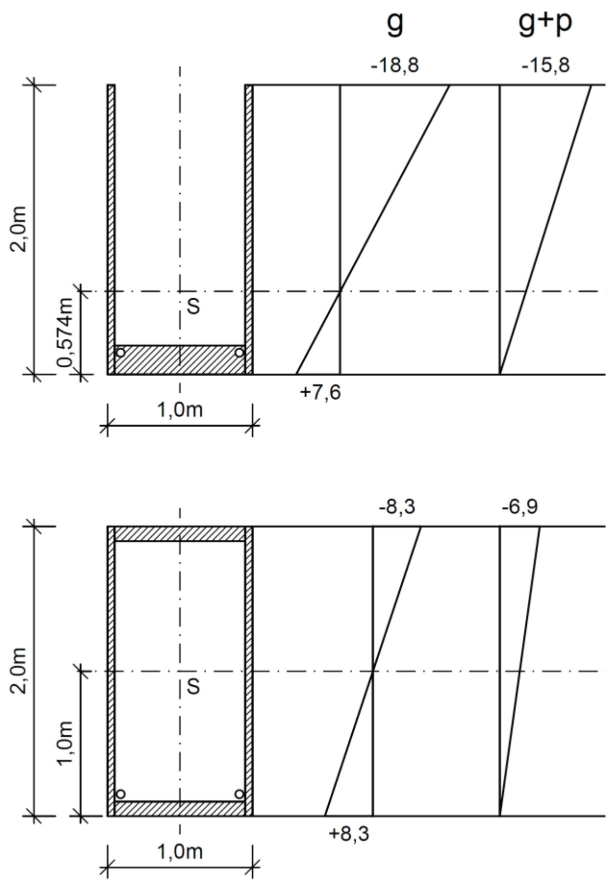

Figure 6. Stresses in the cross sections.

Table 1. Comparison of cross-sectional properties

	U-shaped girder	box girder
area A_C [m²]	0,38	0,38
Moment of inertia I_C [m⁴]	0,144	0,229
Radius of gyration [m]	0,616	0,777
Moment of resistance (top) [m³]	-0,101	-0,229
Moment of resistance (bottom) [m³]	0,251	0,229

The bending moment due to dead load in the centre of the span is equal to 1900 kNm for both girders. Assuming uncracked sections the linear stress distribution over the height at the midspan of the girders can be easily compared with the cross-sectional properties contained in Table 1. In the case of the U-shaped girder a compression stress of -18,8 N/mm² is acting at the top of the cross-section, whereas the corresponding stress for the box-girder is only equal to -8,3 N/mm². Maximum stresses in the bottom plate due to self-weight are similar for both girders. The superior qualities of a box section in comparison to a U-shaped section can clearly be seen in Figure 6 for the load case dead load (g) and post-tensioning (p), where the post-tensioning force is chosen to achieve the state of decompression at midspan. The compressive stress at the top of the U-shaped cross-section is more than twice as large as the corresponding stress for the box section. In order to achieve the state of decompression a post-tensioning force of 1310 kN is required for the box girder, whereas a post-tensioning force of 1750 kN is required in this example for the U-shaped girder. This corresponds to a higher amount of strands and anchorages (+34%) in the case of the U-shaped girder in comparison to the box girder.

3 Proposal for building bridges using thin-walled box girders.

A proposal was recently made [3] to produce bridge girders with a box section from pre-fabricated slab elements, in order to take advantage of the superior load carrying behaviour of box girders in comparison to U-shaped girders.

In a pre-casting plant the pre-fabricated elements are produced under industrial conditions. The pre-fabricated elements have a rectangular shape and are equipped with ribs, made out of steel crossbeams. At the construction site segments are produced by assembling the pre-fabricated elements. Figure 7 shows a segment of a box girder made out of thin-walled pre-fabricated elements. The connection between the pre-fabricated elements is achieved by connecting the end plates of the crossbeams with bolts and nuts. These segments are then connected to each other with the aid of post-tensioning tendons forming a bridge girder. The bridge girder is moved to its final position with a construction method as for example the incremental launching or the balanced lift method. In the final position pumped in-situ concrete is added first to the flanges and then to the webs.

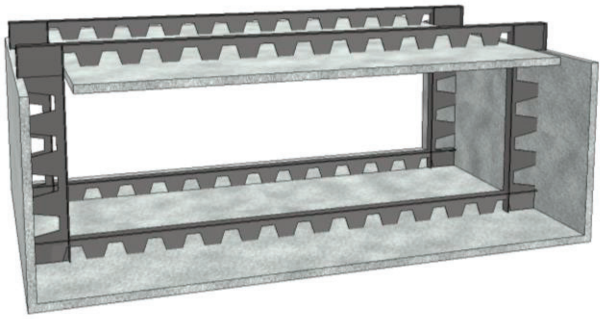

Figure 7. Segment made from thin-walled pre-fabricated concrete elements and steel crossbeams

A post-tensioned bridge erected by the incremental launching method was analysed, whereby two cross-sections were compared. In one case, the launching was carried out with the final cross-section and in the other case with a cross-section consisting of pre-fabricated elements. The cross-section of the bridge, built according to the conventional incremental launching method, is shown in Figure 8 (a). The cross-section is taken from a bridge project, which was recently completed in Vienna. The weight per unit length of this cross-section was equal to 179,3 kN/m.

The cross-section for the alternative design using thin-walled pre-fabricated elements is shown in Figure 8 (b). In order to simplify the alternative design, the transverse slope of the bridge was disregarded. The unit weight of this cross-section during the construction phase is only equal to 25 kN/m, which is just 14% of the weight per unit length of the original bridge. In the calculation of the weight per length of a bridge with a cross-section according to Figure 8 (b) the weight of the steel crossbeams, which are installed every 1,75 m and the weight of the blisters of the straight tendons has been included. Figure 8 (c) shows the final cross-section of the alternative design, which is obtained after adding layers of concrete to the bottom plate, the webs as well as the deck plate. It is envisaged to build the cantilevering parts of the deck according to a method developed by Fuchs et al. [4].

The moment envelope curves for both methods during the launching process are compared in Figure 9. Since the weight of the box girder made from thin-walled pre-fabricated elements corresponds to only 14% of the weight of the box

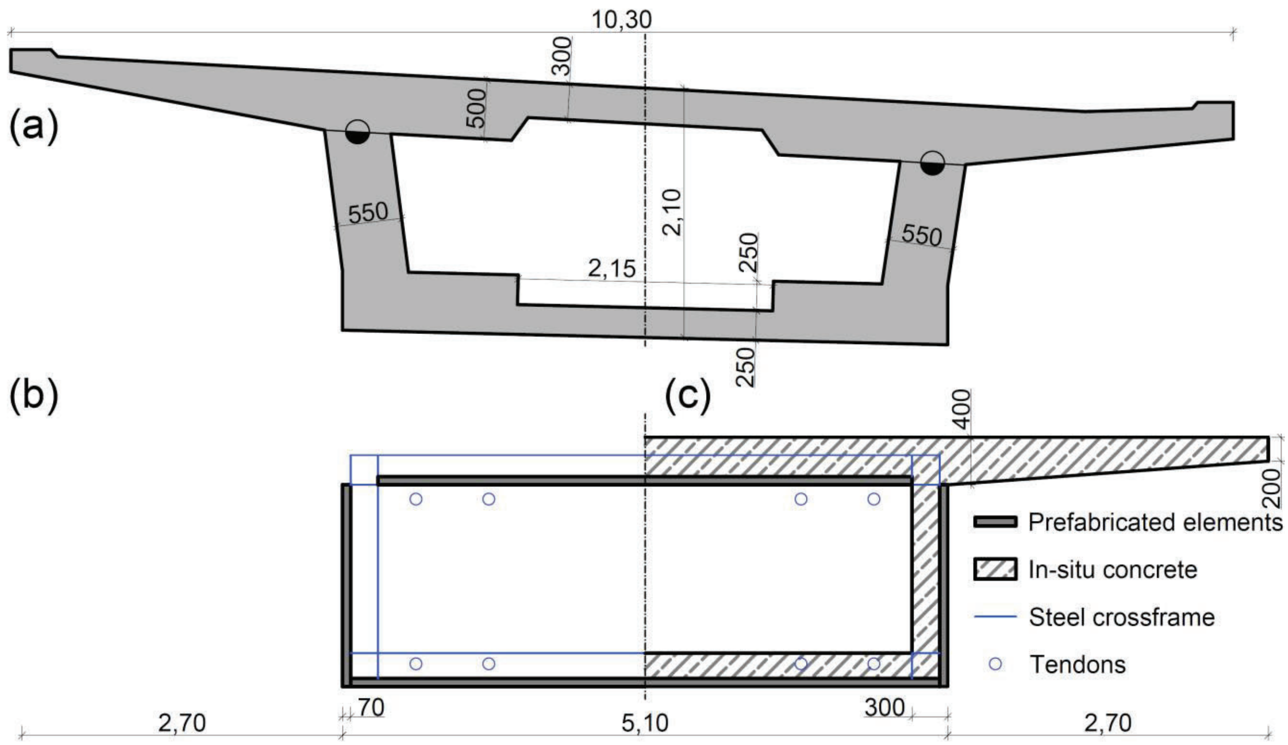

Figure 8. Cross-section of incrementally launched bridges (a) conventional design, (b) design with pre-fabricated thin-walled elements, (c) design with pre-fabricated elements after completion

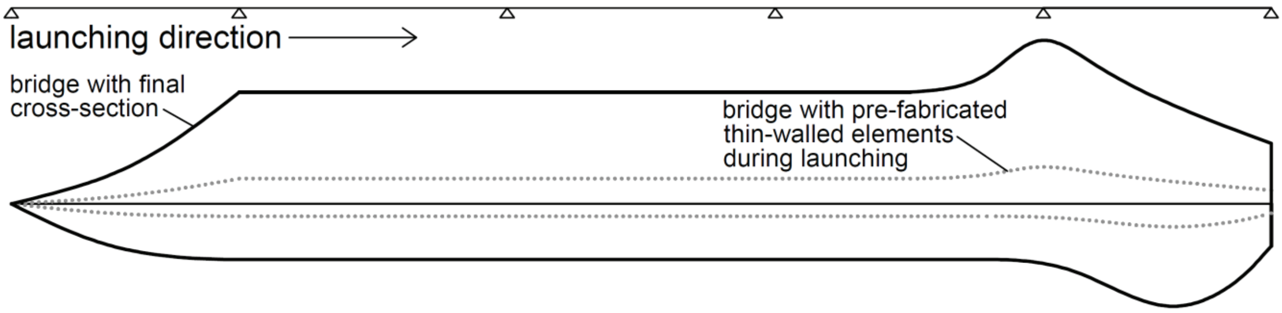

Figure 9. Bending moment envelope curves of an incrementally launched bridge with completed cross-section (solid line) and with thin-walled pre-fabricated elements (dashed line)

girder with the final cross-section, the moments during the incremental launching are much smaller for the box girder according to the new proposal. A large amount of the centric post-tensioning tendons can be saved for the thin-walled bridge girder in comparison to the conventional solution. Also, the expenditures for the temporary bearings, which are required during the incremental launching, can be reduced because of the reduced weight. A drawback of the new method is, that the bridge girder must still be completed after reaching its final position. Concrete layers have to be added to the bottom plate, the deck plate and the webs. It is proposed to install most of the reinforcement of the bridge girder at the assembly area and to provide wire mesh at the location of the boundaries of the planned casting sections. Then the work which still has to be done after the bridge girder has been moved to its final position consists of placing the additional concrete and stressing of the tendons.

4 Summary

A new proposal to build post-tensioned box-girder bridges has been presented in this paper. Pre-fabricated elements, which can be produced under industrial conditions, are used to produce thin-walled segments at the construction site. These segments are connected to each other with the aid of post-tensioning tendons. In an example of an incrementally launched bridge the conventional method and the new proposal were compared. The comparison showed, that the new method will permit savings in the amount of centric post-tensioning tendons, temporary bearings and construction time for assembly. However, further studies and experiments are required to explore the full potential of this new bridge construction method.

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