New Modular Construction Method for the Erection of Multi-span Concrete Bridges

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Abstract. Recently a new construction method for thin-walled post-tensioned bridges was developed at the Institute of Structural Engineering (TU Wien). Innovative precast elements for the longitudinal girders and the deck slab were designed to keep up with the latest trend in resource- and time-efficient building. The semi-finished precast deck slab elements consist of thin plates stiffened by one to two cross-beams. In addition, upstands are arranged, which act as a formwork for the cast-in-place concrete. The precast deck slab elements can be placed on the completed longitudinal girders and span in the transverse direction. These girders are composed of several precast thin-walled hollow box segments, which are clamped together with post-tensioning cables at the construction site and span in the longitudinal direction. For the placement of the precast elements, either a launching gantry or cranes, when the topography allows, can be used.

The combination of thin-walled hollow box segments, precast deck slab elements, cast-in-place concrete, and post-tensioning cables allows for the fast construction of multi-span concrete bridges. In the span range from 30 m to 60 m, this method will make the erection of one span per week possible, thus achieving the same construction speed as segmental bridge construction. Compared with segmental box girder bridges, the new construction method permits a reduction of construction materials and avoids transverse joints extending over the entire height of the cross-section.

The first application of the new construction method took place in Austria in September 2022. The pilot project represents a railway bridge for the Austrian railway company "ÖBB-Infrastruktur AG".

Keywords: Precast deck slab element · Precast girder · Post-tensioned bridge · Segments · Sustainable · Thin-walled

1 Introduction

Several building techniques have been developed in the last decades for building multi-span concrete bridges. The state of the art can be looked up in "Bridge Deck Erection Equipment" [1]. Altogether, ten construction methods are described:

1. Precast balanced cantilever erection by launching gantry,
2. Precast segmental span-by-span erection by launching gantry,

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3. Precast girder erection by launching gantry,
4. Precast full span erection by launching gantry,
5. Cantilever erection by lifting frames,
6. Progressive cantilever method using stay cables,
7. In-situ form travelers,
8. Movable scaffolding systems,
9. Incremental launching method, and
10. Prefinished bridge installation methods.

More than half of the listed construction methods can be assigned to the construction method with precast elements. This shows the importance and the current demand for building with precast elements. In many cases, building with prefabricated elements also accelerates the construction process [2].

Hällmark [2] states that accelerated construction progress is paramount for all involved. The total cost of a bridge or roadway project is not limited only to the amount spent on the materials like concrete, steel, and labor. Also, the user costs must be considered. The typical flow of traffic disruptions around a project area should be minimal.

Another important topic in today's world is the consumption of resources. The construction methods developed so far with precast elements were mainly concerned with optimizing the construction process with a reduced construction time [3]. This development was detrimental to resource consumption. The requirements of temporary construction conditions often determine the dimensions of the cross-section.

This conference paper aims to introduce the latest developments at the Institute of Structural Engineering regarding accelerated bridge construction processes for multi-span concrete bridges with reduced material consumption.

An extraordinary building technique for multi-span concrete bridges with a double-T cross-section is described in [4]. This technique is called the "balanced lift method" or "balanced lowering method". Thin U-shaped precast elements are first assembled in a vertical position. After they are connected by steel hinges, they can be rotated into the final horizontal position. When everything is fixed, the prestressing work and the placement of the filling concrete can start. During the first application of the "balanced lowering method" in concrete bridge engineering, excellent experiences with thin precast elements were gained. Two bridges were built across the rivers Lahnbach and Lafnitz, which form the border between the federal states "Styria" and "Burgenland" in Austria. Figure 1 shows one of the thin U-shaped precast elements. The walls have a thickness of 70 mm, and the bottom plate has a thickness of 120 mm. Almost all the reinforcement and ducts for the tendons, which are necessary for the final state, are already contained in this element. The project showed that the combination of thin precast elements, which serve as formworks, and in-situ concrete led to fast construction progress. Only the construction of the deck slab could not keep up with the rapid construction progress of the bridge girders. A formwork carriage was used to build the concrete deck slab. For this reason, formwork stripping times had to be observed before the formwork carriage could be moved to the next construction section.

Fig. 1. U-shaped thin precast element for a bridge girder

2 The Concept of the New Modular Construction Method

Since good experience has been gained with thin-walled precast elements, a new construction method for post-tensioned bridges with a double-T cross-section was developed [4]. This construction method unites the advantages of a fast construction progress for the whole bridge structure with the quality of a bridge cast with in-situ concrete.

The new bridge construction method includes conceptual considerations of the precast segmental span-by-span erection method (with transverse joints between the segments) and the technique for precast girder erection by launching gantry (with girders oriented in the longitudinal direction). This new modular construction method can achieve a weekly cycle for producing a construction section with a length corresponding to the span [5]. Only limited reinforcement laying work must be done at the installation site.

In the case of long bridges with multiple spans, a launching gantry was developed to place the precast elements (Fig. 5). It can move the precast girders to their final position. Moreover, the launching gantry is designed in such a way that it can also move the precast elements for the deck slab to their final position. If the topography allows, the prefabricated elements can also be placed by cranes.

2.1 Description of the Precast Elements

Precast Girder for the Bridge Webs. The precast girder consists of several hollow box segments, either connected on the already finished deck slab or at the building site. The minimum number of segments depends on the span length of the bridge, the maximum possible transportation length, and the allowable transport weight in the respective country.

An example of a precast girder is shown in Fig. 2. The production of the individual hollow box segments takes place in a precast plant. First, the two wall components are cast in a horizontal position. This leads to a high quality of the elements because the filling height of the concrete is low. After they are set up, the bottom and the top plate can be cast. A cross-section of the hollow box segments is shown in Fig. 4.

The precast girder in Fig. 2 consists of five segments, which form a total span length of 55 m. The segments are connected with an additional in-situ concrete layer on the bottom plate and internal bonded tendons (type 1). These tendons are anchored in the bottom plate of the first and last hollow box segments. Before the segments are clamped together, the vertical joints must be grouted. The wall elements have shear keys on the front and back sides for the transition of shear forces. The precast girder in Fig. 2 belongs to a construction variant where fixed (passive) and stressing (active) anchors are arranged in the diaphragm over the pier. These anchors are necessary for the external tendons (type 2). In the span sections, they run above the bottom slab. At the end of the first and the beginning of the last hollow segment, they are deviated to reach a higher position over the pier sections. Due to the external tendons, a continuous bridge deck and the coverage of the negative bending moments are ensured.

In this design variant, the first and the last segment include installations, like blisters, thickenings of the walls, diaphragms, and deviators (Fig. 2). These are required to transfer the prestressing forces into the thin elements.

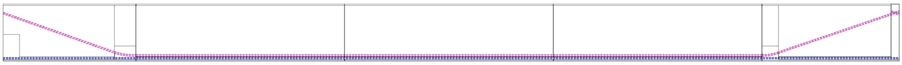

Fig. 2. Longitudinal section of a precast girder with installations and ducts (tendon type 1 in blue and type 2 in purple color)

Precast Elements of the Deck Slab. The precast elements for the deck slab consist of plates, which are connected by cross-beams. Figure 3 shows a precast element for the deck slab, which already exhibits the entire width of the bridge. Two reinforced cross-beams connect three thin plates. The element has upstands at the cantilever ends to form a barrier for the additional concrete layer. To create a sufficient bond between the new and the already hardened concrete, the surface of the plates must have a certain roughness and reinforcement that protrudes from the thin plates. The precast deck slab element can support its dead load, the additional concrete layer, and a construction crew, which can use the precast element as an operating platform. Consequently, the precast element acts as a formwork and operating platform at the same time. It can be fully included in the structural analysis.

Almost all the reinforcement required for the final state is contained in the precast deck slab element. Only the splice, the upper longitudinal, and the transverse reinforcement must be installed at the construction site.

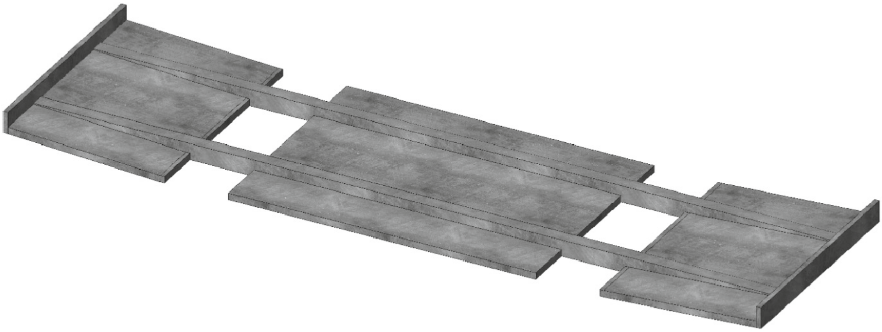

Fig. 3. Precast element for the deck slab

The Connection Between the Precast Girder and the Deck Slab Elements. The precast girders and the deck slab elements are connected with reinforcement and an in-situ concrete layer. The shear reinforcement in the thin wall elements protrudes from the hollow box segments at the top. The in-situ concrete layer creates a sufficient bond between the elements. After the top concrete layer has hardened, the double-T cross-section is finished (Fig. 4). A rendering of a 3D visualization of the construction process with a launching gantry is shown in Fig. 5.

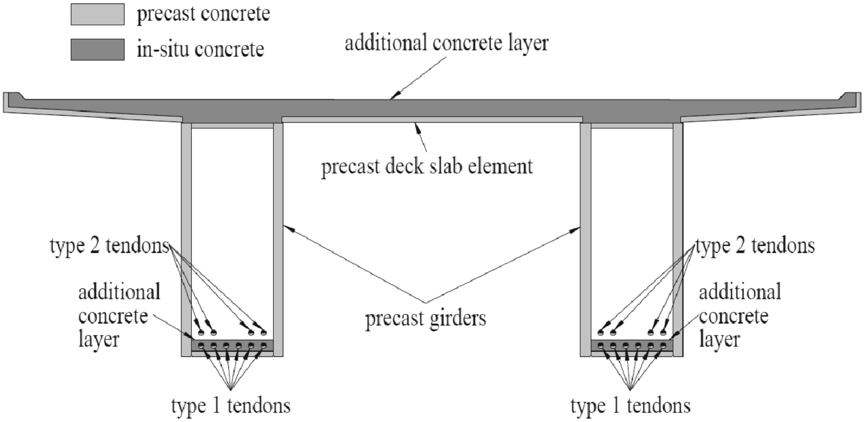

Fig. 4. Cross-section of a finished bridge deck

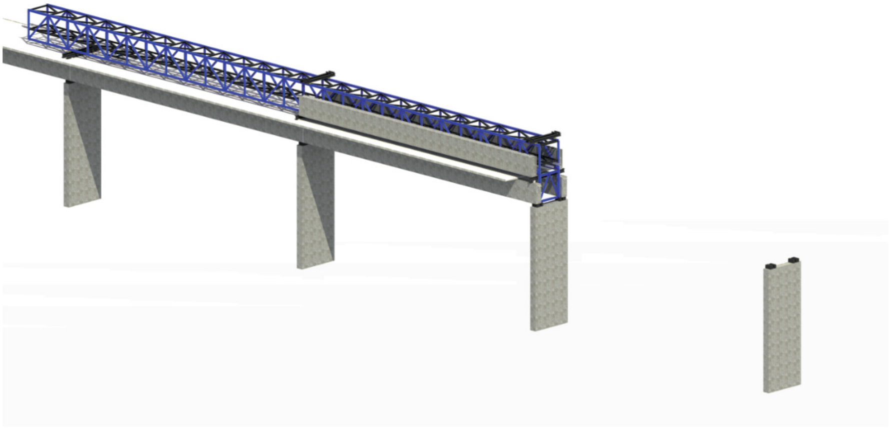

Fig. 5. Construction process with a launching gantry

3 Pilot Project in Austria

In September 2022, the first railway bridge with one track was built using the new modular construction method. The bridge owner is the Austrian Railway Company "ÖBB-Infrastruktur AG".

The static system is a frame structure with a clear width of 20.05 m. The frame stanchions were built using in-situ concrete, and the beam of the frame was built using the new modular construction method. After the longitudinal beam and the deck slab elements were placed, the whole bridge deck was connected rigidly with the frame stanchions, which were produced in advance. Since the longitudinal girder of the bridge remains hollow, over 40% of concrete could be saved compared to the initial planning.

During a five-week track closure in August and September 2022, the existing bridge was demolished, and the new bridge was constructed. Figure 6 shows a photo of the Pinkabach bridge after the frame and the track construction work were completed. During the construction work, the water of the Pinka was led through a pipe so that a working surface could be created in the area of the bridge.

After demolishing the existing bridge from the 1950s, the abutments were built on piles using conventional construction methods. Subsequently, the precast longitudinal girder was lifted into place by two cranes. The longitudinal girder had a hollow box-shaped cross-section, a length of 19.05 m, a width of 3.0 m, and a height of 1.35 m. The weight of the longitudinal beam was equal to 67 t. The thickness of the bottom plate of the longitudinal beam was 180 mm, and that of the top plate was 80 mm respectively. The webs had a thickness of 150 mm, which was increased to 300 mm in the area of the abutments due to structural reasons. Diaphragms with a thickness of 100 mm were placed at both ends of the longitudinal girder to prevent the concrete from penetrating into the box girder during the construction of the frame corners. The clear height inside the longitudinal girder is 1.09 m. A closable opening is arranged in the bottom slab to allow inspection of the inside of the hollow box girder. The low clear height of 1.09 m inside the box girder was accepted by the bridge owner, ÖBB-Infrastruktur AG, to allow the first application of the LT bridge construction method.

Fig. 6. Pinkabach bridge (Photo: Matthias Heisler)

Six deck slab elements were placed on the longitudinal girder in the following work step. The dimensions of one deck panel element were 3.44 m in the longitudinal direction and 6.51 m in the transverse direction of the bridge. The weight of one deck slab element was 5.5 t. The cross-beams were dimensioned to be able to support the weight of the cantilevering parts and the cast-in-place concrete of the deck slab. With the stirrup reinforcement protruding from the top of the longitudinal beam and the connection reinforcement in the deck slab elements, the components were connected to form a monolithic structure after applying the top concrete layer.

The longitudinal girder and the six deck slab elements were lifted into place at the construction site on a Monday. On Tuesday, the upper longitudinal reinforcement and the reinforcement in the frame corners were placed. The placement of the concrete for the top concrete layer was carried out in two stages. On Wednesday, the top concrete layer was placed near the frame corners. In the first working hours on Thursday, the middle part of the deck slab was cast. The construction of the horizontal part of the frame structure was thus completed in three and a half days. The construction work at the Pinkabach bridge and the subsequent laying of the track was completed on schedule within the five-week track closure period. The companies involved in the project are shown in Table 1. The excellent cooperation between the project participants contributed significantly to the successful initial application of the new construction method for the Pinkabach bridge.

Table 1. Project participants in the construction of the Pinkabach bridge.

Bridge owner	ÖBB-Infrastruktur AG
Designer	TU Wien, KOB ZT-GmbH
Site supervision	OPUS Bauconsult GmbH
Contractor	LEYRER + GRAF Baugesellschaft m.b.H
Precast elements	Rauter Fertigteilbau GmbH

4 Conclusion

By applying the new construction method, multi-span concrete bridges can be built with thin-walled precast girders, precast deck slab elements, and in-situ concrete. This new method eliminates the need for formwork, scaffolding, and most of the reinforcement work at the construction site. Using this method, a construction section (according to the span length) of 30–60 m can be produced in one week. This method is capable of keeping up with the precast segmental span-by-span erection speed. At the same time, the durability of the bridge corresponds to bridges built with cast-in-place concrete. No transverse joints extend over the entire height of the cross-section. The top concrete layer creates a continuous bridge deck over many spans. Since the longitudinal girders of the bridge remain hollow for the final state, fewer building materials are consumed.

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