LT-bridge Construction Method for the Material-saving and Fast Construction of Post-tensioned Concrete Bridges

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Abstract Owners of bridges in the Danube Basin will face enormous challenges in the coming years because many bridges need to be renovated or rebuilt. They can either not withstand the current loads or have developed durability problems. Discussions with owners have shown that rapid construction progress is crucial for bridge replacements. The construction sites should disrupt the normal traffic flow as little as possible. As a result, a new, resource-saving, and fast construction method for bridges has been developed at TU Wien. Innovative prefabricated elements for the longitudinal girders and the deck slab were designed to fulfill these requirements. The prefabricated elements are connected by reinforcement and an in-situ concrete layer at the construction site. A comparison of the environmental impact based on the construction materials (life cycle phases A1–A3) between a construction section of an LT-bridge and a typical German motorway bridge shows a much lower global warming potential for the new bridge construction method due to the savings in construction materials in comparison to a conventional post-tensioned concrete bridge with in-situ concrete.

1 Introduction

The analysis of bridge statistics from 2023, provided by the Federal Highway Research Institute (BASt) [1], has shown that most of the bridge area of Germany's federal trunk roads was built and put into operation in the 1960s and 1970s. The oldest bridges from this period are around 60 years old, corresponding to 60% of their planned service life according to current standards. However, a new replacement is currently being planned or built for around 940 bridges. Two-thirds of these structures were built during the periods mentioned above.
These numbers show that bridge owners, civil engineers, and contractors will face a considerable challenge in maintaining the current infrastructure with sufficient safety for road users in the coming years.
Discussions with bridge owners have made it clear that the speed of construction progress plays a

decisive role in the successful completion of the project when a new bridge replacement is required. In this way, a considerable amount of traffic disruption can be avoided, significantly impacting the life cycle assessment. In addition, the resource efficiency of bridge structures will become an increasingly important evaluation criterion for awarding contracts in the future.

Various solutions have already been developed for bridge structures over existing infrastructure. One example is the VFT® construction method [2], with which two directional carriageways with several lanes can be spanned quickly, with a low construction height and without central supports. A new development, made possible by the future version of the BEM-ING in Germany [3], is the use of high-performance concretes with concrete grades of up to C80/95 [4]. With this technology, precast elements spanning around 45 m can span six-lane highways as single-span girders without intermediate supports [5]. For bridges with even larger spans of up to 80 m, UHPFRC precast segmental bridges are proposed [6]. In contrast to segments with conventional concrete grades (e.g., C40/50), resource consumption can be significantly reduced with particularly thin-walled segments with ribbed structures and high-performance concrete.

A new bridge construction method for highway and railroad bridges in the span width range of 30 to 50 m was developed at the Institute of Structural Engineering (TU Wien). Particular attention was paid to the resource efficiency and the construction time.

2 LT-Bridge Construction Method

The name of the bridge construction method is derived from the span directions of the precast elements. The longitudinal girders span in the longitudinal (L) direction of the bridge, while the deck slab elements are spanned in the transverse (T) direction. The monolithic connection of the longitudinal girders with the deck slab elements is achieved using connecting reinforcement and an in-situ concrete layer.

Figure 1 illustrates a 3D view of an LT-bridge and shows the precast elements, the in-situ concrete layers, and the substructures. Figure 2 shows a cross-section of the components.

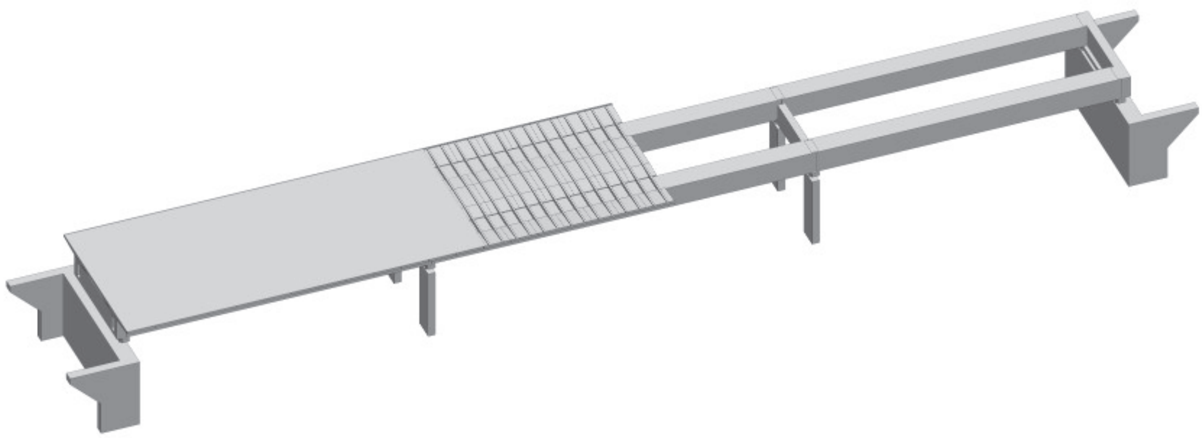

Figure 1: LT-bridge: 3D view showing the precast elements and in-situ concrete layers

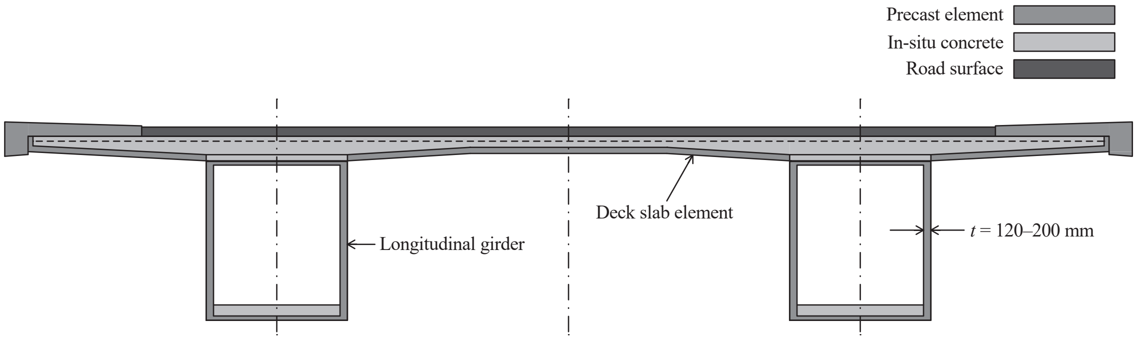

Figure 2: LT-bridge: Illustration of various components in cross-section (center of the field)

2.1 Precast elements

Longitudinal girder

A longitudinal girder consists of wall elements, a bottom plate, and a top plate. The length of a longitudinal girder nearly corresponds to the span length. If it is not possible to transport the longitudinal girder at its entire length to the construction site, in that case, manufacturing it from several partial segments and connecting them with tendons on the construction site is possible. The longitudinal girder is made of high-strength concrete (C80/95). This allows for keeping the weight low during transportation and lifting operations. The decisive factors for the wall thickness of the box girder are the maximum load-bearing capacity of the concrete compression struts (shear and torsional stresses) and the interaction of shear force and transverse bending in the thin-walled elements. Using high-strength concrete allows the construction of very thin-walled elements (t = 120–200 mm). Another measure to minimize the weight of the longitudinal girder is the use of thin top and bottom plates (t = 60–70 mm).

The built-in parts in a longitudinal girder are tendon anchorages and deviators for tendons. Figure 3 shows a longitudinal girder with anchorages, deviators, and tendons. The rear part of the illustration shows the longitudinal girder as it arrives at the construction site from the precast plant, while the front illustration shows the longitudinal girder as installed. If the longitudinal girder is only assembled from segments on-site, the tendons (blue) are prestressed on-site at an assembly area. Once the longitudinal girder has been installed, a layer of in-situ concrete is first added to the bottom slab and then to the top slab.

To ensure that the bridge has continuous longitudinal reinforcement, screw couplers are used at the pier sections. These couplers are used to couple the lower longitudinal reinforcement located on the bottom plate of the longitudinal girder in the in-situ concrete layer. The upper longitudinal reinforcement is not installed until the deck slab elements have been placed on the longitudinal girders. The shear reinforcement protrudes from the wall elements on the top of the longitudinal girders and serves as connecting reinforcement to connect the longitudinal girders and the deck slab elements with in-situ concrete.

Deck slab element

The deck slab element is the lower element of the deck slab and is also produced in the precast plant

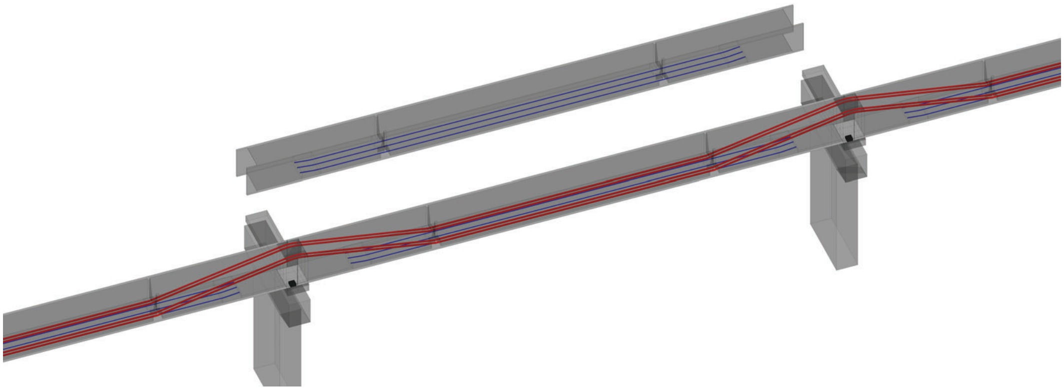

Figure 3: Longitudinal girders in the precast plant (rear) and installed (front)

(see Figure 4). It consists of thin slabs (t = 100 mm) connected to each other by cross beams. Upstands are arranged at the lateral ends of the deck slab element, which serve as vertical formwork for the in-situ concrete layer. There are recesses around the longitudinal girders where the connecting reinforcement (stirrups and lattice girders) of the longitudinal girder can be accommodated. In this area, the top slab of the longitudinal girder acts as the lower formwork for the concrete topping. The deck slab elements are mounted on the longitudinal girder using elastomeric bearings.

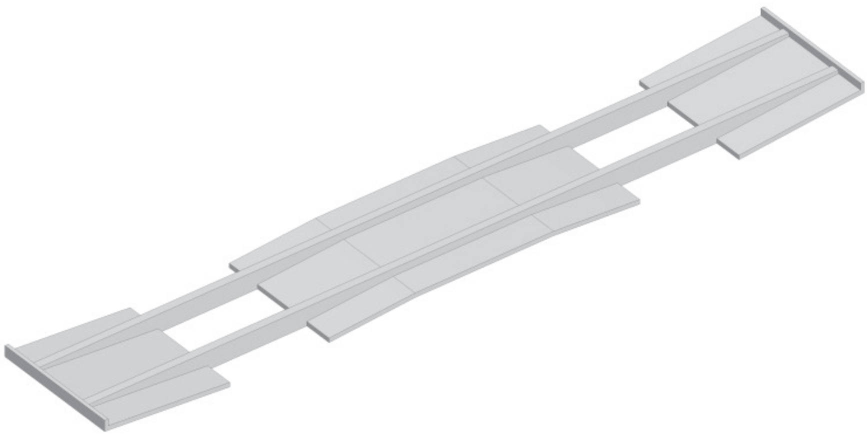

Figure 4: Precast deck slab element

2.2 Tendons

Various types of post-tensioning are used for the LT-bridge construction method:

- Type 1 tendons (internal, strands in PE duct, grouted with cement grout)
- Type 2 tendons (external, mono strands in PE duct, grouted with cement grout)
- Transverse tendons for the deck slab (internal, without bond)

If the longitudinal girder can be transported in one piece from the precast plant to the construction site, the prestressing is already carried out in the precast plant using type 1 tendons. Otherwise, the individual segments are post-tensioned at the construction site to form a longitudinal girder that corresponds approximately to the length of a span. The type 1 tendons are straight and run just above the bottom plate of the longitudinal girder. Starting from the pier axes, the tendons are moved inwards by around 10% of the span. After post-tensioning, the PE ducts are grouted. The ducts are not yet surrounded by in-situ concrete at this stage. The concrete is only applied to the bottom slab when the longitudinal girder is installed.

Type 2 tendons are required to create a continuous bridge structure. They run externally inside the longitudinal girders. The high points of the tendons are located at the deflection points above the piers, while the low points are located at the deflection points in the longitudinal girder, which are positioned at 25% and 75% of the span. Some codes require that the external tendons must be de-tensionable, replaceable, and re-tensionable. Accessibility with a stressing jack must, therefore, be guaranteed both during construction and later. Thus, the stressing anchorages are positioned so that a stressing jack can be applied subsequently. During construction, the type 2 tendons are post-tensioned in stages to ensure that no tensile stresses occur in the precast elements and in-situ concrete.

A transverse post-tensioning without bond is arranged in the deck slab. This allows for a reduction in the thickness at the start of the cantilever of the deck slab. In addition, there are further advantages, such as improved fatigue resistance in the transverse direction [7]. The thickness at the end of the cantilever slabs can be kept to a minimum using tendons with strands arranged side by side in the anchorage structures.

3 Comparison of environmental impacts based on building materials

This section compares the environmental impacts of a construction section of an LT-bridge erected using crane assembly and a typical German highway bridge in prestressed concrete construction built on scaffolding. Figure 5 shows the cross-sections of the two bridge variants. The resource consumption resulting from the construction materials of the superstructure is represented by the life cycle phases A1–A3 and considers the procurement of raw materials, transportation, and production. The following consumption of building materials is analyzed:

- Concrete
- Reinforcing steel
- Post-tensioning steel

Using the data from the formwork, reinforcement, and tendon plans in combination with selected environmental product declarations (see Table 1), the global warming potential (GWP) can be calculated for the two bridge variants, which is given in the unit "CO2-eq.".

Materials	Unit	GWP in kg CO_2-eq.	Source
Concrete (C40/50)	m^3	293	[8]
Concrete (C80/95)	m^3	389	[6]
Reinforcing steel (B500B)	kg	0.64	[9]
Post-tensioning steel (Y1860 C)	kg	2.3	[10–13]

Table 1: Characteristic values of the global warming potential (GWP) of the building materials used in life cycle phases A1–A3

3.1 Calculation model of the LT-bridge

The calculation model for the LT-bridge was created using the SOFiSTiK 2022 software. SOFiSTiK 2022 and the non-linear cross-section calculation program INCA2 were used to verify the serviceability and ultimate limit states.
A 152 m long LT-bridge with four spans was modeled. The lengths of the two end spans are 34 m, and those of the middle spans are 42 m. The topography of the valley to be spanned allows a crane assembly. The bridge is built using the span-by-span erection method.
The basic standards for the structural calculations are Eurocode 1 and Eurocode 2 with its associated national German application documents. The second construction section, with a span of 42 m, is analyzed to evaluate the global warming potential.

3.2 Results

The volumes and weights of the construction materials for the in-situ concrete bridge were taken from the formwork, reinforcement, and tendon plans of a typical German highway bridge with end spans 34 m long and central spans 42 m long. The masses from the second construction phase were used for the comparison. Based on the static calculations of the LT-bridge, formwork, reinforcement, and tendon plans were drawn up, from which the volumes and weights of the construction materials could be determined. A summary of the construction material masses for one span (42 m) for the two variants is shown in Table 2. Figure 5 shows the data evaluation from Table 1 and Table 2.

Variant	Material	Volume in m^3	Mass in t
In-situ concrete bridge	In-situ concrete (C40/50)	620.6	1489.3
	Reinforcing steel (B500B)	8.2	64.1
	Post-tensioning steel (Y1860C)	3.2	25.2
LT-bridge	Concrete	379.0	909.6
	Precast concrete (C40/50)	75.6	181.4
	Precast concrete (C80/95)	81.3	195.0
	In-situ concrete (C40/50)	222.1	533.2
	Reinforcing steel (B500B)	6.2	48.4
	Post-tensioning steel (Y1860C)	1.7	13.2

Table 2: Volumes and weights of the building materials for one span (42 m) for the two construction variants.

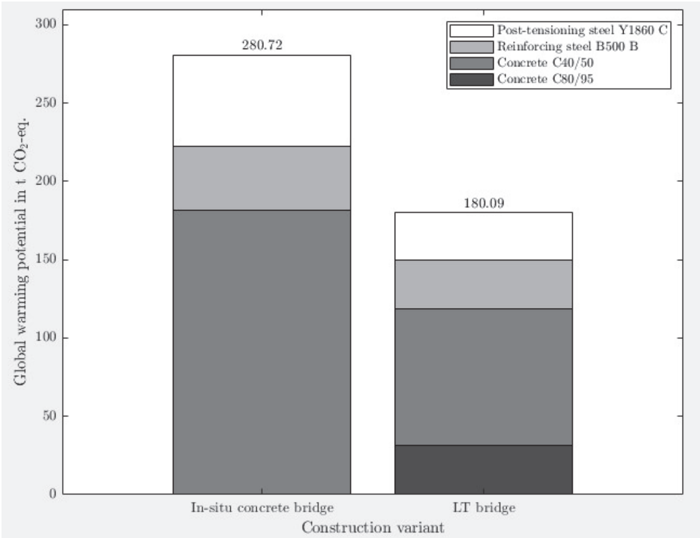

Figure 5: Global warming potential in life cycle phases A1–A3 of the two construction variants for a typical span

A direct comparison of the two construction variants shows a reduction in global warming potential of 35.9% for the LT-bridge. Savings can be seen primarily in the consumption of concrete post-tensioning steel. This results from using high-performance concrete combined with a simultaneous reduction in volume through a hollow cross-section with a greater construction height. The resulting lower dead weight of the superstructure has a beneficial effect on the decompression analysis of the cross-section, which means that a smaller amount of post-tensioning steel is required. A reduction in the global warming potential also results in the consumption of reinforcing steel. However, this is not as significant in the balance as the savings in concrete and post-tensioning steel. This can be attributed to the regulations in Eurocode 2 regarding minimum reinforcement ratios. The height of the LT-bridge was increased by 80 cm compared to the in-situ concrete bridge, which leads to more favourable values in the calculation of the resistance moments. However, this increase is accompanied by a reduction in the slenderness of the LT-bridge.

4 Conclusion

The LT-bridge construction method is a technique that combines prefabricated elements with in-situ concrete, offering a modern solution that meets the current requirements in bridge construction. There are advantages in terms of both resource consumption and speed of construction compared to the established in-situ concrete construction method. A direct comparison with a typical German highway bridge showed that using high-performance concrete and increased construction height (more favorable cross-section values) results in a lower global warming potential in the life cycle phases A1–A3. The next step is to consider the global warming potential in the remaining life cycle phases with subsequent verification in the climate limit state. In the author's estimation, the speed of the construction process in life cycle phases A4–A5 (construction) will positively affect the environmental balance. In the case of new replacements, transportation, installation, and assembly should be assessed, as well as the environmental impact of traffic jams and the increased volume of traffic during detours.

The LT-bridge construction method represents a promising alternative to conventional in-situ concrete bridges in Austria and Germany. From an international perspective, this innovative construction technique offers an alternative to the segmental bridge construction method.

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