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BRIDGE CONSTRUCTION USING THIN-WALLED PRECAST CONCRETE ELEMENTS

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ABSTRACT: Under normal circumstances concrete bridges are either erected using prefabricated full span girders, precast segmental erection when it comes to large bridges or in-situ cast concrete. The construction progress is directly dependent on the weight of the mostly full-cast concrete segments or the time consuming hardening of the in-situ cast concrete. The Institute of Structural Engineering of the TU Wien has developed a new building method which not only combines the positive properties of the traditional building techniques but also discards some of their negative ones. It was decided to repurpose thin-walled precast elements, which are normally used in building construction, creating lightweight girders which would be easier to handle on the construction site and would be filled with in-situ concrete once placed in their final position. Once filled a monolithic superstructure is attained in the final state. The results of the research were different sized lightweight girders which were all built in full scale and tested in various ways. The experiences gained from the large scale tests were used to optimize the girders designs resulting in a construction method which cannot only reduce the needed amount of the required building material but construction time as well, therefore improving the efficiency in bridge construction. The paper describes the "evolution" of the girder cross-section from the humble beginnings over large-scale destructive tests to a refined lightweight cross-section.

KEYWORDS: thin-walled concrete elements, prefabrication, bridge building, lightweight girder, post-tensioning

1 INTRODUCTION

Due to very competitive costs to in-situ concrete as well as steel elements, the precise execution and the economic value, precast elements are able to not only reduce the construction period but also reduce construction costs. Despite all the significant advantages, contractors, as explained in detail in [1], unfortunately often shy away from the application of prefabricated concrete structural components in bridge construction due to their low opinion on the durability of the intersections and joints or other specific technical issues, which they believe to be existent. The Institute of Structural Engineering of the TU Wien decided to challenge the prejudice and show how easily thin-walled precast elements can be used for bridge erection creating an actual competitive option to steel girders. By repurposing standard and cost-efficient prefabricated elements, which would serve as permanent formwork for the subsequently added in-situ concrete, creating monolithic structures, considerable reduction in the on-site construction work would be achieved. The high production quality of the thin elements would ensure the durability of the main structural parts and the cast in-situ concrete that of the intersections. Bridge girders where developed for both bridges with large spans as well as for bridges with short spans. Prestressed box girders composed of hollow wall elements and thin-walled precast elements were designed for bridges with large spans and trough-shaped cross sections for bridges with short spans.

2 STARTING POINT: BALANCED LIFT METHOD

The idea of building bridge cross-sections out of thin-walled precast elements was born out of necessity. The development of the balanced lift method with patents granted in Germany (DE 102006039551), the USA (US 7996944), Russia (RU 2436890), Canada (CA 2661311) China (CN 101535571) Australia (AU 20007288151) Japan (JP 5302195), India (IN 022359), Norway (NO 338580) as well as the European Patent (EP 2054553), initiated the deliberations on lightweight thin-walled precast concrete girders, due to the fact that the weights of the girders used during the lifting and rotation process were of utmost importance for this method. As shown in Figure 1 for bridges with tall and short piers, the individual girders of the bridge are assembled in a vertical position and are then rotated into their final horizontal positon with the aid of compression struts, much like the opening of an umbrella. In the case of the construction of a bridge with a short pier an additional temporary pier is needed for the erection process. This kind of erection could be very favourable depending on the given boundary conditions as for example limitations of work space underneath the bridge itself, therefore eliminating the possibility of building with falsework [2,3].

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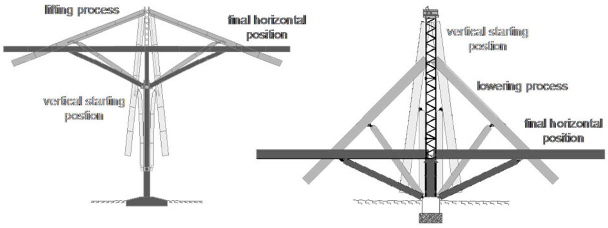

Figure 1: *Balanced lift method for bridges with tall and short piers [4]*

2.1 Trough sectioned girders of the S7 Bridges

The balanced lift method will find its first application in the construction of the crossings of the S7 Motorway over the Rivers Lafnitz and Lahnbach in south-eastern Austria. A total of eight trough-shaped girders will be erected using the balanced lift method before they are filled and the slabs are cast creating the finished bridges. It was possible to convince the Austrian Motorway Agency ASFINAG of both financial and aesthetic benefits of the design in comparison to the originally planned steel-composite bridge as shown in Figure 2 [5].

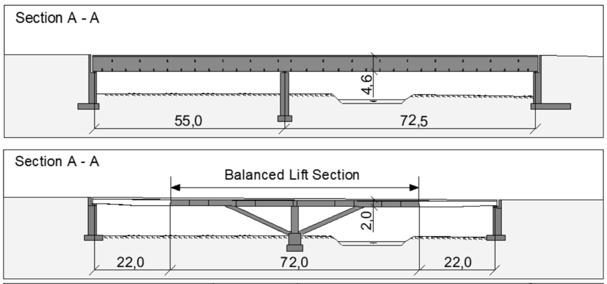

Figure 2: *Top: Original design of the steel-concrete composite bridge. Bottom: Design based on the balanced lift method for a posttensioned concrete bridge*

Prior to the constructions which started late 2018 various preliminary tests to ensure the feasibility and investigate the structural behaviour of the developed trough-shaped girders were conducted. Three 30 m long girders as well as a 70% scale of the S7 bridge structures, as shown in Figure 3, were built and tested. The girders were constructed using thin-walled precast elements and were tested unfilled for their structural behaviour, studied during filling with cast in-situ concrete and finally submitted to torsion loading [3]. The stress redistribution between the precast elements and the cast in-situ concrete and the creep behaviour of the entire girder were monitored over a period of four years and show how the initially high stresses in the prefabricated outer shell are gradually reduced with the cast in-situ concrete subsequently subjected to axial compression strength [6]. The production of all the prefabricated elements for the S7 bridges started in spring 2019 with the first assembly and lowering act set for August 2019. The production of the thin-walled girders in the manufacturing plant is shown in Figure 4. The finished thin-walled girders awaiting the transport to the construction site of the S7 Motorway can be seen in Figure 5.

Figure 3: *The 70% scaled test structure during mounting of the thin-walled girder (top), the lowering process (middle) and finished (bottom)*

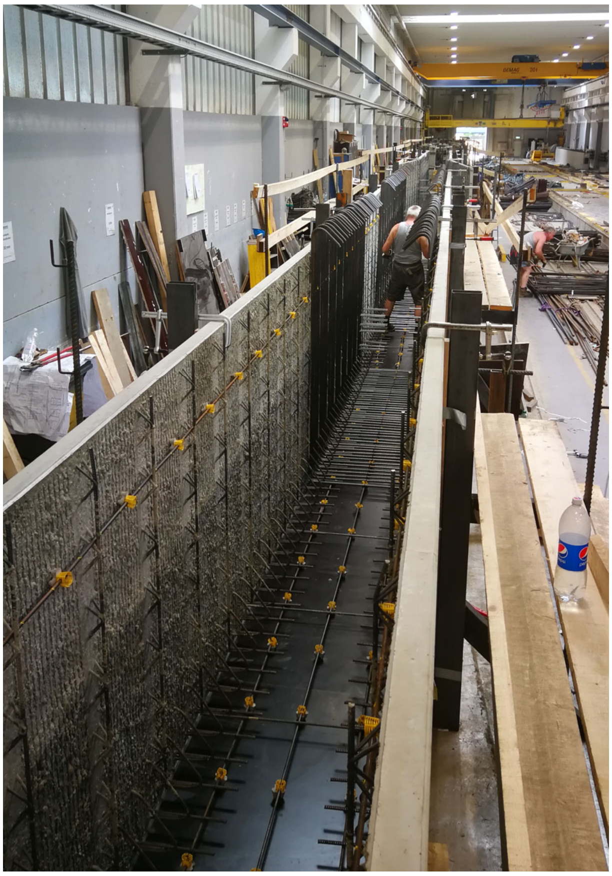

Figure 4: *Setting up the thin-walled precast elements in order to cast the bottom plate to create the trough shaped girders for the S7 Motorway*

Figure 5: *Thin-walled prefabricated bridge girders waiting at the storage yard of the manufacturing plant for transport*

3 BOX SECTIONED GIRDERS

In order to erect bridges with large spans using lightweight thin-walled precast concrete girders, sturdy box-cross-sections were developed. The objective, as it had been for the development of the cross-sections for bridges with smaller spans, was the creation of a girder made of precast elements light enough for transport and erection by conventional transport and lifting equipment. As is the case for the trough-shaped cross-sections, the precast elements should serve as a permanent formwork for the subsequently added in-situ concrete, therefore considerably reducing the necessary formwork and falsework on the construction site. Once mounted to their final position the missing and hollow parts of the box-sections would be cast with in-situ concrete creating a massive monolithic structure. This building technique would be applicable with most bridge construction methods and would be especially advantageous for those with big differences in the bending moment distribution between the construction stages and the final state.

3.1 Cross-sections using lattice-girder slabs and double wall elements

The initial idea for the construction of the box-sectioned girders was to use 80 mm thick lattice-girder slabs as floor and deck slabs and double wall elements for the webs. By repurposing these standard prefabrication elements it would be possible to create very cost-efficient and lightweight bridge girders. The webs and deck slab would be prefabricated in a production plant, then transported to the construction site, where all elements would be assembled and the bottom slab would be cast.

The production of two full-scale prototypes, as shown in Figure 6, was commissioned with the goal of testing the feasibility of the construction method. During the production and the assembly process valuable insight into various possible improvements were made. Once the feasibility was proven, the segments were tested with two symmetric loads applied to the deck and bottom slabs for their stability.

The two prototypes were additionally subjected to shear testing. During the load tests, the segments were supported by four load cells, with two of them hinged to achieve support without constraint. The original bottom slab was strong enough to withstand the high bending moments due to subsequently added concrete in contrast to the connecting elements between the shells of the double wall elements which needed strengthening, to allow the two shells to act together as one continuous beam in the web of the box-girder.

Figure 6: *Prototype made from thin-walled prefabricated elements*

3.2 Cross-sections using crossframes

The insights gained from the production and testing of the first prototype allowed the development of cross-sections out of thin-walled concrete elements strengthened by steel crossbeams as is shown in Figure 7. The elements can be produced in highly automated manufacturing plants, as is the case with lattice-girder slabs and double wall elements, are then transported to the construction site where they can be assembled to segments using standard steel connections with screws. By eliminating the casting of the floor slab and the complicated connection of the lattice-girder slabs to the double walls, the efficiency of the assembly process was increased.

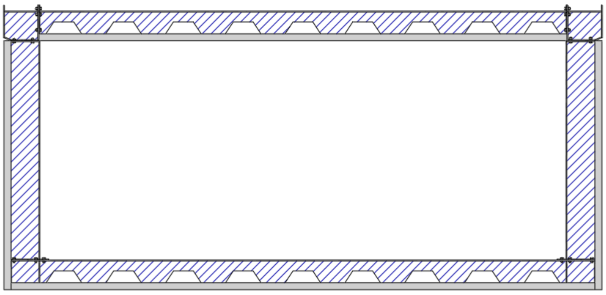

Figure 7: *Box-shaped girders with crossframes*

The main advantages of these new cross-sections is the easy transport of the separate elements, the fast assembly, the very small lifting weight in comparison to full-cast girders of the same length (less than 20%) and the ability to create a monolithic structure using post-tensioning and cast in-situ concrete once placed in its final position. Through the change in the static system, which occurs throughout the construction process the stresses in the superstructure are reduced therefore leading to a more efficient and material saving superstructure.

4 CONCLUSION

Bridges are, with a great variety of possible construction methods, a core element in modern road construction. As is the case for most construction methods, experts are looking for innovative, economical and rapid methods to optimize the construction process, thus saving costs and time. At the same time huge emphasis is placed on the durability and perfect execution. A possibility to meet all these demands stated was investigated by the Institute of Structural Engineering of the TU Wien over the past years.

Initiated by the demand for lightweight bridge girders needed for the construction of bridges using the balanced lift method, a construction method for prefabricated concrete girders was developed. The method was tested and various varieties of the girders were designed, manufactured and tested. The result of all research for the application of these thin-walled precast elements in bridge and engineering structures was rather intriguing. It was shown that the girders were able to compete with steel girders in an economic and financial aspect.

With the first application of the balanced lift method and therefore of the thin-walled precast girders developed at the TU Wien, further aspects of the entire process will be tested in an actual building environment. The large box-sectioned girders still await their implementation but the research team is confident, with all positive attributes of this building method speaking for themselves, that this will be the case in the near future.

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