LIGHT PRECAST AND PRESTRESSED ELEMENTS FOR BRIDGE CONSTRUCTION

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ABSTRACT

In order to develop light precast elements for bridge construction, thin prestressed precast elements were designed to carry the weight of subsequently cast in-situ concrete. The U-shaped precast elements are used as lost formwork and consist of 70mm thick wall-elements and a 120–200mm bottom plate. They include all the reinforcement and tendons which are necessary for the final state. A set of full-scale tests was carried out to test the fabrication and the load capacity of the elements. A 30m single span beam was built consisting of 3 separate elements. In a second test a 50m bridge section was erected by using the light U-shaped precast elements in combination with the balanced lift method. The balanced lift method is a new construction method which proposes to assemble the bridge girders in a vertical position. With the aid of precast compression struts the girders can be rotated into the final horizontal position without using the area under the bridge. The full-scale tests have impressively demonstrated the rapidity of the construction method. Using prefabricated construction elements in combination with the balanced lift method is an attractive alternative compared to steel-girders, which are used for steel-concrete-composite bridges.

Keywords: Bridge, Construction method, Heavy lifting, Full-scale test, Precast elements

INTRODUCTION

In conventional applications of precast concrete elements in bridge engineering, either match-cast elements are installed by using gantries or heavy bridge girders are lifted by mobile cranes. A different approach was investigated in a research project at Vienna University of Technology. The underlying idea was to minimize the weight for the transport and the lift operations. U-shaped sections were produced by means of webs with thicknesses between 50 mm and 70 mm and a connecting bottom slab with a thickness between 100 mm and 200 mm. The webs consisted of prefabricated elements regularly used for the construction of slabs in buildings and can be produced economically. The U-shaped prefabricated elements are basically developed as formwork for the webs of T-beam bridges. They have to exhibit sufficient stiffness to carry the load of in-situ concrete (Fig. 1). To guarantee crack-free elements during transport and the placing on-site the elements are post-tensioned. Therefore, every necessary pre-stressing cable and anchor is already casted in during the prefabrication.

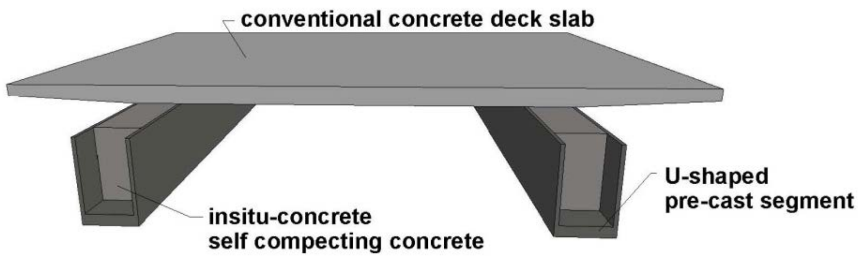

Fig. 1 Schedule of the construction process

The schedule of the construction process is based on mounting the pre-cast-elements and casting in-situ concrete subsequently. The newly formed square-section girder will be completed with a conventional reinforced concrete deck slab, just like in a composite bridge. All things considered, the construction period on the building yard can be minimised significantly because of the high pre-fabrication-level.

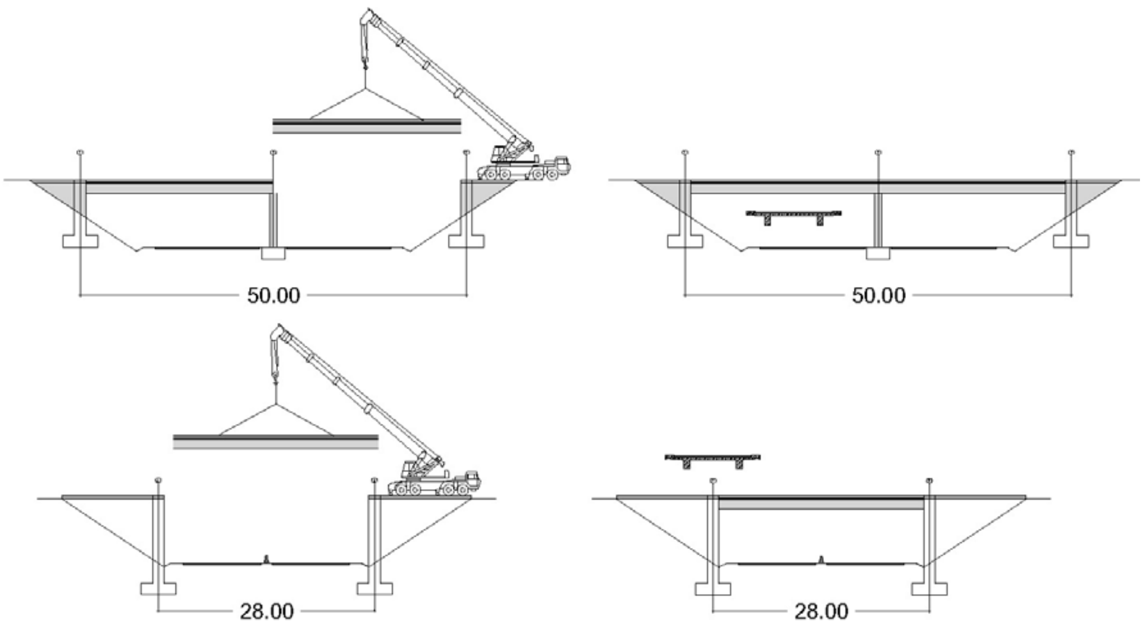

Fig. 2 Erection of single- and two-span bridges

The elements can be used for single- and multiple-span bridges with an effective span of 30 to 50 m (Fig. 2) with the main advantage of being able to erect the bridge without using the area under the bridge, thus the traffic can flow uninterrupted throughout the construction period. Using the light and U-shaped prefabricated elements is an attractive alternative option compared to steel-girders used for steel-concrete-composite bridges.

Another possibility of applying the ultra-thin precast concrete elements is in connection with the balanced lift method.

THE BALANCED LIFT METHOD

The balanced lift method is a new construction method and was conceived and developed at Vienna University of Technology in 2006. International patent applications have been filed[1,2]. The application of the balanced lift method for building valley bridges with high piers is shown in Fig. 3. Compression struts are assembled adjacent to the pier and, subsequently, the bridge girders are built in a vertical position preferably by using climbforming. By lifting the lower end points of the compression struts, the bridge girders are rotated from the vertical position into the final horizontal position. If the topographical situation requires a design with piers of small or medium height, an auxiliary pier is used for the lowering process of the bridge girders as shown in Fig. 4.

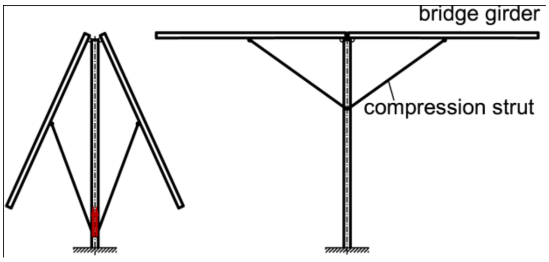

Fig. 3 Balanced lift method for bridges with high piers

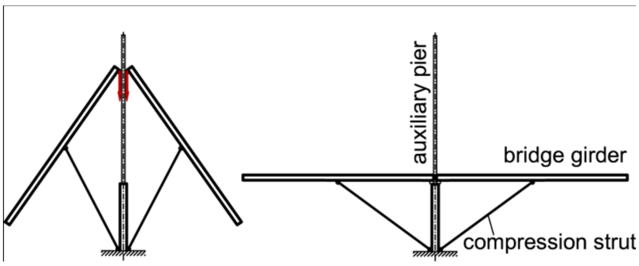

Fig. 4 Balanced lift method for bridges with piers of small or medium height

The bridge girders and compression struts can also consist of precast concrete elements, which can be assembled in a vertical position. An advantage of using U-shaped precast elements is the low weight of the bridge girders, which leads to a smaller lifting force. If general conditions allow the application of precast elements in connection with the balanced lift method, the construction period will be reduced significantly.

BRIDGES ON THE S7 MOTORWAY

The Austrian highway management company (ASFINAG) commissioned an alternative design using the balanced lift method. The original design was done for steel-concrete-composite bridges. The planned erection procedure for the two-span composite bridges was incremental launching because the construction site is an environmentally protected area and access to the construction site is only permitted at the central pier and at the abutments. It could be shown that the construction costs for the post-tensioned concrete bridges erected with the balanced lift method amounted to only 70 % of the calculated costs of the composite bridges.

In the course of the new S7 motorway "Fürstenfelder Schnellstraße" between Riegersdorf and Staatsgrenze the section crosses the rivers "Lafnitz" and "Lahnbach". The total length of the S7.21 Lafnitz-bridge is about 120 metres and the S7.22 Lahnbach-bridge about 100 metres. The cross section (Fig. 5) of the S7 motorway in this line section is traced out for two separate directed lanes, therefore the bridges across the rivers should be erected separately, regarding prospective reconstruction measures. Both areas are ecologically sensitive and part of the nature reserve „Natura 2000".

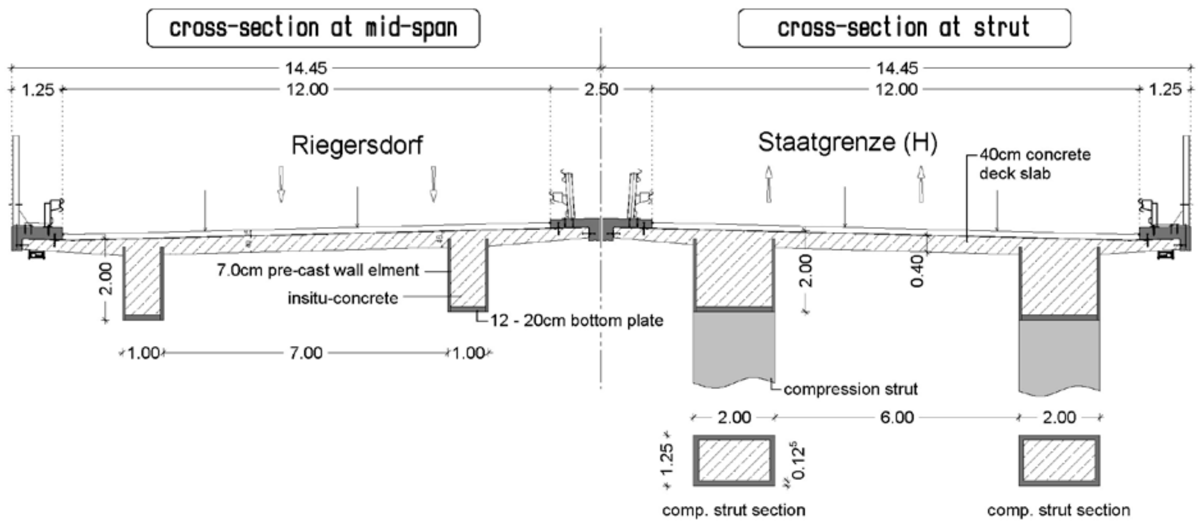

Fig. 5 Cross section of S7.21 and S7.22

The bridges are basically necessary to allow the rivers to meander and to provide options for the deer pass. To avoid encroachment in nature habitats, an erection on a falsework is not desired on the part of the owner. The manipulation areas on the building site should be as small as possible. The access to the construction site is only permitted at the central pier and at the abutments. Thus, only balanced cantilever method, incremental launching or the balanced lift method are possible manufacturing technologies for building these bridges.

For this reason, the S7.21 and S7.22 bridges will each be built using the balanced lift method for bridges with piers of small height (Fig. 4) to produce the central sections of the bridges (Fig. 8). This central section consists of two bridge girders with lengths of 35 m and two 18 m long compression struts and will be built eight times, two for each separate directed lane. Therefore, a high pre-fabrication-level is suitable for recurring construction sections. The cross sections of the bridge girders are U-shaped pre-cast-elements with 70 mm thick wall elements and 200 mm bottom plates. The prefabricated compression struts have a box-profile with a wall thickness of 120 mm. The pre-cast elements are designed as light as possible for a better handling during the lowering and assembling operations and for lower forces during the transport. However, the U-shaped prefabricated elements, which are basically developed as formwork for the webs, have to exhibit sufficient stiffness for carrying the load of in-situ concrete.

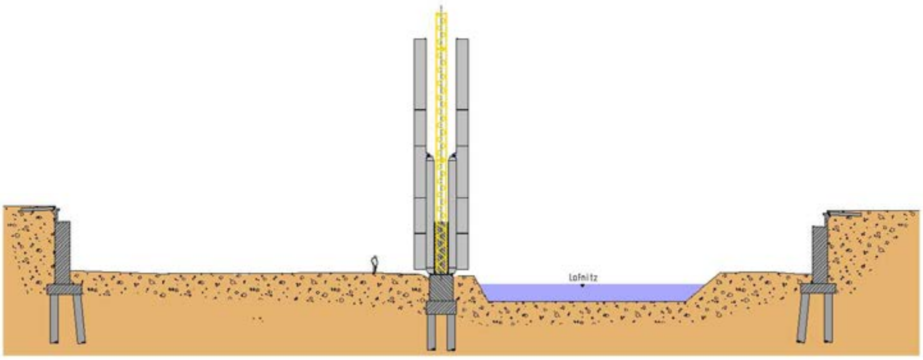

Fig. 6 Mounting auxiliary piers and pre-cast elements in vertical position

In the first step of the assembling operation the abutments, the central pier and the associated foundations will be erected. Then two auxiliary piers, equipped with guiding rails, can be assembled (Fig. 6). These temporarily fixed supporting pylons are needed for the installation of the pre-cast bridge elements in a vertical position and for adjusting horizontal forces during the lowering operation (Fig. 7). All connections between the construction-elements have to allow a rotation, in case of the connection between compression struts and bridge girders exceeding 155°. During a full-scale test, realised in September 2010, economic hinge connections could be developed. Each end of the two bridge girders is connected by high tensile pre-stressing strands with a heavy lifting strand system, fixed on the top of the auxiliary piers. The heavy lifting system is needed to lower the structure from the vertical into the final horizontal position (Fig. 7). The superstructure of both bridges should show a longitudinal gradient of 1.25 %. This decline can be achieved by stressing or relaxing the monostrands which connect the two bridge girders and by raising or lowering the end points of the bridge girders at the pier.

The next step of the assembling operation is to fill the compression struts and the bridge girders with cast in situ concrete and to adjust the deflections of dead load by stressing separate monostrands for each casting section. After hardening of the central section, the distance from the end points of the cantilevers to the abutments will be spanned by means of prefabricated beams with the same cross-section as the balanced lift part (Fig. 8). In order to connect these suspension beams with the central section, a continuous tendon will be attached. These tendons reinforce the two newly formed square-section beams, so that the girders can carry the load of the subsequently cast in situ concrete deck slab. Based on the application of the balanced lift method and the high prefabrication level, the construction period can be minimised significantly and a T-beam bridge can be erected without using area under the bridge, which means less encroachment in natural environment.

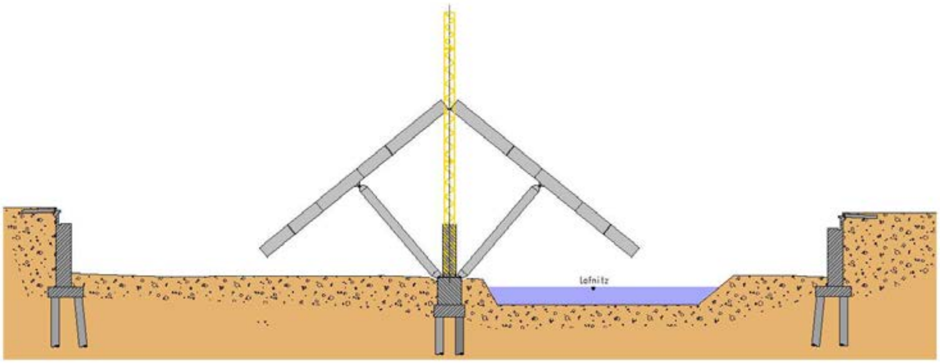

Fig. 7 Lowering operation

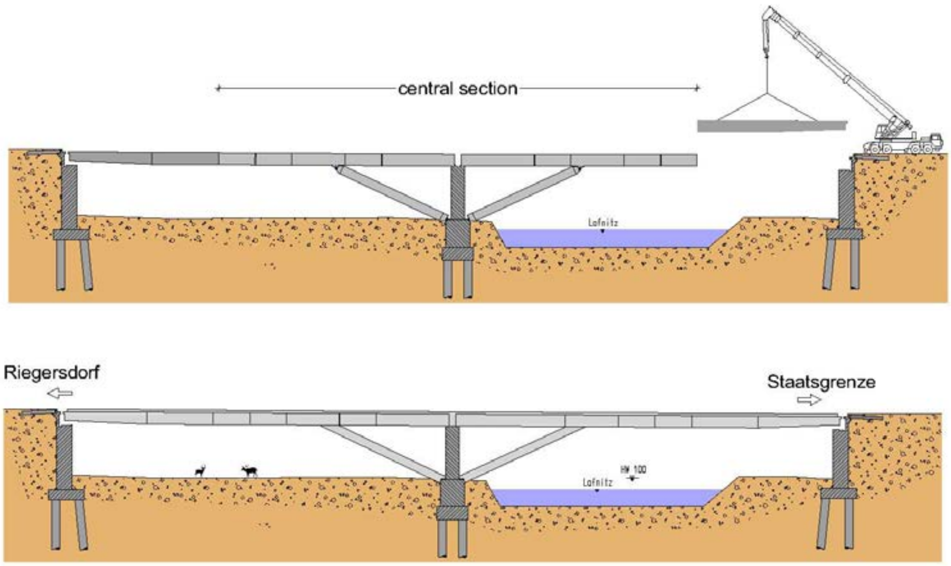

Fig. 8 Complement with suspension beam and deck slab

PREFABRICATION OF BRIDGE GIRDERS AND COMPRESSION STRUTS

In the course of a research project on using thin precast concrete plate elements for bridge construction, it became possible to carry out a full-scale test according to the balanced lift method. The full-scale test structure is similar to the bridges planned for the S7 motorway and represents the central section of Lafnitz- and Lahnbach-bridge. In September 2010, a bridge structure with a total length of 50.5 m was built at the stockyard of a pre-casting company in Gars am Kamp,. Austria. In order to keep the weight of the bridge parts, which have to be moved during the balanced lift process, as low as possible, hollow reinforced concrete elements with small element thicknesses were prepared. The side walls of the bridge girders with a length of 25 m consisted of 70 mm thick concrete elements which are quite frequently used as slab elements in combination with cast in situ concrete for buildings.

Fig. 9 U-shaped concrete bridge girder

These elements were first assembled on a steel formwork and then connected with a 120 mm bottom slab of reinforced concrete. The height of the U-shaped section of the 25 m long bridge girders was equal to 1.26 m and the width varied from 0.7 to 1.4 m. The width of the bridge girder was variable because a larger width was required at the point of connection with the compression strut (Fig. 9). This thin-walled bridge girder with a U-shaped cross-section and a weight of 20.8 tons would have been too fragile for transport, assembly and the lifting process. Therefore, a truss made of reinforcing bars (transverse bars with a diameter of 20 mm at 600 mm and diagonals with a diameter of 12 mm) was welded to reinforcing elements protruding from the precast side wall elements at the top side of the U-section. By installing this truss, the U-section was converted into a box section which proved to be very robust in all the later assembly and lifting operations. For the installation of monostrands, the bridge girders were equipped with transverse concrete beams in regard to future post-tensioning operations.

Fig. 10 Prefabrication of the compression struts

The 13 m long compression struts (width 1.4 m, height 0.875 m, weight 15 tons) were built in a similar way but this time with a slightly increased wall thickness (Fig. 10). The thickness of the side walls was equal to 120 mm. The top and bottom slabs were produced with a thickness of 112 mm in order to incorporate the anchor cones for the tie rods within the concrete section. The tie rods were installed in order to carry a part of the concrete pressure during a later filling of the hollow compression struts with cast in situ concrete.

ASSEMBLY OF ELEMENTS AND LOWERING OPERATION

The assembly of all the elements and the lifting operation was accomplished by the authors and two master students within a week.

First, two 24 m long sections of a tower crane with plan dimensions of 1.2 m by 1.2 m were fixed to the foundation slab. The tower crane sections, equipped with guiding rails, served as auxiliary piers. The weight of both auxiliary piers was equal to 10.2 tons. The top parts of the auxiliary piers were not connected with each other. The distance between the vertical guiding rails amounted to 800 mm on top of the auxiliary piers. On the second day, the compression struts were assembled in vertical position. The bottom ends of the compression struts had been equipped with 30 mm thick steel plates. These steel plates were positioned quite accurately on concrete filled steel tubes with an outer diameter of 150 mm in order to provide an inexpensive hinge connection. The compression struts were temporarily fixed to the auxiliary piers. In the third step of the assembling operation the bridge girders were transported from the prefabrication plant to the stockyard by truck. A 100 ton mobile crane lifted the bridge girders which were subsequently fixed to the top end of the compression struts with four bolts of 16 mm diameter (Fig. 11). Although a tolerance of only 2 mm had been provided for the cylindrical openings in the joining steel plate, the assembly operation could be carried out without any problems.

Fig. 11 Lifting of bridge girders

The tilting of the bridge girders from the vertical position into an inclined position, with the top ends touching each other, was realised on the fourth day. The tilting was achieved by the simultaneous lifting of the two top points of the bridge girders by means of the 100 ton mobile crane. Subsequently, twelve monostrands were installed in the two bridge girders. The monostrands were anchored at the connecting points of each bridge girder and the compression struts. In the top section of the bridge girders, circular saddles with a radius of 544 mm had been formed during pre-casting. After the installation of the twelve monostrands, the strands were slightly stressed to prevent sagging.

Fig. 12 Lowering operation of bridge girders

On the fifth day, the top points of the bridge girders were lowered with the aid of two mobile cranes (Fig. 12). The maximum lifting force had been calculated to be equal to 27 tons, which corresponded well with the lifting force measured by the cranes. After lowering the bridge girders into the final horizontal position (Fig. 13), the geometry of the structure was checked. In this state, the geometry of the structure can be adjusted easily by stressing or relaxing the monostrands and by raising or lowering the end points of the bridge girders at the pier. However, it turned out that the geometry of the bridge girders was already within an acceptable range right after the lowering operation so that no further adjustments were necessary. The original plan was to fill the compression struts and the bridge girders with cast in situ concrete as would be the procedure when building a "real" bridge. However, considering that the bridge was only meant to be a test structure and in order to be able to show the thin-walled concrete elements and the node connections to interested engineers at a later date, it was decided to fill only the node above the pier with concrete in order to provide a higher resistance against horizontal wind loads.

Fig. 13 Central section in the final horizontal position

CONCRETING WITHOUT FALSEWORK

To demonstrate the feasibility of building bridges with ultra-thin precast concrete elements, a second field test was realised. The major aim was to test the behaviour of the elements under the load of the subsequently cast in-situ concrete.

Fig. 14 Erection of a 30 m single-span girder without falsework

A 30 m single-span beam was built consisting of two 6m long end parts and an 18 m long middle part (Fig. 14). The parts were connected with 20 mm grouting joints and 2 tendons, with 19 strands each. The single-span beam had no continuous longitudinal reinforcement. Thus it was necessary to pre-stress the precast concrete elements before filling them with in-situ concrete. After the first pre-stressing level the filling process began. With a rising fill height the pre-tensioning force was increased stepwise until the whole U-shaped element was filled with self compacting concrete. The erection process, which included the measuring of deflections, reaction forces and strains, could be arranged in two days. The second test has impressively demonstrated the speediness of the construction method.

CONCLUSIONS

The combination of thin-walled precast elements and post-tensioning proved to be advantageous for the application of the balanced lift method. Due to the small weight of the elements the joints could be designed economically and the lowering process could be accomplished by mobile cranes, which were already on site, because they were used to assemble the elements in the vertical position.

Another advantage of using thin-walled elements, which are filled with in-situ concrete and post-tensioned at a later stage is, that a structure is obtained which can be considered to be very close to a monolithic structure.

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