Stress redistribution in prestressed concrete bridges built with ultra-thin precast girders

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ABSTRACT

The balanced lift method for bridge construction proposes to build the bridge girders in a vertical position and to rotate them into the final horizontal position with the aid of compression struts.

During the construction process, when the bridge girders are rotated from the initial vertical position into the final horizontal position, it is of utmost importance for an economic application of the balanced lift method that the structural members are as light as possible.

In a test beam (length = 30.02 m, height = 1.44 m, width = 0.7 m) the actual filling process with concrete was carried out. Subsequently, the longitudinal strains on the outside of the beam were monitored over a period of four years in order to investigate the creep behaviour. Due to creep, the initially high stresses in the prefabricated outer shell are gradually reduced and the in-fill concrete is subjected to axial compressive stresses.

INTRODUCTION

In the conventional bridge construction methods the production of the bridge superstructure is carried out in horizontal position. By using the balanced lift method, developed at Vienna University of Technology, the bridge girders are erected next to the pier in a vertical position and are subsequently rotated into the final horizontal position (Kollegger & al. 2014). In order to rotate the bridge girders, additional structural elements (compressions struts or tension ties) are required. These elements then become an integral part of the finished bridge. The rotation of the bridge girders functions similarly to the opening of an umbrella, which is displayed in (Fig. 1) for the example of a bridge with compression struts.

Figure 1. Balanced lift method for bridge with high pier.

The example displayed in (Fig. 1) is suited for a valley bridge with high piers. The application of balanced lift method for bridges with piers of small height is possible, if an auxiliary pier is used as is shown in (Fig. 2).

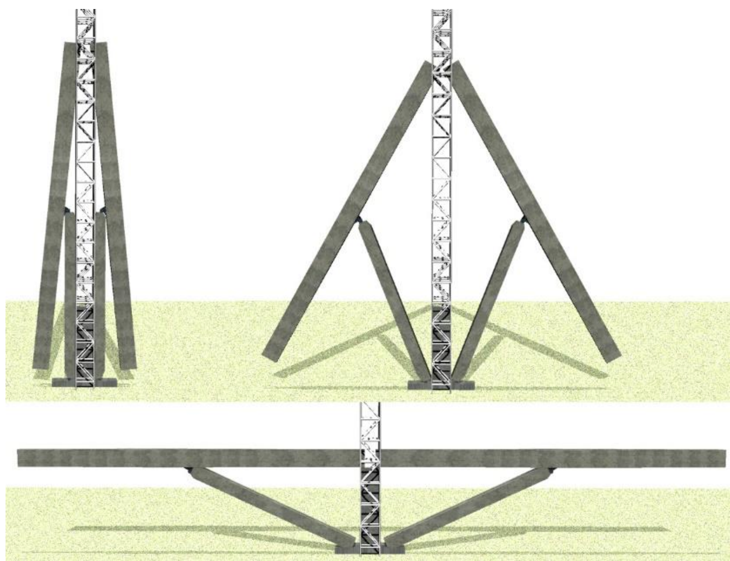

Figure 2. Balanced lift method for bridge with low pier, compression struts and auxiliary pier.

During the construction process, when the bridge girders are rotated from the initial vertical position into the final horizontal position, it is of utmost importance for an economic application of the balanced lift method that the structural members are as light as possible. It was therefore suggested to produce the bridge girders and the compression struts using thin prefabricated concrete elements. In building construction, lattice girder floor slabs have been successfully used for years. These precast elements of 50 to 70 mm thickness serve as permanent formwork for the subsequently added in-situ concrete. The advantages of this construction method are planned to be applied in bridge construction as well. A research project was implemented at the Institute of Structural Engineering at Vienna's University of

Technology in collaboration with the Association of Austrian Concrete and Precast Plants, Austrian National Railways (ÖBB), and the Austrian Expressway and Highway Financing Company (ASFINAG). In this research project the application of precast elements for bridge structures was investigated (Wimmer 2013). The objective was the development of precast concrete girders light enough for transport and erection by conventional transport and lifting equipment. The trough-shaped precast elements are intended to be used as formwork for the filler concrete and will be cast at the construction site to considerably reduce the use of formwork and scaffolding (Fig. 3).

The required reinforcement and the ducts for the tendons can be installed at the precast plant (Fig. 5). It is also possible to supplement the appropriately cast girders with a conventional roadway slab, similar to steel-concrete composite bridges. The advantages that can be gained through the use of precast girders are very promising: Industrialized prefabrication, which is independent of the weather, considerably reduced construction time at the site as well as for the periods during which traffic must be rerouted. Apart from the minimized cost and time required for installing the reinforcement and for building the formwork at the site, the good concrete quality achieved in precast plants is another advantage for this construction method. Other than with composite steel-concrete construction, the connection between web and roadway slab can be established with conventional connecting reinforcement and obviates the need for expensive, welded-on head-bolt dowels.

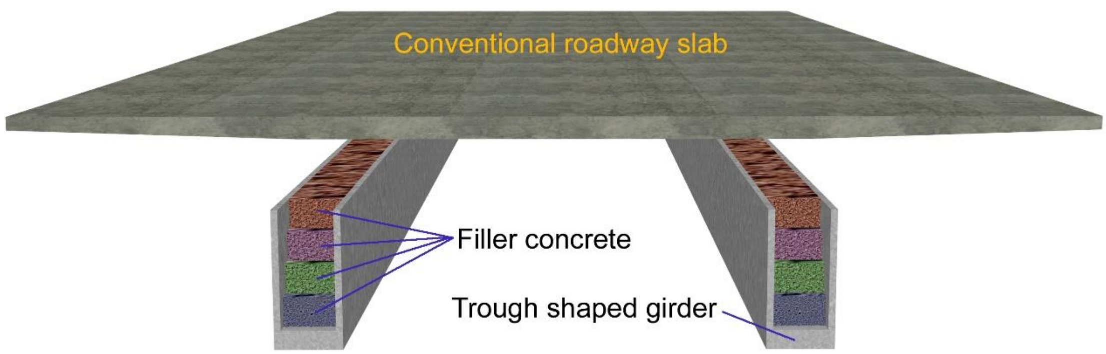

Figure 3. Schematic sketch of bridge with trough shaped precast girders.

PRODUCTION OF 30 m BEAM FOR STRESS REDISTRIBUTION EXPERIMENT

In order to demonstrate the feasibility of building bridges with thin precast concrete elements, a field test was realized with the aim of testing the behaviour of the thin-walled elements under the load of the cast in-situ concrete and, at a later stage, of measuring the stress redistribution between prefabricated girder and filler concrete due to creep.

A longitudinal section of the left half of the 30,02 m long test beam is shown in (Fig. 4). Transverse beams, each with a length of 3 m, were built at both ends of the test beam. The test beam consisted of three prefabricated parts, namely two 6,02 m long end sections with transverse end beams and a 17,98 m long central section.

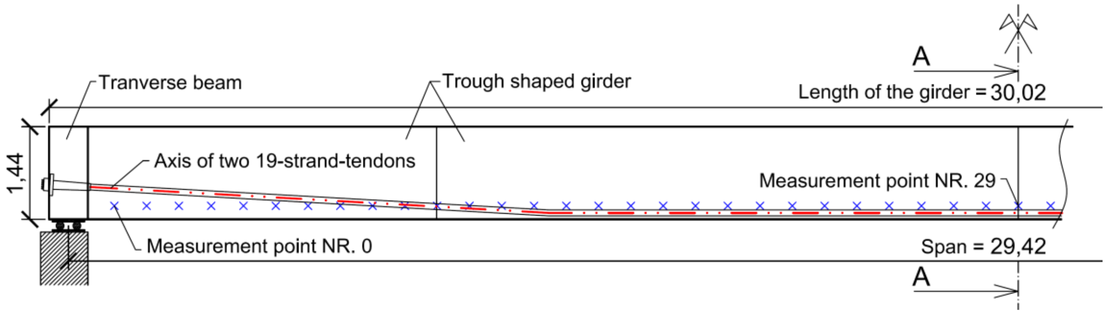

Figure 4. Longitudinal section of test beam.

The thickness of the wall elements was equal to 70 mm and the bottom plate had a thickness of 200 mm. The overall dimensions of the section amounted to a width of 700 mm and a height of 1440 mm. The photograph in (Fig. 5) shows an interior view of a pre-fabricated end part. The steel ducts for the two 19-strand-tendons as well as the lattice girders (consisting of two reinforcement bars, diameter 6 mm, placed in the wall elements, one reinforcement bar, diameter 10 mm, placed at the inside of the beam and diagonal bars with a diameter of 7 mm) are clearly recognizable.

Figure 5. Interior view of the prefabricated end part.

The three pre-fabricated parts were transported to the test site, placed on temporary supports, the ducts were connected and the 20 mm wide joints were filled with a high-strength grout. In the next step the two tendons were stressed to 1500 kN each, which resulted in an upward movement of the central part of the test beam. Due to the upward movement the self weight of the beam (g=7,84kN/m) was carried over the distance of 29,42 m between the load cells by the beam itself.

Within a time difference of 24 hours, the filling concrete was placed in four layers with a thickness of 0,31m (Fig. 6, Fig. 7 and Fig. 8). During the pouring of the concrete, the post-tensioning force was increased stepwise up to 5300kN. Details of the manufacturing procedure can be found in (Table 1).

Table 1. Production sequence of test beam.

Day	*Time*	*Activity*
1		Casting of bottom slabs of prefabricated parts of the girder
29		assembly of prefabricated parts on temporary supports and filling of joints with high-strength grout
30		Stressing of post-tensioning tendons P = 1 500kN
31	11:05	increase tendon force to P = 2 500kN
	11:10	casting of filler concrete layer 1
	11:34	increase tendon force to P = 3 000kN
	12:00	casting of filler concrete layer 2
	12:10	end of casting
32	9:50	increase tendon force to P = 4 500kN
	10:25	casting of filler concrete layer 3
	10:38	end of casting
	10:46	increase tendon force to P = 5 300kN
	11:25	casting of filler concrete layer 4
	11:40	end of casting

The 28-day compressive strength of concrete for the precast elements as well as for the filler concrete was determined using concrete cubes. The 28-day strength for the precast elements and the filler concrete was equal to 43,2 MPa and 41,9 MPa, respectively (Kromoser 2011).

The filling of the test beam with in-situ concrete is shown in (Fig. 6). The hydraulic jack positioned at the stressing anchorage can be seen at the end of the beam. There was a second jack placed at the other end of the test beam since the stressing of the two tendons was carried out simultaneously. A more detailed description of the production of the test beam is contained in (Kromoser 2011 and Wimmer 2015).

Figure 6. Filling of 30m test beam with in-situ concrete.

NUMERICAL SIMULATION AND COMPARISON WITH EXPERIMENT

The test beam was modelled using 44 beam elements. The specified concrete strength was equal to C30/37 and the material parameters were chosen according to Eurocode 2.

An important feature of the numerical analyses was the modelling of the incremental production of the test beam. Also the increase of the modulus of elasticity of concrete and the time dependent creep behaviour was taken into account.

The calculated stresses in the centre of the beam (section A-A of Fig. 4) at the top and bottom of the precast girder are shown in (Fig. 7 and Fig. 8). It can be seen that the central cross-sections of the test beam is always in a compressed state. This fact is of utmost importance at the joints between the individual precast elements since no longitudinal reinforcement is provided at these locations.

During the production of the beam compressive stresses are calculated for the first and second concrete layer for the time equal to 32 days, because the strength of these concrete layers (age equal to 1 day) is taken into account in the numerical calculations (Fig. 7 and Fig. 8).

Although the concrete compressive stresses are quite high during the filling of the test beam with in-situ concrete, it can be noted that these stresses are quite reduced for the final state (time equal to 100 years) according to the results shown in (Fig. 8). The redistribution of stresses between the prefabricated girder and the filler concrete is important for the economic application of this construction method, because the stress limitation of Eurocode 2 have to be observed.

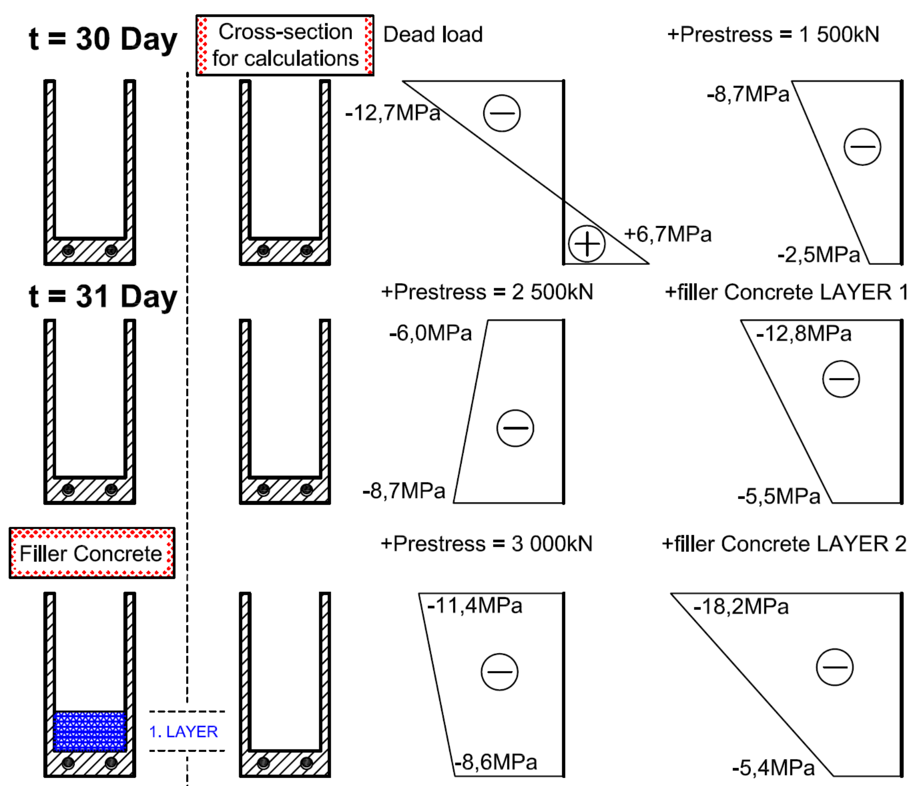

Figure 7. The calculated stresses in the centre of the beam (section A-A – Fig. 4).

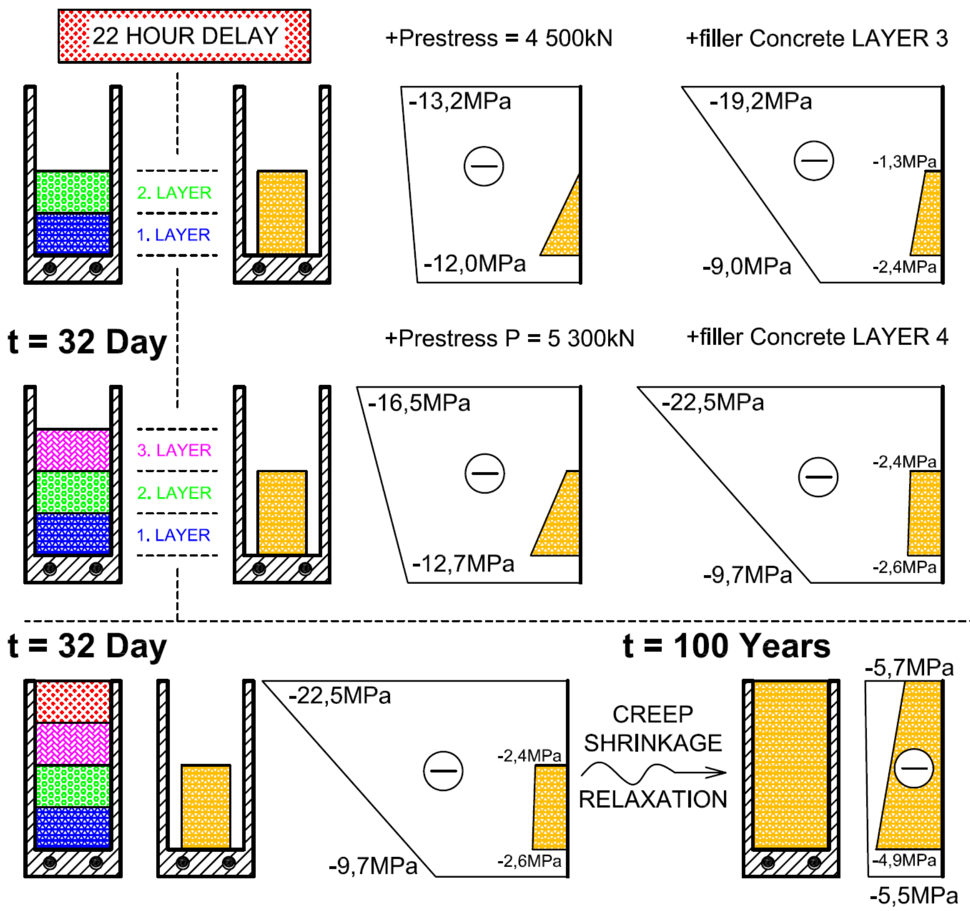

Figure 8. The calculated stresses in the centre of the beam (section A-A – Fig. 4).

A comparison of measured concrete strains and calculated concrete strains was carried out in order to assess the quality of the numerical simulation of the test beam. 58 measurement points had been fixed close to the bottom fibre in the longitudinal direction of the test beam (Fig. 4). With the aid of an extensometer the relative displacement between the measurement points could be determined. The results of the strain measurements from October 2010 to August 2014 are shown in (Fig. 9). The calculated strains are also shown in (Fig. 9) with solid lines. A good correlation of measured and calculated strains can be noted from the results displayed in (Fig. 9).

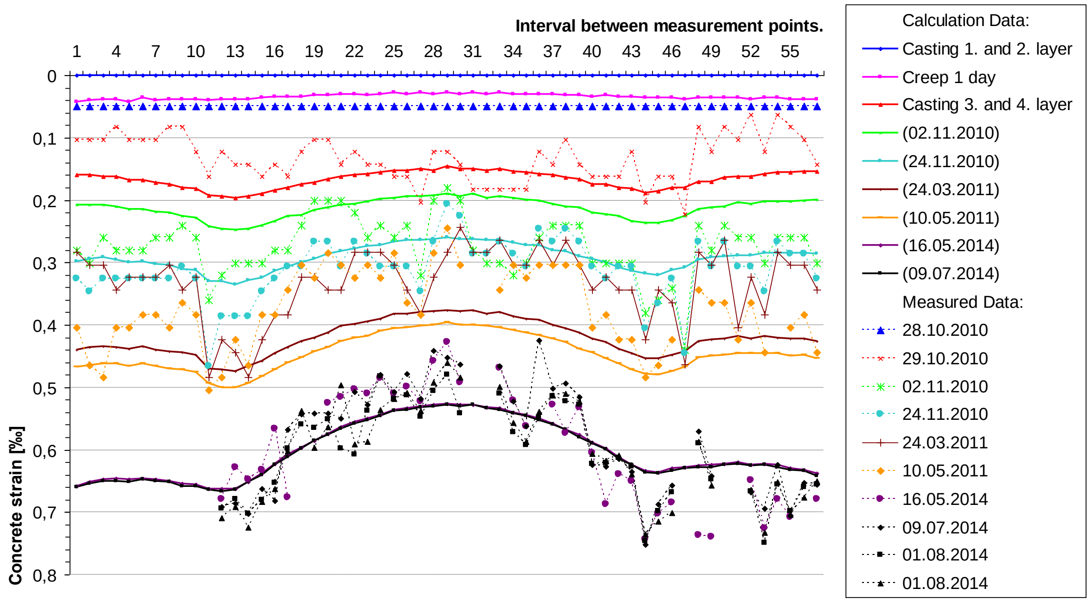

Figure 9. Comparison of measured and calculated concrete compressive strain of test beam.

CONCLUSION

The balanced lift method is a new bridge building method, which enables the construction of elegant and economical valley bridges. A careful and meticulous analysis of the different construction stages is required for designs based on this method, because light structural elements are used during the balanced lift. These light elements are subsequently filled with in-situ concrete, which leads to many different construction stages and structural elements with changing cross-sections. It could be shown in this paper that a considerable redistribution of concrete stresses does occur, which should be taken into consideration in the design calculations for economic reasons.

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