Construction of precast segmental box girder bridge

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Abstract. New road segmental bridge have been built near the city of Žilina, aligned on European highway corridor. The use of segmental concrete box girder was chosen as the flexible system and appropriate method in a municipal zone. The same parallel precast post-tensioned box girder structures were used with main spans of 60.5 m for total length of 1042 m. The balanced cantilever method, with the self-launching gantry was used for erection. The shorter end spans, adjacent to the abutment, had to be built by employing falsework. Generally, the early segmental bridges have not been realized without problems following to the structure collapse. In order to assure the safety under construction stage of bridges and subsequently in service, the data was collected during casting and erection of the bridges since August 2016 to November 2017. The experimental research was divided into the laboratory testing and continuous in-situ strain and temperature monitoring of the bridge superstructure. The paper illustrates fabrication and erection process of the bridge and some results of superstructure testing.

1. Introduction
Segmental construction is preferred in highway bridges for many reasons. One advantage of this technique is elimination of conventional falsework and temporary supports by adopting cantilever construction method. The major part of the work is performed in the precasting yard and erection process can start simultaneously with the foundation work. It is adaptable to almost any conceivable site conditions. Horizontal and vertical alignments, straight or curved bridges can be built without any difficulty. The long span structures have been built without any objection to traffic, over deep valleys or difficult terrain. Therefore, this method is used for large urban and suburban viaducts for most road and rail bridges all over the world. Nevertheless, there are some limitations due to the cost for precast yard and erection equipment. Generally, the method is more economical when number of segments exceeds 350 to 400 units per bridge [6]. Precast cantilever method is suitable for 40 to 150 m span length depending on erection method (span-by-span method, balanced cantilever method or progressive placement). The post-tensioned structure is made of individual precast units stressed together. The joints are either dry (in areas where climate permits) or made of a very thin epoxy resin (Europe, Asia). The joints are of negligible thickness without any structural function. To lock the segments together the shear keys are cast into the joint faces. They transmit shear forces and help in exact alignment of the segments. During the construction process, the structure changes in static system, in support, loading and magnitude of external prestressing. The whole section remains in compression under both dead and live load. An accurate evaluation of stresses and deformation in each construction stage is essential to maintain safety levels and to ensure the final required bridge alignment.
2. Bridge details

The segmental bridge is a part of the new Slovak motorway connection from Bratislava to the Ukrainian border forming the international connection E-50, located in the urban area of village “Lietavská Lúčka” near the city Žilina. The bridge is composed of the two separate precast concrete structure. The total length of both structures is 1042 m. The similar segmental structure consists of a total of eighteen continuous spans with lengths 46.10 +15 x 60.50 + 49.80 + 32.80 m. The balanced cantilever method was accomplished utilizing the self-launching gantry for erection.

The roadway has a variable width from 11.75 to 13.25 m between barriers and the total deck width varying from 14.25 to 15.75 m. The typical cross section consists of post-tensioned box girders of the constant depth 3.0 m for all the spans providing the most efficient section for casting. The span-to-depth ratio is corresponding to 20. The typical cross section is shown in figure 1. The constant web thickness 500 mm was determined by shear considerations, as tendon ducts internal to the concrete were present. Box girder webs are inclined. The local haunches are used at the intersection of the bottom slab and the webs to provide sufficient space for accommodating the required number of tendon ducts. The box segment has a bottom slab width of 6.5 m. The bottom flanges are 200 mm and 350 mm thick. The top slab thickness is variable, resulted from the limit deflection criteria under the live loading.

Two pairs of reinforced concrete column piers of square-shaped section provide vertical supports for spans at intermediate points. In addition to transferring the superstructure vertical loads to the foundations, the piers should resist the higher lateral actions caused by potential earthquake events in this low seismic area and consequently ductility aspects had to be provided by their design. The seat-type abutments were constructed separately from the bridge superstructure as the reinforced earth-retaining structure using multiple-layer strips from non-gradable fabrics to reinforce the fill material in the lateral direction. The face panels as slabs anchored by the strips are subjected to the lateral soil pressure. The bridge superstructure seats on the abutment stems through the pot bearings comprising plain elastomeric disks confined in shallow steel rings. Teflon sliding surfaces of expansion bearings can accommodate the translational movement. Keeper plates are used to retain the superstructure moving in presumed direction. The fixed bearings allowing only rotations, but restricting movements, are located at the top of the central piers. The placement of expansion joints within these long viaducts was necessary to accommodate the change in length of structure 560 mm due to creep, shrinkage, and thermal changes. The expansion joints are located at the centerline of the end abutments.

3. Fabrication and erection process

The segments were erected in existing stationary yard in Prefa Senec factory, allowing superior quality control. The short line match casting system was used and the rate of the segment production was four segments per line every 5 days. Total number of segments casted in stationary yard was 928 units. The
The precasting operation was divided into segment casting, geometry control, segment handling, and storage. The control setting of the precast yard allowed production similar to an assembly line environment.

The box girder was designed as the most efficient and economical cross-section for segmental bridges. The torsional stiffness of a box girder allows for temporary out-of-balance forces during the erection. The constant depth (3.0 m) and weight (60 t) of the segments was designed by the capacity of transport and placing equipment. The five types of segments were designed for each bridge. The three main types: abutment segments, pier segments, span segments and two other types of modified span segments - segments with anchor block for upper continuity cables and segments located near the pier. Pier and abutment segments are 1.65 m in length, the span segments are 2.2 m long. The span segments were designed of concrete class C 45/55 and pier segments of C 55/67. The pier segment was designed for both permanent and temporary conditions [9]. The stressing and grouting of the transverse tendons in pier segments were done in the storage yard before the shipping for erection. The three tendons has been designed with characteristic strength 1860 MPa consisting of 5 strands with diameter 15.7 mm. The longitudinal post-tensioning was designed as bonded tendons with low relaxation strands of 15.7 mm and characteristic strength 1860 MPa.

The multiple shear keys were designed to provide locations for joints of adjacent segments and to carry shear load, figure 2. They were formed across the full width of the web and in the top and bottom flanges. The typical segment was made of reinforcement cage prefixed using jigs, figure 4. The web form was supported by a frame connected to the casting cell foundation.

The new segment was match-cast against the previous one. When the new segment had hardened, it was moved to the match-cast position to serve as a front bulkhead of the casting cell for the next segment, figure 3. Control points were located over the webs to eliminate any influence of the top slab movement. The center points establish theoretical centerline. The successive segments were cast against the adjoining segment in the correct relative orientation with each other starting from the first segment away from the pier. To obtain a vertical curve of the bridge, the match-cast segment had first to be translated and given a rotation in the vertical plane. To obtain a horizontal bend, the conjugate unit was given a rotation in the horizontal plane. All these adjustments of the conjugate unit had to be combined for obtaining the desired geometry of the bridge. The balanced cantilever method requires additional geometry control to account for the temporary construction loads on the structure, than an additional camber was built into the segments.

![Figure 3. Precasting bed.](image3.png)  
![Figure 4. Reinforcement cage.](image4.png)

The typical cycle of erection consists of placing segments, installing and stressing post-tensioning tendons and launching the gantry to its next position.

The 60-ton segments were precast and delivered by trailers. The transportation may produce excessive stresses, which were considered. Segments were lifted into place by a self-launching gantry placed on the previously completed portion of the deck (figure 5). In order to assure the safety under construction of bridges. The self-launching gantry has a length slightly longer than the typical span. The construction started from the piers cantilevering out to both sides to minimize the negative
moments. The each phase was tied to the previous ones by the post-tensioning tendons, incorporated into the permanent structure. Cantilever tendons are designed as internally bonded within the top flange.

During the erection of the cantilever, the centre leg rests on the pier while the rear leg reposes on the cantilever tip of the previously erected span, which must resist the corresponding reaction. Prior to launching, the back spans had to be made continuous. Then, the centre leg was moved to the forward cantilever tip, which had to resist the weight of the gantry plus the weight of the pier segment. This stage controls the design of the gantry, which must be made as light as possible, and of the cantilever. The use of epoxy joint requires a perfect fit between the ends of adjacent segments. The joints were made of 2 mm thin epoxy resin, which provides water tightness and durability at the joints and did not alter the match-cast geometry.

![Figure 5. Balanced cantilever construction with launching gantry.](image)

The mid-span closures between cantilevers were constructed by casting in-situ joint of concrete class C 35/45 and approximately 0.6 m in length. Grouting procedure provides corrosion protection to the prestressing steel and develops bond between the prestressing steel and surrounding concrete.

The end spans adjacent to the abutment had to be built on falsework. It helps to balance moments in different spans under operating loads and provides positive support reactions on the abutments. In order to allow the movement necessary for right joints, the jacks with capacity of 2000 kN were placed between the bottom of the segments and the falsework.

The several actions had to be considered in checking verification. Firstly a possible out-of-balance one segment on the cantilever. Then, the presence of a stressing platform, live loading on one side of 1.5 kN/m², wind loading acting during the construction and the possibility of one cantilever having a 2.5% higher dead weight than the other [1-2, 8].

4. The measurement and monitoring of the bridge structure
The monitoring of the bridges is able to detect reliably structural changes or damage that is not visually achieved [4]. Structural changes may result from other causes such as sudden settlement of foundation, ground movement, excessive traffic or failure of post-tensioning tendons [5]. To avoid the unpredictable structural changes both bridge superstructures were monitored. The program was divided into following parts:

- Laboratory tests of mechanical properties.
- Strain and temperature recording during the erection.
- The static and dynamic load tests.
- Long-term monitoring of bridge performance in service.
The data have been collected continuously during the fabrication and erection process in 2016 and 2017. The magnitude of stresses was evaluated at all the stages of construction. The specimens were tested in Accredited Laboratory of Civil Engineering at University of Žilina.

4.1. Verification of mechanical properties

Uniform quality and higher strength of concrete are essential for segmental construction. It is recommended the ideal concrete mixes as near as practical zero slump [7]. The zero slump concrete allows for direct stripping of the unhardened product after filling and vibrating the mold and subsequent transport to a place with defined curing condition.

The main purpose of the laboratory tests was to verify the real values of basic mechanical properties of concrete such as compressive strength, modulus of elasticity and long-term concrete strain development over time due to creep and shrinkage, figure 6. The compressive strength as the common performance property was measured by breaking cube concrete specimens of 150 mm and cylindrical concrete specimens of 150 x 300 mm size in the laboratory compression testing machine and calculated from failure load divided by the cross-sectional resisting area. The specimens were tested in curing room with temperature of 20 ± 2°C and relative humidity of 80% [10]. Three specimens from each batch of selected casting segments were tested. The results from the cast cubes and cylinders validated existing concrete strength, as well as adequacy of curing and protection measures [3]. Measured material properties were used in computing model for non-linear analysis to calculate stresses and deflection of the bridge structure.

The next test method measured the load-induced time-dependent creep strain on molded concrete samples subjected to sustained longitudinal compressive load (figure 6b). Creeping testing machine consists of main unit using disk springs specifically selected to maintain constant load over the range of deformation probable during creep tests and measured using externally mounted mechanical gage points. For strain time dependent variation, the seventh and sixteenth mid-spans, as well as the two neighboring piers sections of the left bridge, were implemented with sensors during the fabrication and erection process. The vibrating wire strain gauges, suitable for long term readings were placed on the concrete deck and on the girder web. Four strain gauges according to figure 6c were placed at the intersection of the slabs and the webs of cross sections and spaced along the length of each girder. Since there were two selected segments in each span, a total of 16 strain gauges were placed on the left bridge (span no. 7 and no. 16) and also on the right bridge (span no. 2 and no. 9). The histories of strain development were recorded and structural response computed from the measured readings. At the same time, temperature measurements were made on the specified 32 different locations across the centre of the span and pier sections. The data acquisition for each site investigation took about six
hours. Figure 7 illustrates the normal stresses variation in the mid-section of the sixteenth span of the left bridge during the construction stages (in the stage of cantilever, Pnk), before loading (PZS) and in loading test (ZS). The prediction stress distribution and obtained values in bottom and top slab of the cross section achieved acceptable agreement.

**Figure 7. Normal stresses variation (span no. 16).**

5. Conclusions
Prestressed box girder bridges typically exhibit small deflections during the first years of service. Global stresses and deformations of segmental box-girder bridges due to the effects of dead load and post-tensioning, as well as the long-term effect of creep can be predicted during the design process by the use of a computer analysis program. But the real values are dependent, to a large extent, on the method of the structure construction, the age of the segments when post-tensioned and the time when other loads are applied [3]. Real more correct behaviour, especially of major structures can be identified only by field measurements. Monitoring system is a way for understanding the complex behaviour of bridges, especially early structural changes in service condition. The results of this study could help in design, construction process and especially in bridge maintenance of the precast segmental bridges in further years.

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