Design and construction of Cetina River arch bridge

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ABSTRACT: A new concrete arch bridge with 140.30 m span was constructed across the Cetina River canyon near the town of Trilj. The beautiful river canyon is an environmentally protected area, and arch structure was selected as it harmoniously blends into the landscape. The arch is of span 140 m with a rise of 21.5 m, giving rise-to-span ratio of 1/6.5. The construction of the bridge across the Cetina River canyon commenced in the year 2005 and it will be opened for traffic in June 2007.

1 INTRODUCTION

A reinforced concrete open spandrel deck arch bridge was designed to cross the Cetina River near the town of Trilj (Runjić, 2005). The beautiful river canyon is an environmentally protected area, and arch structure was selected as it harmoniously blends into the landscape (Radić at al, 2006).

The roadway alignment at the Cetina arch Bridge lies in a straight line in ground plan and the vertical alignment is in a constant slope of 0.5%, lying approximately 340 m above the sea level. The width of the canyon at the grade line elevation is 216 m. The total bridge length including abutment wing walls amounts to 236 m.

The overall width of the superstructure is 10.5 m, accommodating two-lane roadway (2 x 3.50 m) as well as 1.25-m wide sidewalks and 0.5 m edge strips on both sides. The roadway surface has 2.5% slope in transverse direction.

2 BRIDGE ESSENTIALS

The arch is fixed of single-cell cross-section with constant outer dimensions: 2.5 x 8.0 m (Fig. 1). In order to improve the side view of the arch, the lateral surfaces are curved. The 40-cm thick top and bottom chords of the arch increase only from the first spandrel columns towards the arch springings where they reach a maximum value of 60 cm. Webs are 50 cm thick. The arch is connected to arch abutments by a 3.0 m long diaphragm. Vertical diaphragms in the arch are placed under spandrel columns, with width equalling to the width of columns they support. The arch (Fig. 2) spans 140 m with a rise of 21.5 m, giving rise-to-span ratio of 1/6.5. The designed concrete class for the arch was C45/55.

The soil is limestone rock. Abutments and columns are founded on shallow spread foundations. Each double column has a joint foundation. Abutment foundations are of cascade type following the terrain slope. Arch foundations are massive with the cascade type bottom to reduce excavations and attain the minimum foundation depth of 2.0 m for the whole foundation. The arch foundations are of C30/37, and all other foundations of C25/30 concrete class.

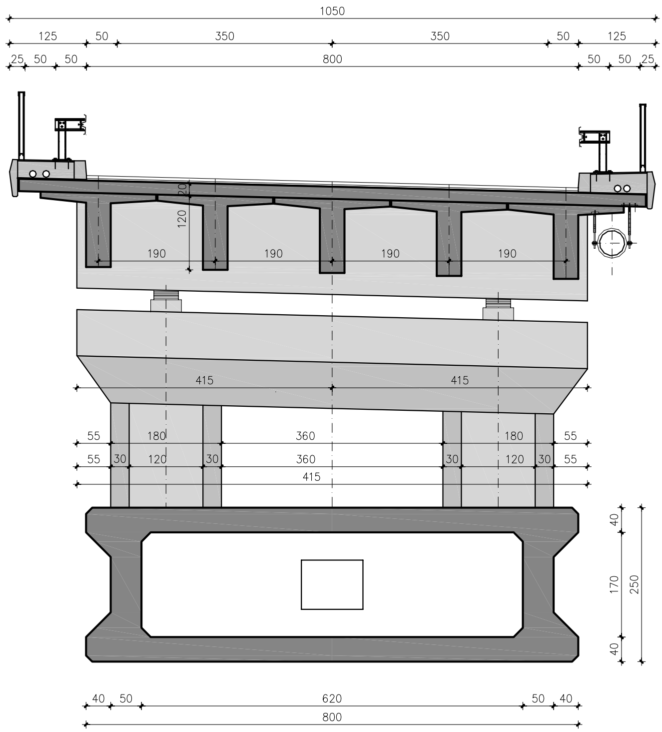

Figure 1: Arch and superstructure cross section of Cetina River bridge

Abutments are standard of closed-end type with parallel wings of C30/37 concrete class. Nine pairs of columns support the deck structure, of which six pairs are connected to the arch. 8.30-m long cap-beam connects the columns in transverse direction. The width of the cap-beam is 1.50 m. Columns are of box cross-section 1. 50 m x 1.80 m with 30 cm thick walls, except the highest columns which are located at the arch springings. These are 90 cm wider, with the appropriate widening of the cap beam at the top. All columns are of C30/37 concrete class.

Cross sections of particular columns were determined on the basis of stability calculations (Fig. 3).

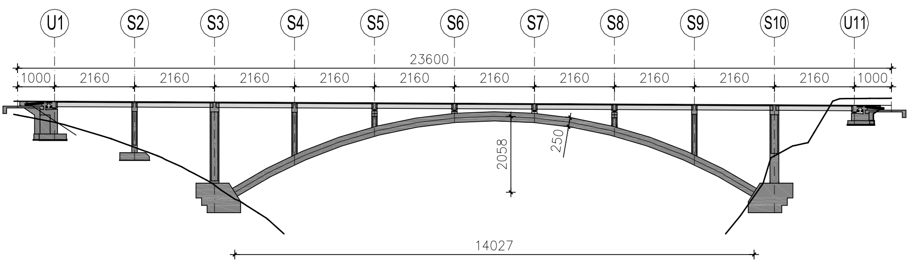

Figure 2: Longitudinal layout of Cetina River bridge

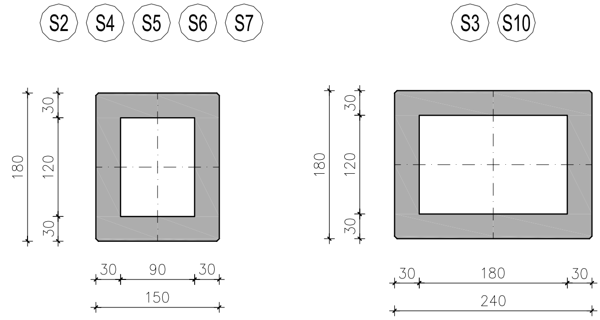

Figure 3: Column cross sections of Krka River bridge

The 10-span continuous bridge superstructure consists of precast prestressed concrete girders, cast-in-site deck plate and cross-girders at supports only. The typical span is 21.60 m. The cross-section comprises five 1.20 m deep post-tensioned T-girders, with 40 cm wide webs at a centre-to-centre distance of 1.90 m. The continuity at supports is provided by nonprestressed reinforcement only. The deck slab 10.20 m wide, made of C40/50 concrete class, has uniform depth of 20.0 cm. The post-tensioned T-girders are also of C40/50 concrete class.

Columns S2, S3, S4, S9 and S10 are fixed to the deck. Longitudinally fixed bearings are placed on shortest spandrel columns on both sides of the arch crown S5, S6, S7 and S8. The longitudinally fixed bearings installed on top of columns S6 are special structural bearings that can sustain longitudinal horizontal forces of up to 1000.0 kN, but when these values are exceeded they transform to the longitudinally movable bearings.

The material consumption for the Cetina River bridge, without abutments and foundations, is shown in Table 1.

Table 1: Material consumption of Cetina River bridge

Concrete	Class	quantity	consumption
Arch	C 45/55	1411.0 m^3	0.69 m^3/m^2
Columns	C 30/37	615.0 m^3	0.30 m^3/m^2
Prestressed T-girders	C 45/55	693.0 m^3	0.34 m^3/m^2
Deck plate	C 45/55	445.0 m^3	0.22 m^3/m^2
Reinforcement			
Arch	BSt 500 S	545.2 t	265.4 kg/m^2
Piers	BSt 500 S	196.3 t	96.0 kg/m^2
Prestressed T-girders	BSt 500 S	151.8 t	73.9 kg/m^2
Deck plate	BSt 500 S	193.7 m^3	94.3 kg/m^2
Tendons			
Prestressed T-girders	St 1570/1770	33.8 t	16.5 kg/m^2

Thus the stiff structural system is achieved in the longitudinal direction for normal working conditions and at the same time adequate safety is attained for seismic events with the most of seismic loads taken by viscous dampers, provided at both abutments (Fig. 5) and just a fraction by flexible columns.

The one layer waterproofing membrane of welded polymer bitumen was placed on the concrete deck under the roadway. The roadway pavement was of hot asphalt concrete type, installed in two layers, the protective course and the wearing course. The first protective course, 4.0 cm thick, of AB 8 asphalt concrete was carefully installed on the finished waterproofing.

The wearing course of 4.0 cm AB 11 asphalt concrete was placed on top of the protective layer. The bridge drainage is of closed type to prevent pollution of the protected bridge environment.

3 NUMERICAL ANALYSIS

Numerical models for statical and dynamical analysis of the main load bearing system comprised the whole bridge structure, the arch, columns, structural bearings and grillage superstructure. All loadings were based on the German bridge norm DIN 1072 (DIN 1072, 1985) except for the wind loading which was computed according to the British standard BS 5400 Part 2 (BS 5400, 1978) and the seismic loading which was assessed on the basis of EC 8 (EN 1998-1, 2004). Positions of the live loading producing maximum effect were determined on the basis of influence lines. Creep and shrinkage effects were computed utilizing DIN 4227 (DIN 4227 T1, 1988). Movements of structural bearings and expansion joints were calculated for uniform temperature changes +75 K/-50 K.

All critical loading combinations were additionally investigated by applying geometrical and material nonlinear numerical analysis. The arch stability was assessed by such an analysis on deformed arch shape, obtained on the basis of shapes of first three modes of free vibrations in the vertical plane normalized to the maximum initial eccentricity of 1/400 of the buckling length and by applying the global safety factor of 1.75 to all loadings.

Detailed analyses of all construction phases of the arch free cantilevering performed, resulting in an erection strip, which was strictly adhered to during bridge construction.

Seismic design was based on the design response spectra for the design acceleration of 0.4g and the soil category A. Twelve eigenmodes were calculated and obtained eigenfrequencies ranged from 1,064 Hz for mode 1 to 5,882 Hz for mode 12. The total active mass was 9.028,4 tons. Seismic response was computed by modal superposition utilizing CQC method. Behavior factors were defined as q=1.2 for the arch, as q=1.0 for the superstructure and structural bearings and as q=1.5 for limited ductile columns. Under these assumptions the bridge turned to be very flexible in the direction of the bridge axis. For this reason viscous dampers were introduced at both ends of the superstructure to dampen the structure and transmit longitudinal horizontal seismic induced forces to massive abutments. Two dampers were installed at both abutments of 2000.0 kN capacity each.

4 BRIDGE CONSTRUCTION

The construction of the bridge across the Cetina River canyon commenced in the year 2005 and will be completed in June 2007.

The sequence of construction works was, as follows. In the first phase all foundations, including arch abutments, were executed. Columns on the river banks were constructed next, utilizing climbing formwork in 5.0 m long segments, followed by the construction of both bridge abutments. Then, the approach spans were completed by placing precast girders, and on-site concreting of the deck and cross-girders. Truck-mounted crane of 300 tonnes lifting capacity was used to place the precast girders into final position. At the same time the whole cross section of the arch was constructed by free cantilevering, on travelling formwork carriages, in segments 5.01 meters long, starting symmetrically from arch springings (Fig. 4). The arch was supported during construction by stays equilibrated by anchor stays, connected to rock anchors. The 18.5-m high auxiliary steel pylons were erected on top of columns at the arch springings to facilitate the arch construction from the 3rd segment onward.

Two-level suspension was used: the lower level stays were anchored into the columns at the arch springings, and the upper level stays were anchored in the cross-girder of the auxiliary steel pylon. The horizontal component of the forces in stays was equilibrated by back-stays connected to rock-anchors through transfer beams. Temporary stays were of Dywidag system, consisting of naked 0.62" strands of St 1570/1770 steel grade.

The construction of spandrel columns and superstructure above followed after closing of the arch and removal of temporary stays and backstays (Fig. 5). A 6-tonnes capacity cable-crane was used for on-site transport of formwork, concrete and reinforcement cages for the arch and spandrel columns.

In the final step bridge furnishings, including waterproofing, roadway pavement comprising two layers of hot asphalt and safety barriers are now installed to complete the bridge construction (Fig. 6).

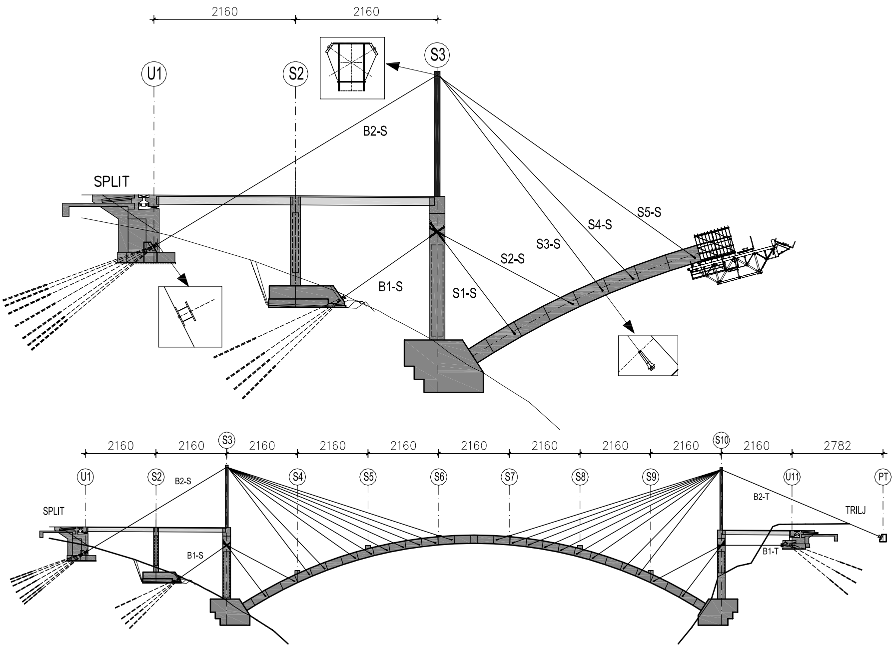

Figure 4: Arch construction by free cantilevering

Figure 5: Superstructure construction

Figure 6: Superstructure construction

5 CONCLUSION

The bridge was designed by Konstruktor design office. After completing the main design, construction plans were executed by the same team, together with the team from the Structural Department of Civil Engineering Faculty in Zagreb. The analysis of all construction phases and auxiliary steel structures were provided. Designers were permanently in touch with the Contractor and every phase of the building process was monitored on site, thus providing necessary input for the adjustments of the structural analysis covering the bridge construction. This model of work proved to be very successful, resulting in high quality of works. The deviations of bridge geometry from the designed one were reduced to the minimum, amounting to about 2.0 cm for the arch axis.

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