Arch Bridges
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# KRKA RIVER BRIDGE NEAR SKRADIN

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**Abstract.** *The new Adriatic highway crosses the canyon of the Krka river in protected environment, in proximity of the national park. The location of the bridge is in the Mediteranean area of high seismic risk. Several preliminary designs have been reviewed for this crossing, and finally a concrete arch of 204 m span had been chosen for construction. The arch cross – section is of the double cell box type. The superstructure is composite, comprising steel girders and reinforced precast concrete deck-plate. The bridge is currently under construction, to be completed by the end of 2004. The arch, which was completed in April 2004, was built by free cantilever procedure, using cable-stays and steel auxiliary pylons. The steel superstructure grillage is erected incrementally in three phases, the first two from both abutments to the main piers to facilitate transport to auxiliary steel pylons and the third one launching the steel superstructure above the arch.*

## 1 INTRODUCTION

Along several hundred kilometers of new highways that are currently under construction in Croatia, some new bridges in Adriatic coast region are particularly interesting[1]. The Krka river bridge near the town of Skradin is an outstanding structure among numerous dull standard beam bridges and viaducts. Besides the general description, some interesting engineering problems that were solved during its design and construction are discussed in the paper.

## 2 LOCATION

The new Adriatic highway crosses the canyon of the Krka river in the proximity of the entrance to the environmentally very valuable and protected area – the Krka river national park. The location of the bridge is situated near the estuary, in the area where sea water mixes with river water, in the moderate aggressive environment.

The bridge lies horizontally in straight line and the grade line is in constant slope of 1.326%, lying approximately 66 m above the water level. The width of the river bed is 190 m, and the width of the canyon is about 390 m.

The overall width of the roadway is 21 meters, including the median strip of 3 m and total width of the superstructure is 22.56 meters.

The Croatian Adriatic coast is an area of high seismicity. The seismic design has been done according to EC 8[2]. The soil class for bridge is A (solid rock), while the design acceleration has been prescribed to 0.20 g.

## 2 THE DESIGN

Several preliminary designs have been reviewed for this crossing, comprising both beam and arch structures, and finally the concrete arch of 204 m span had been chosen for construction (Fig 1). The designer offered two alternatives with the arch of the same span and similar shape. The first one envisioned conventional prestressed concrete superstructure made of precast girders and in situ slab, (similar to Maslenica arch bridge, spanning the sea strait on the same highway[3]), while in the second one a composite superstructure was proposed. The arch has considerably smaller dimensions for the second alternative.

The composite superstructure, comprising steel girders and reinforced concrete deck-plate was finally chosen. A similar concept was utilized for two large arch bridges in France: La Rance, with 261 m span, completed in 1992 and Morbihan, with 201 m span, completed in 1994[4]. The intention was to obtain lighter structure, in order to reduce seismic forces and also to blend more harmonically into the beautiful environment.

The rise to span ratio of the concrete arch is 0,25 (f/l=0.25). The arch is fixed of double cell box cross section with constant outer dimensions b/h=10 x 3 m. The arch cross-section is constant (Fig 2), except in the proximity of arch abutments, where the thicknesses of the flanges increase from 50 cm to 60 cm.

Vertical diaphragms are constructed inside the arch, below the piers that rest on the arch[5].

The continuous composite superstructure is supported on longitudinally movable bearings on stiff short piers and abutments, and longitudinally fixed bearings on tall flexible piers.

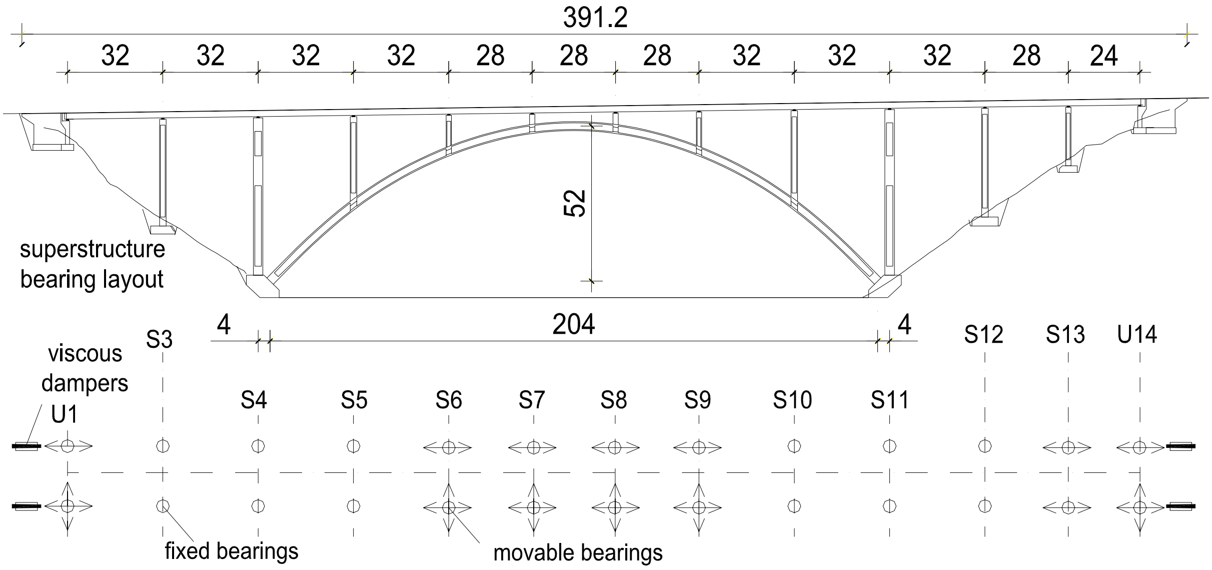


Figure 1. Krka river bridge near Skradin, longitudinal and bearing layout.

On one of the piers closest to the arch crown special longitudinally fixed bearings shall be installed to stiffen the superstructure in the longitudinal direction. These bearings can sustain longitudinal horizontal forces of up to 1000 kN, but when these values are exceeded, in the case of large earthquake, they transform to the longitudinally movable bearings by yielding of special sacrificial elements[5].

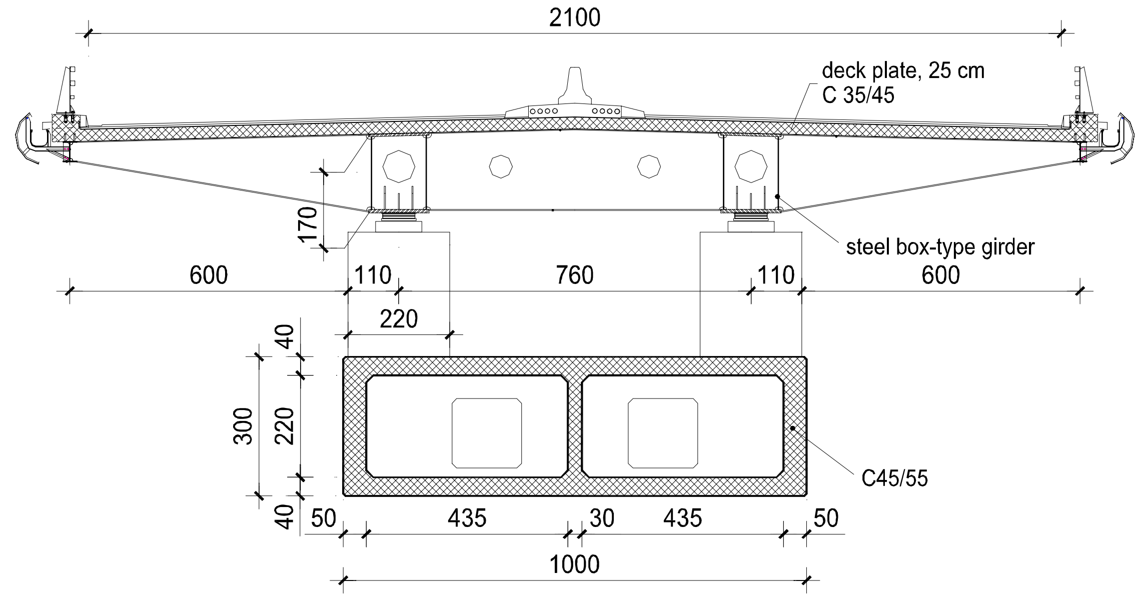


Figure 2. Krka river bridge near Skradin, cross-section.

The superstructure steel grillage system consists of two main longitudinal girders spaced at 7.6 m, cross beams spaced at 4 m and edge girders. Box type main girders are 1.7 m high.

The deck slab is 25 cm thick. Its main load-bearing direction is longitudinal.

The superstructure is longitudinally very flexible, which resulted in large horizontal movements in case of a seismic event. Longitudinal displacements are 340 mm, according to linear dynamical analysis, based on modal superposition. These large movements would have an adverse effect on all piers with longitudinally fixed, non movable bearings on top.

For this reason viscous dampers are to be introduced at both ends of the superstructure, transmitting longitudinal forces to massive abutments. Two dampers shall be installed at both abutments of 2000 kN capacity each. According to nonlinear dynamical analysis, with dampers included, longitudinal displacements are 50 mm[6] (Fig. 3).

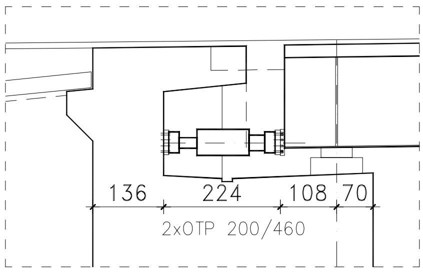


Figure 3. Krka river bridge near Skradin, dampers at abutments.

The designer proposed circular piers, which would have improved appearance of the bridge, but the contractor asked for square-shaped piers, in order to facilitate their construction. All piers are of box type cross section, except for the shortest ones, near the arch crown (Fig 4).

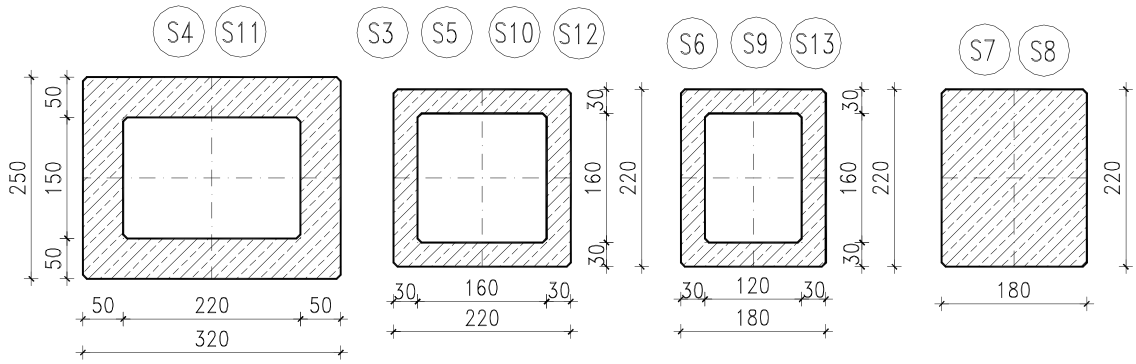


Figure 4. Krka river bridge, cross-section of the double piers.

Material consumption for bridge elements is shown in Table 1.

| Concrete | quality | quantity | consumption |
|---|---|---|---|
| Arch | C 45/55 | 2 988,0 $m^3$ | 0,40 $m^3/m^2$ |
| Piers | C 35/45 | 2 019,0 $m^3$ | 0,27 $m^3/m^2$ |
| Deck plate | C 45/55 | 2 172,0 $m^3$ | 0,29 $m^3/m^2$ |
| **Reinforcement** | | | |
| Arch | BSt 500 S | 747,0 t | 98 $kg/m^2$ |
| Piers | | 363,4 t | 48 $kg/m^2$ |
| Deck plate | | 630,0 t | 83 $kg/m^2$ |
| **Structural steel** | | | |
| Superstructure | St 52-3 | 1700,0 t | 224 $kg/m^2$ |

Table 1. Material quantities for the main bridge elements.

## 3 THE FORM (SHAPE) OF THE ARCH

The shape of the arch should be selected in such way that bending moments under permanent actions are minimized. In most reinforced-concrete arches, the shape of the arch axis follows a theoretical thrust line, determined by an appropriate analytical or graphical procedure.

The optimum arch shape for the Krka bridge was found by utilizing the equilibrium catenary shapes under concentrated loads applied at the pier locations. They are equal to the total mass of piers and superstructure, but inverted in direction. The weight of the catenary is equal to the weight of the arch. Based on this idea, a computer program for finding the optimum arch shape has been created, assuming that the arch carries all loadings (stiff arch – flexible superstructure)[7].

For the selected arch span and rise, column distances and loadings, the program finds the arch shape producing minimum bending moments by an iterative procedure. The procedure comprises a set of catenaries between neighboring columns with discontinuities eliminated by spline functions in the second iteration phase.

## 4 CONSTRUCTION PROCEDURE

The Krka river arch has been constructed by free cantilevering, on traveling formwork carriages, in segments 5.25 meters long, starting symmetrically from arch abutments. Piers at the arch abutments had to be extended by auxiliary steel staying pylons to facilitate successive cantilevering.

The arch was supported during construction by stays equilibrated by anchor stays, connected to rock anchors. The last, closure segment, 2,0 m long, was completed in April 2004 (Fig. 5, Fig. 6).

During the construction of first twelve arch segments, superstructure had been assembled behind the abutments. The steel grillage has been launched from the abutments to the main piers at the arch springing. After the launching procedure, the superstructure has been lowered to the permanent bearings.

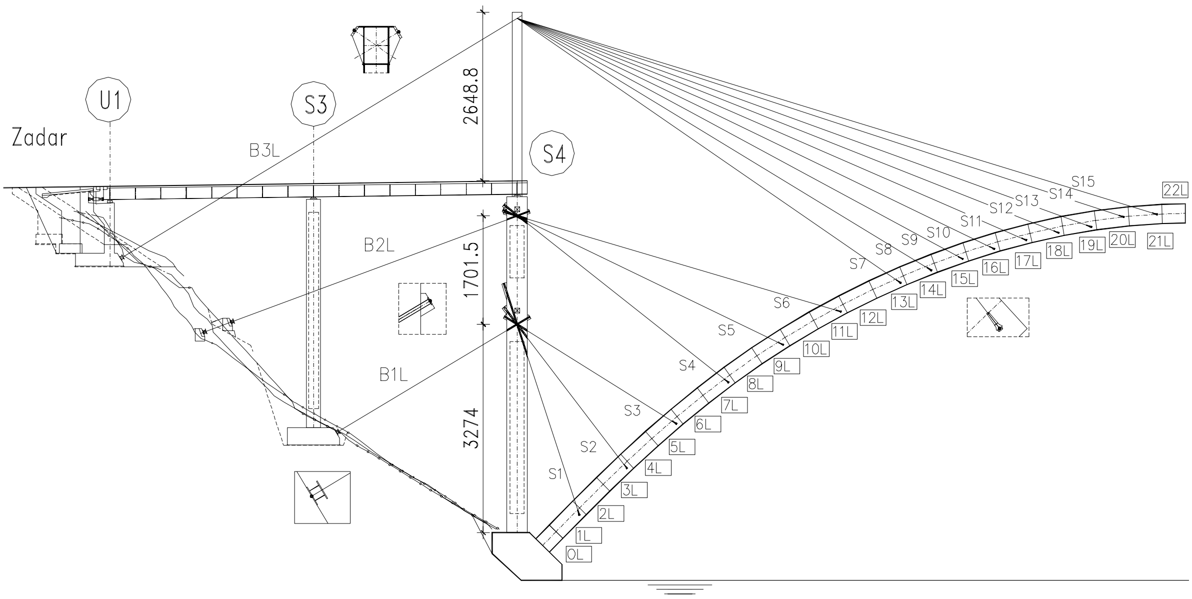


Figure 5. Construction scheme for Krka river bridge arch.

In the next construction stage, precast reinforced concrete slab elements, measuring 6,4 x 3,5 meters in plan and 25 cm thick have been placed (Fig. 7). Precast elements were interconnected by on site concreting of longitudinal and transversal joints above shear connectors, thus completing the composite superstructure (Fig. 5).

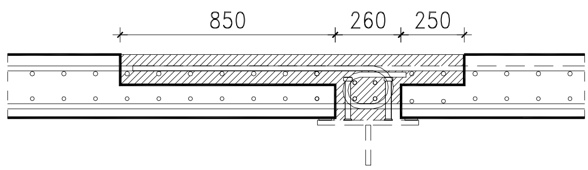


Figure 5. Construction joints in the precast RC slab, 25 cm thick.

Upon the completion of the superstructure between abutments and the piers closest to the arch, temporary pylons were erected in order to continue with cantilevering of the arch.

The installed oscillatory cable-crane of 500 meters span and 6.0 tons capacity is utilized for the transport on the site.

After the completion of the arch, temporary stays and backstays have been removed. Casting of the piers above the arch in a strictly prescribed order is to follow. The next construction phase comprises the launching of the steel superstructure above the arch from the west side. The composite superstructure shall be completed by placing precast concrete slabs and concreting wet joints.

## 4 CONCLUSIONS

The bridge was designed at the Structural Department of Civil Engineering Faculty in Zagreb, Croatia. After completing the Main design, construction plans were made by the same team, together with the analysis of all construction phases. The designers are in constant touch with the Contractor, and every phase of the building process is monitored on site, thus providing necessary input for the adjustments of the structural analysis covering the 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 (4,5 cm for the arch axis).

In our opinion, the example of Krka bridge shows that arch bridges may be competitive to other structural types in the span range from 200 to 400 meters if site conditions are favourable for arches.

## 5 PARTICIPANTS IN DESIGN AND CONSTRUCTION

Preliminary design, Main design, Construction drawings:
Structural Department of Civil Engineering Faculty in Zagreb, Croatia
Client: Croatian Highway Authorities (HAC), Zagreb
Contractor: Konstruktor-Inženjering, Split, Croatia
Steelwork subcontractor:
Đuro Đaković montaža d.d., Slavonski Brod, Croatia

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Figure 6. Construction of the closure segment of the Krka river arch - April 2004.

Figure 7. Composite superstructure above the Krka river arch - construction phase.