Arch bridges made by Croatian builder Kruno Tonković

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ABSTRACT: From time to time an individual emerges who with his new and innovative solutions creates a great step forward. Kruno Tonković was certainly one of those individuals. With his original ideas and designs he significantly contributed to bridge engineering in Croatia. During his career he designed many bridges that are still admired and studied.
In this paper some of the most beautiful and advanced arch bridge structures designed by Kruno Tonković are shown. Some of his most important bridges include the Liberty bridge in Zagreb over the river Sava (100 m span) in 1953 and the Skradin arch bridge (110 m span) constructed in 1955 with concrete filled steel box arch girder just to mention a few of many remarkable bridges. In this paper it is shown that it was possible to build unique, beautiful, more functional and different bridges, which were superior in all aspects in his time and in some segments even today.

1 INTRODUCTION

Professor Kruno Tonković was the greatest Croatian bridge builder of all times. Kruno Tonković was born in 1911. In his lifetime he built many important bridges and other structures. He wrote many books on structural engineering and scientific papers. He also educated many generations of Croatian builders, and in his specific way he initiated and envisioned many great projects for the future. Some of them were completed a few years or even a decade after he designed them and some still wait to be completed.

Professor Tonković always tried to direct his creativity and form his expression firmly based on beauty and balance. The large number of important buildings created by professor Tonković, his life as an scientist, his life as professor, writer of many books, unique, original and productive lifestyle earns him his place as the greatest Croatian bridge builder of all times.

His legacy for future generations of structural engineers, based on his lifestyle and work ethics can be summarized in few guidelines:

- The first and main value of each structure is shown in its functionality.
- The main aim of a structural engineer is to avoid problems and only if it is not possible to solve them.
- The greatness of a structural engineer is shown in his ability to seek out new and different ways of expression.
- The civil engineering history provides an endless pool of ideas and inspiration for contemporary structures.
- Durability and beauty are values worth investing in.
- Written records are important facts for the history so the same should apply for the civil engineering history.

Professor Tonković died in 1989.

2 ARCH BRIDGES DESIGNED BY KRUNO TONKOVIĆ

Professor K. Tonković (Radić 2003) has marked forty years of Croatian bridge building after the II World war. He left an impressive list of dozens of bridges built all across Croatia, which include many original solutions as well as careful considerations of future requirements. Several of his numerous bridges entered the textbooks on bridge design as the examples of beautiful and structurally efficient structures, well harmonized with surroundings.

These are the qualities that may characterize them as structural art.

One of his most interesting projects was the reconstruction of a bridge across Krka River near Skradin (Fig. 1) during 1953 to 1955 (Radić 2006). The old bridge with steel arch trusses above the roadway was demolished in the II World war. All usable parts were incorporated into the new structure which resulted in efficiency and economy. They were used in two ways; first, as framework for two parallel arch girders of 90 m span, and later, after the removal of scaffolding, as the rigid reinforcement of the arches. This bridge is much more economic than the old one it has a higher navigation clearance, wider roadway and is more logical and beautiful.

The arch is a composite structure. The two steel arch tubes are filled with high grade concrete. This structure was mentioned in literature but until then it was not implemented. An experimental beam was tested on the site. The results were favorable and as expected so this composite structure was built. The arches are 70 cm wide spaced at 5.0 m (Fig. 2).

In this way professor Tonković has, as Freyssinett in similar circumstances, tested numerically and experimentally construction innovations and challenges. This and some other research were not adequately publicised.

For the concrete filed arch it was imperative to achieve the best concrete quality possible and complete concrete compaction in the steel tube. The creep and shrinkage effects needed to be minimized. The concrete technology was developed with great care. During the concreting of the steel tubes sections the steel tube was warmed to the calculated temperature. In this way the steel arch was filled in expanded position and the shortening of the steel equaled the shrinkage of the concrete.

The heating procedure was very simple. The water was heated at the arch crown. Around the steel tube section that was concreted a wooden crate filled with sand and gravel was made which was heated with hot water. During this procedure the temperature of the steel and the concrete were recorded. The procedure lasted for the necessary period.

Since the opening of the bridge after thorough testing where the deformations and vibrations were even better than calculated after more than 50 years there are no visible signs of deterioration even though the maintenance is minimal almost nonexistent.

During the construction permanent monitoring devices were installed.

Professor Tonković did not only design the bridge but was also directly conducted during critical construction phases on site.

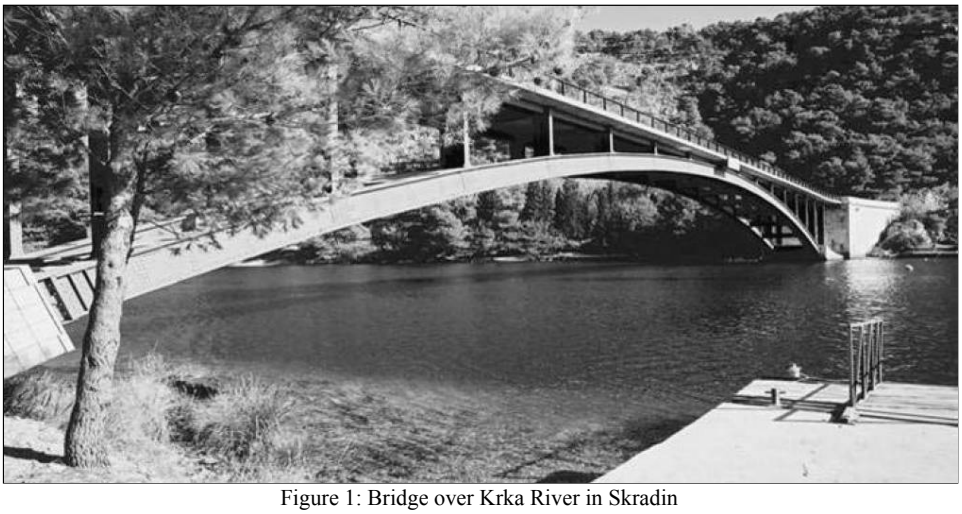

Figure 1: Bridge over Krka River in Skradin

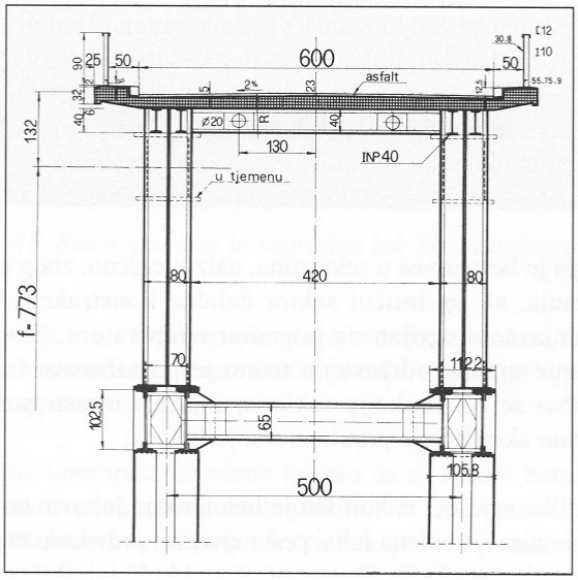

Figure 2: Bridge over Krka River in Skradin, cross section

The Liberty bridge in Zagreb (Fig. 3,4) crosses the main watercourse of Sava River with one elegant arches 100 m in span comprising two vaults and numerous small spans of 15 m across inundations. The chosen solution is an uncommon one for Sava River, but it still has the economic arguments – increased expenses for a main span is compensated with cheaper structure for small inundation spans. Due to rise to span ratio of 1:13.6 arches are made of steel. Arches gradually increase depth from 100 cm at the crown to 130 cm at the abutments and have the width to depth ratio of 4:1. Without doubt this solution is original and beautiful and very well incorporated in environmental proportions.

The arches have a box type cross section. Abutments for the two arches are very large, 24*30 m and are founded at the depth of approximately 13 m.

Steel parts of the bridge comprise many details and solutions which were designed by professor Tonković based on his experience further enhancing the development of steel structures.

Figure 3: Liberty Bridge in Zagreb

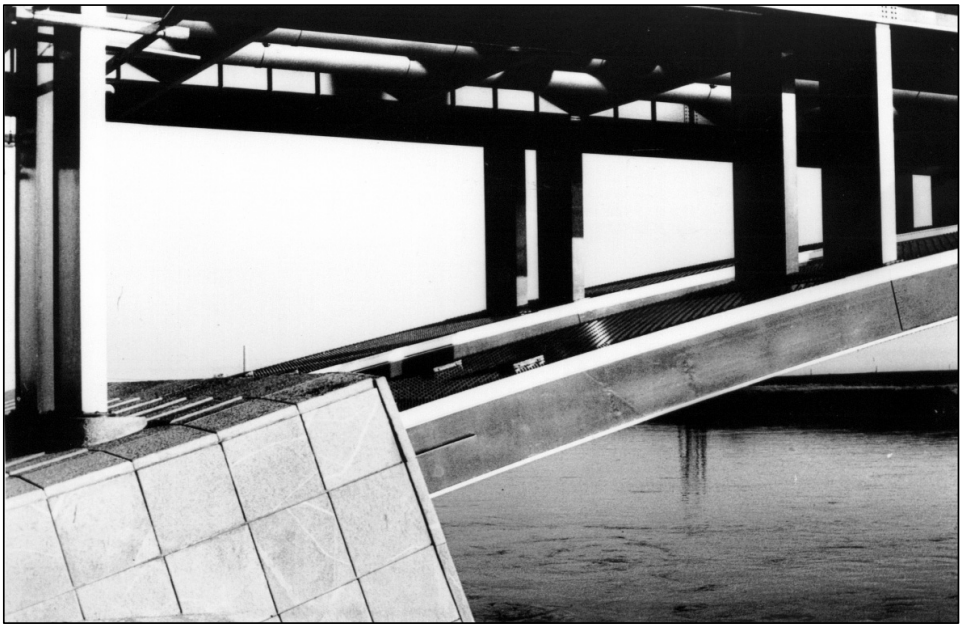

Figure 4: Liberty Bridge in Zagreb, arch abutments

At the arch crown the lower part of the deck construction merges with the arch (Fig.5). In this way the visually insufficient mass proportions were compensated.

The design of the Liberty bridge lasted several years and did not include only the bridge design but also the connection of the two parts of the city on opposite sides of the Sava River. The main accomplishment was that at that time the city of Zagreb was only on the northern side of the river but for professor Tonković it was evidently clear that the city would develop to the south.

Professor Tonković designed the bridge railings aiming to contrast the calm shapes of the structure for this city bridge (Fig.6).

For the Liberty bridge professor Tonković has chosen calm and classical features of the bridge and not original and even bizarre solutions. At that time he knew that many new bridges will be constructed so for this central bridge he chose a simple and beautiful structure which defined the city development.

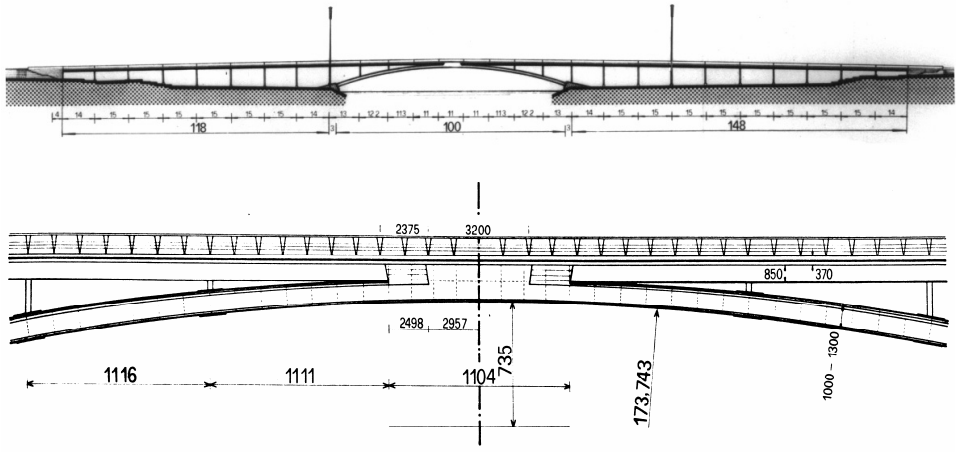

Figure 5: Liberty Bridge in Zagreb, longitudinal section and arch crown

Figure 6: Liberty Bridge in Zagreb, railings

The bridge over Korana River in Selište at the entrance of the Natinal Park Plitvice lakes (Fig. 7) has an arch span of 60 m with a rise of 16.1 m. The arch consists of two vaults with a gradual increase of depth form the 90 cm at the crown to 147 cm at the abutments. On the same road professor Tonković already designed two other bridges one girder bridge fixed on Y-shaped piers and the Slunčica arch bridge. For this bridge same detailing was implemented as for the first two bridges.

During the vaults construction part of the formwork were 8 cm thick precast concrete slabs which remained part of the structure.

At the crown Tonković joined the arch to the superstructure to mollify the difference between the thin superstructure and considerably massive arch.

Each line of spandrel columns is connected to one vault. The columns have a diameter of 86 cm. Columns were constructed in 8 cm thick concrete scaffolding which was left as part of the structure. The plate superstructure is fixed on the columns.

This is a very simple structure in regard to design and construction.

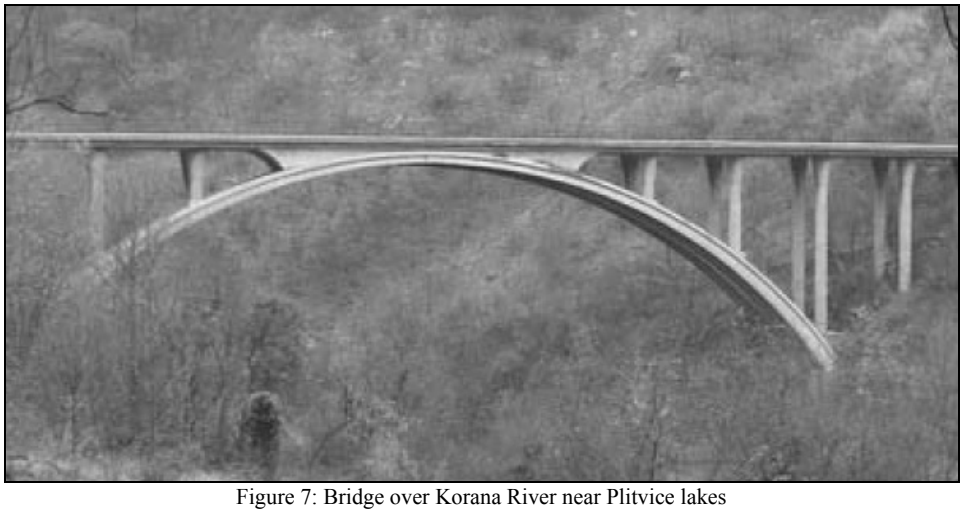

Figure 7: Bridge over Korana River near Plitvice lakes

Figure 8. Bridge over Slunjčica River in Slunj

Harmony with an extremely demanding area has been achieved with an arch bridge over Slunjčica River in Slunj (Fig. 8,9). The arch opening is 72.61 m with a rise to span ratio of 1:7.3. A light slab superstructure is set on two piers in transversal direction. Piers distance increases from 120 cm at the abutments to 180 cm at the crown, which is functional advantage due to loading transfer but also enlarges space impression of bridge.

The arch consists of two vaults with a gradual increase of depth form the 85 cm at the crown to 120 cm at the abutments.

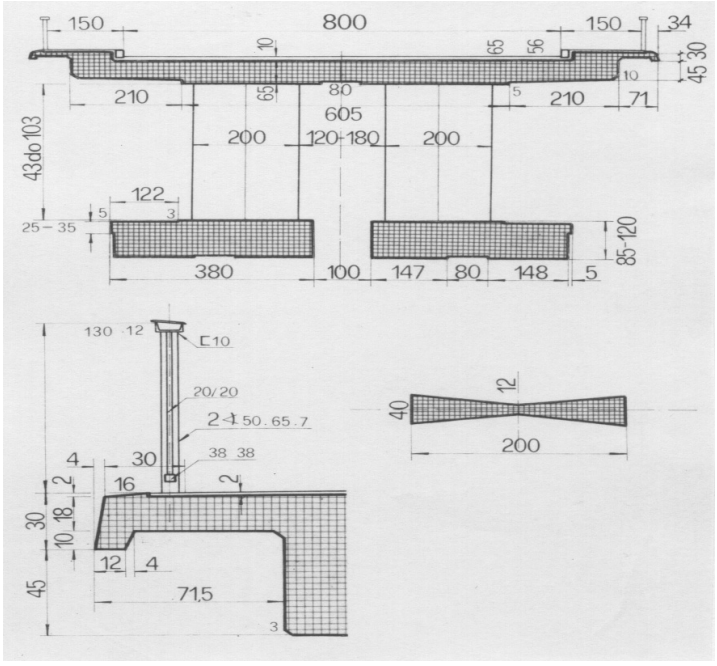

Figure 9: Bridge over Slunjčica River in Slunj, cross sections

Figure 10. Bridge over Korana River in Karlovac (Rakovac)

Bridge over Korana River in Karlovac (Fig. 10) was the last one constructed based upon Tonković design. Although the plane area with a weak soil characteristics is not sutable for thrust arch systems, after a detailed analyses Tonković choose main concrete arch bridge structure with a span of 56 m and rise to span ratio 1:9.7 together with beam approaches with spans of 12.5 m. He stipulated the use of hydraulic jacks at the bridge crown in order to eliminate adverse movements of foundations.

Unfortunately this bridge was not constructed completely according to the design which led to certain difficulties. They were eliminated at the time but with serious consequences on foundations.

The cross section (Fig. 11) comprises two parts 4.5 m wide. In the middle there is a gap for the water pipe. The thickness of the slab is constant.

For this bridge the main inspiration were the suggestions given by Freyssinet for his 1000 m span arch bridge. At this bridge professor Tonković analyzed on smaller scale his proposal for the 500 m span arch bridge for the Krk island crossing which was later not accepted.

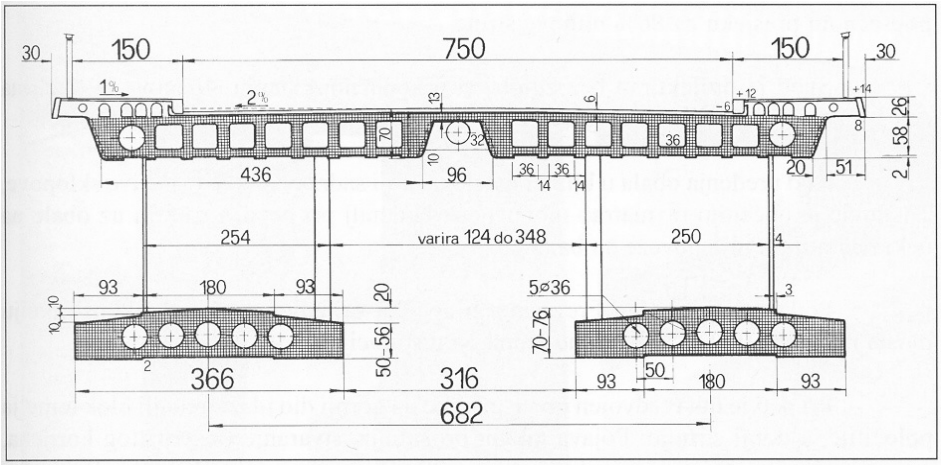

Figure 11. Bridge over Korana River in Karlovac (Rakovac), cross section

3 THE DESIGNERS APPROACH

Professor Tonković was versatile, educated, experienced and brave designer and constructor constantly trying to incorporate in his work a clear esthetic component. He developed a large number of very original structures after a detailed analysis he incorporated the results of this studies in some of his constructed works but some remained for the future to be analyzed.

In his lifetime he developed arch structures in concrete up to 400 m span and in steel up to 600 m span. It is very hard to distinguish between his work as a teacher and a constructor. Most of his research and study was directly inspired by unsolved or poorly solved problems in bridge construction practice.

Most of his research results were not published but they were directly implemented in his design and construction.

Professor Tonković was known among his colleague, coworkers and students as a man with very interesting deliberations on different segments of civil engineering and many common topics. Those thoughts were often incorporated in his lectures and discussions.

Prerequisite of the bridge existence is that the bridge structure needs to be safe and durable to always enable crossing the obstacle. But one should not stop only at accomplishing those goals but look further and analyze all the circumstances which should produce comfortable, harmonious and good-looking structures.

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