CULTURAL HERITAGE AND AESTHETICS OF ARCH BRIDGES ON THE TERRITORIES OF CROATIA AND BOSNIA AND HERZEGOVINA

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SUMMARY

From Roman time till today many arch bridges have been built on the territories of Croatia and Bosnia and Herzegovina, including some UNESCO World heritage sites. Rich cultural heritage of arch bridges is consequence of their outstanding position on important traffic routes and at the crossroads of great civilizations, each wanting to leave their mark. The most significant historic arch bridges built on the Croatian, Bosnian and Herzegovinian soil, e.g. Mostine Aqueduct, Old bridges in Mostar, Višegrad and Konjic, are described in the paper. Structural characteristics and aesthetic values of arch bridges built during Roman and Ottoman Empire are discussed, highlighting main similarities and differences in design.

Keywords: *Stone, semi-circular arch, segmental arch, pointed arch, roman arch, ottoman arch.*

1. INTRODUCTION

Rich cultural heritage of Croatia and Bosnia and Herzegovina is consequence of their outstanding position on important traffic routes and at the crossroads of great civilizations, each wanting to leave their mark. Exceptional diversity of cultural heritage on a small surface makes it clear that large European civilizations had mixed here, and right here the influences of Europe's largest ethnic groups of Slavs, Romans and Germans had come together. Border between Croatia and Bosnia and Herzegovina were the former Western and Eastern borders of Christianity, and Western and Eastern European culture. This is where the last line of defence used to be for the overcoming Islamic civilization in the late Middle Ages. Throughout the turbulent history our builders have had contacts with the contemporary practice of European and Oriental construction of roads and bridges.

In the first almost two millennia long period bridge construction in Croatia and Bosnia and Hercegovina was marked by stone arches. According to the structural characteristics and aesthetic values, development of the masonry arch bridges in Croatia and Bosnia and Hercegovina can be divided into several groups: Roman bridges, medieval bridges, Ottoman bridges, bridges built on military roads and bridges built in 19th and 20th century.

During the Middle Ages the land traffic was low and the bridge construction decreased. The first medieval bridges were built mostly of timber, while some stone arch bridges have been built only later, in 15th century. Good examples of medieval bridges are three semi-circular arches in Dubrovnik (Fig. 1): at Pile Gate, with three spans of 6.7 m; at Revelin fortress with a single span of 12.20 m and at Ploče Gate, with two spans of 6.7 m (Fig. 1). Medieval arches are designed as massive and solid structures, like ancient Roman arches, with special attention given to design of details, e.g. stone balustrade [1, 2].

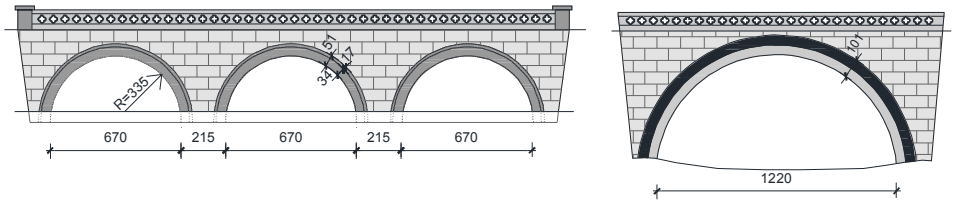

Fig. 1. *Bridge at Pile Gate (left) and at Revelin Fortess (right) in Dubrovnik.*

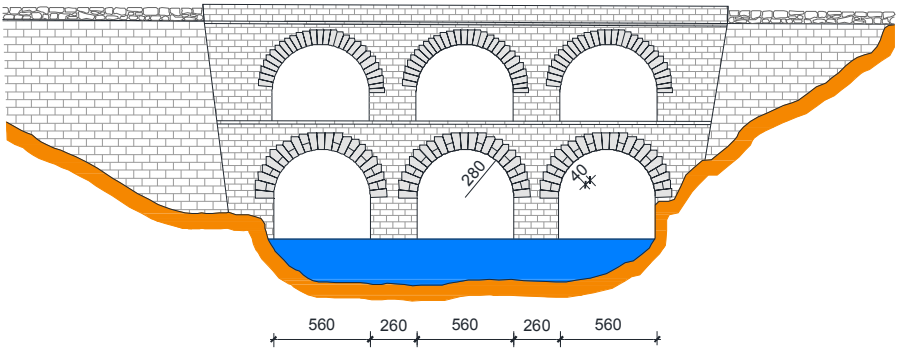

Fig. 2. *Bridge over Tounjčica River at Tounj.*

Bridges, built between 15th and 18th century on Croatian territory which was not under Ottoman rule, were designed according to the Austrian military engineering practice, because the roads to the border with the Ottoman Empire had, besides economic importance also great military importance. Those bridges are massive classical structures with large safety reserves, because of the constant threat of war.

Road construction on the Croatian territory has been improved in the first half of 19th century during French rule and Austro - Hungarian Empire, while in the second part of the same century construction of railways started. Once war threat disappeared, steep roads, which satisfied military requirements, had to be reconstructed for commercial traffic. Namely, the increase of live loads and traffic intensity required reduced allowable slopes on road. Good adaptation from the military to commercial traffic requirements can be seen on the bridge over Tounjčica River at Tounj with two floors (Fig. 2). The lower bridge was built in 1775, while upper bridge is built in 1836. Each floor has three arches with span of 5.60 m [1-3].

Advance in bridge engineering at the beginning of 20th century was influenced by introducing new materials: steel and reinforced concrete. Moreover, the peak of stone arches was achieved by Croatian expert Milivoj Frković, who designed two the most beautiful masonry arch bridges in Croatia (Fig. 3): across Kupa River in Sisak, built in 1934, and across Lika River in Kosinj, built in 1935 [3].

Fig. 3. *Bridge across Kupa River in Sisak (left) and Bridge across Lika River in Kosinj (right).*

Structural characteristics and aesthetic values of arch bridges built during Roman and Ottoman Empire are discussed in next chapters, highlighting main similarities and differences in design and construction.

2. ROMAN BRIDGES

Although true arches were already known by the Etruscans and ancient Greeks, the Romans were the first to fully realize the potential of arches for bridge construction. The Romans also realized that timber structures, particularly those embedded in water, had a short life, were prone to decay, insect infestation and fire hazards. Prestigious buildings and important bridge structures were therefore built of stone.

The Romans realised that voussoir arches could span further than any unsupported stone beam, and would be more durable and robust than any other structure. Romans used to choose semi-circular shape of arch, with the thrust from the arch going directly down on to the support pier. This meant that piers had to be large. If they were built wide enough at about one-third of the arch span, then any two piers could support an arch without shoring or propping from the sides. In this way it was possible to build a bridge from shore to shore, a span at a time, without having to form the entire substructure across the river before starting the arches [4-5]. Several Roman stone arch bridges were made in segmental form which offered greater protection from forces of flood waters and enabled builders to infuse less material into bridge itself, making it lighter.

The Roman bridges are characterized by geometrical perfection; all arches of the multi-span bridge are the same from the springings to the keystone, and over the whole of the vault width. Roman bridges generally have small, low, triangular cutwaters, most of them finishing off at the height of the arch springings. The Romans built triumphal arches on some bridges, in the centre or at the ends of bridge, e.g. Alcantara and Flaviano. Alignment of the Roman bridges is usually horizontal or slope slightly [1, 4-5].

Construction of stone arch bridges was not an easy task. Builders first had to create wooden arches in exact measurements as a finished bridge, and then use that wooden construction as a contained for stones and another substance that enabled Roman Empire to become such an architectural force – mortar. They were the first civilization on earth which discovered the mortar indissoluble in the rain. Stones that were used for building

bridges were usually found locally, but mortar components from volcanic rock had to be imported from far away [1, 4-5].

The Roman stone arch bridges were so strong, that they had the potential to carry as much load as its own weight or even more. With such powerful knowledge in their hands, roman road builders spread across the Europe, Asia and Africa, building many wondrous bridges, lengthy aqueducts with multiple arches, bridges with flood openings on the piers, etc. More than 400 Roman stone arch bridges, built between 2 century BC and 3 century AD, are preserved till today and over 70% of them have a span of less than 12.5 m [1,2,4,5].

2.1. Diocletian's Aqueduct

The oldest preserved bridge in Croatia is an aqueduct of Diocletian's Palace. Emperor Diocletian, who voluntarily gave up the throne of the Roman Empire, in the turn of the 4th century built the palace and after his retirement on May1, 305 settled on the beach near Salona, the capital of the Roman province Dalmatia. The so-called palace was a massive structure and contains not only the palace itself, but also buildings, intended for housing military garrison. The whole complex occupied around 30,000 square meters. Today these ruins lie in the heart of the city of Split [1,3,6].

The aqueduct was constructed during the years 284 to 305 to carry freshwater from the source of Jadro River near Salona over the distance of 9.4 km to the Palace. A height difference of end points is 33 m. The aqueduct contains several larger buildings on its route: four bridges and one tunnel 1268 meters long [1,3,6].

The largest, most impressive and best preserved among them is Mostine bridge (Fig. 4) also known as Dry Bridge, with a total length of 234 m and a maximum height of 19 m. The bridge contains 19 semi-circular arches. Spans of arches were carefully selected in order to achieve harmonious proportions with the thickness of piers and the height above the ground. The two main arch spans of 8.9 m with pier's thickness of 2.9 m have a typical Roman pier-to-span ratio of 1:3.The other arches have a span of 4.7 m while the piers between arches are 2.1 m thick. The total width of the bridge is 2.4 m. Channel for the water in the upper part has the cross section dimensions of 0.6 x 1.2 m. At the highest elevation where the road passes underneath it, the aqueduct is built as a prestigious piece of architecture in the best building techniques, with large, regularly dressed and finally worked stone blocks of the Brač quarries [1,3,6].

Karabaš Bridge with 17 semi-circular arches with span of 3.8 m has the total length of 156 m. Smokovik Bridge contains three semi-circular arches with the span of 3.8 m and a very long stone walls making the total length of 114.5 m. Bilice Bridge with seven semi-circular arches with span of 3.8 meters, has a total length of 69 meters [1,3,6].

The Diocletian's aqueduct was one of the last large aqueducts built in the Roman Empire, as most triumphal examples of Roman arched architecture and engineering excellence and is preserved until nowadays. The aqueduct was destroyed in the invasion of Goths in the middle of 6th century and did not work for thirteen centuries after that. The first reconstruction of the aqueduct took place during the reign of the Austro-Hungarian Empire (1877–1880). The aqueduct was abandoned from 1932 when the modern water station Kopilica was built [1,3,6].

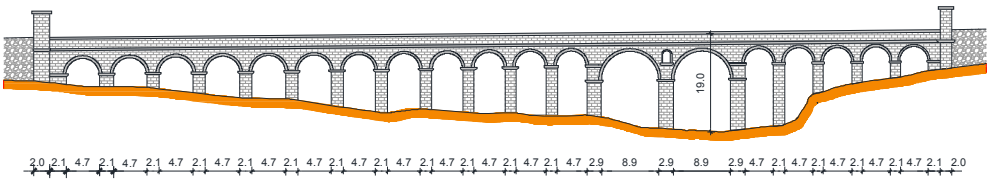

Fig. 4. *Longitudinal layout of the Mostine bridge.*

2.2. Bridge over the Buna River in Kosor

Although significant Roman roads passed through Bosnia and Herzegovina, only remains of the bridge over the Buna River in Kosor (Fig. 5) are visible today, mainly under the water. The bridge has fourteen semi-circular arches with total length of 57 m and width of 4 m. The bridge was destroyed in 1945 during Word War II [7].

Fig. 5. *Bridge over the Buna River in Kosor before WWII [7].*

3. OTTOMAN BRIDGES

The tradition of Roman architecture was preserved by the Eastern Roman Empire, whose period ended with the Ottoman conquest of Constantinople in 1453. Considering the fact that the Kingdom of Bosnia was under Ottoman rule from 1463 until 1878, it is not surprising that numerous significant Ottoman bridges were built in Bosnia and Herzegovina between the 15th and 16th centuries. On the other side of the border, Croatia, as *Bulwark of Christianity*, had the key role in stopping the further penetration of the Ottoman Empire in the west Europe.

Ottoman stone bridges are remarkable due to their massive towers on the bridge centre or at the ends, pointed arches, cornices, buttresses, and the circular and polygonal structural openings. The bridges over wide rivers would consist of several arches with spans from 10 to 15 m, while a narrow, deep river bed were spanned by only one arch with longer span. The pier width - arch span ratio is significantly smaller than at Roman bridges, while pier length in transversal direction is larger in order to ensure transverse stability of the bridge. The increasing span and rise of arches towards the bridge centre provides a better flow rate during the flood. Alignment of the Ottoman bridges has a higher slope, equal from each end of the bridge creating a characteristic break in the alignment over the central pier [8].

3.1. The Old Bridge in Višegrad (Mehmed Pasha Sokolović Bridge)

Mehmed Pasha Sokolović Bridge over the Drina River in Višegrad (Fig. 6), built between 1571 and 1577, is one of the most magnificent works of Ottoman architecture in Bosnia and Herzegovina. The construction of the bridge was entrusted to the great court architect Koca Mi'mar Sinan (1490-1588), one of the leading architects of the Ottoman Empire [9].

The bridge has ten arched openings with spans from 10.70 to 14.80 m, while the last span on the right bank rests on two retaining walls with the smallest span of 5.20 m. The bridge is supported by nine great stone piers with a width from 3.50 to 4 m, and a height of about 11.50 m. The main part of the bridge is connected with an access ramp at right angles with four arches on the left bank of the river [9].

The width of the road over the bridge is 6.00 m. The parapet walls are 60 cm thick and 179.44 m long. The arches of 85 cm thickness are classical pointed arches with relatively small eccentricity of the centres (1.00 m), making them almost semi-circular. The limestone was quarried in Banja, about five kilometres downstream on the right bank of the Drina. Some of the stone blocks are held together by iron clamps sealed with lead [9].

Above the facing walls, at the level of the roadway, is a moulded limestone cornice 30 cm high on which rests a solid stone parapet. The sixth pier is ornamented. On the upstream side, it is of triangular profile, grading into a rectangular extension bearing a blind portal with chronogrammatic inscription. On the downstream side it is polygonal in shape, grading into a rectangular extension with built-in seats, which are still used to this day [9].

The bridge has experienced numerous floods, war damages and deteriorations, and has been repaired several times during its service life.

The bridge construction is described in the book “The Bridge on the Drina”, written by Croatian writer Ivo Andrić, which won Nobel Prize. The bridge is inscribed on UNESCO's World Heritage List since 2007. The unique elegance of proportion and monumental nobility of the property as a whole bears witness to the greatness of Ottoman architecture.

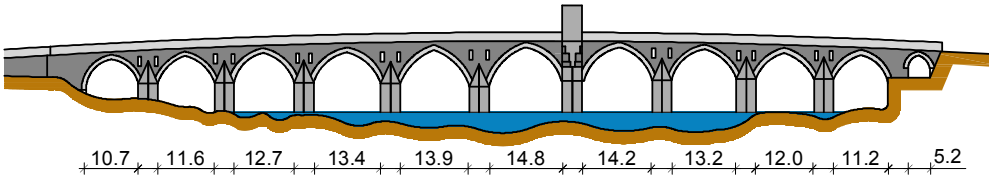

Fig. 6. *Longitudinal layout of the Old Bridge in Višegrad [1].*

3.2. The Old Bridge in Mostar

The Old Bridge over the Neretva River in Mostar (Fig. 7) is built between 1547 and 1556 by architect Hayruddin, Sinan’s student. The stone arch has span of 28.7 m, the rise is 12.02 m, while the rise-to-span ratio is f:L=1/2.39. The arch width is 4 m and dominates the river from a height of 20 m. The arch of the bridge was made of local

stone known as tenelija. The shape of the arch is the result of numerous irregularities produced by the deformation of the intrados; geometrically it was nearer to an ellipse [8].

Characteristic of the bridge is two fortified towers on each end. Instead of foundations, the bridge has abutments of limestone linked to wing walls along the waterside cliffs. Measuring from the summer water level of 40.05 m, abutments are erected to a height of 6.53 metres, from which the arch springs to its highest point [8].

The Old Bridge stood for 427 years, until it was destroyed in 1993 during the War in Bosnia and Herzegovina, but it was re-built in 2004. The Old Bridge, an extraordinary technological achievement of bridge construction, is inscribed on UNESCO's World Heritage List since 2005.

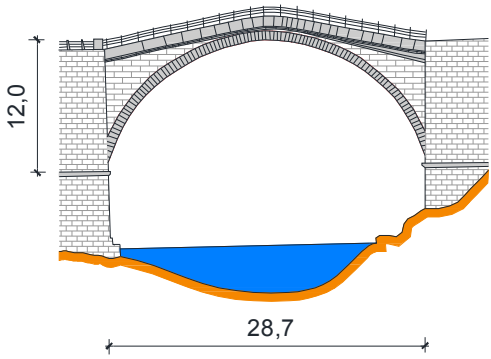

Fig. 7. *The Old Bridge in Mostar.*

3.3. The Old Bridge in Konjic

The Old Bridge over the Neretva River in Konjic (Fig. 8) is built in 1682. The stone bridge is set on six pointed stone arches with a span ranging from 6.77 to 13.52 m. The arches rest on five stone masonry piers and two abutments on each river bank. The piers are 3 m wide and 5.25 m long in transversal direction. On the upstream side the piers terminate in prominent triangular breakwaters, and on the downstream side in polygonal buttresses ending in pyramidal shape and terminating on the spandrel walls on both upstream and downstream sides. The arches of the bridge begin at approximately half the height of the vertical part of the piers, on a gently slanting cornice, and follow the line of a pointed arch increasing symmetrically from aperture to aperture from each bank towards the centre of the bridge. The end arches, smaller in span and rise, rest on piers and abutments. Spandrel vaults are forming slight archivolts, emphasizing the curvature of arches. The span of the bridge from the shore to the centre is equal on each side, creating a characteristic break in the alignment over the central pier [9].

The road over the bridge is 4.75 m wide; the stone slab parapet is 90 cm high and 30 cm thick. The total length of the bridge is 84.9 m, the total height from the foundation level to the highest point of the bridge is 13.25 m and 16.25 m to the top of the portal [9].

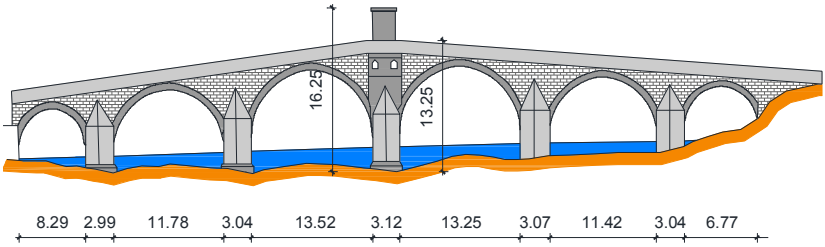

Fig. 8. *Longitudinal layout of the Old Bridge in Konjic.*

3.4. Other Ottoman bridges

The biggest concentration of the Ottoman bridges in urban area was in Sarajevo across Miljacka River. The exact number of bridges is unknown but there was at least seven stone bridges from the Ottoman period of which four, built in 16th and 17th century, are preserved (Fig. 9): the Roman bridge, with seven arches and length of 52 m, Šeher-Ćehaja bridge, with four arches and length of 40 m, the Goat bridge, single-arch bridge with length of 42 m; and the Latin bridge, with length of 40 m and four visible arches of the original five [1].

Fig. 9. *Ottoman bridges across Miljacka River in Sarajevo: Roman bridge, Šeher-Ćehaja bridge, Goat bridge and Latin Bridge.*

Fig. 10. *Arslanagić Bridge across Trebišnjica River in Trebinje.*

The Arslanagić Bridge across Trebišnjica River in Trebinje (Fig. 10), built by Mehmed Pasha Sokolovic in 1574, represents one of the most attractive and beautiful Turkish bridges in Bosnia and Herzegovina. The bridge has two large and two small semi-circular arches above which are semi-circular openings. In 1970s the whole bridge was moved stone by stone several kilometres away due to construction of hydropower plant [1].

The Ottomans built two main types of bridge structures: stone arches and long timber bridges with continuous beams over pillars. Among timber bridges it is worth to mention the Great Osijek Bridge built in 1566, internationally known at that time as a world construction wonder. Construction of the bridge was ordered by sultan Suleiman the Magnificent. The Osijek Bridge was the largest and most important structure in the European part of the Ottoman Empire and in whole Europe at that time, providing a crucial link on the main route from Istanbul to Buda. The bridge was approximately 8 kilometres long connecting Osijek to village Darda. Seen as a great threat to Christian Europe, the bridge was attacked several times, and was finally burnt down in 1686 [10].

4. CONCLUSION

Historical overview of the masonry arch bridge construction on the territories of Croatia and Bosnia and Herzegovina is shown in the paper. Structural characteristics and aesthetic values of arch bridges built during Roman and Ottoman Empire are discussed, highlighting main similarities and differences in design. Common characteristic of the Roman and Ottoman bridges are durability of stone arches which demonstrate the power and strength of the Empire.

Typical shape of roman arches is semi-circular or segmental, while Turkish bridges have pointed arch and at their time other forms of arch axis, e.g. elliptical, are introduced. The Roman bridges are characterized by geometrical perfection; all arches of the multi-span bridge are the same from the springing to the keystone, and over the whole of the vault width. On the other hand, Turkish multi-span bridge used to have different spans and often is not symmetrical.

Contrary to the Romans, Ottoman Empire did not pay much attention to agriculture and did not invest in melioration and too expensive hydrological interventions on our area, but they preferred to build a pontoon or long timber bridges in the swampy area, while stone arches had better protection against floods: pier length in transversal direction is larger in order to ensure transverse stability of the bridge, the increasing span and rise of Ottoman arches towards the bridge centre provides a better flow rate during the flood.

Alignment of the Ottoman bridges has a higher slope than Roman alignment, equal from each end of the bridge creating a characteristic break in the alignment over the central pier.

For the multi-span bridge, the typical Roman pier width - arch span ratio is 1:3. The same ratio is used for the medieval bridge at the Pile Gate in Dubrovnik from the 15th century. Ottoman bridges have significantly smaller pier to span ratio, for example piers width of Old bridges in Višegrad and Konjic from 16th century are approximately one-quarter of the arch span. The largest pier - span ratio of 1:2 has bridge across Tounjčica River in Tounj, built in 18th century, whose robustness had an important military role during constant threat of war.

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