Existing historical foundation system of two Old Bridges from the Ottoman period in Bosnia and Herzegovina

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ABSTRACT: Authenticity evaluation of cultural and historical buildings is one of the most important elements of their categorisation. Therefore, on the occasion of rehabilitation or reconstruction it is necessary to give special consideration to the correct assessment of state of existing foundation construction. Literature on historical foundations is very scarce comparing with literature on other structural elements, leading to a situation where engineers are seldom familiar with the problem. This paper provides description and more detailed research on foundations of two masonry arch bridges dating from the Ottoman period in Bosnia and Herzegovina, Old Bridge over the River Neretva in Konjic and Old Bridge over the River Drina in Visegrad. Upon examination on the spot, it has been established that both bridges have similar foundations i.e. multi-layered timber grillage.

THE OLD BRIDGE IN VISEGRAD (MEHMED-PASA SOKOLOVIC BRIDGE)

Historical background

The bridge was built between 1571 and 1577 over the river Drina on the road linking Bosnia with Istanbul. The construction of the bridge was entrusted to the great court architect Koca Mi'mar Sinan (1490-1588), not only the leading architect of the Ottoman Empire but one of the greatest builders in the entire world. The benefactor who funded the construction was Mehmed pasa Sokolovic, Grand Vezier to three sultans from 1565 to 1579: Suleyman the Magnificent, Selim II and Murat III. Mehmed pasa Sokolovic was born in the village of Sokolovici near Visegrad (NMA a).
The bridge is known to have been repaired in c. 1664, and again in 1875 and 1911. The bridge has experienced a number of major floods, of which the worst was in 1896, when the level of the Drina was 1.60 m above the bridge. When the Austrians withdrew from Visegrad in 1914 one of the openings of the bridge was destroyed, and the following year the Serb army destroyed another one when retreating.

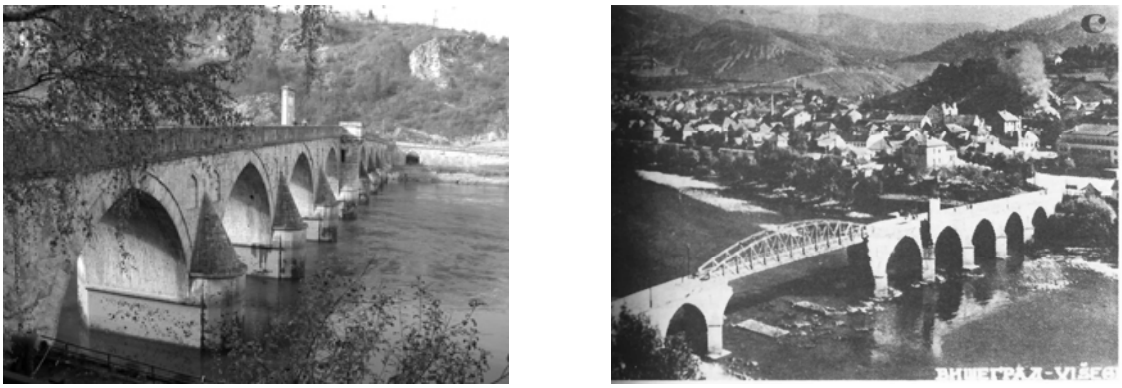

Figure 1: The Old Bridge in Visegrad to date (left) and 1935 (right); (NMA a)

During the intervening period, 1915 to1939, the sections of the bridge that had been destroyed were provided with an iron structure to make the bridge passable, see Fig. 1 right. The bridge remained in this condition until 1939 when it was repaired. When the Germans retreated in October 1943 that part was also destroyed. After that, the bridge was reconstructed in the period from 1949 to 1952.
Fresh damages, caused by bad maintenance, heavy traffic and the operation of hydroelectric power plant Bajina Basta were found on the Bridge in 1977. The plant was built downstream in 1968. That was soon followed by the development of a Bridge improvement project and by works that were suspended in 1981 due to lack of funds. That had an unfavourable impact at a later point, since the construction of the upstream hydroelectric power plant Visegrad was launched in 1984, which, in the meantime, was also placed into operation (Gojkovic 1989). The problem of heavy traffic was solved by building a new bridge 2 km downstream in the late 1980-ies.
On the initiative of the Commission to Preserve National Monuments in Bosnia and Herzegovina, the research programme was completed in autumn 2007 and field researches for making a rehabilitation project are in process. The World Heritage Committee inscribed this Bridge on UNESCO's World Heritage List on 28 June 2007.

Description of the Bridge

The bridge is one of the most magnificent works of architecture of the XV to XIX century in Bosnia and Herzegovina. The part of the bridge that spans the river consists of eleven arched openings, of which the last opening on the right bank rests on two retaining walls with the smallest span of 5.20 m. The other ten arches have a span from 10.70 to 14.80 m. The bridge is supported by nine great stone piers with a width from 3.50 to 4 m, and a length of about 11.50 m. On the left bank the endmost opening rests on the angle of the bridge where it grades into the ramp. 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 excentricity of the centres (c. 1.00 m), making them almost semicircular.
The stone (limestone) from which the bridge was built 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. 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.

Description of the foundation structure

The archive plans of the existing condition in 1908 and 1909 show the foundations consisting of several, stepwise descending foundation layers and a double-layered timber grillage (NMA b). Some footings were lowered to the rocky substrata and in the places where the river is deeper, the foundation was made on the upper, coarse-grained, incoherent layer. Piles have not been noted, although they are mentioned in some references. One may consider them remains of the old cofferdams, and not short or long piles.
On basis of the above mentioned plans, Austro- Hungarian engineers made a reconstruction project in 1911. Repair works were carried out on the foundations of piers 4 to 9 in 1912. Pier marks are shown in the Disposition of the Bridge (Fig. 2).
The reconstruction plans were saved in the Commission to Preserve National Monuments of Bosnia and Herzegovina Archive, out o which one typical reconstruction plan for the pier foundation is outlined, see Fig. 3.

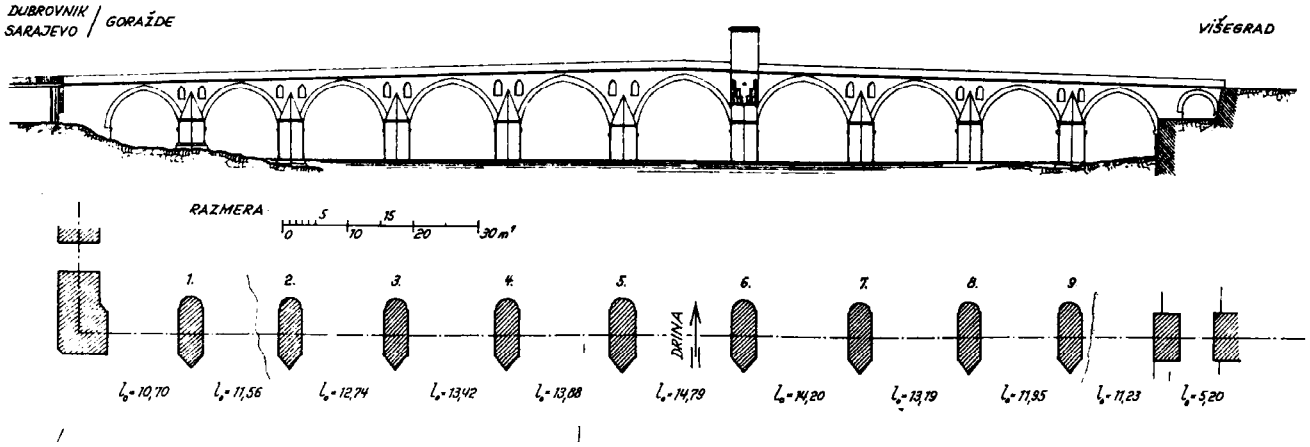

Figure 2: Disposition of the Bridge (Gojkovic 1989)

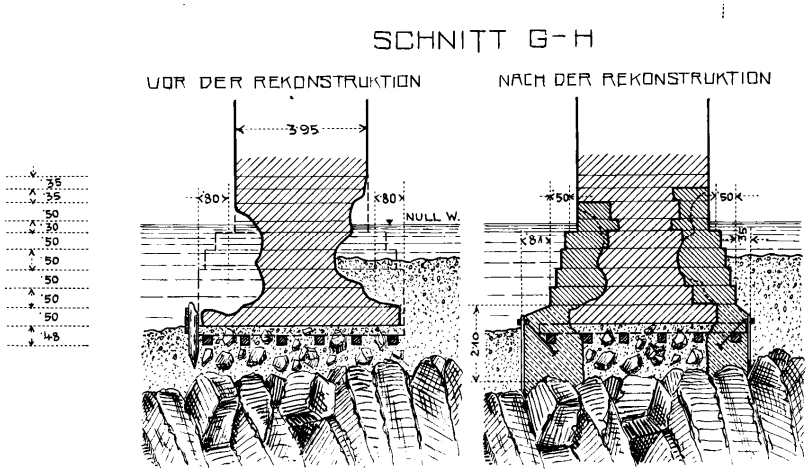

Figure 3: Pier 6, sec. G-H, plan of the existing condition and reconstruction proposal from 1911 (NMA c)

Description of the foundation repair carried out in 1980/81

After it was found in 1977 that the Bridge had suffered significant damages due to bad maintenance, heavy traffic and unfavourable influence by the accumulation reservoir of the Bajina Basta hydroelectric power plant, necessary research was conducted and an repair project developed. The Faculty of Civil Engineering in Belgrade developed the project. Some repair details, which professor Gojkovic published in his book 1989, are shown below.

The repair project was divided into two phases: I – replacement of the roadway structure and new insulation, II – repair of the foundations of river piers. Relieving the heavy traffic was foreseen as a special permanent protection measure. It was for that reason that a modern bridge was built two kilometres downstream in the late 1980-ies. The Bridge has been closed to freight traffic since then, and it has been closed to all motor vehicles only since 2003, by a decision of the Commission to Preserve National Monuments of Bosnia and Herzegovina.

According to Gojkovic, the repair project for the foundations of river piers comprised the following:

- Carrying out all repair works on the foundations in dry conditions in order to achieve permanent improvement and desired quality;
- Providing the existing footings with a more suitable hydraulic shape in their lowest parts;
- "Lowering" the footings all the way to the rock by injecting river deposits, so to directly transfer great load to the rocky substrata.

During the years of 1980 and 1981, the foundations of three piers V, VI and VIII were repaired. At the end of 1981, the works were suspended due to lack of funds. In the meantime, the Visegrad hydroelectric power plant was built and put into operation. The projects for the Bajina Basta hydroelectric power plant downstream and the Visegrad hydroelectric power plant with a dam directly upstream from the Bridge endangered the foundations of this historical monument additionally.

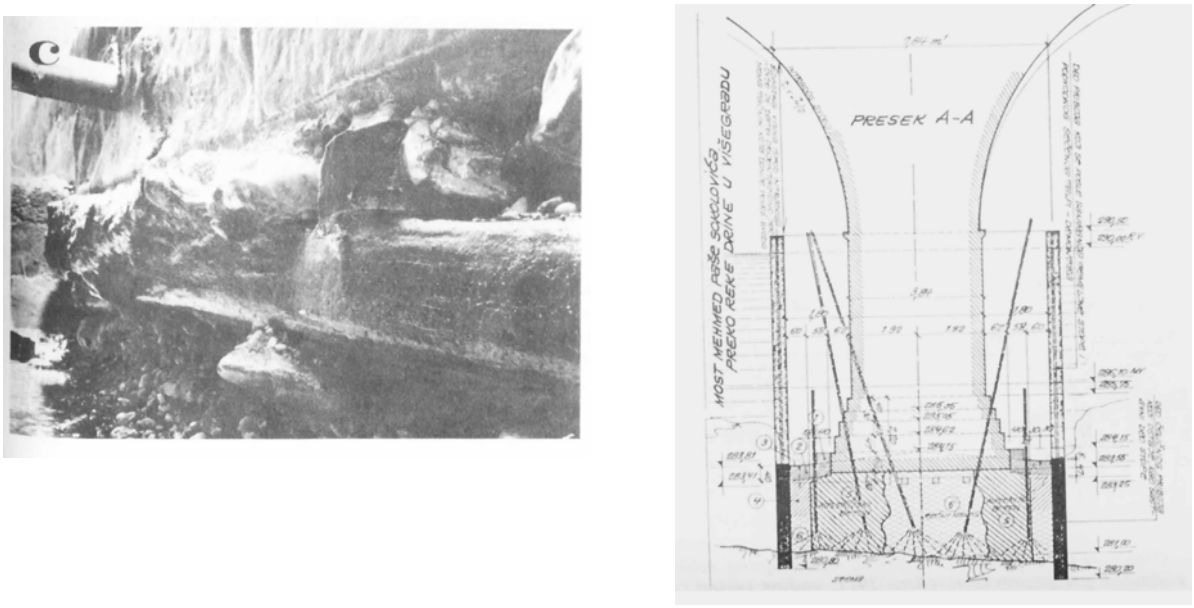

Figure 4: Details of the 1980/81 foundation repair (Gojkovic 1989)

THE OLD BRIDGE IN KONJIC

Historical background

During the Ottoman period, three bridges were built in Konjic: two timber and one stone masonry bridge. The first bridge over the Neretva in Konjic was built by the Mostar legator Hajji Mehmed-beg Karadjoz prior to 1570. The Karadjoz-beg Bridge in Konjic was a timber structure 15 to 20 m downstream from the stone bridge built at a later date in 1682. The stone bridge was a masterpiece of XVII century architecture and one of the finest monuments of its kind in Bosnia and Herzegovina (Fig. 5). From a ferman (imperial decree) of Sultan Mehmed IV from 2 to 12 May 1685, sent to the mutesserif of the Herzegovina sandzak, Husein, the builder of the Konjic stone bridge is identified as Haseci Ali-aga. This ferman was found in the Oriental Collection of the Provincialate of the Franciscans of Herzegovina (Hasandedic 1976).
In order to ensure that the German troops could escape from the surrounding Partisans, half of the stone bridge was destroyed in 1945, during their retreat. Since this bridge was the only crossing over the Neretva in Konjic, a temporary timber structure was laid over the pier remains. In 1946 a new concrete bridge was built in Konjic somewhat lower than the stone bridge, which is now used as the main bridge for both road and pedestrian traffic.
In late 1976 and during 1977, at the initiative of the regional Institute for the Protection of Cultural Monuments in Mostar, steps were taken to reconstruct the old bridge in Konjic. Based on existing technical and historical data and a detailed survey of the remains of the bridge, a study or design concept for its reconstruction was drawn up. Preliminary postulates and solutions were adopted and consent was given to draw up a main design project. However, since there were insufficient funds available, further work on this major project was suspended until 2004.

Figure 5: The Old Bridge in Konjic before 1945 (GDH a)

Description of the Bridge

The stone bridge is set on six pointed stone arches with a span ranging from 6.77 to 13.52 m. The distance between the arch intrados and water level during the summer period, ranges from 4.30 to 8.70 m. The arches rest on five stone masonry piers and two abutments on each river bank. The piers, which belong to the original state, are 3 m wide (with minor variations), and 5.25 m from side to side of the bridge in the direction of the current stream. 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 (Fig. 6).
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. The increasing span and rise of arches towards the bridge centre was the practice in the Ottoman bridge architecture of the time which provided, among other benefits, a better flow rate during the flood.
According to the reconstruction project of the Konjic Bridge (GDH a), 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.

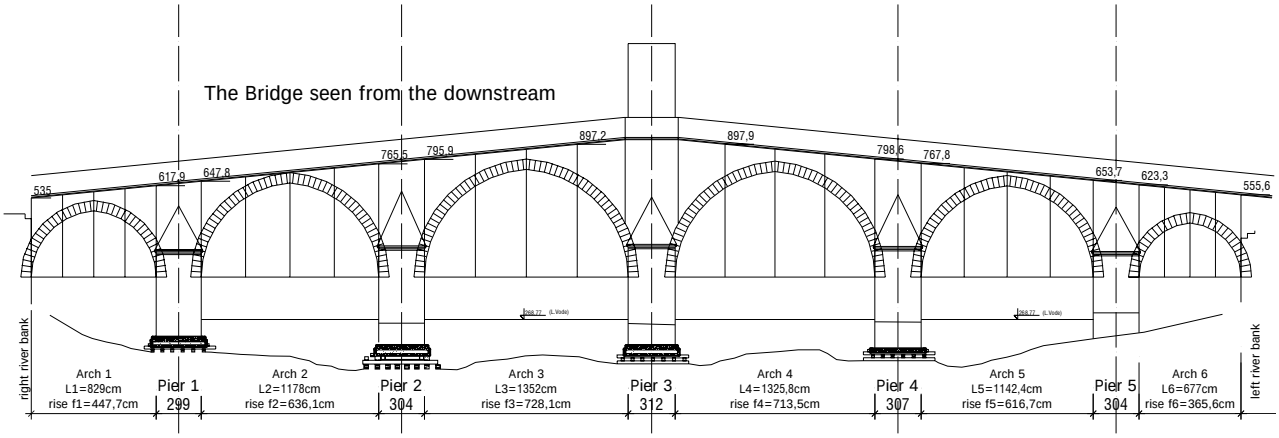

Figure 6: The Old Bridge in Konjic, downstream elevation

Description of the foundation structure

In the summer of 2004, on the initiative of the Konjic Municipality, the Faculty of Civil Engineering of the 'Dzemal Bjedic' University in Mostar developed a programme and thereupon carried out the investigative works on the Old Bridge in Konjic remains. The most important investigation aspect dealt with the least known foundation of piers and their current condition.

A detailed assessment of the condition of piers and foundations of the Bridge was made based on several investigative activities:

- hole drilling,
- videoendoscopy,
- underwater recording of the Bridge foundations,
- physical-mechanical, chemical and mineralogical-petrographic laboratory analyses of stone, mortar and timber grillage samples.

Drilling of 130/80 mm holes through axes of the piers and 3.0 to 5.0 m long holes into the rocky ground, their interpretation and underwater recording revealed the possible foundation type and its condition, including the type and level of damage to the rocky ground of the foundation.

Recording of drill-hole walls, using a TV video camera for endoscopy, was carried out only up to the area near the foundation layer, since the muddy water of the Neretva made it impossible to make any further recordings. This surface recording of drill-hole walls discovered the infill of Bridge piers, composed of different sizes and types of stone, with joints that are filled with rather solid mortar, washed out in places.

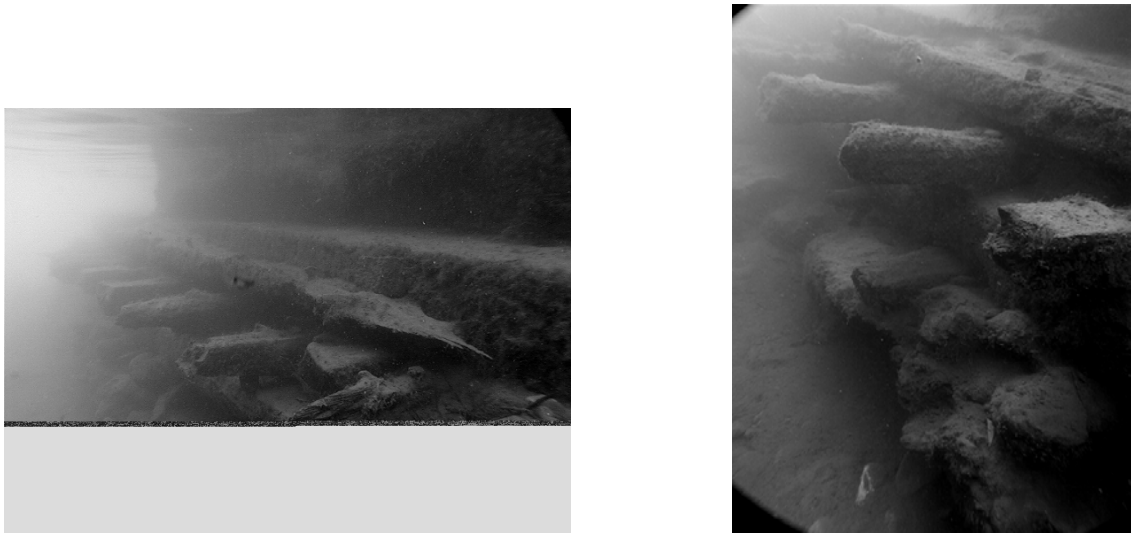

Figure 7: Underwater photo of the condition of the timber grillage, Pier 4; (FCE a)

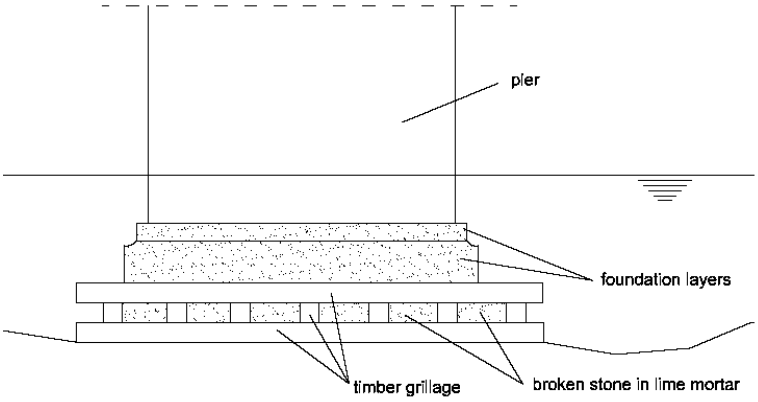

Figure 8: The characteristic cross section of the examined pier foundations

The underwater recordings found wide timber grillages underneath the treated foundation layers, which are made of longitudinal and lateral timber beams joined together with forged nails and leaned against the rocky ground. The condition of the timber grillage at pier 4 is given in the image taken by the underwater camera (Fig.7). The foundation principle is practically identical in all four examined river piers, and only the arrangement, number, distance, dimensions and level of deterioration of the beams are different. Foundation layers and timber grillage are presented in a characteristic cross section of one of the examined pier foundations (Fig. 8). Both visible beams and those assessed to have existed were marked.

The existence of the timber grillage under the foundation layers was also ascertained by drilling holes through the axes of the Bridge piers. Core samples of timber were drilled out of the foundation grillage. The investigation found out that the foundation grillage is leaning against the dolomite rocky ground of different compactness levels.

Regularly shaped stone blocks are placed between the outer ends of the beams, while the grillage is probably filled with broken stone in lime mortar. Technical conditions did not allow examining this more thoroughly. Broken stone material was drilled out of this level. The grillage beams were fastened using 35 to 40 cm long forged nails. Stone blocks of foundation layers were interconnected with iron cramps sealed with lead. The foundation layers are partly damaged and some beams of the timber grillage, which have been physically damaged over time and whose cross-section is reduced, are missing (or cannot be seen).

Preliminary analysis of the bearing capacity of the foundations was made based on these investigations. Permissible bearing capacity of 543 KN/m^2 with safety factor of three was obtained. Stresses obtained in some cross-sections, regardless of the timber grillage, are relatively low and they correspond to the cracked and dilapidated dolomite rocky ground (Table 1). According to the investigation, the current average strength of sample remnants of the timber grillage vertical to the fibre direction is 3.95 MN/m^2 and parallel to the fibre direction is 7.97 MN/m^2.

Table 1: Overview of stresses obtained in characteristic cross-sections (FCE a)

Cross-section	Compressive stress kN/m^2
Cross-section at the bottom of a pier	440.85
Cross-section on the contact surface between foundation layer and grillage	293.89
Cross-section on the contact surface between grillage and foundation ground, taking into consideration that, apart from stone infill, timber beams also play a role in taking over the load	271.80
Cross-section on the contact surface between grillage and foundation ground, disregarding the surface of timber beams of the grillage	449.70

It has been shown that, from the load-bearing point of view, the foundation ground can take over the Bridge load with an adequate safety factor. In order to avoid washing out of the dolomite grus underneath the timber grillage over time, contact or bond injection grouting is suggested in case of some pier foundations, which would ensure and prolong the durability of this architectural structure. The foundation repair works haven't been performed at the time of writing this paper. The appropriate method will be decided within the design for the river bed treatment where the river flow and its destructive influence on foundations needs to be analysed and solution provided.

There is an especially complex problem with regard to finding an adequate calculation model for the foundation of piers on the timber grillage and for the assessment of its future role and of the level of deterioration and safety. It is possible that the timber grillage has a predominantly structural role, as an element of aseismic construction. This problem has not been discussed here any further. It has been presented above that the analysed cross-section, without the co-influence by the timber grillage, has adequate bearing capacity.

CONCLUSIONS

Exploring historical conditions of existence and usage of old bridges represents an important segment in the choice of needs and ways of reconstruction in modern conditions. Existing historical foundation system of two old bridges from the Ottoman period in Bosnia and Herzegovina were presented in the work with special emphasis on description of foundation structure. The presented timber grillage foundation system for the two historical bridges is a challenge for further studies of reconstruction methods, bearing in mind preservation of their authenticity and providing the level of safety in accordance with the contemporary requirements.

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FCE a, Report on the investigative works on the Konjic Bridge remains, 2004

General direction of Highways, Division of historical bridge, Istanbul (GDH):
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The Commission to Preserve National Monuments Archive, Sarajevo (NMA):
NMA a, Decision No. 08.2-6-101/03-5 from 4 March 2003, the historical monument of Old Bridge in Visegrad is hereby designated a National Monument of Bosnia and Herzegovina.
NMA b, The Plans of the existing condition of Old Bridge in Visegrad in 1908 and 1909
NMA c, The reconstruction plans of Old Bridge in Visegrad in 1911
NMA d, Decision No. 08.1-6-5/03-4 from 2 July 2003, the historical structure of the Old Stone Bridge in Konjic is hereby designated a National Monument of Bosnia and Herzegovina