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MATERIALS AND TECHNIQUES IN OLD BRIDGE OF MOSTAR RECONSTRUCTION

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ABSTRACT
The reconstruction of Old Bridge in Mostar was a pilot project of City of Mostar, World Bank, UNESCO and donor countries.
The reconstruction itself had many phases: from it's beginning with material survey, design determination, to it's actual reconstruction and maintenance.
Main UNESCO demand was usage of original materials and techniques. German company LGA made testing of all materials from the original bridge and then compared numerous samples from local sources in order to determine its origin
Main materials used for the bridge construction were: stones (tenelija, hard limestone, breca-conglomerate), mortar, metal (iron and lead).
Now days we can say that it was one of the most successful complete reconstructions in the world. Usage of ancient materials, old techniques and understanding of its structure made this monument alive again and provided him a ticket to UNESCO list of World heritage.
Keywords: Old Bridge, ancient materials, ancient building techniques

1. ABOUT THE BRIDGE

The Old Bridge of Mostar was built in 1566 by Hajrudin, a student of Kodza Mimar Sinan, the greatest Ottoman architect. It is a stone bridge overly slender and elegant shapes: its profile and its skyline are so thin and so high over the river waters that it is hard to believe that such a structure could be made out of huge stone blocks.

The Bridge was destroyed in November 1993 by shelling during the recent war events. Its reconstruction was one of the biggest and most complicated projects involving UNESCO, The World Bank and many local and international experts. The

Figure 1. Old Bridge

task was to build a New Old Bridge - precisely the same in all details as the Old one. After many studies, tests and shape determinations, the project was completed and the actual reconstruction work could begin. Ancient techniques and methods, original materials and a perfectly reconstructed shape gave this Bridge its new life in post-war Mostar.

2. CONSTRUCTION OF THE BRIDGE

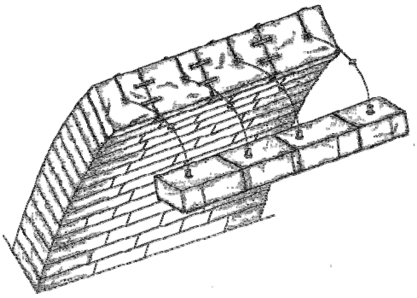

Figure 2. Scheme of the load bearing atch composition

Figure 3. Assembling of the load bearing arch

The load bearing arch, the most important portion of the bridge, is composed of the voussoirs which are connected by many reinforcing devices, present to ensure efficient joint connections.
To better understand how voussoirs were assembled, it has to be pointed out the following:

- the load bearing arch is composed by 111 rows of voussoirs in a thickness of cm 395;
- each row contains 2-5 voussoirs (average 3-4);
- rows of voussoirs were mounted from both sides of the bridge simultaneously;
- joints, among voussoirs belonging to one row, were shifted compared to the preceding row, (as it happens in an ordinary masonry layout);
- a mortar layer was used to combine adjacent voussoirs, (as in an ordinary masonry work);
- additional metal elements were mounted across the joints.
- three different strengthening metal devices were used for the arch stones: dowels, side cramps and extrados cramps;
- metal elements, and purposely built carvings to host them, were of dimensions and sizes quite variable in the bridge structure.

Each arch stone was linked to one or two voussoirs of the preceding row by one or more metal dowels. Dowels were applied to the stone blocks in purposely carved slots, (holes), and melted lead was poured in the slots to connect metal and stone elements.
Adjacent voussoirs of each row were connected with double side cramps crossing the joints; even in this case cramps were linked to the stone by melted lead, poured in purposely built slots. Side cramps were quite regular, of similar shape and size and they had not so many variations along the load bearing arch.
Extrados cramps were located over the extrados of the load bearing arch: there were five rows of cramps that ran in parallel directions following the curved profile. The extrados cramps acted like tying chains, or at least they were conceived with this purpose, being one adjacent to each other. These cramps were different from all the others that have been found in the bridge stone structure, because they were dimensioned depending exclusively on the arch stone measures: where one cramp ended, the other started, sharing the same stone-slot to allow continuity of the tying action.
Lower cornices are located directly over the extrados of the load bearing arch, jutting out of the vault profile to protect below structure. Lower cornices, being assembled on a curved profile, required special care during the adjusting procedures and were, anyhow, anchored to the arch with a mortar layer. On top side of the cornices, across the joints, it was placed a single row of cramps approximately located along the longitudinal axe of the stone elements.

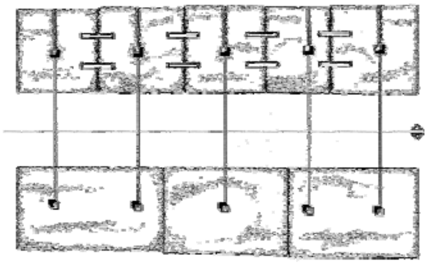

Figure 4. composition of the voussoirs

Figure 5. Extrados cramps

Spandrel walls were made in ordinary ashlars masonry work with thin mortar joints. On top side of the spandrels, across the joints, it was placed a single row of cramps approximately located along the longitudinal axe of the stone elements, but variability of this parameter was quite high being also related to the ashlars thickness dimensions. Stone block rows were sometimes assembled with an imperceptible gradient, may, be due to ordinary constructive imperfections or to due to optimisation of the connection with the load bearing arch.

Upper cornices were placed, on a mortar layer, over the spandrel walls, with high accuracy to gain a direction that on top had to be tangent to the lower cornice, and at the same time, cornices were jutting out from the spandrel walls profile to protect them from rain water. Upper cornices were generally bigger than lower cornices, and may be for this reason, had two rows of cramps instead of one. Moreover cornices were provided with slots, and related channels, that were used to host the dowels of the parapets.

Parapets were assembled over the upper cornices with a mortar layer and with the dowels, that were supposed to be previously mounted on the lower edge of the parapet, and inserted in the slots of the upper cornices: the whole was linked by pouring melted lead in the purposely carved channels over the cornices. On the top edge of the parapet some other cramps were placed crossing the side joints, (linked as well with mortar). It seems that parapets, getting to the top of the bridge, were purposely assembled slanting slightly outwards, may be with the aim of obtaining an optical effect that could give the impression of a wider footpath.

Fences were most probably assembled in a subsequent period to protect people from falling down. Fences were made in forged iron.

3. MATERIALS

3.1. Stone

Most of the stone elements of the bridge including the vault, cornices, spandrels and parapets, were made in “tenelija” stone (Category I), which is a local oolithic limestone rock of light and warm colour and high porosity, resistant to compressive strengths of about 20 MPa; (from the Mukoša quarry). This stone is characterise by high porosity which results from the geometrical structure of spheres, which are partially not in compact state. While cutting tenelija, the stone is cut through the pores and not through the grains. The result of this is an open porous texture that provides room for environmental wear and also for biological growth which causes adverse effects to the durability and visual function of the stone. Tenelija colour changes after fresh cut from Yellowish and ivory to grey with time,

The pavement and the stone slabs over the lightening voids were in “krecnjak” stone, a light-colour hard and resistant marble-like limestone.

Major parts of abutment wings are built of “breca” – a classic conglomerate of small to large size gravel and pebbles, which have been geologically cemented to form the characteristic thick rock banks of the Neretva river.

3.2 Metal

Metal connectors, cramps and dowels, were in forged iron as was the fence.

One of the most important materials used in Bridge construction was led. The Bridge itself was organic structure, capable to resist different kinds of pressures: strong wind, river, earthquakes and so on. That kind of flexibility was possible because of metal cramps and dowels, firmed within the stone cavities with led. Led was melted to 380 – 390 °C, in special heater, and poured with smaller can into the hole.

One of the most important and the most delicate procedures during the building of the bridge was pouring of the led into the voussoir stones. Lead was poured trough canals to the “hidden” (already inserted) dowels between the rows of the arch. The canals had to be dry and clean, and the speed of the pouring led optimal. Even small amount of water would cause ”explosion” that could harm the stone (that could not be replaced once in its position) and the workers. This dangerous procedure was performed with 100% success.

3.3 Mortar

All historic mortars depend strongly on their regional tradition and historic periods of production.

Its main components were lime, artificial puzzolanic material (powdered bricks), mineral aggregates (different size for each characteristic mortar – arch, abutment walls..) and water.

Terra rossa - red colour bauxite was mixed in mortar beneath the pavement as the waterproof layer. This was prevention against leakage of the water into the bridge construction because porous structure of tenelija would “suck in” huge amount of the water that would additionally burden the load bearing arch.

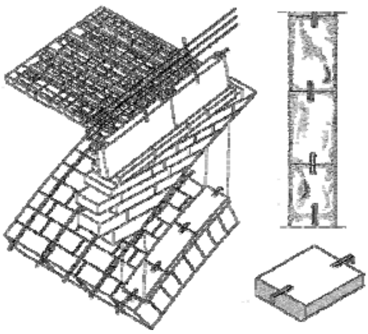

Figure 6. Scheme of assemblance of the lower cornice

Figure 7. Assembling of the spandrel walls and middle rib

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