CONSTRUCTION TECHNIQUES AND RESTORING INTERVENTION OF THE OTTOMAN BUILDINGS AND BRIDGES IN MOSTAR

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1. ABSTRACT

During the last war in Bosnia-Herzegovina, many historic buildings and bridges in Mostar were damaged even very seriously. Some of these monuments have been repaired or restored thanks to European Administration and UNESCO. We present the restoring works we carried out and the studies necessary to get a better knowledge of these buildings and bridges before designing the consolidation.

2. INTRODUCTION

The city of Mostar in Bosnia-Herzegovina, had its best development during the Ottoman domination, when, in the 16th and 17th century, lot of buildings, mosques and the famous bridge over Neretva river (Stari Most = Old Bridge), were built using refined techniques.

In 1992-93 the historical city was bombed and the city was divided into two parts. The troops led not only to the deliberate damage of many monumental buildings, but also to the collapse of the Old Bridge. European Administration and the UNESCO have provided to a first important safeguard of the most important monumental buildings, tightly considered the real city’s heritage. In particular, the domes and the minarets of the most important mosques have been consolidated, and the study on restoration of the historical bridges has been carried out.

In this paper we present the restoring works we carried out and the study about the consolidation. The complex constructive geometry of the religious buildings and the famous Old Bridge (1566) together with the rich and advanced construction techniques, with the constant use in the minarets and in the bridges of well squared stones kept together by plumbed metal stirrups, show many relations to Sinan Ottoman architecture and to the old classic roman rules as suggested by the following quotation.

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".... using the stones he got extracted, he ordered a bridge to be built, welding together the stones by means of iron and lead", Erodoto, Libro I, 186-2 (V cent. B.C.)

3. GEOMETRY AND CONSTRUCTIVE TECHNIQUES

The XVI century ottoman architectural culture finds its references in the architecture of Istanbul the capital of the Empire, which can be considered direct heir of the great Roman architecture. The geometrical schemes of the monumental buildings are referred to simple figures, like squares, circles and rectangles whose sides are generally in ratios of 1 to 10 or 1 to 12.

In order to understand the constructive geometry correctly, it is very important to relate all the dimension of a building to a local useful unit length.

The length unit used in the XVI century ottoman culture was the Arsin, which could assume different values - 71.12 and 75.80 centimetres - depending on how it was used and when.

The constructive techniques used for the erection of different buildings as well as, mosques, minarets and bridges testify the great refinement of the ancient ottoman architects. In particular the finish techniques and the choice of such different materials for different structural parts indicates the high care in constructive problems.

The materials used for the erection of the monuments interested by restoration works reported in this pages are of four different types:

a) a stone called "tenelija" of sedimentary origin, easy to carve and used for outdoor facades, decorations and for many minarets;

b) a calcareous remarkably resistant stone called "Krecnjak" rather difficult to cut and used for rough ashlar walls and in pebbles for paving;

c) a stone called "breca", made of strong conglomerate, resistant to dampness and permeable, owing to a network of tiny holes, is used for foundations and basements;

d) a stone called "travertin" very porous and light with low mechanic resistance, is used for the domes.

3.1. The Mosque of Karadzozbegova (1557)

The Mosque of Karadzozbegova is the most important work of sacred Islamic architecture of 1500 (or the sixteenth century) in Herzegovina and it is also the oldest of the domed mosques of Mostar.

It is made up of a square chamber 12.8 m. long each side (i.e. 18 Arsin) and surmounted by a dome. The porch is covered by three smaller domes. The minaret was one of the tallest and richest in decorations. A wooden roofing opposite the porch protected the entrance.

The mosque is built with perfectly squared stones outside and plastered ones inside. Three different types of stones were used: "tenelija" for the outside, the decorations and the whole minaret; "breca", for foundations and basement; "travertin", for the domes.

Even if a reliable tracing of this monument is not available, it should be noted that the whole was designed and built in a most rigorous geometrical way using Arsin, - a measurement mentioned in textbooks as that used by the builders and equivalent to about 71.12 cm - (fig. 3.1). The dome is a spherical vault practically constant in thickness - about 53 cm - with a centre depressed with respect to the impost and placed halfway in the drum. The inner room is exactly 15 Arsin, the wall thickness is 1,5 Arsin.
- equal to $1/10$ of the inner diameter of the dome. The thickness of the dome is $3/4$ Arsin, that is, $1/2$ of the inner diameter. Also the inner disposition of the masses and the windows are regulated by rigorous geometric ratios - which recall the great classical architecture arrived in Mostar through the interpretation of the Ottoman World and particularly of Sinan.

The collapse on the front caused by a shell made it possible to find out interesting building details. Two little rooms rectangular in shape have revealed the likely presence of wooden hooping tie-beams, probably placed as shown in figure 3.2.

In the masonry were found earthenware jars, their openings turned towards the inside of the dome and regularly arranged in two rows at a distance of about 1 Arsin. They may have had a decorative or even an acoustic function.
The dome contained a long-standing radial crack network which is typical of masonry domes with insufficient external contrast.

It also interesting the building technique followed for the minaret, with perfectly squared stones with hooping which was carried out in all the laying surfaces with iron stirrups fixed in the stones with lead; an expensive, refined and particularly effective system (fig. 3.3).

3.2. Mosque of Koski-Mehemed Pasina (1617)

The mosque of Koski-Mehemed Pasina is perhaps the most famous as it commands a splendid view over the left bank of the Neretva, near the well-known “Stari Most” bridge. Its shape is almost the same as that of the Mosque of Karadzozbegova and the proportions of these two mosques are very similar. The geometry is equally rigorous and the building technique is the same.

During the war the dome and walls were rent at different points and the minaret was completely destroyed.

3.3. Mosque of Vucijakuvicia (1564)

The Mosque of Vucijakuvicia is the smallest of the mosques with domes in Mostar but all the same its shape and dimensions are similar to the two previous ones. However the masonry is not in squared stones but in rounded krecnijak stone ashlar which suggests greater economy. The minaret instead was made with the same technique of the others.

3.4. Kriva Cuprija bridge and Stari Most bridge

There are several affinities between old domes and bridges in Mostar. In fact construction details and geometrical schemes of Stari Most and Kriva Cuprija are similar to those used in mosques.

It has been hypothesized that Kriva Cuprija bridge was used as a model for the erection of the better known Stari Most, now destroyed, but this assumption is not supported by any documents. In order to understand the relation between these two bridges it is therefore necessary to examine the differences between the two constructions. The two bridges have very different dimensions: Kriva Cuprija has a span of about 8.4 m and Stari Most had a span of about 28 m.

The geometry of Kriva Cuprija is on a dodecagonal basis. Considering that the value of an Arsin is about 71.3 cm; the main arch has a semicircular profile with a radius of 6 Arsin. The cross section of the arch is 3 Arsin large (fig. 3.4). The thickness of the main arch is half an Arsin, according to the constructive rules, generally referred to as Leonardo da Vinci’s rules although they were applied even before the XVI century as is shown by the geometry of the PONTE VECCHIO in Florence (1334).

Stari Most was designed on a modules of 4 Arsin and on decimal basis, with a bending radius of 20 Arsin. Its arch does not have a semi-circular profile (like Kriva Cuprija) but its centre is lowered by 4 Arsin under the line of impost (fig. 3.5). Comparison between theoretical and surveyed geometry shows little differences, likely attributable to deformation of the centring, to elastic deformations of the vault and to some settlements occurred during the past.
As well as in the minarets, in the bridges squares stone blocks connected by metallic elements were used (fig. 3.6 and 3.7).

A Squared tenelija stones
B Cornice in tenelija stone
C lightening ribs
D Mixed stones masonry
E iron dowel fixed by lead
F Iron stirrup fixed by lead
4. THE RESTORATION WORKS

All the restoration works were carried out with the utmost care. When possibly the original stones were used. In case of substitution, all the new stone, of the same kind of the original ones, were hand carved and finished with filing by skilled workmen according to traditional techniques.

4.1. Karadzozbegova Mosque

During the war the dome had been severely damaged, particularly on the front side, where a shell destroyed part of the drum. Also the wooden roofing was completely destroyed.

The dome was reinforced with active hooping located at the extrados under the lead layer and all the lead was substituted (fig. 4.1).

Particularly serious was the situation of the minaret that was probably saved only thanks to the presence of the connecting stirrups between the stones. The spire above the balcony had been completely destroyed and a shell had produced a rent half way up.

The restoration work proved to be difficult and risky. It was carried out with the active propping of the minaret with a "cuci-scuci" technique, replacing all the original metal stirrups. All the stones of the higher part of the minaret and those from the portico were found and catalogued.

4.2. Koski-Mehemed Pasina Mosque.

The restoration work covered the dome and the stone fronts: the dome was hooped and partly re-built. The stones in the front and cornices were partly substituted or restored. All the lead covering was substituted. As regard the minaret only the clearing and protection work of the remaining base could be carried out.
fig. 4.1 - New iron hooping-tie in Karadzozbegova and Koski-Mehemed Pasina mosque.

4.3. Mosque of Vucjakovicia (1564)

It was the mosque that was the least damaged as only the finishing touches were damaged and only the top of the minaret was destroyed. In this case too the covering lead layer was substituted and a provisional protection was carried out on the minaret.

4.3. Kriva Cuprija Bridge

The present condition of the bridge is the result of deterioration caused by time and of the damage suffered during the recent war. Fortunately only non-structural parts are damaged and the overall resistance is not reduced. The arch is made of squared block of tenelija stone. It was properly restored in 1967 and now it is solid, without any cracks or fissures, all its stones are well closed at the intrados. On the right upriver side the vault is a little flattened and its curvature is slightly reduced. This defect involves only part of the width of the vault and no sign of structural weakening has been noticed. Possibly it was caused by a settlement of the center during the construction or by subsequent trouble. Some external stones of the arch are slightly damaged by little shells. Only a block, located near the keystone on the upriver side, is more damaged with one of its edges removed (fig. 4.2.). The spandrel walls are in good conditions, with only some little hole or scratch caused by shells. The parapets are made of tenelija stone slab put vertically over a cornice, linked to each other with metallic stirrups and connected to the vault by metallic dowels. The parapets are the most damaged part of the bridge. They were destroyed, together with the cornice, on both sides for about half their length from the left impost to the center of the bridge. In the remaining part there are lots of holes and scratches, even deep, caused by fire arms. The bridge footpath is paved with cobblestones and narrow slabs of krennijak stone and is widely damaged in the central part of the bridge. (fig. 4.3)
The mechanical behaviour of the bridge have been studied by means of several tridimensional finite element numerical models reproducing the exact geometry of the bridge, as revealed by the results of the survey. Linear and non-linear static analysis have been carried out (fig. 4.4) and they showed the good resistance capabilities of the bridge, so that it is not necessary to proceed with any structural-strengthening works. A complete restoration of the damages caused by the war is quite sufficient.

The restoration plan is finalized to a complete revitalisation of the bridge and its environment also providing a complete revitalisation of the neighbouring tourist area.
About the restoration of the bridge, the project covers what is strictly for the substitution of the damaged parts by using materials of the same kind as the original ones. In particular, tenelija stone will be used for the replacement of lost elements in parapets and cornice (fig. 4.5 and 4.6), Krecnijak stone blocks for the restoration of paving.

fig. 4.5 - Restoration plan of Kriva Cuprija Bridge

fig. 4.6 - Restoration plan of Kriva Cuprija Bridge

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5. CONCLUSIONS

The skill used in these buildings construction is a unequivocal sign of refined culture in evident opposition with the present destructive madness of man. We hope that with the peace we can carry on, with greater calm and serenity, the study and complete restoration of all the monuments damaged during the war. This will be an occasion to discover new aspects of the art and techniques followed during the Ottoman period. In our opinion the knowledge and the respect for the original techniques, materials and geometry is an indispensable aspect when designing a restoring intervention and we hope we have followed this rule in our job in Mostar.

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