# REHABILITATION AND RECONSTRUCTION OF TWO HISTORICAL TIMBER ROOF STRUCTURES AND ONE WOOD BRIDGE IN SERBIA

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***Abstract**: This paper presents rehabilitation and reconstruction design of two historical structures with timber roofs, which are under the protection of The Institute for Protection of Cultural Monuments of the Republic of Serbia. An overview of reconstruction of the medieval keep tower in Bač, which was built in 1329, is given. Reconstruction was largely related to the roof structure. Bridge over the Mileševka River, near the Mileševa monastery is a very interesting project. which was developed based on historical data on similar bridges and on a single footage of the former bridge. Reconstruction of the Carmel Monastery roof structure in Sombor, which was built in 1904, was carried out by replacing the existing roof structure with a completely new modern structure made of glued laminated timber. All rehabilitation and reconstruction designs described in this paper were developed at Faculty of Civil Engineering in Belgrade.*

***Key words**: Fortress; Tower; Masonry; Chimney damages; Rehabilitation; Repair; Monument; Bridge; Church; Monastery; Roof structure*

## 1. Reconstruction of medieval tower in Bač

Medieval fortress Bač with its suburb is located in the southwestern part of Bačka, about 14 km from the most important European river Danube. It was built near the town with the same name on the river Mostonoga. The fortress in Bač is a very important multilayer archaeological locality and a historical place, which is why it was placed under the protection of the state Srebia in 1949[1]

Archaeological research of the fortress in Bač (in 1958-59, 1980-81 and 2003) found that the location where it was built was settled from the Middle Stone Age. According to the written sources from the 11th century, the seat of the county, the bishop and the archbishop were located in Bač.

The fortress was built according to the "water town" principle. The fortress has an irregular tetragon base on which corners are protruding towers. Three corner towers have a circular base, while the northwest tower has a rectangular base (Fig. 1 and 2). Initially, the fortress was surrounded by moat filled with water. This moat is still visible today. The fortress was entered through a drawbridge.

Within the ramparts of the fortress, the most dominant and only freestanding structure is the keep tower (the watchtower). This tower is noticeable for its height, which

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is in accordance with its basic purpose, to observe the surrounding territory from it and to defend the fort.




**Fig. 1.** Bač fortress in 1668



**Fig. 2**. Bač fortress before the watchtower roof reconstruction

The tower has almost a square base (10,26 x 10,16 m) and is oriented with diagonals to the sides of the world with a spiral staircase in the northwest facade and a potable water riser on the northeast facade. The tower has a height of 34.33 m, and it has a ground floor (basement), three floors and an attic overhanged on cantilevers (Fig. 3).

The watchtower has been repaired and reconstructed on several occasions in its history, but due to lack of maintenance, its decay has occurred. The biggest damages occurred after the fire in 1993. (Fig. 4).

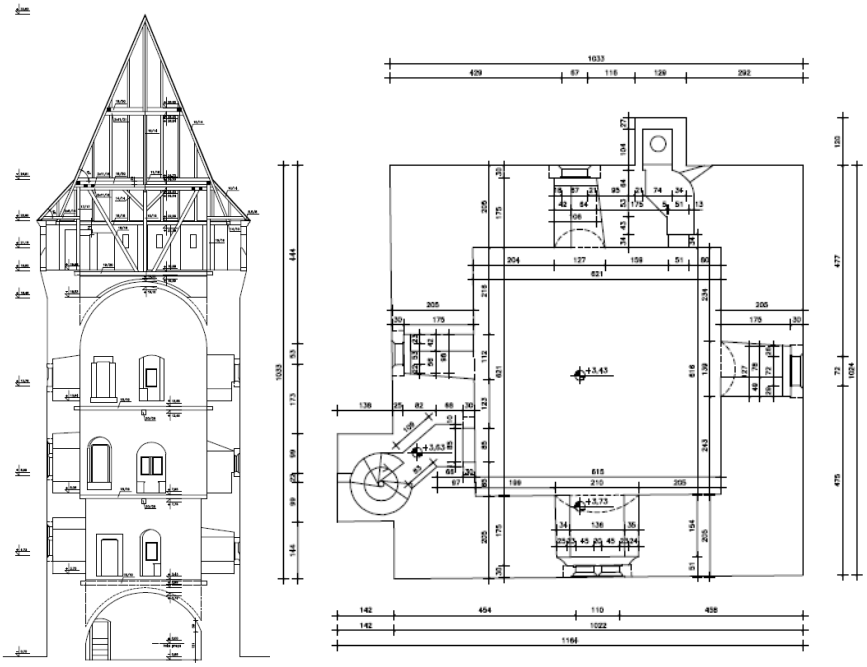


**Fig. 3.** Structural plan and the cross-section of the watchtower



**Fig. 4.** Fire damaged timber floor joists and damages the roof structure

Reconstruction of the tower, and above all the roof, was done so that the damaged roof structure was completely replaced by the new one. The old roof shape was kept, but new members to the roof structure were added to increase its stability. Furthermore, the dimensions of almost all the members were increased, and their surface treatment was carried out by sealing, as it was undoubtedly done more than six centuries ago, when the tower was built (Fig. 5). All visible connections of timber members were constructed with wrought iron, which contributed to the authentic appeal of the structure. The roof is covered with old yellow tiles, which were previously protected. With the roof reconstruction, an attractive area with visible roof is provided in the attic, suitable for exhibitions and observation of the surrounding flat Bačka landscape.



**Fig. 5.** Final works on roof reconstruction

**2. Reconstruction of the bridge over the river Mileševka near Mileševa monastery**

In the immediate surroundings of monastery complex Mileševo, beside the monastery water mill, there was once an old timber bridge. The exact time of its construction is unknown, but according to some historical data it is assumed that it was constructed in the middle of the 19th century. This bridge was destroyed after enormous floods which struck the Monastery and its surroundings at the end of 19th century[1].

The design of the bridge reconstruction had to be prepared in a way that completely corresponded to the existing written and drawn historical data and adequate preservation conditions. Since a reconstruction of an unique historical engineering structure was in question the design was based both on knowledge on bridge construction at the end of 19th century and even earlier in this region and on authentic data on stone block paving on the

part belonging to the bridge and on the right hand abutment which represented the remainder of the destroyed bridge.

Documentation for design preparation were: an old photograph of the bridge (Fig. 6), graphic layouts, plans and cross sections and the river Mileševka regulation.

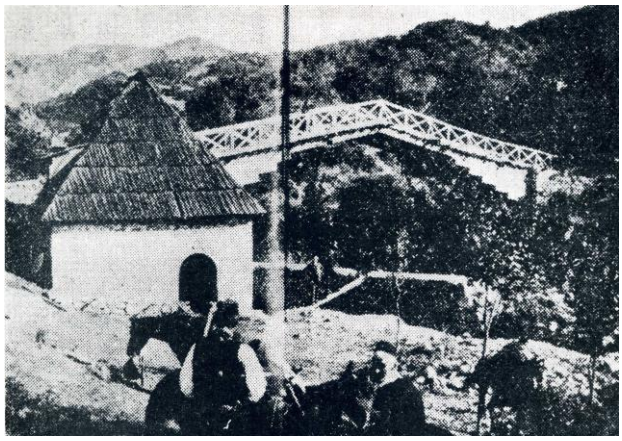


**Fig. 6.** Old photograph of the water mill and the former bridge

Until completion of the new bridge construction, a provisory two-span structure was used (Fig. 7). The larger span (10.4 m long) was bridged by a steel structure – frame of a freight vehicle, while the shorter span (5.5 m long) was bridged by timber beams. Sheet timber beams and boards existed partially over these load-bearing elements. The river pier was a concrete block with dimensions 3x3x4 m.



**Fig. 7.** Provisory structure used for crossing the river before the new bridge construction

It was known that the structure of the old bridge, which was destroyed by flood flow at the end of 19th century, was a timber one, supported by massive abutments built with ashlar. Only the right-hand abutment remained until today and it gives certain data on the way that destroyed timber structure was supported. The left-hand abutment was probably destroyed together with the bridge itself. By analysing the existing data - old photographs and surveyed situation, the left-hand abutment was fixed and thus the bridge span size of 17.6 m was defined. The adopted size of the bridge span fits favourably into the transverse profile of the river Mileševka at the bridging site.

The size of the bridge span and authentic historical data point out that the bridge superstructure was an unusually shaped structure. During the late medieval times, and even earlier, a specific system of timber structures characterised by "composite beam" girders was often used in the bridge construction. These girders with several simple cross sections are placed one above other, and overhang toward the middle of the bridged profile. Since the authentic data indicated that the destroyed bridge by the mill had such "composition", same as in case of destroyed bridges in Polimlje (over the river Seljanšica and over the

river Lim), there was no doubt while selecting the "system" of the timber bridge – timber structure with main girders consisting of several simple cross sections (six beams one on top of another) with girders in which certain beams gradually overhang toward the centre of the river (Fig. 8). Taking the useful width of the bridge into consideration three main girders spaced at 1.17 m were adopted.

Since the bridge is intended exclusively for pedestrians, useful width of the bridge 2.3 m was adopted.



**Fig. 8**. Bridge in erection stage

Other details – pavement, bridge guard rail and the shape of the levels are identical to the existing autochthonous historical data.

The main girders were fixed to the abutment using steel anchors and concrete blocks.

Newly designed elements of the abutments were built using old ashlar from the existing – old bank protection wall downstream from the mill.

The main girders, as already stated, were designed as composite beams consisting of six cross sections in system of fixed beam with a hinge in the mid-spam. Some of the beams are coupled by timber dowels (by transverse joints and screws) – Fig. 9 and 10.



**Fig. 9**. Completed bridge from the downstream side



**Fig. 10**. Completed bridge from the upstream side

Irregular, that is, ununiform arrangement of dowels along the girder resulted from the insight into the old photographs of the destroyed bridge.

The pavement surface was made from timber boards, and a special system for rain dewatering was not planned considering the relatively small length of the bridge and considerable slope of the levels. Three stone steps were made on both approaches to the bridge (Fig. 10) in order to prevent access of vehicles onto the bridge.

## 3. Reconstruction of the roof structure of the Carmel monastery church in Sombor

### 3.1. Structure and roof description before reconstruction

The Church of the Carmel Monastery in the centre of Sombor is also known as the Church with Two Towers (Fig. 11). Construction of the church began in 1860 and was completed in 1904. Its base dimensions are 58x25 m, where in structural terms the church is a masonry structure with a timber roof structure[1].



**Fig. 11.** Carmel monastery church

In addition to large outside walls, which are almost 2 m thick, the masonry structure of the building consists of two rows of middle columns with cross sections of approximately 160x160 cm, which are longitudinally positioned in relation to the structure at axial distances of approximately 7.6 m.

Above the described masonry structure, a timber roof structure was constructed. It is a very complex structure which is a combination of queen post roof truss and a roof with a hanger in the middle of the span (Fig. 12).

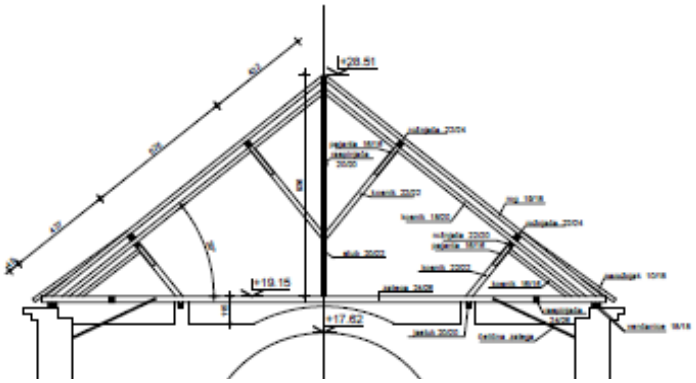


**Fig. 12.** Main roof structure before repair

### 3.2. Visually-macroscopic examination results

Visually-macroscopic examination of the roof structure revealed significant damages to the roof cladding (crown tile), as well as the battens over which it was placed (Fig. 13).



**Fig. 13.** Snow drifts on the roof structure as a consequence of roof cladding and battens damages

In addition to the roof cladding damages, the examination revealed following damages to the roof structure:

- rot, which is present in many places (Fig. 14a);
- a wormhole, in a very large number of timber elements (Fig. 14b);
- loosening of some connections (Fig.15a and 15b);
- deformations (deflections) of structural elements, (Fig. 15c);
- cracks in timber (Fig. 16a);
- fractures of a certain number of timber elements (Fig. 16b).

a) b)



**Fig. 14.** Details of rot (a) and wormholes (b) in timber elements

a) b) c)



**Fig. 15.** Two cases of damages - loosening of connections of structural elements (Figures a) and b)) and very pronounced deflection of purlin (Fig. c))

a) b)



**Fig. 16.** Crack in the horizontal beam (a) and element fracture between trusses (b)

### 3.3. Condition of the structure analysis and proposed repair interventions

Based on the findings related to condition of the roof structure in question and their analysis, it was concluded that this structure requires very radical repair interventions immediately.

Considering all the problems observed in the existing roof structure, two solutions were considered: the first meant repair of the existing structure, while the second meant that, instead of the repair, a completely new, modern glulam roof structure be made. After considering in detail all the advantages and disadvantages of both, the second solution was adopted, which, among other things, guarantees the functionality, serviceability and durability of the structure over a period of time that could be measured in hundreds of years.

### 3.4. Design and construction of the new roof structure

When the new glulam roof structure was designed, shape of the existing roof structure was considered, that is, the inclination of the main roof planes, its elevations and the roof design itself (Fig. 17, 18 and 19).

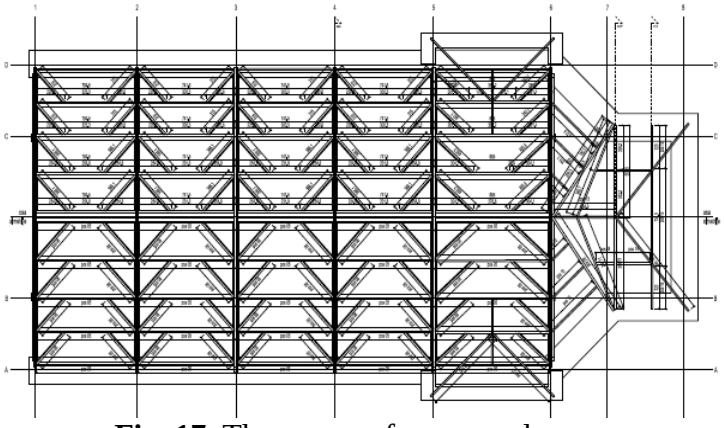


**Fig. 17.** The new roof structure layout

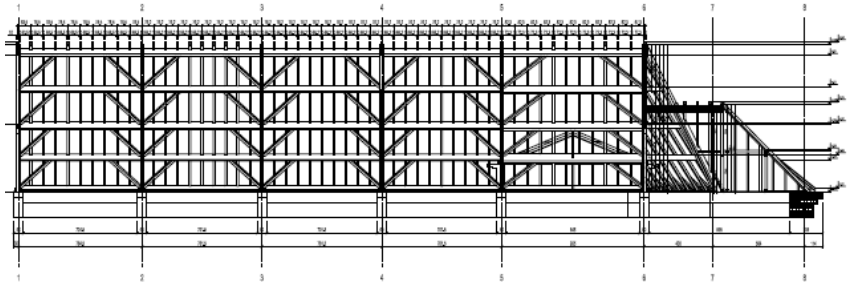


**Fig. 18.** Longitudinal section of the new roof structure

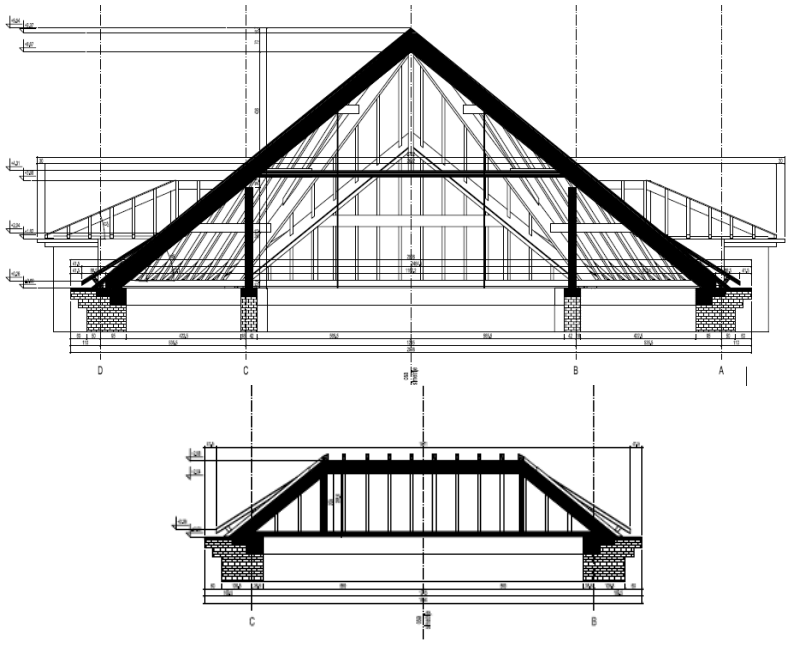


**Fig**. **19**. Cross sections of the new roof structure

Positions of the new roof structure supports were conditioned by the existing walls, whereby it was intended that reinforced concrete ring beams be constructed over the upper surfaces of the walls - along the entire length of the walls.

The roof structure shown in Fig. 17, 18 and 19 is designed as a system of primary main trusses connected by secondary beams - purlins with corresponding diagonal braces, over which tertiary beams - rafters are placed.

All connections between timber elements within the truss were constructed using suitable steel elements.

Some characteristic details of roof construction are shown in the following photos.

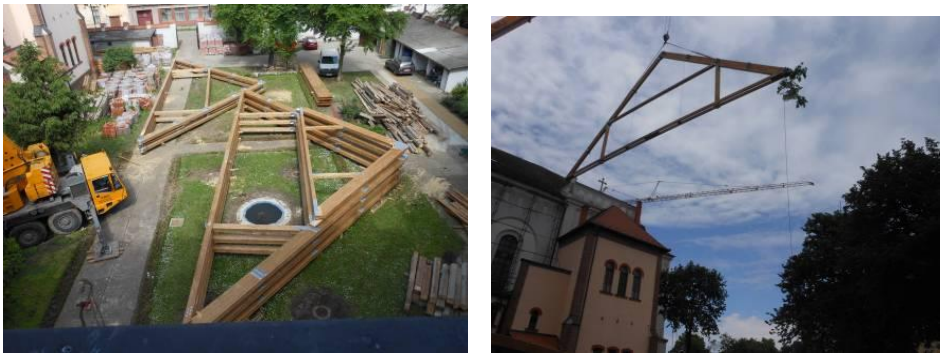


**Fig. 20.** Main roof trusses construction

a) b)



**Fig. 21.** Part of the completed roof structure from the inside



**Fig. 22.** Works on the roof part above the church alter



**Fig. 23.** View of finishing works and completed roof

## REFERENCES

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