ACCIDENT WITH TIMBER COLONNADE OF THE 200 YEARS OLD CHURCH AND METHODS FOR THE STRENGTHENING

Petar Grekov [1], Anton Gorolomov [2] , Doncho Partov [3], Bohumil Straka [4] , and Radoslav Nikolov [5]

University of Structural Engineering and Architecture, VSU “L. Karavelov”, Sofia, University of Technology in Brno, Czech Republic,

***Abstract**: The article describes an accident in colonnade of the 200 years old church,“Sv. Uspenie Bogorodichno” in Kyustendil. The article has investigated several interesting approaches to amplify damaged wooden columns in historical structures in China, Azarbaijan, Iran, Spain and USA. The decision was made to temporarily reinforce the whole structure of the church during its renovation and the method of strengthening the damaged wooden columns in the church was propose.*

***Key words**: wooden structures, damaged wooden columns, mechanical joints*

1. Introduction –

About the history of the erection of the church building we can say that the church was built in 1816, and is made of stone walls and a wooden roof structure. It is built according to the traditions of the Revival Age in Bulgaria and consists of walls with stone masonry, wooden floor constructions for emporium, wooden beams and columns. The outside walls are made of brick stone with a thickness of 60-70 cm. On both sides and outside, these walls are plastered with mortar. The building of the church is on one floor with height to the emporite-3.30m, height to the roof of the church with H-2.40m, with double sided roof, made with wooden constructions and roofing: boarding, waterproofing and tiles and three drum wooden dome (Fig.1a, b). The entire roof structure of the temple is wooden. Inside the church are two rows of wooden columns (6 in the main space-naos). On the columns, at the level of the floor beam designed for the emporium are located longitudinal beams embodying, respectively, the weight of the amporium and the weights of the respective parts of the roof structure. The building of the church is executed from the outside with powerful stone walls, the upper end of which reaches the level: 3,30m. In the interior of the church there are 12 main wooden columns in the longitudinal and transverse direction, which reach the level of the floor structure on the first floor of the church (the emporium).

[1] Petar Grekov,Assoc.Prof., PhD, USEA, “L.Karavelov”, e-mail: petar_grekov@abv.bg
[2]Anton Gorolomov,Assist.Prof., USEA, “L.Karavelov”, e-mail: tonyngor@gmail.com
[3] Doncho Partov, Prof.,PhD, USEA, L.Karavelov, e-mail: partov@vsu.bg
[4]Bohumil Sraka, Assoc.Prof., PhD, TU, Brno. Czech Republic, e-mail:straka@bohumil.eu)
[5] Radoslav Nikolov, MSc, USEA, “L.Karavelov”, e-mail: radoslav.nikolov91@gmail.com

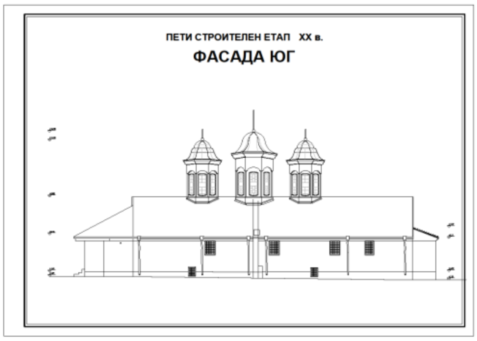


Fig.1a, b. Facade "South" and a general view on the southern façade of the building of the church

According to the plan, the church is a dyed single-pseudo-three-nave pseudo-basilica with a wooden roof structure and geometric plan dimensions: 23,60m x 14,40m (Fig.2.a.b).

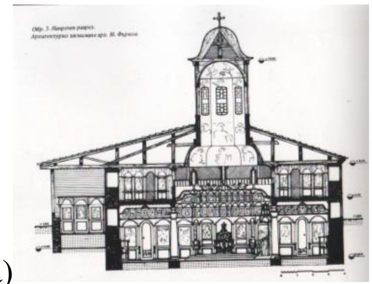
2a)  2b) 

Fig. 2a, b. Crossed architectural section of the church and look at the naos of the church

In the longitudinal direction, the columns are axially spaced through: 3,70 +2,40 +290 +2,70 +2,60 + 3,03m. In the transverse direction, the columns located on the axes of the building B and B are at a distance of one another axially through 6,230m. From the longitudinal stone walls these columns are symmetrically located at 3,510 m distances. Thus the total transverse light of the church is 15,280m. In the longitudinal direction, the first row of columns is located from the stone wall, which is after the narthex at a distance of 1,800m. The last row of columns is located from the stone wall of the altar at a distance of 2,400-2,600m. Thus, the total length of the light church of the two stone walls is 24,600m(Fig.2b). The wooden pillars of the church are dressed in a special casing, covered on top with a lime - cement plaster. The columns are supported at the bottom, on stone steps whose depth of foundation at this stage of project development has not been established (Fig. 4a, b, c). At the upper end, the columns in the longitudinal direction are connected with decorated curvilinear parts, over which a longitudinal belt extending continuously along the whole length of the church is developed (Figures 3a, b, c).

3a)  3b)  4c) 

Fig. 3a, b, c. View on the inside of the church and in particular on the lower and upper end of the wooden columns

At the top, the columns before being connected to the vaults are decorated with special ornaments, which are in good condition (fig.3c). The coating of a part of the wooden columns taking the loads from the roof structure on 15.06.2015 is severely cracked during the night, which indicates a degraded load bearing capacity which imposes their emergency reinforcement with a metallic scaffold mounted between the columns (Fig. a, b). On the day of 16 June 2015, a partial temporary reinforcement of the church's support structure was carried out, covering certain areas under the longitudinal wooden beams above the wooden columns, with metal stands from the Ninebeck scaffold (Figures 4a, b, c).

4a)  4b)  4c) 

Fig. 4a, b, c. Replacing in certain places the longitudinal wooden beams located above the wooden columns with metal stands from the Huenebeck scaffolding on the A axis.

The observation carried out on the damaged and cracked cover on the columns and its detection in several places made it possible to describe the following facts. The wooden columns have a circular cross-section with a diameter of 46cm. Their support is done on stone base that protrude above the floor of marble slabs at a height of about 50cm. The revealed wooden columns show an interesting composite wooden-steel structure, made of timber, on which steel rings are attached (Fig.5a, b, c).

a)  b)  c) 

Fig. 5a, b, c. Cracked outer cover of the column in the church shot at16.06.2015 at 18.30 hours. The ties are arranged side by side, on which about 40 cm are placed steel rings with a height of 40 mm and a thickness of 2.0 mm. The rings are attached to the wooden column with ordinary iron nails

2. Brief literature review - survey of examples concerning strengtening of the timber pillars in the historic structures

2.1 Example 1: Investigation about the decay of the timber structure of an ancient wine cellar in la rioja (spain) and sanitation proposal[1]

In 2011 the collapse of one of the timber pillars of the centuries-old warehouse of maceration that the firm "Bodegas Bilbaínas, S. A.", helds in the town of Haro (La Rioja), occurred[1]. According to the level of decay, the assessment of the damage in the different elements of the timber frame through non-destructive testing is analyzed. Based on the results obtained, it is proposed the repair process necessary to preserve the timber structure, taking into account the heritage significance and the extension of the *harm* of their components. The company is the owner of many modern pavilions for winemaking and other auxiliary buildings. Specifically, these primitives maceration and fermentation naves, which still keep the ancient *wooden vats built in 1859 (Fig. 6 and 7).*

Fig. 6 Vats

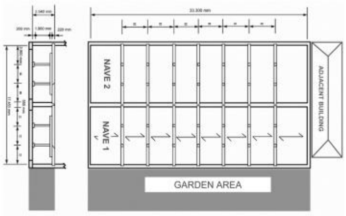
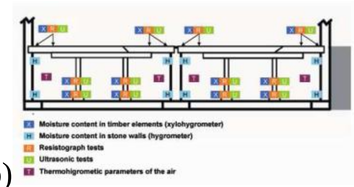


Fig.7. Cellar floor timber structure and cross section respectively

The structure of the nave consists of load bearing stone walls in the perimeter of the building, with thickness 60 cm. The inside masonry walls divides the cellar into two areas of nearly identical inner dimensions: 33.30 m long and 8.70 m wide. The pillars, spaced at regular distances of 2.90 m from each other and the side walls, with approximate section 220x220 mm and height 1.90 m, lead from stone bases of 200 mm on edge. On the other hand, indicate that each portico has a large girder or spreader beam of 200x200 mm section that bridges the joint, and connect the heads of the pillars, allowing a perfect load distribution. The cellar floor and its structure is shown in Fig. 7. The moisture content in all the pillars looked to be certainly high, especially in the lower part of the support, in contact with the stone bases. In fact, in some cases fungi colonies were detected during the visual inspections (Fig. 8a). *By contrast, no singularities or defects such as cracks, knots, ring shakes, or deviations of fiber, which jeopardize the stability of the parts, were observed.* Moreover, as discussed above, to a height of only 1.90 m, sections close to the 220x220 mm, the associated mechanical slenderness round the value of λ= 32.90, so it can be said that the security against buckling, for all the timber pillars in the same condition, is fully guaranteed.

a)  b) 

c) 

Fig. 8a. Fungal decay **Fig. 8b.** Testing program **Fig. 8c**. Resistographic test

However, evidences of significant moisture content in both the factories and in the timber components were detected. Furthermore, during the previous inspection, high humidity content in the indoor air was detected. According to the information gathered, the action plan and the tests to be performed on each portico and on the load bearing walls were defined as follows (Fig. 8b): The water content of the pillars should be assessed by xilohigrometers, placed in two different positions; Next to the stone bases, and 50 cm above it. In the same points, the resistograph and the ultrasonic unit should be also applied, in order to analyze the level of damage of the timber elements. From the data collected along the inspections, and the results of tests on structural timber elements some conclusion was made: The material used for the bases is too porous, and favours the rise of water from the ground to the pillars. Through the analysis of the pillar affected by termites, it could be known that it consists of *common elm* (Ulmus minor). The square ends of the pillars and beams that rest on the south wall are seriously affected by moisture, despite of the natural resistance to degradation of the common elm. Along the time, the water contained in the ground rose by capillarity. And later, when the moisture took contact with the wood, favoured the termite attack, causing it to collapse. Fig. 8c shows the resistograph device applied to a timber pillar. Fig. 9 shows a resistographic profile taken from the square head of a beam very close to the Southern wall As it can be seen, both graphics are completely different. The first one allows to appreciate the important decay because of the probably termite attack, while the other one keeps almost in perfect condition. The constant supply of water from the garden area, leads that the indoor surrounding air keeps a state close to saturation, with a relative humidity around 90%. In other words, that the condensation on the stone components is constant.

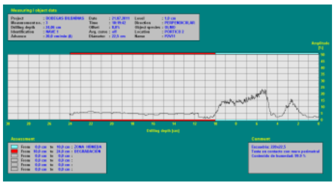


Fig. 9. Resistographic test and profile (beam on Southern wall).

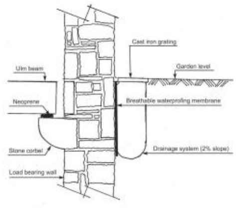


Fig. 10. Proposed solution

According to these problems, a group of correcting measures were suggested, in order to improve the current situation, and prolong the life of the building, preventing its demolition and subsequent reconstruction in reinforced concrete. In this sense, garden, is proposed to remove the ground to a depth of 1.0 m, and build there an open drain with minimum slope 0.5% (Fig.10). This solution should collect the rainwater, and at the same time should allow the evaporation of the humidity contained both in the wall and in the timber elements. For the pillars, since up to a height of 20-30 cm, counted from the level of the base, all of them present an excessive moisture content, there are suggested three possible actions: removal of existing supports and their bases, and supply new ones, with the treatment and moisture content suitable for the type of exposure; or remove the bases, cut the pillars at a height of 40 cm, replacing the degraded part by a wooden prosthesis glued by adhesive; and also remove the bases, cut the pillars to a height of 40 cm, and place new non-porous stone bases, 40 cm high, waterproofed in support. Finally, the timber structure should be protected with biocides. The treatment method may be by injection, to limit the area of action and not affect the vats. Along the surrounding area, a baiting system against termites should be placed. These measures will be achieved to preserve the original timber elements of the building, ensuring its stability and security for a long time. In addition, these classic solutions have been used for centuries in strengthening structures, so that at no time will be lost the entity and the traditional style of the cellar.

2.2. Example 2: The conservation and renovation of the timber constructions in the palace museum[2]

The Palace Museum, which was constructed in the 18th year (1420) of the reign of the Yingle emperor, is the largest and the most complete ancient palace complex existent in China as well as in the world. It has manifested traditional Chinese construction technology and **revealed** a remarkable achievement in art. By illustrating the main types of the ancient timber constructions and representing the construction features, the following text provides some useful references for the conservation and renovation of the northern palace-style buildings that were constructed during the Ming and Qing Dynasties[2]. As concerning the basic structural type of timber construction: Architectural types of the Palace Museum are varied, while the main type is bond to the shape of roof. On the basis of the building's sections, the Palace Museum buildings can be divided into four types: Diantang style, Tingtang style, Column-beam style and Composite style.

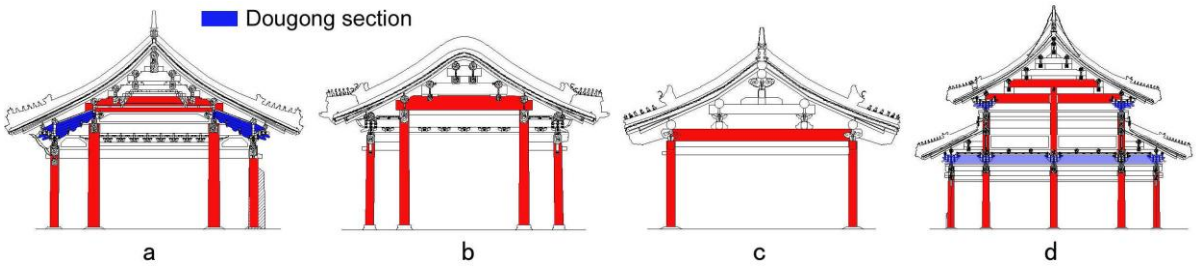


Fig. 11a,b.c,d. Sections of four kinds of structural types

In the Palace Museum, all members of the timber structures are jointed by mortise and tenon(Fig.12,13,14,15). The gaps between the mortise and tenon leave room for movement of the timber members. Under external forces, the joints connected by timber members mobilize friction on the contact surfaces of the mortise and tenon. This friction guarantees the stability of the mortise and tenon joints. Several mortise and tenon typologies can be applied to connect the timber members. Important forms used in the Palace Museum are as follows: pin tenon, dovetail tenon, corner tenon, straight tenon and half tenon. The pin tenon is used to make the column base, and it restrains the column from transversal displacements. In some large-scale constructions, the column is stable due to its thickness and the effect of the walls. The column base and column top are formed to be flat and the pin tenon is omitted, so as to make the construction less complicated.

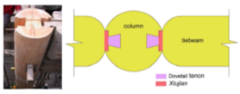
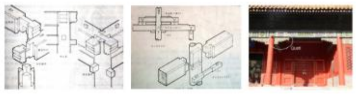
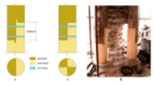
12)  13,14,15)  16) 

Fig.12 ,13,14,15 and 16. Dovetail tenon and Xiujian, Conner tenon, Half tenon – Queti, Two kinds of Dunjie methods

As concverning the renovation of the timber constructions for timber structural constructions, daily maintenance and renovation are necessary. The common methods including mending, matching, reinforcing, replacing, etc. These methods are applied according to each particular situation. The following specific cases of the renovation and protection of ancient buildings in the Palace Museum will be discussed in detail. According to the result of on-the-spot investigation, many of the wooden columns are rotted only on their bases; and the upper parts are intact. In such circumstance, should preserve the upper part of the column and repair the bases partially, usually by using Veneering method or by Dunjie, thus replacing the column's base, according to the extent of its decay, thus restoring the columns' bearing capacity. *Veneering method*: Generally speaking, the veneering method is used when the degradation happens only on the surface of column bases, while the core is intact and the depth of surface degradation is less than 1/5 of the diameter of the cross-section of the column. To veneer the base of the column, the Japanese chisel is used to cut off the decayed parts, and then the veneering timber is built according to the shape and size being cut off. *The veneering woods should be the same sort of old dried timber as the original column*, and the moisture content should meet the requirements (≤ 25 %). If the base of the column is only partially decayed, the veneering timber is used to replace just the missing parts. If the decay circles the column, the veneering timber is used to wrap the surface, with the same diameter of the column, and then reinforce the veneering wood with one to two strips of iron hoop, to ensure the balance of loading force on both original and new timbers. Both of the situations mentioned above should guarantee the smooth and fully roundness of the column after veneering. *Dunjie method:*When the area of decay is larger than 1/2 of the cross-section, or if the centre of the column is rotten, and the decay of column-out-of-wall is less than 1/5 of the total height, and the decay of column-in wall is less than 1/4 of the total height, the Dunjie method will be used: the column's base will be replaced to recover the bearing capacity of the column. For example the Juanqin Zhai project, the column is embedded in the wall, which was dismantled to carry out the operation. Before the Dunjie operation, the weight was taken off the column, with support posts being placed beside the column, in order to bear the force from the top. Before the operation of Dunjie, supports on the second floor were set between the floor and the floor beam. Then the decay of column-in-rear-wall was examined, the decayed parts were sawn off (sawing action would be stopped rightly when any sound timber was found. The height of Dunjie parts was also controlled, because the higher the Dunjie, the weaker would be the column after the operation. The height of Dunjie should be less than 1/4 of the height of the column. The Dunjie timber requires the same sort of old dried timbers as the original columns'. Thus it is necessary to make sure the moisture content meets the requirement (≤ 25 %). The most common operation of Dunjie are "half tenon Dunjie" and "cross tenon Dunjie". "Half tenon Dunjie" (Fig. 16-a) is to cut off half of the diameter of the timber as the overlap parts, and the lapping length should be 1.5 times to the diameter of the column, but not less than 400 mm. Then making tenons on the top of the timbers, each 20-30 mm wide. "Cross tenon Dunjie" (Fig. 16-b) is to cut the original column and the Dunjie timber separately in 4 parts, then cut off diagonally 2 parts and to insert them. Both of the methods of Dunjie require tightness of fit in the joining points. After Dunjie, the joining parts should be bound with two to three strips of iron hoops. The hoops should be embedded into the column, making the surface of column smooth and round, thus to ensure the firmness and stability of the joining points, and to prevent movements in the joining area.

2.3. Example 3:-wood assessment and historical research on timber testing at fort Aams, Newport, Rhode island in USA[3]

Fort Adams, located in Newport, Rhode Island, USA, designed by French military engineer Simon Bernard and American military engineer Joseph G. Totten, was constructed from 1824 - 1857. Construction was overseen by Totten from 1824 through 1838. Built of stone, brick, and timber, the fort served as a testing laboratory for determining the strength of various types of stone, mortar, and timber species. An investigation was undertaken to assess the current conditions of the timber and investigate the historical significance of the testing programs developed by Totten. The following text focuses on three aspects of the project: (1) The timber testing program and its implications for construction of the fort and subsequent timber testing in the U.S. (2) using non-destructive testing to identify causes and patterns of deterioration, and recommending actions to extend the service life of the historic timbers. (3) Correlating the findings of the condition assessment with the published results of Totten's experiments. Using *Field Procedures and Findings and method of the Species identification:* Wood species were identified from various structural members by removing small samples from which the species or species group was identified using microscopic features of the wood. All of the samples removed from structural members within the fort were identified as southern yellow pine (*Pinus spp*.). As concerns moisture content measurements identify wood with favorable moisture levels for the growth of wood-decay fungi. Generally, if moisture content is less than 20 percent wood-decay fungi are unable to grow. Moisture contents from 20 to 30 percent indicate areas of concern where moisture is sufficient for fungi to grow but not sufficient to support long-term active decay. Moisture contents above 30 percent are often an indication of advanced decay with internal voids and/or surface deterioration. Moisture content measurements were taken randomly throughout the fort with an electronic resistance-type moisture meter. Evidence of moisture damage of the wood and efflorescence of the masonry is prevalent in almost every casemate, indicating high moisture contents within the masonry and the wood (Fig.17). Moisture contents were typically greater than 30 percent, indicating that the wood has a favorable moisture environment for active wood decay. However, the fort's close proximity to the Atlantic Ocean and the presence of efflorescence on the masonry and wood, as well as the presence of "fuzzy" wood (Fig. 18), indicates the presence of salt in the wood, which can dramatically influence moisture content readings taken with an electronic meter. Archival research has also revealed that the engineers at Fort Adams were negotiating with the holders of the U.S. rights to John Kyan's process of treating timber against decay with a "corrosive sublimate" material that likely contained mercury salts, which, if used, would also have an influence on the moisture content readings. Additional testing of material samples, such as chemical analyses and oven-drying samples to attain true moisture content readings will be required to confirm whether the timbers were treated and what effect the treatment had and may continue to have on the performance of the timbers.

17)  ***18)*** 

Fig. 17 and 18. Moisture stains, efflorescence on joists within a corner casemate and arch;

Fig. 18. Fuzzy (PUH,MAH,ZACAPAN,NEYASEN) wood on a timber joist along the west wall

2.3.1. Visual inspection, probing, and decay quantification

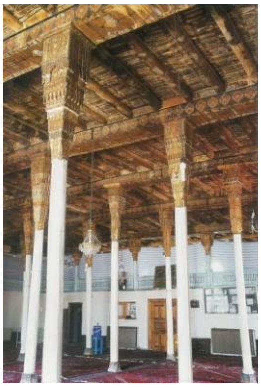
Visual inspection, used in combination with probing the wood with an awl, allows for the rapid identification of missing or broken elements as well as voids, incipient decay, and advanced decay present near the surface of the wood. For the quantification of internal deterioration, resistance drilling must be used. Resistance drilling, a quasi-nondestructive technique, is used to identify and quantify internal voids and decay by determining the relative density profile of the wood. At the fort, a combination of visual inspection, probing, and resistance drilling was used to identify and quantify deterioration in the structural timbers. Wood conditions found within the fort were divided into three classifications: good, fair, and poor. Good condition describes wood that may exhibit moisture staining and/or efflorescence but is not structurally impacted and has no evidence of insect damage or deterioration from wood decay fungi. Wood in fair condition may have minor insect damage and may also exhibit evidence of past moisture damage, including minor deterioration from wood decay fungi. Wood in poor condition may have severe visible insect damage and may also exhibit ongoing deterioration caused by wood decay fungi. In general, most of the structural members within the fort were found to be in fair to good condition along their lengths; areas of poor condition tend to be limited to the bearing areas. In a few instances, the structural members are in extremely poor condition and have failed due to deterioration caused by wood decay fungi (Fig. 19). Some of the posts are "brooming" at the base due to a combination of high moisture content and deterioration by wood decay fungi (Fig. 20).

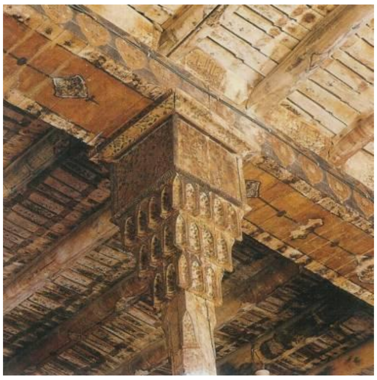
Fig. 19: Deteriorated girder and joists within a casemate.

Figure 20**: Brooming** at the base of a column.

2.4. Example 4: Mosques with wooden construction – south of East Aazerbaijan province, functions and methods of conserving[4]

Wooden mosques of the south region of Azerbaijan have specific characteristics and being built in different towns such as Maraghe, Bonab, Ajab- Shir, and Qoravan village[4]. The local materials are wood, stone, brick, and adobe. Pillars and beams were made of poplar, species of willow, and aspen. Although wood was rare in the region and structure of the buildings were arch and dome, wooden construction became popular and common for the aesthetic characters and beginning of new style in Safavid period (17th Century). As is wel known, wooden pillars and columns were used in Shabestan and walls. All pillars play the role of the structure and the ornaments are the parts of the construction. Pillars were constructed in 3 parts: base, wooden body, and capital in different forms. The main beams, pillars, sub beams, all, were made of wood and joints had special characteristics which add to the resistance of the building. In this study Bonab Mehrabad mosque is highlighted(Fig. 21a,b,c).





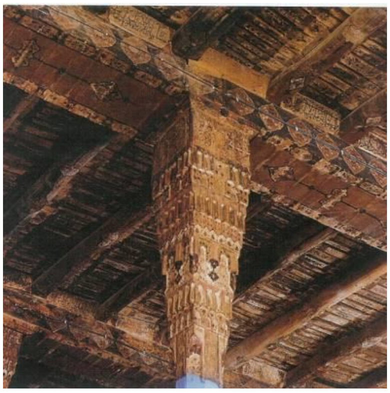


Fig.21a,b,c. Chamber(Shabestan) of Mehr- abad mosque; Sample of capitals in Mehr- abad mosque- Bonab

The wooden structures of Azeri architecture can be observed in the West of Iran like Maragheh, Bonab, Ajabsher, Gougan. As it was mentioned this style has been used in Isfahan at the time of ruling shah-abbas and it has been imitated in many glorious Safavids palaces.(Fig.21). The foundations of wooden mosques are located in the depth of 1.5 m and by the dimension of 1.70*1.50 cm. The only decoration of the walls is perforated mud brick works with keel shaped arches. Some of them also are made of stone with the height of 90 to 150 cm and the local Sinjan stones. *The columns and the level ceiling of the mosques are all made of wood.* The height and stem of trees, poplar (Tabrizi) and aspen trees used to cover the columns, ceiling, beams and the main beams. The main function of the wooden columns is structural and decorative. All the columns have three parts: column base, column body and capitals (Fig. 22a,b).

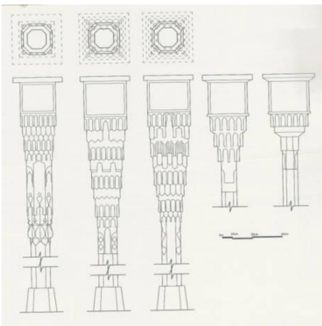
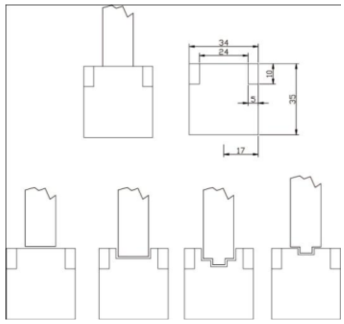
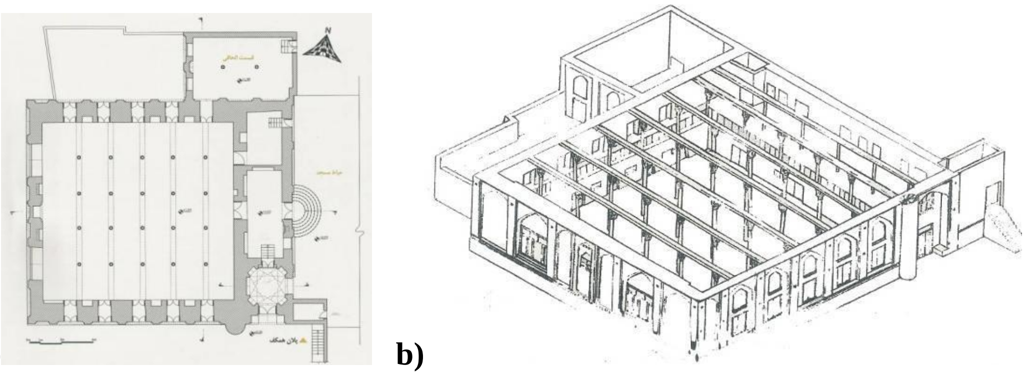
a)  *b)* 

Fig. 22a,b. a) Capitals of Mehr- abad Mosque- Bonab; b) The method of arranging pillars on stone

The column bases are all made of stone and in different mosques have different forms and thickness(Fig.22b). The form and shape of the column bases are circle, square, and hexagon, but the bases are generally square on the floor and the upper part is hexagon. The material of the mentioned column bases is all black and white sedimentary stones or engraved marbles. The bases have been located on foundations that their dimension is about 1.5*1.5 m and the estimated depth is 80-90 cm. Connection of the stone bases to the foundation: flat; mortise and tenon. The column is directly located on the stone and there is no connection or mortar between the bases. The load which is transferred from the column to the base keeps the column body firm on the base. The end part of the column body is located on the mortise of the stone base which is different in the mosques. This connection is called mortise and tenon. In this connection like the flat one, there is no connection and mortar; however, in rare cases there is a space between the connections which mostly has been considered for expansion and contraction. The last part could be located inside a special pad. As the height of the column increases, its volume increases too. In high caps, this combination or increasing the volume of the caps from down to the top is influential in dividing the load. The diversity in columns and column caps in addition to showing the ability of the carpenters, could create diversity and movement in the space. Generally the caps of the columns in the mosques are divided to five groups according to their stalactite works. The column caps with rectangle section or square with decorative arches are decorated in the form of a horn of the goat. Column caps with rectangular or square section with sharp arches such as Mehrabad and Kabood mosques in Bonab. Caps which have changed from rectangle to circle. As mentioned, most of the columns are lead to the cubic wooden box where the pad) of the column cap is located on it.

2.4.1. Example 4.1-about the Mehr-Abad Mosque in Bonab[4]

One of the mosques of the region with wooden columns is Mehr-abad mosque in Bonab which has been located in the eastern side of Motahhari St. Mehrabad is one of the old allies of Bonab and the mosque is called by the same name. A stone inscription clearly shows the date of construction and the builder of the mosque. Totally, there are four stone inscriptions in the northern walls of shabestan and eastern wall. The building date has been mentioned in two inscriptions. Considering the date, the mosque has been built in Safavid era (17 Century). The mosque has only one minaret that mostly it is built in Qajarid era. It is located in the eastern wall and the southern part of the entrance. It is decorated with small blue, azure, yellow, green tiles and geometrical designs. Mehrabad mosque is rectangular and it develops north-south that includes main parts such as shabestan with columns, terrace or women's part, porch, nave, howzkhane, and ablution place, etc. To enter the mosque, there are two porches that they are related to each other through the lane and yard of the mosque. The dimension of shabestan is 18.80 x 19.60 m. and it has 36 columns. Twenty of the columns are in the middle space and 16 of the half-columns are in women part and balconies. The columns of the middle part are located in four rows with five columns and all of them have caps with stalactite works. All the columns are wooden and hexagon with the height of 4.75 m. The bases are similar to the columns of the other mosques; made of stone and polygonal; however, the caps are different. they have different designs, colors and drawings. Generally, stalactite works include the deep and semi-deep arches and the volume of those works increases upwards(Fig.23a and Fig.23b).



a) **b)**

Fig. 23a,b. Ground floor plan Mehr- abad mosque; Perspective section Mehr- abad mosque - wooden structure

As concern the pathology of wooden structures in mehrabad mosque in Bonab, we can say that the main element of damage on the body and decoration of Mehrabad mosque is decay of the materials, overloading and humidity in the inner spaces. Overloading, decay of the materials and the foundation because the columns lose their stability, bend, and the stone bases are moved. To solve the problem, piling the columns, replacing the stone bases, and enforcing the foundation was carried out(Fig.24a,24b). Then the columns and the stone bases are returned to their former position. The other problems include the breakages in wooden parts of the column caps, and the boxes because of the pressure inserted through metal joints (nails) and lack of resistant against the inserted pressures. In this stage, by using the piling and raising the main beams, the caps are separated from their original place; so, some of them are repaired and some are renewed. The loose parts are restored and the metal joints are fixed. In the parts that wooden parts were decayed, these parts are changed and the caps are restored on their original place.

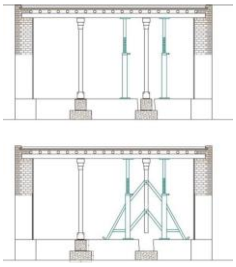


Fig. 24a: Collapsing the decayed foundation and restoration of the foundation

Fig. 24b: Restored foundation and stone base

2.5. Example 5: Development of an in situ repair strategy for the timber roof of the breeding barn at shelburne farms

Shelburne Farms quickly became one of the most ambitious model farm operations in the U.S.A(Fig.25a) The Breeding Barn at Shelburne Farms, a National Historic Landmark, is dominated by its complex-sloped 8094 m2 hipped roof with multiple dormers and an enormous central lantern. The timber-framed building has a main block that is approximately 32.6 m wide by 127.4 m long, with a two-story annex centered on the rear facade. The main interior feature is the riding ring, approximately 22 m wide and 114 m long, constructed for daily exercise of the horses. The roof system over the riding ring consists of a series of composite principal trusses of iron and timber, supporting a deck of timber purlins and common rafters. Trusses are supported on timber columns around the perimeter of the riding ring and bear most of the roof weigh(Fig.25b). Construction was begun in August of 1890 and by December 1891 the building was nearly complete. The barn, designed by architect Robert Henderson Robertson, was the center of Seward Webb's horse breeding operation, one of the largest in the country. **Strengthening of the wooden columns was done by cutting of the decayd part and substitute by with new wooden part(Fig.25c).**New column bases were placed on limestone plinths and white oak shims, elevating them above a concrete floor installed in the mid-20th century (left). In four cases, column splices were made at the aisle level, requiring renewal of girt joinery and replacement of the girts on either side (right))25d).

a)  b)  c)  d) 

Fig.25a. Fig.25b. Fig.25c Fig.25d

Conclusion

The proposal for a design-construction solution for the rehabilitation of wooden columns in the naos of the church Sv. Uspenie Bogorodicno", taking into account the high pressures in them, the disturbance of the wood structure at the lower end and the unfavorable humidity and temperature conditions for many years of work will be done in several option acoording the above mentioned examples. For our cases, however, the most commonly applied solutions are the dentures of columns with wooden dentures which reach 1-2 m height.

Acknowledgement

This paper was supported by the project: Past, Present and Future of Timber Structures in Buildings-Symbols, with great Culture and Historic Significant for our Country. "Granted from Ministry of Education in Bulgaria".

REFERENCE

[1] Luengas, L. M., Fernández, M. G., Fouz,D. L. and Ayúcar, J. B.; Investigation about the Decay of the Timber Structure of an Ancient Wine Cellar in La Rioja (Spain) and Sanitation Proposal, In Proceedings "Structural Health Assessment of Timber Structures", 2nd International Conference on Structural Health Assessment of Timber Structures (SHATIS'13), September 4-6, 2013, Trento, Italy,pp.977-982.

[2] Peng, Z., Hong, G. and Xiaoli, C.; The conservation and renovation of the timber constructions in the Palace Museum, In Proceedings "Structural Health Assessment of Timber Structures", 1st International Conference on Structural Health Assessment of Timber Structures (SHATIS'11), June, Lisbon, Portugal, pp.012-1-11.

[3] Dugan, K. D., Trelstad, D. and Anthony, R. W.; Wood assessment and historical research on timber testing at Fort Adams, Newport, Rhode Island in USA, In Proceedings "Structural Health Assessment of Timber Structures", 1st International Conference on Structural Health Assessment of Timber Structures (SHATIS'11), June, Lisbon, Portugal, pp.075-1-14.

[4] Kamali, F. P. and Omrani, B.; Mosques with wooden construction – South of East Azerbaijan Province, Functions and methods of conserving, In Proceedings "Structural Health Assessment of Timber Structures", 1st International Conference on Structural Health Assessment of Timber Structures (SHATIS'11), June, Lisbon, Portugal, pp.122-1-11.

[5] Porter, D. and Anthony, R. W.; Development of an *in situ* repair strategy for the timber roof of the Breeding Barn at Shelburne Farms, In Proceedings "Structural Health Assessment of Timber Structures", 1st International Conference on Structural Health Assessment of Timber Structures (SHATIS'11), June, Lisbon, Portugal, pp.134-1-13.