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TIMBER TIE BEAM REINFORCED MASONRY IN OTTOMAN BATHS

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ABSTRACT

In this study, some Ottoman baths in Turkey are examined where the support of timber tie beam in masonry construction has been detected, in places where a moderate and high seismic activity is present. The aim is to verify the contribution of these devices to the structural behavior of the buildings under seismic actions. The two case studies: Gazi Mihal Bath and İsmail Bey Bath, which are the Ottoman bath buildings, constructed in 15th century, abandoned and partially ruined were examined. The case study bath structures and the methodological approach were taken from the PhD thesis [1] in "Politecnico di Milano". The methodology for those study buildings was adapted to static collapse analysis of the timber tie reinforced masonry. The paper concludes with the interpretation of the behavior of the two masonry buildings according to the presence of timber tie beams.

Keywords: *Timber ties, Masonry baths, Collapse analysis*

1. INTRODUCTION

The objective of this paper was to understand the behavior of the timber tie-beam inserted in some historical masonry wall structures observed in areas of moderately high seismicity. Static collapse analysis of some case study structures were determined for realizing their behavior under the effect of the seismicity.

The research paper is divided into three main sections. In the introductory part, classification of timber tie beams and their deterioration problems are introduced. In the second part, the "rule of art" is recalled and described with the introduction of the method of kinematic analysis of the mechanism of collapse. In the last part, the case studies, İsmail Bey bath and Gazi Mihal Bey bath were examined according to the "rule of art" which guided to analyze the collapse effects under possible seismic actions and the effects of timber tie reinforcements on the structures. In this section, the earthquake behavior of timber tie-beam reinforced masonry construction is briefly discussed with respect to the methodology of collapse analysis. Their collapse mechanisms and the effect of the timber tie beams are examined from minor to major details.

1.1. Classification of timber tie beams and their deterioration problems

Traditional masonry walls were built up of different types of stones such as tuff, sand-stones, trachyte, granite, basalt, which are in the classification of sedimentary, metamorphic and magmatic stones.

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The type of stone, which was used for the construction was decided according to the stone mines that were close to the settlements. As well, the workmanship for constructing the masonry and the cultural stylistic background were the deterministic factors for the building design of the masonry walls [9].
For building the traditional Ottoman masonry walls there were some rules for constructing them. The minimum thickness of the wall were not less than 0,50 cm. Diatonic stones were used across the masonry and on the corners big stones had to be placed. The tie beams, which were made up of timber or brick materials, were used in certain lengths in the masonry [7].
Timber tie beams were another aspect for constructing traditional Ottoman masonry walls. In each 1,5 m length of the wall, timber ties had to be placed. Pine and cedar trees were used to produce timber tie beams for the masonry walls for extra durability for the external atmospheric conditions. The cross-section dimensions of those timber ties were from 8 cm × 8 cm to 10 cm × 10 cm. [9].
For some of the masonry walls which had non-uniform stone workmanship, timber tie beams were essential for keeping the wall structure stable. There are big differences in dimensions of the timber tie beams and the thickness of the wall. Therefore keeping the masonry wall structure stable, timber tie beams were used inside and outside of the masonry wall and attached together with perpendicular timber connections which were placed in a certain distances [6].
The usage of the timber tie beam construction technique inside of the masonry walls based on 2500 years of time. The main idea of this construction is keeping the stone materials stable and uniform under the vertical and horizontal forces. With the assistance of the timber tie beams, the slenderness and the height proportion of the masonry decreased as well the durability of the masonry were increased. The cracks on the masonry could not go further on the surfaces because of the effect of the tie beams. The main problems that faced for timber tie beams were the decay in the course of time. The decay effect of water on the timber materials continues with swelling and drying out the masonry material and caused sagging on the walls [2].
In Figs. 1, 2, 3 below, some traditional construction examples of timber tie beams and their connections techniques were shown [9].

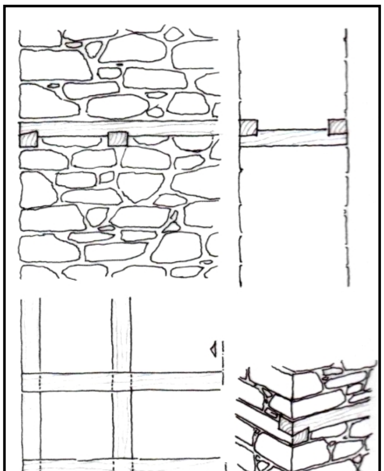


Fig. 1 Half tongue timber tie beam connection

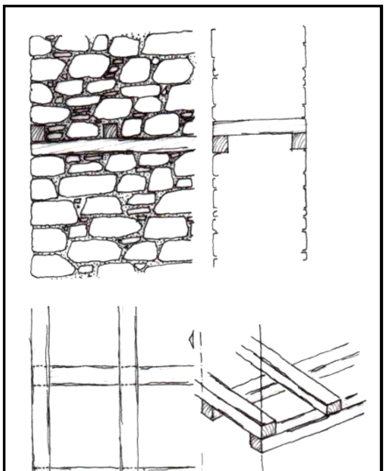


Fig. 2 Corbel timber tie beam connection

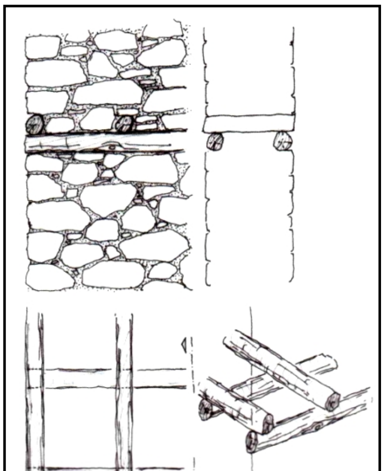


Fig. 3 Round sectional timber tie beam connection

2. THE “RULE OF ART”

The “rule of art” referred to masonry walls means also “art of building” which contains and brings together all the experiences that characterized the history of the building. The idea of this is; ensuring the building appears at the same time robust and secures the structure [3].

The mechanical qualities of the historical walls which forms the rule of art includes:
– presence or absence of elements such as cross connections of diatones;
– geometry, shape, type and size of the elements;
– horizontality of bed joints and offset of vertical joints;
– the quality and consistency of the mortar and the presence of wedges and chips;
– the characteristics of possible inner core and the homogeneity of materials.

Timber tie beams are the bases of the comparison and organization of the wall structures [3].

Naturally, stone masonry and their technical quality was primarily affected by stone base material that was locally available. This situation determines also deep differences in mechanical properties. "The rule of art" differs from type to type of stones depending on availability of square blocks of hewn stones in masonry walls. In more important buildings, the masonry walls are made up of perfectly squared stones, which are very close to the ideal of the perfectness. Mortar only performs the function of regularizing the contacts between the stones. When the mortar becomes powdery, it is not the fundamental behavior of the masonry [3].

The rule of art in stone masonry lasted more or less until the beginning of last century. According to this rule the stone rows must be horizontal. The top and the bottom of the walls must be sufficiently flat. In the bed joints of the stones they use lime mortar, in larger cavities they use chips of stone or brick. Particularly decisive for the resistance to outside plane action is the presence of diatones and timber tie beams which connected the two leaves of the masonry. The vertical joints are staggered appropriately [3].

The effectiveness against the actions of stone masonry structures is reflected both in static and dynamic conditions. In the first case, the effect of the applied loads is stabilizing masonry wall ; in the second case, the masonry wall rotates according to the horizontal axes of the applied loads. The intensity of the seismic activity and constraints of the structure prevents tipping of the walls and allow returning to the initial conditions of the structure. In absence of horizontal layers, it is impossible to form the axes of rotation, and the recurrence of oscillations disintegrate the masonry wall in chaotic manner [3].

Also masonry stone walls constructed with small elements demonstrated excellent mechanical characteristics. The tensile strength of the mortar allows certain limits. The mortar is good for distributing the loads in a continuous elastic form. But if the masonry construction is mostly standing with the support of physical, chemical and mechanical properties of the mortar, the behavior of masonry wall cannot attain the reliability of the masonry wall structure. In this type of masonry structure, the inner leaf inside of the wall is filled with disorderly pebbles without following the rules of masonry construction. If the mortar is not effective this type of masonry structure can collapse under the seismic activity [3].

Various masonry structures were detected in Marmara Sea region and their collapse analysis were done with reference to the "rule of art" under the three main actions.

2.1. Qualitative response of masonry under external actions

A brief characterization of the behavior of the masonry walls is dependent on three main actions [3], that can be summarized as:
a) Vertical loads,
b) Horizontal loads, out of plane action,
c) Horizontal loads, in plane action.

2.1.1. Vertical loads

A wall submitted to vertical loads could have break up for two main reasons: lateral instability or compression failure. Breakup happens by compression, if the resistant element is weak, at least for the ordinary loads of the traditional buildings, or the masonry is strongly degraded, for instance because masonry was subjected to weathering or to moisture conditions. If one of these two conditions is verified, then the quality parameter of the masonry is set to "not respected". It comes directly to a lowest category without performing further evaluations. The possibility of breaking the masonry by compression and instability facts is facilitated by the presence of high vertical stresses within the masonry wall. The schematic description of this action shown in Figures 4 and 5 [3], [4].

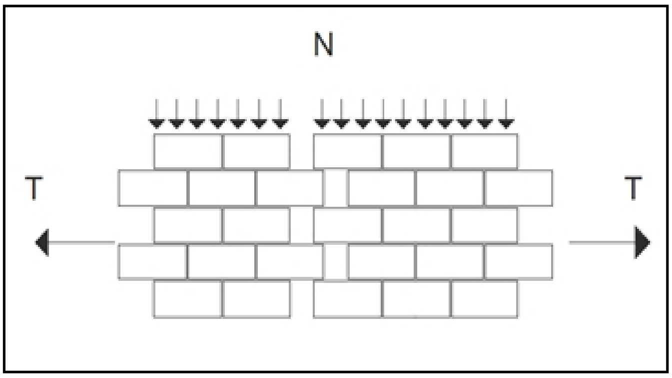


Fig. 4 Tension failure with vertical action [3]

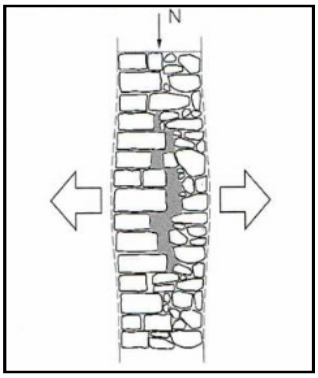


Fig. 5 Instability failure under vertical action; section of the masonry wall [3]

2.1.2. Horizontal loads; out of plane action

A wall subjected to horizontal actions that tend to deform out of its plane has the resistance limit of the masonry are subjected to strong compressive stresses. Namely, consider the internal side of a wall, which is overturning, and the tensions that tend to crush the stones positioned close to the horizontal hinge. For this reason, description of the lowest masonry quality can be: "degraded resistant elements or weakly resistant to compression" [3], [4].

Conversely, the aspect considered essential for the response of the walls to out of plane actions, is their monolithic behavior due to the presence of diatones. As well as other parameters, which have been assigned a higher weight. The presence of horizontal rows, which allow the oscillation of the wall around horizontal hinges, and the shape of resistant elements. The schematic description of this action is shown in Fig. 6 [3].

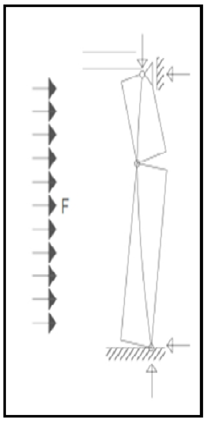


Fig. 6 Out plane action [3]

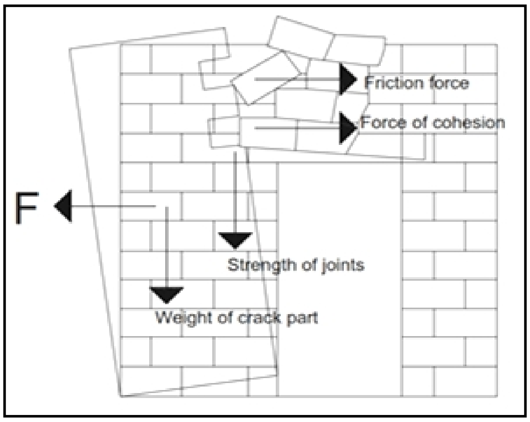


Fig. 7 In plane action [3]

2.1.3. Horizontal loads in plane action

Even in the case of stress shearing in horizontal plane acting on the wall, which is non-resistant to compression, or highly degraded, leading directly to the lowest quality of the masonry. The schematic description of this action is shown in Fig. 7 [3], [4].

The resistance of a wall to horizontal in-plane actions is mainly due to:

- Cohesion, dependent from the mortar quality.
- Friction, that is carried on horizontal surfaces (due to the verticality of the dead load) of bed joints and resistant elements in contact with each other, hence the importance is given to the parameter: "form of the resistant elements". But also the staggering of vertical joints and the friction between them are important parameters.
- Meshing and interlocking of the blocks, and this aspect can even define the slope of the lesion that will form in case of an earthquake. The joint between the blocks is essential for this aspect if square blocks are present and vertical joints are staggered [3].

Squared blocks, staggered vertical joints and quality of the mortar are the three important parameters considered essential in the methodology to provide to the wall a good resistance against the actions. Great importance is given to the presence of diatones, which ensure that the masonry wall can react to horizontal actions with the entire thickness of the wall [3], [4].

2.2. Method of the kinematic mechanism of collapse

The objective of the method of the kinematic analysis of mechanism of collapse is first to identify the possible mechanisms of collapse of the masonry buildings. Furthermore, to assess the minimum multiplier of the loads, if they are applied in a static manner to the structure, that causes the loss of balance and could start the kinematic chain. The structural analysis in order to identify the structural deficiencies of the building are essential for determinate its consequent collapse mechanisms [3].

For analysis of the kinematic mechanism of collapse, the behavior of macro structural elements were very essential to criticize. Macro portions in which are divided into masonry wall sections due to seismic actions. These portions have a certain internal monolithic behavior which is produced by static and seismic loads as well as the disconnections inherent of the building due to the type and construction methods. As well, the kinematic mechanism of collapse is effective by the kinematic chain that made it possible by the mutual movement of one or more macro elements. The starting movement for the kinematic chain of the masonry structure occurred by seismic action [3].

The macro elements of the masonry structure will tend to behave monolithically if the wall is constructed in good quality of materials and construction techniques. Without internally disconnection of materials, the masonry behaves like a rigid body. If the masonry wall does not present exceptional quality and good implementation, the behavior of the masonry wall is not monolithic. Therefore the wall behavior is like a "double separate leaves". Such behavior is the tendency of the masonry wall to be divided into two monolithic leaves, which has to be taken into the consideration in collapse mechanism of the structure [3].

If the masonry wall was in the lowest quality which categorized as the weakest type wall under the seismic actions. When this wall faced with the seismic action, there is a disconnection between the materials internal of the wall and there is no forming of separation of monolithic leaves. The wall crumbles to the pieces of stones without formation of macro elements under the seismic action [3].

Depending on the direction of the seismic action with respect to the plane of the wall, identify damage mechanisms of first and second type.

– If the mechanism of the damage happened in the first type: which tend to displace the masonry wall in a direction perpendicular to its plane of resistance. These mechanisms must be absolutely avoided; these mechanisms are often produce disastrous actions, even if they are not carried to the extreme force. And also the causes of instability are difficult to heal. To avoid such of these mechanisms, monolithic masonry wall structure and its well meshed thickness are provided. However masonry walls infilling with double leaves are particularly susceptible behavior towards the mechanism of the first type. For this reason enormous importance are given to the effectiveness of the connections between the floors, domes etc. and masonry walls which are perpendicular to them [3]. Therefore timber tie beams and their connections are very important for the behavior of the structures under the seismic actions.

– The mechanism of damage happened in the second order; masonry walls are affected from the seismic action parallel to the longitudinal direction, which is the greatest strength of the wall. If the fabric is in good quality, the damages may occur also in certain extent without the wall loses to its load-bearing capacity. The fundamental aspect of this behavior is under the fact that, the masonry walls which are able to withstand with higher loads in that direction than the first order. As well, timber tie beams were very effective for giving extra resistance to the masonry wall in second order.

The damage mechanism of first or second way, in most real cases these mechanisms are combined manner. It is often possible to observe that the cracks are formed on the elevations of the buildings on the basis of second order. This is clear that when the actions that are the appeared form earthquake, it cannot separated into components, which are orthogonal or coplanar. However, they involves the building entirely, that they may be resulted damages on first or second order [3].

The identification of the failure mechanisms in an existing masonry building is the most difficult part of the analysis method in macro. It can only be achieved by a thorough structural survey of the building. Need of identification is facilitated for carry out studies on buildings that are already

damaged by an earthquake in macro portions of the structure because they bounded the damages produced by seismic actions. Through the crack types that are happen in masonry structures, their motion graphics with various macro elements in the buildings under the seismic activity are identified [3].
The priority of the identification of the failure mechanisms as a result of survey drawings, the characteristics structure and they executed based on assumptions. They are developed specifically for the case study, which identified of mechanisms of collapse. The failure mechanisms are identified according to the hierarchy of dangerousness among the possible mechanisms [3].
The first is to identify masonry walls according to their collapse mechanisms. According to the pragmatic point of view, it is acceptable to extend the analysis of the damage mechanisms only external walls of the structure [3].
The masonry walls that are located on the perimeter of the building, their connection between horizontal elements like floors, external and internal walls and possible presence of anti-seismic principals are determines the fundamental conditions of collapse analysis. A masonry wall stressed by an action perpendicular to its middle plane, tend to separate into protruding by the means of a kinematic chain [3].
The sequence of the action happened according to the steps on the below:

- Consistency of compressive strength of masonry wall.
- Tensile strength of the masonry wall.
- The constraints of the horizontal movements. The macro element is move only the rotation of the horizontal hinge axis.
- The constraints of the vertical movements. Two masonry walls neither are separated nor rotate around the vertical axis passing through the clamping.
- The constraints of internal movements. Only the walls devoid of diatones and timber tie cross beams can be separated into two leaves of masonry under the movement of out of plane action.

Clamping of the masonry walls were constructed with iron bars, diatone stones and the timber tie-beams. According to Table 1, the mechanism of collapse of the masonry walls in function of the boundary conditions are summarized [3].

Table 1 Mechanism of collapse of the masonry walls in function of the boundary conditions [3]

Mechanisms of collapse of the masonry walls with their function of the boundary conditions			
Horizontal constraint	Vertical constraint	Internal constraint	
		Monolithic wall	Double leaves wall
Upper bonded wall	Clamp one side	One side of the masonry is overturning with two sided crack	
	Clamp two sides	Two sides of the masonry is overturning with two sided crack	
	No clamp	Vertical bending (monolithic)	Vertical bending (double leaves)
Free upper wall	Clamp one side	Rollover part of the masonry wall in one side (monolithic)	Rollover part of the masonry wall in one side (double leaves)
		Overturning single part of the masonry	Overturning single part of the masonry
	Clamp two sides	Horizontal bending (monolithic)	Horizontal bending (double leaves)
		Overturning part of the masonry with two sided crack	Overturning part of the masonry with two sided crack
	No clamp	Overturning (monolithic)	Overturning (double leaves)
		Horizontal bending (monolithic)	Horizontal bending (double leaves)

As it mentioned before the typical failure mechanisms of the stone masonry walls subjected to three different actions. Those actions effected and caused; cracks on the masonry walls, sagging or breaking of timber tie beams [5].
In Fig. 5, schematization of the timber tie beams inside of the masonry wall is shown. In Figs. 6, 7, the possible sagging schematization of the timber tie beams under the loads that the masonry wall are shown.

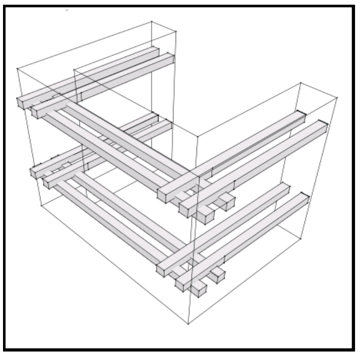


Fig. 8 Schematization of timber tie beams inside masonry

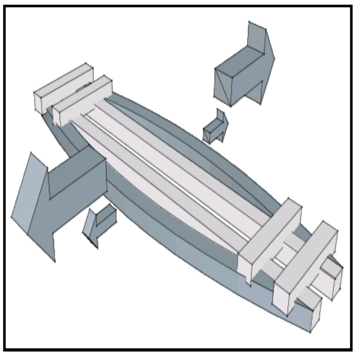


Fig. 9 Possible horizontal sagging of the timber tie beams

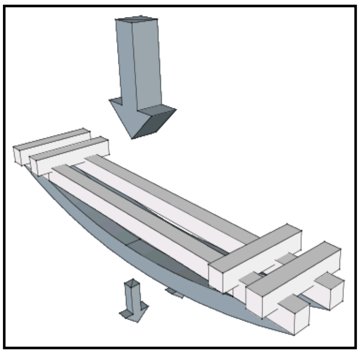


Fig. 10 Possible vertical sagging of the timber tie beams

On Tables 2, 3, 4 the collapse analysis of the masonry walls strengthened with timber tie beams were examined. In those tables, the schematic static collapse analysis of structural units were prepared according to three different actions with the classification of various structural elements from the basic single units to the angular, cellular and closure units.

Table 2 Failure mechanisms found in buildings that are subjected to different seismic actions, horizontal loads: in-plane action and out-of-plane action; single wall and angled wall [3], [8]

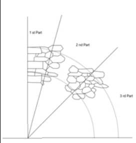
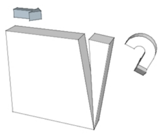
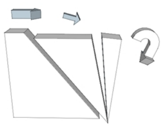
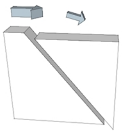
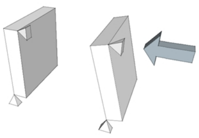
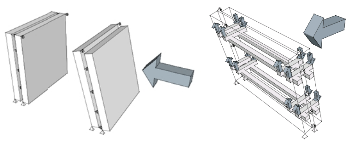
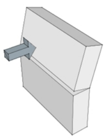
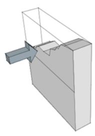
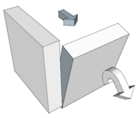
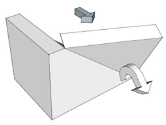
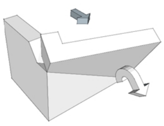
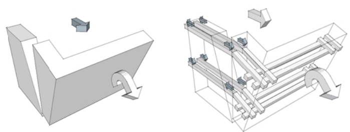
Failure mechanisms that are subjected to different seismic actions found in buildings			
HORIZONTAL LOADS IN PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	Masonry cracks and possible of sector of rotations caused by actions coplanar with the wall. Timber tie beams are occurred extra strength for this horizontal rotation.		Sector of rotations; part A. Emphasizing the main effect of the kinamatic mechanism which essentially consist of rigid rotation of the broken part.
	Sector of rotations; part B. The kinematic horizontal mechanism in sector B is occured in higher values of the seismic effects on the structure.		Sector of rotations; part C. It is a critical line, seismic actions diverted static compression and they can be transfered to the foundation.
HORIZINTAL LOADS OUT OF PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	Overturning a monolithic wall under the seismic actions.		Over turning a two leaves wall under seismic actions. The perpendicular connections of the timber tie beams are occurred extra strength for this action.
	Horizontal forces applied to the well arranged masonry wall with straight horizontal joints.		Horizontal forces applied to the chaotic masonry wall without straight horizontal joints. In this type of collapse behavior of masonry wall, there are no timber tie beam connections.
Masonry angled wall failure mechanisms			
	Overturning a monolithic wall. In this type of collapse behavior of masonry wall, there are no timber tie beam connections.		Mechanism of diagonal damage. Timber tie beam connections are occurred extra strength for this action.
	Mechanism with formation of an intermediate diagonal hinge. The perpendicular walls and timber tie beam connections are occurred extra strength for this action.		Mechanism of damage and crack start from diagonal of the wall. The perpendicular walls and timber tie beam connections are occurred extra strength for this action.

Table 3 Failure mechanisms found in buildings that are subjected to different seismic actions: vertical loads [3], [8]

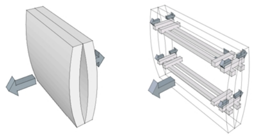
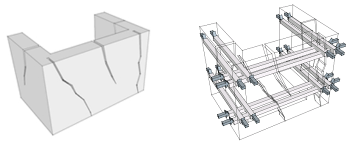
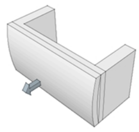
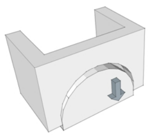
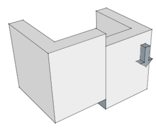
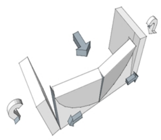
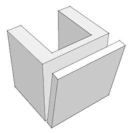
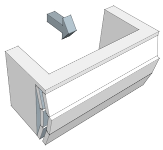
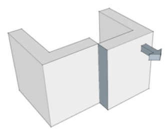
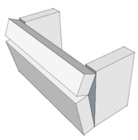
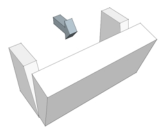
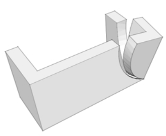
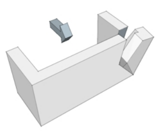
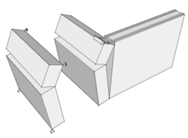
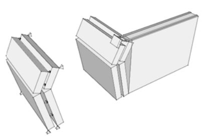
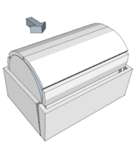
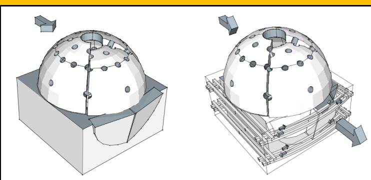
Failure mechanisms that are subjected to different seismic actions found in buildings			
VERTICAL LOADS; Masonry cracks and possible of sector of rotations			
Masonry single wall failure mechanisms			
	The compressive force pushed away two-masonry leaf from each other. The masonry wall gets into the formation of symmetric bulging. Timber tie beams are occurred strength against horizontal symmetric bulging.		Vertical cracks on the masonry wall that tends to collapse of the structure. Timber tie beams are keeping the unity of the masonry against the vertical cracks which caused by vertical loads.
	Outer vertical deflection. Inside leaf of the masonry wall under pressure. Therefore outside of the leaf pushed away from the wall. Timber tie beams are occured strength against horizontal bulging.		
Masonry cell failure mechanisms			
	Bottom part of the masonry wall tend to separate from the cell. Horizontal timber tie beams are sagging in this action and occurs vertical strength against the separation.		Half part of the cell tend to move downward. Horizontal timber tie beams are under the effect of shear force. However, they are occurred vertical strength against the shear force.

Table 4 Failure mechanism found in buildings subjected to different seismic actions, horizontal loads, out of plane action [3], [8]

Failure mechanisms that are subjected to different seismic actions found in buildings			
HORIZINTAL LOADS OUT OF PLANE ACTION; Masonry cracks and possible of sector of rotations			
Masonry cell failure mechanisms			
	The mechanism of damage on a masonry cell wall structure under the horizontal forces. Timber tie beams are behaved like arch against for this action.		Reversal of the external leaves. Perpendicular timber connections occurred extra strength for this action.
	Bending deflection outward of the masonry. The crack lines are the parts that are the void spaces for timber tie beams.		Half part of the cell tend to move outward. The timber tie beams are under the effect of shear force. However, they are occurred strength against this action.
	Monolithic vertical deflection. Angular masonry walls and timber tie beams are occurred extra strength for this action.		Tilt mechanism composed of double corner cracks. Angular masonry walls and timber tie beams are occurred extra strength for this action.
	Tipping masonry piece with an single corner and with simple diagonal crack. Angular masonry walls and timber tie beams are occurred extra strength for this action.		Tipping masonry piece with double corner and double diagonal crack. Angular masonry walls and timber tie beams are occurred extra strength for this action.
	Monolithic masonry wall is attached from the top with timber ties. Bending stress applied to the wall.		Double leaf masonry wall attached from the top with timber ties. Bending stress applied to the wall.
Masonry cell closure failure mechanisms			
	Folding mechanism amplified by the thrust distribution of the barrel vault. Angular masonry walls and timber tie beams are occurred extra strength for this action.		Folding mechanism of rupture in bending out of plane, amplified by the central thrust of the segment. Timber tie beams behaved like arch against for this action. As well, they are occurred extra strength for keeping unity of the wall and resist the extra loads, which are produced by dome.

3. EXAMINING TWO CASE STUDIES ACCORDING TO THE METHODOLOGY

3.1. İsmail Bey Bath – 15th cent (Bursa-İznik)

Table 5 Critical damaged parts of "İsmail Bey" bath [1]

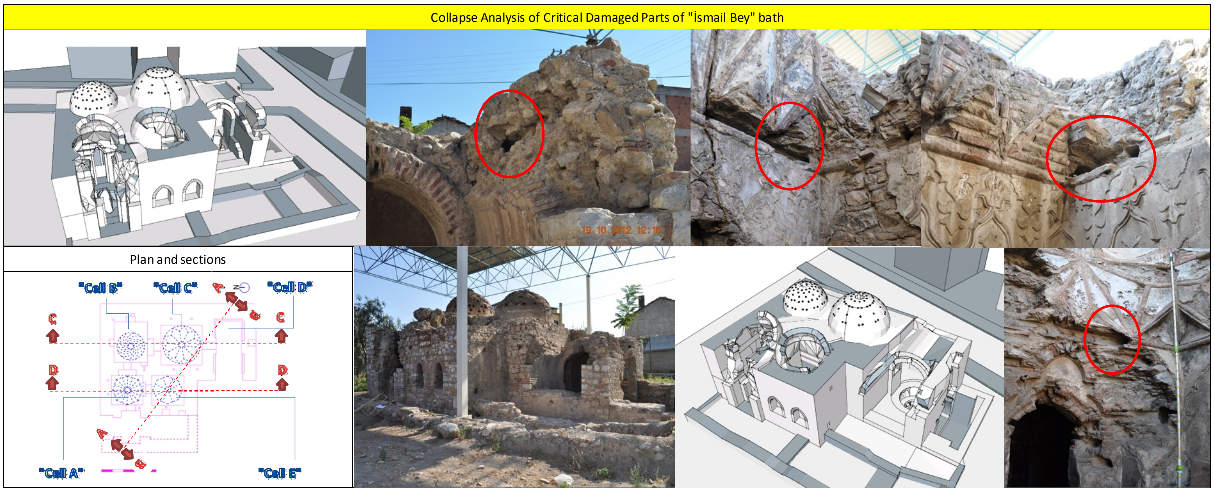


Table 6 Collapse analysis of critical damaged parts of "İsmail Bey" bath, Sec: A-A [1]

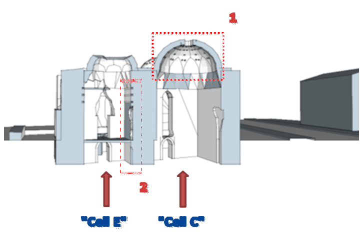
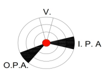
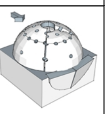
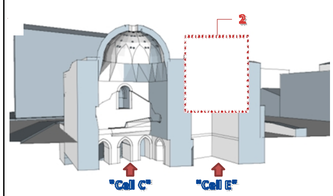
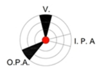
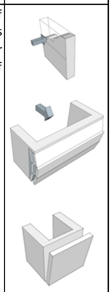
Section A-A	Detail 1	
	Symbolic Description of Action Analysis	Symbolic Collapse Mechanism
	Very high risk of collapse if this element under in plane and out of plane actions. 	

Table 7 Collapse analysis of critical damaged parts of "İsmail Bey" bath, Sec: B-B [1]

Section B-B	Detail 2	
	Symbolic Description of Action Analysis	Symbolic Collapse Mechanism
	Very high risk of collapse if this element is under vertical and out of plane actons. 	

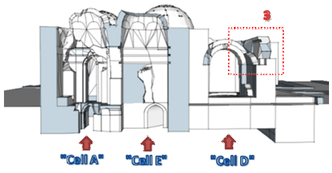
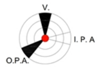
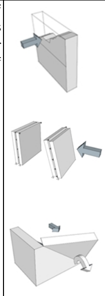
Description of collapse mechanism:

Detail 1: dome has a damage on its top and critical line between tension and compression. The perimeter walls of the dome are thick. However, the perimeter walls have big damages on their outer layer. Some parts of the outer layers were collapsed. And there is a big crack on the dome and continue through the masonry walls and the next cell. Decayed timber tie beams, which left holes inside of the masonry walls, weaken the bearing and strength capacity of the wall structure. Folding mechanism of dome was formed by bending the outer walls through the out of plane action and in plane action.

Detail 2: The dome is collapsed. The bearing walls supporting the dome deteriorated. In the area of transitional elements, inner leaf of the masonry is collapsed and the masonry wall became thin. In addition, the empty timber tie beam sockets weaken completely the masonry wall. Therefore, inner leaf of the wall structure or the total wall could collapse in three different types.

Detail 3: The part of the masonry wall was maintained in the previous consolidation projects. However some parts of the wall left in its original status. The part of the wall was deteriorated and inside and outside leaves was broken down. The wall is very weak for vertical and out of plane actions. In addition, empty timber tie beam sockets weaken the inside of the cell masonry leaf.

Table 8 Collapse analysis of critical damaged parts of "İsmail Bey" bath, Sec: B-B [1]

Section D-D	Detail 3	
	Symbolic Description of Action Analysis	Symbolic Collapse Mechanism
	Very high risk of collapse if this element under vertical and out of plane actons. 	

3.2. Gazi Mihal Bey Bath – 1421 A.D. (Edirne)

Table 9 Critical damaged parts of "Gazi Mihal Bey" bath [1]

Collapse Analysis of Critical Damaged Parts of "Gazi Mihal Bey" bath

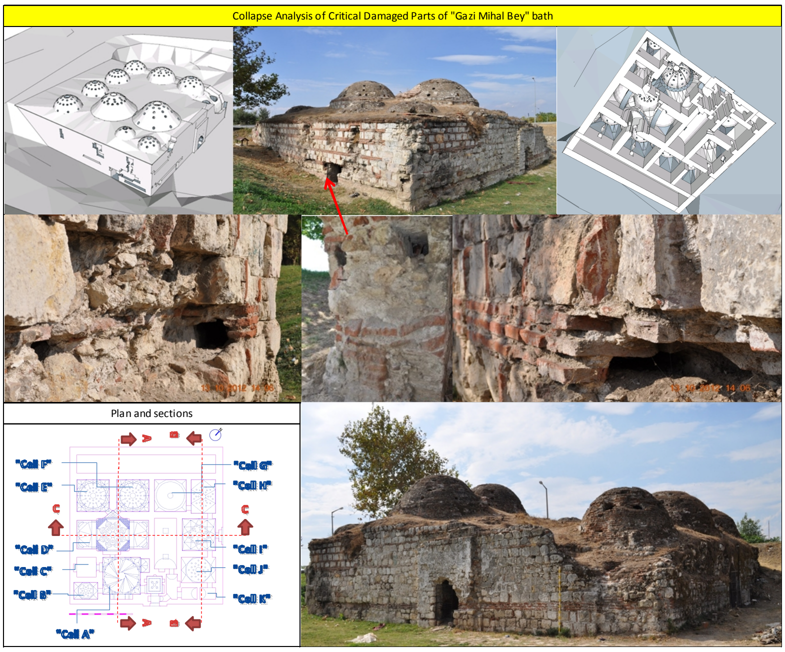


Table 10 Collapse analysis of critical damaged parts of "Gazi Mihal Bey" bath, Sec: A-A [1]

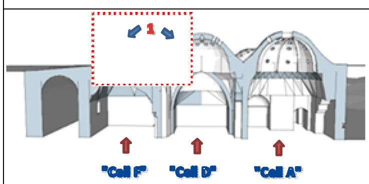
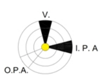
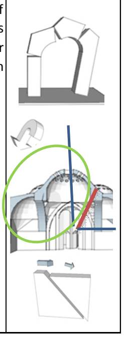
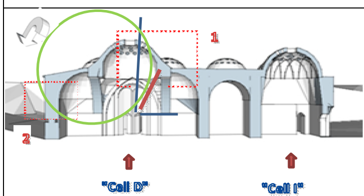
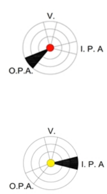
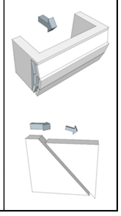
Section A-A	Detail 1	
	Symbolic Description of Action Analysis	Symbolic Collapse Mechanism
	Very high risk of collapse if this element is under vertical and in plane actions. 	

Table 11 Collapse analysis of critical damaged parts of "Gazi Mihal Bey" bath, Sec: C-C [1]

Section C-C	Detail 2	
	Symbolic Description of Action Analysis	Symbolic Collapse Mechanism
	Very high risk of collapse if this element is under out of plane actions. And for detail 1, in plane actons. 	

Description of collapse mechanism:
Detail 1: In this detail, damage is a big crack which is starting from the door opening arch and continue to two adjacent domes. This crack is separating two wall masses each from the other. The collapse mechanism of the arch is similar to the typical collapse mechanism of this structural part. The cracks on the domes tend to open the perimeter of the base of the dome. However, the neighbors of the dome support masses are keeping the structures stable. Nevertheless, in seismic actions these masses are separated to each other. In this detail vertical and in plane actions are considered for collapse risk.
Detail 2: The critical big crack in “detail 1” affected the “detail 2” under the out of plane actions. Detail 2 was become weak because of the deterioration of the masonry, adhesion between the mortar and the stones and the empty timber tie beam sockets. This wall was important for supporting the half dome and the dome masses. As seen on the section C-C, the wall became weak and narrow because of the voids and deteriorations. The assumption of the possible collapse could be activated by the failure of outer masonry wall and kinematic chain of collapse continues with addition of dome masses.

4. CONCLUSIONS

The discussion of the application of the “rule of art” give the information obtained above, according to the methodological analysis of the case studies; this is summarized below.
In İsmail Bey Bath, six mechanism of collapse analysis were analyzed. In those studies, the bath structure is highly sensitive to the vertical and out of plane actions; however the building is more resistant to the in plane actions compared to the other actions.
In Gazi Mihal Bey Bath, three mechanism of collapse were studied. In those analyses the bath structure is highly sensitive to out of plane actions. However, in plane action could have caused a risk of collapse chain. The structure could be seen to show more resistance to vertical actions.
In the two case studies, the timber tie beams were used as reinforced elements for seismic precautions. Moreover the masonry walls are clamped on two sides to other adjacent perpendicular walls. However, there were no diatones in the cross sections of the masonries. In the course of time, the decay and the disappearing the timber tie beams inside the masonry caused plucked cross sections of the walls. It resulted to weaken wall structure towards the loads that can be applied from vertical to horizontal direction. The extra strength of timber tie beam reinforcement in the past vice versa changed to extra weaken the masonry wall structures in present times.

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