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Structural Specifications of Turkish Bath's and Collapse Analysis Scenario of Ismail Bey Bath, Iznik-Turkey

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Abstract

Stone was used as structural material in historical buildings. The structural failures of stone material causes failures on structural elements such as lintels, walls, arches, vaults and domes. Degradation of stone walls can be associated with many different factors such as the type of stone, as well as the forces that are applied to the materials for combining the stones together. Mortar and ties made up of brick and timber were used in traditional Turkish bath structures for preventing them from the horizontal forces. Horizontal forces are seismic forces that are generally the main reasons for the degradation of masonry wall structures.

Structural degradation of the historical masonry walls of the baths occured mainly because of the lack of timber tie beams inside the walls. With time the timber tie beams slowly decayed and released the masonry. The structure had been become weak from the horizontal and seismic forces.

In this study, the historical Turkish bath structures during the Ottoman period from the 15th century, were chosen from one seismic area, in order to analyze how preventive construction techniques for the seismic forces like timber ties and linear brick pattern layouts, relate to the degradation of the structures. This case study was ruined and some parts of the structure were collapsed. The collapsed mechanism of the structure was analyzed and the reasons that led to this were listed.

The methodology of this research started with a seismic point of view of the historical bath settlement. Secondly, general structural qualifications of the Ottoman bath were analyzed, to explain the behavior of the structure as a result of the horizontal forces. Thirdly, the construction details of the masonry walls were analyzed and the decay of timber and brick ties was determined, in order to understand the mechanisms of the collapsed parts of the case study bath structure.

Finally, the outputs of this research were: how the collapse mechanisms in relation with the decay of the structural building elements like timber ties and linear brick pattern layouts lead to the degragation of the bath structure.

Keywords: Degradation, wall structures, collapse mechanism

Introduction

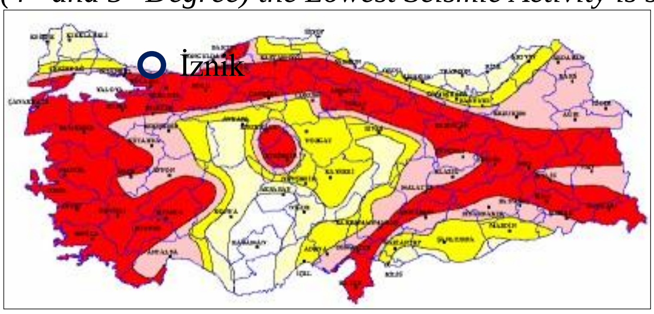
In this paper, the relation between the degradation of historical Turkish bath structures with the historical preventive construction techniques against the seismic forces was analyzed. Some special construction techniques, which were used in this bath structure could be anti-seismic construction skills. These construction skills and degradation of the bath structure showed us the technological development of the structural preventive techniques against the seismic forces. The question of this paper was; which were the construction techniques in historical Ottoman bath structures in seismic magnitudes. Construction techniques, decayed construction elements and collapse mechanisms of the structure of the bath were the methodological tools of this paper for approaching the conclusion.

In the Ottoman Empire, the masonry wall structures, domes, vaults and arches were the major structural elements and also the major geometrical forms. The historical structures have very complex load carrying behavior due to the massive and continious interaction of domes, vaults, arches, pillars and walls. Typically, these structures are more massive than contemporary structures and they usually carry their actions primarily in compression. The structural resistance depends on the geometry of the structure, the shape of the structural components, the characteristic strength and stiffness of the materials and the special construction details. The characteristic thickness of the masonry structural components should be able to resist compression, tension and shear stresses resulting from the structure's own weights and those imposed by earthquakes.

Case Study Bath Structure Locations and their Seismic Point of View

İznik (Nicaea) in Anatolia was an important location of the Ottoman Empire. This was one of the capital cities in the historical period of the Ottoman. In addition İznik, the ancient Nicaea were hosted by Romans and Byzantines in the historical times. Therefore, it was very rich in architectural heritage. İznik was affected by seismic activities in previous times.

Figure 1. *Seismic Map of Turkey; in Red Areas Highest Seismic Activity (1st Degree) is seen, in Pink (2nd Degree), in Yellow (3rd Degree) and in Light Color Areas (4th and 5th Degree) the Lowest Seismic Activity is seen (2011) [2].*



The data from the past earthquakes in İznik can be seen in (Table 1). In the Ottoman era, big earthquakes in Bursa affected the İznik district. These two locations were too close to each other, so seismic effects affected both of them (Fig 1), [1, 6].

Table 1. *Past Earthquakes in Marmara Region in Anatolia [1, 6]*

Date	Latitude	Longitude	M	Location
08.01.1010	40.6	27.0	7.4	Gelibolu
23.09.1053	40.8	27.4	7.4	Barbaros
??.09.1055	40.4	30.0	6.8	İznik
??.??.1231	41.0	28.6	6.9	İstanbul
01.05.1296	40.5	30.5	7.0	Gevye
18.10.1343	40.7	27.1	6.9	Ganos
18.10.1343	40.9	28.0	7.0	Ereğli
01.03.1354	40.7	27.0	7.4	Gelibolu
15.03.1419	40.4	29.3	7.2	Bursa
10.09.1509	40.9	28.7	7.2	İstanbul
10.05.1556	40.6	28.0	7.1	Erdek
18.05.1625	40.3	26.0	7.1	Saros
17.02.1659	40.5	26.4	7.2	Saros
25.05.1719	40.7	29.8	7.4	İzmit
05.02.1737	40.0	27.0	7.0	Biga
29.07.1752	41.5	26.7	6.8	Edirne
02.09.1754	40.8	29.2	6.8	İzmit
22.05.1766	40.8	29.0	7.1	Marmara
05.08.1766	40.6	27.0	7.4	Ganos
07.02.1809	40.0	27.0	6.1	Gönen
06.10.1841	40.8	29.0	6.1	Adalar
19.04.1850	41.1	28.3	6.1	Manyas
28.02.1855	41.1	28.6	7.1	Bursa
11.04.1855	40.2	28.9	6.3	Bursa

The historical sequence of the seismic forces in the Bursa and İznik regions are shown in (Table 1). As seen in the table and the Turkish map, the seismicity and the frequency of seismic activity in İznik and its surroundings have higher rates compared to other locations in Turkey.

Higher seismicity in İznik, could help us understand seismic preventive construction techniques of that period of time.

Analyzing Ottoman Bath Structures with the Reference of Typical Materials and Construction Techniques

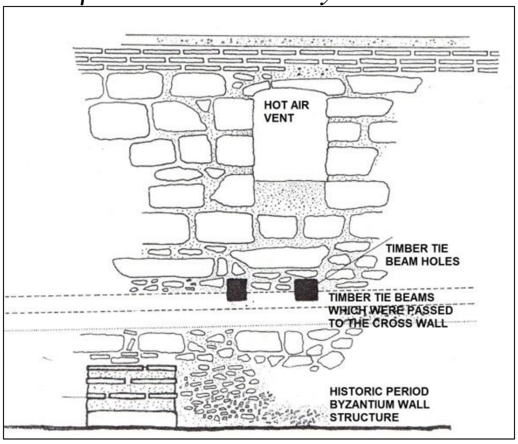
In this study, the Ottoman Bath structures are analyzed according to their construction techniques and materials. Vertical support elements (walls), transitional elements (pendentives), Turkish triangles (squinchs) and superstructure elements (domes) are analyzed in this study. The main focus is the wall structures.

Walls

The wall elements in the Ottoman monuments were differentiated according to the structure. The thickness of the walls differentiated according to the spaces. The thickness of the outer masonry walls differentiated from 70 to 85 cm and interior walls distinguished from 60 to 80 cm. The exterior surfaces of the bath structures were not plastered, however the interior wall surfaces were finished with lime and brick-lime plaster [5].

Stone masonry walls were connected to each other with a timber tie beam connection system which was located 20 to 70cm vertically apart from the foundation level. These timber tie beams decomposed in time and in the tie beam holes, pine resin was found. This gives us a hint that pine timber material was used as tie beam in these structures (Fig 2), [5].

Figure 2. *Cross Section of the Stone Masonry in Tahtakale Bath in İstanbul [5]*



Timber beams were generally constructed in two rows. One row positioned inside of the wall and the other outside of the wall. The outside row of timber tie beam passed behind thorough brick bonds or on the edge of the surface. Other timber tie beams were located inside the masonry wall [11]. The timber tie beams were connected to each other with vertical timber studs. This timber grid mesh was used in large spaces 150cm apart from each other in three codes of horizontal level. In small spaces, 16x16 cm to 20x20 cm, cross sections of timber tie beams were used on the edge surface of masonry wall structures. However, 24x24 cm cross section timber tie beams were used in big spaces and located inside the stone masonry wall structure between the rubble stone and mortar. These timber tie elements could not be seen from the facade of the masonry structure. Timber tie beams were overlapped with tongued joints or nails. Nails were passed through timber tie beams, 4 cm on their bottom lines. These 4cm parts were kept inside the mortar for anchoring the timber ties in to the masonry wall. This nail anchoring held the timber tie beam in the masonry wall structure motionless. In some of the bath structures, between the stone layers, ‘horosan’ mortar was poured like a beam. However, there was no evidence of this beam that circulated around the masonry wall structure [5].

In stone masonry structures, piping systems were differentiated in two groups. In hot spaces, terracotta pipes were used in horizontal direction for the water circulation system. In vertical direction, piping systems were used for the heating of the wall structures [5].

There were different bonding techniques for stone masonry structures. These bonding techniques are explained in steps below.

Rubble stone bond;

Three different rubble stone bonding techniques were used in bath structures. In plain rubble stone bond, baffling vertical joints were used together with small and large stones. Exterior surfaces of the bath structure rubble stone and small stones were used together for generating a smooth surface. The inner part of the masonry was filled with mortar and rubble stone (Fig 3), [11].

The second type of rubble stone bonding was generated with rubble stones and large pieces of bricks in joints. Brick pieces were placed into the lime mortar for filling the voids (Fig 4), [11].

The third type of rubble stone bonding was generated with rubble stones, bricks and in some parts of the wall, large pieces of bricks were used in joints. In this type of rubble stone bond, bricks were used in horizontal and vertical joints of the wall surface between the rubble stones (Fig 5), [11].

Figure 3. *Rubble Stone Bond [11]*

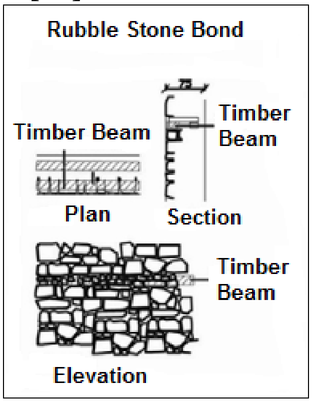


Figure 4. *Rubble Stone / Large Pieces of Bricks in Joints [11]*

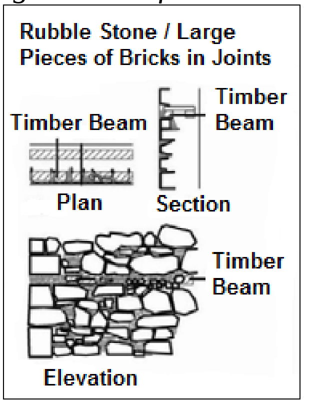


Figure 5. *Rubble Stone / Bricks in Some Places Large Pieces of Bricks in Joints [11]*

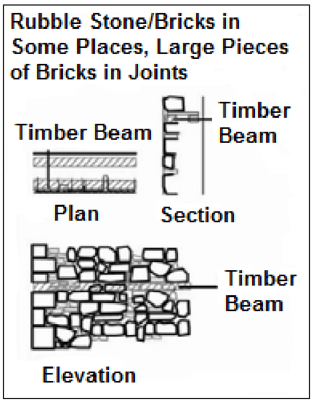
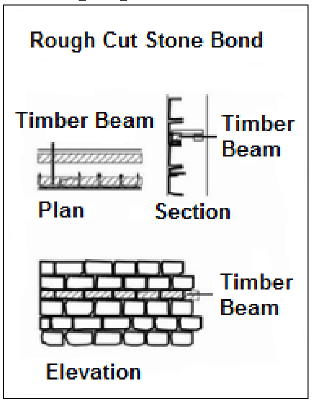


Figure 6. *Rough Cut Stone Bond [11]*



Rough cut stone bond;

In this type of masonry, cut stone with well-arranged bonds were used on the surfaces of the stone masonry wall. Inner layer of the masonry wall were filled with rubble stones and mortar (Fig 6), [11].

Alternating bond;

In this type of masonry, alternating bonding techniques were used. These techniques are listed in steps below [11].

- Rubble stone / brick alternating bond; two layer of horizontal brick bonds were placed between the rubble stone masonry. In some of the baths these brick bonds placed horizontally and vertically. Pieces of bricks and lime mortar were used to fill (Fig 7) the inner layer of the masonry walls.
- Rough cut stone / brick alternating bond; stone masonry walls were improved by bricks in some part of the masonry wall. On the exterior surface of the wall 1 to 1.5cm joints were used for connecting the stone masonry. Rubble stones and lime mortar were used to fill the inner layer of the masonry (Fig 8).
- Cut stone / brick alternating bond; Cut stone with two layers of brick were used in this type of stone masonry structure. These two layers of thin brick were used for layering places in horizontal or vertical on the masonry wall structures (Fig 9).

Figure 7. *Rubble Stone / Brick Alternating Bond [11]*

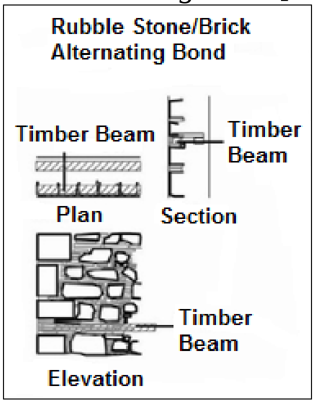


Figure 8. *Rough Cut Stone / Brick Alternating Bond [11]*

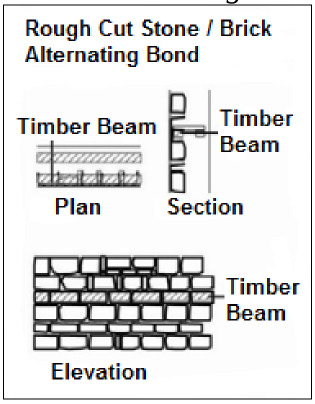
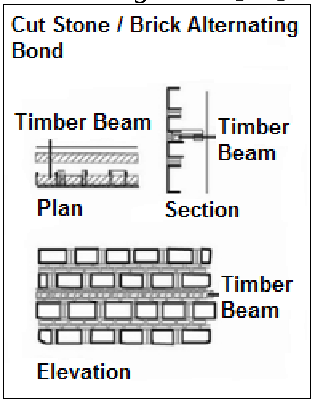


Figure 9. *Cut Stone / Brick Alternating Bond [11]*



Arches

The arches were seen as structural elements under the squinchs in bath structures. There were also blind arches on the surface of the walls of interior spaces [11].

In bath structures, arch constructions were made up of brick elements. The dimensions of these elements were differentiated according to spans that were passed [5]. The dimensions of the bricks were differentiated between 32x3-4 cm, 10.5x32x3-4 cm and 16x21x3-4 cm. The arches were constructed by the support of mold. Bricks were placed angled and the joints were filled with 'horosan' mortar. Joints were 1-1.5cm thick in the intrados and large joints 3-4cm thick in the extrados [5, 11].

Transitional Elements

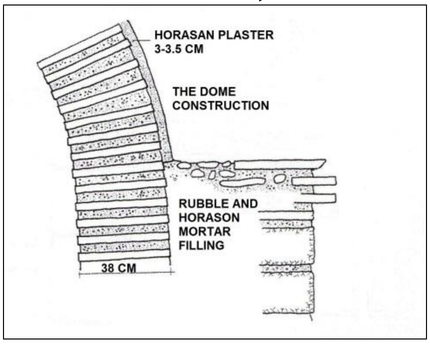
Pendentives, Turkish triangles, squinchs were used in bath structures between the dome and the perimeter walls. They transfer loads from the dome to the walls. These structural elements were made by brick and were constructed with lime mortar, plastered with 'horosan' mortar and finished with lime plaster [5, 11].

Covering Elements

For the bath structures the dome and the vault were used as covering structural units. They were always built with bricks and lime mortar. The brick dimentions and specifications were differentiated in dome structures. The brick dimentions were differentiated between 4 x 38 x 24-29 cm. The thickness of the joints were differentiated inside the dome approximately 3cm. Outside the dome the thickness of the joints were differentiated 3 -6 cm. [5]. On the top of the dome there were openings for the oculus, which was used as a lighting element for the bath structure. For these, opening terracotta pipes were used on the construction of the dome structure [11].

The vault structures were used in rectangular spaces which were constructed with brick, rough cut stone and lime mortar. The curvilinear arch vault was constructed with bricks with radiant arranged order. In some of the vault construction, the structure was supported with arches [11].

Figure 10. *Dome – Perimeter Wall Section, Tahtakale Bath, İstanbul [5]*



General Structural Qualifications of Case Study, İsmail Bey Bath in İznik against Horizontal Forces

In this chapter, as it was mentioned before, one case study was analyzed according to its structural qualification. In this part, the plan, section layouts of the case study and the construction details against the horizontal forces were examined. This information was the initial part of the research paper for examination of the chapter; ‘degraded parts and collapse mechanism of the bath structures’.

İsmail Bey Bath was located in İznik, ancient Nicaea (Fig 11). In different bibliographies the building date of the İsmail Bey Bath varies. However, the general decision of the building date was in the 15th century. The general interpretation of this building is that it was a private bath and part of a mansion ‘konak’. Today, this building is ruined and half demolished [10].

Figure 11. *İsmail Bey Bath and its Collapsed Parts, İznik*

In İsmail Bey Bath, the rectangular plan shape of the structure was built with a rubble stone brick alternative bond (Fig 12). The thickness of the walls was approximately 1m. Walls were three layered; inside of walls rubble stone was used as a filling material (Fig 13, 14), [3, 4, 11, 13].

Figure 12. *Stone Pattern Arrangement in İsmail Bey Bath, İznik*

Figure 13: *Wall Section-Timber Beam Hole, İsmail Bey Bath, İznik*

Timber tie beams were used horizontally inside of the walls for providing strength for the lateral forces. The square voids inside the walls remained after the dissolution of the timber beam (Fig 13, 15).

Figure 14. *Section of Masonry Wall in İsmail Bey Bath, İznik*

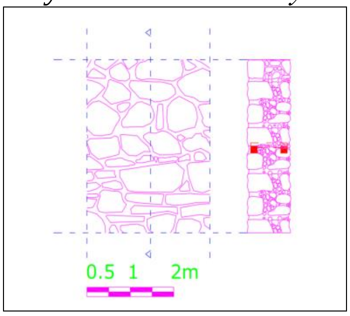


Figure 15. *Wall Section-Timber Beam Hole, İsmail Bey Bath, İznik*

The transitional elements and the domes were constructed with brick elements. Geometrical forms were given with brick materials by using their thin sides to form the linearity of the triangular transitional elements (Fig 15). This building was essential for its ornamentation on transitional elements. There were four domes and one vault which were made up of brick for covering the bath structure. The plan, section drawings of the building are seen in (Fig 16, 17, 18), [12].

Figure 16. *Plan of İsmail Bey Bath, İznik*

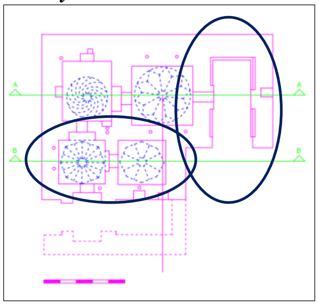


Figure 17. *Section of İsmail Bey Bath, İznik*

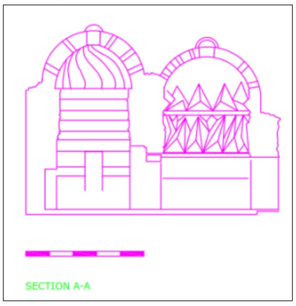
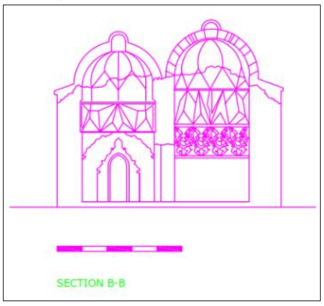


Figure 18. *Section of İsmail Bey Bath, İznik*



Degraded Structural Parts and Collapse Mechanism of the İsmail Bey Bath Structure

Crack patterns and collapses were diffused in the İsmail Bey Bath structure. Seismic activity or deterioration of the environment could be the reason of these damages (Table 1). In İsmail Bey Bath part of the structure, two domes and one vault were collapsed (Fig 16). Half of the masonry walls of this structure were reconstructed. Therefore, it was not possible to find the wall crack patterns of the bath structure. From the collapsed part of the structure, crack patterns, sections and the used materials inside of the masonry wall could be seen clearly. The situation of the crack patterns on transitional elements was seen easily from the parts that were fallen down.

Collapse Analysis Scenario of İsmail Bey Bath, İznik

In this part, İsmail Bey Bath's collapsed dome and vault were structurally analyzed.

The Dome

The walls could be damaged through environmental effects as well as seismic forces. Therefore, binding capacity of the mortar with stones was degreased on the wall. The round dome base implemented pressure to the upper side of the wall and the top of the wall could not resist this pressure that was coming from the dome base round and finally it collapsed (Fig 19) [7, 8, 9].

Afterwards, the dome collapsed. And now the existing parts of the dome can be seen on the structure, as well the new reconstructed parts of the wall (Fig 20).

Figure 19. *Schematic Collapse Behavior of Masonry Wall and the Dome in İsmail Bey Bath, İznik*

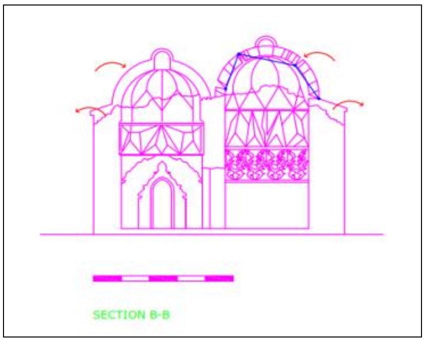


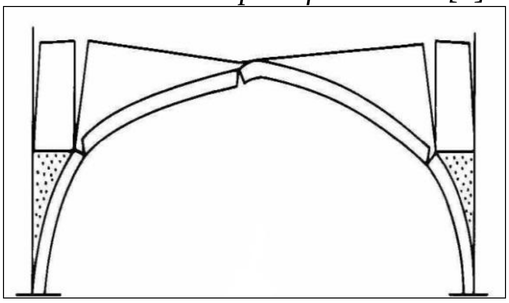
Figure 20. *Collapsed Dome and Reconstructed Wall, İsmail Bey Bath, İznik*

The Vault

A big part of the vault collapsed. The crack patterns could be seen under the vault structure (Fig 21). These crack patterns guided the collapse mechanism of the vault (Fig 22). The environmental effects include seismic activity and degradation of the construction materials that could be the reason for the collapsing of the vault structure.

Figure 21. *Cracks Under the Vault*

Figure 22. *Schematic Structural Collapse of the Vault [8]*



The brick pattern layout on the masonry wall patterns could not affect this collapse. However, timber ties could be one of the reasons for this collapse. The masonry walls were stabled and tied by the timber tie beams. Decay of the timber beams would leave the upper part of the masonry walls and free them to slope inside the vault. The higher load which passed the carrying limits of the vault could be the reason for the startof the collapse mechanism of the structure (Fig 22), [7, 8, 9].

Conclusions

As a result, with the guidance of these methodological steps and the comparative study, it is realized that construction preventive techniques against the horizontal forces were used in this case study. Brick layers on the walls and timber tie beams were evidence of keeping the structure stable for horizontal forces. However, these techniques in some part of degradation of the historical baths were not sufficient enough for preventing collapse. The datawhich was gained from the collapse analysis show that the degradation of the materials could be the starting point of the collapse of the structure.

The high magnitudes of seismicity in İznik settlement show high collapsed rates in this structure. The structural state of İsmail Bey Bath in İznik, is half demolished. Big part of the İsmail Bey Bath was collapsed. However it doesn't mean that only the environmental as well as seismic effects were the reasons for the degradation and collapse. The quality of the construction and materials, wars that caused damages, frequency of renovations and different functional usages of the structures could be other reasons of decay.

Finally, seismic history of the settlement, decayed structure construction and collapse analysis could be a way of research for understanding preventive construction techniques against the seismic forces and their relation to the degradation.

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