16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 3088 (Abstract ID)

Registration Code: S-H1463080614

ANCIENT MEASURES TAKEN FOR DISASTER MITIGATION IN ANATOLIA

E. G. Arun

Prof. Dr., Hasan Kalyoncu University, Faculty of Fine Arts and Architecture, Gaziantep, Turkey, goruna@gmail.com

Abstract

Vulnerability of ancient masonry structures to dynamic actions in seismic areas, are mostly due to the ageing, environmental factors and lack of knowledge in the interpretation of the building construction methods and details during intervention. The study of building construction method and structural details has a great importance in the mechanical and dynamic behavior of a building. Selection of appropriate preservation methods and materials for correct interventions and achieving preservation in a building's historical and cultural context, and diagnostic studies for understanding the causes and mechanism of decay are an indispensable scientific and technical basis. Such diagnostic studies have to be based on historical information, construction methods of the time, environmental monitoring and evaluation of the present level of safety.

Earthquake was always one of the most threatening actions to buildings in Anatolia, the far west peninsula of Asia. In order to make buildings safe, there exist several ancient construction code texts. In order to make buildings safe, it is suggested that the building has to maximise the energy absorption capacity of structure and minimise seismic action. To maximize energy absorption capacity of the structure, the structure has to have capacity to dissipate energy and be redundant. To minimise seismic action, building has to be light, minimise amplification of ground acceleration and avoid actions that that will cause the instability of the structural elements. Ancient building masters, using techniques developed by previous cultures, their own trial and error, and techniques transferred from one generation to another, sized the structural elements and designed their buildings taking proper account of environmental actions.

The main objective of this paper is to point out the importance of acknowledging the design skills of master builders during diagnosis of the failures in historic buildings. This paper will discuss risk sources and passive protection measures taken against disasters. The main sources causing disaster were fires for timber, and earthquakes for masonry structure. Moisture in buildings caused loss of material and weakened the structure in the long term. Today, many traditional constructions with a variety of materials and techniques in Turkey suffer from continuous changes and repair of past works, abandaned during their lifetime and interventions ignoring the engineering skills of the master builders.

This study consists of the construction methods and structural details of master builders from various civilizations lived in Anatolia. It is based on reviewing the archaeological and history of architecture publications, discussions with archaeologists and experiences during diagnosis phase of restoration works. Lessons taken from these measures may enlighten the measures to be taken for today's risk mitigation.

Keywords: Risk mitigation, Underground water control, Ancient construction methods

1. Introduction

The conservation and enhancement of the architectural heritage that represents the social, economic and environmental identity is a vital part of the future sustainability and to the maintenance of social, economic and technical traditions. Nevertheless, due to aging, the aggressive environmental effects as earthquakes, soil settlements, increased loading from traffic vibrations, air pollution, etc. and the fact that many old buildings and historic centers were not maintained properly, a large part of this architectural heritage suffers structural problems that reduce the safety of buildings and people.

Vulnerability of ancient masonry structures to dynamic actions in seismic areas are mostly due to the ageing, environmental factors and lack of knowledge in the interpretation of the building construction methods and details during intervention. The study of building construction methods and structural details has a great importance in the mechanical and dynamic behavior of a building.

The decision making process of the preservation of these culturally valuable and potentially functional architectural structures should keep the structures' original and authentic architectural messages. It requires accurate evaluation procedures, efficient repair methods and rational design criteria. To achieve preservation in a building's historical and cultural context, diagnostic studies for understanding the causes and mechanism of decay based on historical information, environmental monitoring, evaluation of the present level of safety and selection of appropriate preservation methods and materials are important scientific and technical basis for correct interventions.

The study of historical constructions oriented to their preservation requires multidisciplinary teams of specialists formed in relation to the type and the scale of the problem [1]. And it requires special technical and analysis tools adapted to the structure's geometry, building materials and changes it had passed all throughout its lifetime [1]. Today, significant knowledge is available through modern testing and advanced analysis of heritage structures for the assessment of failures. Constraints to be considered in the preservation of the architectural heritage are working together with a multidisciplinary team, the need of experienced professionals who can collaborate with different disciplines and the lack of knowledge in the interpretation of the building construction methods and structural details in the evaluation of structural problems for intervention decisions.

Historical documentation records should be investigated by experts and historians who are able to adequately interpret the ancient texts, in cooperation with the structural engineers, assisting the historian in the identification of structurally meaningful records. In investigating heritage buildings mostly constructed with the leading technology of their time and to understand their mechanical and dynamic behaviour, it is important to take into account the engineering knowledge and practice of their time for proper interpretation of the causes of the failures and for decisions on proper intervention.

Earthquake was always one of the most threatening actions to buildings in Anatolia. Today, the seismic zone map of Turkey in 2007 Specification for Structures to be built in Disaster Areas, classifies the country into five seismic zones- in which Zone 1 is most severe. During the investigation, it has been noticed that in seismic areas, the master builders introduced special techniques to make the structure withstand the lateral forces in substructure and superstructure. The ignorance of the accumulation of master builder's knowledge and construction techniques of their time may lead to incorrect intervention and long-term harmful effects on the structures. Besides, these techniques may give clues for the design of contemporary structures.

This paper points out the importance of acknowledging the design skills of master builders during diagnosis of the failures in historic buildings while explaining the construction method and structural details design of master builders from the various civilizations who lived in Anatolia. Anatolia was in the heart of cultural and trade routes of the Europe, Asia and Africa. This paper is prepared through reviewing archaeological and history of architecture publications, discussions with archaeologists and experiences met during diagnosis phase of restoration works.

.

2. Building Masters

The ancient building master had to assume the roles of architect, structural engineer, mechanical engineer as well as the city planner and the contractor. The writings of the Roman architect Vitruvius and the studies on the previous master builders like Ottoman Imperial architect Sinan, clearly demonstrate that the “master builder” of the past was responsible for every aspect of creating a new building.

In order to make buildings safe, there exist several ancient construction codes from Assyrians, Acadians and Hittites, partly parallel to portions of the Hammurabi code, a well-preserved Babylonian law code, dating back to about 1772 BC. This Code of Hammurabi consists of 282 laws, with scaled punishments, adjusting "an eye for an eye, a tooth for a tooth" depending on social status, of slave versus free man. In terms of Construction, it represents one of the oldest written standards. It is not a prescriptive code but some sort of a performance code, stating basically the punishment for failure in construction [2]. For example:

- If a builder built a house for a man and do not make its construction firm and the house which he has built collapse and cause the death of the owner of the house, that builder shall be put to death.
- If it causes the death of a son of the owner of the house, they shall put to death a son of that builder.
- If it destroys property, he shall restore whatever it destroyed, and because he did not make the house which he built firm and it collapsed, he shall rebuild the house which collapsed at his own expense.

So, ancient building masters had to construct their buildings well to protect themselves and their family members. However, the available technology and scientific knowledge were within the grasp of a single person. The tablets Assyrian building masters placed on important buildings, describing each sequence of the construction [3], are one of the methods of transferring knowledge to the future generations.

These building masters, in creating buildings that still stand, used techniques developed by previous cultures, their own trial and error, and techniques transferred from one generation to another. Taking proper account of the environmental actions, they were able to empirically size and design the masonry structural elements.

3. Organization of the Structure

Masonry structural elements composed of stone, brick or adobe units are laid dry, joined to each other with metal clamps or laid in mortar. Resistance of a masonry building to exposed loads depends on the geometry of the structure, the strength and stiffness of the materials used, geometrical configuration of the units and the way the units are connected to each other. In order to make buildings safe, it is suggested that the building has to minimise seismic action and maximise energy absorption capacity of the structure.

3.1 Maximize the energy absorption capacity of the structure

To maximize the energy absorption capacity of the structure, the structure has to have capacity to dissipate energy and be redundant.

Assyrian architects usually posted tablets explaining the method they used in their construction. In one of the tablets it writes that masonry units have to move in order to dissipate energy [3]. In historic masonry buildings the metal clamps used to connect stone units were laid in lead. Lead covered the iron, avoided corrosion of the iron and let the blocks move. If stone and clay brick blocks are laid in mortar, using weak, rather than strong mortar let sliding along the bed joints dissipating energy so that the masonry unit will be safe. Here, mortar of the wall acts like the sacrificial part of the wall. The mechanical property of the mortar changed according to the strength of the masonry unit. İgnorance of this knowledge and construction technique may lead to incorrect interventions. Nikaloas Balanos, who led restorations of Parthenon from the late 1800s to the mid-1900s used iron clamps to hold the blocks of the columns together without coating them with lead. The damage caused by uncovered clamps has made it necessary to undertake several conservation interventions later [4]. And recent earthquakes in Italy, Greece and Turkey showed that encaging masonry walls applying shotcrete damaged these walls severely.

Redundancy of the structure depends on the nature of the structural system and the detailing of the elements. Masonry structures are inherently redundant structures. Arching action, inherent in masonry, prevents collapse of the structures from severe environmental actions. Building masters, knowing that the physical dimensions of height to thickness ratio and length to thickness ratio of the wall are important factors that affect the seismic performance of masonry walls, provided horizontal lacings that tied the outer faces of the walls and vertical supports at certain intervals. The lacings as timber or brick for stone, or stone for brick walls served to limit the support movements, to prevent wall bulging under gravity loads, to reduce the slenderness ratio of the wall and to prevent crack initiation at other locations. According to the 1840 building regulations, it was advised that masonry buildings will stand lateral forces better if they use metal ties. Afterwards, iron or copper ties were used as lacing. Metal lacings were joined to each other either with metal agrafe (Fig. 1a), seen out of the wall or inserted in lead in a round clevis, not apparent from outside (Fig. 1b). It is important to identify their placements in order to assess the slenderness ratio of the wall.

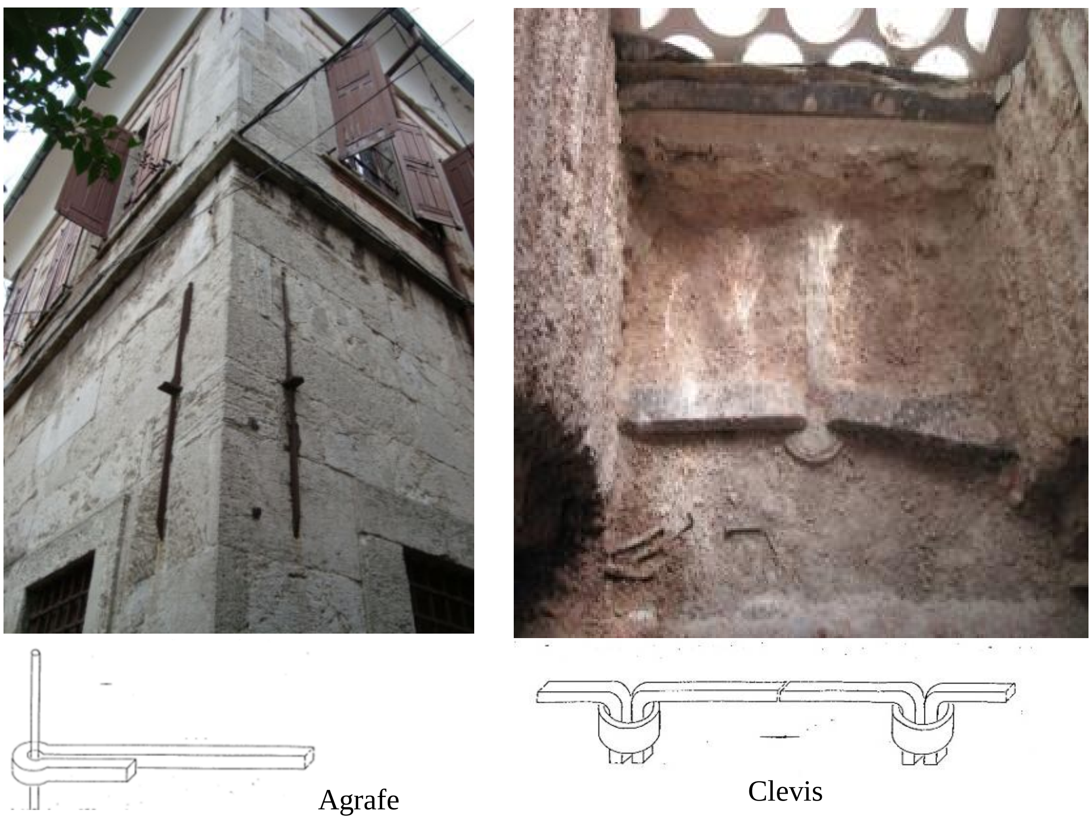


Figure 1 Metal lacing

Building masters, knowing that long projections and different weights of building components should be separated, provided seismic joints by not joining the masonry units of the adjacent structures to each other. Such construction features may be incorrectly interpreted as damage. Different weighted parts of Süleymaniye mosque in Istanbul and the Davutpasha hammam in Skopje has two arches side by side belonging to different weighing parts of the buildings (Fig. 2). Also in the archaeological excavations, it is seen that the structures built upon old foundations and the foundations of different parts of the building were not completely bounded to each other.

Figure 2. Double arches in Süleymaniye mosque and Davutpasha hammam

3.2 Minimize seismic action

To minimise seismic action, a building has to be light, to avoid actions that that will cause instability of the structural elements.

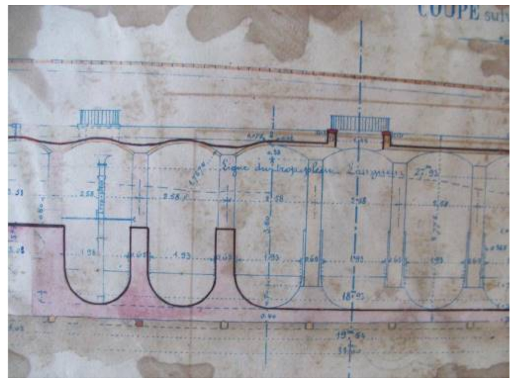
Masonry walls are heavy elements. The only way to reduce the weight of the structure was to make light roof and floors. In most places in Anatolia, due to the scarcity of wood, masonry vaults or domes were built to span plan areas. Ancient building masters knowing the geometry and behavior of these structural elements they constructed and provided proper measures to reduce the weaknesses. Some vault geometries such as cylindrical and torus vaults and spherical domes inherently have tension at the base along one of their principal curves. To counter the tensile stresses building masters provided wall thickening or changed the tension area into a corbelled system or closely spaced arched columns or piers at the base. While thickening the area of tensile stresses, they used clay pipes in the area of compression to reduce the weight of the vault or dome. To construct a flat roof or a floor over these vaults or domes, they either emptied the space between the compression area of the vault/dome and the roof/floor surface or filled it with amphora or clay pipes not to give extra weight to the vault or dome surface (Fig. 3). The steep vault with an elliptical parabolic surface which looks very similar to a pendantive dome and a paraboloid dome has compression on both of its principal curves. In this case these surfaces didn't necessitated any heavy area. So, to make a flat roof, whole space between the surface and the roof was filled with amphora or clay pipes.

Figure 3. Reducing the weight of the vault or dome

3.2.1 Foundation organization to minimise amplification of ground acceleration

Foundations, distributing loads from superstructure to the earth below, have to resist compression, tension and shear stresses imposed by the soil pressure and earthquake forces. The ancient building foundations of stone or brick masonry generally were deep in to the hard soil. The foundations of the buildings usually didn't pass the underground water level. The construction of foundation wall was either solid or a three leaved wall, where the space between the two rows of stones is filled with rubble and mortar or earth. Although the use of wood at the bases of foundation trenches was a standard practice, the use of wood ties in the cavity wall construction of the foundation has rarely been noted in the foundation systems. In the city walls of Istanbul, a wooden grillage could be found in the walls.

The thick ancient building foundations were generally a vertical wall down to the hard soil. During the process of time as the wall thicknesses reduced the smaller sizes of foundation walls widening at the foot were practiced. If the wall was composed of closely spaced piers and there was not sufficient depth to step the foundations, sometimes inverted arches or vaults were made (Fig. 4). Soft soil was consolidated by timber piles. The foundation walls rested on timber grllage embedded in a khorasan mortar over these timber piles.



Terkos Archive notebook

Figure 4. Inverted vault foundation of Edirnekapi Cistern

The foundation construction of the walls depends on the type of soil. The nature of the soil depends upon its grain structure and its geological history. Acceleration, generated by ground displacements, is amplified or attenuated by the soil structure. To minimize amplification of acceleration input and prevent resonance, adequate construction would be stiff structure on soft soils, flexible structure on hard soils and rock. Generally, the old foundation systems that support the historical structures are different from the current practice in terms of materials used and foundation organization. In high seismic zones, to provide the lateral stability of structures, building masters introduced special techniques to change the natural frequency of soil.

If the rock bed or hard soil was deep, the foundation walls rested on a pillow layer of sand, gravel or small stones as in Phaselis, Antalya (Fig. 5). If the hard soil was not so deep, the foundation walls rested on three layers of brick or stone blocks as in Alaca Höyük from Chalcolithic era [5], and in Urartian buildings at the east and Greek temples at the southwest of Turkey (Fig. 5). An Assyrian tablet says that the soil was cut to the rock and the foundation was placed after filling the trench to 28 elbows height [3]. The foundations of masonry village houses at east Anatolia were constructed on a layer of ~40cm sand till 1960s. The thick layer of sand, gravel or stone pieces provided a change in the natural frequency of soil as well as adequate subsurface permeability to avoid a high water table condition [6].

Phaselis in Antalya

Urartian Castle in Van

Figure 5. Pillow layer of gravel at Phaselis

If the bed rock was close to the surface, a flexible base was provided by placing single or more layers of a wooden grillage at the foundation base (Fig. 6). At the bottom of the foundation wall in Beycesultan, a single layer of round wood poles projecting out 1.0-1.5m out from the foundation wall was laid side by side with small stones in between them [5]. Foundation walls of a Byzantine chapel in Üsküdar, Süleymaniye Mosque from 16th C. [6] and the inverted vault foundation of Edirnekapi Cistern from late 19th C. in Istanbul are constructed over two layers of wooden grillage laid perpendicular to each other (Fig. 4). The foundation of the Konjic Bridge, an Ottoman bridge in Bosnia & Herzegovina also contained two layers of wooden grillage laid in between two dolomite layers forming a platform for the foundation footing [8].

Figure 6. Wooden grillage of a Üsküdar and Sirkeci Byzantine chapels in Istanbul

If the rock bed was on the surface, the rock was carved in the form of trough so that each stone of the foundation wall could be placed in the rock as if resting in a cradle [5] (Fig. 7). In between the rock and the foundation stone; briar, pieces of coal or animal skin was placed [9]. Such rock foundations in the form of trough were often met in tells at southeast Turkey, in Boğazköy, a Hitite settlement at Middle Anatolia [5] and the Temple of Diana at Ephesus [10].

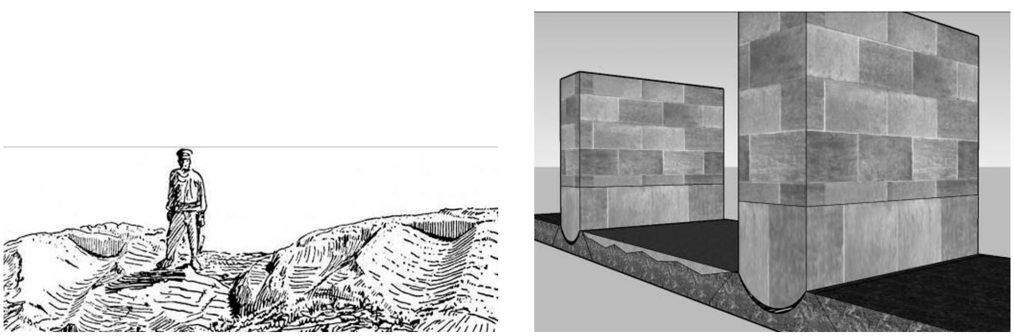


Figure 7. Foundation wall on rock

Another different foundation system practice was met at the 16th century octagonal tomb foundation of the Yavuz Selim Mosque complex. Around 4m distance away from the octagonal tomb, 6m high buried stone wall having 2m thickness in the same octagonal form was found as if a retaining wall to absorb the first shock of earthquake forces (Fig. 8). Its effect on keeping the octagonal building from seismic forces has to be studied.

Figure 8 Retaining wall of the tomb at Yavuz Selim Mosque

3.2.2 Avoid instability of the structural elements.

Ancient building masters were aware that water was the most serious non-seismic threat to masonry buildings in areas of both high and low seismicity. Depending on the porosity of foundation construction material and soil characteristics it can damage the wall and soil by eroding away portions and by reducing the strength. To prevent instability of the building from underground water movement and to collect the surface water of rainfall they designed an effective drainage system.

In archaeological excavations, it is seen that surface and subsurface drainage was given high priority during design and construction. The foundation rituals in Sumerian, Akkadian [11] and Egyptian texts [12] for temples, palaces, tombs, and forts actually consisted of marking the corners of the building with stakes and tying a cord to link them. In the morning, the priest representing the Earth God loosed the cord so that it slipped down the stakes marking the limits of the building on the ground and started the first foundation trench of the building with a wooden hoe. Then the earth was cut through to the water table which represented the upper limit of the water god, Nun. Before starting the construction of the foundation, they constructed a well to unite the Water God to the Earth God. To reach the water table, sometimes they had to cut the rock layer. This construction system, constructing a well in the building, was practiced until late 19th century especially in high seismic zones in Anatolia (Fig. 9).

[1]  [2] 

Figure 9. Wells, gates, channels in the building

The major components of the drainage system to drain interior ground surfaces of a building included wells or cisterns in the basement, galleries or channels that discharge the water out of the building, and gates for ventilation of the building (Fig. 9). The depth of the galleries or channels connecting wells to each other or discharging water away from the building varies from 30-40cm to 1.0-2.5m depending on the size of the building. These are generally constructed of stones or bricks with mortar binding [10]. These channels removed the water from surface and underground water, and served to keep the structure warm in the winter and cold in the summer. And during earthquake, they discharged the raising underground water avoiding soil liquefaction.

In settlements, the channels, penetrating the walls, generally continued to the other building's drainage system then was discharged to a channel along a main road or to a cistern or to a fountain tank. In most of the Byzantium buildings in and around Istanbul, the underground water was discharged to a cistern or the foundation of the buildings included cistern. In the area of Topkapı Palace, more than forty cisterns were found within the substructures of buildings [13]. The twelfth-century the church of Pammakaristos includes a large colonnaded and vaulted cistern that extends under the naos and parts of the ambulatory, now filled with soil. Yavuz Selim Mosque in Fatih district includes a large gallery heading toward a cistern that is blocked by the foundation of the mosque. There is also a cistern near the Fatih Mosque. In Ottoman settlements, the channels, penetrating the walls, generally continued to a nearby fountain tank.

Because this practice is completely forgotten demolished drainage systems due to new constructions around heritage structures is a frequently met phenomenon. Such blocking of the subsurface water control system causes water to rise to the building and soften the soil which leads to the building settlement. During diagnosis of the failures of the building, if this knowledge is ignored consolidation of the soil will not solve the problem. For intervention, the blocked or demolished channel has to be found to provide proper discharge of the water.

During investigation in 1994, the piers of Küçük Ayasofya Mosque- former Church of Sts. Sergios & Bacchos (527-536 AD) were in saturated form and the building had developed many cracks due to partial settlement. The environmental change by filling the sea in front of the mosque must have demolished the underground water discharging system. In restoration during 2004-2007, a well was found in the building and its rectangular discharging galleries were filled with concrete thinking that this rectangular holes were the places of rotten timber ties. Now, after 11 years of restoration, piers started to get moisture again and have 70-100% moisture.

4. Conclusion

Ancient building masters, with accumulation of knowledge from previous cultures minimised seismic action and maximised energy absorption capacity of the structures and were able to size and design structural system through;

- Connecting the masonry units properly so that they dispersed energy
- Providing seismic joints by not connecting the different weight components of a building.
- Constructing vaults and domes taking into account the stresses caused by their geometry.
- Designing effective underground drainage systems
- In EQ areas; changing the natural frequency of soil by providing flexible bases of pillow layers of sand or gravel under the foundations, placing round wood layers at the foundation bases and carving the rock in the form of a trough.

Before making a decision on structural intervention it is indispensable to determine first the causes of damage and decay, and then to evaluate the safety level of the structure with experts of multi-disciplinary team [1]. In diagnosing the failures, investigation of the historical records is important. Historical records should be investigated by experts and historians who are able to adequately interpret the ancient texts, in cooperation with the structural engineers, assisting the historian in the identification of structurally meaningful records.

Ancient engineering systems are different than current ones. The knowledge of the old construction technique was lost during the last century. In investigating heritage buildings, it is important to take into account the engineering knowledge of their time. Ancient building masters introduced special techniques to make the structure withstand the lateral forces and to control the underground water movement. Ignorance of the master builder's knowledge and construction technique may lead to incorrect intervention and long-term harmful effects on the structure.

.

5. References

[1] ICOMOS Charter 2003: Principles for the analysis, conservation and structural restoration of architectural heritage, ratified by the ICOMOS 14th General Assembly, in Victoria Falls, Zimbabwe, October 2003.

[2] Izquierdo - Encarnación, J. M. (2011): “Codes and Specifications as Applied to Historic Preservation Projects”, WCCE-ECCE-TCCE Joint Conference 2, Seismic Protection of Cultural Heritage, Antalya, Turkey.

[3] Sevin, V. (1998): Neo Assyrian Art- Architecture, (in Turkish) Publication of Atatürk Cultural Center.

[4] Tzonis, A., Rodi, A. P. (2013): *Greece: Modern Architectures in History*, London: Reaktion Books Ltd

[5] Naumann, R. (1991): *Old Anatolian Architecture*, (in Turkish), Third Edition, Publication of Turk History Association, Ankara, Turkey

[6] Arun, G. (2009): “Ancient Building Foundation Systems in Seismic Areas”, Wiadomosci Konserwatorskie, *Journal of the Association of Monument Conservators,* nr 26/2009 pp: 278-288, ISSN 0860-2395

[7] Aksoy, I.H. (1982): *Foundation Systems Applied on Historic Structures in Istanbul Historical Peninsula*, (in Turkish), ITU PhD Thesis

[8] Sert, H. (2007): “Konjic Bridge / Bosnia and Herzegovina”, *Proceedings of the Int. Symposium on Studies on Historical Heritage* - SHH07, Antalya, Turke

[9] Plinius Secundus, C. (1601): *The Historie of the World*. Book 37 translated by Philemon H

[10] Ousterhoud, R. (1999). *Master Builders of Byzantium*, Princeton University Press, Princeton, New Jersey

[11] Lawton, I. (2000). Ancient Mezopotamia, http://www.ianlawton.com/mes1.htm (28.03.2008)

[12] Montet, P. (1964). “Le ritual de foundation des temples Egyptiennes” Kemi 17 pp: 74-100

[13] Eyice, S. (1973). “Byzantium Ruins in Degirmenaltı, Tuzla”, (in Turkish) *Sanat Tarihi Yıllığı 5*