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Seismic Behavior Investigation ofHistorical Bath Structures

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ABSTRACT: Some of the historical structureshave been keeping their existence with good shape whereas the majority of them have not been able to.To investigate the reason behind this behavioral difference, it is quite important to know the seismic behavior. It is also important to transfer the historical structures to the future generations. The historical structures reflect the form of social life, culture and regional construction techniques of the past.In this study,dynamic analysis was carried out for historical bath structures with selected case studies from Anatolia namely Minor Asia, as Meram Sahip Ata Bath and Kastamonu Foundation Bath structures which are important examples of the historical bath structures in Anatolia. The selected case historical bath structures were investigatedby modelling with finite element modeling.In the anlaysis, SAP2000 software was used to determine the structural behavior of historical bath structures under earthquake loading. Time history analysis was carried out for modelled bath structures by using 10 different ground motion data. The values obtained by the end of the analysis were compared with eachother. In the result of the study, the seismic behavior of the bath structures was defined with the detailed structural investigation under the earthquake effect.
Keywords: Hictorical bath structures, time history analysis, structural investigation

I. INTRODUCTION

Bath structures are the historical variant of the Roman bath to Turkish bath, steambath, sauna, or Russian banya, distinguished by a focus on water, as distinct from ambient steam (Wikipedia, 2017).In Anatolia, namely, Minor Asia, bathstructures are modest historical structures in terms of their construction techniques and architectures.Therefore, thesebath structuresare not attractive as much as the the other existing historical structures such palaces or mosques.The bath structures which are one of the important structures of the civil architecture have been remained in the backgroundnowadays because of the alternative cleaning facilities appearingwith the development of technology and had lost the economical and functional values in time from Ottoman time to present.

In bath structures, cleaning areas are the basis, and these areas were formed by using areas for the purpose of meeting the requirements(Aydin et al., 2007, Ilica, 2002). From the hamma word which means heating in Arabic and which means stream bath is one of the social spaces where people meet for cleaning(Aktan, 2010).The bathstructures are among the most important examples of Seljuk and Ottoman architecture.They changed the traditional construction of historical Islamic bath. The difference between the Islamic bath and the Victorian Turkish bath is the vantilation and air circulation techniques in the construction. Cleanliness was very important at Seljuk and Ottoman period. Therefore, the bathstructures also gainedgreat importance such as mosques. A large number of them were constructed at the Seljuk and Ottoman period.These historical structures which are considered as cultural heritages and responding to a great need in the past periods should be transferredto future generations(Aktan, 2010; Ilica, 2002).Bath strctures were constructed by using ruble stone, rough stone, brick, wood and bindinglime mortar(URL-a, 2016;Ani anitsal, 2013; URL-b, 2016).The outer wall thickness ranges from 70cm to 80cm and the inner wall thickness ranges from 60cm to 80cm. These walls constitute the vertical carrying elements of the structure (Canet al., 2012, Reyhan, 2004).

II. MERAM SAHIP ATA BATH AND KASTAMONU FOUNDATION BATH

Sahip Ata Bath forming a part of Sahip Ata Precinctsis located in the town of Konya Meram.Sahip Ata Bath commissioned to Keluk Bin Abdullah by Fahreddin Ali in 1283 as a double bath.The dimension of Sahip Ata bath is 25.52mx47.74m.This bath structure has rectangular plan and it composedfrom the cold, warm and hot sections. The other name of Sahip Ata Bath is Sultan Bath.The historical Sahip Ata bath is shown in Figure 1.Kastamonu foundation bath was built at the end of the century by Muzaffereddin Yavlak.Currently, there is one closed entry in its East at the outside is the available entrance of bath today.The South wall of the bath which is in 1350cm length and the Northern wall of it which is in 1340cm length were constructed with stone rubble and cement mortar was usedin both walls.The historical Kastamonu Foundation bath is shown in Figure 2.

Figure 1. Meram Sahip Ata Bath (URL-c, 2016,Anitsal, 2013)

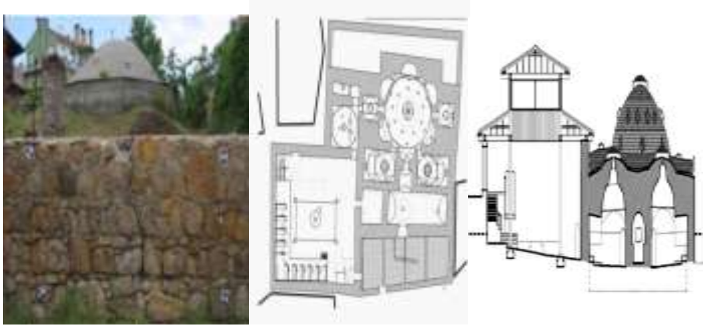

Figure 2. Kastamonu Foundation Bath

III. STRUCTURAL ANALYSIS

Numerical modelling is transformed into the appropriatemathematical terms according to the basic rulers of the mechanic of the carrying system elements with different material and cross sectional geometry. Numerical modelling is very important in finite element modelling of the historical structures (Can et al., 2012; Kırlangic, 2008).The basis of the finite element method is to solve bysimplistic approach.Area to be examined with finite element methods consists of sub-regions referred to as small finite element which is numerous simple.When a structure was considered with finite element modelling, the structurewas described by dividing in one, two or three dimensional finite elements which connected to each otheranda finite element mesh, which represents a structure, is generated.The real geometry of structure represented by depending on the increase of the number of finite elements can be better represented. Modelling with the finite elements method of all elements of a structure increases the solution time of problem. Therefore, Softwares that providethe networkderivation opportunity and required data entry were used(Peker, 2005,Vatan, 2005).

Shell element is three or four pointed elements allowing to the loadings in the plane and perpendicular to the plane. This element has six degrees of freedom which has shift at X, Y, andZ directions and rotational freedom around this axis. Shell elements are also used in modelling of the smooth curved surfaces as shells as shell elements in the different shapes are shown in Figure 3 (URLd, 2016).

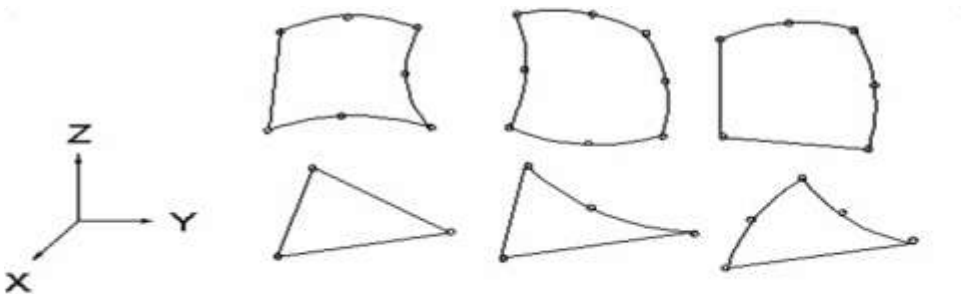

Figure 3. Different Shell element shapes (Autodesk, 2016)

In the present study, Meram Sahip Ata Bath and Kastamonu Foundation Bath structures were modelled with finite elements method by using SAP 2000 software. When the mathematical modeling of the structures wereconstructed, the needed geometric features and dimensions were taken according to the existing drawings.Three-dimensional modelingof historical bathsare shown inFigure 4.Meram Sahip Ata Bath was modelled with 20249 nodes and 19838 shell elements and Kastamonu Foundation Bath was modelled with 4326 nodes and 4377 shell elements.

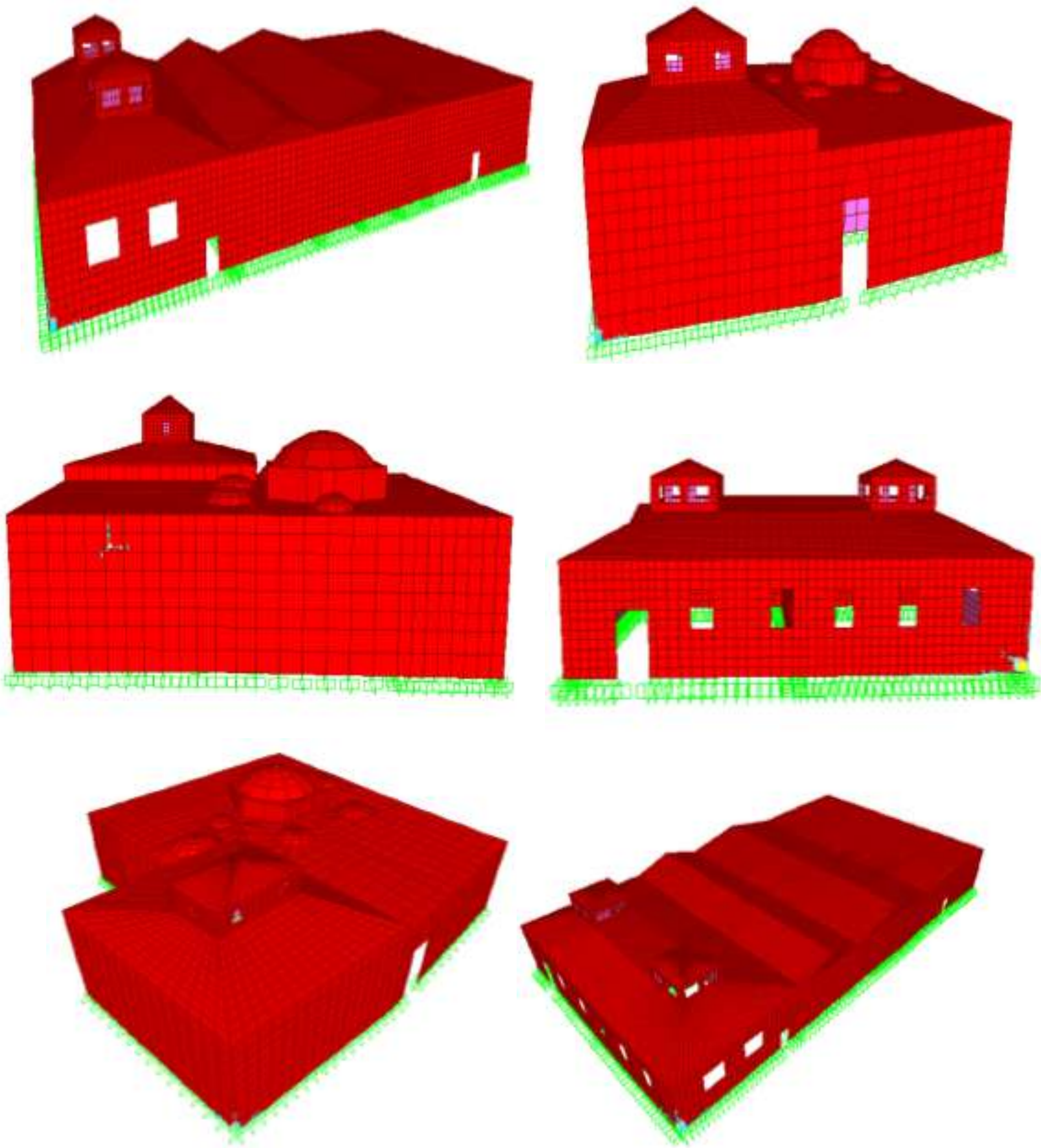

Figure 4. Finite element model of Meram Sahip Ata Bath and Kastamonu Foundation Bath

Many historical structures were built usingnatural stone and binder materials. These materials were considered in the present study. Used material properties are given in Table 1. When determining these properties, previous research works were also investigated in detail and all information have been collected through a detailed literature content analysis. For the analysis of the existing models, time history analyses were carried out with the real earthquake ground motion records.The earthquake ground motion records used are given Table 2 (Turk and Cosgun, 2012, Peker, 2005, Reyhan, 2004).

Table 1 . Material properties used in the modeling

	Modulus of Elasticity (KN/m^2)	Unit volume weight (kN/m^3)	Mass (kN)	Poisson Ratio
Walls (stone and plaster)	450000	24	2, 4473	0, 2
Covering Material	13000000	2,2	0, 2243	0, 16

Table 2. Ground motion records used in analysis

No	Earthquak e	Date	Moment Magnitu de (Mw)	Record	Ground Velocity (cm/s)	Ground Acceleration (g)	Epicenter distance (km)	Type
1	Anza	25/02/1980	4.9	AZF22 5	3.3	0.065	12.1	lateral slip
2	Cape Mendocino	25/4/1992	7.1	CPM-UP	63	0.754	8.5	Oblique
3	Coyote Lake	06/08/1979	5.7	G01320	8.3	0.132	9.3	lateral slip
4	Lytle Creek	12/09/1970	5.9	CSM09 5	1.8	0.071	88.6	Oblique
5	Kobe	16/01/1995	6.9	KJM00 0	79.3	0.8213	6.9	lateral slip
6	Loma Prieta	18/10/1989	6.9	G01090	33.9	0.473	11.2	Oblique
7	Parkfield	28/06/1966	5.6	C12320	6.8	0.0633	14.7	lateral slip
8	San Fernando	02/09/1971	6.6	ORR02 1	15.6	0.324	24.9	Oblique
9	Victoria, Mexica	09/06/1980	6.1	CPE045	31.6	0.62	34.8	lateral slip
10	Whitter Narrows	10/01/1987	6.0	ALH18 0	22	0.333	13.2	Oblique

IV. SEISMIC BEHAVIOR OF HISTORICAL BATH STRUCTURES

SAP 2000 finite element softwarewas used in process of the structural behavior determination of the historical bath structures under eathquake loading. 12 mode were considered in the dynamic analysis process.The values of the displacements and stresses inX and Y directions for each earthquake ground motion record applied to the structureswere obtained and the results are shown with graphics.The period values in the result of the modal analysis are shown in Table 3.The values of the displacement and stress obtained for Meram Sahip Ata and Kastamonu Foundation bathstructures are shown in Figure 5, Figure 6, Figure 7, and Figure 8.

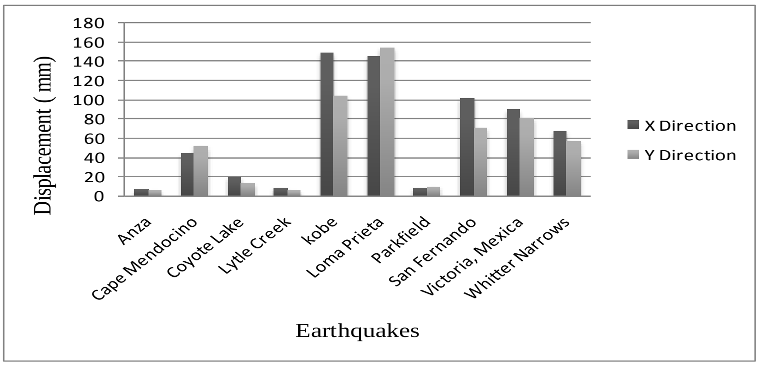

Figure 5. Displacement values of Meram Sahip Ata Bath

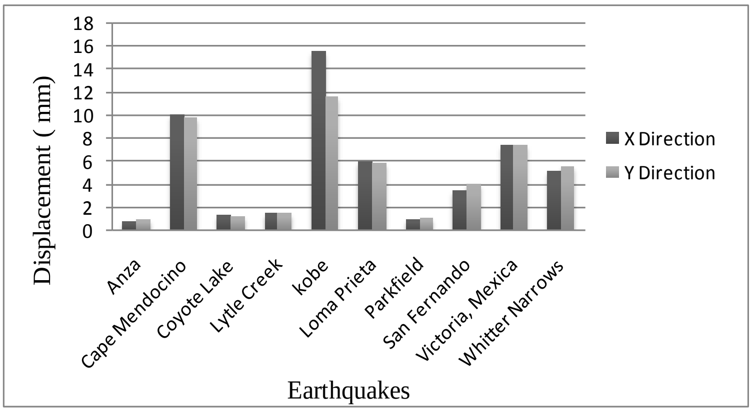

Figure 6. Displacement values of Kastamonu FoundationBath

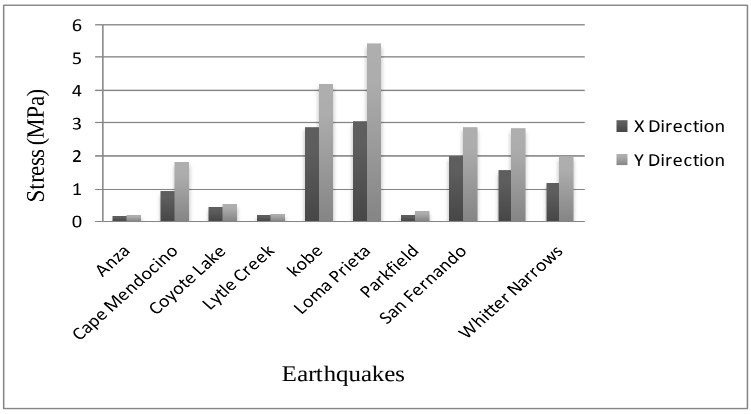

Figure 7. Stress values of Meram Sahip Ata Bath

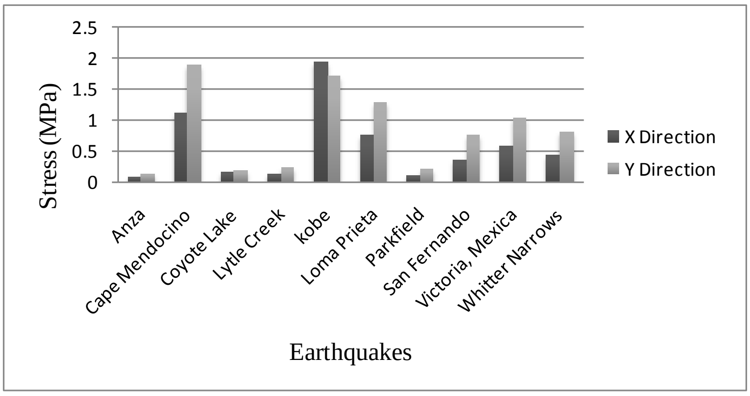

Figure 8. Stress values ofKastamonu FoundationBath

Table 3. Period obtained from historical bath models

Periods (sn)	**Meram Sahip Ata Bath**	**Kastamonu Foundation Bath**
T_1	0.416354	0.175441
T_2	0.362473	0.144597
T_3	0.350537	0.107727
T_4	0.346153	0.100408
T_5	0.344766	0.095648
T_6	0.341649	0.091312
T_7	0.340472	0.089871
T_8	0.33884	0.08469
T_9	0.335897	0.083221
T_{10}	0.331335	0.082553
T_{11}	0.329235	0.079246
T_{12}	0.326285	0.076893

V. RESULTS

Comparing to residential structures, historical structures are exposed to the more seismic loading because of their structure weights. Comparing with the other structures,historical structures are more affected from earthquakes. The knowledge of the behavior of the historical structures under earthquake effect is very important in terms of sustainability of these structures.In this study, Meram Sahip Ata Bath and Kastamonu Foundation Bath were modelled by using SAP 2000 software with their real dimensions and the earthquake behavior of the structures was examined.The dynamic analysis were performedby using10 earthquake ground motion data. The highest displacement value at both structureswere occured at Kobe Earthquake and highest point of structures.The lowest displacement was occurred at Anza Earthquake at the base of the structures.The highest stress values were occured in Kobe Earthquake which were obtained with the highest displacement values. When comparedthe results of the displacement and stress values obtained from both structures, it was seen that,the results of Meram Sahip Ata Bath which is geometrically higher and wider dimensional is higher according to the Kastamonu Foundation Bath.

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