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An Example of the Analytical Solution of Historical Structures

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ABSTRACT— ***In this study, the examples of Beylerbeyi turbesi in Edirne, which had been the capital of the ottoman empire for nearly a century and still contains many examples of civil and religious architecture, were examined and the structural performance was presented in terms of static and dynamic finit elements. ın order to obtain information about the general behavior of the structure, analyzes were carried out by using the material properties given in the literature and the formulas given in the earthquake regulations. according to the analysis using sap2000 v18 package program, methods to increase the structural performance of the existing structure have been proposed by determining critical locations in terms of static.***

Keywords— Historical Structures, Structural Performance, Strengthening, Masonry Structure, Vaults, Domes

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1. INTRODUCTION

Our country has hosted many civilizations and possesses historical accumulation structures like historical buildings, walls, mosques, bridges, churches. While the earthquake safety is considered in the design of the newly constructed structures, it is necessary to evaluate the earthquake performances of the existing historical structures from the other side and to take the necessary precautions [1].

In time, some problems arise as a result of various effects such as nature conditions and natural disasters in materials used in historical buildings and structure. For this reason, it is very difficult to quantify modeling and real behavior of masonry and tombs such as mosque and mausoleum in historical buildings [2]. The details of the carrier systems of such structures are very different from the carrier systems of traditional building types, and details are at the forefront and make modeling difficult [3-4].

2. EVALUATION OF HISTORICAL STRUCTURES BY MODELING

2.1. Used Parameters modeling

Because of it is not always possible to carry out experiments that will determine material properties by taking samples from historical structures, it is sometimes very difficult to determine the bearing capacities of structural members according to the calculation results. The parameters used in the calculation of the structural earthquake forces are given below.

A_0 (Earthquake Region Coefficient) = 0,1 (Region 4)

If the ground class is not foreseen, S(T) = 2,5 according to DBYBHY

I (Structure Importance Coefficient) = 1

R (Carrier System Behavior Coefficient) =2

In describing the masonry wall material, the Elasticity Module of the masonry units used for wall construction according to the regulations is 200 times the character pressure resistance of the material,

$$Ed = 200\ fd\ * \qquad (1)$$

The pressure resistances of natural stones to be used in the construction of bearing walls according to Turkish standards 2510 should not be less than 350 kgf/cm^2.

$$fd = \text{free compression strength } *0.5 \qquad (2)$$

f_d = 0,5*x350= 175 kg/cm^2
E = f_d *x200
E= 175x200=35000 kg/cm^2

The safety pressure tension for the stone masonry walls is suggested as f_{em}=0,3 MPa , f_{em}=0,3 MPa.

Tension safety tensions can be accepted as 15% of the value determined as pressure safety tension. In this case, the tensile safety stress for the stone wall is calculated as $f_{m(çek)}$= 0,3× 0,15 = 0,045 MPa. The earthquake force from the wall is divided into the horizontal cross-sectional area of the wall, and the shear stress that occurs in the wall will be calculated. The safety tension will be compared with τ_{em}. (DBYBHY2007)

$$\tau_{em} = \tau_o + \mu\sigma \qquad (3)$$

$$\tau_{em} = 0{,}10+0{,}5(0{,}3/2) = 0{,}175 \text{ MPa}$$

2.2. Beylerbeyi Tomb

On the way of Saraçhane and in the graveyard of the Beylerbeyi Mosque. For Rumeli Beylerbeyi Sinaneddin Yusuf Pasha, it is thought that it was built together with the mosque in 1429. A sufficient number of visual and written sources about the Beylerbeyi Tomb have not been reached. The oldest photograph from the visual documents belongs to 1932, and the structure is also ruined at that time [5]

2.2.1. Pre-restoration architectural features

The information given in this section was taken from the restoration, restoration and restoration reports prepared for Beyler Beyi Tomb of Edirne Vakıflar District Directorate in 2008 before restoration of the building. In figure 1, the pictures of the turbine before and after the repair are given.

Figure 1. Status of Beylerbeyi Turbes in 2008

2.2.2 Structural model and analysis

The analysis of the finite elements made to finite the structural performance of the Beyler Beyi Turbine is based on the stresses calculated in the SHELL elements and the tensile or compressive stresses (defined as S22 according to the format of the SAP2000 V18 program) vertical to each element's own axis (according to the format of the SAP2000 V18 program S12) gives the most descriptive conclusion about the strength of the shear stresses. SAP2000 V18 finite element program is used for modeling. The walls of Yapi consist mainly of at least three main materials, stone, brick and mortar (plaster). However, since the general behavior of the structure in the model is concerned, it is assumed that the carrier elements are formed from a single material and the related unit volume weight, modulus of elasticity and Poisson's ratio are used. Based on the building survey project, the wall thickness in the numerical model is defined as 0,8 m and the variable thickness of the cube is defined in three different thicknesses, 0,3 m, 0,4 m and 0,5 m, respectively, taking into consideration the measurements specified in the project till the end of the dome. The material of the wall is stone, the material of the dome is brick, and the material of the pulling ring is reinforced concrete. In the model, the carrier elements of the structure are defined as shells. In the prepared structure model, 303 shells (area) were created by using 329 knot points. 40 fixed supports are defined in the points that are transferred to the floor.

The results obtained are given in terms of colored stress distributions and graphs, since the results of the analysis obtained are very difficult to give at each node and each element.

Based on the build survey project, in the numerical model, the wall thickness is defined as 1.1 m, and the thickness of the cove is defined as 0,25 m. The materials of the wall and the minaren are stones, and the material of the dome is brick. The carrier elements of the structure are modeled as shells. In the prepared structure model, 559 shells (field) were created by using 558 nodes. 51 fixed supports are defined in the points that are transferred to the floor. Modeling of the structure is given in Figure 2.

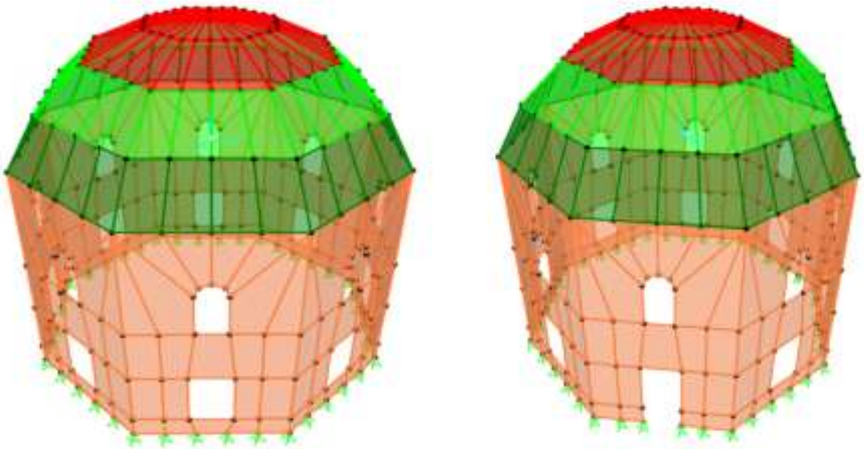

Figure 2. Structural modeling of Beyler Beyi Tomb

The results obtained are given in terms of colored stress distributions and graphs, since the results of the analysis obtained are very difficult to give at each node and each element.

2.2.2.1. Analysis under dead loads

By using the unit volume weight (γ), elasticity modulus (*E*) and Poisson ratio (ν) values of building materials, weight effect of construction is taken into consideration.

The weight of the construction is G=5156,43 kN'dur.

As a result of the statistical analysis of the three dimensional finite element model of Beyler Beyi Tomb under its own weight, the possible stress distributions in the structure, the strain values were reached and critical locations where cracks could occur were determined.

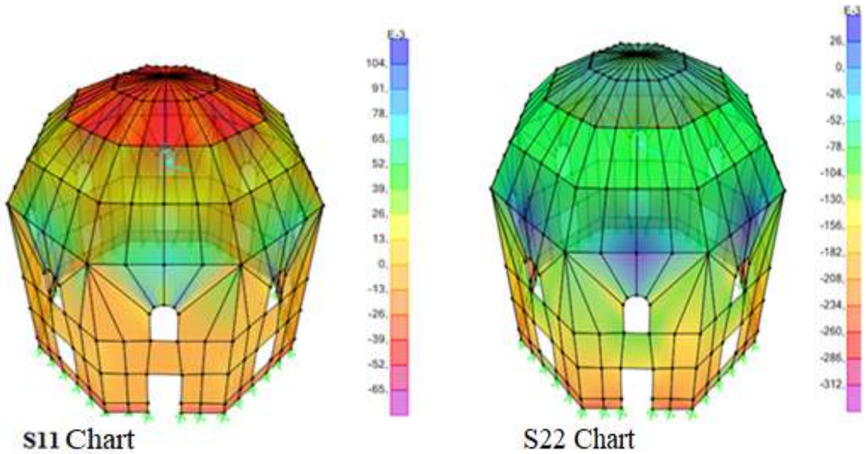

Figure 3. G loading S11 (X direction) and S22 (Y direction) tensile distribution (10^{-3}N/mm^2)

Individually prepared according to the load G affecting the behavior of the structure of S22 and S11 (tensile and compression) S12 tensile value graph (slip) when stress values chart is analyzed, the adverse pressure stresses calculated in S22 graphics from 0312 MPa and most unfavorable tensile stresses are also S11 chart of 0104 MPa as. Under the maximum bearing G load determined from the S12 curve, the largest displacement in the structure is about 0,533 mm in the vertical direction at the top of the dome. Since R=2 is used in this analysis, the elastic displacement should be calculated as 0,533 mm×2=1,066 mm. As a result, when the effects obtained in the structural analysis are examined under the G loading, it is observed that the bearing walls of the structure have not exceeded the pressure and shear stress values proposed for the aggregates in the Turkish Earthquake Directive. The compressive stress is 0,035 MPa. This value is also below the safe shear stress value.

2.2.2.2 Modal analysis

In spectral seismic solution, constant spectral coefficient S(T)=2,5 and effective seismic coefficient A_0=0,1 were assumed. In determining the earthquake effects, the method of joining the modal effects is adopted and it is aimed to obtain the elastic behavior of the structure under vertical and earthquake effects, using the method of exact quadratic joining. The earthquake load reduction factor R=2 is considered in all periods. With modal analysis, the mode shapes and periods are obtained by using the mass and stiffness matrices of the structure system. The modal analysis of the Beyler Beyi Turbine end element model was performed on the SAP2000 program and as a result, 30 modal and free vibration periods were obtained. The sum of the mass participation rates of the first 30 modes is 92%. The mass participation rate of the first mode showing the lateral displacement movement of the main body in the X direction is calculated as 66% and the mass participation rate of the second mode showing the lateral displacement movement in the Y direction is 65%. Since the structure is symmetrical, the mass participation rates give almost the same value.

2.2.2.3. G+E_x ve G+E_y earthquake loads

Shape changes occurring in the modal spectral analysis resultant structure under earthquake loads reduced by the earthquake load reduction coefficient (R = 2) affecting the dead loads in the X and Y directions are given in Figure 4.

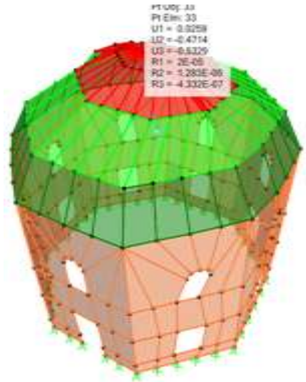

Figure 4. Location changes of the dome under the G+E_x earthquake loads of Beylerbeyi Tomb (mm)

The G+E_x earthquake loading brings a lateral displacement of 0,47 mm and 0,53 mm in the X direction. The G+E_y earthquake loading brings the lateral displacement of 0,47 mm and 0,53 mm in the Y direction. As a result of the analyzes made, it was determined that the most difficult parts of the structure in the static state are the edges of the upper window cavities

In the case of G+E_x earthquake loading, it is seen that the regions where the S11 and S22 stresses in the building are unsuitable are at the corner points of the dome and wall junctions and the windows and door openings. The maximum compressive stress at the construction is calculated as 0,286 MPa, which does not exceed the pressure safety stress of 0,3 MPa. However, the tensile stresses determined at 0,242 MPa exceed the tensile safety stress and reinforcement is required

The calculated maximum shear stress was 0,110 MPa. This value is under the calculated value of safe shear stress at 0,175 MPa

3. RESULTS

In the extent of the study, Beylerbeyi Tomb is a historical structure covered with a square-shaped, single-volume dome, from early Ottoman architectural examples. As a result of the analyzes made, the following results were obtained).

Beylerbeyi Tomb: The maximum tensile stresses were calculated as 0.286 MPa / 0.3 MPa, the maximum tensile stress 0.242 MPa / 0.170 MPa, and the maximum shear stress 0.110 MPa / 0.110 MPa, respectively, before and after the tensile test. The construction was observed as of January 2017, no visible damage to the building was found. The earthquake behavior of historical stacking structures, horizontal and vertical load carrying arrangements, the calculation of horizontal and vertical stresses on the walls, and many other issues do not find enough room in civil engineering education. In this regard, architects and architectural firms are more actively involved, leaving static criteria in the shadow of architectural studies in assessing the earthquake resistance of historical mounds and determining their fate.

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