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EVALUATION OF THE HISTORICAL IPLİKÇİ MOSQUE ACCORDING TO DBYBHY 2007 AND TBDY 2018 REGULATIONS

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Highlights

- It is necessary to carry out the necessary controls and maintenance in order to protect and maintain the historical structures that have existed from the past to the present.
- While there is only unreinforced masonry building type in the 2007 earthquake regulation regarding the design rules of masonry buildings, 3 new masonry building types have been added in addition to the unreinforced masonry building type in the 2018 earthquake regulation.
- In 2007 earthquake regulation, the calculation method of safety stresses is used while making the investigations. With 2018 earthquake regulation, the calculation method of safety stresses was abandoned and the method of calculation of bearing capacity began to be used.
- The calculation methods for masonry buildings with the 2018 earthquake regulation are more detailed and comprehensive than the 2007 earthquake regulation.
- Earthquake parameters can be obtained directly from AFAD by entering the coordinates where the building is located in the earthquake hazard map of Turkey in the 2018 earthquake regulation.
- There is no separate section in our 2018 earthquake regulation for studies on historical buildings.
- It is necessary to create an additional section to our earthquake regulation regarding the calculation methods of historical buildings.

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ABSTRACT: Preservation of historical structures that have survived from the past to the present and their sustainability; It is possible with education, knowledge and ongoing care. Historical buildings have been damaged over time due to natural and artificial reasons. However, thanks to the craftsmanship of the period in which they were built, they have managed to reach the present day. It is very important to examine the current conditions of these structures, to determine the damage, to choose the most appropriate technique for repair and strengthening, and to make the necessary intervention in a timely manner.

In this study, the Historical İplikçi Mosque in Konya was modeled with the finite element model in the SAP 2000 program. On the model, earthquake resistant design rules and calculation methods were compared according to the Regulation on Buildings to be Constructed in Earthquake Zones (06/03/2007) and Turkey Building Earthquake Regulation (18/03/2018). As a result of the study, it was seen that the calculation methods used with TBDY 2018 and the rules to be followed have changed and new building types were added. As a result of the analyzes obtained from the examined structure, it was seen that the structure did not meet the DBYBHY 2007 principles, but the TBDY 2018 principles.

Keywords: *Code, Comparison, Earthquake, Historical Buildings, Masonry*

1. INTRODUCTION

Historical buildings; are the structures that human beings have built for different purposes from past to present, that we need to protect today and that we are responsible for transferring to other generations. To such structures; mosques, madrasas, churches, synagogues, palaces, schools, hospitals, administrative buildings, water structures, military barracks, fortifications and towers can be given as examples [1].

Historical buildings are artifacts that have been built from the natural materials of the region they are located in, have different functional properties, and have survived from the time they were built to the present day. Investigations should be carried out in the buildings in order to maintain and protect the historical buildings. According to the damage assessments obtained as a result of the examinations, it is necessary to select the appropriate repair and strengthening techniques.

Different studies have been carried out in the literature on issues such as the repair and strengthening of historical buildings and their behavior under the influence of earthquakes. In his study on the bearing systems of masonry structures, the types of materials used, the examination of earthquake safety, the repair and strengthening of historical buildings, Kara [2] conducted a study on the examples of the practices made on these issues and the repair and strengthening methods that can be applied currently. Aköz [3] worked on the repair and strengthening of historical masonry structures and modeled a historical masonry structure in three dimensions and made static and dynamic analyses on the model. He focused

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on the need to determine the earthquake safety of the structure and strengthen it and the strengthening methods. Döndüren et al. [4] in their studies, they discussed in detail the types of damage seen in historical buildings and argued that static problems and new methods should be developed by adhering to the original, except for the cleaning and repair works of historical buildings. Tetik [5] created the finite element model of the Seyh Süleyman Masjid in the Historical Peninsula of Istanbul. By examining the condition of the structure under its own weight, vertical loads and earthquake loads; static, dynamic and time history load analyzes were performed. Similarly, in her study, Chamaky [6] created models of the historical Çinili Police Station, Fatih Primary School and Sirkeci Kredi Han buildings in Istanbul using the finite element method and analyzed them with linear methods. In a different study, Türker [7] examined the Istanbul University Faculty of Pharmacy building to investigate the causes of damage to historical buildings. He set up an Excel-based program for the earthquake analysis of the building. Fırat et al. [8] interpreted the damages in the Hacı Yusuf Taş Mosque, which was affected by an earthquake in 2020, near the Sivrice District of Elazığ. The current state of the building and the solution proposals were modeled with the finite element model and analyzed. Işık and Halefoğlu [9] carried out a structural analysis of Hoca Ahmet Mosque in Diyarbakır. As a result of the examination, they offered suggestions that could be useful for repair and strengthening works for the existing structural problems they identified. Fırat and Kayabaşı [10] investigated the effect of the tie-rod system on the behavior of the stone arch in their study. They tested the repaired belt with one reference without tie-rod system and six tie-rod systems under vertical loading. They also analyzed the samples in a computer program called LUSAS [11]. They compared the experimental results with the results obtained from the program. In a different study, Nuhoğlu et al. [12] examined the structural problems in the eastern fortifications of the Ayasuluk Castle in Izmir, determined the repair and strengthening methods and implemented them. Doğan [13] determined the structural problems of Beyzade Efendi Mansion in Elazığ and suggested solutions. Fırat et al. [14] examined the method of strengthening damaged dome building forms with clamping. In their study, they compared the experimental results of the reference dome and the reinforced dome. They concluded that the clamping method, which is widely used in dome reinforcement, did not increase the bearing capacity of the dome.

With the change of earthquake regulations in our country, new and old earthquake regulations have started to be considered together. Keskin et al. [15] studies, they examined the 2007 Regulation on Buildings to be Constructed in Earthquake Zones (DBYBHY) [16] and the Turkish Building Earthquake Regulation (TBDY) [17] which entered into force on 18 March 2018 for the province of Kırklareli. Using the Elastic Design Spectra in the 2007 earthquake regulation and the 2018 earthquake regulation, they obtained and compared the Horizontal Elastic Design Spectra for two different soil classes. According to the 2007 and 2018 earthquake regulations, they calculated the earthquake analysis of a 4-storey building in different ground classes using the ETABS [18] program and compared the results. Similarly, Başaran [19] calculated and evaluated the equivalent earthquake loads on 5 and 10 storey reinforced concrete frame models for Afyonkarahisar Center. In another study, Nemutlu [20] compared the 2007 and 2018 Turkish earthquake regulations and examined the innovations introduced and analyzed 3 different reinforced concrete structures and showed the differences between the regulations on the calculation. In their study, Özmen and Sayın [21] analyzed a five-storey reinforced concrete building using the SAP2000 [22] package program according to the 2007 and 2018 earthquake regulations using the Equivalent Earthquake Load Method. They concluded that the results obtained from the 2018 earthquake regulation were more reliable and realistic. Baran et al. [23] analyzed a 2-storey masonry building in StatiCAD-Masonry [24] and SAP2000 package programs. They used the 2007 and 2018 Turkey Building Earthquake regulations in the analysis. They compared the base cutting forces obtained as a result of the analysis for both regulations. They also compared the results they obtained from the two different package programs they used. In a different study, Çetinkaya [25] examined the reinforced concrete school building in Bilecik according to the 2007 and 2018 earthquake regulations. He proposed reinforcement for the structure and concluded that the reinforcement and the structure met the criteria for the life safety performance level.

In this study; The Historical Iplikçi Mosque in Konya was modeled in the SAP2000 V20.2.0 program. The sections of the DBYBHY 2007 regulation and the TBDY 2018 regulation on the design rules and calculation methods of masonry buildings were compared on the building model.

2. MATERIAL AND METHODS

In the study, the Iplikçi Mosque, which was built in Konya province at the beginning of the 13th century, was examined. The survey and restoration information of the building was obtained from the Konya Regional Directorate of the General Directorate of Foundations. The mosque examined was modeled in three dimensions with the help of SAP2000 V20.2.0 finite element program. On the model, analyzes were made according to the Regulation on Buildings to be Constructed in Earthquake Zones (06/03/2007) and the Turkish Building Earthquake Regulation (18/03/2018). In this section, information about Iplikçi Mosque is given. The model of the structure in SAP2000 V20.2.0 program and the 2007 and 2018 Turkish earthquake regulations were explained.

2.1. Iplikçi Mosque

There is no certainty about the construction date of the Historical Iplikçi Mosque in Konya. According to the researches, the first construction date of the Iplikçi Mosque, known as Ebu'l-Fazl Masjid and later also known as Ahmet Bey Mosque, dates back to the beginning of the 13th century. According to the repair inscription found in the mosque, the structure was repaired and renovated in H733/M1332 by Samurcu Mesud Zade Hacı Ebubekir, who is also claimed to be a descendant of Iplikçi, during the Karamanoğulları period who is also claimed to be a descendant of Iplikçi, during the Karamanoğulları period [26].

Mosque; it consists of 32 column, 44 arches, 4 domes and 32 strut elements. The external appearance of the mosque, which has been renovated and taken its current form, is misleading compared to its former form. In Figure 1 and Figure 2, external images of the old and new state of the building are given. In Figure 3, there are images of its current state.

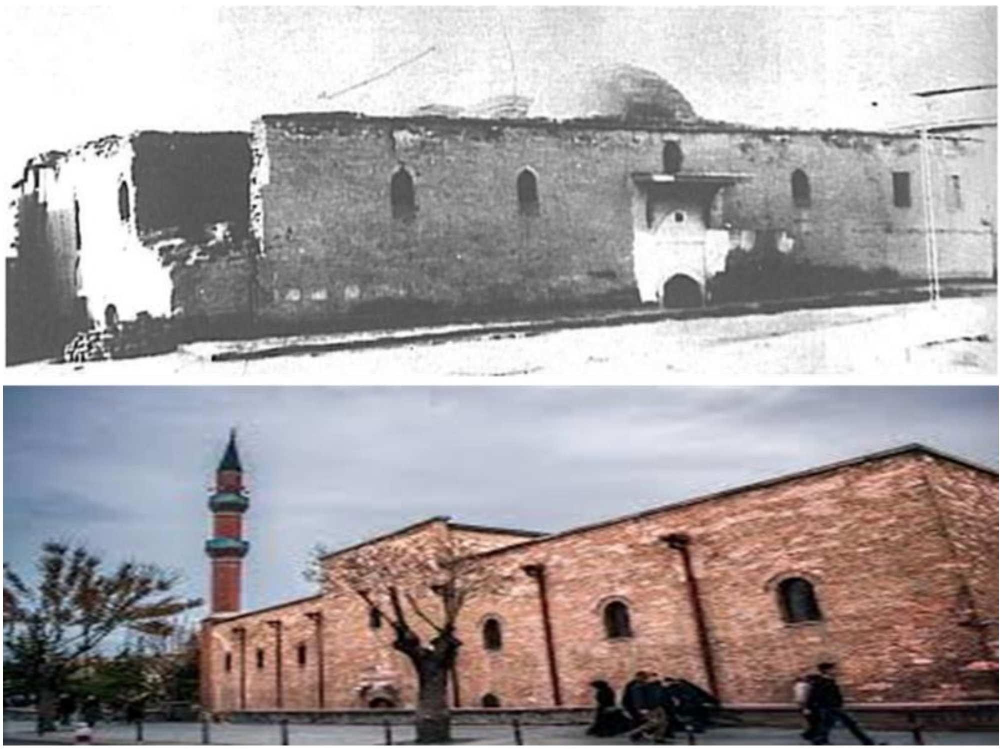

Figure 1. North side of Iplikçi Mosque

Figure 2. South side of Iplikçi Mosque

Figure 3. Images from the current state of Iplikçi Mosque

2.2. Modeling in SAP2000 program

Considering the survey of the building given in Figure 4, the wall thickness was taken as 1.07 m in the modeling. The dome of the heating room on the south side of the mosque, which has 4 domes in total, has a thickness of 76 cm. The thickness of the remaining 3 domes is 50 cm. While the building was being repaired in the 1940s, the domes were surrounded by walls. The top of the mosque is filled with a prism 8 meters wide and 4 meters high. Since the domes are in a rectangular prism, they are not visible when looking at the structure.

Brick material is defined for walls and domes, stone material for column and arches, and wood material for braces. The properties of the materials are given in Table 1. In the model (Figure 5), column and arches from the bearing elements of the structure are defined as frames, and other bearing elements are defined as shells. 17332 nodes were used in the modeled structure. A total of 15057 shells were created. In the model, 359 fixed bearings are defined at the points transferred to the ground.

Table 1. Properties of materials used in building

Eleman Tipi	Elastisite Modülü E (kN/m³)	Özgül ağırlık(kN/m³)	Kütle(t/m³)	Poisson Oranı
Taş (harç ile)	3500000(3500 MPa)	24	2,45	0,2
Tuğla	3000000(3000 MPa)	0,0177	0,0018	0,2
Ahşap	12500000(12500 MPa)	6	0,6	0,001
Kaplama	13000000(1300000 MPa)	2,2	0,22	0,16

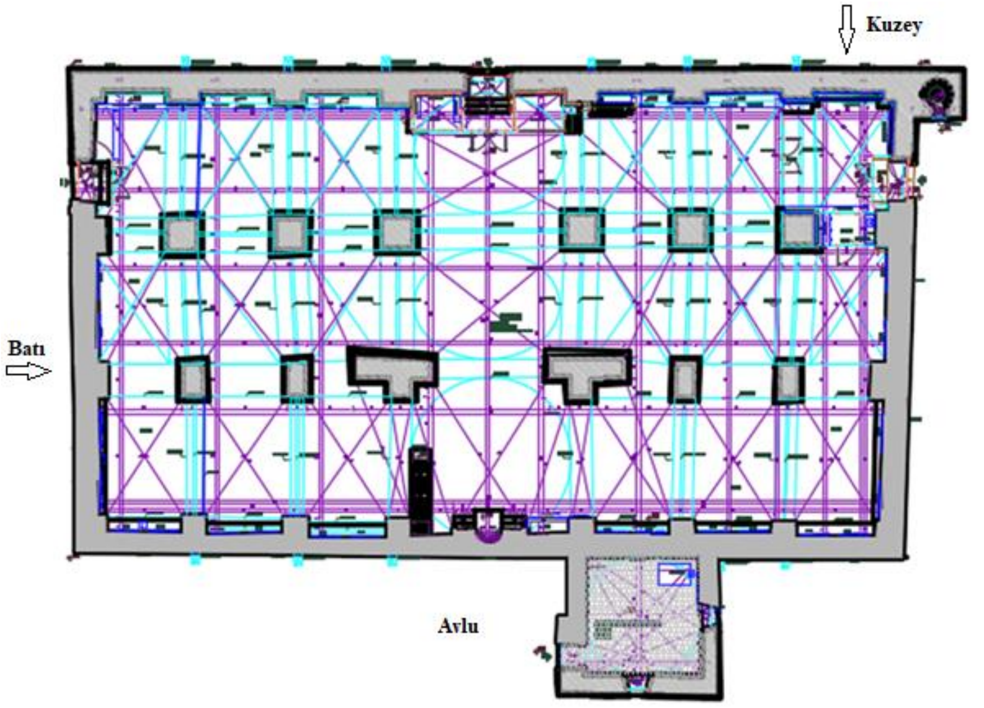

Figure 4. İplikçi mosque survey

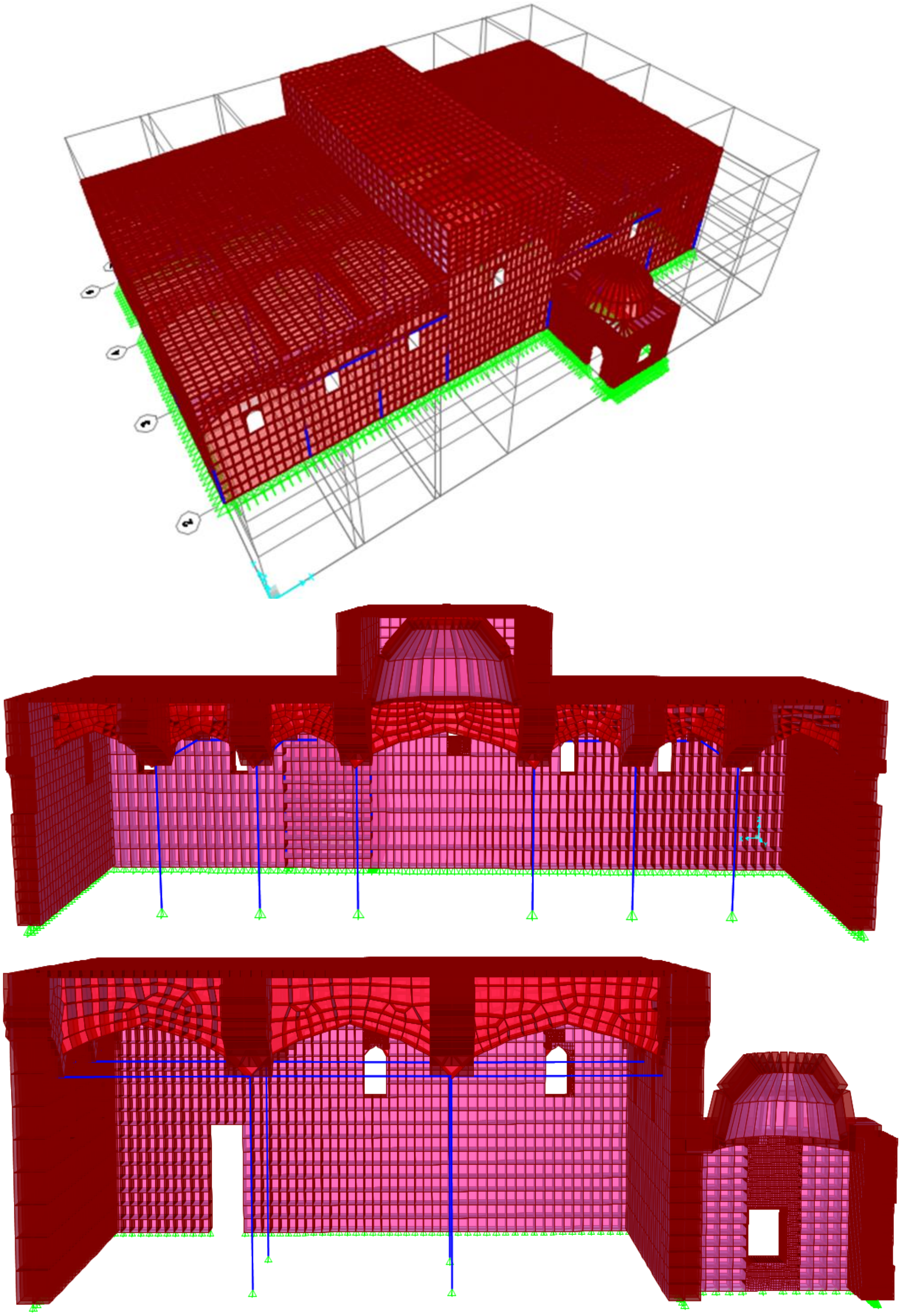

Figure 5. Structural modeling of the Iplikçi Mosque

On the prepared structure model, two separate loads with fixed loads and earthquake loads are defined. Earthquake loads were applied in both directions, x and y (EQx and EQy). Calculations in earthquake strength were made according to the mode superposition method.

In order to easily evaluate the results, G, G±Ex and G±Ey load combinations were prepared by taking into account G (constant loads), EQx and EQy (Earthquake loads).

Finite element analysis method was used to determine the structural performance of the Iplikçi Mosque. After the analysis, the tensile or compressive stresses and shear stresses generated for the DBYBHY 2007 regulation according to the local axis of each Shell element provide information about the strength of the structure. The tensile or compressive forces and shear forces that occur for the TBDY 2018 regulation provide information about the strength of the structure.

According to the format of the SAP 2000 program, in the analysis made according to the DBYBHY 2007 regulation, tensile or pressure stresses are defined as S11 for x direction and S22 for y direction, and shear stresses are defined as S12.

In the analysis made according to the TBDY 2018 regulation, the tensile or pressure forces are defined as F11 for the x direction and F22 for the y direction, and the shear forces are defined as F12.

Interpreting the results obtained from structural analyzes made using the finite element method in historical buildings is different from interpreting the calculation results of the structures produced today. It is quite complicated to determine the material properties and bearing capacities of building elements, especially since it is very difficult to take samples from historical buildings and test them in our country.

The properties of the materials used for the calculations in the Iplikçi Mosque were determined by using both the correlations proposed in the international literature and the studies of previously built structures similar to the work examined.

2.3. Turkish Earthquake Code (DBYBHY – 2007)

Parameters used in the calculation of earthquake forces that will affect the structures:

- A0 (Earthquake Zone Coefficient) = 0,1 (4th Zone)
- If the soil class is not foreseen, S(T) = 2.5 is taken in accordance with DBYBHY.
- I (Building Importance Coefficient) = 1,0
- R (Carrier System Behavior Coefficient) = 2
- Local Soil Class = Z3

Stress calculation was made for the structure. Tensile, pressure and shear safety tensile values were found.

2.4. Turkish Earthquake Code (TBDY – 2018)

The parameters used in the calculation of earthquake forces that will affect the structures according to TBDY 2018 are:

- I (Building Importance Coefficient) = 1,2
- BKS (Building Use Class) = 2
- R (Carrier System Behavior Coefficient) = 2,5
- D (Strength Excess Coefficient) = 1,5
- BYS (Building Height Class) = 8
- DTS (Earthquake Design Class) = 3
- Earthquake Ground Motion Level = DD2
- Local Soil Class = ZD

Map spectral acceleration coefficients, local ground effect coefficients and periods to be used in the calculations (Table 2); For the x = 37.871906, y = 32.496726 coordinates where the structure is located, it was obtained from the Earthquake Hazard Maps at https://tdth.afad.gov.tr.

Table 2. Map spectral acceleration coefficients, local ground effect coefficients and period information

Short period map spectral acceleration coefficient (S_S)	0.306
Map spectral acceleration coefficient for a 1.0 second period (S_1)	0.073
Short period design spectral acceleration coefficient (S_{DS})	0.476
Design spectral acceleration coefficient for a 1.0 second period (S_{D1})	0.175
Transition period to the constant displacement region in the horizontal elastic design spectrum (T_L)	6
Local ground effect coefficient for 1.0 second period (F_1)	2.400
Local ground effect coefficient for the short period region (F_S)	1.555
Spectrum corner period (T_B)	0.368

The calculation was made according to the Bearing Power Method for the structure. With the calculation of the vertical load design strength of the wall, the design shearing force strength of the wall was calculated.

3. RESULTS and DISCUSSIONS

In this study, a structure with a masonry carrier system used as a historical mosque in Konya province at the coordinates x = 37.871906, y = 32.496726 was analyzed according to DBYBHY 2007 and TBDY 2018. The differences between the calculation results and the regulations are explained.

3.1. Calculation Results According to 2007 Earthquake Code

As a result of the calculations made according to DBYBHY 2007, the pressure safety stress, tensile safety stress and shear safety stress values of the Historical Yarn Mosque were obtained (Table 3).

Table 3. Safety stresses of brick wall

Malzeme Tipi	Basınç Emniyet Gerilmesi (MPa)	Çekme Emniyet Gerilmesi (MPa)	Kayma Emniyet Gerilmesi (MPa)
Tuğla	1.0	0.9	0.373

High stresses were obtained in the finite element model created using the SAP2000 program of the structure (Figure 6). These stresses exceeded the safety stresses calculated in the regulation. The 2007 earthquake regulation did not meet the boundary requirements.

Although high stresses were obtained as a result of the structural analysis, large and risky cracks were not found when the door and window gaps and wall junction zones, which are critical areas for masonry structures, were examined. In this case, it can be said that the structure retains its stability.

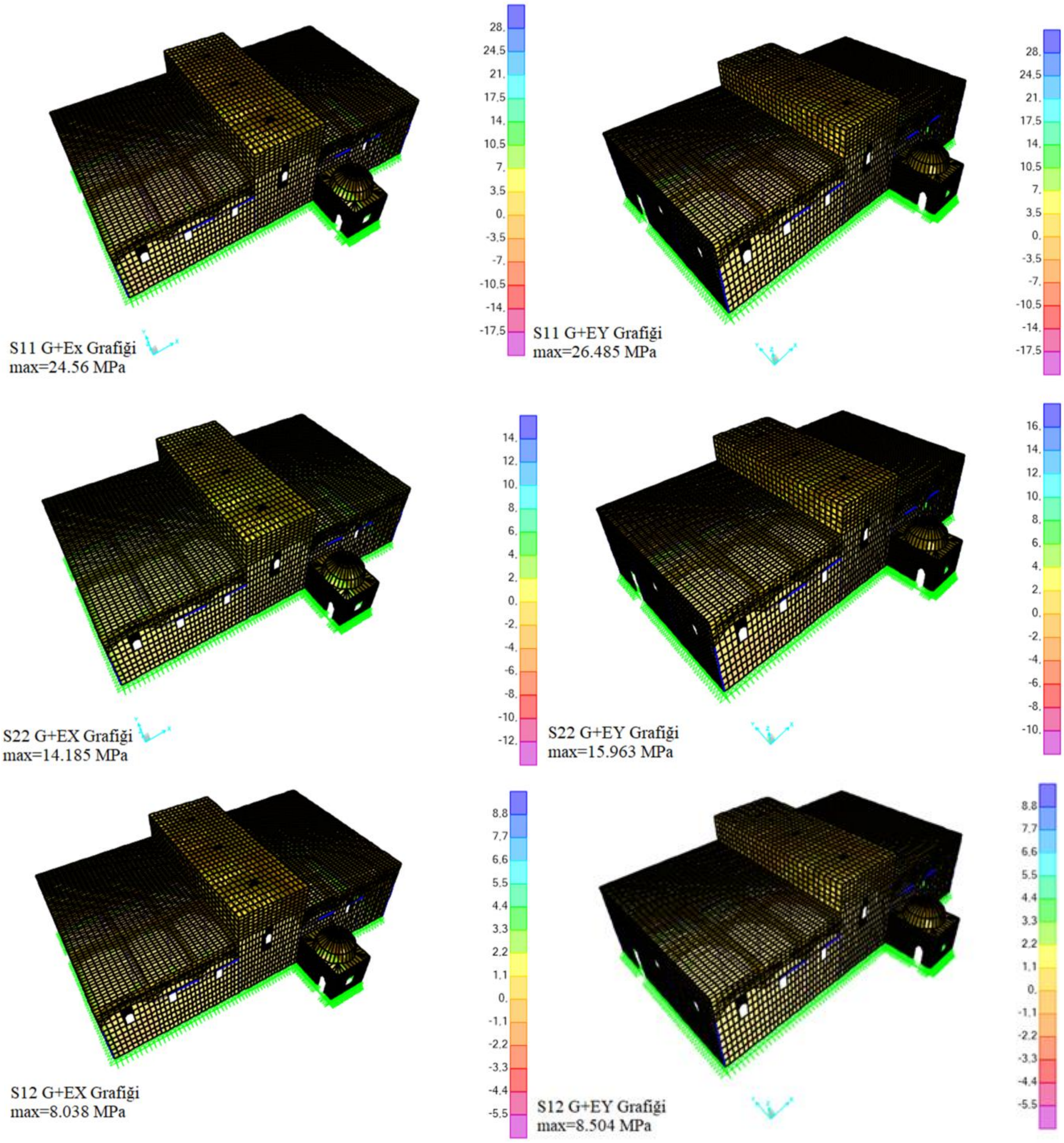

Figure 6. Stress distributions in load combinations for DBYBHY 2007

3.2. Calculation Results According to 2018 Earthquake Code

From the calculations made according to TBDY 2018, the vertical load design strengths and design shear force strengths of the Historical Iplikçi Mosque were obtained. As stated in the regulation, these calculated design strengths are above the design force and design shear force values (Table 4). This suggests that the accounts meet the principles of TBDY 2018. It was also observed that the forces obtained in the finite element model created using the SAP2000 program of the structure (Figure 7) did not exceed the forces calculated in the regulation.

Table 4. Design strength and design forces of the brick wall

Malzeme Tipi	Düşey Yük Tasarım Dayanımı (N_{Rd})(ton)	Düşey Doğrultuda Etkiyen Tasarım Kuvveti (N_{Ed})(ton)	Kesme Kuvveti Dayanımı (V_{Rdx} - V_{Rdy}) (ton)		Tasarım Kesme Kuvveti (V_{Edx} - V_{Edy}) (ton)	
Tuğla	48608	3229.4	631.6	350	73.9	79.4

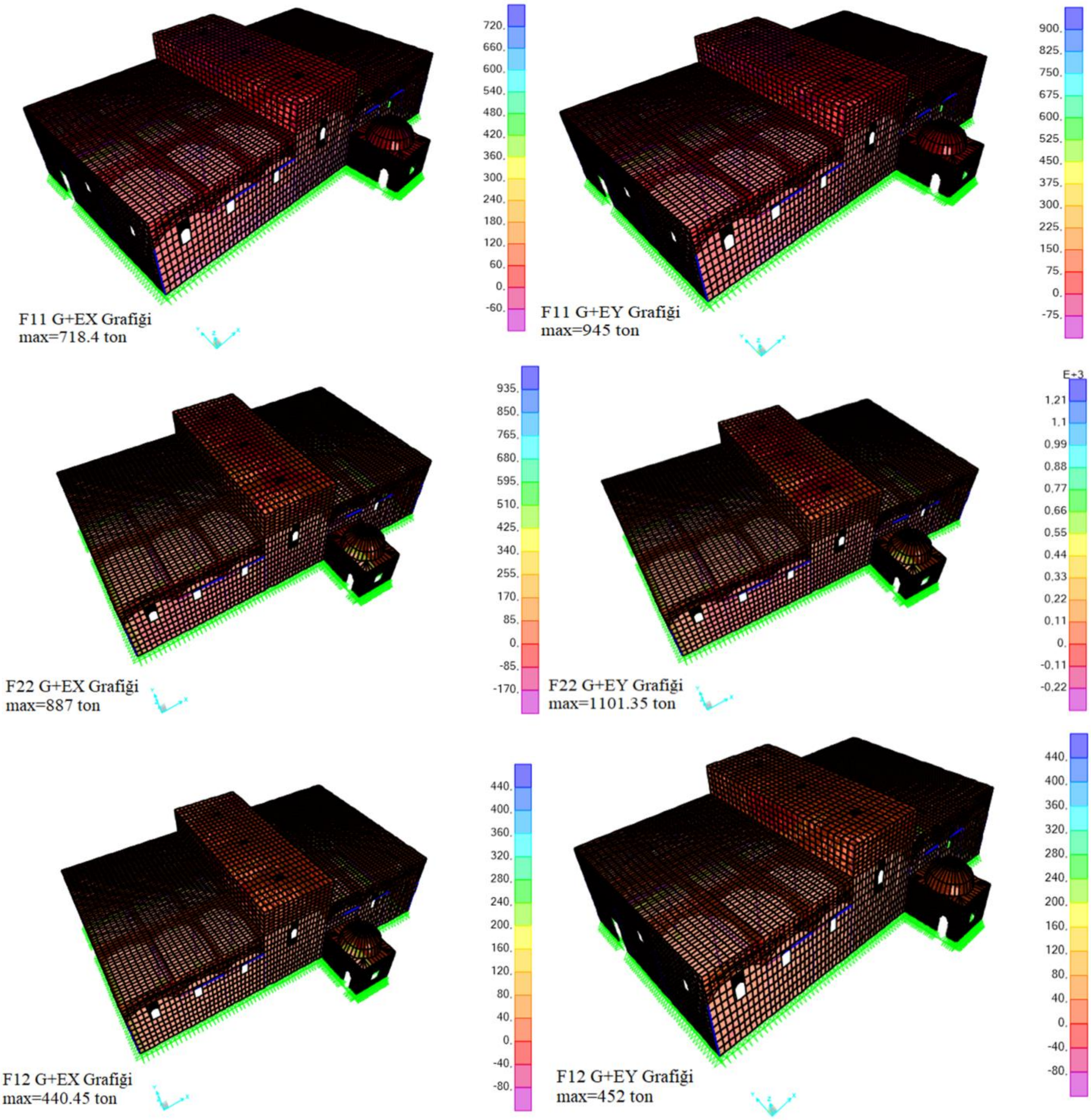

Figure 7. Force distributions in load combinations for TBDY 2018

3.3. Results of Mod Combination Method

The sum of the effective masses calculated for the mode superposition method applied according to DBYBHY 2007 within the framework of earthquake-resistant building design should not be less than 90% of the total mass of the building. In TBDY 2018, it was updated that the sum of the calculated effective masses should not be less than 95% of the total mass of the building.

As a result of the modal analysis of İplikçi Mosque in the SAP2000 program, 60 modes were defined and free vibration periods were obtained. The mass participation rates for DBYBHY 2007 and TBDY 2018 and the ratios of effective masses to the total mass of buildings for x and y directions are given in Table 5 and Table 6, respectively.

Table 5. Mass participation rates for DBYBHY 2007 and TBDY 2018 regulations

	KÜTLE KATILIM ORANLARI	
	X YÖNÜ	**Y YÖNÜ**
DBYBHY 2007	0,71 (MODE 5)	0,76 (MODE 3)
TBDY 2018	0,64 (MODE 8)	0,74 (MODE 3)

Table 6. The ratio of the sum of the effective masses to the total mass of the building for the DBYBHY 2007 and TBDY 2018 regulations (%)

	ETKİN KÜTLELERİN TOPLAMININ BİNA TOPLAM KÜTLESİNE ORANI (%)	
	X YÖNÜ	**Y YÖNÜ**
DBYBHY 2007	%86	%85
TBDY 2018	%74	%83

When Table 6 is examined; In the values taken from TBDY 2018, it was seen that the ratio of the sum of the effective masses to the total mass of the building was below the 95% value given in the regulation and came very close to this value which was 90% in DBYBHY 2007.

3.4. Displacement Results

In both regulations, both in the control of constant load (Figure 8) and in the displacement control according to combinations (Figure 9), the most displacement occurred in the upper floor (roof).

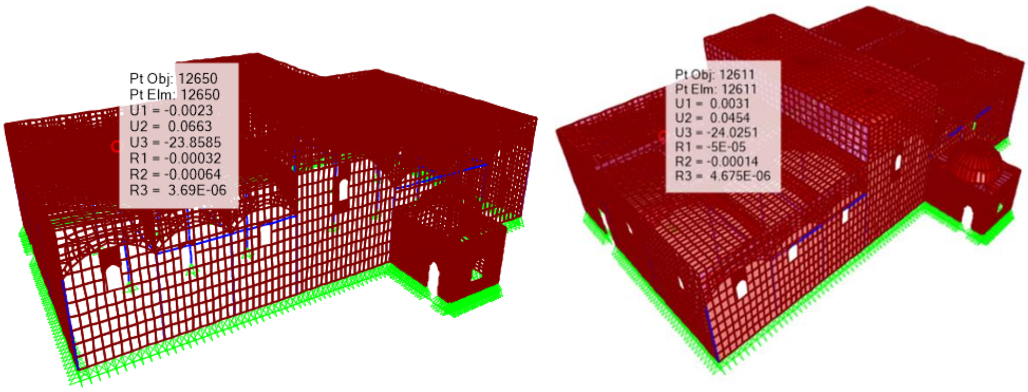

Figure 8. Maximum displacement under G loading (mm) for DBYBHY 2007 and TBDY 2018

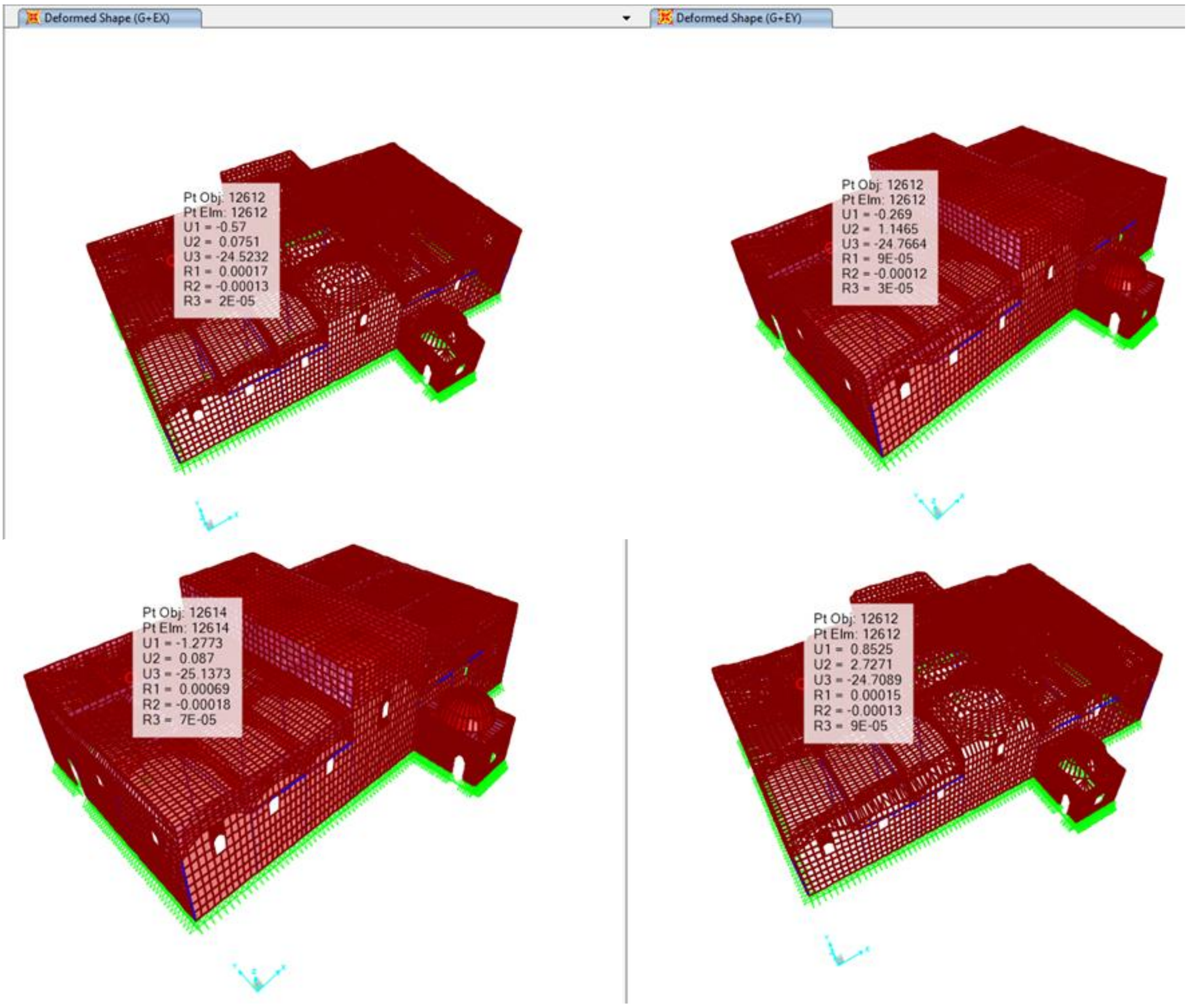

Figure 9. Maximum displacement under G+EX G+EY loading (mm) for DBYBHY 2007 and TBDY 2018

3.5. Differences Between DBYBHY 2007 and TBDY 2018 Regulations and Discussion

As a result of the studies, it was seen that there were significant changes between DBYBHY 2007 and TBDY 2018 regulations. The changes concerning the section related to the design rules of masonry buildings and the results obtained from the study are briefly summarized below.

- While there was only one type of masonry building without reinforcement in the 2007 earthquake regulation, 3 new masonry building types were added in addition to the unreinforced masonry building type in the 2018 earthquake regulation. These; reinforced masonry building, surrounded masonry building and reinforced panel system building. In TBDY 2018, calculation methods and boundary conditions of new masonry building types were added. With TBDY 2018, it is possible to construct masonry buildings with more floors than in previous years.
- In DBYBHY 2007, the calculation method of safety stresses is used while making the investigations. With TBDY 2018, the calculation method of safety stresses was abandoned and the method of calculation of bearing capacity began to be used.
- For the mode coupling method applied according to DBYBHY 2007, the ratio of the sum of the effective masses to the total mass of the building should not be less than 90%, while this value was changed to 95% in TBDY 2018.

- In TBDY 2018, the coordinates of the structure are entered on the earthquake hazard map of Turkey and the earthquake parameters are determined. In DBYBHY 2007, earthquake parameters were calculated manually from the relevant section.
- While the carrier system behavior coefficient is taken as 2 in masonry structures for DBYBHY 2007, the carrier system behavior coefficient is taken as 2.5 in TBDY 2018.
- According to DBYBHY 2007, the modulus of elasticity was calculated as 200*fd (fd: masonry wall design compressive strength). In TBDY 2018, it is calculated as 750 * fk (fk: masonry wall characteristic compressive strength).
- According to DBYBHY 2007, the investigations made using the safety stresses calculation method and the stresses obtained from the finite element model created using the SAP2000 program of the structure were compared. These stresses exceeded the safety stresses calculated in the regulation and did not meet the principles of DBYBHY 2007.
- According to TBDY 2018, the investigations made using the bearing power calculation method and the forces obtained from the finite element model created using the SAP2000 program of the structure were compared. It was observed that these forces did not exceed the strengths calculated in the regulation and met the principles of TBDY 2018.
- As a result of the analysis, it was seen that the ratio of the sum of the effective masses to the total mass of the building was very close to the value given in DBYBHY 2007 (90%), but it was below the value given in TBDY 2018 (95%).
- In both regulations, it was seen that the most displacement occurred in the upper floor (roof) in both constant load control and displacement control according to combinations.

It has become clear that the new calculation methods for masonry buildings are more detailed and comprehensive. However, there is no separate section in our 2018 earthquake regulation on the studies on historical buildings. While conducting studies on the subject, it is necessary to make some acceptances. An additional section should be established in our earthquake regulation on the calculation methods of historical buildings.

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