JSACE 1/30

Received 2021/04/13

Accepted after revision 2022/01/10

Structural Assessment of the Sustainability of the Historical Clock Tower as a Landmark

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http://dx.doi.org/10.5755/j01.sace.30.1.28882

Abstract

In the historical process, many tools have been used to measure time. With technological advances, clock towers were built with mechanical clocks. But today, rather than their original function, historic urban centers have become an image of cities. First built in Europe, clock towers were built in various cities of Anatolia during the Ottoman Period. The protection and sustainability of clock towers, which are one of physical identity, is important for the continuity of cultural heritage. Determining the damages that earthquakes will contribute to the protection and sustainability of clock towers. In the study, the historical clock tower in Çorum was modeled in three dimensions and subjected to static and dynamic analysis. In static analysis, it is seen that the upper part of the main entrance door and dynamic analyses increase in the transition from the octagonal plan in the lower region to the circular cross-sectional zone in the upper region. Also, it was determined that the maximum values of deformations appeared as displacement in orthogonal directions at the top of the tower. As a result, as a strengthening proposal, it is thought that iron tensioners passing through the stirrup plane of the entrance door conveyor belt should be added.

Keywords: Clock tower, dynamic analysis, finite element analysis, static analysis, urban identity.

Introduction

Kevin Lynch (1960) in the cities of Boston, Jersey City and Los Angeles in his book "The Image of the City", urban identity components of physical identity components into five groups as include paths, node, district, and landmark. Landmarks, which are the unique images of the city, which are called the symbols and totems of the cities, provide the definition of the city, and create the sense of belonging to the citizens. Buildings that are the reference point of the city, symbolize a city or region, provide distinctiveness from other settlements, and add identity to the place are defined as landmarks. Lynch (1960) referred to these signs as a physical object such as a building, sign, store, or mountain. Landmarks such as the Eiffel Tower, Statue of Liberty, Burj Khalifa, Burj Al Arab Hotel, Sydney Opera House or the Egyptian Pyramids have become the symbols of the cities they belong to and have played an important role in the recognition of the cities.

Mechanical clocks, invented to measure the concept of time that is important to humanity, were in the towers or building facades built. The clock towers, which are a sign of power and wealth, started to be built in the Ottoman Empire after Europe and spread rapidly in Anatolia. Today, clock

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Journal of Sustainable Architecture and Civil Engineering
Vol. 1 / No. 30 / 2022
pp. 153-162
DOI 10.5755/j01.sace.30.1.28882

towers with different architectural styles and typological characteristics form an important part of cultural and architectural heritage. The clock towers, which were built as an independent structure or as part of the historical structure, are important landmarks that form the silhouettes of the historical city centers today. Clock towers, one of the images of cities, must be preserved for cultural sustainability. In this context, this study aims to investigate the structural behavior of historical clock towers in Turkey, which is located on important earthquake fault lines, and to present proposals for restoration works to be carried out.

The architectural features of the clock towers, which are one of the symbols of historical cities, have been researched in the architectural literature for their preservation and sustainability. The effects of clock towers in different cities on the urban identity, visual effects on the silhouettes of cities, and creating a square were investigated from an architectural and design perspective (Gelmez & Altıntaş, 2018; Gulick, 2007; Hung, 2003). In addition to architectural research, in engineering and earthquake engineering, studies on clock towers have been researched the behavior of structures under static and dynamic effects, and restoration suggestions were made.

The fact that the building material of the historical clock towers is stone increases the risk of demolition and damage due to the delicateness and structural irregularity of the structure (Ferraioli, Miccoli, & Abruzzese, 2017). There are various studies on this subject in the literature; improvement and strengthening recommendations are presented with linear and nonlinear analyses. In this context; Zarandi and Maheri (2008) examined the dynamic properties of brick masonry towers by including ground parameters. Towers with different heights, material properties, and geometry were subjected to detailed analysis in the finite element environment according to the location of the earthquake epicenter and the intensity of the earthquake for different ground types. As a result, the effect of the relevant parameters on the dynamic behavior of the towers has been determined. Mirtaheri, Abbasi, and Salari (2017) presented data on a historic minaret in Iran in the first stage, including geometry and material properties. He then measured the structure with the devices and determined the dynamic characteristics of the minaret. By modeling the minaret in three dimensions in the numerical environment, the results obtained were compared with the results of the experiments, and recommendations were presented. Şeker (2015) examined the structural behavior of two separate historical clock towers built on existing historical buildings in Amasya province. In the study, static and dynamic analyses of towers modeled in three dimensions in a numerical environment were performed. During the earthquake, it was determined that the additions reduced the strength of the existing historical structure.

Girardi, Padovani, and Pellegrini (2017) tested a newly developed application for modal analysis of masonry structures in a clock tower in Lucca. In this method, the effects of the stress area consisting of thermal changes are taken into account in the calculation of structure natural frequencies and mode shapes. Akbaş and Çakır (2014) analyzed based on the performance of a historic clock tower in eastern Turkey. Korumaz et al. (2017), Attia, Sayed, and Abdel-Haleem (2010), Mustafaraj and Yardım (2016), and Pavlovic, Trevisani, and Cecchi (2016) created a three-dimensional model of a historical tower (minaret or clock tower) in a finite element environment and its static and dynamic analyzes were made. It has determined the difficult parts of the building and the parts that need improvement.

Soyluk and İlerisoy (2013) analyzed the model of the Dolmabahçe historical clock tower in Istanbul in a finite element environment with ground effects. Milania, Shehua, and Valentea (2017) analyzed the historical clock tower using non-linear static procedures. Sarhosis, Fabbrocino, Formisano, and Milani (2017) proposed a formula for estimating the precision of towers, taking into account the parameters of the fragility and cross-sectional area of masonry towers with different geometries. Acito, Bocciarelli, Chesi, and Milani (2014) analyzed non-linear static (pushover and kinematic limit analysis) under two main seismic events of a clock tower.

History of Clock Towers as Landmarks

Although the clock was first developed in the East in the historical process, clock towers were first built in the West. In 1386, the oldest tower clock was placed in Salisbury Cathedral in England. In 1389, a clock tower that rings every quarter-hour was built in Rouen, France (Rossum, 2003). Clock tower construction, which became widespread in Europe in the 14th century, started in the Ottoman Empire at the end of the 16th century and spread from west to east in the 18th and 19th centuries (Acun, 2008). The first clock tower in the Ottoman Period was built in Bosnia-Herzegovina in 1579 by Bosna Governor Ferhat Pasha (Acun, 1993). The first clock tower in Anatolia was built in Safranbolu in 1797 (Figure 2a) (Acun, 1994). Clock towers were built throughout the Ottoman Empire during the reign of II. Abdülhamit in 1901, when he directed the governors to build clock towers with the cülus, which gold coin distributed by the sultan (Acun, 2008).

Tower and facade clocks in every town in Europe were first built in the Ottoman Period to adopt Western culture. However, since the European clock was not used in the Ottoman Empire yet, it was built to show the power of the state, as it has symbolic meanings. (Kokal, 2007). Mechanical clocks have been attracted by the public since their first arrival in Istanbul and have spread rapidly in mosques, timing houses, building facades, and residences (Üçsu, 2011). Clock towers, usually built by courtiers or governors, were built in historical city centers and on the peaks of settlements. Clock towers are in areas such as mosques, churches, palaces, mansions, and municipalities overlooking the public squares. Squares designed around clock towers in Europe began to emerge in the Ottoman Empire (Figure 2b). Clock towers, which are an indispensable part of life in the historical process, have become an important part of the urban fabric. Today, it has become one of the components of the identities of historical cities.

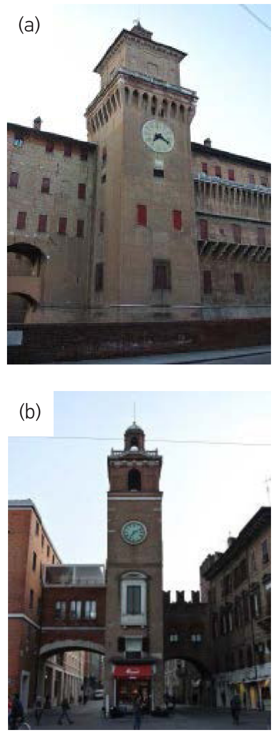


Fig. 1

Examples of Clock Towers a)Castello Estense in Ferrara b)Piazza Cattedrale in Ferrara (Gürcu, 2016)

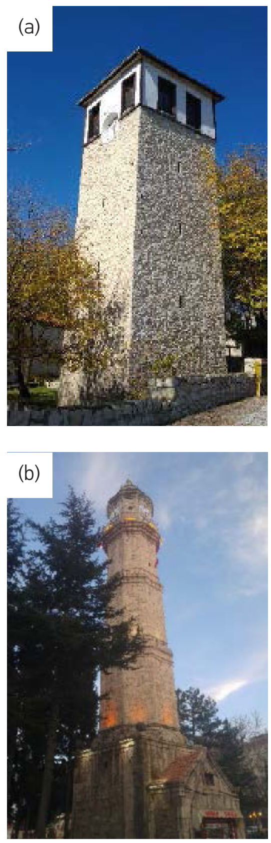


Fig. 2

Clock Tower in Anatolia a) Safranbolu Clock Tower (Özkaynak, 2018) b)Tokat Clock Tower (Özkaynak, 2020)

Çorum Clock Tower Architectural Properties

Çorum clock tower is in the city square in the historical city center of Çorum province (Figure 3). Around the clock tower, there is a mosque, church, Turkish bath, Ottoman Bazaar, khan, and government house.

According to the inscription of the building on the round-arched door of the clock tower opening to the south, it was built by Beşiktaş Guard Çorumlu Hasan Pasha in 1896 during the Abdulhamid Period. (Acun, 2011). Built with yellow-cut stone material, the body section of the tower sits on an octagonal pedestal. The octagonal pedestal of the clock tower at an altitude of 28 meters is 3.90 meters long (Acun, 1994). The shoe on the octagonal pedestal passes to the trunk. There is a tower balcony at the top of the body.

Fig. 3

Çorum Clock Tower (URL-1)

An 81-step staircase leads to the tower balcony section through the round-arched door (Acun, 1994). The honorary part of the building is surrounded by iron railings. Above the tower balcony is a square-form mansion. There is one hour on the four fronts of the pavilion section and there are diamond-shaped windows on the dials. The top of the structure is covered with a lead-covered dome. The section between the pedestal part of the structure and the balcony was built in the form of a minaret, while the top section of the balcony was built in the form of European clock towers.

Methods

In this study, it was aimed to restore a historical clock tower, which is a landmark of a city, in accordance with the earthquake, and to protect it during the earthquake and its sustainability. In this context, the behaviour of the historical Çorum clock tower, which was chosen as a sample, was examined by using the records of a large earthquake that took place before. In this study, which is a case study for clock towers, the historical tower was first modelled in 3D. In the second stage, the static analysis of the structure was made according to the physical and mechanical material properties of the model using the ANSYS program. In the third stage, mode shapes were obtained by modal analysis of the historical tower. Finally, maximum stress values and total deformation values in east-west and north-south directions were obtained by time history analysis under the Erzincan earthquake records in 1992. As a result of the findings, structural assessment of the historical clock tower was determined during earthquake, and a restoration proposal was made for the sustainability of the city's landmark.

Material Properties

To analyze the structural assessment of historical buildings during the earthquake, it is necessary to determine the material properties. Because of the cultural value of historical buildings, destructive experiments and samples cannot be taken on the building. Regarding the heterogeneous structure of the tower, the real mechanic and physical properties can be calculated approximately.

In the clock tower investigated in this study, it is seen that sandstone, which has the same characteristics as other historical buildings in the region, was used. The results of the test on stone samples taken from a historical mosque in the district of Merzifon near the building are given in Table 1 (Şeker, Çakır, Doğangün, & Uysal, 2014). The properties given below are also used for the analysis of the clock tower.

Table 1

Physical and mechanical properties of the materials used in the clock tower

Structure Material	Modulus of Elasticity (Young Modulus)(Pa)	Poisson's Ratio	Specific Bulk Density (kg/m^3)	Mean Compressive Strength (MPa)	Mean tensile Strength (MPa)
Masonry	1,018E+10	0,17	2358	50,92	5,092

Structural Analysis

It is necessary to make some acceptances for the analysis of masonry structures with complex geometry and heterogeneous material properties such as historical towers. Firstly, when material properties are taken into account, TYDRYK (2017) the mechanical and physical properties of the masonry wall are defined according to a different unit and mortar strengths. In this way, the mechanical and physical properties of the wall can be determined depending on the strength of the units that make up the masonry structure. These obtained features are assigned as material properties to the model created in the finite element environment and static and dynamic analyses are conducted. In terms of modeling, this material, which is assigned as a single gross part in the tower finite element environment, is connected to the floor by built-in bearing and it is accepted that the parts that make up the structure are fully connected and there are no deformations such as deterioration or disintegration. The structure is analyzed according to these acceptances. The three-dimensional model of the tower is seen in Figure 4.

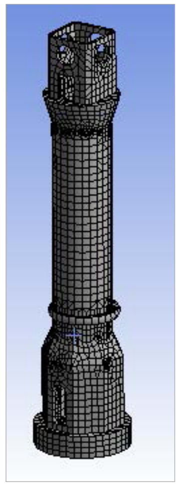


Fig. 4

Çorum Clock Tower Finite Element Model

The structure is analyzed by accepting linear elastic material under its load. although the material can work beyond linear, this analysis is useful for determining the forced regions of the structure in the first place and for detailed determination of the load flow. In such highly delicate structures, this analysis can yield valuable results. ANSYS finite element program was used in the analysis for this purpose. In the analysis, the Finite Element Solid 186, available in the ANSYS library, with displacement on all three axes, was considered.

Results

Static Analysis

The Clock Tower Finite Element Model has been analysis by ANSYS. The model consists of 40517 nodes and 12624 elements in total. The results of the analysis are shown in Figure 5. The study also covered the Drucker-Prager material model (Betti & Vignoli, 2008).

When the results of the analysis are evaluated, it is seen that the deformations have maximum values at the top of the tower and the values towards the lower regions decrease. The maximum deformation value is 0.78 mm ~~Mpa.~~ When the movement of the deformation shape in the finite element environment is examined, it is determined that the deformations are concentrated in the sections where the tower section expands in the lower regions and the upper areas of the entrance door below it. Side openings can be expected in these regions because of vertical weight (Figure 6).

When the static analysis stress distribution is examined, it is seen that the stresses reach maximum values in the upper region of the main entrance gate in the lower region. With the increase of vertical loads in this region, stresses occur where the arched part of the main door that creates the gap is located, and over time it becomes a stretch of pulling and becomes able to break the stability of this region by opening the keystone. An improvement should include increasing the thickness of this area or a tensioner system that will connect the arch points (Figure 7).

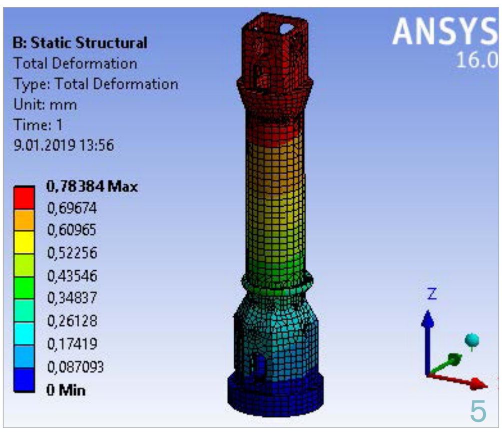


Fig. 5

Çorum Clock Tower Static Analysis Total Deformation Distribution

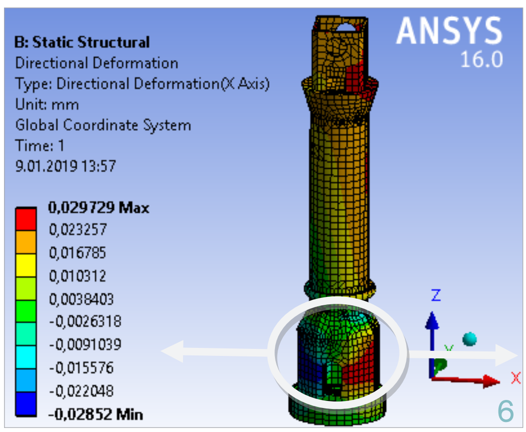


Fig. 6

Çorum Clock Tower Deformation Distribution on X-Axis by Static Analysis

Fig. 7

Çorum Clock Tower Static Analysis Maximum Principal Stress Distribution

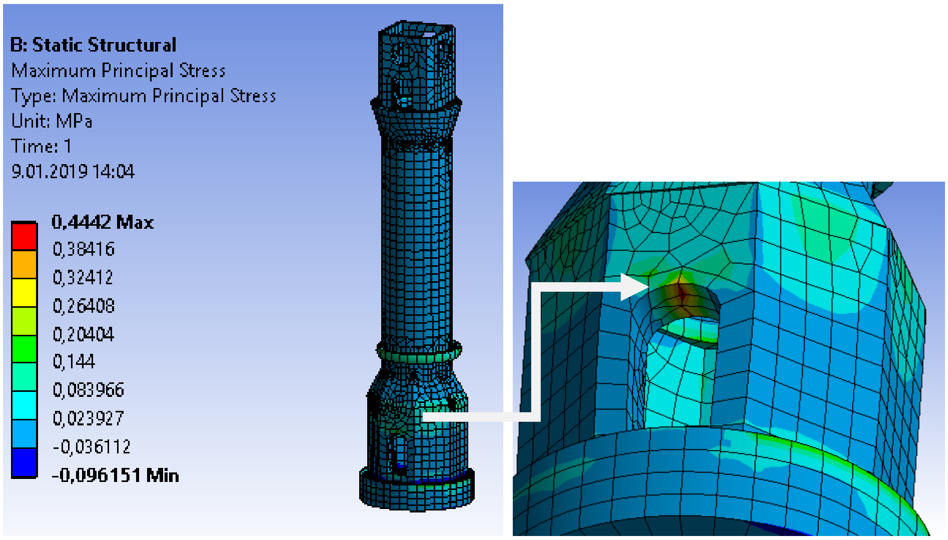


Table 2

Modal analysis periods and mass participation ratios

Mode	Period	Mass participation ratios	
		X axis	Y axis
1	0.39151	0.000100468	0.393824
2	0.38391	0.39180	0.00010
3	0.084036	0.226211	0.00010
4	0.082474	0.000216	0.21047

Modal Analysis

With modal analysis, which constitutes an important part of dynamic analysis, free vibration mode shapes of the structure are determined. This analysis informs about the way the structure moves during the earthquake, and accordingly, the forced areas of the structure can be determined. A total of 200 mode shapes were discussed according to the article specified in the earthquake regulation, which stipulates that the active mass in both directions should be handled not less than 90% of the total building mass. The mod contribution rates and periods of the most effective of these mode shapes were calculated and given in Table 2 (Figures 8 and 9).

When the active mode shapes are examined, it is observed that the main movement is a displacement in two directions, and in the form of another effective mode in the advancing modes, the off-plane behavior of the parts close to the upper regions of the tower is effective with the displacement. With these displacement patterns, it is determined that the structure will be intensified in the lower regions of the tower, in the transition from the octagonal planned part to the circular area above, and the lower areas of the tower balcony part.

Time History Analysis

The geography of Turkey is in a large earthquake zone. Many different fault lines are active in Turkey. The North Anatolian fault line is one of them. There have been some very damaging earthquakes on this line in the past. The clock tower researched in this study is also located on this fault line. Therefore, it is important to examine the structural assessment during the earthquake. For this purpose, the structure was analyzed in the field of time definition in both orthogonal directions and the results obtained were given. In this analysis method, the structure was examined under the 1992 Erzincan earthquake record, which was effective in the region. The records of earthquake acceleration, east-west, and north-south direction were applied to the structure in the same direction of the structure. The time step was taken as 0.005 and the 10 sec time frames

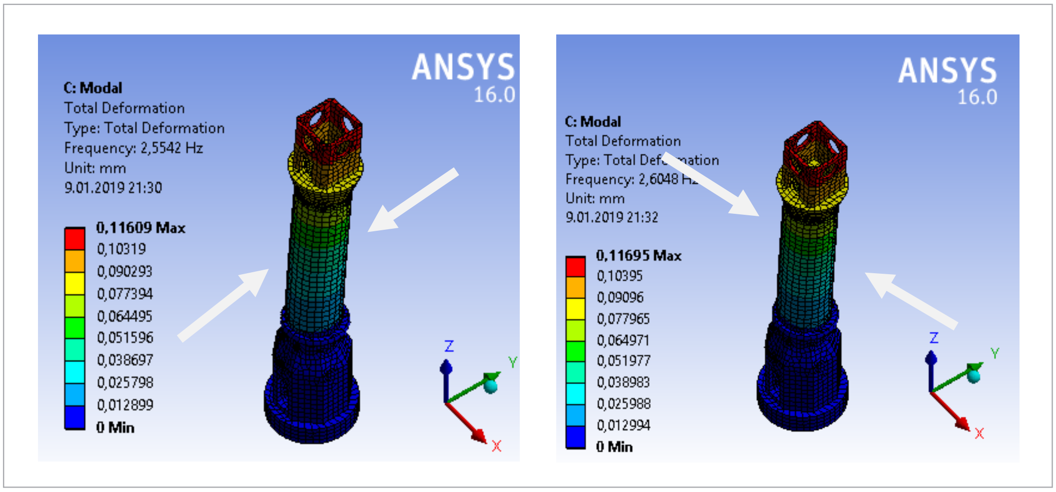


Fig. 8

Çorum Clock Tower Modal Analysis 1st and 2nd Mode Shapes

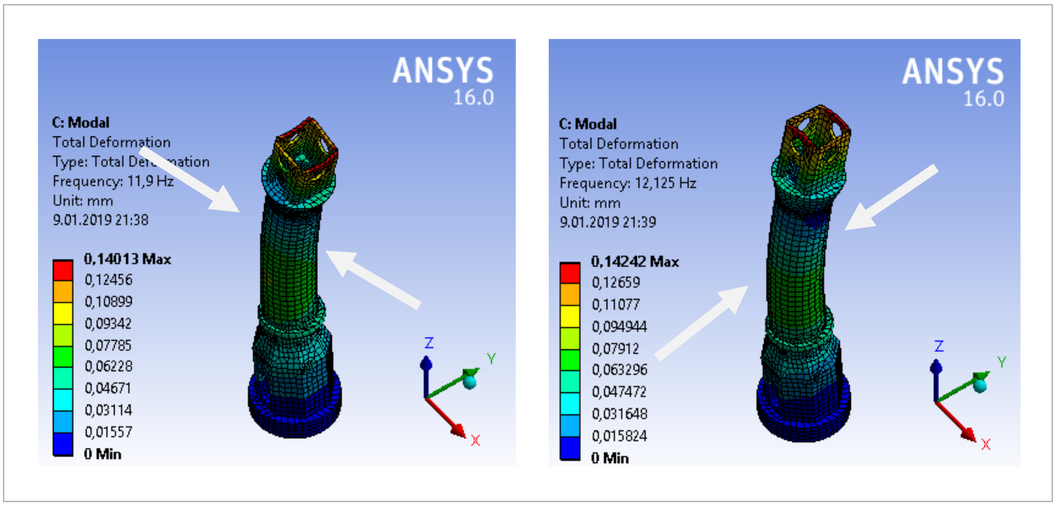


Fig. 9

Çorum Clock Tower Modal Analysis 3rd and 4th Mode Shapes

containing the maximum values of acceleration was discussed in the analysis. As a result of the analysis, stresses and deformations of the structure were calculated. Earthquake acceleration values are seen in Figure 10.

When Figure 11 is examined, it is seen that the maximum stresses occur in the tower transition zone. As a result of horizontal displacement, which is effective in dynamic analysis, it is determined that these regions will be subjected to large tensile stresses by shifting similarly to the movement of the built-in beam. It is seen that the maximum stress generated in the 10-sec depress recording is 12.15 Mpa and this value occurs at 2.965 s. When the deformation change in Figure 12 is examined, it is observed that the maximum deformation occurs at the top point of the tower as displacement. The horizontal displacement value is 52.21 mm. The ratio of horizontal dis-

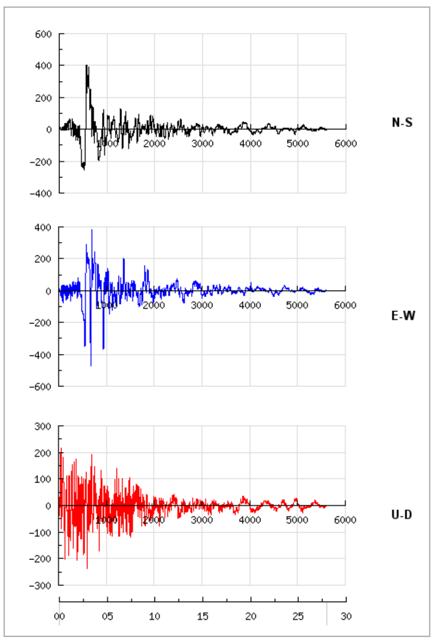


Fig. 10

Erzincan Earthquake Acceleration record values(mm/sn²) placement to tower height is 52.21/27500=0.001898 and remains below the 0.003 limits given in the regulation.

When the analysis results in Figure 13 are examined, it is seen that the prime stress values formed in this direction (north-south) analysis reached 8.85 Mpa, which is also in the same region but lower. It can be considered that the entrance door cavity causes this stress differentiation. Again, it was determined that the total deformation value reached 48.593 mm, which was aha? low. The ratio of horizontal displacement to tower height is 48,593/27500=0.00177, which is considerably lower than the 0.003 limits given in the TYDRYK (2017).

Fig. 11

Erzincan Earthquake East-West Direction Analysis t= 2.965 sn Principal Stress Values Distribution

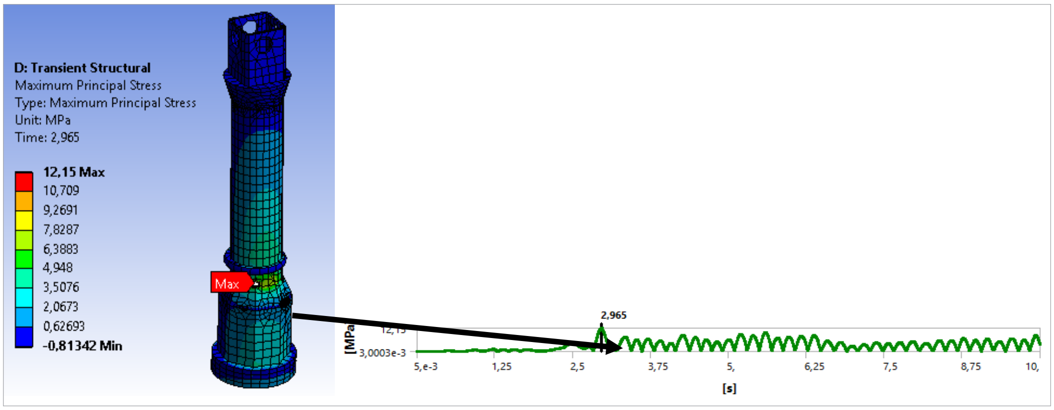


Fig. 12

Erzincan Earthquake East-West Direction Analysis t= 2.96 sn Total Deformation Values Distribution

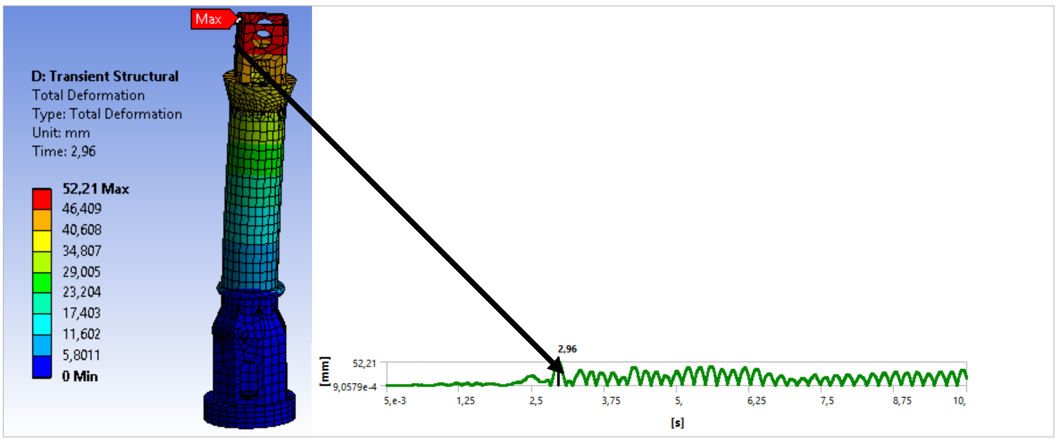
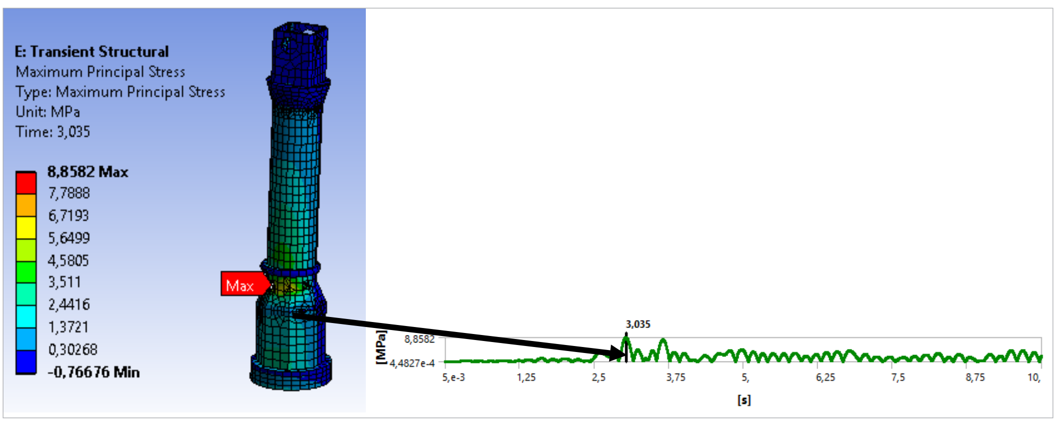


Fig. 13

Erzincan Earthquake North-South Direction Analysis t= 3.035 sn Principal Stress Values Distribution



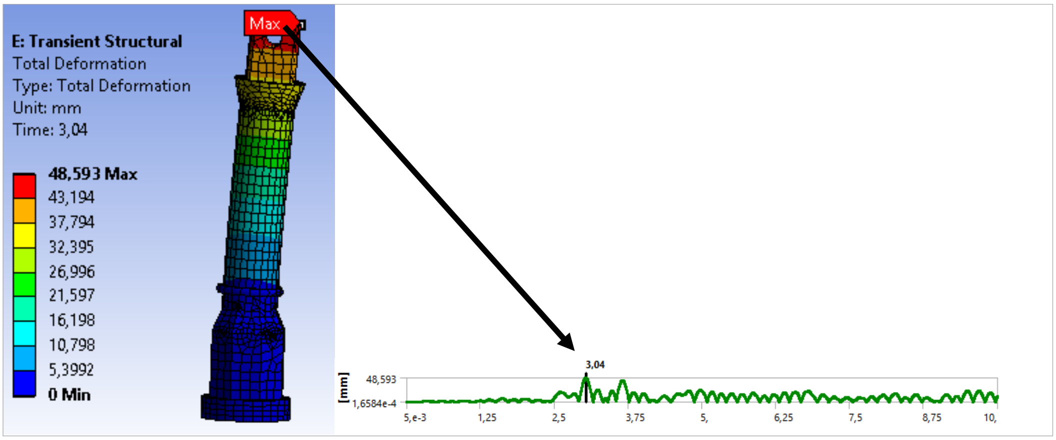


Fig. 14

Erzincan Earthquake North-South Direction Analysis t=3.04 seconds Total Deformation Values Distribution

Conclusions

Historical buildings are the most important structures that reflect the historical, cultural, social, and economic structures of the cities, the traditions, and customs of the past civilizations, the construction techniques, and the materials they use. The components of urban identity must be preserved and onto future generations with their sustainability. In this context, historical buildings need to be strengthened with appropriate techniques and methods to increase their resilience to external influences. With today's technology, appropriate interventions can be made timely and accurately by detecting areas of such artifacts that can be easily examined in a finite element environment, especially in the face of the most important destructive impact, such as earthquakes. In this study, the historical clock tower of Çorum, an image of the city, was subjected to static and dynamic analysis. As a result, it was determined that the upper area of the tower entrance door and the tower crossing area are sensitive areas to deformation and strain. Çorum Clock Tower, one of the components of urban identity, can be protected by strengthening operations from the designated points. Also, with the method applied in this study, the earthquake behavior of clock towers should be examined, protected, and onto future generations. It is expected that the findings from this study will be a guide for the experts working in this field.

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