Journal of Materials and Engineering Structures

Research Paper

Structural Assessment of the Historical Yozgat Clock Tower

Burçin Şenol Şeker [a,*], Gizem Büyükgüner [a], Merve Özkaynak [a]

[a]*Department of Architecture, Faculty of Architecture, Amasya University, Amasya, Turkey*

A R T I C L E I N F O

Article history:

Received : 23 January 2021

Revised : 26 january 2022

Accepted : 28 january 2022

Keywords:

Brickwork & masonry

Buildings, structures & design

Structural frameworks

Cultural heritage

A B S T R A C T

Many methods and tools have been used to measure time throughout history. People started using mechanical watches instead of sundials and hourglasses because of technological advances. After that, they built clock towers, which have become a symbol of cities. Although clock towers were first constructed in Europe, they soon spread to the Ottoman Empire. Now these structures are considered an important component of a country's cultural heritage, and therefore must be preserved for future generations. The clock tower in Yozgat, Turkey is one such structure. For this study, a three-dimensional model of the Yozgat clock tower was constructed in a digital environment and subjected to static and dynamic analyses. The static analyses demonstrated that the structure is safe in terms of stress and displacement. However, the dynamic analyses demonstrated that damage would be formed in the lower regions of the tower base and extend all the way to the balcony in the event of an earthquake. Both the linear and nonlinear analyses yielded similar results in terms of where the damage would occur. This study could be used as a guide for future restoration studies or endeavors.

1 Introduction

Towers that have withstood the passage of time have been constructed with a variety of different styles and geometric features; as such, they constitute an important part of the world's cultural and architectural heritage. These structures have been built as stand-alone units and as components of other historical buildings. Clock towers were constructed with the primary aim of communicating the time, but they also were built high to warn people about fires and gather them to the city center for other important matters. In some European countries, they were built to indicate power and wealth [1]. Most of these historical towers were constructed of brittle stone; that vulnerability, plus any structural irregularities the building might have, increases their risk of collapse and damage [2]. There has been a diverse array of studies on this topic, including linear and nonlinear analyses, as well as investigations of techniques for improving and strengthening these structures.

The paper assert the dynamic properties of brick masonry towers, including their soil parameters [3]. Towers with different heights, material properties, and geometric designs were subjected to finite element (FE) analyses for different soil types according to the location of an earthquake's epicenter and its intensity. This study determined the effect of relevant parameters on the dynamic behavior of towers. It states on paper that there are many unknowns (material properties,

* *Corresponding author. Tel.: +090358 250 0017.*
E-mail address: senol.seker@amasya.edu.tr

e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

geometric design, boundary conditions, etc.) that make creating numerical models of historic buildings difficult. Based on their experimental results, they proposed the Bayesian approach as an accurate way to construct numerical models of historic buildings despite these uncertainties [4]. It declines on paper, presented data on a historical minaret in Iran, including its geometric features and material properties; they also determined the minaret’s dynamic properties by taking measurements with devices. Based on these measurements, they were able to create a three-dimensional model of the minaret in a digital environment and compare the model’s results with the experimental results. Mirtaheri et al. concluded by suggesting some intervention methods that could be used for future restoration projects [5]. Seker investigated the structural behaviour of two separate historical clock towers in Amasya that had been built on existing historical structures. This preliminary study provided information about the material properties and geometries of the towers, and subjected the three-dimensional models of the towers to static and dynamic analyses in a digital environment. The results showed that the tower additions created extra stresses on the existing historical structures at certain points in their static loading, as well as during earthquakes. Therefore, Seker recommended that these types of additions should be avoided, or, if necessary, the additions should be constructed with light materials [6]. Girardi et al. applied a newly developed procedure for modal analysis of masonry structures to a clock tower in Lucca. This method considers the effects of the stress field caused by thermal changes when calculating the natural frequencies and mode shapes of the structure [7]. The paper [8] are analysed the performance of a historical clock tower in eastern Turkey. Attia et al. constructed a three-dimensional FE model of a historical minaret [9], while they used historical towers to construct their FE models [10, 11]; all three studies subjected their models to static and dynamic analyses. All three studies identified the stressed parts of the structures and how they could be improved.

Facchini et al. performed nonlinear analysis on a masonry fixed-supported beam model [12]. To perform this analysis, they also developed four different mechanical damage models. The paper is performed an FE analysis on the Dolmabahce historical clock tower in Istanbul to consider the effects of soil [13]. Milani et al. also analyzed the Dolmabahce historical clock tower but did so using nonlinear static procedures [14]. Sarhosis et al. presented an equation for estimating the sensitivity of these types of towers; the equation considers the vulnerability and cross-sectional area parameters of masonry towers with different geometries [15]. Aside from the literature described here, there have been other, similar studies on towers and tower-like structures [16-26].

2 General Information About the Clock Towers in Anatolia

The clock tower architectural tradition first started in Europe in the 13th century and influenced the Ottoman Empire by the end of the 16th century. Accordingly, the first Ottoman Empire clock tower was built in Safranbolu, Anatolia in 1797. The edicts published on the 25th anniversary of Sultan Abdul Hamid II's accession to the throne and the 30th enthronement anniversary led to the construction of many clock towers. Previously, Ziya Pasha had numerous towers built during his time as the lieutenant governor of Adana and Amasya.

In some cities, clock towers were built in the city center as a representation of the central authority, while others were located on a hill or a slope overlooking the city. On the other hand, there are towers combined with other buildings, such as the towers that rise above historical castles.

Although most clock towers are made of stone, there are also some that were built from wood. While some towers become prominent due to their aesthetic value, most of them are in harmony with their surroundings, sharing the general characteristics of Islamic architecture. In addition to functioning to tell the time, clock towers have also been used as fire and watchtowers. Some tower types were equipped with barometers and thermometers. The clock towers in Anatolia generally consist of base, body, and pavilion sections. The base section contains a room and a stair to the body section; the body section typically has a “Z” shaped or spiral stair to the pavilion section; and the pavilion section contains the clock mechanism.

3 Architectural Characteristics of the Tower and General Information

The Yozgat clock tower was built to the Şakir master by Tevfikizade Ahmet Bey, in 1908. It is a tall, square prism tower in the middle of Yozgat. The tower consists of six floors with transverse moldings, and its upper section is surrounded by a minaret-like balcony. It has a bell-shaped cone made of wood at the top. The entrance to the tower is through a round-arched door from the north façade, and people can go up through “Z” shaped wooden stairs. Under the minaret-like balcony, on each floor there are four windows with small round arches [27]. The tower is 16.75 m high. Its base dimensions are 3.5 x 3.5 m, and its walls are 40 cm thick. Photographs of the tower and an acsonometric wireframe drawing of it are shown in Figure 1.

Fig. 1 – Photographs [27] and axonometric wireframe drawing of the Yozgat clock tower

4 Material Properties

There are many different types of materials used in the monuments of Anatolia. The material differs depending on whether the structural section carries load or not. Materials with high compressive strength and low tensile strength, such as stone and brick, have been used in the load-carrying elements of historical structures. In some buildings, wood was used throughout the entire structure. The primary material used in the Yozgat clock tower is stone, and it was used to construct the entire height of the building. The physical and mechanical properties of the stone were obtained by performing laboratory tests on the local stone material available in the region [28]. The values obtained are shown in Table 1.

Table 1 - Physical and mechanical properties of the materials used in the Yozgat clock tower

Tower Section	Main Body
Elasticity Modulus (MPa)	3000
Poisson’s Ratio	0.2
Density (kg/m^3)	1600
Mean Compressive Strength (N/mm^2)	3.0
Mean Tensile Strength (kN/m^2)	0.3

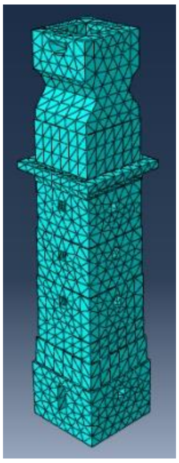


Fig. 2 – Finite element model of the Yozgat clock tower

5 Structural analyses

Historical artifacts have very complex structures in terms of both material and geometry. However, due to recent advances in computer technologies, these complex geometries can be digitally modeled and analyzed in three dimensions. Thus, detailed, realistic models can now be produced that allow access to previously unavailable insights. In this study, to perform structural analyses of the Yozgat clock tower, a three-dimensional model of the tower was created in the Abaqus V10 (Dassault Systems) program using an FE solution algorithm [29]. The analysis performed with the macromodeling technique used a C3D10 (10-node quadratic tetrahedron) solid element with three degrees of freedom at each node. The analysis performed with the FE model had 7163 elements and 13745 nodes. The stress and strain distributions were depicted in colored scales due to the large number of nodes in the building geometry. Analyses were carried out by assuming that the foundation of the tower was fixed-supported. The three-dimensional model of the tower is shown in Figure 2.

5.1 Static Analysis

For the static analysis, the structure was analyzed to determine how it bears its own weight with the linear elastic material assumption. Although the material is suitable for constructing buildings that go beyond the Yozgat clock tower's linear region, a static analysis is a useful first step for determining where the strained areas of the structure exist and for understanding the load flow in detail. The principal compressive stress distribution for the Yozgat clock tower is shown in Figure 3.

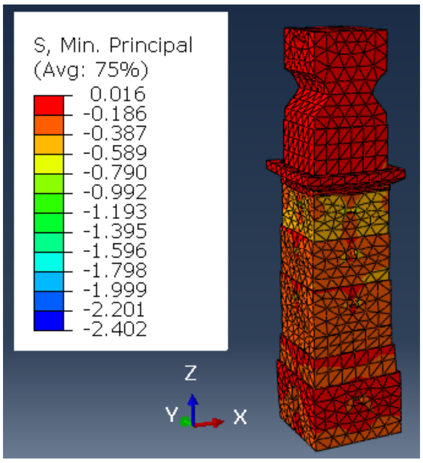


Fig. 3 – Static analysis of the Yozgat clock tower principal compressive stress distribution

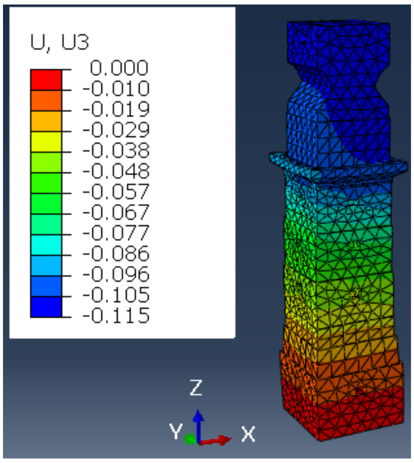


Fig. 4 – Static analysis of the Yozgat clock tower overall displacement distribution

The static analysis results show that the highest values for principal compressive stress occur around the window openings under the tower balcony. The maximum value observed in these areas is 2.402 MPa. This value is much lower than the compressive strength of the material. In other words, the tower can safely bear its own weight. Figure 4 depicts the Yozgat clock tower's displacement values, which shows that the building's maximum displacement values occur at the top of the tower, with the lowest displacement values at the building's base. The maximum displacement value the Yozgat clock tower obtained is 0.115 mm.

5.2 Modal Analysis

Free vibration mode shapes of the structure were determined by modal analysis, which is significant for dynamic analysis. Modal analysis provides information about the movement of the structure during an earthquake, which means that stressed areas of the structure can be identified. According to the article specified in the earthquake code, the effective mass in both directions should not be less than 90% of the structure's total mass; as a result, 50 mode shapes were considered. The modal participation ratios and periods of the most effective modal shapes are shown in Table 2.

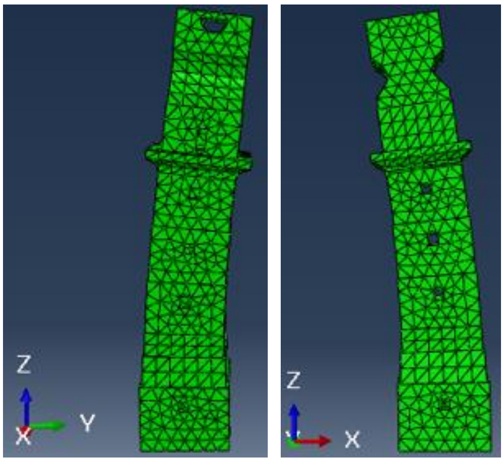


Fig. 5 – Modal analysis of the Yozgat clock tower1st and 2nd mode shapes

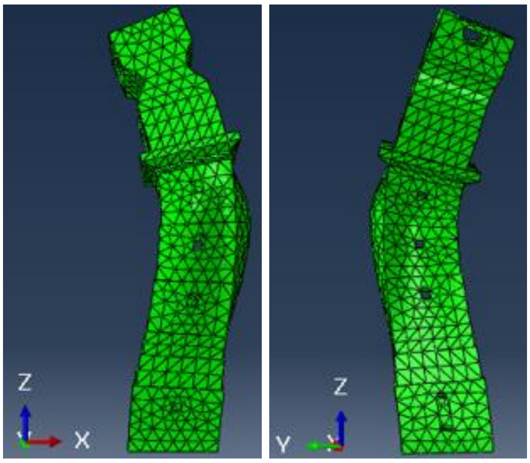


Fig. 6 – Modal analysis of the Yozgat clock tower 4th and 5th mode shapes

The effective mode shapes shown in Figures 5 and 6 demonstrate that the structure's main movement is a translation in both directions. Furthermore, the torsion effect prevails in the upper parts of the tower in addition to the translation mode. With these displacement shapes, the lower parts of the tower balcony and the top of the upper section would likely be deformed in the event of an earthquake.

Table 2 - Modal analysis of Yozgat clock towerperiods and mass participation ratios

Mode	Period (s)	Mass participation ratios	
		X-Direction	Y-Direction
1	0.11375	0	0.59
2	0.11272	0.60	0
4	0.0217	0.14	0
5	0.0215	0	0.15

5.3 Seismic assessment of the Yozgat clock tower

This section describes the results of the linear material properties analysis and the results of the nonlinear analysis, which was carried out using the Concrete Damage Plasticity (CDP) model available in the material library of Abaqus V10 software. The CDP model was developed to describe the behavior of concrete material with different stress-strain curves for compression and tensile conditions, considering the plasticity and damage effects. The CDP model has also been used to analyze masonry materials that exhibit similar behaviours as concrete. The constitutive theory aims to capture the effects of irreversible damage associated with the failure mechanisms that occur in brittle materials. Strain rate decomposition is assumed as:

$$\varepsilon = \varepsilon^{el} + \varepsilon^{pl} \tag{1}$$

where ε is the total strain rate, ε^{el} is the elastic part of the strain rate, and ε^{pl} is the plastic part of the strain rate. The inelastic stress–strain curves characteristic of materials such as concrete are shown in Figure 7 [30].

As can be seen in Figure 7, the CDP model shows elastic behavior up to the maximum stress values for tensile and compression behaviors. Exceeding this value causes micro-cracks in the material's tensile behavior and collapse in the material's compression behavior. Mathematical expressions for the damage caused by various tension and compression conditions are shown in Equations 1 and 2 [31].

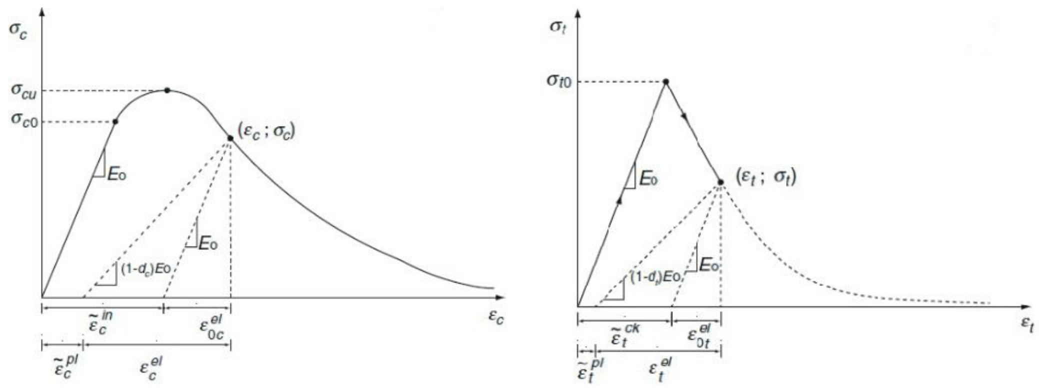


Fig. 7 – CDP model inelastic stress and strain curves [30]

$$\sigma_{to} = \left(1 - d_t\right) E_0 \left(\varepsilon_t - \varepsilon_t^{p1}\right) \tag{2}$$

$$\sigma_{cu} = \left(1 - d_c\right) E_0 \left(\varepsilon_c - \varepsilon_c^{p1}\right) \tag{3}$$

where E_0 is the initial (undamaged) elastic stiffness of the material and d is the scalar stiffness degradation variable, which can take values from zero (undamaged material) to one (fully damaged material). Damage associated with the failure mechanisms therefore results in a reduction in the elastic stiffness. Within the context of the scalar-damage theory, the stiffness degradation is isotropic and characterized by a single degradation variable, d. For any given cross-section of the material, the factor $\left(1 - d\right)$ represents the ratio of the effective load-carrying area to the overall section area [32].

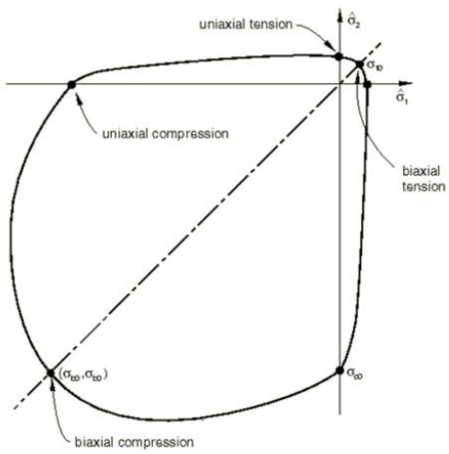


Fig. 8 – CDP model Biaxial Failure Surface [33]

The parameters required to define the yield surface consists of four constitutive parameters. The Poisson’s ratio controls the volume changes of material. When the critical stress value is reached material exhibits an increase in plastic volume under pressure. This behavior is taken into account by the parameter called angle of dilation. In CDP model ψ is the dilation angle measured in the $p - q$ plane at high confining pressure. ε is an eccentricity of the plastic potential surface whose default value is 0.1. The ratio of initial biaxial compressive yield stress to initial uniaxial compressive yield stress, σ_{b0}/σ_{c0} , with default value of 1.16. Finally, K_c is the ratio of the second stress invariant on the tensile meridian to compressive meridian at initial yield with default value of 2/3. Biaxial yield surface in CDP Model is shown in Figure 8 [33] and other parameters used to define the CDP model are shown in Table 3 [3].

Geographically, Turkey is located on a major seismic belt. There are many different active fault lines in Turkey. One of them is the North Anatolian fault line. There have been some quite damaging earthquakes on this line in the past. The Yozgat clock tower is located close to this line (Figure 9).

Table 3 – Material parameters used in CDP Model

Dilation angle	Eccentricity	σ_{b0}/σ_{c0}	K
10^0	0.1	1.16	0.666

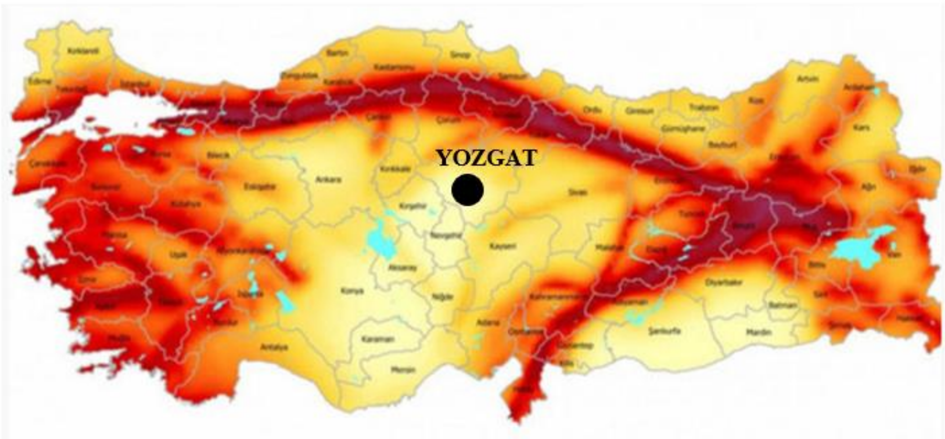


Fig. 9 – Turkey's Earthquake Map [34]

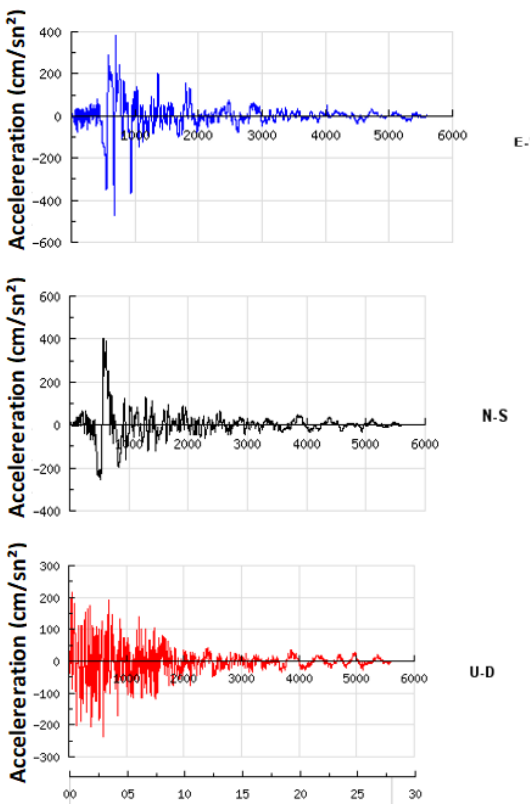


Fig 10 – The acceleration values of the 1992 Erzincan earthquake (cm/s²) [35]

Therefore, it is important to examine how the structure might behave during an earthquake to identify possible damage situations. In the linear and nonlinear analyses performed for this study, the structure was examined using the seismogram of the 1992 Erzincan earthquake. The earthquake's acceleration in east-west and north-south directions was applied to the structure. Earthquake acceleration values are shown in Figure 10. The time step was 0.005 and the damping ratio was 0.05. As a result of these analyses, the stresses and displacement in the structure were calculated.

5.3.1 Linear time history analysis

In the linear analysis performed using the acceleration records of the 1992 Erzincan earthquake, the maximum displacement contours obtained in both directions were at the top of the tower (see Figure 11). The maximum displacement contours were 294.198 mm for the north-south direction and 352.625 mm for the east-west direction.

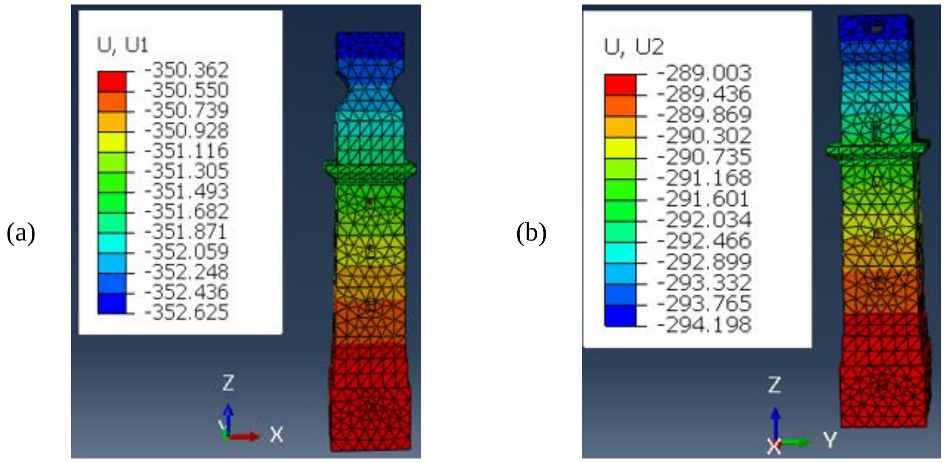


Fig. 11 – Maximum displacement (mm) contours in linear time history analysis: a) north-south direction, b) east-west direction

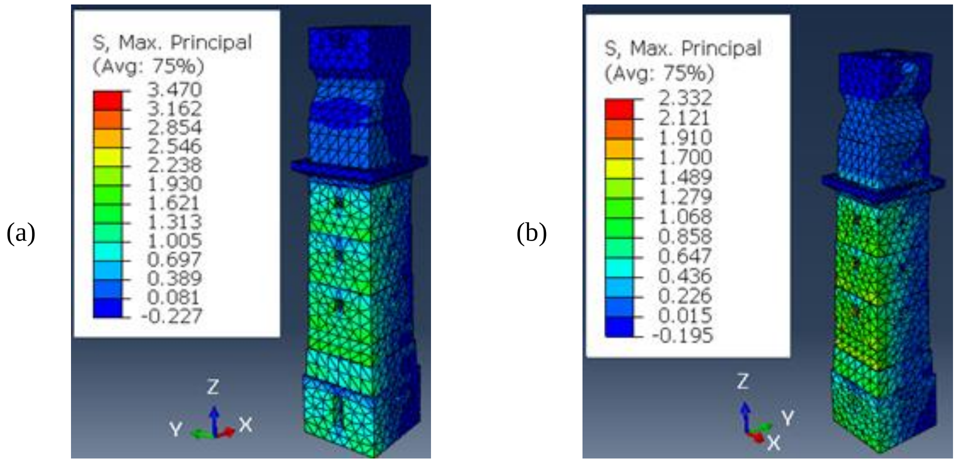


Fig. 12 – Maximum principal stress (MPa) contours in linear time history analysis: a) north-south direction, b) east-west direction

The maximum principal stress distribution for both directions is shown in Figure 12. Stress values were the highest between the tower balcony and base sections. While the maximum principal stress in the north-south direction was 3.470 MPa, it was only 2.332 MPa in the east- west direction. For this study, the allowable tensile stress was determined to be 0.317 MPa; accordingly, heavy damage can be expected in these sections of the tower in the event of an earthquake.

For the minimum principal stress distribution (see Figure 13), the highest stresses were 2.385 MPa and 2.409 MPa in the north-south and east-west directions, respectively. These values were observed in the first level of the base of the tower. In the middle section extending up to the tower balcony, high stress values were dominant. The allowable stress value (3.00 MPa) was not exceeded.

(a) (b)

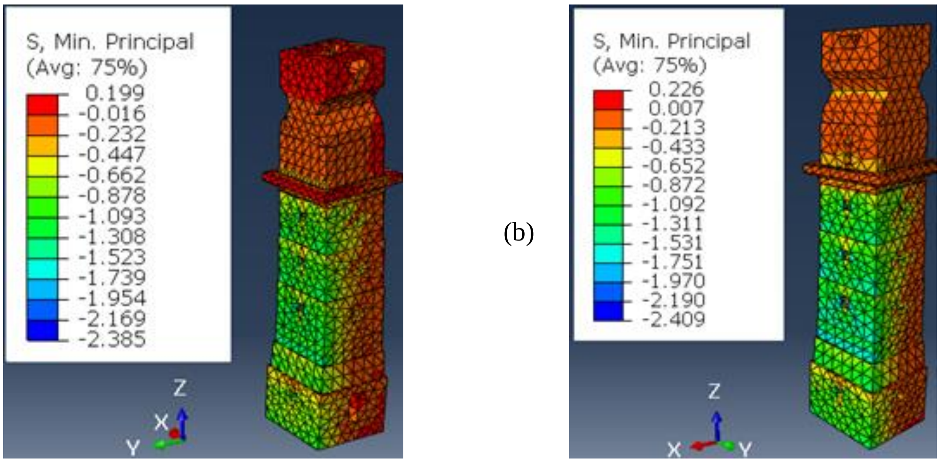
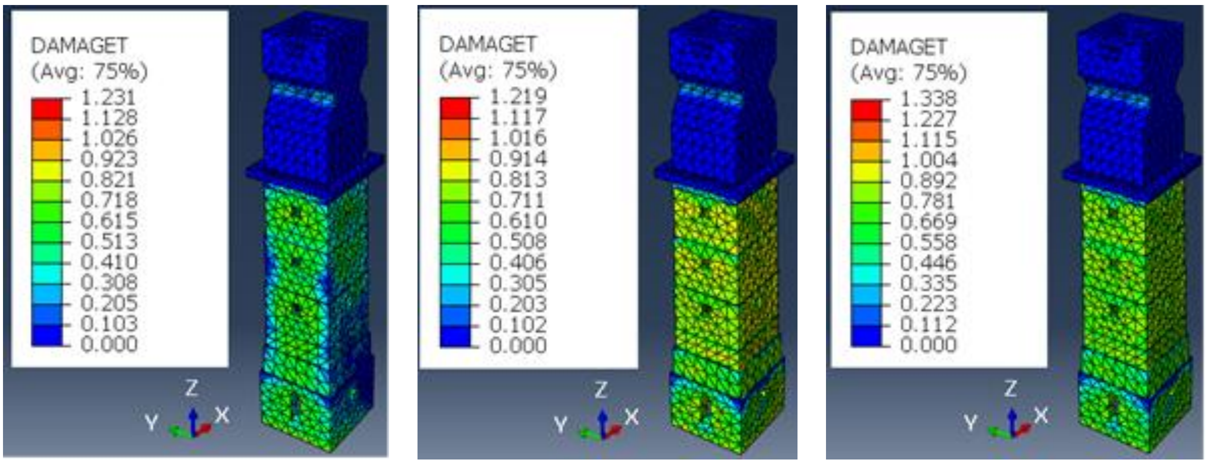


Fig. 13 – Minimum principal stress (MPa) contours in linear time history analysis: a) north south direction, b) east west direction

5.3.2 Nonlinear time history analysis

Damage caused by tensile stress is shown in Figure 14. Damage starts to form at t = 1.327 s and extends towards the balcony up to t = 12.92 s. Damage in this analysis was most intense around window openings and the main entrance door.



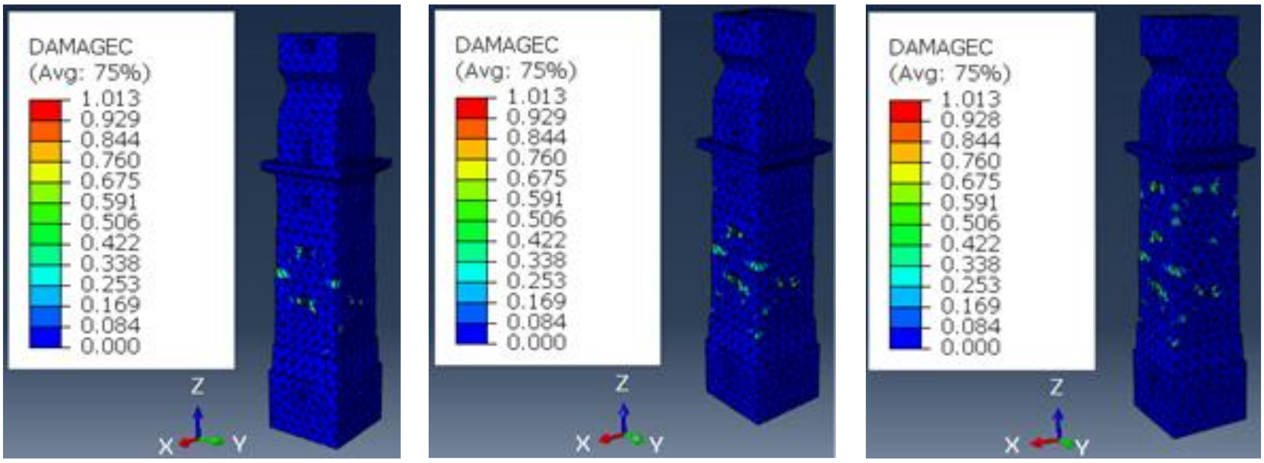
t = 1.327 sn *t = 5.170 sn* *t = 12.92 sn*

Fig. 14 – Tension damage contours for different time steps

Figure 15 shows compression damage contours for different time steps. The compression damage is concentrated mainly in the transition areas of the tower levels and in the area under the balcony.

6 Conclusions

It is of great importance to preserve historically significant structures for future generations. These structures, which are rightfully considered works of art, should be strengthened over time with appropriate intervention methods so they can survive and resist external effects. Appropriate interventions can be made in a timely and accurate manner by determining which areas of these artifacts would be stressed because of destructive forces such as earthquakes. The areas that would be most stressed can be easily examined in a FE environment with today's technology.



t = 5.811 sn *t = 15.38 sn* *t = 26.20 sn*

Fig. 15 – Compression damage contours for different time steps

In this study, the historical clock tower in Yozgat was subjected to static and dynamic analyses. Within the structural dynamic analysis, in addition to the linear analysis, a nonlinear analysis was also performed using the CDP model. The main results from the analyses are as follows: The Yozgat clock tower is very safe under static loads. The structure's stress and displacement values are within the limit values. This indicates that the tower's cross-section and its dimensions are sufficient for its own weight. The modal analysis demonstrated that effective modal changes would occur as translation in both orthogonal directions. Maximum displacements occurred at the tower peaks. Also, in two subsequent modes, six of the out-of-plane translations for the tower balcony participated in the movement with high mass participation ratios. Maximum displacement contours occurred near the top of the tower in both directions. The maximum principal stress values were concentrated in the region extending from the tower base to the balcony. The minimum principal stresses occurred as compression, and their highest values occurred at the lower regions of the tower. The nonlinear analyses made with the CDP model identified the areas that would be damaged by both tensile and compression stresses. In the model, tensile damage occurred between the tower base and balcony. Compression damage was concentrated in the transition zones of the tower levels, a much narrower area compared to the damage caused by tensile stresses. Because of these results, improvements should be made in the region from the tower base to the balcony, specifically using elements that would eliminate the effect of tensile stresses. When comparing the results of the linear analysis with those of the nonlinear analysis, the damaged regions of the structure are clearly compatible with each other, although there are differences between the numerical values of the analyses. The tensile stress distribution in the linear analysis particularly highlights this issue.

This study's analyses of the Yozgat clock tower demonstrate that it could be seriously damaged in a severe earthquake such as the 1992 Erzincan earthquake. The damages would start with the lower regions of the tower and could extend to the balcony during an earthquake. Both the linear and nonlinear material models resulted in this finding. Although the linear analyses yielded different values from the nonlinear analyses in terms of stress and displacement, they showed that the same regions of the tower would be damaged. Therefore, any improvements made in these areas would increase the safety of the tower in the event of an earthquake. It is expected that the findings of this study will guide experts who work in this field.

REFERENCES

[1]- A. Preciado, G. Bartoli, H. Budelmann, Fundamental aspects on the seismic vulnerability of ancient masonry towers and retrofitting techniques. Earthquakes Str., 9(2) (2015) 339-352. doi:10.12989/EAS.2015.9.2.339.

[2]- L. Miccoli, Seismic risk assessment of the Santa Maria a Vico bell tower. Ambient vibration measurements and numerical model tuning, in 3rd International Conference on Protection of Historical Constructions (PROHITECH 2017) Lisbon, Portugal. (2017).

[3]- S. Zarandi, M.R. Maheri. Seismic vulnerability of historical brick masonry towers. in Proceedings of the 14th World Conference on Earthquake Engineering. Beijing, China. (2008), 12-17.

[4]- G. Bartoli, M. Betti, L. Facchini, A.M. Marra, S. Monchetti, Bayesian model updating of historic masonry towers through dynamic experimental data. Procedia Eng., 199 (2017) 1258-1263. doi:10.1016/j.proeng.2017.09.267.

[5]- M. Mirtaheri, A. Abbasi, N. Salari, A seismic behavior and rehabilitation of the historic masonry minaret by experimental and numerical methods. Asian J. Civ. Eng., 18(5) (2017) -.
[6]- B.S. Seker, Behavioural assessment of clock towers subsequently added to historic structures. Građevinar 67(9) (2013) 879-886. doi:10.14256/JCE.1169.2014.
[7]- M. Girardi, C. Padovani, D. Pellegrini, Effects of the stress field on the dynamic properties of masonry bell towers, in XXIII Congresso Associazione Italiana di Meccanica Teorica e Applicata AIMETA 2017At: Salerno Salerno, Italy,. (2017). 216-229.
[8]- B. Akbas, F. Cakir, Performance-Based Evaluation of Historical Structures, in Proceedings Workshop on Seismicity of Historical Structures İstanbul. (2014). 1-6. doi:10.13140/2.1.3993.4243.
[9]- W.A. Attia, T.A.E. Sayed, A.A. Abdel-Haleem. Behavior, Repair & Strengthening of Historic Stone Masonry Towers. in Proceedings Second International Conference on Construction in Developing Countries. Cairo, Egypt. (2010.
[10]- E. Mustafaraj, Y. Yardım, Determination of structural behavior of a unreinforced masonry clock tower using FEM analysis. Am. J. Eng. Res., 5(1) (2016) 100-104.
[11]- M. Pavlovic, S. Trevisani, A. Cecchi, Experimental and Numerical Analysis of a Historical Bell Tower. Int. J. Archit. Envir. Eng., 10(12) (2016) 1500-1507. doi:10.5281/zenodo.1127517.
[12]- L. Facchini, M. Betti, R. Corazzi, V.C. Kovacevic, Nonlinear seismic behavior of historical masonry towers by means of different numerical models. Procedia Eng., 199 (2017) 601-606. doi:10.1016/j.proeng.2017.09.103.
[13]- Z.Y. İlerisoy, A. Soyluk, Dynamic analysis of Dolmabahce masonary clock tower. Građevinar 65(4) (2013) 345-352. doi:10.14256/JCE.885.2012.
[14]- G. Milani, R. Shehu, M. Valente, Seismic Assessment of Masonry Towers by Means of Nonlinear Static Procedures. Procedia Eng., 199 (2017) 266-271. doi:10.1016/j.proeng.2017.09.022.
[15]- V. Sarhosis, F. Fabbrocino, A. Formisano, G. Milani. Seismic vulnerability of different in geometry historic masonry towers. in 6th International conference on computational methods in structural dynamics and earthquake engineering. Greece: Eccomas Proceedia. (2014), 2519-2532.
[16]- C. Gentile, A.E. Saisi, G. Marco. Post-earthquake dynamic monitoring of a historic masonry tower. in Proceedings of the 9th International Conference on Structural Dynamics, EURODYN 2014. U. Porto, Facultade de Engenharia, FEUP Edições. (2014), 1469-1476.
[17]- G. Bartoli, M. Betti, A. Vignoli, A numerical study on seismic risk assessment of historic masonry towers: a case study in San Gimignano. Bull. Earthquake Eng., 14(6) (2016) 1475-1518. doi:10.1007/s10518-016-9892-9.
[18]- S. Caddemi, I. Caliò, F. Cannizzaro, B. Pantò. The seismic assessment of historical masonry structures. in Proceedings of the 12th International Conference on Computational Structures Technology, Naples, Italy. (2014), 2-5.
[19]- C. Rainieri, A. Marra, G. Fabbrocino, On the estimation of the fundamental modal properties of Italian historical masonry towers. Ingegneria Sismica, 3 (2014) 1-15.
[20]- A.E. Saisi, C. Gentile. OMA and seismic assessment of a historic masonry tower. in 5th International Operational Modal Analysis Conference. University of Minho. (2013), 1-11.
[21]- A. Saisi, C. Gentile, M. Guidobaldi, M. Xu, Dynamic Monitoring and Seismic Response of a Historic Masonry Tower. Key Eng. Mater., 628 (2015) 55-60. doi:10.4028/www.scientific.net/KEM.628.55.
[22]- A. Ural, F.K. Firat, Evaluation of masonry minarets collapsed by a strong wind under uncertainty. Nat. Hazards, 76(2) (2015) 999-1018. doi:10.1007/s11069-014-1531-7.
[23]- G. Bartoli, M. Betti, S. Monchetti, Seismic Risk Assessment of Historic Masonry Towers: Comparison of Four Case Studies. J. Perform. Constr. Facil., 31(5) (2017) 04017039. doi:10.1061/(ASCE)CF.1943-5509.0001039.
[24]- A. Anzani, L. Binda, G. Cardani, P. Condoleo, A. Saisi. Damage evaluation of historic towers: a procedure for their integrity assessment. in Proceedings 2nd Canadian Conference on Effective Design of Structures, McMaster University Hamilton, Ontario, Canada. (2008), 1-10.
[25]- S. Casciati, L. Faravelli, Vulnerability assessment for medieval civic towers. Structure and Infrastructure Engineering, 6(1-2) (2010) 193-203. doi:10.1080/15732470802664290.
[26]- A.F. Genç, M. Ergün, M. Günaydin, A.C. Altunişik, Ş. Ateş, F.Y. Okur, A.S. Mosallam, Dynamic analyses of experimentally-updated FE model of historical masonry clock towers using site-specific seismic characteristics and scaling parameters according to the 2018 Turkey building earthquake code. Eng. Failure Anal., 105 (2019) 402-426. doi:10.1016/j.engfailanal.2019.06.054.

[27]- H. Acun, Osmanlı imparatorluğu saat kuleleri. Atatürk Kültür Merkezi, 2011.

[28]- H.O. Anadut. Tarihi yapıların dinamik davranışlarının incelenmesi, Master's thesis. Fen Bilimleri Enstitüsü, 2016.

[29]- Dassault Systems "Abaqus V10", [computer program] Available at: https://www.3ds.com/products-services/simulia/products/abaqus.

[30]- E. Hökelekli, A. Demir, E. Ercan, H. Nohutçu, A. Karabulut, Seismic Assessment in a Historical Masonry Minaret by Linear and Non-linear Seismic Analyses. Periodica Polyt. Civ. Eng., 64(2) (2020) 438-448. doi:10.3311/PPci.15126.

[31]- M. Valente, G. Milani, Non-linear dynamic and static analyses on eight historical masonry towers in the North-East of Italy. Eng. Struct., 114 (2016) 241-270. doi:10.1016/j.engstruct.2016.02.004.

[32]- Abaqus, Abaqus Theory Manual,Damaged plasticity model for concrete and other quasi-brittle materials, at : https://classes.engineering.wustl.edu/2009/spring/mase5513/abaqus/docs/v6.6/books/stm/default.htm?startat=ch04s05ath120.html.

[33]- Y. Sümer, M. Aktaş, Defining parameters for concrete damage plasticity model. Challenge Journal of Structural Mechanics, 1(3) (2015) 149-155. doi:10.20528/cjsmec.2015.07.023. .

[34]- Disaster & Emergency Management Authority Presidential of Earthquake Department, at : https://deprem.afad.gov.tr/deprem-tehlike-haritasi?lang=en.

[35]- T.B.E. Code, Disaster and emergency management presidency. Ministry of Interior, Ankara, Turkey, (1992).