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Behavioural assessment of clock towers subsequently added to historic structures

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Professional paper

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Behavioural assessment of clock towers subsequently added to historic structures

Many historic structures across the world undergo alterations over time due to urban requirements and conditions, and their occupancy is either changed or new structures are built on the existing ones. These changes usually involve use of different materials or construction of a new structure above the original one. Each such change can reduce the building's functionality, and negatively affect the stability and carrying capacity of the structure. Structural properties of clock towers built on a portal in the historic city of Amasya are analysed in the paper.

Key words:
historic clock towers, subsequently added structures, structural performance, mechanical tests

Stručni rad

Burcin S. Seker

Procjena ponašanja tornjeva sa satom nadograđenih na povijesnim građevinama

Mnoge povijesne građevine diljem svijeta izložene su promjenama tijekom vremena zbog urbanističkih zahtjeva i uvjeta, što najčešće pretpostavlja prenamjenu uz promjenu konstrukcijskog sustava. Te promjene obično se odnose na primjenu dodatnih drugačijih (modernih) materijala, ali katkad i nadogradnju potpuno drugačije konstrukcije na postojećoj. Takve promjene mogu ugroziti koncept nosivosti postojeće građevine, odnosno negativno utjecati na pretpostavljeni prijenos sila, što u konačnici može ugroziti nosivost i stabilnost građevine. U radu se analizira ponašanje konstrukcija dvaju tornjeva sa satom koji su izgrađeni na postojećim povijesnim građevinama u gradu Amasyi.

Ključne riječi:
povijesne građevine, nadograđene konstrukcije, konstrukcijska svojstva, mehanička ispitivanja

Fachbericht

Burcin S. Seker

Verhalten von nachträglich angebauten Glockentürmen bei historischen Bauten

Viele historische Bauten weltweit sind im Laufe der Zeit Veränderungen ausgesetzt, die auf urbanistischen Anforderungen und Bedingungen beruhen, sowie Umgestaltungen oder den Anbau neuer Objekte verlangen. Diese Veränderungen beziehen sich hauptsächlich auf die Anwendung verschiedener zusätzlicher Materialien oder die Erbauung neuer Tragelemente, die sich auf die bestehende Konstruktion stützen. Jede solche Wandlung kann die Funktionalität des Bauwerkes verringern, sowie Stabilität und Tragfähigkeit der Konstruktion negativ beeinflussen. Diese Arbeit analysiert Tragwerkseigenschaften der Glockentürme, die am Portal der historischen Stadt Amaysi erbaut wurden.

Schlüsselwörter:
historische Bauten, Konstruktionen mit Anbau, Eigenschaften von Tragkonstruktionen, mechanische Prüfungen

1. Introduction

The easiest and most effective way to preserve historic structures and prevent their collapse is to ensure their continuous utilisation. However, it is very difficult to use these structures in keeping with their original occupancy and functions intended when they were first built. In line with the preservation and maintenance principles, many historic structures undergo alterations and their intended use is changed by adding new functions, in response to changing requirements and conditions. Turkey has a lot of buildings that served different purposes in the course of time, and were sometimes modified by alterations. This type of structures can now be seen in almost every city. However, the practice of adding clock towers onto historic structures is quite rare.

Clock towers and high clock towers were built during the Ottoman Period in several cities across Turkey [1]. While some of these towers have preserved their integrity, some were unable to survive and collapsed due to external factors. The majority was built as masonry structures, which were sometimes built in random locations. While some of these facilities were built as detached structures, some were added onto existing structures. The effect these structures have on the main structures and their engineering behaviour was not adequately examined. However, it is thought that because of their geometric form and structural limitations, these structures are more at risk compared to other masonry structures [2]. It is therefore very important to determine seismic behaviour of these buildings, taking into account their geographic position and earthquake zone in which they are situated. During an earthquake, structures of this type, often characterized by quite complex and varying internal structures, can be affected more severely than other structures due to their height. In addition, their impact on main structures, especially with regard to self-weight, must be determined. To this end, two clock towers added on historic gates in the historic city of Amasya are discussed, and their structural behaviour is investigated. Laboratory analyses were first conducted to determine the engineering properties of construction materials, and the finite element model of each structure was prepared to determine their structural performance through static and dynamic analyses.

2. General information

Located in the Central Black Sea region of Turkey, Amasya is one of the most important cities in Turkey in terms of its historic and cultural significance. Situated along the ancient Silk Road, the city has hosted many civilizations and many different nations. Amasya is the meeting point of cultures and civilizations, and it has not only served as a social, cultural and strategic centre during its long existence, but it has also accumulated cultural traces of all civilizations it has been in contact with [3]. Therefore, this city exhibits a rich historic heritage, with various cultural and architectural traces of different civilizations. Historic clock towers located in the city centre and its sub-provinces rank among the most important examples of its cultural heritage.

Two clock towers located in two different sub-provinces of Amasya are investigated in this study. The first of these clock towers is situated in Merzifon sub-province, and the second in Gümüşhacıköy sub-province. The clock tower in Merzifon is located on the gate of the Madrasa of Sultan Mehmet Celebi. Mehmet Memişoğlu Ebu Bekir built this clock tower on the order of Sultan Mehmet Çelebi. Later on, in 1866, it was repaired by Ziya Pasha, Governor of Amasya [4]. The tower consists of two parts. The bottom part is cylinder-shaped and is made of brick. The upper part is made of wood, it is square-shaped, and has a clock accessory. Clocks facing four directions were placed on this wooden part. In addition, arched windows were opened in all directions to ensure that the clock bell can be heard better. Operating on the basis of a weight system, the tower is still in use, and shows the time (Figure 1).

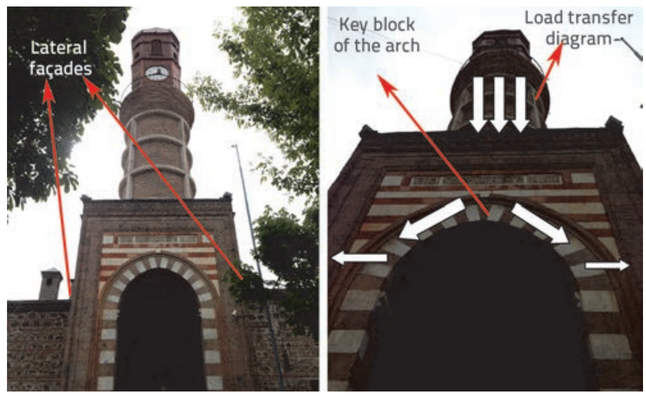

Figure 1. Merzifon Clock Tower

The other tower was built on the eastern gate of the bazaar in Gümüşhacıköy sup-province by Ali Riza Bey, the son of the Ottoman pasha Yanyaki Mustafa Pasha in 1898 [4]. Known to have undergone several renovations and repairs over time, the clock tower assumed its current form after repairs in 1971. It was built in one piece with wooden elements on the gate made of ashlar. The minaret balcony of the tower, with clocks showing the time in four directions, is also made of wood. The upper part is sealed with a wooden cone to protect the tower from external influences (Figure 2).

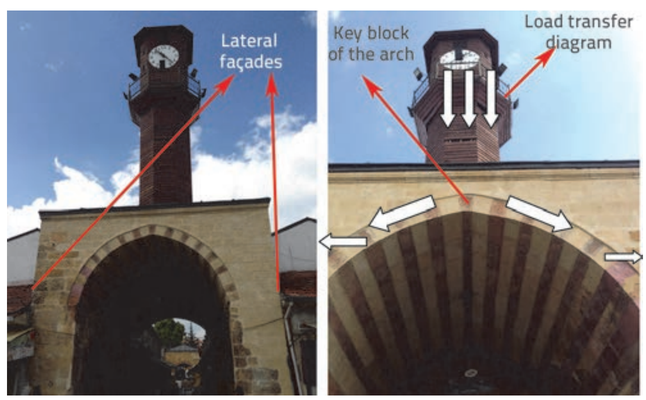

Figure 2. Gümüşhacıköy Clock Tower

2.1. Structural deformation of towers

An in-situ investigation relying on visual analysis was carried out in this study in order to determine structural deformations of the towers. Visible signs of structural deterioration were visually examined in the light of structural features and architectural characteristics. Deteriorations observed in the towers were mainly concentrated in key blocks of main arches (Figure 3). More specifically, several micro and macro cracks were detected on the upper parts of the lateral façades of Merzifon Clock Tower. Some significant micro and macro cracks were also discovered at external surfaces of the inside section of Gümüşhacıköy Clock Tower. These cracks are considered to be visual signs of structural deformations (Figure 4). In addition, flaking, powdering, swelling, dampness, and stains, were observed at the internal section of Gümüşhacıköy Clock Tower.

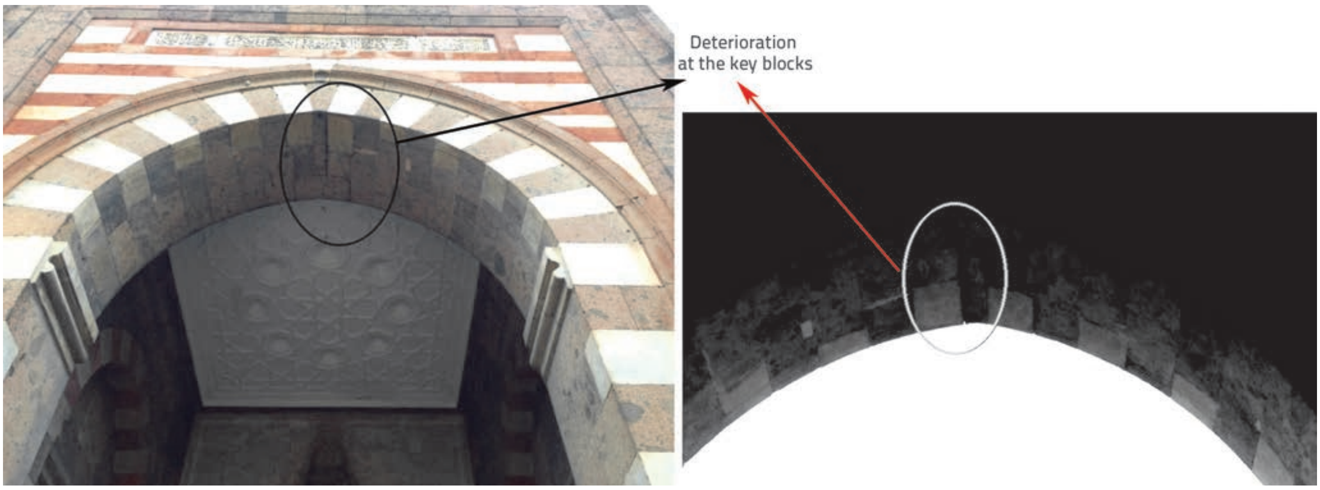

Figure 3. Deterioration at key blocks of Merzifon Clock Tower

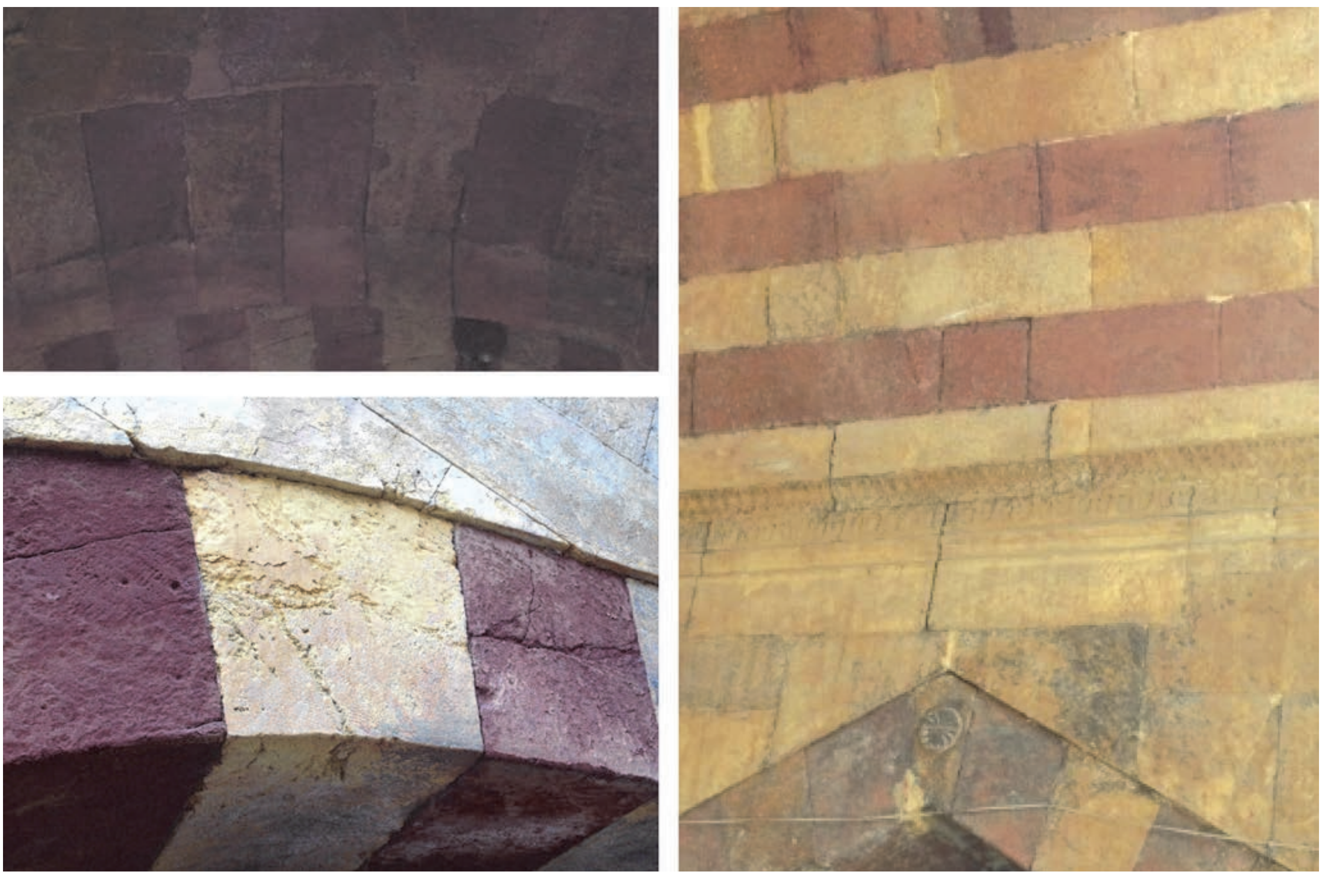

Figure 4. Some micro and macro cracks at Gümüşhacıköy Clock Tower

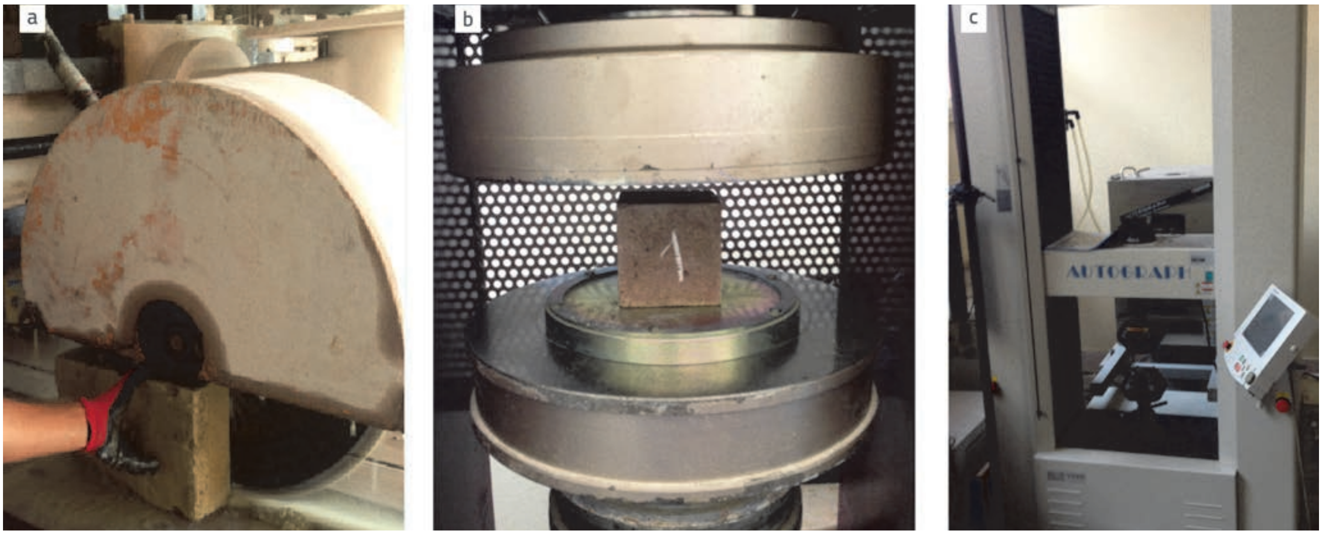

Figure 5. a) Preparation of samples; b) compression test; c) tensile test

3. Mechanical characteristics of materials

In the first step, the objective was to identify the current situation of the structures and engineering properties of the materials used. To this end, field studies were conducted to examine the structures in detail. In this study, material samples could not have been taken from the structures directly because of restrictions contained in Turkish specifications that prevent such practice. Therefore, samples were taken from the surroundings of the structures. It is believed that these samples, which are actually the remains of previous restoration works, accurately represent the structures. The samples were prepared for mechanical testing according to relevant standards for the conduct of mechanic tests. First, the compression and three-point tensile tests were performed on the bricks and stones, which was followed by the compression and tensile tests on timber elements along the direction of fibres (Figure 3). In the experimental studies, care was taken to perform the analyses with at least five samples [5-9]. Test results are presented for each sample in Table 1 and Table 2.

Table 1. Characterisation of materials from Merzifon Clock Tower

Samples	Bricks		Stone		Timber	
	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]
1	21.22	1.52	43.45	2.98	33.12	11.89
2	20.98	1.37	45.78	2.84	31.42	10.82
3	19.84	1.42	45.93	2.83	29.98	12.21
4	19.21	1.49	43.80	2.90	32.20	11.99
5	22.05	1.40	42.23	3.09	30.87	11.58
Average	**20.66**	**1.44**	**44.24**	**2.93**	**31.52**	**11.70**

Table 2. Characterisation of materials from Gümüşhacıköy Clock Tower

Samples	Bricks		Stone		Timber	
	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]	Compressive strength [N/mm^2]	Tensile strength [N/mm^2]
1	21.01	1.65	45.84	2.96	31.46	10.84
2	19.89	1.78	46.04	2.84	30.05	12.24
3	22.32	1.42	42.75	3.13	31.25	11.72
4	19.38	1.50	44.19	2.93	32.49	12.10
5	21.25	1.83	43.50	2.98	33.16	11.90
Average	**20.77**	**1.63**	**44.47**	**2.97**	**31.68**	**11.76**

4. Numerical analysis

In order to determine protection methods for the masonry towers, it is very important to determine their seismic behaviour, structural integrity, and failure mechanisms. It is difficult to determine seismic behaviour of historic structures by means of common engineering methods. Therefore, the use of the finite element method is more convenient and reliable in the structural analysis of masonry towers. In this study, the historic clock towers were modelled using ANSYS [10], and the static and dynamic analyses were carried out on the model. The parameters and assumptions examined in the numerical model and analyses are listed below:

- The 20-node Solid186 element with 3 degrees of freedom per node found in the ANSYS library was used during the modelling [10].
- The first clock tower was modelled using 62748 three-dimensional nodes and 31738 solid elements, while 76929 nodes and 48412 elements were used for the second tower (Figure 6).

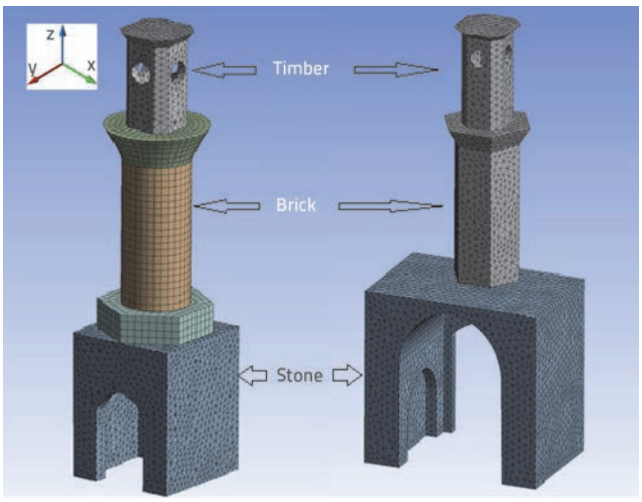

Figure 6. Finite element models of (a) Merzifon Clock Tower, (b) Gümüşhacıköy Clock Tower

- Fixed boundary conditions were assumed in the foundation sections and sidewalls.
- The damage and degradation in the structures were not taken into account during the modelling, and their undamaged condition was considered to accurately determine the stress that is likely to cause damage.
- The time history analysis method was used in the dynamic analysis, and the north-south (NS) component of the 1999 Kocaeli earthquake's acceleration records was taken into consideration during the analyses [11].
- According to the local coordinate system of elements, σ_{11}, σ_{22}, and σ_{33} are the direct stresses acting on the faces in the x, y and z directions, respectively. σ_{max} is the maximum principal stress, and σ_{min} is the minimum principal stress. In this study, the maximum value of the maximum principal stress is the tensile stress, and the minimum value of the minimum principal stress is the compression stress. Moreover, mechanical properties of the materials used in the model are presented in Table 3 and Table 4.

Table 3. Mechanical properties of materials from Merzifon clock tower

Structural parts	Young modulus [N/mm²]	Poisson ratio	Density [kg/m³]
Stone parts	8000	0.15	2500
Brick parts	6000	0.18	1875
Timber parts	9000	-	500

Table 4. Mechanical properties of materials from Gümüşhacıköy clock tower

Structural parts	Young modulus [N/mm²]	Poisson ratio	Density [kg/m³]
Stone parts	8250	0.15	2500
Brick parts	6300	0.18	1898
Timber parts	9000	-	500

4.1. Static analysis

Static analyses were first performed on the finite element models to determine structural behaviour, i.e. to observe behaviour of these structures under their own weight. Comparative static analysis results are provided in the following figures. The static analysis indicates that maximum principal stresses amounts to about 0.32 MPa for Merzifon Clock Tower and 0.20 MPa for Gümüşhacıköy Clock Tower. It can be seen that the stresses occur at the top of the arches at the entrance and the skewback of the arches in the lateral façades as tension (Figure 7). Additionally, the maximum compression stresses were found to be about 0.92 MPa and 0.65 MPa for Merzifon Clock Tower and Gümüşhacıköy Clock Tower, respectively. The compression stresses are concentrated at the base sections (Figure 8). Furthermore, maximum vertical displacements occur at the top of the towers and amount to about 0.40 mm and 0.18 mm for Merzifon Clock Tower and Gümüşhacıköy Clock Tower, respectively (Figure 9).

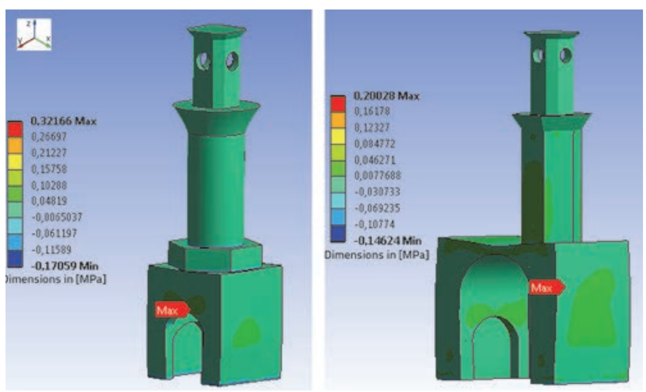

Figure 7. Maximum principal stresses

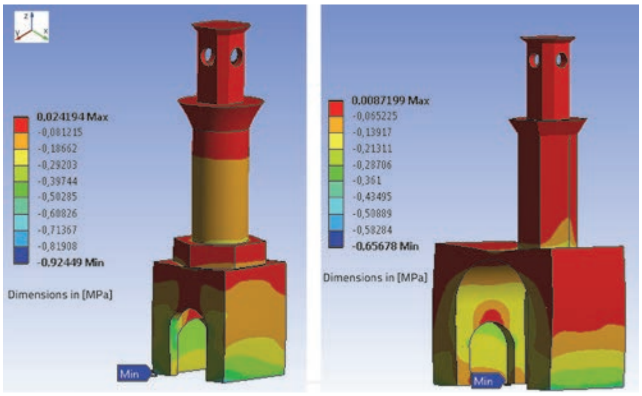

Figure 8. Minimum principal stresses (MPa)

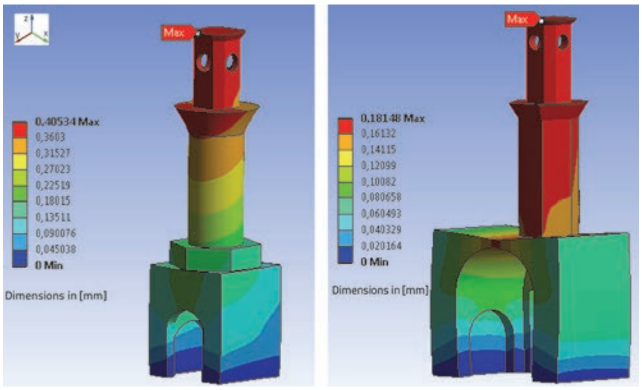

Figure 9. Maximum vertical displacement

4.2. Modal analysis

In the second stage of numerical analysis, a modal analysis was performed to determine free vibration modes of the structures and, as a result, their mode shapes and free vibration periods were identified. According to Turkish Seismic Code - 2007 (TSC-2007), the analysis may be conducted according to the criterion that the sum of effective participating masses, calculated for each of the given x and y lateral earthquake directions perpendicular to each other, may in no case be less than 90 % of the total building mass. To respect this condition given in TSC-2007, the number of modes was set to 30 and the focus was placed on the first four modes.

Table 5. Periods and modal participating masses of first four modes at Merzifon Clock Tower

Mode	Period [s]	Effective mass to total mass ratio		
		X	Y	Z
1	$1.58 \cdot 10^{-1}$	$6.50 \cdot 10^{-5}$	0.328009	$0.130618 \cdot 10^{-3}$
2	$1.53 \cdot 10^{-1}$	0.375287	$0.517739 \cdot 10^{-4}$	$0.297790 \cdot 10^{-6}$
3	$7.07 \cdot 10^{-2}$	0.491750	$0.163143 \cdot 10^{-7}$	$0.574498 \cdot 10^{-5}$
4	$5.42 \cdot 10^{-2}$	$7.91 \cdot 10^{-8}$	0.457494	$0.169110 \cdot 10^{-2}$

Mode shapes, frequencies, periods, and modal participations are presented in Figure 10 and Table 5 for Merzifon Clock Tower, and in Figure 11 and Table 6 for Gümüşhacıköy Clock Tower.

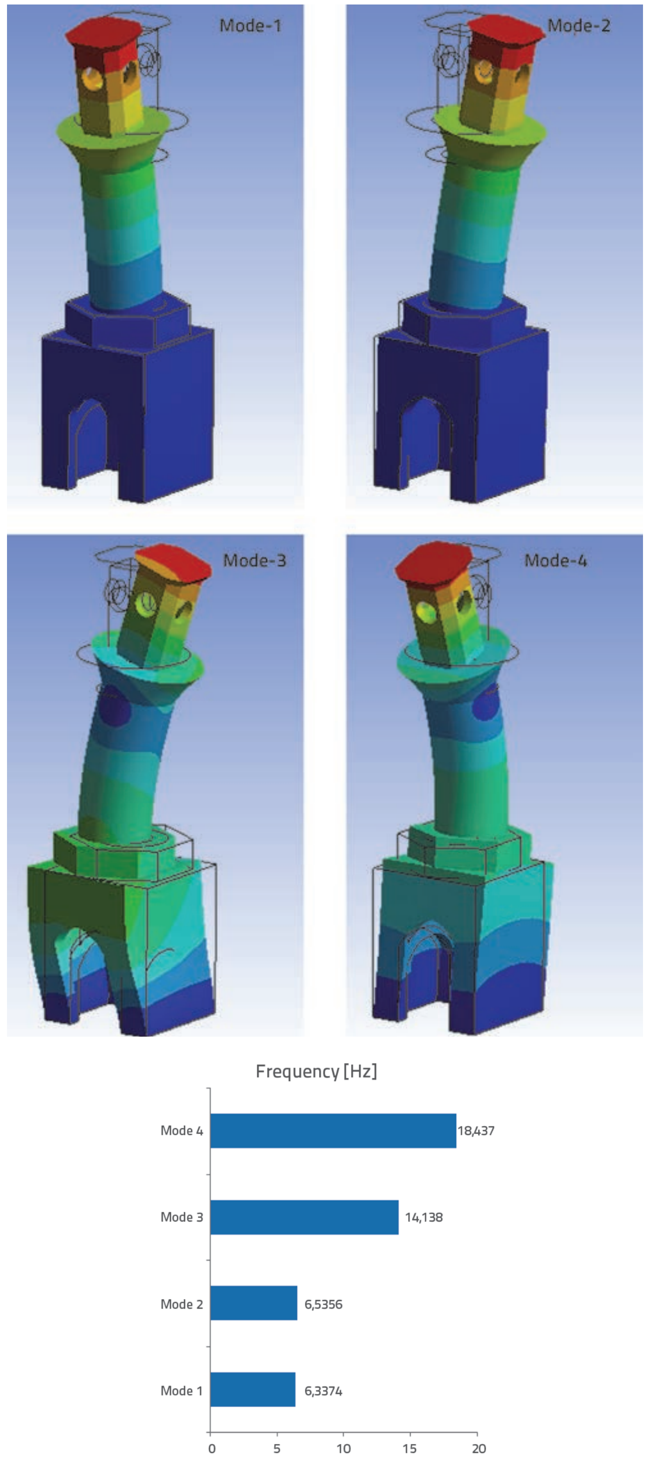

Figure 10. Mode shapes and frequencies of Merzifon Clock Tower

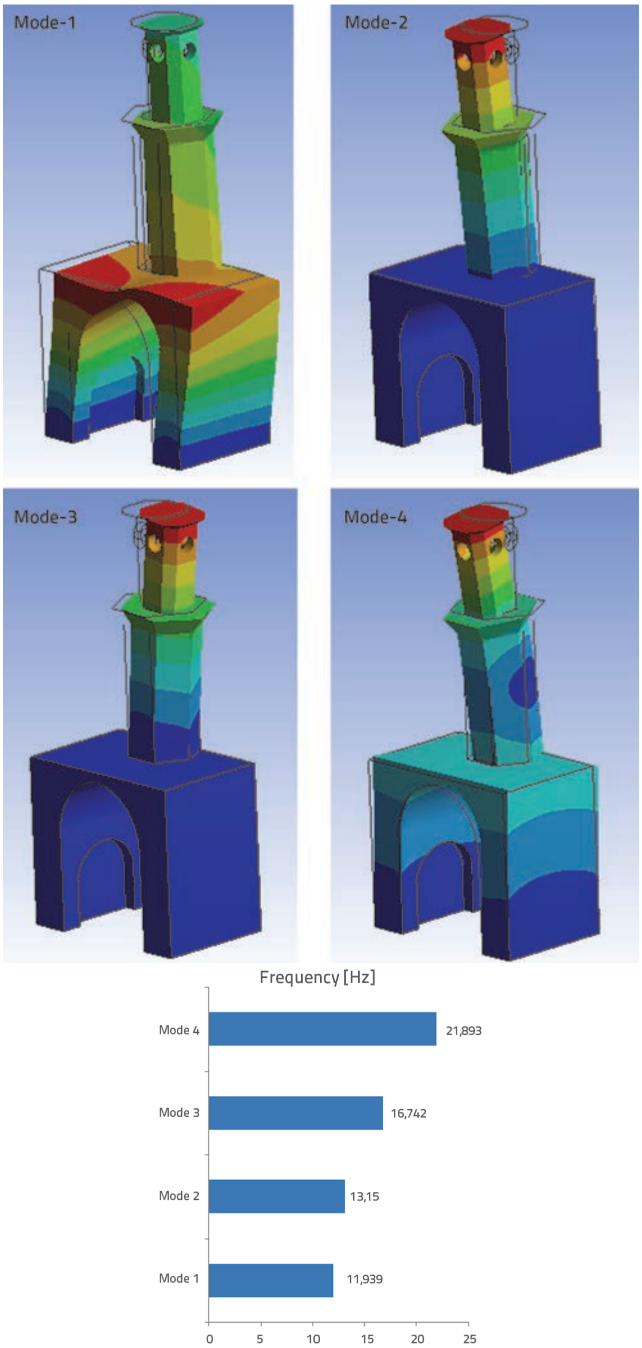

Figure 11. Mode shapes and frequencies of Gümüşhacıköy Clock Tower

Table 6. Periods and modal participating masses of first four modes at Gümüşhacıköy Clock Tower

Mode	Period [s]	Effective mass to total mass ratio		
		X	Y	Z
1	$1.58\cdot10^{-1}$	$6.50\cdot10^{-5}$	0.328009	$0.130618\cdot10^{-3}$
2	$1.53\cdot10^{-1}$	0.375287	$0.517739\cdot10^{-4}$	$0.297790\cdot10^{-6}$
3	$7.07\cdot10^{-2}$	0.491750	$0.163143\cdot10^{-7}$	$0.574498\cdot10^{-5}$
4	$5.42\cdot10^{-2}$	$7.91\cdot10^{-8}$	0.457494	$0.169110\cdot10^{-2}$

4.3. Dynamic analysis

Amasya and its surroundings are located in the first-degree earthquake zone. Therefore, Amasya has so far seen many destructive earthquakes and suffered from significant loss of life and property. In this study, The Kocaeli earthquake that occurred on 17 August 1999 and caused major destructions, and its east-west component of moment magnitude (Mw) of 7.5, were taken into consideration (Figure 12), while its dynamic analyses were conducted using the time history method. The comparative analysis results, with stress and displacement values, are presented in the following figures (Figures 13-15).

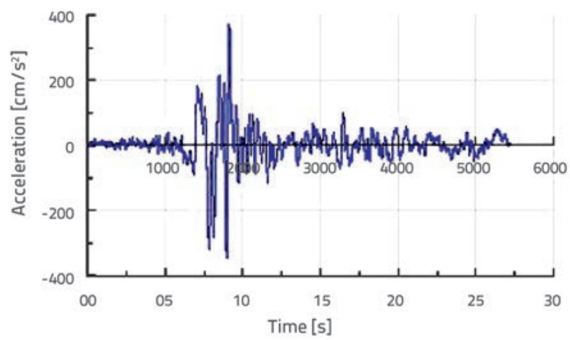

Figure 12. Ground motion record of Kocaeli earthquake [11]

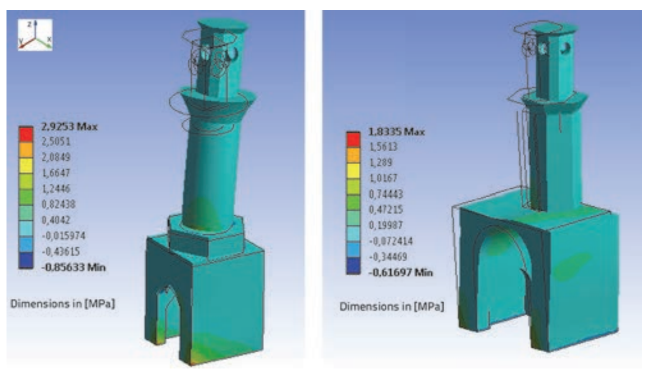

Figure 13. Maximum principal stresses for Kocaeli earthquake

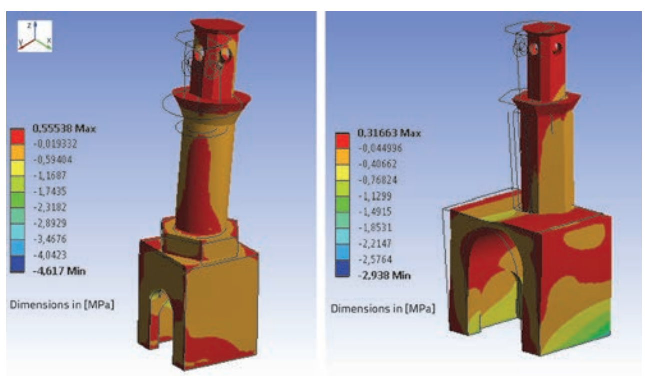

Figure 14. Minimum principal stresses for Kocaeli earthquake

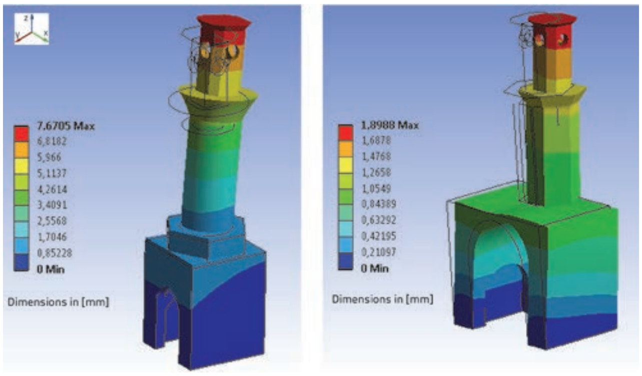

Figure 15. Maximum lateral displacements for Kocaeli earthquake

5. Results and discussion

The structural performance of two different clock towers constructed with materials of different rigidity and mechanical properties is investigated in the present study, using appropriate static and dynamic analyses. The analyses conducted in the paper show that the towers subsequently added onto the existing structures have caused some problems to the underlying structures. Static analyses indicate that the arched girders located at the gate entrances, as well as the towers, are overstrained, and that there are additional tensions around their key blocks. As the entrance doors were not initially designed to carry the load of such magnitude, additional loads have gradually lead to deterioration of initial structures. The comparison of deteriorations observed at the existing structures with the numerical analysis results points to the accuracy of the analyses. Again, according to static analysis, stress concentrations are observed around the key blocks on the lateral facades, and also at the main key block. Different levels of the arch-system key blocks at the entrance gates, onto which the towers are fitted, cause tension at the peak point of the weakest arch system. With respect to the modal analyses, it may be suggested that the towers will suffer additional deformation during an earthquake. Also, the fact that the towers and structures are strained by different movements causes more tension at transition areas of these structures. This behaviour can especially be observed at the first mode of Gümüşhacıköy Clock Tower. Therefore, these areas may be expected to deform during an earthquake. Dynamic analysis results suggest that the principal stresses during an earthquake will be concentrated on the junction point of the base of the towers and the entrance gates, while the tower structure that is significantly higher compared to the underlying structure may not keep up with the shift and collapse. Furthermore, a comparison of the results for both towers indicates that Gümüşhacıköy Clock Tower made of wood has caused less damage to the underlying structure. Thus, if it is absolutely necessary to add a structure, then a less solid material should be preferred. The analysis results suggest that tension will increase on the base corner points of the entrance gates of the structures as a result of the shift movement during an earthquake, and that recurring earthquakes will adversely affect these bearing points. Regardless of their purpose, structures subsequently added onto the existing ones are believed to cause serious damages to the existing structures.

6. Conclusions

One of our crucial objectives is to preserve historic structures in the most appropriate manner and to ensure their proper utilization in order to prevent their destruction. This study focuses on structural performance of new structures subsequently added onto historic structures, and on their effects on the main historic structures. In this context, two clock towers situated in the historic city of Amasya are discussed and the structural performance of the towers is examined using the finite element method. The results of the analyses have revealed that the clock towers added onto the old structures adversely affect the latter. The structural system may be affected by the subsequently added structures. In addition, besides the adverse effect on load-bearing systems, the additional load imposed on the structures is observed to lead to additional stress, which in turn initiates degradation of the system's stability. Therefore, interventions and additions to historic buildings must be kept to minimum so as to avoid negative influences on the existing load-bearing systems.

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