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Case study

Non-destructive testing of an ancient Masonry Bastion

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ABSTRACT

Historical masonry structures have seismic vulnerability and most damages and demolishes arise from the seismic actions like earthquakes. In this paper, the structural behavior of Zağanos Bastion is examined with experimental and numerical methods. The operational modal analysis technique is used to illustrate the dynamic characteristics of the bastion experimentally. Finite element model is developed by ANSYS software and dynamic characteristics of the bastion, such as natural frequencies and mode shapes are calculated numerically. Furthermore, time history seismic analysis is carried out. The results show that the ambient vibration measurements are enough to identify the structural response of the bastion. Maximum differences between the natural frequencies are attained as 26%. To minimize these differences, finite element model of the bastion should be updated by using some uncertain parameters. The principal stresses are satisfied in general, but the maximum tensile and compression stresses values exceed the allowable code limits at some points of the masonry components.

1. Introduction

Historical structures have an important role in the cultural heritage of societies. Historical structures are one of the main cultural roots of society. Hence, they are important works of art that beautify cities. However, they may be affected by several destructive reasons. One of the most destructive factors of historical masonry structures is earthquake. Seismic activities are the source of demolishing and destroying of many important historical structures. Therefore, seismic investigation of these structures is essential.

Numerical methods are commonly used for analyzing the historical structures due to difficulty of experimental investigations on these structures. Finite element method is widely used for the structural analyses of these structures. In addition to numerical analyses, non-destructive experimental analyses are used to determine the dynamic characteristics of these valuable structures. There are currently two experimental methods: the experimental modal analysis (EMA) and the operational modal analysis (OMA). However, OMA is more convenient for the historical structures, because it is a totally non-destructive testing method [1]. Numerical studies, which supported and updated with the experimental tests, are suitable and reliable for the historical structures.

Many studies of finite element analyses, experimental measurement tests, model updating, and dynamics analyses of historical masonry structures, such as church [2–6], tower [7–12], palace [13], arch bridge [14–16], minaret [17], dome [18–20] were investigated by researchers. There are few studies existing in the literature related to rigid structures, such as castles, fortress and bastions. Linear and non-linear seismic behavior and strengthening design of a castle were examined by a rigid body spring model [21]. In the study of Betti et al. [22], an Italian Medieval castle was investigated by non-linear static analyses, and it presents the reasons of existing damages on the structures.

Castles, fortress and bastions were built in ancient times for protecting the cities. Today, they become major symbols for cities and may occasionally be large enough to surround a city. These structures are of a substantial place in the cultural heritage and need structural investigations and conservations. In this study, numerical-experimental dynamic characteristics and seismic behavior of an ancient bastion is investigated. Dynamic characteristics of the bastion obtained by OMA and FE analyses, firstly. Then, FE seismic analysis is carried out and obtained results from the experimental and numerical methods are examined to determine the structural behavior of the bastion.

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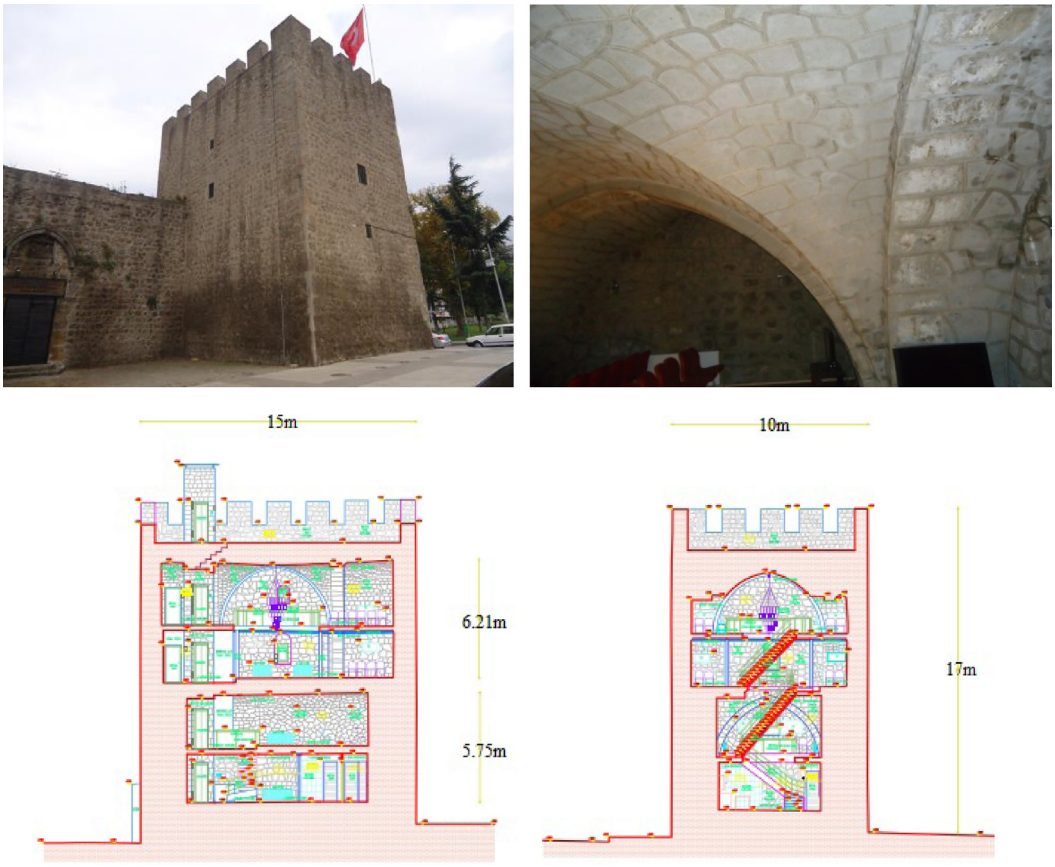

Fig. 1. Some pictures of Zağanos Bastion and longitudinal-transverse sections.

2. Description of the Zağanos Bastion

The Zağanos bastion is placed at the middle part of the Trabzon castle. The bastion was constructed with brown konglomera stones. Masonry technique of bastion is different from other parts of the castle. In the last century, some annexes like lift, RC floor and cement base mortar were added to bastion. Structural system of the bastion is based on the load-bearing walls, vaults and arches. It has approximately 17 m height, 15 m width and 10 m depth. The thicknesses of bastion walls are approximately 2.55 m for up to middle point of the bastion from ground and 1.25 m from the middle points of the bastion to top points. The bastion has two main stores, which have vault roofs, and they were divided into two with RC floors. Some pictures and geometrical data of the bastion are given in Fig. 1 in a proper drawing including sections.

3. Experimental measurement

Ambient vibration test was performed on bastion to determine its dynamic characteristics. In the test, a B&K 3560 data acquisition system with 17 channels and B&K 8340-type uni-axial accelerometers, which have 10 V/g sensitivity, uni-axial, signal cables, PULSE and OMA software were used as the test equipment. The frequency range was selected as 0–15 Hz and eight accelerometers

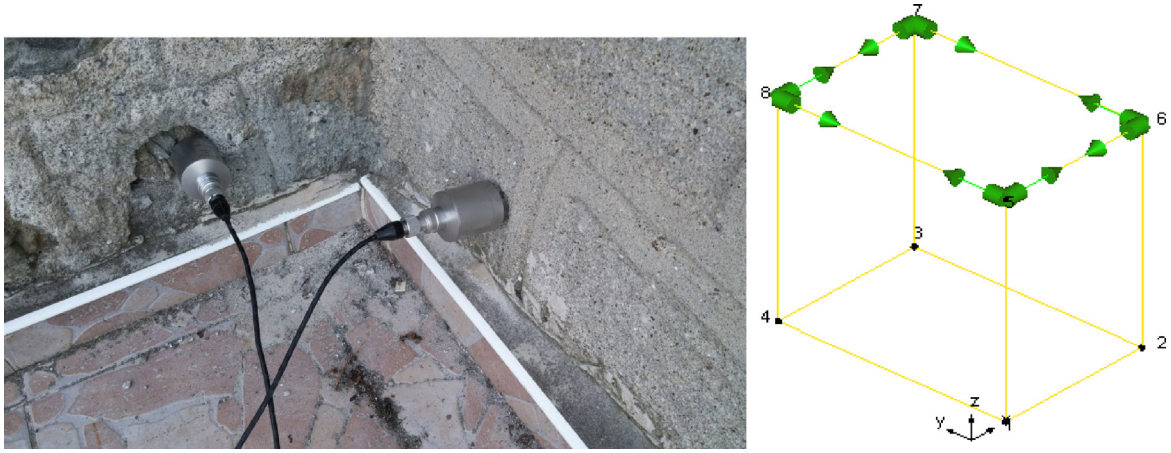

Fig. 2. The accelerometers connections and locations on the bastion.

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