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Nonlinear seismic performance of a 12th century historical masonry bridge under different earthquake levels

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ABSTRACT

In construction of historical masonry structures, only static loads were generally taken into account. Therefore, these structures may be damaged or ruined due to seismic effects. Earthquake performances of historical masonry structures must be obtained for carrying to the future and the preservation of them. In this study, nonlinear seismic responses of Malabadi Bridge, built in 12th century, are evaluated. The main span of the bridge is 38.6 m and it is the widest of all stone arch bridges existing in Anatolia. Three different earthquake levels (D1, D2 and D3) are selected for seismic loading. Synthetic acceleration data are produced by considering seismic characteristics of the region. For determining the material properties of the bridge, uniaxial compressive strength tests, ultrasound tests, Schmidt hammer tests and mass loss tests are conducted. Homogenized material properties for macro modelling technique are obtained by using the test results. A smeared crack model which includes tensile cracking and compressive crushing effect is selected for the masonry material. Drucker-Prager material model is also used for the backfill material. No damage region is obtained at arches and spandrel walls under the D1 and D2 earthquake loadings. However, plastic deformations are observed at backfill material under D2 earthquake loadings. Numerical results are showed that the main arch of the bridge have heavily damaged under D3 earthquake loading.

1. Introduction

Historical masonry bridges are an important part of cultural heritage. These bridges generally consist of foundation, arch, spandrel wall and backfill material. Natural disasters such as flooding and earthquake can damage or ruin these important historical structures. Therefore, assessment of the seismic response of these structures is necessary in order to protect structural integrity.

There are many studies about structural behavior of masonry bridges in literature. Royles and Hendry [1] studied the effect of backfill materials, spandrel walls and wing walls on limit strength of the bridges. For this purpose, 24 arch bridges with three different spans were investigated. The researchers found that spandrel and wing walls increased the strength of the barrel arch. Begimgil [2] investigated effects of spandrel wall restraint on a masonry bridge with 1.25 m span. Deflections were measured across the width of the arch and were found commonly larger at midpoint of the arch. Similar observations for test results of full-scale bridge under service loads were obtained by Boothby et al. [3]. Fanning and Boothby [4] analyzed field test results of three existing masonry arch bridges to specify suitable material properties. For numerical analyses of bridges, 3D solid finite elements (FE) were used. A smeared crack and Drucker-Prager material models were used for masonry and backfill materials, respectively. The bridges were analyzed under service loads, and the obtained solutions were compared to the field test results of the bridges.

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Fig. 1. View of the Malabadi bridge.

Brencich and Sabia [5] assessed The Tanaro Bridge in Italy. The bridge has 18 span masonry bridge and built in 1866. Natural frequencies, mode shapes and damping ratios of the bridge were carried both during service and at different stages of its demolition. Milani and Lourenço [6] analyzed the static nonlinear behavior of three dimensional of two masonry arch bridges by means of finite element code. Sevim et al. [7] conduct a study about linear seismic analyses of two historical masonry arch bridges with operational modal analysis. Sayın et al. [8] generated a 3D finite element model of historical Uzunok Bridge and examine the linear and nonlinear analysis. Pelà et al. [9] investigated seismic assessment of an existing triple-arched masonry bridge. Seismic capacity of the bridge was evaluated by means of time history and pushover analyses. Rafiee and Vinches [10] assessed mechanical behavior of a standard arch bridge and a stone masonry bridge under the different types of static loadings. Altunışık et al. [11] investigated the arch thickness effects on the structural behavior of masonry arch bridges. Sayın [12] evaluated seismic response of a masonry bridge. For this purpose, artificial acceleration records are generated considering the seismic characteristics of the region where the bridge is located.

In this study, seismic response analyses of Malabadi Bridge are obtained. The Bridge is an Artuqid structure which constructed on Batman River near the town of Silvan in south-eastern Turkey (Fig. 1). According to its inscription, it was built in 1147 by Timurtas Bin Ilgazi during Artuqid Dynasty period. The bridge is 227.84 m long and 7 m wide, 25.59 m in height and a main span of 38.6 m. It was constructed by limestone in 12th century and it is the widest of all stone arch bridges existing in Anatolia. The bridge was restored two times in 1930 and 1956 [13]. Last restoration work was also carried out in 2014. Due to cultural and historical importance of the bridge, damage assessment of this structure must be determined by using advanced numerical techniques. For this reason, nonlinear seismic analyses are obtained under three different levels (D1, D2 and D3) [14].

2. Numerical modelling of masonry stone arch bridge

Historical stone arch bridges were generally constructed with stone, mortar and backfill material. Numerical modelling of stone arch bridge is quite complex due to the interaction of these materials. For the numerical modelling of the masonry, micro, simplified micro and macro modelling are used (Fig. 2). In the micro modelling, stone/brick, mortar materials and interface elements are separately modelled. Interaction of the materials are taken into account in the numerical solutions [15,16]. In simplified micro model, dimensions of stone/brick are extended as much as half thickness of the mortar. Thus, stone/brick units with mortar are defined in the finite element mesh and interface elements are used between these units. In the macro modelling, stone/brick and mortar is considered as a homogenized domain. Effective material properties are obtained for the homogenized domain [17,18,19,20].

In this study, a smeared crack model, includes the strain softening, cracking and crushing behaviors of material, is used for nonlinear behavior of the masonry stone walls. This model is three parameters model which a special case of five parameters model of William and Warnke [21]. Zeinkiewicz and Taylor [22] were stated that the model can be used for the brittle materials. This model is used effectively for macro modelling of the masonry structures [2,4,5,17,23,24,25].