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Performance-based assessment of multi-story unreinforced masonry buildings: The case of historical Khatib School in Erzurum, Turkey

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ABSTRACT

Performance-based assessment (PBA) has become a matter of emphasis for multi-story unreinforced masonry (URM) buildings recently. It is however very hard to assess the performance of the multi-story URM buildings because of their complex engineering characteristics and structural performance. The primary goals of this study are to identify the seismic vulnerabilities of the URM buildings and to evaluate their structural performance based on the PBA principles. In this respect, a concept PBA layout is prepared for the URM buildings to describe better the performance assessment. In order to evaluate the structural behavior and seismic risk for the multi-story URM buildings, the study focuses on a case study of Historical Khatib School, which is located in Erzurum, Turkey, and it was assessed using the previously determined layout steps.

1. Introduction

Unreinforced masonry (URM) building can be identified as masonry structures that are constructed by stacking masonry materials, such as stones, bricks or adobe, without any reinforcing materials or with less than 25% of the minimum reinforcement requirement [1]. They are among the oldest and most diverse structures in the world. These buildings were preserved through generations. It is, therefore quite possible to encounter the URM buildings, which bear the cultural and architectural traces of previous civilizations. As an example, while the major part of the building stock consists of reinforced concrete (RC) structures, there are many masonry structures in Turkey and the majority of the masonry structures are the URM buildings. Some of these structures are still being used for their original purposes, some had been changed from their intended purpose and some, especially in the rural regions, have been abandoned to their fate. As/Since these structures were not being used, they possess a greater risk of failure, which would affect not only themselves but also the buildings adjacent to them.

Although current guides and codes [1–4] allow new URM buildings to be constructed only in areas with low risk of earthquakes, many old and historical URM structures were built in seismically prone zones in the past. Therefore, a great majority of these buildings may easily get damage in earthquakes and they are completely destroyed if not retrofitted or strengthened against seismic risks. However, in order to be able to intervene correctly, it is necessary to determine the seismic weaknesses of these structures and to evaluate their current performance in the most appropriate way. In this respect, several authors have discussed the URM buildings

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Fig. 1. Typical structural failures of the URM buildings in Turkey after earthquakes (a) Partial collapse in stone masonry walls of the ground floor, (b) Wall-diaphragm tension tie failure, (c) Spalling of masonry unit faceshells and vertical cracking at toe regions, (d) Spandrel joint sliding problem, (e) Vertical cracks at the corners of the masonry wall.

and their structural performance in previous studies [5–16]. However, authentic evaluation by nonlinear dynamic analysis is rare, and lacks depth so far. Therefore, this study mainly focuses on the URM buildings and their structural performance. In this respect, in the study, a PBA layout is developed to evaluate the structural performance of the URM structures and a case study structure, which is located in Erzurum, Turkey, is evaluated by applying the steps in this layout.

2. Vulnerability of the URM buildings

The structural behavior and seismic response of old masonry structures are different from modern structures such as reinforced concrete (RC) or steel structures. The vulnerability of the URM buildings to earthquakes has been among the most common reasons of the collapse of these structures. Previous earthquakes have shown that the URM buildings are among the most vulnerable structural types due to poor structural behavior under lateral loads [11, 17, 18]. Due to the lack of retrofitting members, the URM buildings cannot withstand the tension forces created by the earthquakes. Since the tensile strength of the materials forming the masonry structures is very low, the tensile stresses that occur in the structure usually lead to permanent deformation.

Masonry structures composed of brittle materials such as stones and bricks that have little under tensile and compressive stresses due to their engineering properties. In other words, under tensile and pressure effects, they suddenly migrate without plastic deformation. Particularly, due to tensile stresses formed in the masonry walls, some cracks occur on the wall. On the inner walls, this behavior and cracking patterns are typical and an expected situation in the URM buildings. Another important parameter that leads to the damage of the URM buildings is shear force. Since the limited shear capacity of the masonry materials is easily exceeded under seismic loads, the masonry walls begin to crack easily. After first cracking and damage, the load bearing capacity of the masonry walls decreases suddenly, which causes local collapses in the structure. This situation makes the URM structures highly vulnerable to seismic loads (Fig. 1).

According to FEMA 306 [1], structural vulnerabilities of the URM buildings depend upon a number of factors and the vulnerability of the URM structures can be classified depending on the weaknesses of the structures. This report uses three different categories to assess the damage to the URM structures; namely, weaker pier-stronger spandrel, weaker spandrel-stronger pier and solid wall. Fig. 2 illustrates crack pattern and failure modes in piers and spandrels in plane behavior while Fig. 3 illustrates crack pattern and failure modes in a solid walls in plane behavior. Moreover, Fig. 4 shows crack pattern and failure modes in a solid walls