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EXPERIMENTAL STUDY ON SEISMIC BEHAVIOR OF MASONRY BUILDINGS RETROFITTED WITH SHOTCRETE

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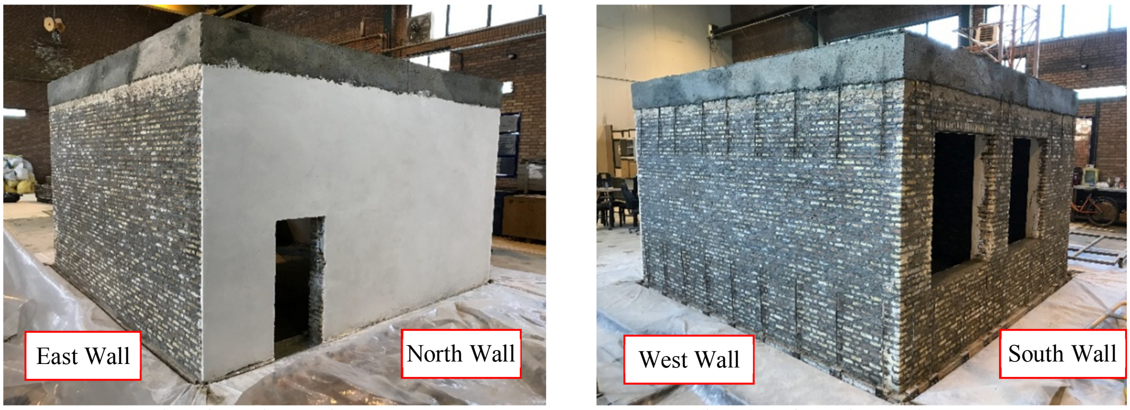
Unreinforced masonry is the most common form of building construction in Iran and many other countries. In developing countries, this type of building is being constructed for residential or educational uses, mostly regardless of engineering design schemes and principals. Previous observations indicate problems such as improper seismic resistant system, ill-suited structural detailing, and weak materials to leave masonry buildings vulnerable even to smallest lateral excitations; so that in the case of a major seismic event such as recent Kermanshah earthquake, there would be no guaranty for the safety of the residents [1]. As many Iranian buildings are masonry and because the occupants often have little financial affordability, replacing these structures cannot be concerned as an alternative, and further investigations are needed in order to develop low-cost, feasible and simple methods for retrofitting these structures and minimizing the damages; this requires fully understanding the seismic behavior of these structures by the means of experimental tests.

Through many years of study, various methods are developed to improve the seismic performance of unreinforced masonry (URM) buildings and each method has its own advantages and disadvantages. Rigid belts, steel bar mesh, vertical and horizontal beams, horizontal tendons, PP bands, steel wires, L shape and vertical rebars, center core, and shotcrete are of the most noteworthy methods [2], amongst which, the application of steel mesh along with a shotcrete layer is commonly used by the Organization for Development, Renovation and Equipping Schools of I.R. Iran (DRES), because of its affordability and ease of application. The performance of the detailing used by DRES is verified by conducting multiple shake able tests in previous researches [3-4].

In general, the failure modes observed in URM buildings can be categorized in [1] (1) in-plane diagonal and horizontal cracks of load-bearing and non-bearing walls, (2) out-of-plane overturning of non-bearing walls, (3) rocking of the piers between or adjacent to windows and openings, (4) toe crushing and crack propagation at the corner of the walls and openings, and (5) sliding of the floor slabs on the walls at the region of slab-to-wall connections. If applied correctly, each retrofitting method is aimed to diminish one or several of the failures and improve the integrity and flexibility of the structure. On the other hand, a method such as shotcrete loses effectiveness in the case of: (1) using poor-quality materials, (2) insufficient splice length for steel bars, (3) immature reinforced wall-to-wall and slab-to-wall connections, and (4) discontinuity of the reinforcement layer at the opening regions. So, it is very important to consider most-probable failure scenarios, use a feasible retrofitting method and carry out the constructions in accordance with standard instructions.

This research is jointly conducted by DRES, Sharif University of Technology (SUT), and Ecole Polytechnique Fédérale de Lausanne (EPFL) and aims to develop an economically viable and well-validated method for the retrofit of school buildings in Iran that are constructed as unreinforced masonry. For this purpose, a half-scale model of a typical room of a school building was constructed and tested on the shake table facility at SUT. The specimen is a one-story 4x4 [m], square room, with a height of 2 [m] and asymmetric openings, designed in accordance with the geometric specifications of common-made Iranian classrooms [5]. The walls are composed of one and a half, half-scaled 5x10.5x2.5 [cm] bricks in thickness. As the representative for a local seismic event, the ground motion data of the Zarand earthquake [6] was used as input excitation for the tests. First, the unretrofitted building was subjected to seven steps of bidirectional seismic excitations with increasing intensity at each step. The specimen was tested up to a moderate damage level to allow highlighting the weak points of the structure. The damages induced by the applied motions and the responses of the structure were investigated through conventional methods including hard-wired instruments and hand drawings. Afterwards, the damaged building was repaired using steel mesh and shotcrete layer. For the east and the north walls, the shotcrete layer was applied to the interior face and the other walls were retrofitted from the exterior face. Moreover, three various cases of retrofitted wall-to-wall connection, including interior-to-interior, interior-to-exterior and exterior-to-exterior shotcrete connections were considered for different corners of the building. The shake-table test was again conducted on the retrofitted specimen (RM), this time in nine steps with increasing magnitudes, up to near collapse. The effect of fixity of the shotcrete vertical rebars in the foundation was investigated through opening the connection in the last three steps of the test. The development and propagation of cracks in different areas of the specimen, such as the corners of the building and openings were recorded and compared.



(a) View from the north-east corner. (b) View from the south-west corner.

Figure 1. Unretrofitted specimen view.

During the URM tests, the specimen failed due to the out-of-plane collapse of the pier between the windows; and the cracks developed at the corner of the openings were greatly affected by the asymmetricity of the window positions, as the crack in the left pier of the south wall penetrated deep into the middle parts of the west wall. In the RM tests, as the first observation, the out-of-plane behavior of the URM south wall was changed into in-plane and fixing the vertical rebars to the foundation eliminated the rocking behavior of the building. Also, the behavior and crack propagations in the URM and RM specimens confirmed the retrofit to increase the strength, integrity, and flexibility. In many areas, the concrete layer created a strong bond that led to an acceptable composite action between the bricks and the shotcrete and prevented the further propagation of the cracks previously developed in the URM tests; despite that, in a few areas such as the side piers of the walls, the concrete delaminated and the cracks re-opened. In contrast with the other two connections, a vertical crack developed at the vicinity of each interior-to-exterior shotcrete connection, indicating the insufficiency of the connection detailing.

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