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TESTING OF AN EXISTING TWO STORY MASONRY BUILDING UNDER LATERAL LOADS

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Abstract

Masonry structures constitute a significant portion of the building stock in many countries with high seismic regions. Understanding the load carrying mechanisms of such buildings and estimating the deformation capacities is important for seismic risk mitigation. In the process of developing new assessment guidelines for Turkey, a comprehensive research project was conducted in order to estimate the expected seismic performance of existing masonry buildings. Within the scope of this extensive research program, an existing two-story masonry building was tested under lateral cyclic loads on site. A seven meter high steel reaction frame capable of resisting 3000kN base shear force was constructed next to the test building. Afterwards, hydraulic actuators attached to the reaction frame were employed to impose one way cyclic displacement excursions. Flexural and shear deformations on a number of walls were measured and crack prorogations were monitored. The structure was tested up to a lateral strength drop of approximately twenty percent from the ultimate load, which occurred at a drift ratio of about 1.2%. The damage in the walls in the building, which were mostly diagonal tension, concentrated mostly in the second story. In addition, sliding shear failure between the second floor slab and walls are observed.

Keywords: In-situ; Pushover Test; Brick Masonry

1. Introduction

Masonry is still a commonly used structural material in rural and even in urban regions due to its advantages such as widespread geographic availability in many forms, colors and textures, its economical nature for construction, fire resistance, thermal and sound insulation, durability and etc. Unfortunately, the strength and stability of masonry structures are critical in the case of cyclic lateral loads such as earthquake ground motion. It is well documented that masonry structures performed poorly under the effect of earthquake excitations, for example in Elazığ-Turkey 2010, Bam-Iran 2003, Kashmir-Pakistan 2005, L'Aquila-Italy 2009. Hence, the masonry buildings with structural deficiencies belong to one of the most vulnerable class of structures, which have experienced heavy damage or even total collapse in previous earthquakes. The design and modeling tools for these structures are rather primitive than their competitors for low rise building construction. This is because the heterogeneous and complex material behavior of these buildings makes the analytical modeling difficult, if not impossible for practical applications.

In the literature, there are numerous experimental investigations on the determination of response of spandrels and piers. In those studies, the effect of aspect ratio, material type and boundary conditions was examined in detail [1-4]. The experimental studies covering the laboratory tests on small building models [5-8] were also conducted to better understand the stiffness and strength characteristics of masonry assemblages and these experimental findings were utilized to calibrate numerical models for design and assessment of masonry structures. Recent studies have focused on key factors such as behavior of spandrel beams, flange effects in walls or out of plane behavior of walls, which contribute to more refined seismic performance assessment procedures [9].

In this study, the lateral load performance of an existing two-story masonry building was studied by conducting physical testing. The load-displacement behavior of each story and damage progression on walls and the failure modes are reported.

2. Test Building

2.1 Test specimens and instrumentation

The test building with the floor plan shown in Fig. 1 is located in the Northern part of Ankara, Turkey. The building is a two-story masonry structure with a floor plan area of about 10 m × 9 m made of solid clay bricks. The building had RC bond beams underneath slabs with thicknesses of 0.13 and 0.10 m in the first and second stories, respectively. The material properties of the test building were determined before lateral load tests. For this purpose, rectangular wallets of 90cm × 90cm sizes were extracted under window openings. The wallet specimens were subjected to uniaxial compression, diagonal tension and triplet tests. The test results reveal that the average uniaxial compressive, diagonal tensile and shear strength were 2.14 MPa, 0.36 MPa and 0.17 MPa, respectively (Fig. 2). In Fig. 2, the test setups for uniaxial compressive, diagonal tensile and triplet tests are also shown.

Fig. 1 – Photo and plan view of test structure

The lateral load testing of the existing building required a stiff reaction wall to apply lateral loads with the hydraulic actuators. For this purpose, a seven-meter-high steel reaction frame was built next to the test building.

This reaction steel frame and its reinforced concrete foundation were designed to resist a maximum base shear force of nearly 3000 kN. Afterwards, hydraulic actuators were attached to the reaction frame and one-way cyclic displacement excursions were imposed at each story level. The shape of the lateral load profile was determined from the modal analysis obtained from finite element model of the test building. In the finite element model, approximately 66,600 eight-node shell elements were utilized. The nodes at the base of the model were assumed to be fixed. The first fundamental vibration mode along the testing direction had an effective modal mass of about 75% (Fig. 3). This relatively high effective mass contribution for the first fundamental mode supported the idea of utilizing the lateral load testing. The ratio of the first and second story lateral applied forces was assumed to be similar to the first mode shape (i.e 1:1.78 ratio for the first and second story applied forces).

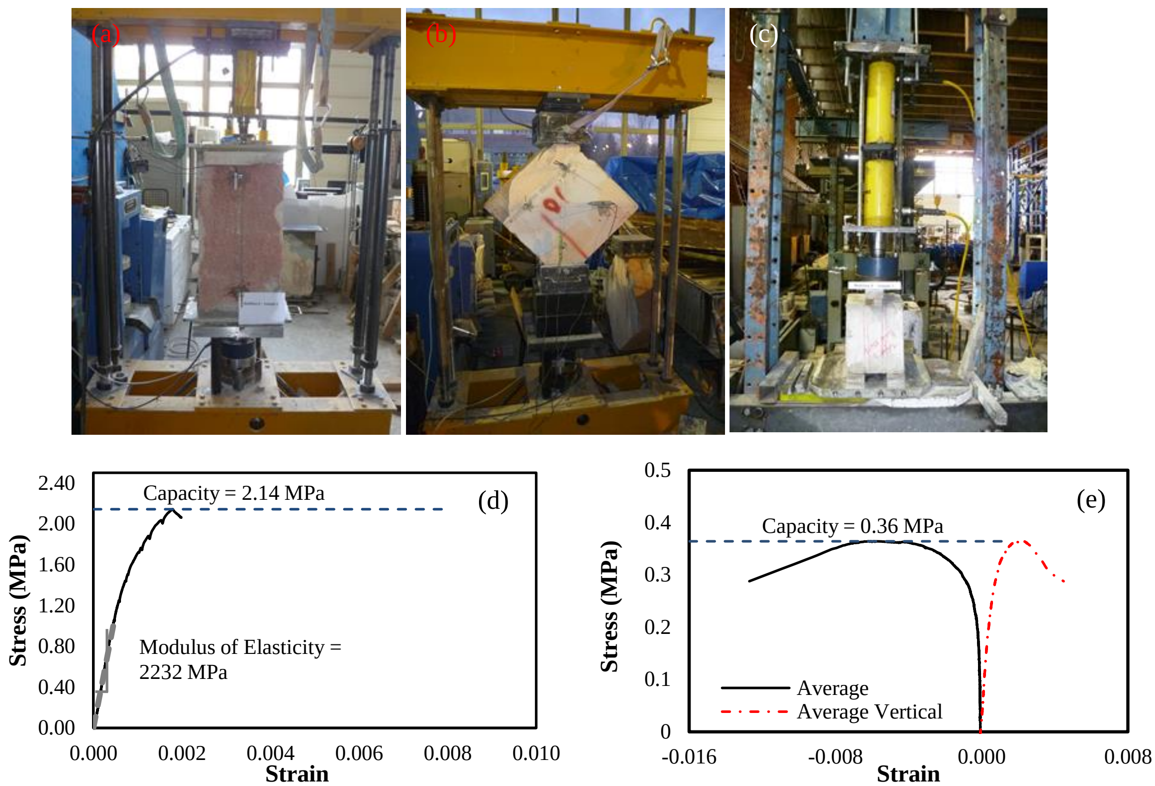

Fig. 2 – (a) Compression Test, (b) Diagonal Tension Test, (c) Triplet Test Setups, (d) Compressive Stress-Strain Curves and (e) Diagonal Tension Stress-Strain Curves

The lateral load testing of the building was conducted by using four hydraulic actuators attached between the steel frame and the test building. The actuators were placed such that the resultant of the force at each floor would approximately coincide with the center of mass of each floor. Displacement-controlled loading was utilized during the experiment. The first story drift ratio was selected as the control displacement and the loading steps were arranged such that the first story drifts were multiples of 0.1% (Fig. 4). If the target displacement was attained, the building was unloaded and the system was reloaded till the next target displacement was reached. This way, the building was subject to one-way cyclic loading. After, the first story displacement became relatively smaller than the second story displacements, the target displacement was changed as the second story displacement. The displacement history imposed on the first floor and roof of the building are shown in Fig. 4.

In addition, the deformations of the walls were measured by using four LVDTs, two measuring vertical deformations, two recording diagonal deformations (Fig. 5). The lateral displacements of each story level were recorded with Linear Variable Differential Transformer (LVDTs) installed at four different locations at the ground, first and second stories. The locations of these LVDT's along with the hydraulic pistons are also presented in Fig. 5.

2.2 Test results

Measured load deformation response of the building is shown in Fig. 7 for the center of mass location. In addition, the deformation profile along the height of the building and the plan deflections at different roof displacements are presented in Fig. 8. The damage pictures of the test building are shown in Fig. 9.

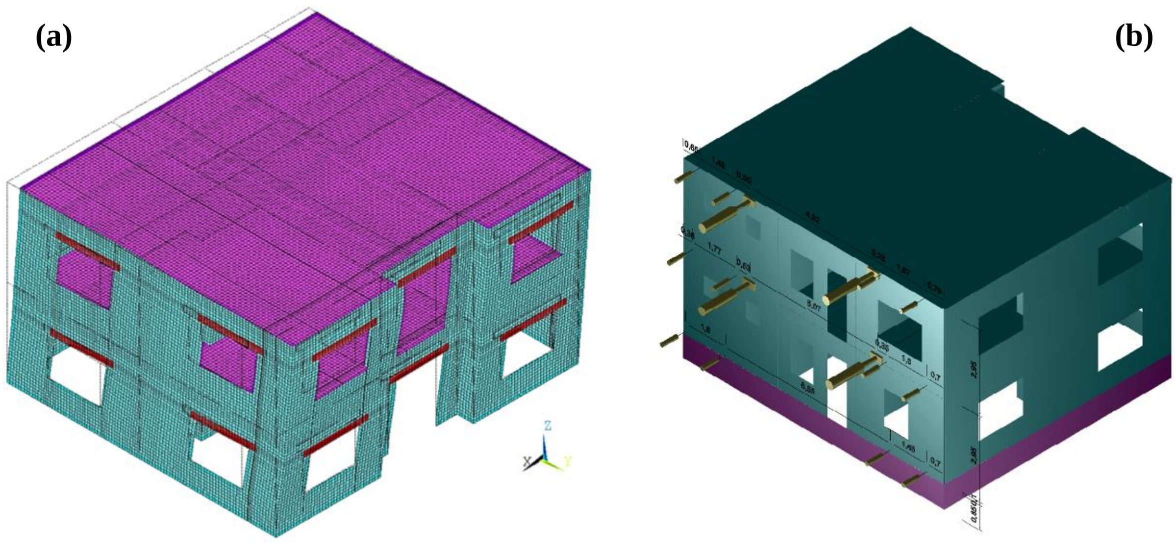

Fig. 3 – (a) Finite element model and (b) first mode shape

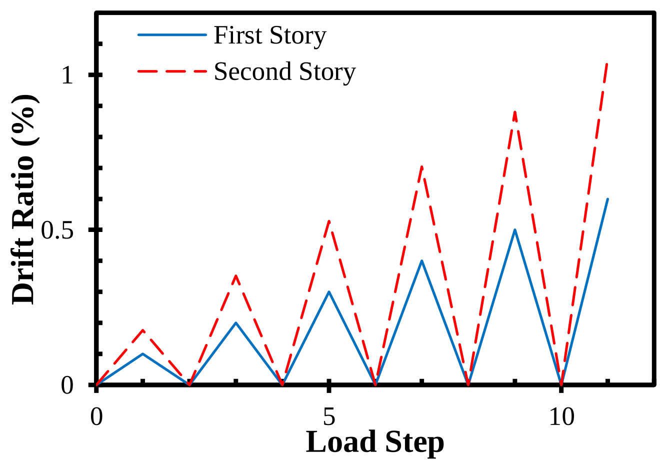

Fig. 4 – Drift ratio histories applied to each story level

Fig. 5 – (a) Side view of LVDT’s and hydraulic pistons, (b) photo of steel frame and (c) photos of hydraulic pistons at the second story

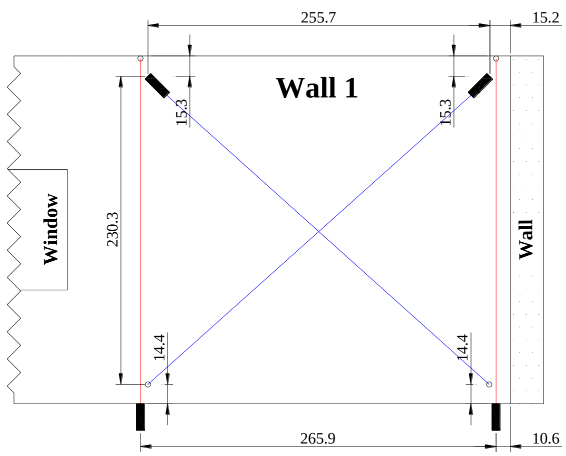

Fig. 6 – The installed LVDT’s for a Representative Wall, Wall 1 (All units are in cm.)

The building responded nearly elastically up to a base shear of about 400 kN. Beyond this level, the lateral stiffness of the test building started to decrease due to the crack formation. The drift profile along the height of the building was detected to be approximately uniform until an interstory drift ratio of 0.50% at the second story (Fig. 8.a). Afterwards, the lateral stiffness loss at the second story was relatively larger due to the enhanced damage accumulation both on the second story walls and at the interface between the slab and the second story walls. In fact, at a base shear of nearly 900 kN, the slab at the second story started slide over the second story walls (Fig. 7). This damage caused a ductile response in the load-deformation response of the second story.

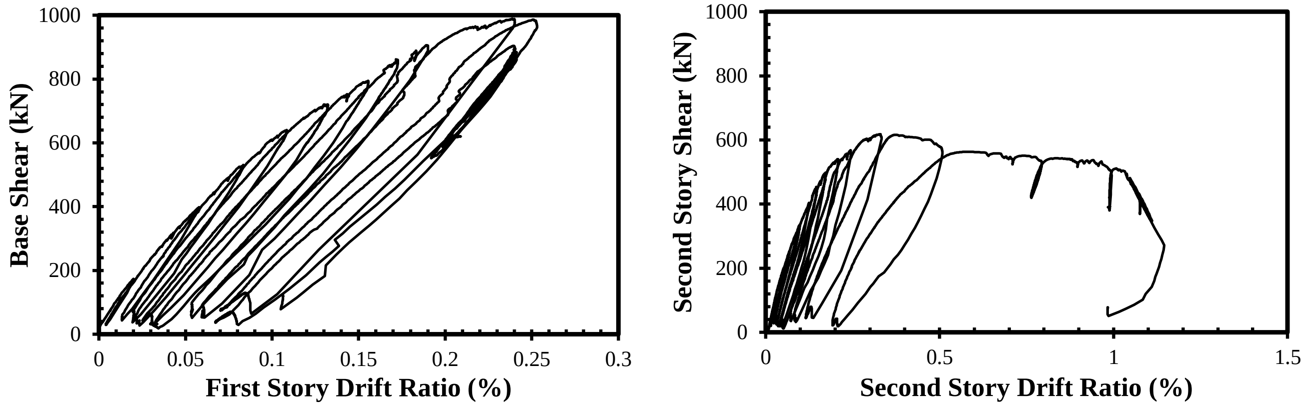

Fig. 7 – Recorded Load – Deformation Responses

The ultimate base shear force recorded during the test was 990kN at overall building drift ratio of about 0.35%, corresponding to a nearly 0.25% of interstory drift ratio at each story level. The test was stopped when the second story drift ratio reached about 1.2% since the test second story lost 20% of its ultimate capacity. Plan deflection sketches of the test building shown in Fig. 6.b showed that the building experienced slight torsional rotations in the clockwise direction at both story levels with increasing nonlinearity due to asymmetric wall damage. The damage of the first story walls were relatively minor during the one-way cyclic displacement excursions whereas there was heavy damage on the second story walls, including severe diagonal cracks, sliding cracks at the slab interface and severe damage at the corners of doors and windows (Fig. 9).

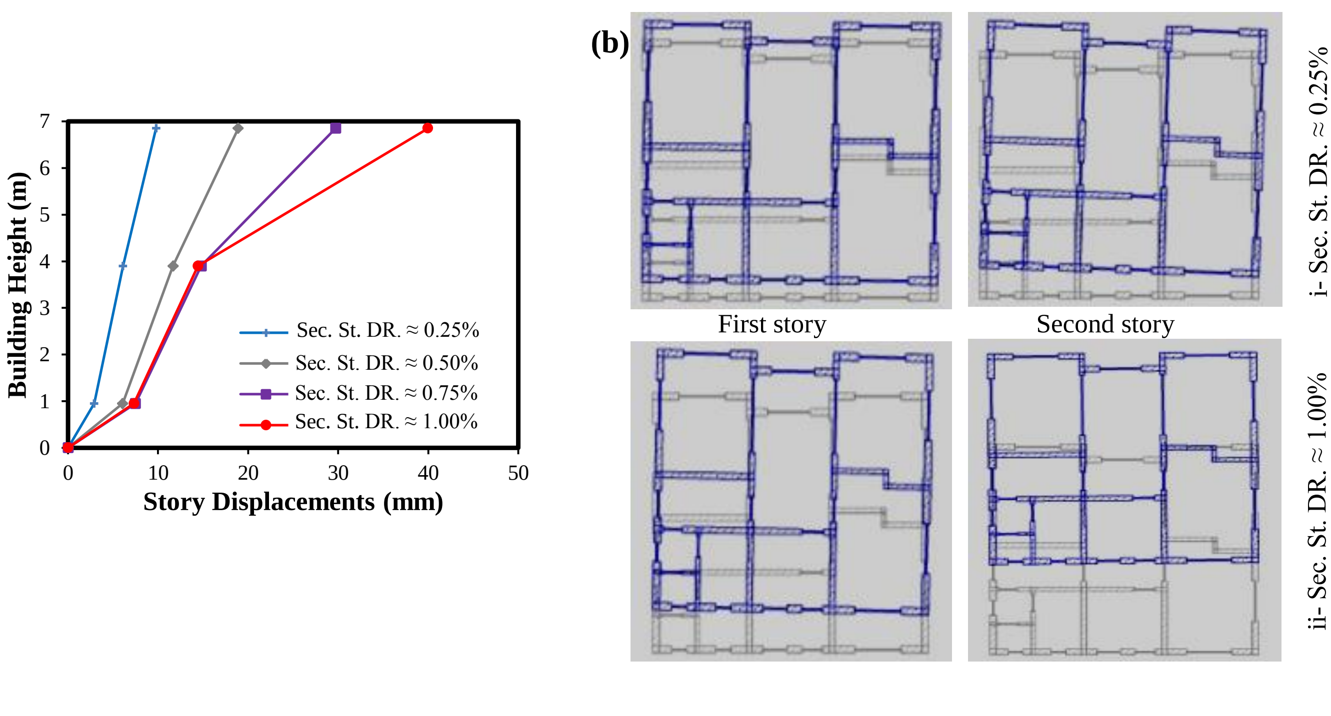

Fig. 8 – (a) Deformation profile at different drift ratio levels of the second story and (b) plan deflection of first and second stories at a drift ratio of (row i) 0.25% and (row ii) 1.00%

Fig. 9 – Different cracks observed during one-way cyclic test in the second story

3. Conclusions

The results of one-way cyclic test of an existing masonry structure are reported in this study. The structure was pushed until 20% of its ultimate lateral load carrying capacity occurred. This corresponded to a drift ratio of about 1.2% at the second story level. In the light of experimental findings, the lateral load carrying capacity of the building is detected to be approximately 40% of its weight. From the capacity curve, the displacement ductility of the test building was determined as about four. The observed wall cracks were mostly diagonal tension. Furthermore, sliding shear failure between the second floor slab and walls were detected. The results presented herein provide invaluable information on the expected performance of an actual building and will be used in the calibration of numerical models and assessment techniques.

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