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CYCLIC LOADING BEHAVIOR OF A PERFORATED UNREINFORCED MASONRY WALL MODEL

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SUMMARY

The behavior under lateral loading of a perforated unreinforced masonry wall model is presented. The masonry was made of plain bricks and low strength mortar. Nonlinear behavior of the wall model was a result of shearing of the central piers. The wall model presented a considerable capacity for inelastic deformations. The experiment described is only a part of an overall research program on seismic behavior of strengthened masonry walls.

INTRODUCTION

Masonry has been used for construction of buildings since ancient times. Nowadays, despite the extensive use of modern construction materials like reinforced concrete and steel, masonry buildings still represent a great part of both residential and public buildings in the southeastern European countries. A large number of buildings were constructed before the development of rational seismic codes and some of them suffered seismic actions on their life. The improvement of the seismic performance of vulnerable buildings is an urgent issue. Undoubtedly, seismic retrofitting before an event in one of the most essential strategies to mitigate disaster. Furthermore, it is important also to retrofit earthquake-damaged buildings. To establish the retrofitting techniques one needs to know the seismic response and damage patterns of this kind of structures.

A common structure used in the ‘20s and ‘30s in Romania, one of European country with high seismic risk, was masonry shear wall building erected with plain brick and low strength lime or lime-cement mortar. The purpose of the experimental study was to evaluate the horizontal loading response of a perforated unreinforced masonry wall model in order to choose the appropriate strengthening technique and to evaluate the behavior of the strengthened wall.

EXPERIMENTAL PROGRAM

Experimental model

The most shear walls in buildings are perforated by window and door openings, so the experimental research was carried out on a perforated unreinforced masonry (URM) wall model. This element modeled a three-story wall in an actual building. Only two stories were constructed (Fig. 1), because lateral testing forces were concentrated at the second level, i. e. in the centroid of an inverted triangular loading for the three-story building.

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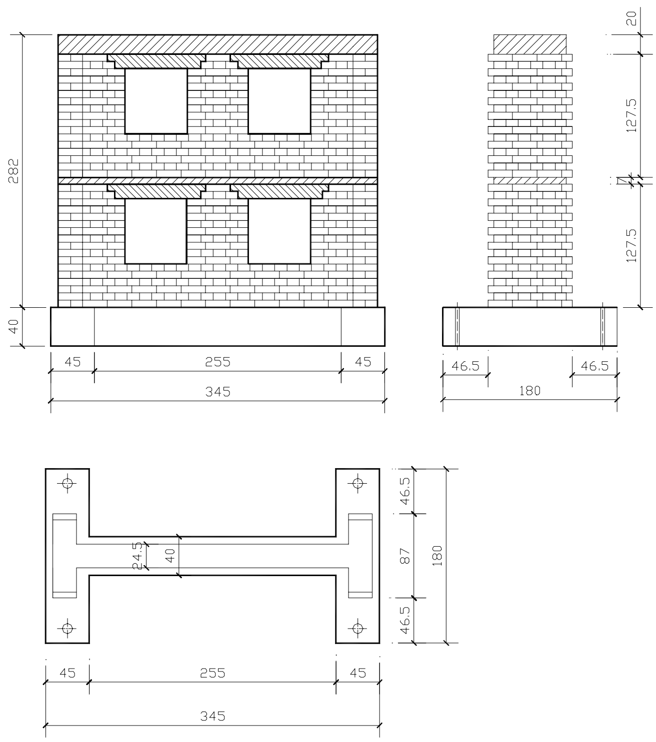


Figure 1. The experimental model.

The wall, with two parallel flanges, had a symmetrical pattern of openings (two window openings at each level). An aspect ratio for piers of about 1,0 was chosen in order to obtain a failure mechanism of “principal stresses” (inclined cracks). Reinforced concrete floor slabs and lintels over the openings were cast in place. The thickness of the top slab was oversized, in order to transmit the vertical forces as uniformly as possible. Half scale was used for lengths and full scale for thicknesses. The wall was made of plain brick of strength of 16,0 MPa, using a mortar mix of cement:lime:sand = 1:2,8:13 with an achieved compressive strength of about 1,5 MPa.

Load application and instrumentation

The model was tested under reversed lateral cyclic loading statically applied, in presence of a constant vertical force. The vertical load was applied on the top slab by means of hydraulic jacks, springs and metal rods hinge supported on the strong floor (Fig. 2). The intensity of the vertical loading was chosen to provide a uniform axial stress of 0,25 MPa – including the wall weight – at the wall’s bottom, which is typical for a three-story actual wall. The axial stress was maintained constant during the test. The lateral loading was applied by a system of 300 kN hydraulic jacks reacting against a strong wall at the top slab’s level. This kind of load application reproduced the real stress distribution in an actual three-story wall only at the first level of the model.

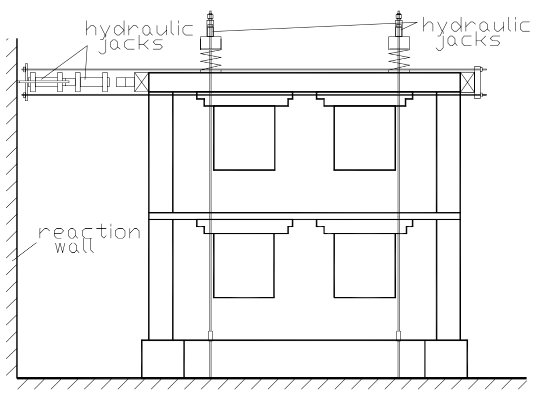


Figure 2. Test set up.

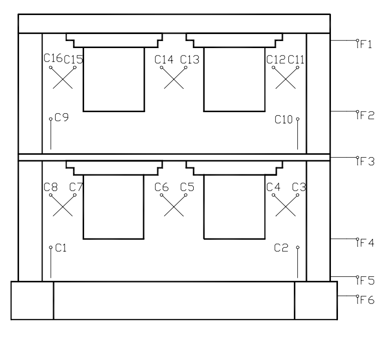


Figure. 3. Model instrumentation.

The test was carried out in increased reversed loading cycles, under a controlled-displacement test regime, after an initial load-controlled cycle at the load level at which the diagonal crack in the central masonry piers occurred. Three cycles for each peak displacement were performed.

The model was instrumented in order to obtain a large amount of data for strains and displacements (Fig. 3).

EXPERIMENTAL RESULTS

Damage propagation and failure mechanism

The most visual evidence of the worthiness of reduced scale physical models in quasi-static procedure is the pattern of cracking. The fact that the cracking patterns follow consistent explanations suggests that similar mechanism might also occur with large-scale structures.

The cracks occurred first at the ends of piers, in bed joints (Fig. 4), to a horizontal load that was approximately 70 % of the measured strength, H^{max}. The drift ratio for the first story was 0,045 %. At a lateral force equal to 80 % of the H^{max}, and an inter-story drift of 0,062 %, a stair-step diagonal crack in mortar joints in the central pier of the first level was observed (Fig. 4).

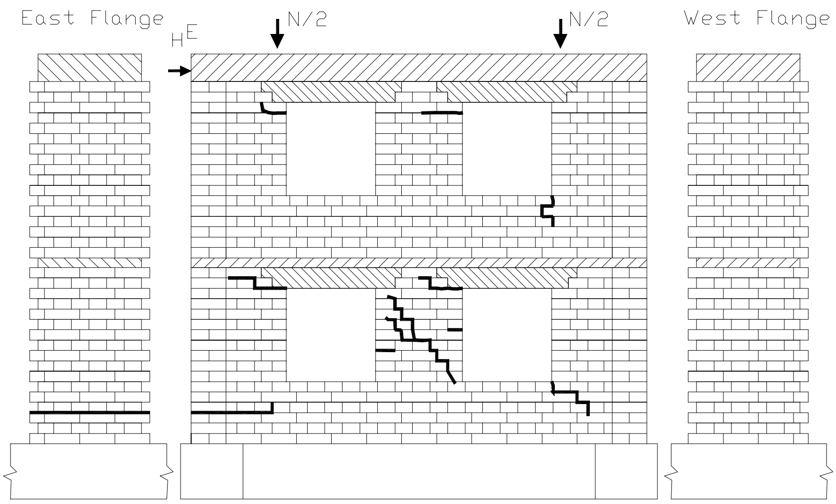


Figure 4. Observed crack pattern in the first half-cycle.

Reversing the lateral force resulted in an identical crack pattern as for the earlier half cycle. It appeared as though that previous loading and damage had little influence on the subsequent behavior.

Diagonal cracks in exterior piers did not appeared until the lateral strength of the model and an inter-story drift of about 0,38 % was reached. The crack patterns in the exterior piers was asymmetrical for the two directions of the lateral loading (Fig. 5) because of alternating axial forces. When one pier was subjected to compression, friction along bed joints was enhanced, the pier attracted shear and an inclined crack occurred. The other pier, subjected to axial tension, attracted little or no shear and no diagonal cracks were observed.

Because of relatively light amount of gravity stress and of low strength mortar, the shear behavior of all piers was a result of sliding along bed joints and separation across head joints.

The test was stopped when an inter-story drift of 0.8 % was attained, because the model was to be strengthened. However, the Romanian seismic design code limits the inter-story drift to 0,35 % for buildings with masonry partition. In the maximum displacement cycles, the head joint crack opening of the main diagonal crack was about 8 mm.

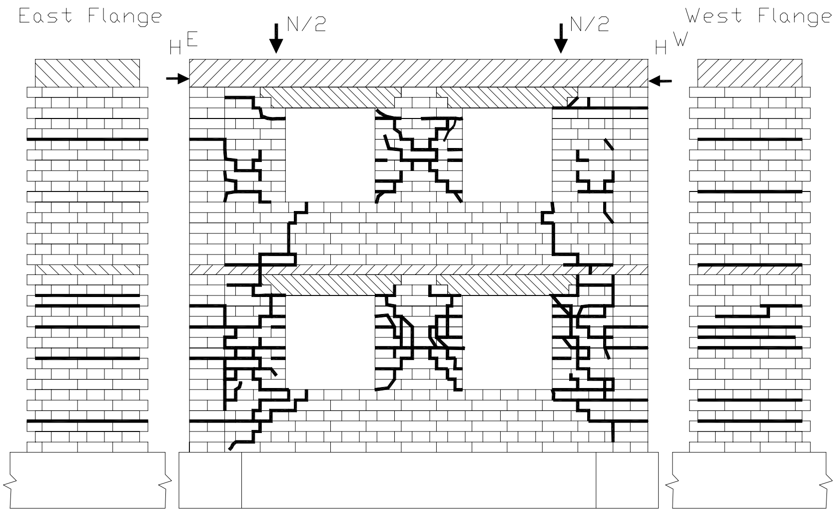
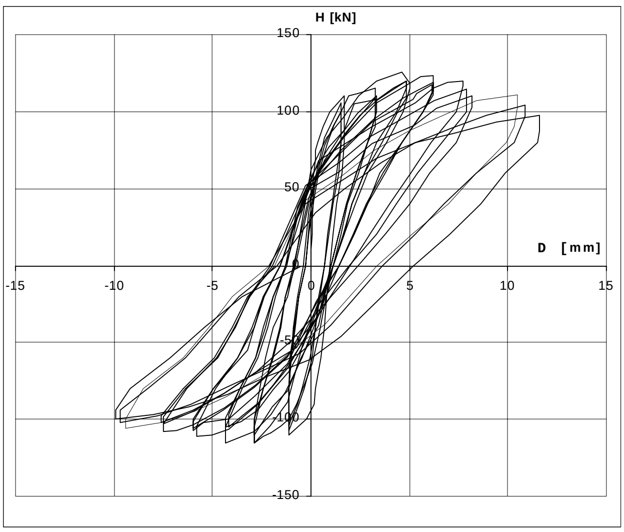


Figure 5. Final crack pattern.

Lateral resistance and deformability

The measured lateral resistance was 126 kN and was attained at an inter-story drift of 0,35 %, just before the inclined crack in the exterior pier occurred. The strength remained nearly constant, controlled by the friction resistance in joints. Strength degradation was greater between the first two cycles performed at the same displacement (3,8 – 6,1 %) than between the last two (0,9 – 5,5 %).

The relation between story shear and deflection at the first story (Fig. 6) showed that the initial stiffness was quite high, but deteriorated rapidly, even before cracking (Fig. 7). This indicated a microcracking process.



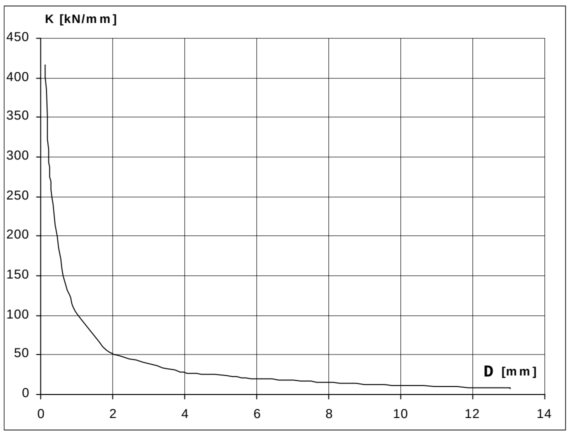


Figure 6. Hysteretic response of the wall. **Figure 7. Stiffness deterioration.**

The secant stiffness degradation measured at the same displacement amplitudes was greater between the first two cycles (max. 11 %) than between the last two (max. 6 %).

The wall model behaved in a ductile manner. If one consider the measured displacement when the diagonal cracks in central piers occurred as critical displacement, lateral displacements as large as seven times the critical displacement was measured at the end of the test.

The wall model could have shown a larger deformation capacity than this if the model had been tested to his ultimate state.

CONCLUSIONS

Results of laboratory experiment on the perforated unreinforced masonry wall model illustrated that:

1. Wall composed of strong solid units and low strength mortar, under low axial load, where the mortar joints cracks dominated, behaved in a ductile manner, having substantial deformation capacity past initial cracking.

2. Nonlinear behavior of the wall model was largely a result of inelastic shearing of the center piers.

3. After cracking the lateral strength was controlled by the friction resistance in joints.

4. At an inter-story drift of 0,7 %, which represent twice times the limit drift in Romanian seismic design code for buildings with masonry partition, the model damage was not extreme.

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