PSEUDO-DYNAMIC TESTING OF UNREINFORCED MASONRY BUILDINGS WITH FLEXIBLE DIAPHRAGM

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SUMMARY

A full-scale one-story unreinforced brick masonry specimen was tested to investigate the flexible-floor/rigid wall interaction. This paper reports on the experimental studies conducted and presents preliminary results from the pseudo-dynamic tests and how fiberglass strips can be used to improve the rocking behavior.

INTRODUCTION

The Uniform Code for Building Conservation (ICBO 1997) *Seismic Strengthening Provisions for Unreinforced Masonry Bearing Wall Buildings* present a systematic procedure for the evaluation and seismic strengthening of unreinforced masonry (URM) bearing wall buildings having flexible diaphragms. This special procedure, adapted from one developed by the ABK joint venture (ABK 1984, FEMA 1992) and used extensively in the Los Angeles area, and described in details by Bruneau (1994a, 1994b), has made it economically possible to significantly reduce the seismic hazard posed by these buildings, as evinced by the considerably lesser damage suffered by seismically retrofitted buildings in recent earthquakes, compared to non-retrofitted ones (Bruneau 1990, 1995, Rutherford and Chekene 1991). However, even though this procedure is founded on extensive component testing, full scale testing of an entire 3-D building having wood diaphragms has not been conducted. Such a test would complement the computer simulations and small-scale shake table tests by other researchers conducted to better understand the flexible-floor/rigid-wall interaction and the impact of wall continuity at the building corners on the expected seismic behavior.

EXPERIMENTAL SPECIMEN

The single-story full-scale unreinforced brick masonry building constructed for this experimental program is shown in Fig.1. This rectangular shaped building was constructed with two wythes solid brick walls (collar joint filled) and type O mortar was used to replicate old construction methods and materials. The specimen has two load-bearing shear walls, each with two openings (a window and a door). Shear walls were designed such that all piers would successively develop a pier-rocking behavior during seismic response. This rigid-body mechanism is recognized by the UCBC to be a favorable stable failure mechanism. The specimen has a flexible diaphragm constructed with wood joists and covered with diagonal boards with a straight board overlay (Fig. 2). The diaphragm was anchored to the walls with through-wall bolts in accordance to the special procedure of the UCBC. Material properties were obtained from simple component tests, such as a three-point flexural bending test of a small beam in order to determine the tensile strength of the mortar used.

At the corners of the building at one of its ends, gaps were left between the shear wall and its perpendicular walls. At the other end, walls were continuous over the building corners. This permits a comparison between the plane models considered by many engineers and the actual behavior at the building corners, and allows to assess the significance of this discrepancy on seismic performance, particularly when piers are expected to be

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subjected to rocking. To some extent, it also permits to observe the impact of in-plane rotation of the diaphragm's ends on wall corners.

EXPERIMENTAL PROCEDURE

Prior to testing, analytical work provided some valuable observations on expected seismic behavior, particularly on diaphragm response respective to wall response, and made possible to considerably simplify the originally planned pseudo-dynamic test set-up. Non-linear inelastic analyses were conducted to investigate the seismic behavior of the one-story unreinforced masonry specimen. Analytical results showed how the wall response is largely driven by the diaphragm response, and that a sufficiently accurate seismic response can be captured by using only a single actuator acting at the diaphragm center-span. This resulted in a much simpler test set-up using only a single actuator (1 DOF).

The unreinforced brick masonry specimen was subjected to a first series of tests under an earthquake of progressively increasing intensity. Non-linear inelastic analyses were conducted to determine an appropriate seismic input motion that would initiate significant pier rocking from the diaphragm response. The selected input motion is a synthetic ground motion for La Malbaie, Canada with a peak ground acceleration of 0.453g

Figs. 3 to 6 illustrate the behavior observed during these tests. Time histories of the diaphragm center-span response for the first 10 seconds of La Malbaie (pga=0.453g x 2) are shown in Fig. 3. Special clip gages (as shown in Figs. 4 and 5) were installed at expected crack location around all the piers to record crack opening and closing during the pier's rocking cycle. This rocking motion is clearly shown in Fig. 6 where the crack opens when the force acts in one direction and remains closed in the reverse direction. Rocking response is shown for the central pier Fig. 6. Interestingly, the shear wall on the building side having discontinuous corners developed a rocking mode, but diaphragm simply slid on top of the piers (without developing rocking) on the building side having continuous corners.

REPAIR

After this first series of tests, the shear walls were repaired using Tyfo fiberglass strips as shown in Fig. 7. Note that these strips are frequently used to enhance the out-of-plane performance of unreinforced masonry walls. They typically enhance the flexural elastic resistance of walls undergoing out-of-plane displacements (Tyfo Systems 1997). The in-plane rocking behavior of unreinforced masonry walls is generally perceived as a stable desirable behavior, but there may be instances where the available rocking strength of such walls may still be inadequate. In that perspective, Tyfo strips were applied to the shear walls to increase their in-plane capacity. They were designed to increase the rocking force capacity of each pier, but keep that rocking capacity below the pier shear capacity. Hence, the objective of this repair strategy is to use the Tyfo strips to preserve the desirable pier rocking mode, increase capacity and enhance the displacement ductility in the repaired shear walls. The corners of the continuous walls were wrapped with Tyfo Web to increase their shear resistance. This fabric not only provides additional shear strength, but also maintains the wall's integrity by preventing spalled portions of the wall from breaking off and becoming safety hazards.

The specimen was re-tested with the same input motion as before. For comparison, the time history of the diaphragm center-span displacement is shown in Fig. 3. This repair solution increased the stiffness of the specimen as shown by the reduced rocking motion (Fig. 8). The repaired unreinforced masonry specimen was able to resist up to large peak ground amplifications (up to nearly 2.0g). At this level of excitation, some strips started to de-bond but still provided enough capacity to allow rocking as shown in Fig. 9 where a crack opening of 22 mm is easily visible. However, for the shear wall having a sliding failure mode, the Tyfo strips provided a limited resistance as shown in Fig. 10 and failed in shear. Some tears were observed in the Tyfo Web wrapping the corners due to out-of-plane tensile cracks (Fig. 11). Finally the specimen was subjected to more conventional cyclic-testing, by increasing center-span displacement until a large proportion of the Tyfo material (strips and web) was almost completely de-bonded from the shear wall surface. Evidence suggests that repointing prior to the repair would not have improved the observed behavior. However, a different behavior could have been observed in a retrofit perspective because the original structure would not have been pre-cracked prior to application of the fiberglass material.

The wood diaphragm nonlinear inelastic hysteretic response is shown in Fig. 12 and is typical of similar diaphragms tested in the ABK methodology. After the test, examination showed that, contrary to pre-test calculations that predicted otherwise, the diaphragm remained relatively intact. Damage was limited to some popped out nails at each ends of the diaphragm.

CONCLUSIONS

Data collected during this test series is being analyzed to explain the observed behaviors, assess effectiveness of the proposed repair and compare results with predictions from existing seismic evaluation methodologies. In particular results are being studied to determine wether the flexible diaphragm deformed in shear or bending and to which extend it behaved as a rigid body.

ACKNOWLEDGEMENT

Authors would like to acknowledge the financial support provided by the Natural Science and Engineering Research Council of Canada (NSERC), Brampton Brick, Fitzgerald Building Supplies (1996) Limited, Ottawa Region Masonry Contractors Association, International Union of Brick Layers and Allied Craftsmen (Industrial Promotion Fund), Canadian Portland Cement Association, George and Asmussen Limited, R.J. Watson Inc., Fyfe Co. L.L.C. Contributions by Dr. Svetlana Nikolic-Brzev are also appreciated.

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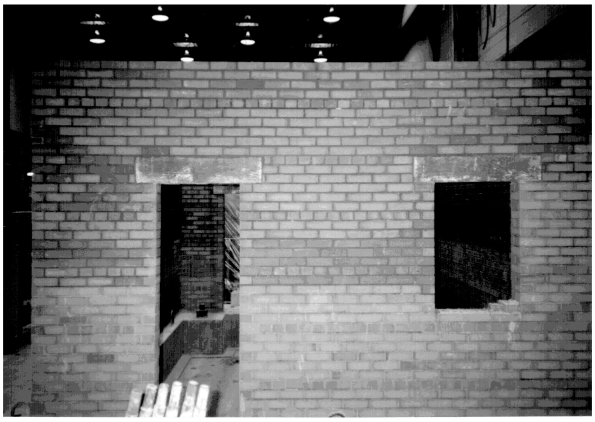

Figure 1: Full-scale URM specimen

Figure 2: Anchored wood floor

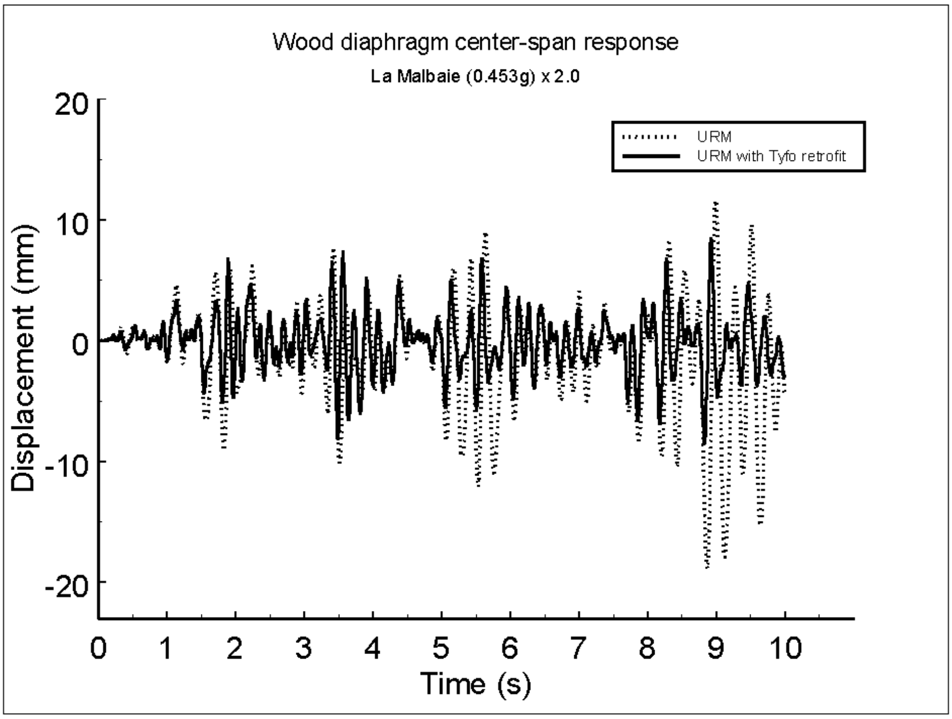

Figure 3: Comparison of diaphragm center-span response with Tyfo repair solution

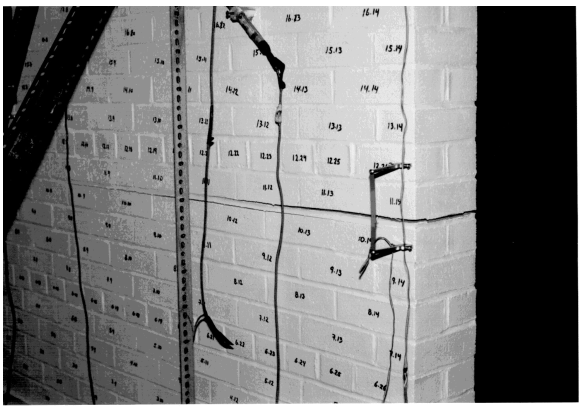

Figure 4: Clip gage recording rocking motion

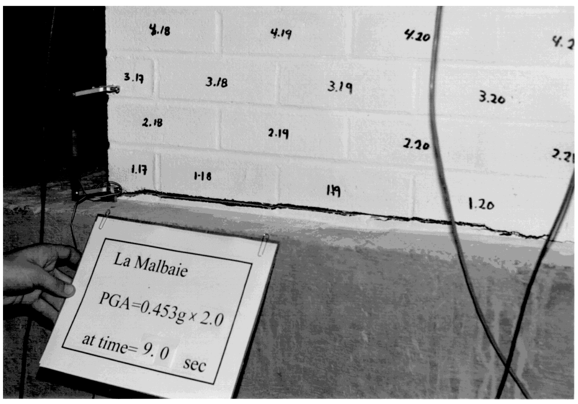

Figure 5: Rocking motion at base of door pier

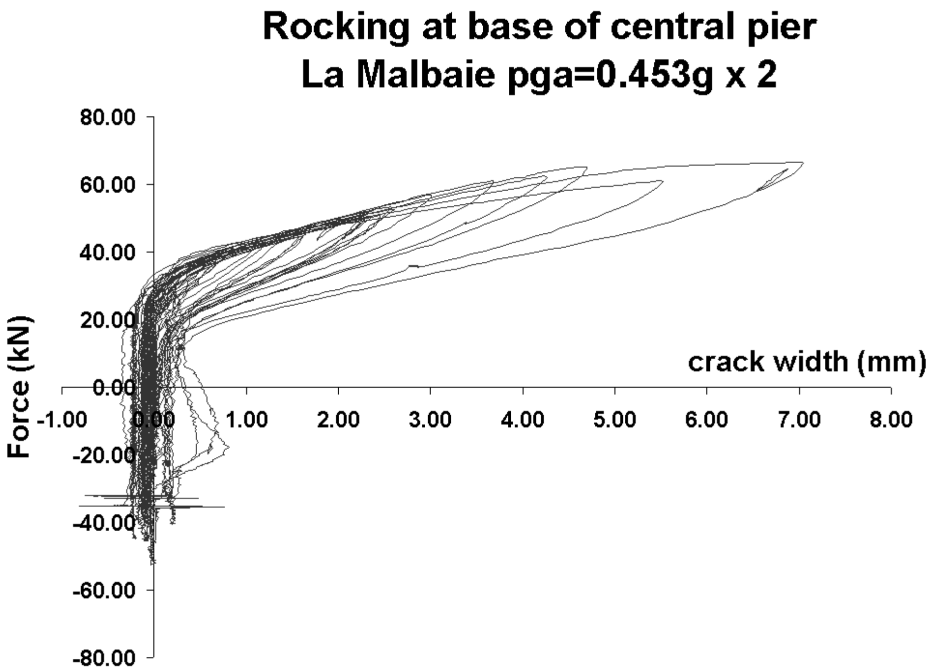

Figure 6: Rocking response for central pier

Figure 7: URM specimen repaired with Tyfo material (strips and web)

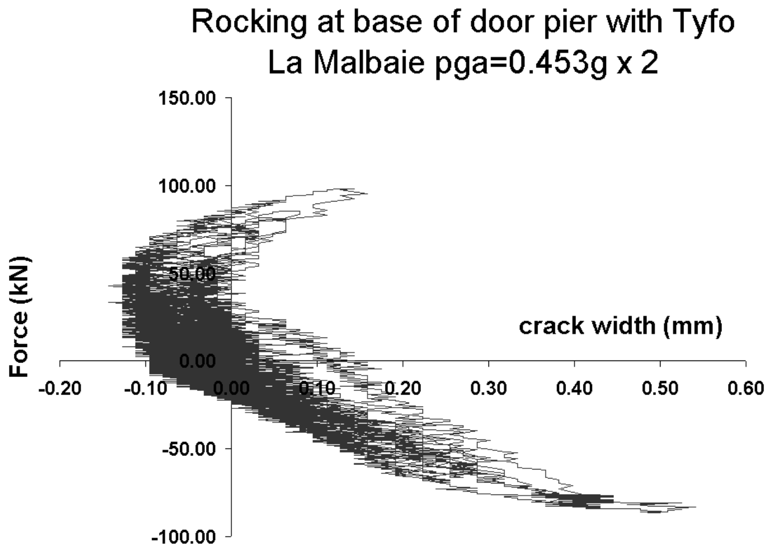

Figure 8: Rocking response with Tyfo repair solution.

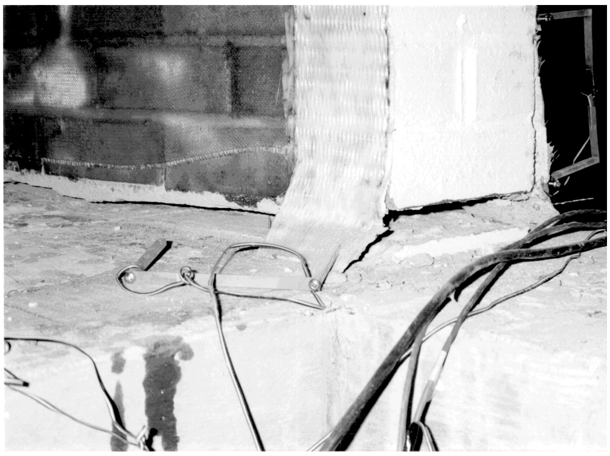

Figure 9: Pier rocking at large displacement

Figure 10: Tyfo strip failed in shear

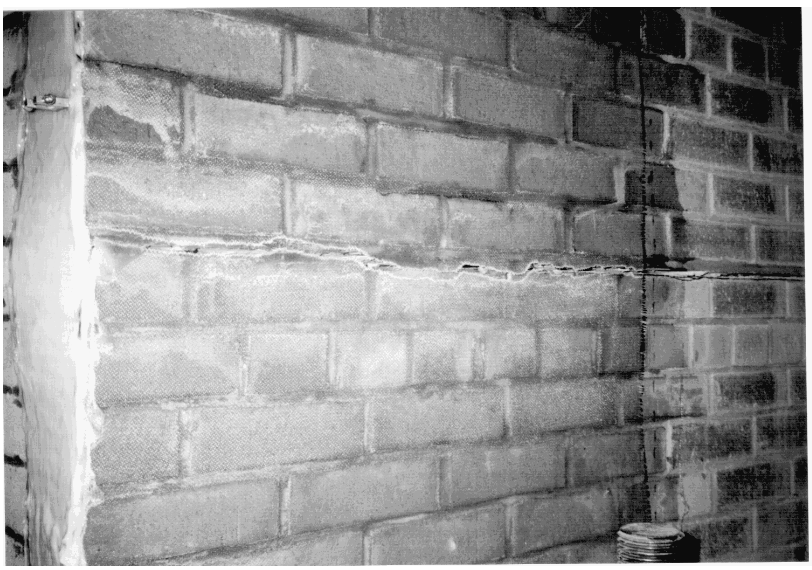

Figure 11: Tears in Tyfo web due to out-of-plane tensile cracks

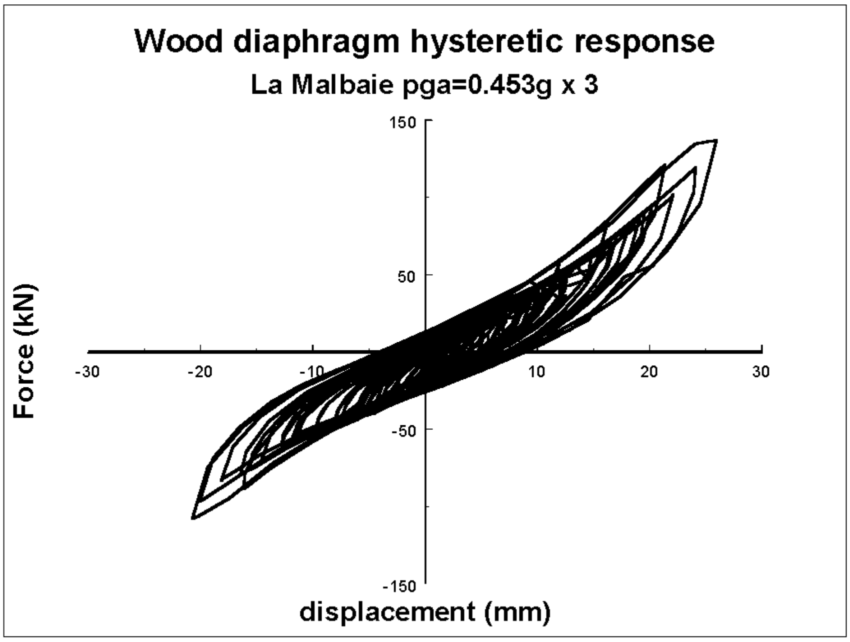

Figure 12: Nonlinear inelastic hysteretic response of wood diaphragm