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LATERAL LOAD BEHAVIOR OF MASONRY VENEER WITH ADVANCED WOOD FRAMING

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ABSTRACT

Clay masonry veneer (CMV) is a popular construction method to form the building envelope in residential construction in the United States. Typically, the CMV is backed by traditional wood framing (TWF). Recent research thrusts are showing that unlike current practice where the contribution of the veneer to the system earthquake resistance is neglected, the masonry veneer does contribute to the energy dissipation and stiffness of the combined system. The current paper investigates the cyclic behavior of CMV with advanced wood framing (AWF) backing. Advanced framing (also termed smart framing, optimum value engineering, etc.) is a technique that uses less wood and provides more room for insulation in the building's structural envelope thus lowering life cycle heating and cooling energy demands, contributing to a more sustainable approach to residential construction. To establish the strength and deformation characteristics of the combined system, TWF-CMV walls and AWF-CMV walls were subjected to reversed-cyclic in-plane loading. The walls were built using standard building code details, and the CMV of both walls was coupled to the wood framing backing with corrugated metal brick ties at code specified spacing. Deformations of the walls were measured with digital image correlation. Digital image correlation is a technology that uses photogrammetric triangulation principles and image recognition algorithms to track facets within digital images in order to develop full field deformations in three dimensions. Comparisons of the wall lateral drift characteristics are used to investigate the cyclic behavior of the system and to begin developing design guidelines for a resilient system that considers combined system performance.

KEYWORDS: *advanced wood framing, clay masonry veneer, seismic, sustainable*

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INTRODUCTION

As energy codes become more stringent and more emphasis is placed on green building techniques, engineers are continually trying to achieve a balance between two seemingly competitive drives in modern civil infrastructure – sustainability and resiliency in the face of extreme events. A large percentage of society's energy and resource demands are tied to residential buildings. Current research thrusts into sustainability in this area are working to reduce both the initial raw material demand through efficient use of material and to reduce life cycle energy demands through constructing more energy efficient structures. Advanced framing (also termed smart framing, optimum value engineering, etc.), a technique for using less wood and providing more room for insulation in the building's structural envelope (thus lowering life cycle heating and cooling energy demands) arose from a joint Housing and Urban Development (HUD) and National Association of Home Builder's (NAHB) initiative late in the last century [1]. At the same time, many are seeking to improve the resilience of infrastructure in the face of extreme events. In this paper, a discussion is presented on the earthquake behavior of the system of clay masonry veneer (CMV) with advanced wood framing (AWF) (see Figure 1) by comparing the behaviors of a TWF-CMV wall and AWF-CMV wall, designed to standard building codes and coupled with corrugated metal brick ties, subjected to reversed-cyclic in-plane loading. It also details a planned investigation where openings and aspect ratio changes of the walls are to be investigated. The consideration of the interaction of the masonry veneer with AWF in residential construction represents a significant innovation and the potential for a system with considerable safety, economic, and sustainability benefits.

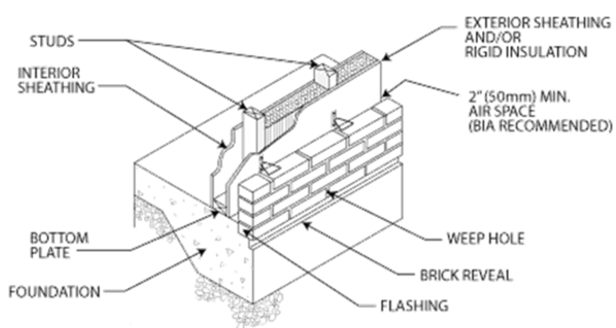


Figure 1: Clay masonry veneer with wood framing backing [2]

BACKGROUND

Advanced Wood Framing (AWF)

The APA-Engineered Wood Association published a guide in 2012 that covers many AWF concepts [3]. According to Lstiburek [1], advanced framing uses 5 to 10 percent less lumber by volume and 30% fewer pieces, reducing construction time and costs. Board feet is defined as a unit of measure for the volume of lumber. With the reduced lumber, additional cavity insulation of up to 60% is employed for energy savings.

Figure 2 illustrates some of the key features of AWF. These include: (1) 2x6 [38 mm x 152 mm (1.5 in. x 5.5 in.)] studs on 610 mm (24 in.) centers rather than 2x4 [38 mm x 89 mm (1.5 in. x 3.5 in.)] studs on 400 mm (16 in.) centers, (2) single top plate rather than double top plate, (3) stack framing of rafters, joists and wall studs to provide a continuous load path, (4) single, engineered headers over openings hung with plates or clips rather than double standard headers with jack studs, (5) use of dry wall clips rather than wood blocking in wall and ceiling corners, and (6) reduced use of cripple studs around openings. To further decrease energy use, rather than sheathing the entire frame envelope with oriented strand board (OSB) or plywood, in recent years some builders are also replacing some structural sheathing with insulating panels. These designs either use structural panels at building corners or let-in bracing to achieve lateral resistance. AWF reduces lumber use and allows additional insulation within the wall, decreasing heat transfer between the interior and exterior and reducing energy costs. These changes all decrease the number of structural elements within the frame.

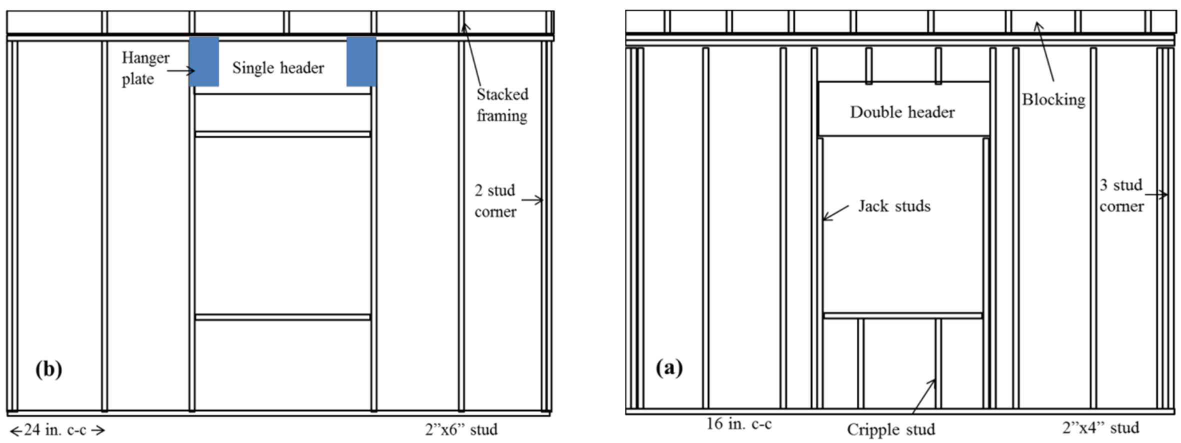


Figure 3: Comparison of wall framing: (a) traditional wood frame (TWF); (b) advanced wood frame (AWF) [Note: 1 in. = 2.54 cm]

Clay Masonry Veneer (CMV)

Clay brick masonry units are commonly used in residential construction to provide quality aesthetics, reduce maintenance costs associated with the exterior of the home, create an improved moisture barrier, and minimize the thermal transfer between the interior and exterior of the home. The masonry veneer wall is connected to the wood stud using ties (typically corrugated metal) that are embedded within the mortar joints of the masonry, see Figure 1. Currently, code previsions require the masonry veneer to be designed to support its own weight and transfer out-of-plane wind and seismic loads to the timber frame backing. Most research to date has focused on the structural behavior of masonry walls as a stand-alone system (e.g. [4], [5], [6], [7]). Little research has examined the behavior of masonry veneer walls. Reneckis et al. [8] investigated the out-of-plane composite behavior of a timber wall coupled with brick masonry veneer under quasi-static and dynamic loading. The main conclusions were that: (1) the brick increases out-of-plane stiffness; (2) inertial forces due to rigid body motion of the veneer transfer to the ties; (3) the stiffer the ties, the more composite the veneer and timber backing behave; (4) tie damage is first observed near the top corners of the wall then additional ties begin to break reducing the stiffness of the wall; (5) there are lower inertial forces from the masonry veneer when stiffer ties are used. Allen and Lapish [9] performed an extensive study of light wood frame masonry veneer subassemblies in compliance with New Zealand Code standards, and found that nail pull out from wood backing was a primary failure mode for monotonic loading, while tie fracture was more significant in cyclic tests. Zisi and Bennett [10] performed an investigation probing the shear behavior of corrugated ties for the combined system. Choi and Lefavre [11] also performed work studying the system, especially the ties.

More recently, the interaction behavior of a traditional wood frame wall with masonry veneer was investigated by Klingner et al. [12]. The behavior of masonry veneer walls when loaded in and out of plane quasi-statically in a cyclic manner was examined. The out-of-plane testing consisted of four 2.43 m (8 ft) high walls that were either 1.22 m or 2.43 m (4 or 8 ft) wide constructed with 100 mm (4 in.) clay bricks using Type N masonry cement and using different fastening mechanisms between the veneer wall and timber backing. The out-of-plane results suggested that traditional nails and corrugated fasteners had poor strength and failed either by nail pullout from the stud or fatigue fracturing of the tie. When using proper screws with greater pull out strength and rigid ties, the masonry veneer was much stronger. In addition, movement of the base of the veneer wall from the timber backing was observed.

In-plane testing was also completed on four 2.43 m (8 ft) high walls. A quasi-static in-plane load was applied at the top corner to push/pull in a cyclic manner. Results showed cracking near the bed joints of the window openings. However, one of the most important observations was the interaction of the timber and masonry walls. There was only a small lag between the timber and veneer wall. Additionally, displacement of the veneer wall was due to rocking and very little sliding, and the wall re-centered when unloaded.

Klingner et al. [12] also investigated the behavior of a single story full scale house tested under simulated earthquake loading representative of the 1994 Northridge Earthquake. Dynamic testing showed many of the same conclusions as the quasi-static laboratory testing on the single walls. Improved fastening mechanisms in the form of rigid ties and appropriate screws are needed to prevent failure. The tests also showed the benefit of the masonry veneer wall in reducing the lateral drift of the shear wall from in-plane loading. Some of the main conclusions from the experimental testing of this research were: (1) Out-of-plane response is primarily governed by the performance of the ties under axial loading. Corrugated ties connected with nails failed due to pullout from the timber backing while rigid ties with ring shank screws pulled out from the masonry. (2) In-plane response was much stronger than out-of-plane. Pullout and rupture of the ties was the primary failure mode. Nonetheless, the timber and CMV appeared to work more as a composite body particularly with the use of rigid ties. (3) The aspect ratio, height-to-length, of the wall influenced the inertial forces. The taller structures tended to rock and induce additional seismic forces on the wood. (4) Rigid ties with ring shank nails perform better than corrugated ties with standard nails. (5) CMV can reduce wall drift and dissipate energy by sliding under seismic loading. (6) "The vulnerability of wood diaphragms and rim joists connections to damage under moderate excitation merits attention."

Many have investigated brick ties with different configurations proposed to achieve performance benefits. In the current project, the walls were constructed using corrugated metal ties, as they currently are the most used in the building industry.

EXPERIMENTAL PROGRAM

Two 1.22 m x 2.43 m (4 ft x 8 ft) timber framed walls with masonry veneer were constructed and tested laterally under reverse cyclic loading conditions. An advanced framed wall with clay masonry veneer (AWF-CMV) and a traditional framed wall with clay masonry veneer (TWF-CMV) were built to US building code standards. For the TWF-CMV wall, four - 5.08 cm x 5.16 cm (2 in. x 4 in.) studs were placed on 40.6 cm (16 in.) centers. Two 5.08 cm x 5.16 cm (2 in. x 4 in.) top plates and a single 5.08 cm x 5.16 cm (2 in. x 4 in.) sill plate were used. A 12.7 mm (1/2 in.) 1.22 m x 2.43 m (4 ft x 8 ft) sheet of oriented strand board (OSB) was nailed to the studs and plates using 8d – 6.35 cm (2.5 in) long nails with a diameter of 3.4 mm (0.134 in). The nails were spaced at 7.62 cm (3 in.) around the exterior of the OSB and at 15.24 cm (6 in.) along the interior studs. The AWF-CMV wall differed in that 3- 5.08 cm x 15.24 cm (2 in. x 6 in.) studs were placed on 60.96 cm (24 in.) centers and a single 5.08 cm x 15.24 cm (2 in. x 6 in.) piece of lumber was used for the top and sill plates. Grades for the 2 x 4 lumber were a mix of #2 and Stud grade, for the 2x6 lumber the grade was #2. Timber dimensions given herein are nominal – actual sizes are somewhat smaller per US convention. Connections of the studs to top and bottom plates used three nails for the TWF wall and four nails for the AFW. These nails were 12d – 8.255 cm (3 ¼ in.) long with a diameter of 3.76 mm (0.148 in.). The AWF wall thus featured several of the items noted from Klinger et al. [12] (such as item 1 and 2) – others, such as items 3, 4, 5, and 6 were not incorporated and could only be included with a more complex testing geometry.

Corrugated metal ties 170 mm (6.69 in.) x 20 mm (0.787 in.) x 1.15 mm (0.045 in.)) were used for bridging the timber frame and masonry and were attached with nails to the exterior of the OSB along the length of each stud at 40.64 cm (16 in.) spacing for the TWF wall and 30.48 cm (12 in.) for the AWF wall using the 8d nails with dimensions as noted above. Professional masons were contracted to construct the masonry veneer. This was to assure the quality of work was similar to typical residential construction. Figure 3 shows the finished assemblies of the walls. The constructed walls were connected through the sill plate to the laboratory floor using 19.05 mm (¾ in.) diameter steel rods on each end of the wall at a spacing of approximately 1.82 m (6 ft).

The bricks used were 24.13 cm x 6.33 cm x 6.33 cm (9.5 x 2.5 x 2.5 in). Prisms representative of the in-place construction were made concurrently with the walls. These prisms were four units tall, cured in the same environment as the walls, and tested in compression at the same age as the walls, yielding an average compressive strength, f'_m of 11.6 MPa (1682 psi).

The instrumentation deployed monitored the behavior of the two walls under reverse-cyclic in-plane lateral loading. Measurements of load and deflection were captured using a load cell, 2-string potentiometers, and a digital image correlation (DIC) system. DIC ([13], [14]) allows nearly-full-field displacement and strain monitoring of measured objects and can be deployed in two dimensions (with one camera) or three (with two cameras). Each 3D-DIC sensor is a pair of cameras that are fixed with respect to one another. Triangulation principles combined with pattern recognition algorithms are used to determine the locations of facets of a stochastic pattern marked on the object.

Load was applied through a 530 kN (120 kip) hydraulic actuator positioned on each side of the wall and attached to a custom built strong back that was fixed to a steel load frame (Figure 6). The walls were loaded 2.13 m (7 ft) above the foundation. An actuator was placed on each side to allow the walls to be loaded in both directions. The load was applied to the exterior wood stud. A string potentiometer was attached 238.8 cm (94 in.) from the bottom of the wall to a stud to measure the lateral movement. To determine if the wall slid along the foundation, another string potentiometer was connected to the sill plate. The DIC monitored the displacements of the masonry veneer as well as the back of the wall to compare the interactive behavior of the timber frame and veneer. To do this, both the masonry veneer and back of the wall were patterned and two separate DIC systems were used. Figure 4 shows the displacement loading history for each wall. At each roof drift increment, the wall was subjected to 3 fully-reversed cyclic displacements, with the roof drift increasing up to failure of the wall.

(a) (b)

Figure 4: Test specimens (a) front view with the TWF-CMV in the background and AWF-CMV in the foreground; (b) rear view with the TWF-CMV in the foreground and AWF-CMV in the background

RESULTS

Figure 5 shows the load displacement response for the two walls. The AWF wall was not able to achieve three cycles at the final drift increment of 63.5 mm (2.5 in). It was unstable in the out-of-plane direction due to failure of the lower OSB/stud/plate joint. The TWF wall was able to resist the entire load sequence, after which it was subjected to increasing lateral load in a single direction until failure. The strength did not increase in this additional load sequence, but the TWF wall was thus able to reach approximately 5% drift at a strength loss of approximately 45% for this final load sequence, which is not shown in Figure 5 for clarity reasons. The AWF wall has approximately 80% of the strength of the TWF wall. Additionally, the initial stiffness of the AWF wall was significantly lower than that of the TWF wall, although this stiffness difference was muted at higher drift levels. Both walls exhibited some re-centering behavior, although the residual lateral deformations increased for higher drift levels. The TWF re-centering ability is somewhat better than that of the AWF.

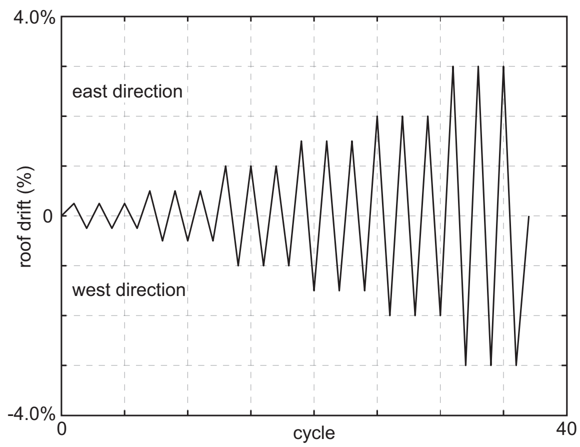
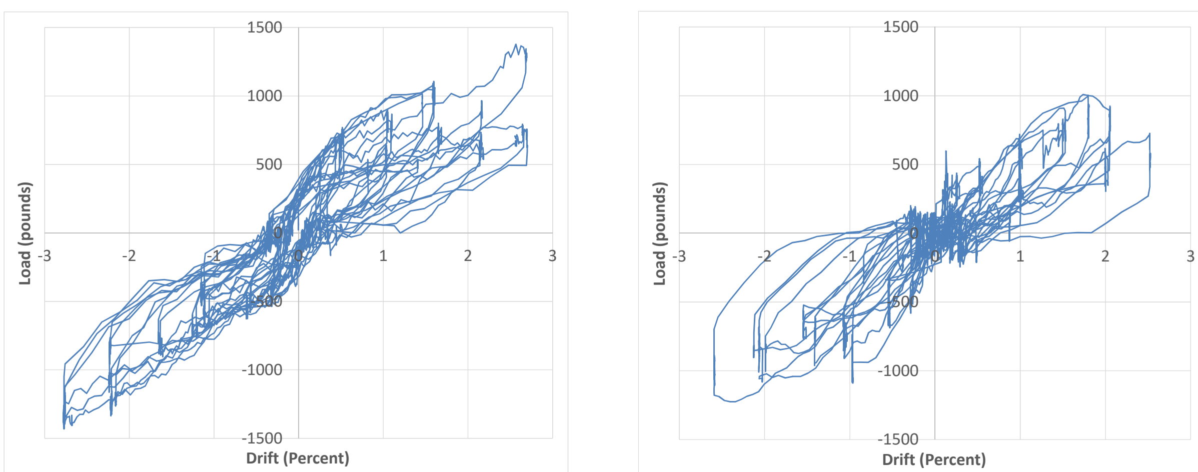


Figure 4: Wall roof drift history



(a) (b)

Figure 5: Load displacement response of: (a) TWF-CMV wall; (b) AWF-CMV wall [Note: 1 lb = 4.4 N]

Both walls failed with in a similar fashion. The failure was precipitated by pull out of the nails connecting the studs to the bottom plate, and the failure of the connection of the OSB to the bottom plate. Figure 6(a), from the test of the TWF wall, shows evidence of these issues. In both tests, the bottom plate exhibited large curvature and deflections between the supports. Figure 6(b), from the test of the AWF wall, shows the uplift experienced by the masonry.

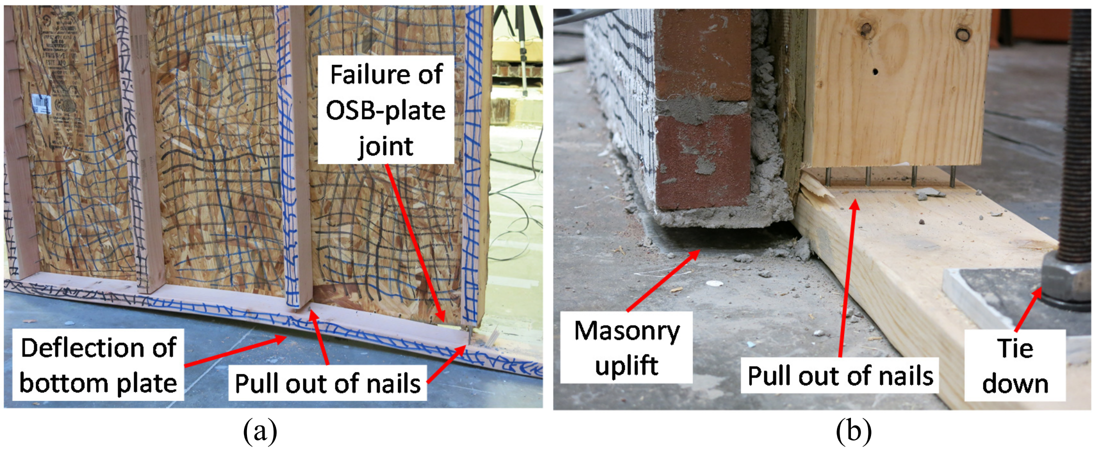


Figure 6: Failure mechanisms of the walls: (a) nail pull out; (b) uplift of masonry

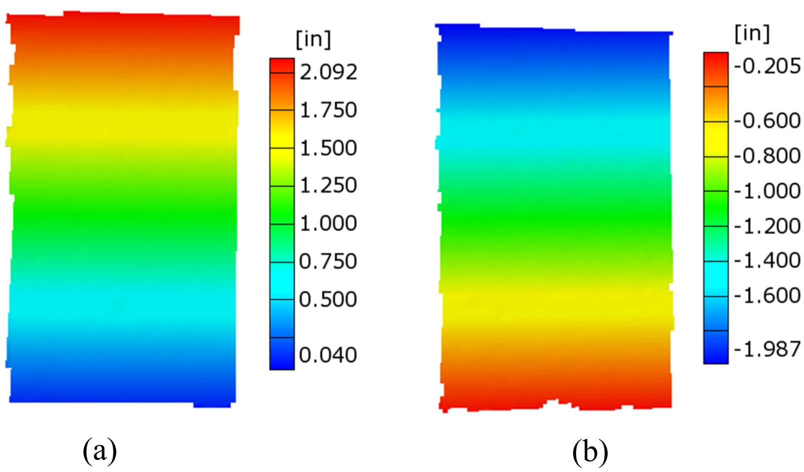


Figure 7: Lateral displacements of the CMV for the AWF wall under: (a) +2.0% drift; (b) -2.0% drift [Note: 1 in. = 2.54 cm]

DIC was used to capture the deformations of the CMV during each load case. As examples, Figure 7 shows the lateral displacements from each test. Figure 7(a) shows the masonry AWF wall at approximately +2.0% drift, Figure 7(b) shows the TWF wall at approximately -2.0% drift. In all of the cases examined, the results were similar, and indicated that the dominant displacement mechanism of the masonry in each of the walls was movement as a rigid body. Strains were small in the CMV of the two walls, likely because there was not a strong load path through the masonry for the lateral load to be transferred to the foundation (the CMV was not positively attached to the foundation, and thus only compressive stresses could be generated within the masonry). The masonry in both walls experienced large uplift at the tension toe of the wall, similar to that exhibited in Figure 6(b). Although the strains were small, comparison of the lag between the displacements of the CMV and the displacements of the wood frame backing showed that the CMV participated more strongly in the response of the TWF wall.

FUTURE WORK

As aforementioned, the aspect ratio of the wall and wall openings play a key role in influencing the performance of a wood framed wall with CMV [12]. Previous experimental testing discussed in this paper [12] evaluated the performance of a 1.22 m x 2.43 m (4ft x 8ft) wall under in plane cyclic loading. The research team has recently began expanding this work to evaluate other size walls and walls with openings. Eight walls, each 2.43 m x 2.43 m (8ft x 8ft) have been constructed, 4 walls are AWF and the remaining 4 are TWF. Furthermore, two of each wall type have 1.22 m x 1.22 m (4ft x 4ft) openings while the others will not. The walls were designed and constructed following building code standards. Figure 8 shows two such timber-framed walls to be tested.

(a) (b) (c) (d)

Figure 8: TWF 2.43m x 2.43m (8 ft x 8 ft) wall specimens: (a) front view with no opening, (b) back view with no opening, (c) front view with opening, (d) back view with opening

To test the contributions of the CMV to the wood framed wall, some walls will be tested with brick and others without. The testing matrix is shown in Table 1. A TWF without an opening will be tested with brick and without and a wall with an opening will be tested with and without brick. The same will be done for the AWF walls. The walls will be anchored by 12.7 mm (0.5 in.) KWIK Bolt 3 Expansion Anchors to the reinforced concrete floor. These anchors were chosen based on the expected tension and shear forces produced at the base of the wall due to in-plane loading.

The testing will follow a similar procedure to that of the previously tested walls. One difference however will be in the hydraulic jack used for testing. An ENERPAC RRH-307 Hollow Double Acting Ram Cylinder with 30 ton capacity pushing and 23 ton capacity pulling was purchased for this testing. The total stroke of the ram is 11.8 cm (7 in.) with 8.89 cm (3.5 in.) in either direction. This will greatly improve the testing process. Each wall will be loaded in displacement control, cycling from its initial resting position to 76.2 mm (3 in.) in increments of 6.35 mm (0.25 in.). A load cell, two string potentiometers, and a DIC system will provide the necessary instrumentations to monitor the response of the walls. The performance of TWF versus AWF construction methods and the contribution of the CMV to the overall strength and deformation characteristics of the wall system under in-plane cyclic loading will be evaluated. The data will also show the effects (if any) of openings and when compared to the previously tested walls, the effect the wall dimensions on the performance.

Table 1: Testing matrix of the 2.34 m x 2.34 m (8ft x 8ft) wall specimens

Variable	Frame Type	
	AWF	TWF
Veneer with Opening	x	x
Veneer with No Opening	x	x
No Veneer and No Opening	x	x
No Veneer and Opening	x	x

CONCLUSIONS

Two timber framed walls with masonry veneer were constructed and tested laterally under reverse cyclic loading conditions. An AWF-CMV wall and a TWF-CMV wall were built to US building code standards. The behavior of the two wall systems were quantified. In general, the participation of the CMV in the response of the two walls seems to have been small as judged by the deflections of the masonry measured with DIC. The dominate displacement mechanism of the masonry in each case for both walls was from rigid body movement. This is likely due to the lack of a strong anchorage of the masonry to the foundation. The CMV participation could likely be increased with simple anchors from the foundation to the masonry.

In all key structural measures, the TWF wall out-performed the AWF wall – it achieved more cycles at peak drift, it had significantly greater strength, it had higher initial stiffness, it had slightly better re-centering capability, and the CMV participated in the response more strongly, as judged by the lag between masonry displacements and timber displacements. The last item may be a key factor – increased CMV participation could explain strength gains in the TWF. The implications of these observations are that AWF may not perform as desired under seismic loading, and furthermore that any future studies of the interaction of wood framing and CMV should include investigations of AWF, or limit conclusions to only TWF. The current research team has scheduled additional testing to determine the behavior of TWF and AWF walls without masonry veneer to evaluate any contribution to strength and stiffness the masonry provides to the system.

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REFERENCES

[1] Lstiburek, J.W.: Advanced framing. *Building Science*, February 2010.

[2] Spague, H.O.: Deflection limits for wood studs backing brick veneer. *Structures Magazine, Codes and Standards*, May 2008.

[3] American Plywood Association (APA): Advanced framing construction guide, Form No. M400, 2012.

[4] Williams, D., *Seismic behavior of reinforced masonry shear walls.* PhD Dissertation, University of Canterbury, 1971.

[5] Tomazevic, M. & Klemenc, I., Seismic behavior of confined masonry walls, *Earthquake Engineering and Structural Dynamics*, 26 (1997), 1059-1071.

[6] Meli, R. Brzev, S., Astroza, M., Boen, T., Crisafulli, F., Dai, J., Farsi, M., Hart, T., Mebarki, A., Moghadam, A.S., Quiun, D., Tomazevic, M., & Yamin, L.: *Seismic design guide for low-rise confined masonry buildings*. Research report: Eathquake Engineering Research Institute (EERI), Publication Number: WHE-2011-02. 2011.

[7] Moreira, S., Oliveria, D.V., Ramos, L.F., Lourenco, P.B., Fernandes, R.P., & Guerreiro, J.: Experimental study on the seismic behavior of masonry wall-to-floor connections. *World Congress on Earthquake Education (WCEE)*, Lisbon, Portugal. 2012.

[8] Reneckis, D., LaFave, J.M., & Clark, W.M.: Out-of-plane performance of brick veneer walls on wood frame construction. *Engineering Structures*, Elsevier, 26 (2004), 1027-1042.

[9] Allen, D., Lapish, E. B. "The interaction of timber framed walls with a tied masonry veneer under cyclic racking loads," Proceedings of the 4th Canadian Masonry Symposium, University of New Brunswick, Fredericktion, New Brunswick, 702-715.

[10] Zisi, N. V., Bennett, R. M. "Shear behavior of corrugated tie connections in anchored brick veneer – wood frame wall systems," *ASCE Journal of Materials in Civil Engineering*, 23, (2), pp. 120-130, (2011).

[11] Choi Y.-H., LaFave, J. M. "Performance of corrugated metal Ties for brick veneer wall systems," *ASCE Journal of Materials in Civil Engineering*, 16, (3), pp. 202-211, (2004).

[12] Klingner, R.E., McGinley, W.M., Shing, P.B., McLean, D.I., Jo, S., & Okail, H.: Seismic performance or low-rise wood-framed and reinforced masonry buildings with clay masonry veneer. *Journal of Structural Engineering*, (2012).

[13] McGinnis, M.J., Pessiki, S., Turker, H.: Application of 3D Digital Image Correlation to the Core-Drilling Method, *Experimental Mechanics*, 45, (4), 359-367: 2005.

[14] Orteu, J.: 3-D Computer Vision in Experimental Mechanics, *Optics and Lasers in Engineering*, 47, No. 3-4, 282-291: 2009.