3rd International Structural Specialty Conference
3ième conférence internationale spécialisée sur le génie des structures

Edmonton, Alberta
June 6-9, 2012 / *6 au 9 juin 2012*

MIDPLY Portal Frame as Lateral Bracing System in Light-Frame Wood Buildings

Abdullah Al Mamun[1], Ghasan Doudak[1], Chun Ni[2], Mohammad Mohammad[3]
[1] Department of Civil Engineering, University of Ottawa, Ontario
[2] FPInnovations-Wood Products Division, Vancouver, British Columbia
[3] FPInnovations - Wood Products Division, Ottawa, Ontario

Abstract: Shear walls have been successfully used to meet the design requirements in building codes for both engineered wood buildings and those designed based on prescriptive requirements to ensure that buildings have adequate lateral load resistance to wind and/or seismic loads. However, there is a need for lateral load resisting systems that can be used where limited space is available for braced walls, for example, in the case of a multi-car garage or open space design concepts. Existing knowledge from corner and full scale tests on portal frames using conventional framing methods and connection details show that the moment transfer capacity of header and narrow braced wall segment is the weakest link in such systems and is detrimental to the lateral load capacity of a portal frame. This prompted a research effort with focus on investigating and improving the moment carrying capacity of the corner in such portal frames. In order to develop portal frame with higher lateral load capacity, the MIDPLY shear wall concept has been used in a series of corner joint tests. The corner joint test results will also be used to identify potential optimum corner joint configuration for full scale portal frame tests. In this paper, the behavior and failure modes of MIDPLY portal frame corner joints has been discussed.

1. Introduction

To resist lateral loads, wood wall assemblies have been successfully used in both prescriptive design (e.g. Part 9 type residential buildings of the NBCC) and engineered design as shear walls (i.e., Part 4 of the NBCC). There is a need, however, to provide an adequate level of capacity and ductility for the lateral bracing systems used in light-frame wood buildings while allowing larger openings and spans. Wood portal frame systems have the potential to meet this need but few research projects (Al Mamun et al. 2011) have investigated these systems in such depth that design provisions and detailing can be developed allowing them to be included in Canadian codes and standards. The development of prescriptive provisions for detailing of portal frame has done by APA - The Engineered Wood Association (APA 2008). The outcome of this work was implemented in the International Residential Code (IRC) since 2006 (APA 2009). More work is needed to develop design provisions for portal frames used in engineered buildings. The current study was therefore undertaken to investigate the behavior of light-frame wood based portal frames and improve their behavior so that they can be used in conjunction with or as a substitute to light frame conventional shear walls with wood sheathing panels.

This paper presents an investigation of one type of portal frame bracing system with detailed vertical framing members similar to the MIDPLY shear walls developed by FPInnovations (Varoglu et al. 2007). The work focuses on investigating the moment carrying capacity and stiffness of the corner detail as the moment transfer capacity and stiffness of header and narrow braced wall segment is considered a critical link in such systems and is detrimental to the lateral load capacity of portal frame.

2. MIDPLY Corner Joint Test

2.1 Specimen Details

The MIDPLY wall system is a special type of stud wall arrangement where wood-based structural panel is used at the center of the wall to increase the lateral load carrying capacity of the wall. The nails connecting the sheathing with studs exhibit higher lateral load resisting capacity due to engagement of double or triple shear (Varoglu et al. 2006). Since the studs are rotated 90-degree about the longitudinal axis relative to standard stud walls, the failure modes such as panel chip-out and nail pull-through failures that are commonly observed in standard shear walls were reduced or prevented, resulting in further increase in the lateral load resisting capacity (Karacabeyli et al. 2004).

The present work considers the use of MIDPLY shear wall detailing in corner joint tests, referred to in this paper as ‘MIDPLY corner joint’. Work was undertaken to identify potential optimum corner joint configuration for full-scale portal frame tests. Tests were conducted with different details and fastening configurations to evaluate the moment resistance of the MIDPLY corner joint.

An L-shaped test assembly was developed to simulate a typical corner in a portal frame. This assembly does not simulate boundary conditions where the portal frame is connected to the foundation or to framing in the storey below. Even though testing the corner in isolation may not be representative of the behavior of the full-scale portal frame, these simple tests provide a base for comparing the corner performance and allow the optimization of the corner detail before full-scale tests can be undertaken. They also provide valuable input for numerical models to predict the behavior of the full-scale portal frame in isolation or as part of a building with other lateral bracing systems.

All corner joints consisted of 1720 mm high and 405 mm wide wall segments connected to a 285 mm header. The header was built with a two-ply beam using nominal 2x12 Spruce-Pine-Fir (SPF) members or nominal 2x12 laminated veneer lumber (LVL).

The wall framing was constructed with 38 mm x 89 mm (nominal 2x4) NLGA stud grade Spruce-Pine-Fir lumber. Nine studs were used in each narrow braced wall segment. Two bottom plates were used to transfer load from loading plate to specimen. Oriented strand board (OSB), 12.5 mm thick with a span rating of 2R32, was used as middle and exterior sheathing panels. A 12mm gap was provided between middle OSB sheathings to allow the rotation during cyclic loading.

The middle sheathing was attached to the studs using 16d common nails (4.06 mm in diameter and 90 mm in length). Five different configurations were tested as shown in Figure 5. For C1 and C2 the used nailing schedule was two rows of nails spaced @100 mm on each face of stud on wall segment, and grid pattern of nails spaced @50 mm on the header. For C3, C4 and C5 the used nailing schedule was two rows of nails spaced @200 mm on each face of stud on the wall segment, and a grid pattern of nails spaced @50 mm on the header. All nails were power driven. Six 5 x 90 mm wood screws were used to connect exterior stud to the header. Simpson Strong Tie LSTA 21 (1000 lb capacity) was used to connect the header and end studs to provide vertical continuity and moment resistance. Average moisture content of the test specimens were continuously monitored before and after manufacture until tested and remained at 16.5%. The moisture content never exceeded 19%. Figure 1 shows the construction detail of MIDPLY corner joint.

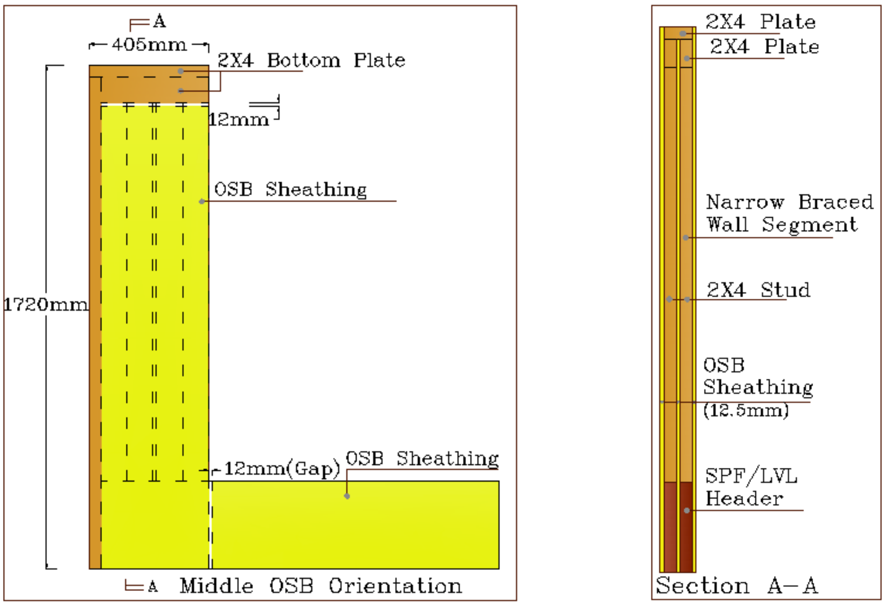


Figure 1: Elevation and cross section of MIDPLY portal frame corner joint

2.2 Test Setup

Figures 2 and 3 show the schematic and laboratory test set-up of the MIDPLY portal frame corner joint. A 12.7 mm thick metal plate, connected to the actuator, was used to apply monotonic or cyclic load at the top of the specimen. The plate was fastened to the top wood plates of the assembly using four Ø12.5 mm lag screws. The SPF/LVL header was fastened to a metal base with steel brackets. The base was anchored to the concrete floor with metal tie rods to resist vertical and horizontal movement. Lateral guides made of 100X100 mm HSS steel members were provided to ensure a consistent unidirectional movement of the corner joint assembly. Two cable displacement transducers, which were placed 270 mm from the top of the wall and 600 mm from the base of the header to measure the lateral deflection of the wall. A vertical cable displacement transducer was placed at the bottom of the exterior stud to measure the uplift of joint assembly from foundation. Fourth cable transducer was placed at the top of header to measure the relative rotation of narrow braced wall segment with respect to header.

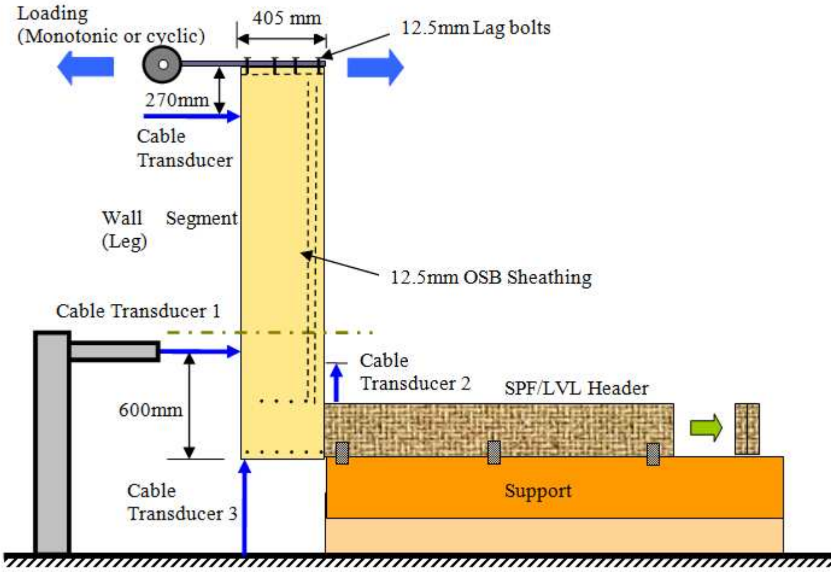


Figure 2: Schematic of the test set-up

Figure 3: Test set-up with MIDPLY portal frame corner specimen installed

2.3 Load protocol

Reversed cyclic loading tests were conducted following the ASTM E2126-08 (ASTM 2009) CUREE protocol shown in Figure 4. The frequency of cyclic tests was 0.25 Hz and the data was captured at a frequency of 10 Hz. The reference displacement that was used to develop the CUREE load protocol for the cyclic loading, obtained from the monotonic test, was 60 mm (2.36 inch) at the top of the wall segment. The monotonic test was performed using a loading rate of testing equal to 8 mm/min with the frequency of data acquisition at 10 Hz.

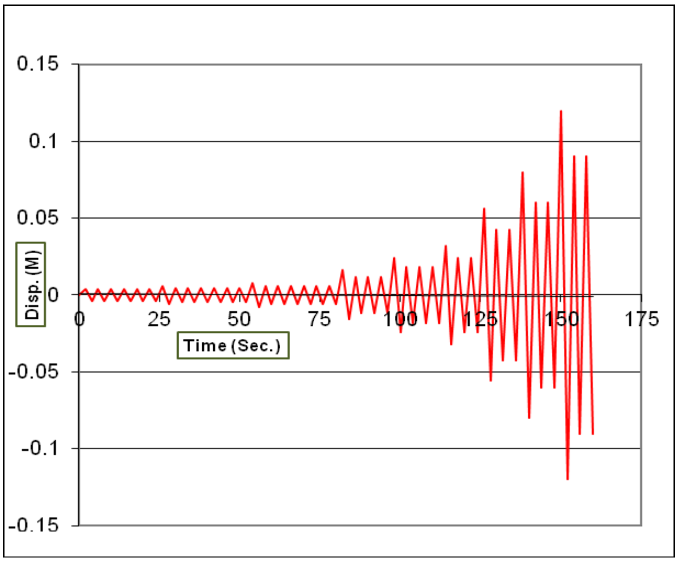
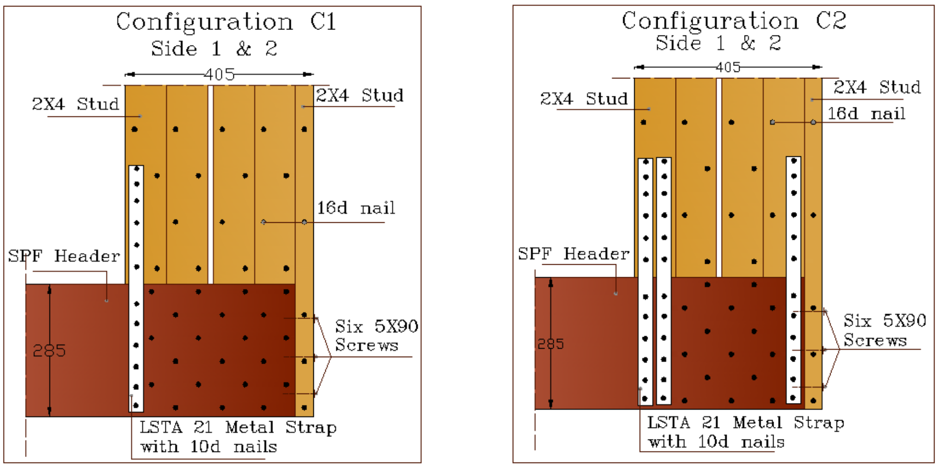


Figure 4: CUREE reversed cyclic loading protocol for the cyclic tests (ASTM 2009)

2.4 Test Matrix

The test configurations of MIDPLY corner joints are shown in Figure 5. Only configuration C1 was tested both for cyclic and monotonic loading. Though configuration C5 with LVL header was tested once, all of the configurations with SPF header were tested twice to ensure some level of repeatability in the results.



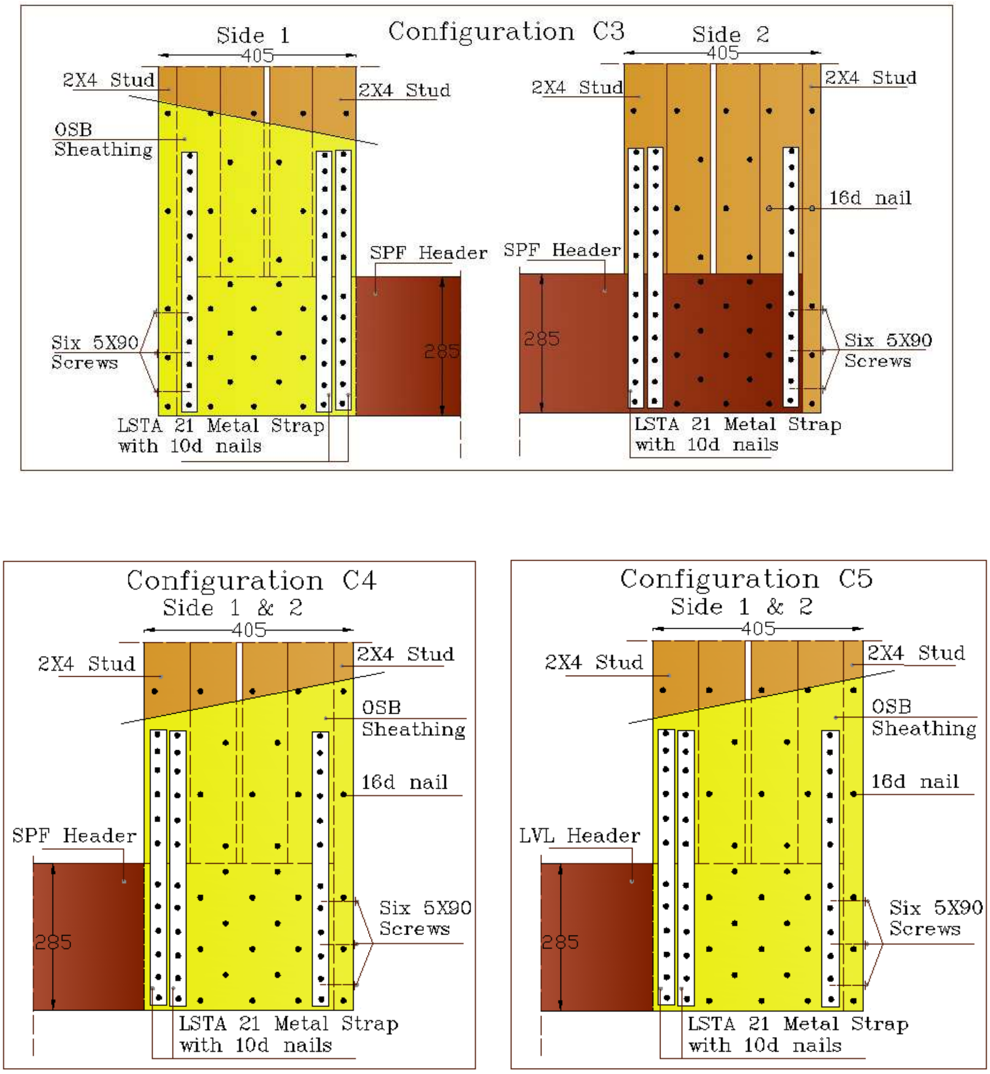


Figure 5: Test configurations of MIDPLY corner joints (all dimensions are in mm)

3. Results of Experimental Tests

Analysis of the test data was carried out in accordance with the Equivalent Energy Elastic-Plastic (EEEP) curve in ASTM Standard E2126 (ASTM 2009). To compare the performance of the various corner joint assemblies, the maximum lateral load capacity and corresponding displacement, initial stiffness, maximum moment and corresponding rotation and rotational stiffness were extracted from the test data. The moment arm used in the calculation was taken as the distance between the center of the header and vertical wall segment corner to the top of bottom plate connected to the load distribution metal plate (i.e. 1.58m).The rotation angle was calculated based on the horizontal deflection of the vertical stud as measured using cable transducer 1 (Figure 2). Failure modes observed for each tested assembly were also recorded. A summary of the test results analysis is given in Table 1.

Table 1: Experimental results of MIDPLY corner joint tests

	Maxm. Load	**Displacement @ Maxm. Load**	**Initial Stiffness**	**Max. Moment**	**Rotation @ Maxm. Moment**	**Rotational Stiffness**
Specimen	**KN**	**MM**	**KN/MM**	**KN-M**	**Rad.**	**KN-M / Rad**
C1-M	**5.37**	**17.1**	**0.476**	**8.48**	**0.037**	**344**
C1-C	**5.18**	**13.8**	**0.449**	**8.17**	**0.030**	**324**
C2-C	**8.58**	**25.4**	**0.493**	**13.53**	**0.056**	**356**
C3-C	**9.02**	**24.2**	**0.575**	**14.24**	**0.053**	**415**
C4-C	**11.22**	**22.3**	**0.805**	**17.70**	**0.049**	**581**
C5-C	**15.14**	**20.4**	**1.009**	**23.77**	**0.044**	**729**

4. Discussion of Test Results

4.1 Maximum Moment Resistance

Figure 6 shows a typical load slip hysteresis graph of MIDPLY corner joint test. The maximum moment resistance of each specimen was calculated from load slip graph as the average of the maximum positive and negative moments of two assemblies. No significant differences were found when comparing assemblies subjected to monotonic loading with those tested under cyclic loading (C1-M & C1-C). Table 1 shows that the maximum moment resistance increases with the addition of metal strap and exterior sheathing to the test assemblies. Configuration C2, with no exterior sheathing and with three metal straps on each face, were found to have 65% more moment resisting capacity than C1 with a single metal strap on each face. By adding OSB sheathing on one side (C3), the moment resisting capacity increased only 5% for the similar configuration without exterior OSB (C2). Configuration C4 with OSB sheathing on both sides and three metal straps on each face had the highest moment resistance amongst all configurations with SPF headers tested (17.7 kN-m) and had 25% more moment resistance than configuration C3 with one side exterior sheathing. BY replacing SPF header with LVL header (C5), the maximum moment capacity was further increased by 34%.

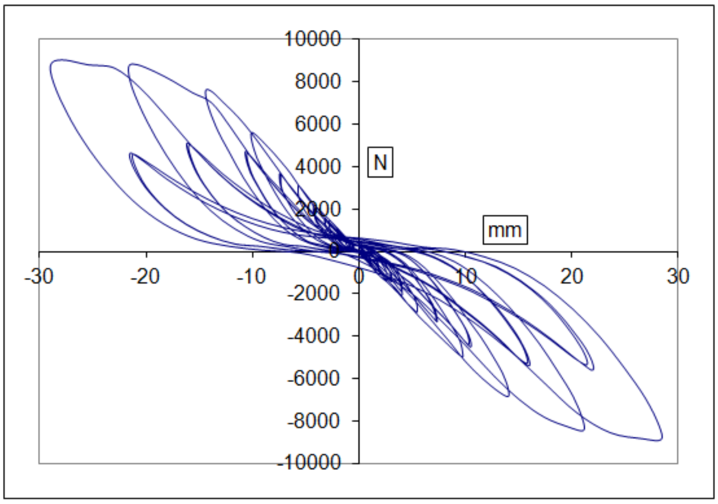


Figure 6: Load slip hysteresis graph of MIDPLY corner joint test (C3-C-2)

4.2 Rotational Stiffness

Figure 7 shows the envelope curves of the MIDPLY corner joint tests. Rotational stiffness was calculated as the slope of the secant line between 0% and 40% of the maximum moment measured from the envelope curve. Table 1 shows that the rotational stiffness increases with the addition of metal strap and exterior sheathing to the assemblies. For the configurations without exterior sheathing, configuration C2, which was constructed with three metal straps on each face, had 10% more rotational stiffness than test assembly C1 with only a single metal strap on each face. Configurations C3 and C4, with respectively one or both sides clad with exterior sheathing, rotational stiffness had increased by 17% and 63% respectively, compared to configuration C2 with no exterior sheathing. Replacing the SPF header with LVL header (C5) increased the rotational stiffness by a further 25%.

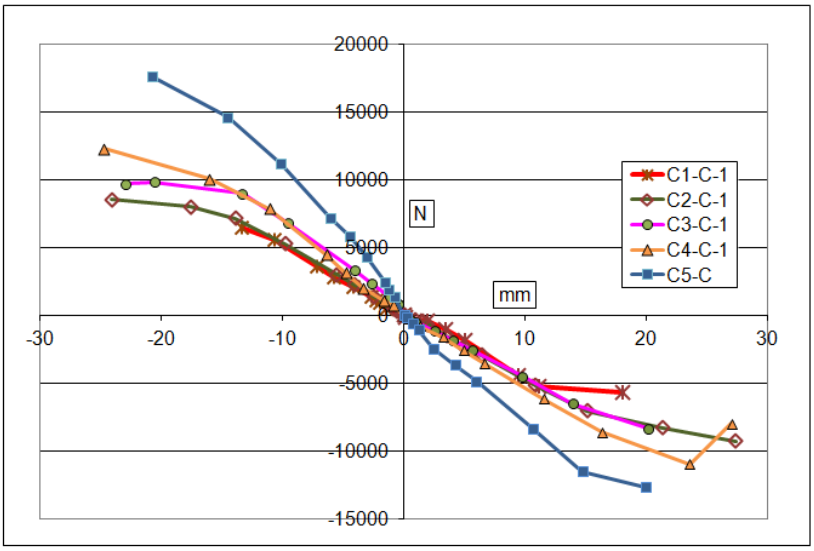


Figure 7: Envelope curves of the MIDPLY corner joint tests

5. Failure Modes

Failure mode of all the corner joint configurations started with the rupture of middle OSB sheathing followed by the rupture of exterior OSB sheathing. After rupture of exterior OSB sheathing, the metal strap carried the entire tensile load until failure occurred due to reaching the maximum capacity or fatigue failure. In configurations C1 and C2, failure happened due to failure of metal strap as shown in Figure 8 (a) and 8 (b), respectively. In configuration C3, failure occurred due to failure of the metal strap on unsheathed side as shown in Figure 8 (c). Failure of SPF header in configuration C4 as shown in Figure 8 (d), indicated that the moment carrying capacity of corner joint was greater than the capacity of header. Though the middle OSB sheathing was ruptured, no failure of metal strap or exterior OSB was noticed. After replacing SPF header with LVL header in configuration C5, failure occurred due to rupture of exterior OSB followed by the failure of metal strap. Figure 8 (e) shows the failure mode of configuration C5.

(a)

(b)

(c)

(d)

(e)

Figure 8: Failure modes of MIDPLY corner joints

6. Conclusion

Portal frame corner joints were tested to evaluate their capacity and to develop construction detailing for use as an alternative bracing system in light frame wood buildings. Maximum capacity, initial stiffness and rotational stiffness were determined from tests and were compared for different configurations. Failure modes have also been identified in order to improve the capacity and performance in future tests. From the test results it is evident that OSB sheathing and metal strap has significant effect on the lateral capacity of portal frame. It was also observed that replacing a typical lumber header with a stronger LVL header significantly increased the moment capacity as well as the rotational stiffness. Future full-scale tests using optimum details developed in this study are planned to investigate the effect of different hold-downs and end fixity.

References

Al Mamun A., Doudak G., Ni C., Mohammad M. 2011. Alternative Bracing Systems in Light-Wood Frame Buildings. *CSCE General Conference,* June 14-17 2011, Ottawa, Canada. GC-101

APA. 2008. Portal frame bracing without hold-down devices. *APA report Form J740*. The Engineered Wood Association, Tacoma, WA.

APA. 2009. Introduction to wall bracing. *APA report Form F430*. The Engineered Wood Association, Tacoma, WA.

ASTM 2009. American Society for Testing and Materials (ASTM) Standard E 2126-09. Standard Test Method for Cyclic (Reversed) Load Test for Shear Resistance of Walls for Buildings. *Annual Book of ASTM Standards*. ASTM, West Conshohocken, PA, USA

Karacabeyli E., Stiemer S., Ni C., 2004. MIDPLY Shear Wall System. *Structural Engineering Odyssey Proceedings of Structures Congress 2001*. ASCE Conf. Proc. Doi: 10.1061/40558(2001)177

Varoglu E., Karacabeyli E., Stiemer S., Ni C., 2006. MIDPLY wood shear wall system: Concept and performance in static and cyclic testing. *ASCE Journal of Structural Engineering*, Vol. 132, No. 9, 2006, pp. 1417-1425.

Varoglu E., Karacabeyli E., Stiemer S., Ni C., Buitelaar M., Lungu D. 2007. MIDPLY wood shear wall system: performance in dynamic testing, *ASCE Journal of Structural Engineering*, Vol.133, No. 7, 2007, pp. 1035-1042.