Universidad de Concepción
Dirección de Postgrado
Facultad de Ingeniería - Programa de Magister en Ciencias de la Ingeniería con mención en Ingeniería Civil

CHARACTERIZATION OF THE RACKING PERFORMANCE OF NAILED AND STAPLED LIGHT-FRAME SHEAR WALLS

(CARACTERIZACIÓN DEL DESEMPEÑO DE MUROS CLAVADOS Y ENGRAPADOS DE MADERA EN SISTEMA TIPO MARCO PLATAFORMA)

Tesis para optar al grado de Magíster en Ciencias de la Ingeniería con Mención en Ingeniería Civil

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CONCEPCIÓN - CHILE
2020

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ABSTRACT

Shear walls are the major components of the Lateral-Force-Resisting System (LFRS) in light-frame wood buildings. With the growing popularity of mid-rise prefabricated light-frame wood construction, engineers need basic design information on the shear walls to design and produce safe structures in case of high winds or earthquakes. The racking resistance of light-frame shear walls depends on many factors, including sheathing and hold-down devices and, most importantly, sheathing-to-framing fastenings. While the performance of nailed shear walls has been studied extensively, and design information is included in the design codes, there is little information on stapled shear walls, especially in the US and Canada. The cost of staples is significantly less than of equivalent nails; hence, the use of staples instead of nails would allow cost savings in mass production if they provide sufficient resistance and displacement capacity in the engineered shear walls. This thesis presents the results of a study which was focused on the comparison of the performance of nailed and stapled shear walls in laboratory tests under monotonic and cyclic loading in accordance with ASTM E564 and E2126, respectively. Several series of tests were performed on 2.4-m (8-ft) square shear walls with 11-mm (7/16-in) OSB sheathing with various hold-downs and various patterns of staples and nails: 5-cm (2-in), 10-cm (4-in) and 15-cm (6-in) spacing and 19-mm and 10-mm edge/end distances of connector. The staples were gauge 16: 50-mm (2-in) long with 11-mm (7/16-in) crown. The nails were power-driven bright common steel wire nails gauge 8d: 63-mm (2½-in) long with 2.87-mm (0.113-in) diameter. The main results revealed a similar racking performance for stapled and nailed shear walls, in terms of initial stiffness, maximum displacement, maximum load, equivalent stiffness and equivalent viscous damping ratio. Moreover, the failure of the wall is a combination of different failure modes in the connectors where the end/edge distance is important. Finally, the principal highlight for stapled shear walls is the less splitting framing when the end/edge spacing fastener is 5-cm (2-in) from the end/edge of the sheathing.

ACKNOWLEDGEMENTS

This research was sponsored in part by the Canadian Natural Sciences and Engineering Research Council (NSERC) Grant no. RGPIN-2017-05890. It was also made possible due to an internship of Roberto Aranda Medina at the Renewable Materials Research Centre (CRMR) of Université Laval in Quebec City, Quebec, Canada, funded by the Government of Canada Emerging Leaders in the Americas Program (ELAP) International Scholarship #168411.

The author thanks Dr. Alexander Salenikovich, Dr. Peter Dechent and Dr. Daniel Dolan for the support in the development of the thesis and the laboratory team for support and collaboration during the construction and test of the specimens.

The author also thanks his family, girlfriend and friends who were emotionally supporting this process.

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CHAPTER 1 INTRODUCTION

1.1 Motivation

Wood light-frame structures are commonly used for residential and non-residential buildings in North America, New Zealand and Europe. The reasons behind the popularity and widespread application of this structural system is the local availability of wood materials at relatively low cost and historical record of good seismic and wind resistance. Usually, walls and floors in these structures are framed using timber studs for walls and timber joists for floors sheathed with different materials, such as wood structural panels, gypsum board or diagonal lumber sheathing, altogether composing a lateral-load-resisting system. In the event of an external excitation, such as wind or earthquake, the load path goes through the floors, acting as horizontal diaphragms, and the walls, acting as vertical diaphragms (shear walls), carrying the load to the foundations and from there to the ground. In multi-story platform-type buildings, where the walls are stacked on top of the floors, the load-path continuity must be provided through shear connectors that resist horizontal sliding and hold-downs that resist vertical uplift of the structural elements.

The structural performance of individual shear walls depends on the grade, size and number of the framing elements, sheathing and fasteners attaching the sheathing to the framing. The racking resistance, stiffness and energy dissipation are largely determined by the type, size and spacing of the sheathing-to-framing connections using metal fasteners, such as nails, staples or screws. All these parameters determine the overall building response to the lateral loads.

While the design values for nailed shear walls published in the US and Canadian codes have been supported by extensive research over the last sixty years, the test data and the performance records on stapled shear walls are very scarce. Therefore, the goal of this research is to characterize the racking performance of stapled shear walls in comparison with the similarly built nailed shear walls. This information would help designers to choose staples as alternative fasteners in wall construction, which may sometimes be a cheaper (the cost of staples fasteners may be cost half price over the nails fasteners) and more convenient option to provide the lateral force resistance.

1.2 Hypothesis

With a correct detailing, the racking performance of light frame stapled shear walls is similar to nailed shear walls under monotonic and cyclic loads.

1.3 Objectives

1.3.1 General Objective

The general objective is to evaluate the racking performance of nailed and stapled light-frame shear walls through monotonic and cyclic experimental tests conducted according to the ASTM Standards, with different edge/end spacing pattern distances.

1.3.2 Specifics Objectives

- Test nailed and stapled light-frame shear walls with an aspect ratio of 1.0 according the ASTM Standards, with different edge/end spacing pattern distances.
- Calculate the different comparison parameters according to the ASTM Standards, for nailed and stapled test's light-frame shear walls.
- Characterize the racking performance of nailed and stapled light-frame shear walls.

1.4 Methodology

This research is based on experimental tests conducted according to ASTM Standards, performed over a test setup located in the Department of Wood Forest Sciences at the

Université Laval, Quebec, Canada. Some different real size specimens (8x8 ft.) of nailed and stapled light frame shear walls were constructed according to the ASTM E72 standard and tested under monotonic and cyclic loads according to the ASTM E564 and E2126 standard, respectively. The data were processed and several parameters were obtained according to the ASTM D7989 to compare the racking performance of the specimens. Finally, the different failure modes for nailed and stapled connectors were compared to characterize correctly the racking performance of the light frame walls.

1.5 Main results and conclusions

A several real scale (8x8 ft.) walls were tested under ASTM standards to evaluate the racking performance of stapled light-frame shear walls and compare its performance with nailed light-frame walls. The main conclusions show a similar performance for both type of connectors, especially from the beginning of the test until reach the maximum load. Furthermore, the tests show which the failure mode of the wall depends on many factors and its collapse is a combination of them. By other side, the stapled light-frame shear walls were over the minimum values presented in the ASTM standards. Finally, it is important considerer a careful detailing during the construction process of the wall, because the edge/end distance of the connector affect directly the after peak performance of the specimen.

1.6 Thesis organization

Chapter 1 present an overview of the research, the hypothesis, the general and the specific objectives and the methodology of the work. Chapter 2 present an updated state of the art of the main performance of nailed and stapled light frame shear walls. Chapter 3 describes the materials and methods, in particular the setup for tested walls, the type of load applied over the specimens, the protocol used and the standards to compare the data. Chapter 4 present the main results of the investigation and a discussion about it. Finally, chapter 5 concluded the work with the main highlights of the stapled shear walls.

CHAPTER 2 THEORICAL FRAMEWORK

2.1 Introduction

This chapter presents a brief literature review on the main scientific researches about the performance of nailed and stapled light frame shear walls under different excitation sources.

2.2 State of Art.

Extensive research has been conducted to evaluate the seismic behavior of multi-story wood light-frame buildings to improve the state of the art knowledge, development along the years a great quantity of experimental tests and numerical models focused in shear walls. The racking resistance of light-frame shear walls depends on many factors, including framed elements and its provenance, sheathing type and thickness, hold-down devices, and most importantly, sheathing-to-framing fastening connection.

To determine and understand the racking performance of nailed shear walls, it has been studied extensively through experimental tests the different boundary conditions which control the phenomenon.

- The load-deflection characteristics of single nail connections between the framing and sheathing (Dolan,1989).
- The aspect ratio and the anchored boundaries affect the performance of nailed shear walls (Salenikovich 2000).
- The effects of loading protocols under nailed shear walls (Gatto and Uang, 2002).
- The influence of vertical load (Dean and Shenton, 2005).
- Tested shear walls with different nail strengths (Leichti et al, 2006).
- Influence of vertical loads on lateral resistance and deflections of light-frame shear walls (Payeur and Salenikovich, 2011).

- Sheathing-to-framing connections in wood shear walls, nails and staples. (Sartori and Tomasi, 2013).

Further, researchers into different projects have studied and develop numerical models, finite elements models and programs to estimate the performance of shear walls under different type of loads. The basis of the models considerer the stiffness, the maximum strength, the total displacement of wood light-frame buildings (within others parameters) and specifically the performance of shear walls where the sheathing-to-framing connection highlights over the other properties:

- Nonlinear elements model the connections between the fasteners, sheathing and framing members (Falk and Itani,1988).
- Hysteresis model includes nonlinearity, strength and stiffness degradation, pinching and historical loading (Foliente, 1994).
- Hybrid dynamic model including hysteretic and stochastic methods (Kasal et al, 1999).
- Modelling hysteretic behaviour of a house (Collins et al, 2005).
- CASHEW program, used to develop fragility information for light-frame shear walls (Li, 2005).
- SapWood program, model using Bayesian predictive distribution fragilities to simulate damage and repair cost (Pei and van de Lindt, 2009).
- SapWood program nail pattern, develop fragility curves based on different possible construction quality and relating the damage to economic loss (Pei and van de lindt, 2010).
- Nonlinear FEM elements, FEM including hysteretic and anchorage behavior is compared to shake-table tests of a six-story apartment building (Pei and van de Lindt, 2011).

To understand the behavior of the light-frame shear walls and more in specific the stapled shear walls is important to know how different parameters and boundary conditions affect the performance of light-frame shear walls, Salenikovich (2000) used the equivalent energy elastic-plastic (EEEP) curve, to characterized and compared the performance of different types of wall configuration with different aspect ratio, founded a minimum aspect ratio for the construction of the light-frame shear walls. By other hand, the CUREE protocol was develop by Krawinkler et al. (2001) and it was researched in extensive for Gatto and Uang (2002) where the protocol showed an adequate behavior for highest levels of demand for light-frame shear walls. Following with research and supported for 10 specimens tested with different vertical loads applied over it, Dean and Shenton (2005) showed how the vertical load increased the maximum load capacity of the light-frame shear walls, finally Payeur and Salenikovich (2011) demonstrated how the numeric methods provided for standards to estimate the racking performance of the wall are correct. However, from all the authors presented before only Sartori and Tomasi (2013) has been studied the staples as fastening connectors, and their research is focusing on the local performance of sheathing panel and wood stud were force is carried out. Following the criteria collected by researchers in nailed shear walls, the goal of this thesis is characterized the racking performance of a real scale stapled light-frame shear walls through monotonic and cyclic experimental tests conducted according to ASTM Standards, and highlights the potential improved performance when staples are used.

2.3 Conclusions

The state of art showed an extensively characterized of nailed light-frame shear walls, its behavior under monotonic and cyclic loads and the different boundary conditions which determinate a correct racking performance. However, there is a brief characterized of stapled light-frame shear walls and its racking performance under monotonic and cyclic loads according the ASTM standards.

CHAPTER 3 MATERIALS AND METHODS

3.1 Introduction

In this chapter it is presented the materials and methods used in the research process, the wall configuration of the test, the materials used to build the walls, the setup and protocol to performed the tests and the standards and codes to obtained and discussed the parameters which characterized the racking performance of light-frame walls.

3.2 Materials

The typical shear wall configuration is shown in Figure 3.1. The shear wall specimens were constructed with sheathing, framing, fastening, anchorage and connections as shown in Table 3.1. The shear walls were constructed according to the ASTM E72 (ASTM, 2015) requirements, with Spruce-Pine-Fir (SPF) 38-mm by 139-mm (2-in by 6-in) framing and studs spaced at 406-mm (16-in) o.c. The wall consisted of a single bottom plate, a double top plate, double end studs, and double middle studs (where an increased framing thickness was required for closer sheathing nail spacing.) All sheathing was 11-mm (7/16 in) thick Oriented Strand Board (OSB) rated sheathing. The walls were an aspect ratio of 1.0, with a 2.44-m (8-ft) long and tall. The staples used to attach the sheathing to the studs were 16-gauge 50- mm (2-in) long with a 11-mm (7/16-in) crown. The nails were 8d steel wire box nails (63-mm (2½- in) long with 2.87-mm (0.113-in) diameter.) Various sheathing staple and nail spacing were used for the tests. Edge fastener spacing of 5 cm (2 in), 10 cm (4 in) and 15 cm (6 in) were used and the edge distances were 19-mm (3/4-in) and 10 mm (3/8-in), as appropriate. Fastener spacing for the interior stud nail lines was 305 mm (12 in).

Simpson Strong-Tie hold-downs (Models HTT4 and HTT22) were used for the wall specimens. The HTT4 and HTT22 hold-downs were attached to the chord members with screws and 10d nails respectively. Both connectors had the same design values. The Model

HDU8 hold-down was used for the test specimens with closer fastener spacing's. It was attached to the end studs with 75-mm (3-in) Simpson Strong-Tie SDS screws.

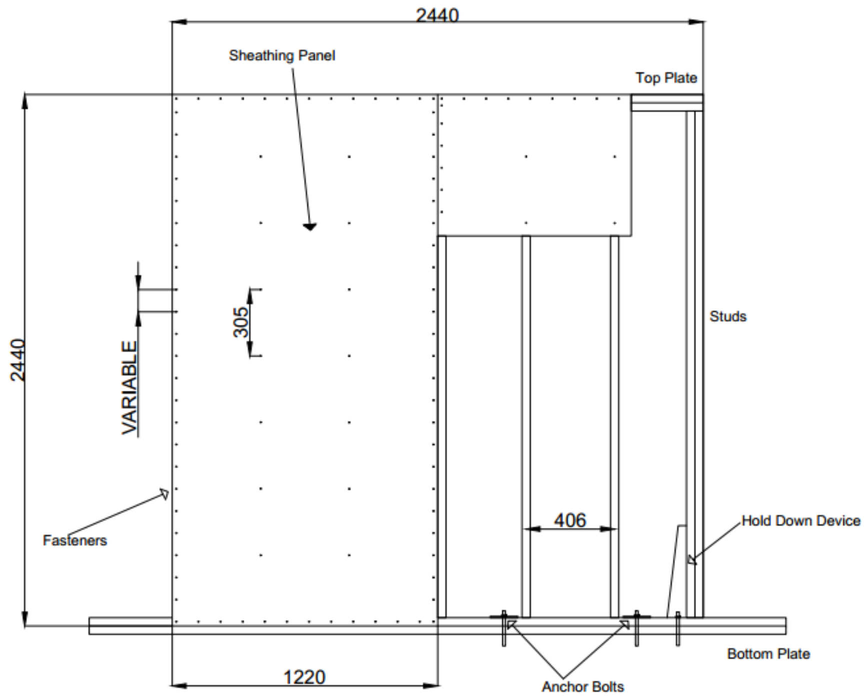

Figure 3.1. Shear wall configuration, measure in mm.

Table 3.1. Shear wall test specimens' configuration.

Wall name	Spacing cm (in)	Test #	Load	Hold-down		Intermediate stud / Number of stitch screws	Edge distance mm (in)
				Model	Fastener		
ST1-2-S	5 (2)	1	Monotonic	HTT4	1.5-in screw	single	19 (3/4)
ST1-2-S	5 (2)	2	Monotonic	HTT4	2.5-in screw	single	19 (3/4)
ST1-2-C	5 (2)	1-2-3	Cyclic	HDU8	3-in SDS	double/6	19 (3/4)
ST1-4-S	10 (4)	1	Monotonic	HTT22	10d nails	single	19 (3/4)
ST1-4-C	10 (4)	1-2	Cyclic	HTT22	10d nails	single	19 (3/4)
ST1-4-C	10 (4)	3-4	Cyclic	HDU8	3-in SDS	double/10	10 (3/8)
ST1-6-S	15 (6)	1	Monotonic	HDU8	3-in SDS	double/10	10 (3/8)
ST1-6-C	15 (6)	1-2-3	Cyclic	HDU8	3-in SDS	double/10	10 (3/8)
N1-4-S	10 (4)	1-2	Monotonic	HDU8	3-in SDS	double/10	10 (3/8)
N1-4-C	10 (4)	1-2-3	Cyclic	HDU8	3-in SDS	double/10	10 (3/8)
N1-6-S	15 (6)	1-2	Monotonic	HDU8	3-in SDS	double/10	10 (3/8)
N1-6-C	15 (6)	1-2-3	Cyclic	HDU8	3-in SDS	double/10	10 (3/8)

3.3 Setup

The test setup is located in the Department of Wood and Forest Sciences at the Université Laval, Canada. The test fixture is constructed of steel wide flange columns and diagonal braces connected with bolts. A horizontal HSS beam bolted to the columns provides support to another horizontal beam through ball-bearing tracks allowing the upper beam to roll freely along the tracks and transfer the load from the actuator to the test specimen. The actuator is connected to the upper beam and applies the load to the specimen through two C-channels welded to steel plates attached to the top plate of the wall using self-drilling screws. In contrast with the “standard connection”, which usually consists of a big I-beam over the wall where the actuator applies the load, the C-channels used in these tests are less rigid than the standard connection, therefore, the deformation pattern of the wall more closely replicates reality than is possible in most other test fixtures as is shown in Figure 3.2. To measure the displacement of the specimens, five laser displacement measuring instruments are used and located as shown in Figure 3.3. Real tests photos are shown in Figure 3.4.

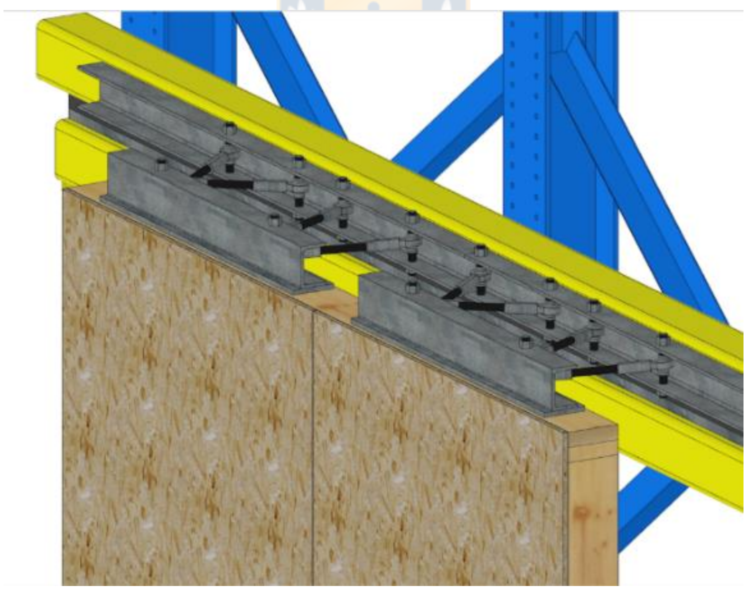

Figure 3.2. Upper beam and C-Channels, test fixture.

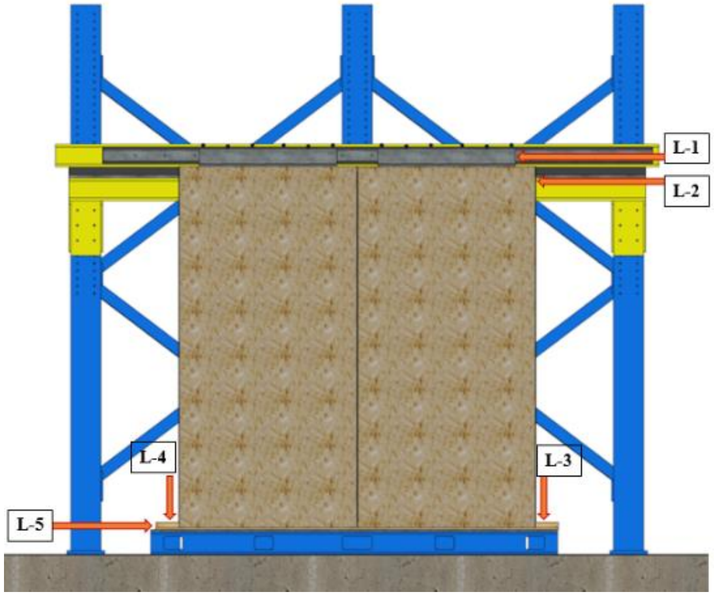

Figure 3.3. Laser distribution during the test.

a) b) c)

Figure 3.4. Real test specimen, Upper C-Channels (a), bottom lasers (b) and upper lasers(c).

3.4 Methods

3.4.1 Test procedure

The walls were tested using monotonic and cyclic loads following the ASTM E564 (2018a) and the ASTM E2126 (2019), respectively, the Method C (CUREE) protocol. According to Krawinkler *et al.* (2001), the protocol was developed with emphasis on the performance of the wall and the statistical simulation of demand contributing significantly to damage at the 10/50 hazard level, as well as adequate simulation of potentially damaging cycles at hazard levels associated with higher performance levels.

3.4.2 Processing data

The data from the tests were processed and for each test, a load-deflection curve (hysteretic curve in case of cyclic test) was plotted, where the displacement considered the racking and bending deformation, the slip displacement was deducted from the data. Along with the average backbone curve and the equivalent energy elastic-plastic (EEEP) curve following the ASTM E2126 standard procedure. Shear strength (v_{peak}), deflection at shear strength (Δ_{peak}), deflection at 0.4 v_{peak} and failure point ($v_{failure}$, $\Delta_{failure}$) were estimated for all the cyclic envelopes curves. The failure point according to standard is considering occur after the v_{peak} decrease 20% in resistance, it is 0.8 v_{peak}. The energy dissipation of the bilinear curve, with a pivot point in P_{yield} and Δ_{yield} is the same produced for the average envelope load deflection curve, as shown the Figure 3.5. Besides, the drift capacity, overstrenght and ductility ratio were estimated following the ASTM D7989 (ASTM,2018b) standard procedure.

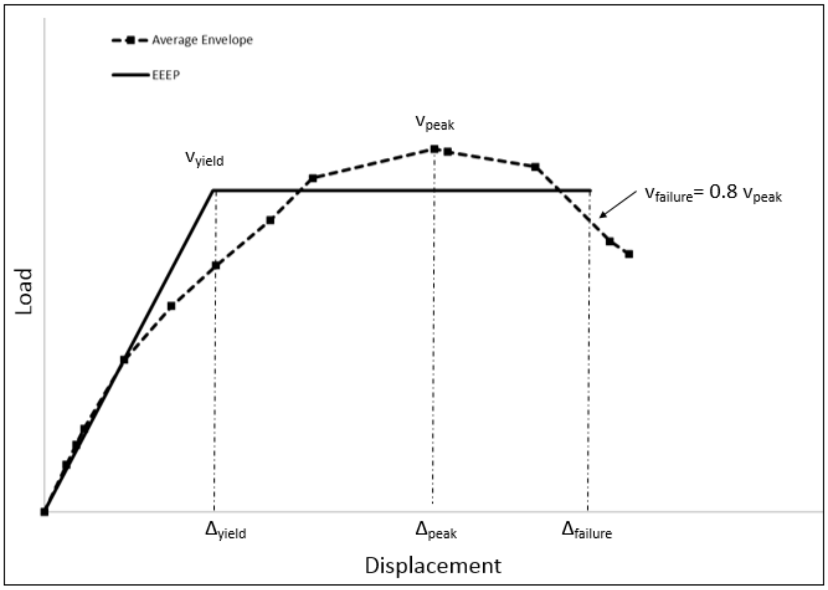

Figure 3.5. Equivalent energy elastic-plastic (EEEP) curve.

During a cyclic test the specimen degrade its properties, through the equivalent stiffness and the equivalent viscous damping ratio it is possible know how much degrade suffer the specimen. The equivalent stiffness its represent by the line OM in the Figure 3.6. Moreover, the equivalent viscous damping ratio, ξ_{eq}, it has estimated for each cycle. Where the potential energy, equals the average triangle OMN and OQP and the damping energy dissipated per cycle by the wall by integrating the hysteretic loop at the corresponding displacement.

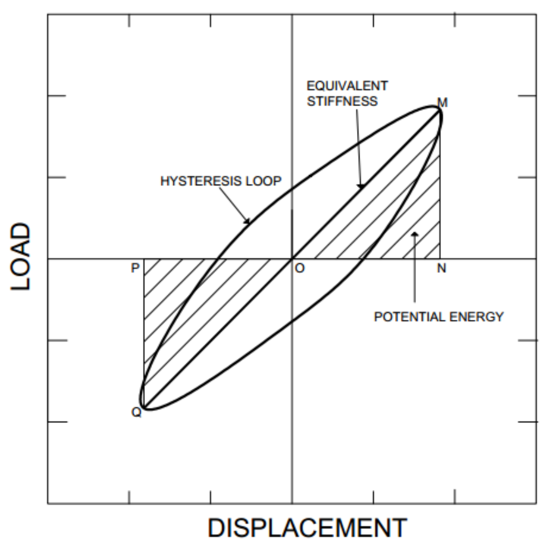

Figure 3.6. Hysteresis cycle, equivalent stiffness and equivalent viscous damping ratio.

3.5 Conclusion

The different test wall configuration was described, the setup and its special conditions were presented and the laser configuration showed. Furthermore, the application of a displacement protocol, different standards and codes, allowed to compare nailed and stapled light-frame shear walls test under the same parameters.

CHAPTER 4 RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the principal results and a discussion around them. The load-deflection curves are presented per each type of test, monotonic and cyclic. For nailed and stapled light-frame shear walls a summarized graph is shown, where the average positive and negative curves are plotted. Moreover, the results and parameters of ASTM E2126 and the ASTM D7989 are shown. Finally, the discussion is presented around the results obtained from the data processed and the failure modes observed during the tests for each typo of fastener.

4.2 Results

A load deflection curve for a monotonic test in a nailed and a stapled light-frame shear wall is shown in Figure 4.1 and Figure 4.2, respectively.

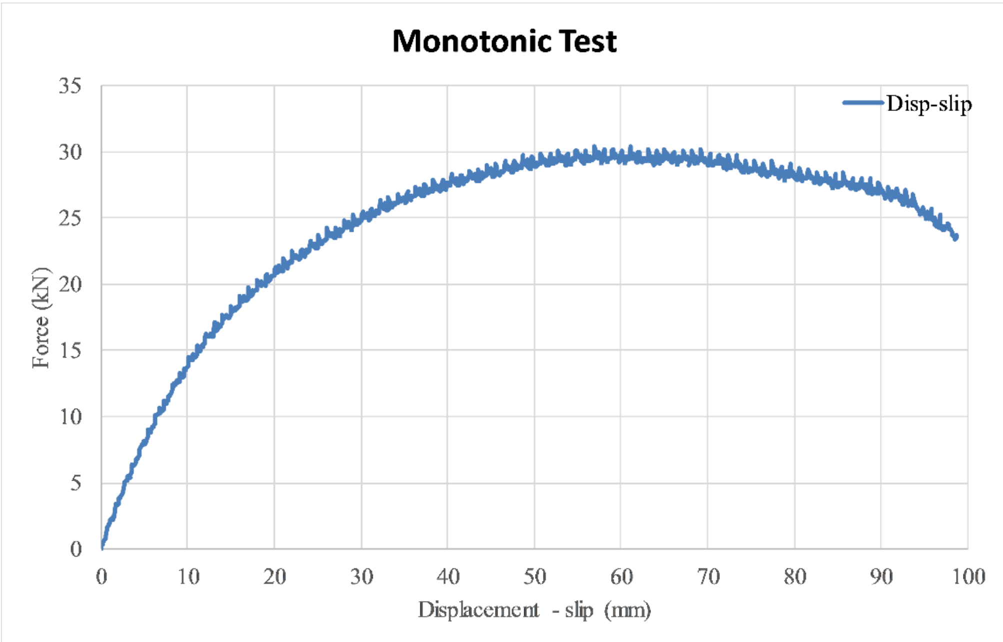

Figure 4.1. Monotonic test, nailed 4-inch edge distance.

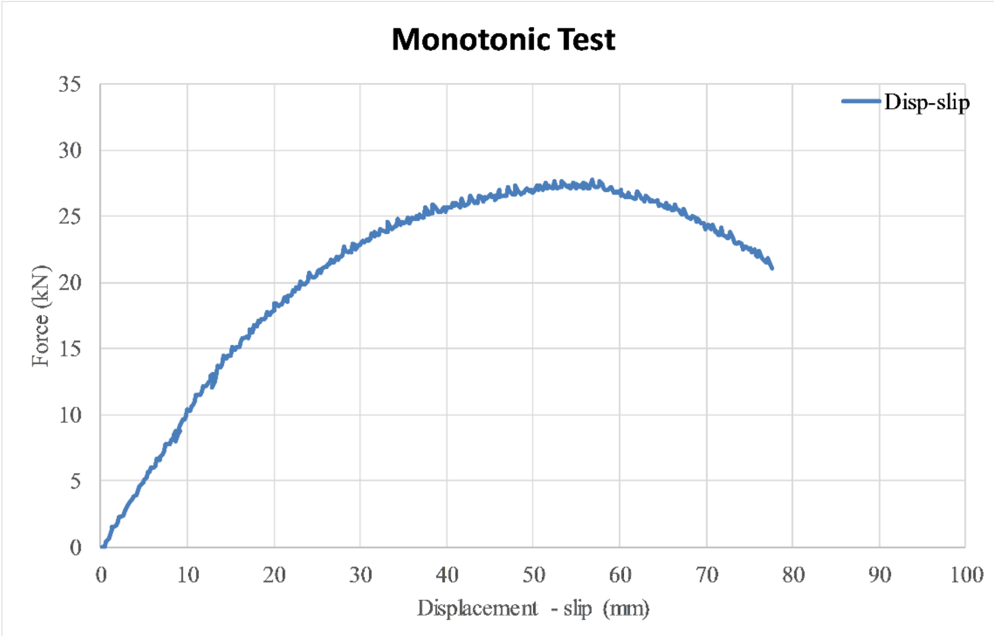

Figure 4.2. Monotonic test, stapled 4-inch edge distance.

A load deflection (hysteretic) curve performance for a cyclic test and the envelope curve stapled and nailed light-frame walls is shown in Figure 4.3 and Figure 4.4, respectively.

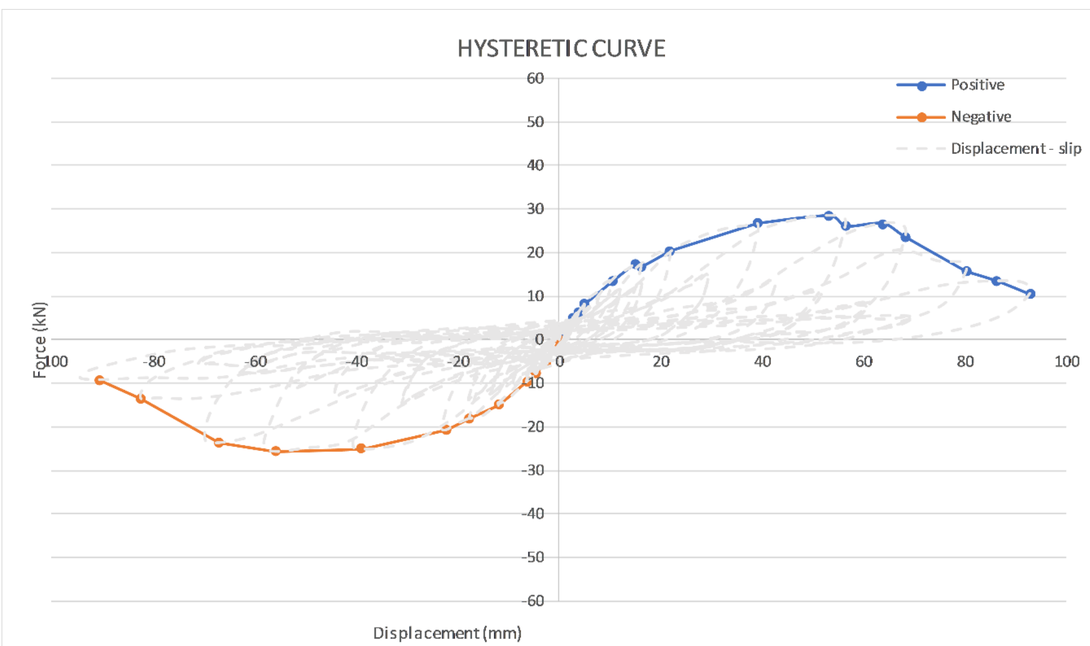

Figure 4.3. Hysteretic and envelope curve, 4 in edge spacing nailed wall.

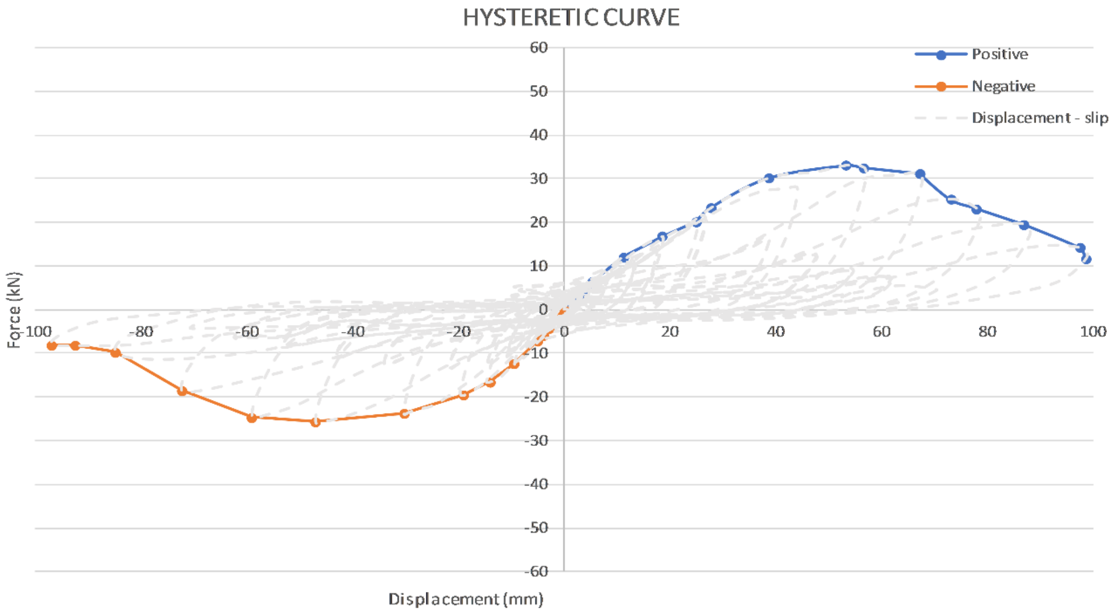

Figure 4.4. Hysteretic and envelope curve, 4 in edge spacing stapled wall.

Monotonic load-displacement curves and cyclic test backbone curves (average of positive and negative envelopes) for nailed and stapled shear walls are shown in Figure 4.5 and Figure 4.6, respectively. The variation in the equivalent stiffness and the equivalent viscous damping ratio for nailed and stapled shear walls is shown in Figure 4.7 and Figure *4.8*, respectively. Furthermore, for each specimen test the experimental results in terms of load and displacement values are summarized in Table 4.1. Finally, the ASTM D7989 parameters are summarized in Table 4.2.

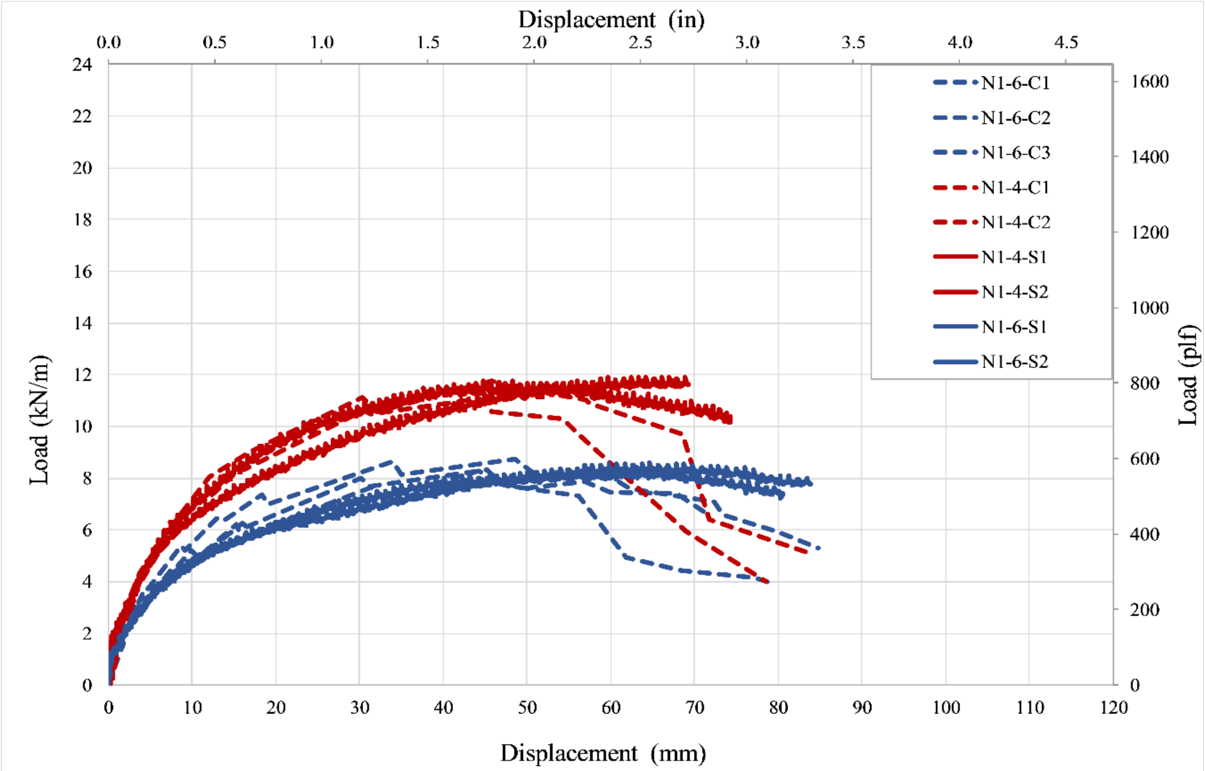

Figure 4.5. Load-displacement and backbone curves, nailed shear walls.

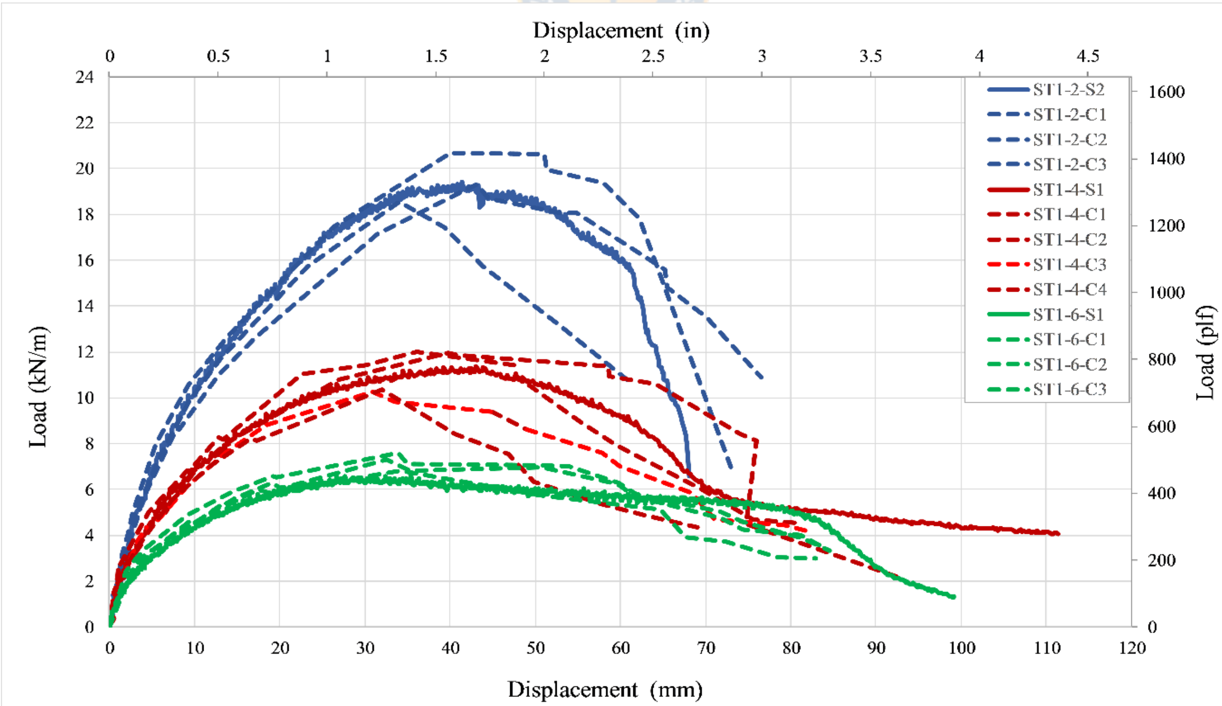

Figure 4.6. Load-displacement and backbone curves, stapled shear walls.

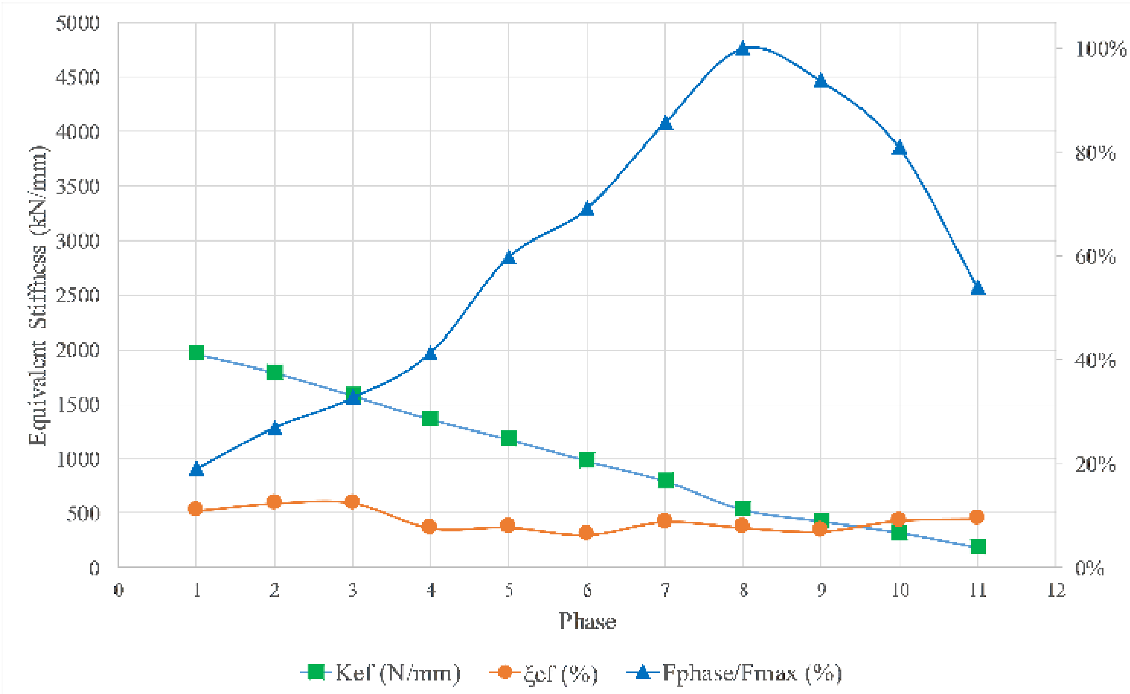

Figure 4.7. Variation in equivalent stiffness and equivalent viscous damping ratio, nailed shear wall.

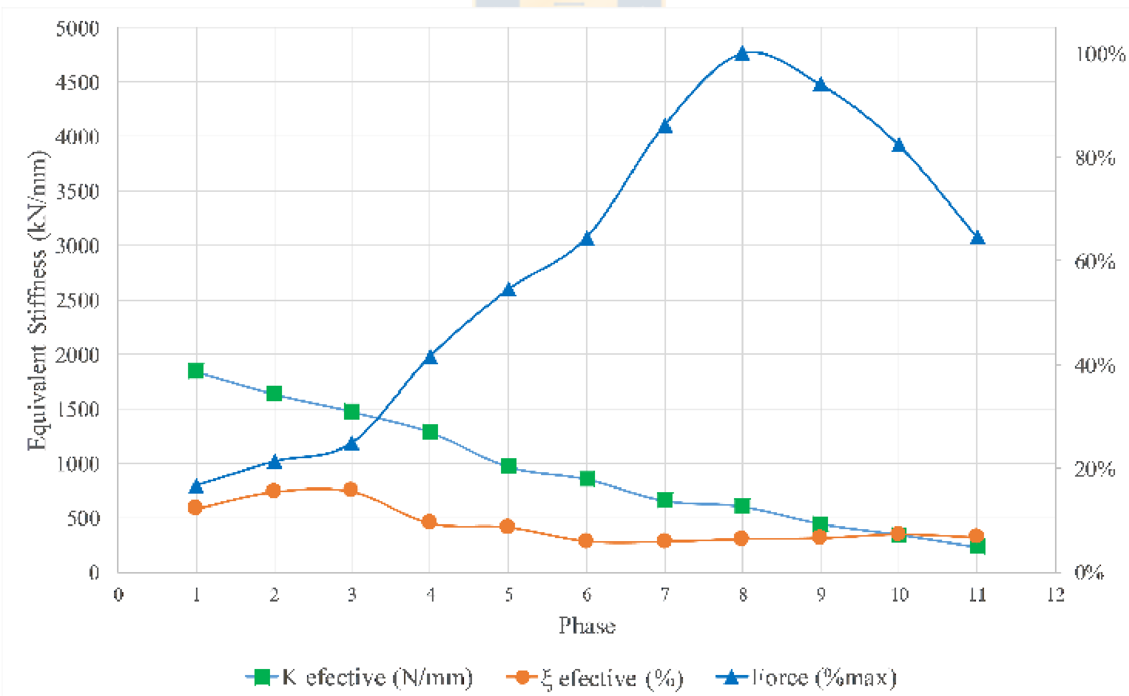

Figure 4.8. Variation in equivalent stiffness and equivalent viscous damping ratio, stapled shear wall.

Table 4.1. ASTM E2126 parameters

	ASD		**LRFD**		**EEEP yield**		**Peak**		**Ultimate**[1]	
	Load	Disp.	Load	Disp.	Load	Disp.	Load	Disp.	Load	Disp.
SPECIMEN	kN	mm	kN	mm	kN	mm	kN	mm	kN	mm
ST1-2-S1[2]	6.2	5.0	8.6	7.1	27.3	22.7	30.9	36.7	24.7	49.3
ST1-2-S2	13.9	9.2	19.5	13.9	42.2	29.7	47.3	72.1	37.9	102.6
ST1-2-C1	11.0	6.0	15.4	9.7	39.3	25.8	45.2	49.6	36.2	65.4
ST1-2-C2	14.4	7.1	20.2	11.0	44.9	24.5	50.5	53.2	40.4	80.2
ST1-2-C3	15.7	7.2	22.0	12.3	40.6	20.7	47.2	55.0	37.7	81.1
ST1-4-S1	6.9	6.8	9.7	9.5	24.6	24.2	27.7	56.6	22.2	74.0
ST1-4-C1	8.1	6.4	11.3	9.4	25.9	21.6	29.3	50.1	23.5	70.1
ST1-4-C2	10.0	7.6	14.0	12.7	25.8	21.2	29.2	53.4	23.4	84.1
ST1-4-C3	10.0	5.0	14.0	10.3	21.7	11.6	25.1	36.9	20.0	60.5
ST1-4-C4	7.2	4.7	10.1	7.8	21.4	16.5	25.3	41.3	20.3	52.6
N1-4-S1	11.7	8.1	16.4	13.4	26.9	19.2	30.4	56.9	24.3	93.1
N1-4-S2	7.3	10.9	10.2	15.2	25.9	38.6	29.1	95.3	23.3	122.1
N1-4-C1	9.5	6.4	13.4	10.4	23.9	17.1	27.0	54.5	21.6	70.6
N1-4-C2	11.5	6.9	16.1	12.1	25.3	15.2	28.7	55.4	22.9	79.6
N1-4-C3	9.2	7.3	12.9	11.1	24.3	20.1	27.8	55.2	22.2	80.4
ST1-6-S1	6.5	5.6	9.0	10.5	13.9	12.2	16.1	42.8	12.9	89.6
ST1-6-C1	7.1	4.7	10.0	9.0	15.8	10.4	17.8	37.1	14.2	70.8
ST1-6-C2	7.4	4.2	10.3	8.6	16.2	9.3	18.4	39.8	14.7	70.0
ST1-6-C3	6.7	4.8	9.3	9.3	14.4	10.3	16.6	40.4	13.3	63.7
N1-6-S1	7.6	9.9	10.6	16.9	17.8	23.4	20.5	74.9	16.4	111.9
N1-6-S2	8.1	9.7	11.3	15.3	18.3	22.4	21.0	76.4	16.8	109.5
N1-6-C1	8.0	7.9	11.2	13.3	17.4	17.1	20.2	53.5	16.1	87.5
N1-6-C2	5.6	6.4	7.8	9.2	18.1	22.0	20.3	56.0	16.2	70.1
N1-6-C3	8.5	5.5	12.0	9.9	18.7	12.6	21.3	55.9	17.1	81.5

[1] 0.8 post peak load.

[2] Premature separation of the chord, because hold-down screws penetrated only one of two studs in the chord.

Table 4.2. ASTM D7989 parameters

	Drift Capacity	**Overstrenght[1]**	**Ductility[1]**
	(Δ_U/h)	P_{PEAK}/P_{ASD}	Δ_U/Δ_{ASD}
SPECIMEN	≥0.028	$2.5 \leq P_{PEAK}/P_{ASD} \leq 5.0$	≥ 11
ST1-2-S1[2]	0.020	5.0	9.8
ST1-2-S2	0.042	3.4	11.2
ST1-2-C1	0.027	4.1	11.0
ST1-2-C2	0.033	3.5	11.3
ST1-2-C3	0.033	3.0	11.2
ST1-4-S1	0.030	4.0	11.0
ST1-4-C1	0.029	3.6	11.0
ST1-4-C2	0.034	2.9	11.0
ST1-4-C3	0.025	2.5	12.1
ST1-4-C4	0.022	3.5	11.1
N1-4-S1	0.038	2.6	11.5
N1-4-S2	0.050	4.0	11.2
N1-4-C1	0.029	2.8	11.0
N1-4-C2	0.033	2.5	11.6
N1-4-C3	0.033	3.0	11.0
ST1-6-S1	0.037	2.5	15.9
ST1-6-C1	0.029	2.5	15.1
ST1-6-C2	0.029	2.5	16.5
ST1-6-C3	0.026	2.5	13.4
N1-6-S1	0.046	2.7	11.3
N1-6-S2	0.045	2.6	11.3
N1-6-C1	0.036	2.5	11.0
N1-6-C2	0.029	3.6	11.0
N1-6-C3	0.033	2.5	14.8

[1] Unitless parameter.

[2] Premature separation of the chord, because hold-down screws penetrated only one of two studs in the chord.

4.3 Discussion

The results showed a similar performance in terms of initial stiffness, maximum deformation and maximum force for stapled and nailed light-frame shear walls, as the Figure 4.5 and the Figure 4.6 shown.

According the graphs showed in Figure 4.5 and Figure 4.6 and the results summarized in Table 4.1 and Table 4.2. The edge/end distance is one of the most important parameters to control during the construction of the wall because it influences directly the performance of the stapled shear walls. For the specimens with an edge/end fastener distance of 10-mm (3/8-in) the nailed shear walls have a higher performance in drift capacity and maximum load than the stapled shear walls. Into this group, for an edge fastener distance of 10-cm (4-in) the average drift capacity would be 36% higher in nailed over stapled shear walls and the average maximum load would be 10% higher in nailed over stapled shear walls. For an edge fastener distance of 15-cm (6-in) the average drift capacity would be 17% higher in nailed over the stapled shear walls and the average maximum load would be 17% higher in nailed over the stapled shear walls. This behavior can be explained by the performance of the sheathing fasteners, to reach a high values of ultimate displacement at 0.8 post peak force the failure mode is important.

For an edge/end distance of 19-mm (3/4-in) the stapled shear walls have the same average drift capacity performance than the nailed shear walls and the average maximum load capacity would be 5% higher in stapled over the nailed shear walls.

The proposed values by the ASTM D7989 standard (2018b) for drift capacity is satisfied for the stapled shear walls by a 12% over the minimum when the edge/end distance is 19-mm (3/4-in). Similarly, the nailed shear walls satisfy the minimum drift capacity by a 15% over the minimum value. Contrarily, the stapled shear walls with a 10-mm (3/8-in) edge/end distance the drift capacity is not satisfy and the average value is around 9% under the minimum.

According the ASTM D7989 standards (2018b) the over strength parameter range should be from 2.5 to 5.0, all the tested walls are over the minimum value proposed. For stapled shear walls with an edge/end distance of 19-mm (3/4-in) the average value is 3.4. For stapled shear walls with an edge/end distance of 10-mm (3/8-in) the average value is 2.75. Otherwise, the nailed shear walls have reached an average value of 2.8. Finally, the ductility parameter estimated according the ASTM D7989 standard [2018b] exceed the minimum expected for all the tested walls. The highest value has been reached for the 15-cm (6-in) edge fastener distance stapled shear walls with a 36% over the minimum value proposed. For all the other walls, the average ductility parameter would be between 5 to 10% over the minimum value.

The equivalent stiffness and the equivalent viscous damping ratio follows a clear tendency during the cyclic test, the specimens start with high values of equivalent stiffness and the parameter degrades after each cycle. On the other hand, the equivalent viscous damping remains relatively constant during the test. For both type of fasteners, nails and staples, the performance is really similar, as shown in Figure 4.7 and Figure 4.8.

The failure modes observed during the tests on walls with nails and staples is shown in Figure 4.9, a) and b) respectively. Three principal modes of failure were observed for the sheathing fasteners: 1) fastener withdrawal from the framing, 2) fastener head pull-through the sheathing, and 3) fastener tear-out through the sheathing edge. Often, the observed overall failure of the wall was a combination of the three modes described, which resulted in a loss in the shear resistance of the specimen. Splitting of framing (horizontal and vertical elements) was significantly more common when nails were used to attach the sheathing than when staples were used during the cyclic tests as the Figure 4.10 shows, especially when the edge distance of the fastener in the framing was small, at 10-cm. By the same side, the tear-out failure mode occurred when the panel edge distance was small.

a) b)

Figure 4.9. Failure modes, nailed (a) and stapled (b) shear walls.

Figure 4.10. No splitting framing in 2 in edge spacing stapled specimen.

4.4 Conclusion

The results obtained from the study were presented. It was possible compare the performance of nailed and stapled light-frame shear walls under monotonic and cyclic tests through the ASTM standards. The main results show the stapled shear walls over the minimum values proposed by the standards when the edge/end distance is 19 mm., also, the results show a really similar performance in terms of initial stiffness, maximum displacement and maximum peak load for both type of fasteners. Finally, it demonstrated which the failure mode of a nailed and stapled light-frame shear wall is a combination of three different failure modes and the edge/end distance of the connector is an important parameter for a correct racking performance of the shear wall.

CHAPTER 5 CONCLUSION

This research illustrates the results of different sheathing-to-framing connectors, nails and staples, under different load patterns, different edge/end distances and different edge spacing fastener. The experimental campaign presented in the thesis performed an 8 monotonic and 16 cyclic tests. The goal of the campaign was the comparison of the racking performance for stapled and nailed light-frame shear walls. According the standards, any cyclic test was performed three times at least, to validate the results of the research. The experimental results were presented in terms of load-displacement and average backbone curves, for monotonic and cyclic tests respectively. For the cyclic test the experimental data in terms of equivalent stiffness and equivalent damping ratio were presented.

The results shown a really similar racking performance for nailed and stapled light-frame shear walls, both reach similar values of maximum load, initial stiffness, equivalent stiffness and equivalent viscous damping ratio. Reaching a similar performance for stapled shear walls in average drift capacity and a higher average maximum load capacity of 5% over the nailed shear walls when the edge/end distance is 19-mm (3/4-in). Moreover, both type of fasteners was over the minimum ASTM standards values, presented in this work. The failure of the wall, for nails and staples, is a combination of different types of mechanism where the edge/end distance of the fastener is an important parameter to considerer during the construction of the specimen.

Finally, how the nailed and stapled shear light-frame shear walls have a really similar racking performance and they are over the minimum values of the standards, the principal highlight for stapled shear walls is the less splitting framing when the edge/end spacing fastener is 2-inch from the edge/end of the sheathing.

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