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Research Article

Simulation of Cold-Formed Steel Shear Wall Sheathed with Steel Plate: Non-Linear Finite Element Modelling and Analysis

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Keywords

Cold-formed steel,
Cold-formed steel shear wall,
Finite element analysis,
CFS,
Shear wall.

Abstract

The usage of cold-formed steel (CFS) is gaining popularity all around the world these days. Buildings made of such elements as an independent structural system are applied in the construction of small commercial complexes, low-raised buildings, industrial units, and single-story sports halls. CFS shear walls sheathed with steel sheets are the most popular lateral-load resisting system in low to mid-raised structures. In this paper, a full-scale steel seated CFS shear wall has been simulated by a non-linear finite element method. Furthermore, parametric studies have been carried out to analyze the effects of the blocking members, fastener spacing at steel plate to boundary frame connections, and steel sheet thickness on the behavior of CFS shear wall sheathed with steel plate. It was concluded that the blocking members prevent the studs from twisting and decrease the local bucking of the studs. Meanwhile, the results indicate that the thickness of the steel plate affects the shear strength of the CFS shear wall system to an extent. Besides, increasing the spacing of the fasteners at the connection of the steel plate to the frame system affects the buckling mode of the steel plate, and by increasing the spacing of the fasteners from 100 mm to 150 mm and 200 mm the nominal shear strength of the wall system decreased by 6.5% and 14.1% respectively, while decreasing the fastener spacing causes web distortion of the boundary column elements.

1. Introduction

Cold-formed steel (CFS) is recently gaining more popularity in the low-rise construction industry due to its high strength-to-weight ratio. CFS construction is among the preferred construction systems for schools, hospitals, and low-rise buildings. The light weight of the cold-formed steel is a beneficial factor in transporting and easy installation of the product. Meanwhile, the lightness, durability, rapid production, and easy installation of cold-formed steel make it a more economical material in low-to-mid-rise structures. Steel-sheathed, gypsum-sheathed, and wood-sheathed shear walls are the most prevalent lateral force-resisting systems in cold-formed steel constructions [1]. International Building Code (IBC) [2] and ASCE7-10 [3] approve the CFS shear walls as a lateral force-resisting system for low-rise residential and commercial buildings. CFS shear walls contain C-shaped studs as vertical members, U-shaped tracks as horizontal members, sheathing (steel or wood-based boards), and fasteners, which are typically self-drilling screws used to connect sheathing and frame members [4]. Among other types of CFS shear walls, the CFS shear wall with steel sheathing is an effective lateral force-resisting system in buildings. In this type of CFS shear walls, steel sheathing is used to provide higher shear resistance to the wall system. Serrette et al. (1997) [5] investigated steel-sheathed CFS shear walls for the first time at Santa Clara University using test specimens featured framing members that were 0.84 mm thick and shear walls that measured 610 mm by 2440 mm and 1220 mm by 2440 mm using 0.46 mm and 0.68 mm steel plates for sheathing. The study program was conducted as a follow-up to the findings of earlier testing on CFS shear walls encased with OSB, gypsum, and plywood that were completed in 1996. The design standards of the North American Standard for Cold-Formed Steel Framing, AISI S213 Standard (2004) [6] were limited to sheathing thicknesses of 0.46 mm and 0.68 mm at that time]. Later, Yu et al. (2007) [7] conducted some experimental studies on CFS shear walls with thicker sheathing and frame thicknesses. It was concluded that using thicker frame members will increase the shear strength of the CFS shear walls sheathed with steel plate. Furthermore, Ong-Tone (2009) [8] conducted some experiments investigating different thicknesses of the steel plate and boundary frames indicating that by increasing the thickness of steel plate and framing members the shear strength of the wall system increases. Cheng Yu (2010) [9] states that increasing the fasteners' spacing will cause the plate to frame screws to pull out and the sheathing to buckle, and decreasing the fasteners' spacing will conclude in the flange distortion of the boundary elements. Rizk (2018) [10] investigated the effect of blocking members stating that installing blocking members increased the shear resistance of the shear wall system. Santos (2018) [11] purposed a different type of CFS shear wall by placing the steel plate at the center of the wall to the middle of the boundary studs. The shear resistance of the shear wall with the steel sheathing at the middle of the chords was four times higher than the one-sided steel plate shear wall system.

In addition to the experimental studies, some analytical and numerical investigations are also conducted to investigate the behavior of these types of shear wall systems. Vieira and Schafer (2012) [12] in a numerical investigation of a sheathed CFS shear wall stated that the deformations of fasteners and sheathing affect the strength of the shear wall system under compression loadings. Ngo (2014) [13] and Ding (2015) [14] created models of shear walls, predicting the strength and failure states of the connections using ABAQUS. On the other hand, Bian et al. (2015) [15] created numerical models to validate the behavior of cold-formed steel shear walls using the finite element software OpenSees. The results showed that fastener-based modeling is an accurate modeling system for investigating the shear wall performance. The numerical modeling methods are divided into micro-modeling and macro-modeling categories. Macro-modeling concentrates on effective modeling that requires less work and computing time, while micro-modeling offers detailed analysis and more precise conclusions using FE approaches. Similar degrees of closeness can be attained with both strategies,

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according to a thorough examination of all the analysis techniques (Usefi et al., 2019) [16].

Most of the cold-formed shear wall characteristics are identified through experimental investigations. The generation of a finite element model is less costly and permits a thorough analysis of the CFS shear walls' behavior both functionally and empirically. In this study, a finite element model of a cold-formed steel shear wall is generated using the ABAQUS software package [17]. Furthermore, the effects of blocking members, sheet thickness, and screw spacing on the strength of the CFS shear wall are investigated.

2. Finite Element Modeling

Experimental, analytical, and numerical strategies are proposed to investigate the behavior of the CFS shear walls. The experimental method is employed frequently and is based on full-scale experiments performed on CFS shear wall systems. This strategy is the most expensive method due to the substantial number of tests that should be performed. On the other hand, finite element methods can be utilized to investigate the behavior of CFS shear walls, overcoming the drawbacks of the experimental methodology. Modeling the CFS shear wall is the first step in using a suitable non-linear finite element method to examine and research the behavior of the CFS shear walls. In this study, the FE models are created using ABAQUS/ Standard [17] software package.

2.1. Modeling details

For modeling the CFS shear wall, a homogeneous shell is used to create each component of the wall system. S4R shell elements are assigned from the element library of the ABAQUS software for each element. S4R is a four-node shell element having three degrees of freedom for rotation and three for translation at each node. Figure 1 shows the components and framing details of the CFS shear wall used for modeling in this study.

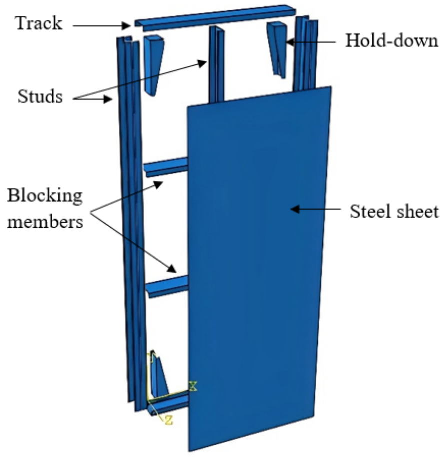


Figure 1. Components of the modeled CFS wall system

In a nonlinear analysis, the stress-strain curve of the material is generated considering the true stress and true plastic strain. Equations 1 and 2 are used to derive the true stress and true-strains curve of the material.

$$\sigma_{true} = \sigma(1+\varepsilon) \quad (1$$

$$\varepsilon_{true} = \ln(1+\varepsilon) - \frac{\sigma_{true}}{E} \quad (2$$

In these equations, σ, ε, and E are the engineering stress, engineering strain, and Young's modulus, respectively (Phama & Hancockb, 2010) [18]. The results of the coupon tests of the experimental specimen were used to obtain the true stress and true strain.

In this modeling, point-based fasteners are used to model the connections of back-to-back studs, stud-to-track, and steel sheet to the boundary frame. The sections of the connections are assigned as per the connection details of the experimental specimen. To prevent members from cutting through each other's surfaces a contact property was assigned to the surfaces of the model. For sliding friction, a penalty coefficient of 0.2 was selected in tangential behavior. In addition, hard-contact interaction was assigned in the normal behavior of the modeling system. Figure 2 shows the details of the finite element model.

2.2. Loading Protocol and Analysis

The loading is applied as a monotonic displacement control loading at the top portion of the shear wall system. To apply the loading, the upper track is tied to a reference point located at the center of the track. The static general analysis is used in this FE modeling, as the applied load in the experimental investigation is a low-speed loading protocol. Static analysis has the ability to solve both linear and nonlinear problems and takes into account the impact of large deformations. Meanwhile, the geometry non-linearity is also considered in the FE modeling.

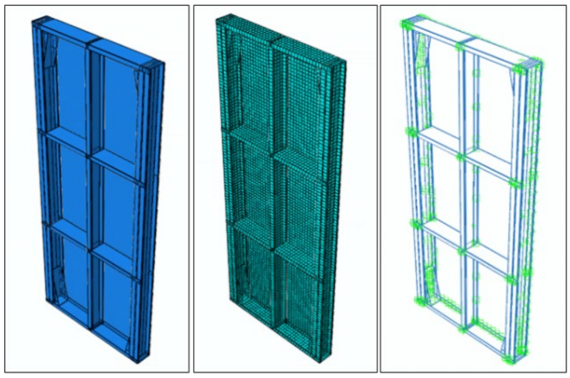


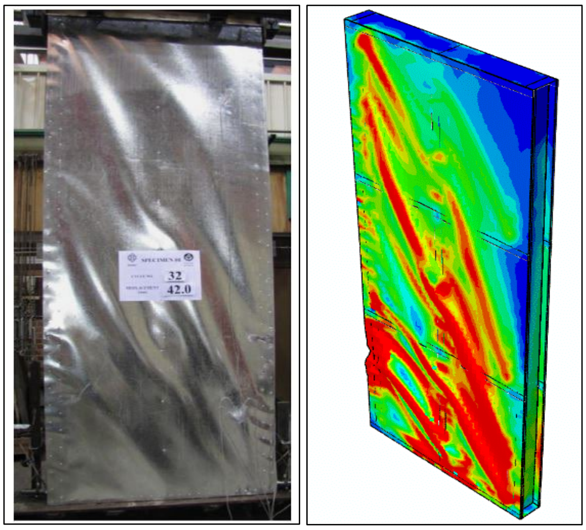
Figure 2. Details of FE Model

2.3. FE Model Validation

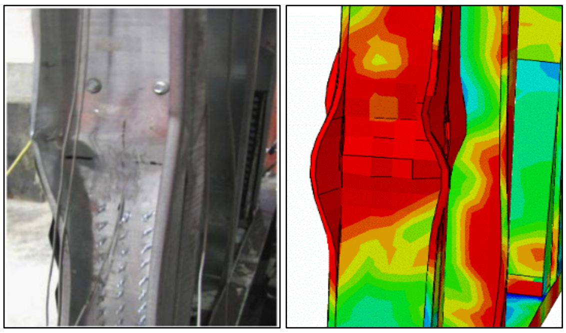
The numerical model is validated using experimental data from Mohebi's (2010) [19] testing of a CFS shear wall sheathed with a steel plate. The experimental specimen is a 1200 mm x 3000 mm shear wall system sheathed with 0.8 mm steel sheet. Studs' dimensions are 150 mm web and 50 mm flange, whereases tracks are made of 155 mm web and 40 mm flanges. The thicknesses of studs and tracks are 1.25 mm. The steel sheet is connected to the framing elements by No.10 self-taping pan head screws positioned at the edges of the steel sheet. Figure 4 shows the applied load vs. drift curve of the experimental and FE analysis of the specified CFS shear wall system. It can be seen that the results of the lateral load vs. drift ratio of the experimental specimen matched the results of the FE analysis. In addition, it can be seen in Figure 3 that the failure modes of the FE model and the failure modes of the experimental specimen are in good agreement. Due to the short distance between screws in the steel plate to frame connection, the steel plate buckles more in the lower part of the wall system. Meanwhile, decreasing the distance between screws in steel plate to the boundary frame connection, causes the local buckling of the column-stud, which is visible in both experimental and FE analysis.

3. Parametric Studies

The combination of several factors determines the strength of a cold-formed steel shear wall system. The strength of the steel plate, the spacing of the fastener in connection of the sheathing plate to the boundary frame, and the wall aspect ratio are among the factors that affect the strength of the cold-formed steel shear wall system. The effect of blocking members, steel sheet thickness and fastener spacing at the panel to boundary frame connection on the strength of the steel sheathed shear wall system are investigated in this paper. Table 1 shows the different wall configurations used in this study. Wall aspect ratio is 2.5 (3000 mm height and 1200 mm length) in all configurations.



(a) Steel Sheet Buckling



(b) Stud Buckling

Figure 3. Buckling response of the experimental specimen and FE model

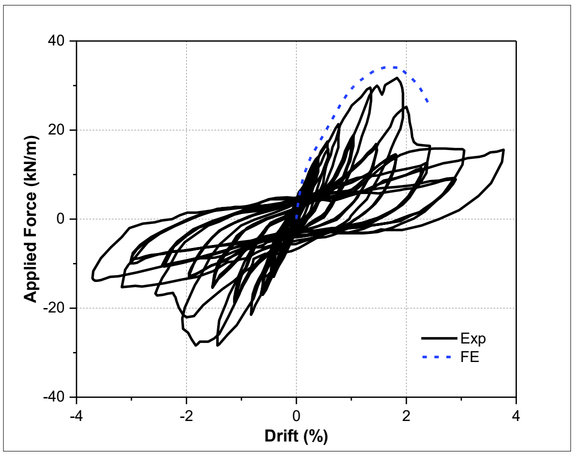


Figure 4. Applied force vs. drift of the experimental specimen and FE model

3.1. Blocking Members

The standard CFS shear walls are made of studs and tracks for framing, a panel for sheathing, and connection elements. The failure modes of the CFS shear walls sheathed with steel plate are generally caused by steel sheet buckling, studs local buckling, and screw pull out at steel plate to frame connections. To prevent the local buckling of the studs, DaBreo (2014) [20] suggested using blocking members to reinforce the frame of the wall system. In this section, two types of wall configurations are considered for analysis. One of the configurations is the same as the experimental specimen that was used for validation. In this configuration two blocking members with the same sections as the upper and lower tracks are used at 1m and 2m of the height of the wall for blocking the frame of the wall system. On the other hand, in the second configuration, the blocking members are not used to support the framing system of the wall. Figure 5 shows the applied force vs. drift ratio of the two wall configurations.

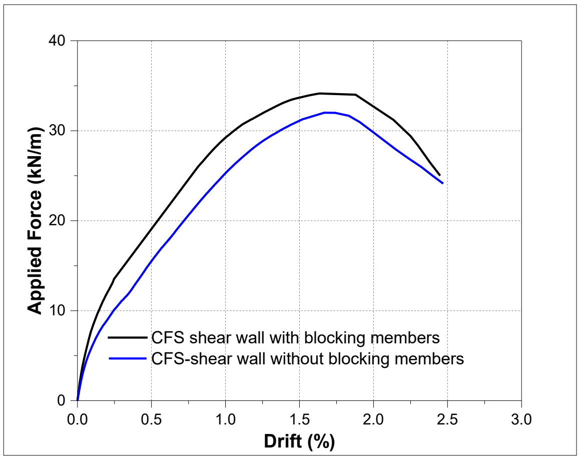


Figure 5. Applied force vs. drift of the blocked and unblocked CFS shear walls

It is seen that using the blocking members increases the shear resistance of the wall system. The blocking members act as bracing to the boundary studs, and using blocking members prevents the studs from twisting as the lengths of unbraced studs are decreased by these members. Meanwhile, blocking members prevented the local buckling of the studs to some extent.

3.2. Screw Spacing at steel plate to frame connection

Connections of steel sheathing plates to the boundary elements have a controlling role in the failure of the steel-sheathed CFS shear walls. The type of connections, the size of the connecting elements, and the spacing of fasteners are the important parameters affecting the failure modes of the shear wall system. In this section a CFS shear wall without blocking members is analyzed using 100 mm, 150 mm, and 200 mm single-line screw spacings. The effect of the applied force vs. drift ratio is shown in Figure 6.

It can be seen in Figure 6 and Figure 7 that the reduction of fastener spacing caused an increase in the shear strength of the wall system. By increasing the fastener spacing from 100 mm to 150 mm and 200 mm, the nominal shear strength of the wall system is decreased from 29.07 kN/m to 27.17 kN/m and 24.97 kN/m that is 6.5% and 14.1%, respectively. In addition, as it is shown in Figure 7, a linear relationship is observed between the screw spacing and the nominal strength of the wall system. Using this relationship, the nominal shear strength at different fastener spacing of the steel-sheathed CFS shear walls can be calculated. Yu (2010) [9] stated that by increasing the spacing of the fastener at the edges of the steel plate, the failure mode of the steel sheathed shear wall system will result from the steel panel buckling and screw pull-out, while, flange distortion at the lower part of the studs were not observed in case of increasing the fastener spacing. In FE analysis of the 200 mm screw spacing at the edges of the steel plate, the same failure mode is observed. Figure 8 shows the FE analysis result of the CFS shear wall with 200 mm screw spacing at the edges of the steel plate. It can be seen in Figure 8 that the buckling shape of the steel plate is changed, and there is not any flange distortion at the lower parts of the column studs that is caused due to increasing the spacing of the fasteners.

Table 1. Wall configurations for parametric studies

Configuration Code	Framing thickness	Steel sheet thickness	Screw spacing
CFSW-0.8-50-B*	1.25 mm	0.8 mm	50 mm staggered
CFSW-1-50	1.25 mm	1.0 mm	50 mm staggered
CFSW-0.8-50	1.25 mm	0.8 mm	50 mm staggered
CFSW-0.6-50	1.25 mm	0.6 mm	50 mm staggered
CFSW-0.8-100	1.25 mm	0.8 mm	100 mm single line
CFSW-0.8-150	1.25 mm	0.8 mm	150 mm single line
CFSW-0.8-200	1.25 mm	0.8 mm	200 mm single line

* All walls except the one used for the validation are modeled without the blocking members

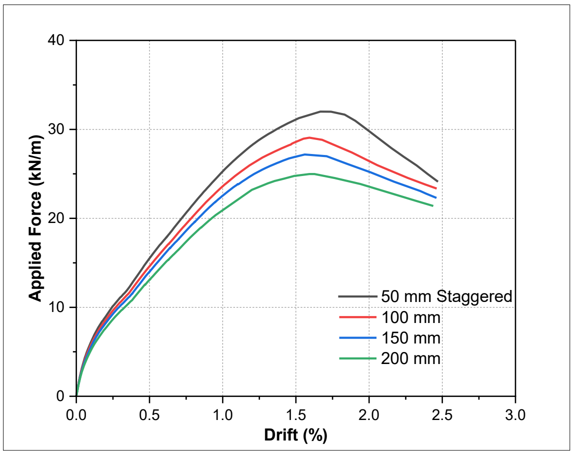


Figure 6. Applied force vs. drift of different fastener spacings

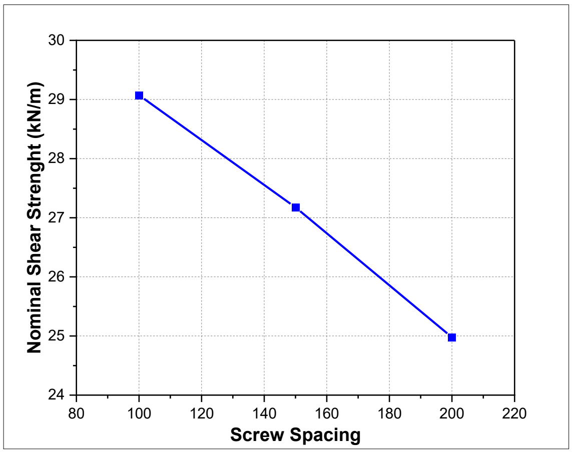


Figure 7. Nominal shear strength vs. screw spacing of the wall system

3.3. Steel plate thickness

In CFS shear walls sheathed with steel plate the steel plate is the main elopement in increasing the shear resistance of the wall system and according to studies the frame alone accounts for only 8% of the total strength of a CFS shear wall. Considering frame to plate thickness ration, in this section three different steel plate thicknesses are considered for the analysis. The steel plate thicknesses are 1 mm, 0.8 mm, and 0.6 mm. Figure 9 shows the results of the applied force vs. drift ratio of the different steel plate thicknesses. Results show that increasing the thickness of the steel plate causes an increase in the nominal strength of the shear wall. The effect of the plate thickness on the nominal-strength of the shear wall sheathed with steel plate is observable while using thinner steel sheets. Meanwhile, increasing the thickness of the plate is effective to an extent, after a limit increasing the thickness of the steel plates does not increase the strength of the shear wall significantly.

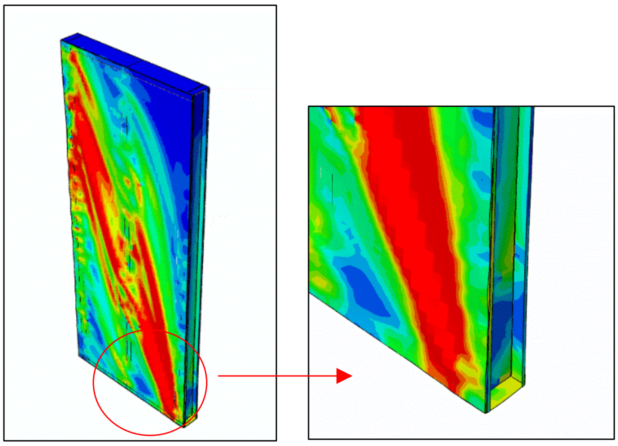


Figure 8. Buckling response at 200 mm screw spacing

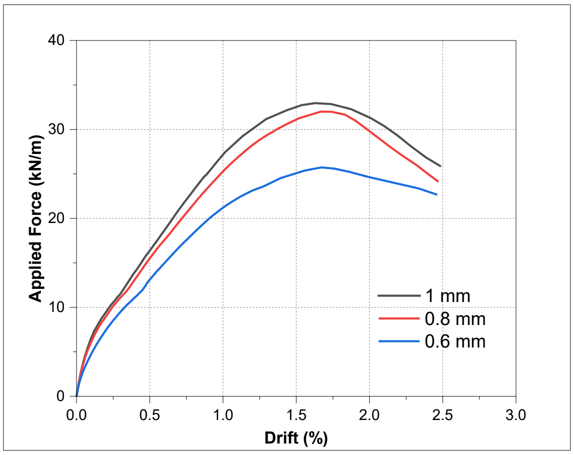


Figure 9. Applied force vs. drift of different steel plate thickness

4. Conclusion

A nonlinear finite element model is used to simulate the cold-formed shear wall sheathed with a steel plate. The results indicated that the FE model analysis and experimental analysis are in good agreement. In addition to the modeling of the shear wall system, the effect of blocking members, steel plate thickness, and screw spacing at the plate-to-frame connection is investigated. The following conclusions are obtained from this study:

- The bocking members are used to brace the frame system of the CFS shear walls and it is observed that adding these members to the wall system prevents the studs from twisting and causes an increase in the strength of the wall.
- The nominal shear strength of the wall system improves with steel plate thickness, but it is limited to an extent.
- By decreasing the steel plate thickness from 0.8 mm to 0.6 mm the nominal shear strength of the wall is decreased by 19.7% while increasing the steel plate thickness from 0.8 mm to 1 mm increased the nominal shear strength of the wall by 3%.
- Increasing the spacing of the fasteners in the steel plate to frame connections decreases the shear strength of the CFS shear wall.
- By increasing the spacing of screws from 100 mm to 150 mm and 200 mm the nominal shear strength of the wall system is decreased by 6.5% and 14.1%, respectively.

Increasing the spacing of screws at the steel plate to frame connection prevents the local buckling of the studs while causing screw-pullout failure.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1.] Brière, V. (2018). Higher capacity cold-formed steel sheathed and framed shear walls for mid-rise buildings: Part 2. McGill University (Canada).

[2.] IBC. International Building Code. Washington (DC): International Code Council; 2006.

[3.] ASCE/SEI 7. Minimum design loads for buildings and other structures. American Society of Civil Engineers, USA; 2010.

[4.] Nie, S., Zhou, T., Zhang, Y., Zhang, B., & Wang, S. (2020). Investigation on the design method of shear strength and lateral stiffness of the cold-formed steel shear wall. Mathematical Problems in Engineering, 2020.

[5.] Serrette, R., Encalada, J., Hall, G., Matchen, B., Nguyen, H., and Williams, A. (1997). Additional Shear Wall Values for Light Weight Steel Framing. Report No. LGSRG-1-97. Santa Clara, CA: Department of Civil Engineering, Santa Clara University.

[6.] AISI S213 (2004). North American Standard for Cold-Formed Steel Framing – Lateral Design. Washington, DC: AISI.

[7.] Yu, C., Vora, H., Dainard, T., Tucker, J., & Veetvkuri, P. (2007). Steel sheet sheathing options for CFS framed shear wall assemblies providing shear resistance. American Iron and Steel Institute (AISI) Specifications, Standards, Manuals and Research Reports (1946 - present). 111.

[8.] Ong-Tone, C., & Rogers, C. A. (2009). Tests and evaluation of cold-formed steel frame/steel sheathed shear walls. Project Report, Dept. of Civil Engineering and Applied Mechanics, McGill University, Montreal, QC, Canada

[9.] Yu, C. (2010). Shear resistance of cold-formed steel framed shear walls with 0.686 mm, 0.762 mm, and 0.838 mm steel sheet sheathing. Engineering Structures, 32(6), 1522-1529.

[10.] Rizk, R. (2018). Higher strength cold-formed steel framed/steel shear walls for mid-rise construction (Doctoral dissertation, McGill University (Canada)).

[11.] Santos, V. (2018). Higher capacity cold-formed steel sheathed and framed shear walls for mid-rise buildings: Part 1. McGill University (Canada).

[12.] Vieira Jr, L. C. M., & Schafer, B. W. (2012). Behavior and design of sheathed cold formed steel stud walls under compression. Journal of Structural Engineering, 139(5), 772-786.

[13.] Ngo, H. H. (2014). Numerical and experimental studies of wood sheathed cold-formed steel framed shear walls (Doctoral dissertation, Johns Hopkins University).

[14.] Ding, C. (2015). Monotonic and cyclic simulation of screw-fastened connections for cold-formed steel framing (Doctoral dissertation, Virginia Tech).

[15.] Bian, G., Padilla-Llano, D. A., Leng, J., Buonopane, S. G., Moen, C. D., & Schafer, B. W. (2015, July). OpenSees modeling of cold-formed steel framed wall system. In Proceedings of 8th International Conference on Behavior of Steel Structures in Seismic Areas.

[16.] Usefi, N., Sharafi, P., & Ronagh, H. (2019). Numerical models for lateral behaviour analysis of cold-formed steel framed walls: State of the art, evaluation and challenges. Thin-Walled Structures, 138, 252-285.

[17.] ABAQUS/standard version 6.14-2.

[18.] Pham, C. H., & Hancock, G. J. (2010). Numerical simulation of high strength cold-formed purlins in combined bending and shear. Journal of Constructional Steel Research, 66(10), 1205-1217.

[19.] Mohebbi, S., Mirghaderi, R., Farahbod, F., & Sabbagh, A. B. (2015). Experimental work on single and double-sided steel sheathed cold-formed steel shear walls for seismic actions. Thin-Walled Structures, 91, 50-62.

[20.] DaBreo, J., Balh, N., Ong-Tone, C., & Rogers, C. A. (2014). Steel sheathed cold-formed steel framed shear walls subjected to lateral and gravity loading. Thin-Walled Structures, 74, 232-245.

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