International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:10, No:12, 2016

Numerical Analysis of Cold-Formed Steel Shear Wall Panels Subjected to Cyclic Loading

H. Meddah, M. Berediaf-Bourahla, B. El-Djouzi, N. Bourahla

Abstract**—**Shear walls made of cold formed steel are used as lateral force resisting components in residential and low-rise commercial and industrial constructions. The seismic design analysis of such structures is often complex due to the slenderness of members and their instability prevalence. In this context, a simplified modeling technique across the panel is proposed by using the finite element method. The approach is based on idealizing the whole panel by a nonlinear shear link element which reflects its shear behavior connected to rigid body elements which transmit the forces to the end elements (studs) that resist the tension and the compression. The numerical model of the shear wall panel was subjected to cyclic loads in order to evaluate the seismic performance of the structure in terms of lateral displacement and energy dissipation capacity. In order to validate this model, the numerical results were compared with those from literature tests. This modeling technique is particularly useful for the design of cold formed steel structures where the shear forces in each panel and the axial forces in the studs can be obtained using spectrum analysis.

Keywords**—**Cold-formed steel, cyclic loading, modeling technique, nonlinear analysis, shear wall panel.

I. Introduction

COLD-formed steel elements are obtained by folding thin steel plates with suitable machines in ambient temperature to obtain an element in the desired form. The thin wall sections are characterized by local instabilities that occur more suddenly, and verifications are thus more severe and diverse than hot rolled steel elements. The analysis of cold-formed steel structures is also different because the structural system is composed of sub-assemblies such as shear wall panels, structural walls, and floor panels. Therefore, the finite element modeling of these structures is based on macro elements composed of several elements (studs, tracks, sheathing plates, and fixing screws). The aim of this work is to validate and implement a modeling technique that can analyze structures with cold formed steel shear wall panels using the finite element program-SAP2000-. Furthermore, the simplified calculation method, the equivalent properties of shear walls are also presented in order to be used by engineers in the analysis and design of cold-formed steel structures. The study was extended to post-elastic characteristics of the shear wall panels to simulate the shapes of the hysteresis loops resulting in cyclic loading.

H. Meddah is a junior researcher at the National Center of Applied Research on Earthquake Engineering (CGS) Hussein-Dey, Algiers, Algeria and Phd student at Blida university, Algeria (e-mail: meddah_hiba@hotmail.fr).

M. Berediaf-Bourahla and N. Bourahla are professors at the Civil Engineering Department, Blida University, Algeria (e-mail: m_bourahla2001@yahoo.fr, nbourahla@yahoo.com).

B. Eldjouzi is PhD student at Blida University (e-mail: brahim_eldjouzi@yahoo.fr).

II. Behavior of Cold Formed Steel Shear Wall Panels Under Horizontal Loadings

Currently, the design of the cold formed steel shear wall panels is essentially based on charts from results of experimental tests. In this concept, the floor acts as a rigid diaphragm in its plane, and transmits the horizontal force to the shear wall panel in his strong plane parallel to the force. The horizontal force is applied along the upper track and transferred to the sheathing which is joined to the studs by screws. The panel carries the horizontal loads to the foundations through the anchoring elements. An overturning moment is developed in the panel, which will be transferred to the coupled tension-compression effort in the end-stud. Fig. 1 illustrates the forces transmission principle.

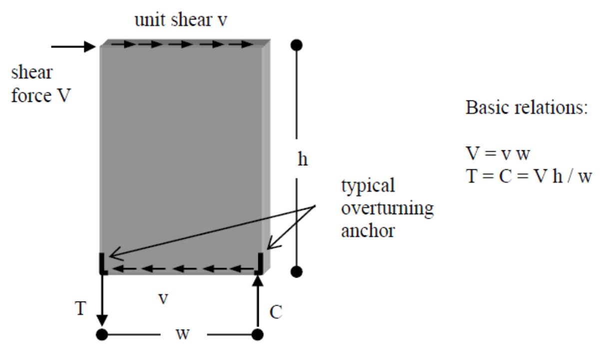


Fig. 1 Illustration of the transmission forces principle [1]

III. Modeling of the Shear Wall Panel

The cold formed steel shear wall panel is made of a frame (studs and tracks) and sheets (metal profiled or plan sheets, wood-based panels or gypsum-based panels). The sheathings are connected to the frame by screws. In this work, we propose a simplified modeling technique in order to simulate the response of the shear wall panel under cyclic load, which is easily integrated into a global model. This can be achieved by an acceptable evaluation of the initial rigidity and the elastic load bearing capacity of the wall. Post-elastic characteristics can be obtained from full-scale experimental results, which are available for different type of sheathing configurations. For this purpose, the panel is idealized by a nonlinear element “shear link” that reflects its behavior in shear, it is connected to the end studs by rigid diagonals which transmit the shear forces to the vertical members intended to take the axial forces that result (Fig. 2).

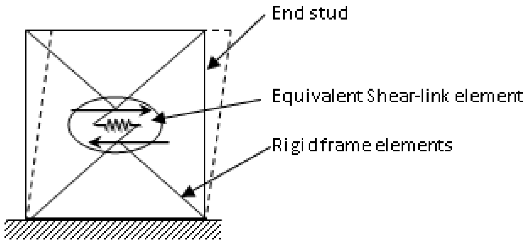


Fig. 2 Illustration of the shear wall model

IV. Multi-Linear Model for Shear Wall Force-Displacement Curve

The elastic rigidities of shear walls are determined by using either an empirical or analytical method. The former can be calculated per AISI standard for cold formed steel framing [2]:

$$K = \frac{R_n \times lengh_{wall}}{\Delta_{total}} \tag{1}$$

R_n is the nominal ultimate shear values to resist seismic forces. It depends on the type, the thickness of the panel and the fixing screws spacing. The nominal resistance can be obtained from the Table C2.1 of the AISI S213 (AISI 2007) [3].

Δ_{total} is the total deflection computed per AISI equation C2.1-2 (AISI 2007) [3].

The lateral strength and the associated displacement can be also evaluated using the analytical method proposed by Xu and Martinez [4], which takes into account a broad range of factors that affect the behavior and strength of SWP, namely: material property, thickness and geometry of sheathing and studs, spacing of studs, and construction details such as size and spacing of the sheathing-to-stud fasteners.

A multi-linear model is derived using the equivalent energy elastic plastic (EEEP) method [5] to match the post-elastic experimental curves of shear walls. Fig. 3 shows a typical model together with the elastic and post-elastic limits. R_u: Nominal shear strength; Δ_u: Ultimate displacement corresponding to R_u; $R_{0.4u}$: Displacement corresponding to 40% of the nominal strength R_u; $\Delta_{0.4u}$: Elastic displacement limit; $R_{0.8u}$: displacement corresponding to 80% of the nominal strength R_u;, $\Delta_{0.8u}$: displacement corresponding to 80% of the nominal strength R_u or a lateral displacement equal to 2.5% of the height of the wall; R_y: Displacement corresponding to 85% of the nominal strength R_u; Experimental results, such those published by Balh et al. [6] show that the displacement ratio α of the ultimate Δ_u to the elastic $\Delta_{0.4u}$ values vary from 3.28 to 2.51, with an average of 2.87. The ratio β of the failure displacement limit $\Delta_{0.8u}$ to the ultimate displacement Δ_u varies from 1.0 to 1.63 with an average value of 1.40.

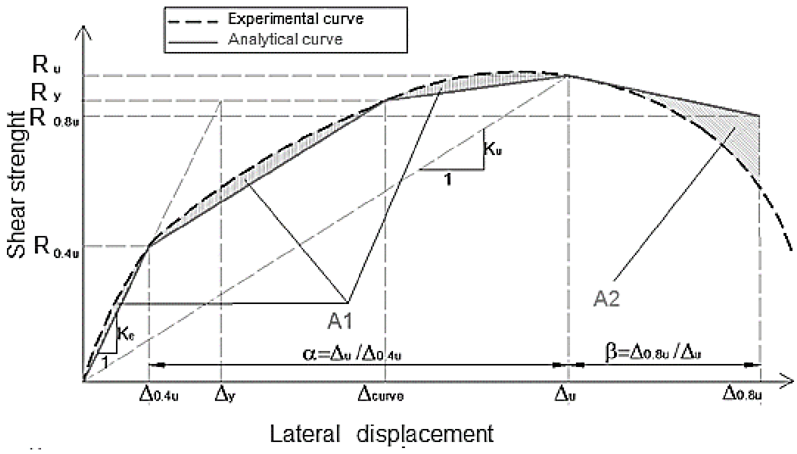


Fig. 3 Multi-linear model for shear wall force-displacement curve

V. Calibration of the Hysterisis Loop

A. Description of Specimens

For calibration purposes, several specimens from the literature were modeled using the shear link element and subjected to CUREE test protocol similar to the experimental loading. Table I summarizes all the studied specimens.

B. Modelisation

The multi-linear plastic-pivot hysteresis model of the FEA software package, SAP2000 (CSI 2004) was used to account for the nonlinear behavior of the cold formed steel panel. The hysteretic model incorporates stiffness degradation, strength deterioration, and non-symmetric response. Two rules are necessary to capture the hysteresis behavior of the shear hinge of a panel [9].

First, the parameters of the strength envelop are specified by using those defined above for the multi-linear curve.

Second, for each loading direction, two factors are specified:

- α, by which the yield strength in one direction is multiplied to define the position of the corresponding

International Journal of Architectural, Civil and Construction Sciences
ISSN: 2415-1734
Vol:10, No:12, 2016

primary pivot point.

- β, by which the yield strength in one direction is multiplied to define the position of the pinching pivot point.

TABLE I
SPECIMENS CHARACTERISTICS

specimen	Height (mm)	Wide (mm)	Sheathing description	Sheathing thikness (mm)	Screw spacing (mm)
1[a]	2440	1220	OSB[e]	11.1	76.2
2[b]	2440	2440	Steel plate	0.762	100
3[c]	2440	610	Steel plate	0.686	50
4[d]	2440	1220	CSP[f]	11.6	150

[a]Specimen 26A of Rogers et al. [7], [b]Specimen 11C-a of Balh [8], [c]Specimen 09C-a of Balh [8], [d]Specimen 08A of Branston [5], [e]OSB: Oriented Strand Board sheathing, [f]CSP Canadien Softwood Plywood sheathing.

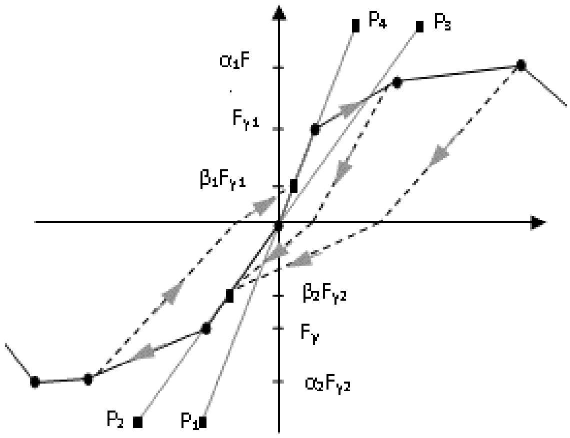


Fig. 4 Multi-linear plastic pivot hysteresis model principle [9]

C. Cyclic Load

For the purpose of comparing the modeling results with those of experimental tests, we use the same type of CUREE cyclic loading protocol used in these tests (Fig. 5).

The CUREE reversed cyclic protocol is based on a reference displacement, which is a function of the deformation recorded during a monotonic test. The monotonic deformation capacity (Δ_m) is defined as the wall top displacement observed when the post-peak wall resistance is reduced to 80% of the ultimate shear resistance (0.8 R_u). This 0.8 R_u resistance level is considered to be the failure point of the test wall, and that is the end of its useful load carrying capacity. The reference deformation, (Δ), is then obtained by multiplying (Δ_m) by γ, where γ is equal to 0.6.

The protocol contains three types of cycles, the first of which is called the initiation cycles. These cycles fall within the assumed linear range of behavior of the walls because they are of small amplitude. The second type of cycle is called the primary cycles. These are of higher amplitude than any other cycles preceding them, and hence, they enter into the non-linear range of behavior of the wall. The last type of cycle is called trailing cycles. They are equal to 75% of the amplitude of the preceding primary cycle [5].

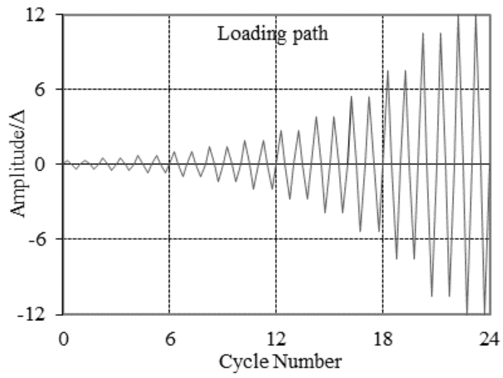
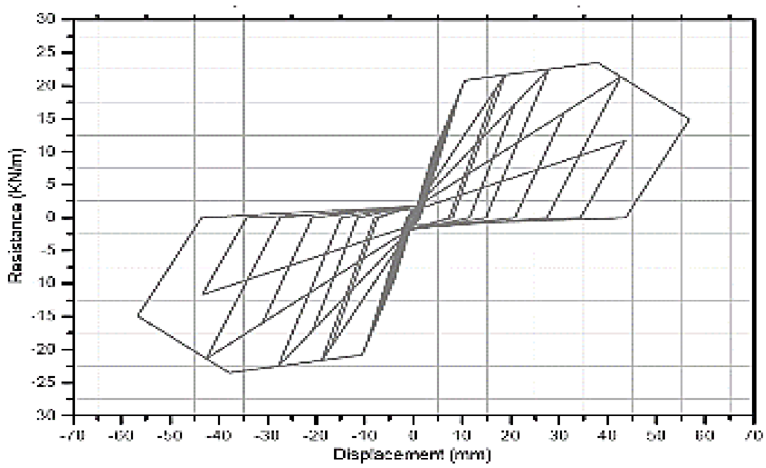


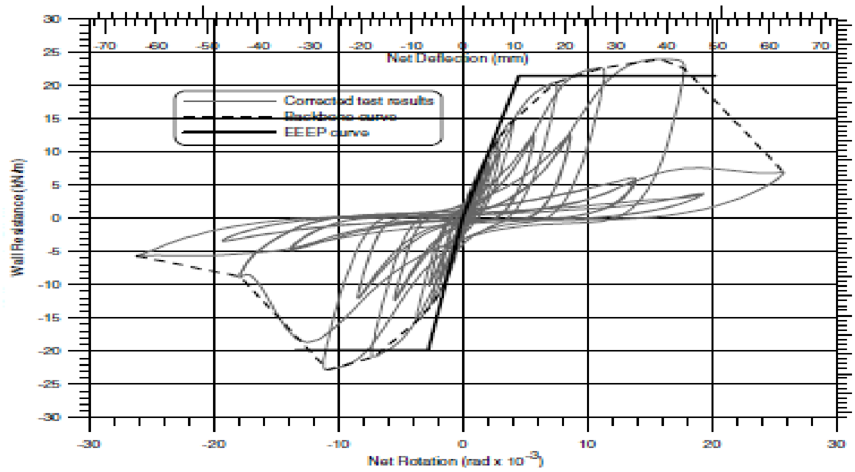
Fig. 5 CURRE reversed cyclic test protocol

D. Discussion of Results

A non-linear static analysis is performed for each of the above panels under cyclic loading of Fig. 5. The results are illustrated by Figs. 6-9.

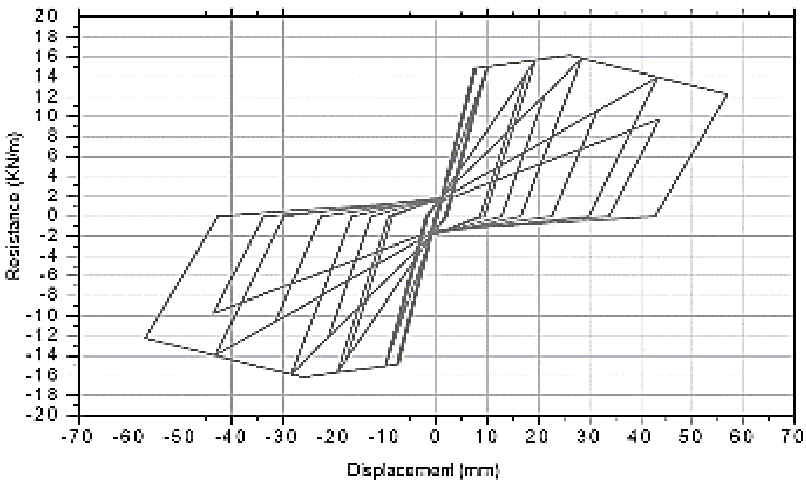


(a) Analytical result

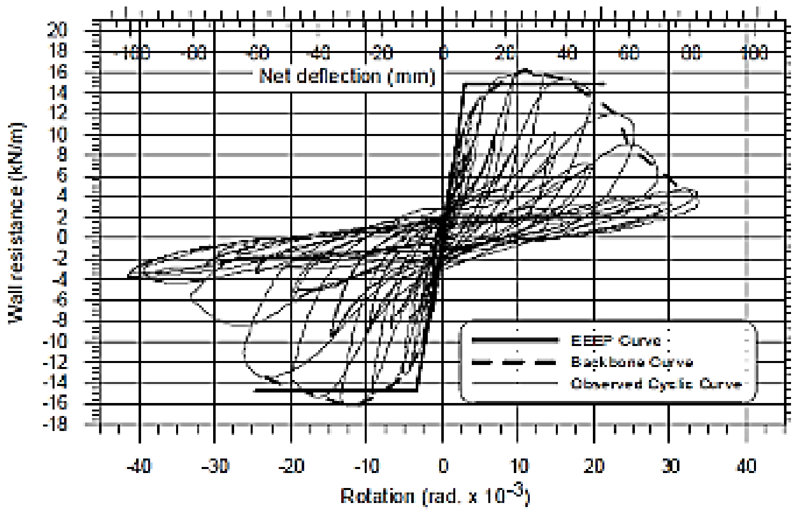


(b) Experimental result [7]

Fig. 6 Wall resistance vs. displacement curve for reversed cyclic loading-specimen 1

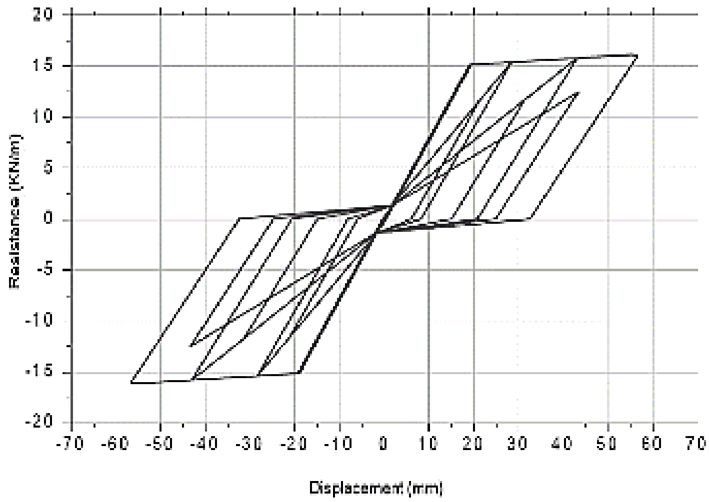


(a) Analytical result

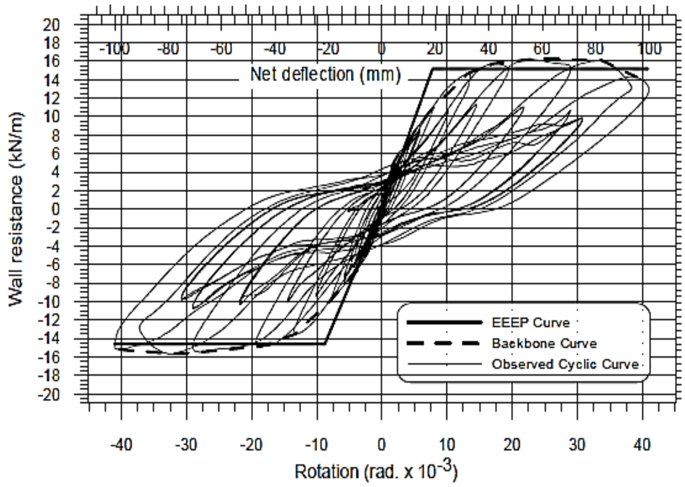


(b) Experimental result [8]

Fig. 7 Wall resistance vs. displacement curve for reversed cyclic loading-specimen 2

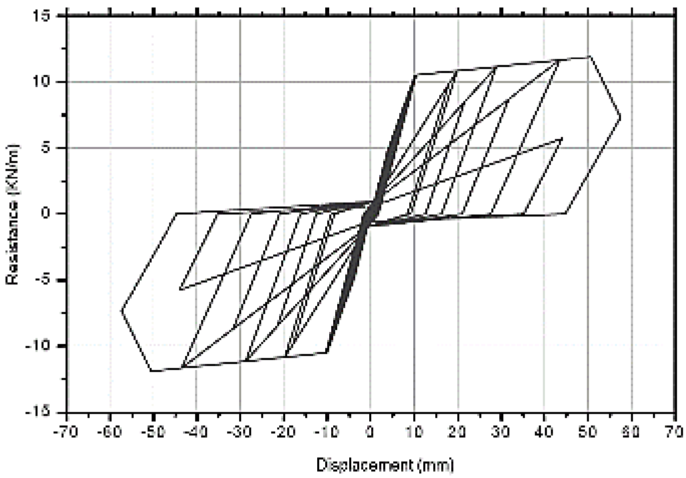


(a) Analytical result

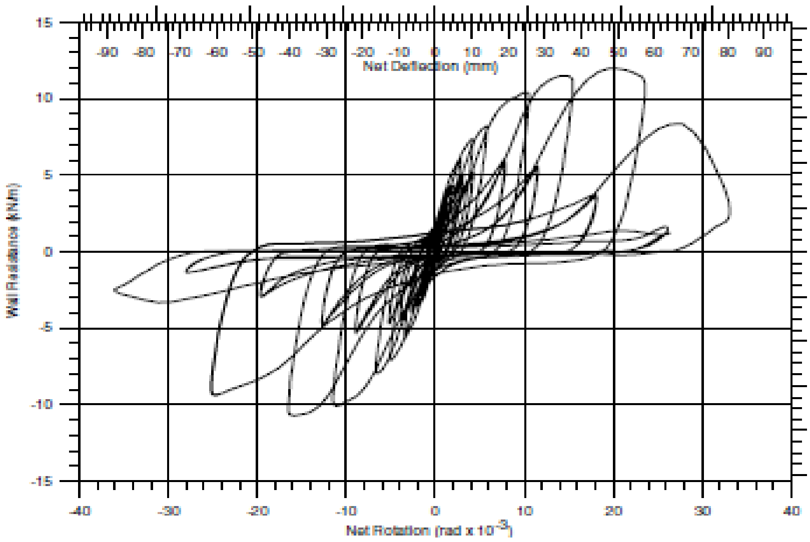


(b) Experimental result [8]

Fig. 8 Wall resistance vs. displacement curve for reversed cyclic loading-specimen 3



(a) Analytical result



(b) Experimental result [5]

Fig. 9 Wall resistance vs. displacement curve for reversed cyclic loading-specimen 4

Overall, the specimen panels simulation with a multi-linear plastic pivot model proposed in SAP2000 can reproduce a similar hysteresis behavior to that of the panels under cyclic loading. However, there is not a perfect agreement between the hysteresis curves of the model with those of experimental specimens, since the shear wall panel has a high non-linearity in the beginning of its loading with curvilinear forms. Moreover, in all the cases studied, the strength degradation is demonstrated when the shear wall panel exceeds its ultimate strength. The shape of the hysteresis curves is not enough stable and reflects a low ductile behavior of the panels due to the failure at the interface of connection and structural sheathing. The resistance curves also show that the shear wall panel achieved large deformations under moderate efforts.

VI. Conclusion

The behavior of cold-formed steel structures in seismic area is different from the hot rolled steel structures and they are characterized by local instabilities and local buckling modes. The structural analysis of the cold formed steel elements is also different because the model is not based on simple elements but subassemblies composed of several elements. In this context, a modeling technique has been proposed and evaluated through cyclic quasi-static analysis on different types of shear wall panels. The results showed the potential and the ability of this technique to simulate the post-yield overall behavior of shear wall panels. The model presented is based on the multi-linear plastic pivot hysteresis curve. This technique can be used by engineers, for the calculation of cold-formed steel structures and can enable them to perform non-linear static analysis both in the design stage or the seismic evaluation of existing structures.

References

[1] L. Fiorino, "Seismic Behavior of Sheathed Cold-Formed Steel Stud Shear Walls: An Experimental Investigation", Doctorate thesis, Napoli university,Italia, 2003.

[2] R. Serrette & K. Chau, "Estimating the Response of Cold-Formed Steel Frame Shear Walls", Research report RP 03-7, American Iron and Steel Institute, Washington, 2006.

[3] American Iron and Steel Institute S213-07, "North American Standard for cold formed steel framing – lateral design", Washington, (2007).

[4] L. Xu & J. Martinez, "Strength and Stiffness determination of shear wall panels in cold-formed steel framing", Thin-Walled Structures, vol. 44, pp.1084-1095, 2006.

[5] A.E. Branstan, "Development of a design methodology for steel frame/wood panel shear walls", Master's thesis, Department of Civil Engineering and Applied Mechanics, McGill University, Montréal, Québec, Canada, 2004.

[6] N. Balh, C. Ong-Tone, K. Velchev, C. Yu and C.A. Rogers "Development of Canadien seismic design provisions for steel sheathed CFS framed shear walls",Proceedings of the 9th U.S. National and 10th Canadian Conference on Earthquake Engineering, Toronto, Ontario, Canada, July 2010.

[7] C. Rogers, A.E. Branston, F. Boudreault & C. Chen, "Steel Frame/Wood panel shear walls: preliminary design information for use with the 2005 NBCC", Proceedings of the 13th world conference on earthquake engineering, Vancouver, B.C., Canada, pp.1999, August 2004.

[8] N. Balh, "Development of Seismic Design Provisions for Steel Sheathed Shear Walls", Master's thesis, Department of Civil Engineering and Applied Mechanics, McGill University, Montréal, Québec, Canada, 2010.

[9] Computers and Structures, Inc., SAP2000 Version 14.0., Database Documentations, Berkeley, California, USA. (2008).