Finite Elements Modeling and Analysis of Cold-Formed Steel Frame Shear Walls

Mahdi Bitarafan, Youssef Hussein- Zadeh, Farzad Pichkah, and Shahin Lale Arefi

***Abstract*—Cold-formed steel frames are light and affordable, they are fabricated and installed very fast; thus they are extensively used in industrial construction. They are reinforced with steel sheer walls to withstand against side forces. This paper is to study behavior of steel shear walls of cold formed steel. For this purpose finite element models are developed. Linear behavior and connection details of the frame analyzed under monotonic load and obtained results compared with empirical ones demonstrate adequate accuracy of finite element modeling. The study included longitude resistance of sheer wall, impacting factors on behavior of cold-formed steel frame shear walls, base sheer and demolition mechanisms of the frame.**

***Index Terms*—Cold formed steel, steel sheer wall, monotonic loading, finite element modeling.**

I. INTRODUCTION

Cold formed steel structures are used for the construction of industrial buildings construction. They are fabricated and installed very fast, they can tolerate higher loads compared with other structures which results in less steel use. Their implementation technique is highly flexible which another advantage so that they are built as wooden buildings, plant prefabricated panels, and modular [1]. These constructions are built very fast and their ever increasing development in north America, Europe , Australia and Japan is due to various flexible connecting components of the structure .fifteen thousand, Seventy five thousand, & three hundred and seventy five thousand of such constructions were built in 1993, 1996,and 2002 respectively[2]. Such structural systems are developed in Iran at present, in new Parand city and in the suburb of Mashhad as well as other regions the constructors use the mentioned technique to construct buildings. Both steel braces and sheer walls are components of such constructions. When steel braces are used To withstand against side forces , connected internal plates to the frame do not undergo any force or load and only studs1 , tracks 2 , cold formed steel and steel braces are under load and transfer the imposed load to the foundation.

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Implementation mood of sheer wall is named sheathing braced designe3; interaction effect of steel profiles with inside plates of the walls, namely sheathing4 is calculated to obtain resistance of these structures. crossed steel bars are used to reinforce roof, floor and wall plates for more resistance against imposed loads ,thus if the elements of reinforced plates could hardly resist enough with adequately connected profiles the system acts like a diaphragm and maintains its resistivity through contact[3].

Many researches have been done on shear walls. McCreless, S. & Tarpy, T. S. (1978)[4] performed 16 experimental investigations on steel stud shear wall diaphragms and plaster panels. Tarpy, T. S. & Girard, J. D. (1982)[5] investigated on shear resistance of steel-stud wall panels to formulate an standard for sheathing braced design where plates were made of different materials through various connection techniques . Serrette, R., Nguyen, H., Hall, G. (1996)[6] performed 24 experimental investigations on monotonic loads and six experiments on shear wall values for light weight steel framing where 3layer fiber board and chipboard were used under axial loads . Salenikovich, A. J., Dolan, J. D., Easterling, W. S. (2000)[7] analyzed their obtained experimental results of racking performance of long steel-frame shear walls and Cold-formed Steel Structures with open and close sections under static and axial loads. Cheng Yu, et al [8] studied Shear resistance of cold-formed steel framed shear walls with 0.686 mm, 0.762mm, and 0.838 mm steel sheet sheathing, Engineering Structures, 2010, where effect of steel sheer plates, gap between connecting bolts of the plates and frame were analyzed under static and axial loads. As pointed out, experimental systems have mostly been used to identify behaviors of such structures under static and dynamic loads. This is an innovative investigation analysis of cold formed sheer wall modeling through finite element software. Development of finite element model costs low and both functionally and empirically facilitates full behavior study of the elements and structure, consequently, development of cold formed frame finite element modeling is a necessity. ABAQUS software has been utilized to analyze light-weight finite element steel bracing and steel frame.

For this purpose, firstly modeling of cold formed finite element shear walls proposed by Cheng Yu, et al at Texas university is commented through using ABAQUS v6.10-1 software, then the verified and authentic model is used to study and interpret behaviors of cold formed frames with sheer walls under alternative and monotonic loads, hysteresis and demolition mode diagram, modified strengths of bolts and sheer wall are interpreted and commented in this paper.

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II. Finite Element Model

A. Numeral Specifications

Finite element model of this research is developed based on experimental investigations of Mr. Cheng Yu, et al [8] of Texas university, researches refers to the following processes: Type 350s150-в 2×, 8 ft wall was simulated, C cross section of the wall illustrates a wall with 1.5 in wide, 3.5 in height and 0.043 in thickness, 350T150-43beams are used, they are different from studs because they do not have edges. Median plate is 0.033 in thick; the gap between self-drilling screws that connect median plate with studs and beams is 6 in .To resist against uplift1 force a S/HD10S hold down 2 manufactured by Simpson Strong-Tie ,has been used (see, Fig. 1).

To produce all elements of sheer wall including stud profiles, beams, median plates of the frame and bottom reinforces, the software has viewed them as 3d dimension deformable extrusion shape shell structure. All elements are shown separately connected to view full structure of the sheered wall structure. Plane element has been used for cold formed finite element model because: cold formed steel profiles are very fine Shell structure is used rather than solid one with ABAQUS software to reduce analysis time and computer fault.

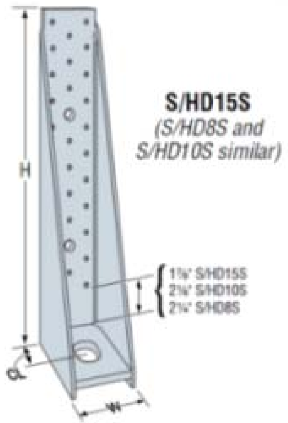

Fig. 1. S10s/HD hold down.

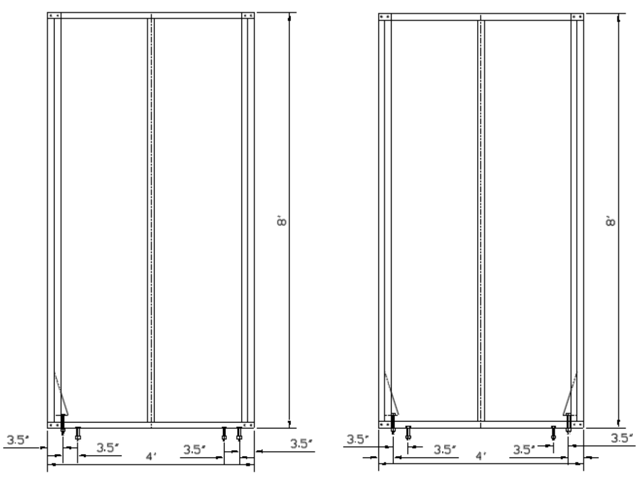

Fig. 2. Framing details for CFS shear walls for monotonic test.

B. Material Specifications

Implemented steel materials of sheer wall elements are assumed to be isotropic. Stress and strain behaviors of materials are analyzed based on finite element model. The relations are viewed as multi-linear graph.

But notice that repetitive independent stress and stain of the diagram facilitate more to get results. Therefore, less discontinuity is a measure to introduce stress and strain diagram. The thesis has shown bilinear curve of stress and tension, line views elasticity and the other views plasticity of the model.

Bended cold formed materials are more reinforced which is different depending on their profile or cross section. Specifications of materials of the software model are based on Coupon test conducted by Cheng Yu, et al, for more details, please see (Table I)

Notice that real stress and strains introduced to ABAQUS software but the obtained results are nominal, accordingly, we used Eq. 1 and Eq. 2 to convert nominal stress and strain to real.

TABLE I: Material Specifications [8].

Concerning element	Sheet metal	Studs	Beams
Thickness (in)	.033	0.043	0.043
Yield stress(Ksi)	43.4	47.6	43.1
Final resistance(Ksi)	53.8	55.1	55.6
Elongation	27%	29%	25%

$$\sigma_{true} = \sigma_{nom}\,(1 + \varepsilon_{nom}) \quad (1)$$

$$\varepsilon^{p1}_{1n} = 1n(1 + \varepsilon_{nom}) - \frac{6_{true}}{E} \quad (2)$$

C. Contact Qualities1

Definition of contact qualities is very complex for finite element modeling. Plate and main frame are contacted surface to surface and their direct impact may deform median plate of the frame. Accordingly interaction feature of the software has been used to create two types of contact to define tangential contact penalty method with 0.2% coefficient of friction is implemented but for normal contact hard method has been used to prevent sinking or interference of the model elements [9].

D. Modeling Procedure of Screw Connections

Self-drilling screws have been modeled as wire objects, sheer or pull out have been simulated to define behaviors of screw connections, when flawing or warning out force is imposed then finite element model of the screw worn too.

Experimental results have shown that pulled out screws have worn out frame of screw connections. Pulled out force of the screws is calculated by Eq. 3. For more particulars of different beams and studs as well as thicknesses of various middle plates of the frame see Table II

$$P_{not} = 0.85\ t_c d\ F_{u2} \quad (3)$$

t_c: Thickness of metal plate
d:diameter of screw

TABLE II: PULL OUT FORCE OF SCREW CONNECTIONS IN A COLD FORMED STEEL FRAME.

Concerning element	Concerning element	Sheet metal
Connected beam to stud	0.043	333.277
Connected studs	0.043	333.277
middle plate of the frame connected to beams	0.033	255.771
middle plate of the frame connected to the studs	0.033	255.771

E. Defining Mesh Size of the Models

The most important point for finite element modeling is to define mesh size. Meshes are modeled through tetrahedron software with specific seed part of every element of sheer wall and structured HEX with standard elements (3D stress) as well as Geometry order linear. Indeed, definition of seed part is based on convergence analysis of sporadic elements of light steel plate.

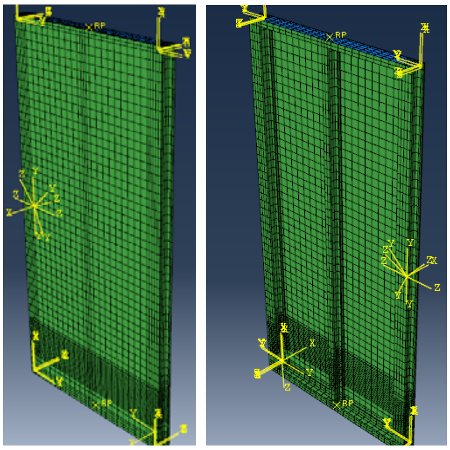

Fig. 3. A view of defiend mesh size model developed by ABAQUES software.

F. Boundary Conditions

Wall is put on a 16×7 w steel beam; it is bolted to the beam in four different points. Also, T shaped beam on the wall is fastened at 3in distance to the centerline with two self-drilling screws.

There are four defined point at the end of wall with 3 different freeness including UX, UY and UZ to be fastened, a solid headstock was used along y to prevent movement on the wall and eliminate the effect of imposed load.

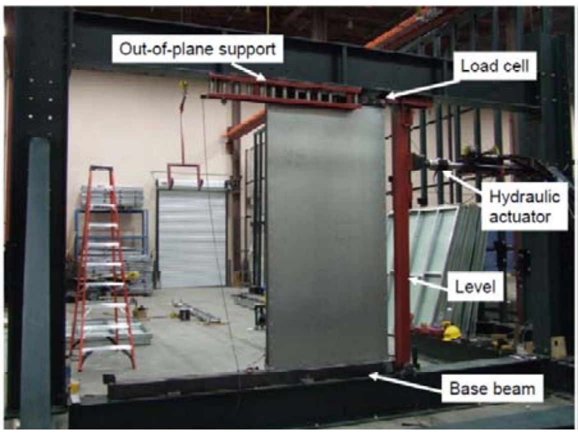

Fig. 4. A view of sample experimented in experimental [8].

To create adequate boundary conditions for some rollers, a solid headstock implemented at X direction by focusing on fastened T beam, MPC fasteners were used to fasten upper beam, freedom of the solid headstock was along y and z direction.

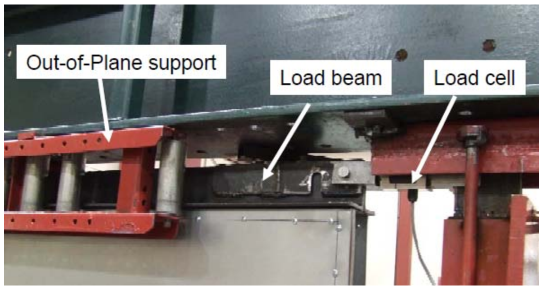

Fig. 5. A view of installed roller to prevent outward movement of the wall plate[8].

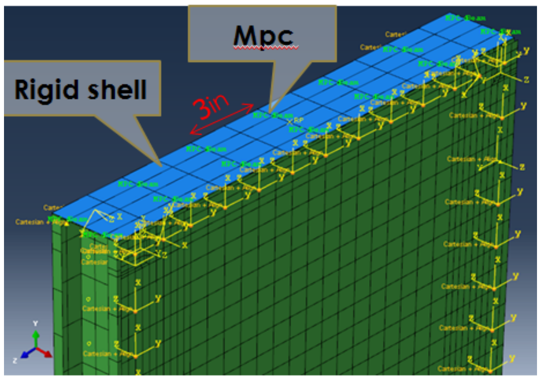

Fig. 6. Upper sheer wall of cold formed steel modeled boundary conditions.

G. Loading and Analyzing Process of the Model

Monotonic load is imposed on the steel frame as follows:

A 56 kip hydraulic jack with constant 0.229 in/s velocity is used to impose load on frame, Fig. 5 is to show how the jack is installed. Loading process is commenced when the upper part of steel frame is uniformly withstanding until frame of the sheer wall is demolished. I need to mention that the loading is imposed on the frame based on ASTM E564 standard. Firstly 1/10 of the anticipated final load is imposed on the frame for five minutes, then it is removed, then it becomes 3/3 , finally the frame is demolished.

Quasi static is used here for modeling boundary conditions through finite element software. Loading is here dynamic , firstly buckling modes were calculated to choose time of loading, then , we increased 10 times the obtained buckling time and chose it as loading time[9]. Finally quasi static behaviors of internal energy were compared with that of kinetic energy [9].

III. CONCLUSION AND DISCUSSION

Concerning Figs of stud sheer maximum displacement of the empirical model were analyzed and compared. For more details please refer to Table III, you see that error rates for stud sheer and displacement are 9% and 3% respectively, they are allowable.

TABLE III: COMPARED MAXIMUM FORCE AND DISPLACEMENT OF FINITE ELEMENT MODEL AND SAMPLE EXPERIMENTAL MODEL.

Experimental sample		Finite element sample	
Maximum stud sheer(plf)	Maximum displacement(in)	Maximum stud sheer(plf)	Maximum displacement(in)
1133.619	1.732498	11164.42	1.57645
Error rate			
Error rate of stud sheer(plf)		Error rate of displacement	
0.09		0.03	

Fig. 7 is modified picture of finite element model and empirical model. Buckling demolition is shown on middle plate of the frame, and screw at the end of right corner of the sheer wall both type of demolitions are comparable for both empirical and experimental model. Fig. 8 is showing how the screw connections of both experimental model and finite element model are put out at the right extremity of the wall.

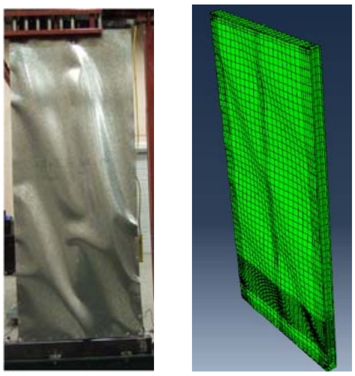

Fig. 7. Deformed shape of experimental model and finite element model are compared.

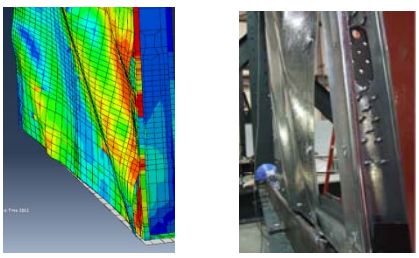

Fig. 8. Put out screw of finite element model and experimental model.

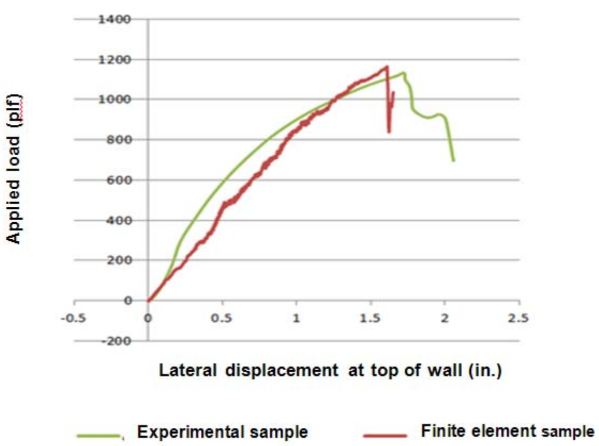

Fig. 9. Load vs. lateral displacement of wall top for monotonic test.

Yielded materials of the model are mainly due to buckling process of middle plate of the frame, fasteners and connected parts of the frame to the plate. Fig. 11 is to viewing output of finite element model bonded to end fastener. A precise review reveals that only part of fastened bottom beam is yielded due to solid headstock and bottom beam.

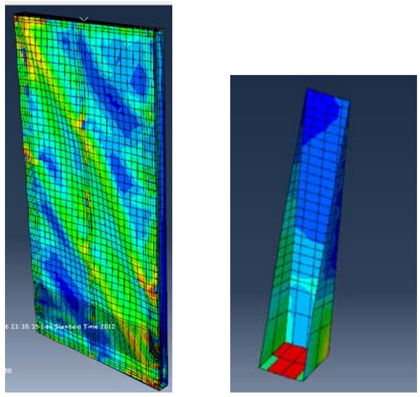

Fig. 10. Stress countor during uniform loading.

IV. CONCLUSION

For the first time self drilling screws are used here to model cold formed steel structure, as wire objects, displacement curve of both samples demonstrate similar experimental and analytical results, indeed solidity of software model was more than that of the experimental, a defect helped us to cognize taht the reduced solidity has facilitaed more its comparison with the experimental model. It is possible to modify linear distances of the fastened screws to middle plate of the frame, studs, and steel beams to possibly examine and analyze more behavior of the sheer wall and to propose a formula.

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