INVESTIGATION ON BEHAVIOR OF LSF PANELS WITH STEEL STRAP BRACING UNDER CYCLIC LOADING

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ABSTRACT: *The use of cold-formed steel as the main framing element in a structure is a popular construction method of low- to mid-rise buildings worldwide, including areas with high seismic hazard. In order to maintain the integrity of these structures subjected to earthquake horizontal forces, the use of diagonal flat steel strap cross bracing may be a practical solution. The straps act as a vertical concentric bracing system, which transfers the lateral forces from the floor levels to the foundation. The overall lateral strength, ductility and stiffness of this bracing system may not be related solely to the steel straps; many other elements in the lateral load carrying path can play a role, such as the strap connections, the gusset plates, the anchorage including hold-down and anchor rod, etc. The aim of this research is to experimentally and numerically evaluate the cyclic load response of steel braced LSF frames. Therefore the performance of cold-formed steel strap-braced frame is examined by experimental tests on 3 half-scale 1.5 m × 1.2 m specimens. Based on these experimental results, a numerical parameter study on different strap arrangements have been introduced, and their performance investigated by means of cyclic loading. Discussion on advantages and disadvantages of using gusset plates, bridging and anchoring is also presented.*

1 INTRIDUCTION

Structural sections processed from thin sheet steel by cold rolling, brake pressing or folding, which called cold-formed steel sections are extremely widespread in use at the present time. However, the growth in structural use and understanding of the behaviour of structures made in this way started during the Second World War.

The major structural advantage of cold-formed steel members lies with the 'thinness' of the material, which can be used, leading to an extremely light-weight construction. This combined with the improving technology of manufacture and corrosion protection which leads, in turn, to the trend towards using conventional steel structures.

Experimental research on LSF sections and frames are extensive to some extent. Gad *et al.*[1] accomplished experimental program in two stages: first, preliminary tests on two-dimensional unlined frames with different frame connection types and second, testing of a one-room-house at various stages of construction. Fülüp and Dubina [2] investigate the seismic performance of LSF shear walls with different configuration experimentally and numerically.

Al-Kharat and Rogers [3] examined the inelastic performance of sixteen 2.44 m × 2.44 m cold-formed steel strap braced walls experimentally.

Velchev *et al*. [4] tested 44 tension-only X-braced walls ranging in size from 610×2440 mm^2 to 2440×2440 mm2 (aspect ratios from 4:1 to 1:1). Their walls were designed and detailed following a capacity-based approach, and tested under lateral loading using monotonic and reversed cyclic protocols.

A numerical study based on finite element analyses is used to study the effects of some parameters on LSF frame behavior. FEAis increasingly used for research purposes since they show many advantages when compared with experimental studies. Valuable time and physical resources can be saved by using FEA instead of experiments.

2 RESEARCH PROGRAM

An experimental program was designed to provide basic information on the behaviour and failure modes of LSF walls braced with strap braces. Then a numerical study was accomplished to study the effects of various parameters on the vertical and lateral performance of LSF shear panels subjected to cyclic loads. In numerical part the following effects were studied.

- Strap angle
- Presence of vertical load and its magnitude on the lateral response,
- Strap thickness

3 EXPERIMENTAL PROGRAM

3.1 Specimen Description

The experimental program consisted of 3 half-scale specimens to evaluate the performance of strap-braced wall. Properties of prototype frame are shown in table 1 and Fig 1. Frame components, i.e. top and bottom tracks and studs, were identical C channels, asshown in Fig. 2, connected together by one rivet at each flange. For this section, and under axial loading, the half wavelength of local buckling is less than 50 mm, for distortional buckling is between 50 and 850 mm, and for overall (flexural-torsional) buckling is greater than 900 mm. Each back-to-back double section was constructed by connecting the web of two sections by screws at 150 mm centers. Bracing was implemented by means straps connected to both sides of the frame. A tension unit (tensioner device) was employed to prevent sagging of straps.

Table 1Prototype frame properties

Strap Size	75 mm x 1.5 mm
Interior Studs	3.5CS1.625T031
Back-To-Back-Chord Studs	3.5CS1.625T031

Track	3.5CU1.625T031
Frame Connections	number 8 self drilling screws
Anchor Rod & Shear Bolt	Bolt M16 8.8

3.2 ***Connections***

Straps were fixed to the wall panels by 18#10, self-tapping screws. Sufficient screws were used to avoid failure at the strap-to-wall connection (tearing of strap, or pull-out/pull-over of the screws) and allow yielding of the strap.

3.3 ***Material Properties***

The mechanical properties of the materials derived by tension test on two specimens based on ASTM A370a-07 and ASTM E111-04. These tests results are provided in Table 2.

3.4 ***Test setup***

Experiments were conducted using a displacement control regime, measuring the shear capacity of the wall at every load interval via a load cell. Each specimen was fixed to the base by means of a steel beam fixed to floor by welding and five M16 high-strength bolts in the vicinity of middle and chords to connect wall to beam. A similar arrangement was implemented to connect the top track to the loading beam. Moreover, to reduce the possibility of overturning and to provide a proper load path from the strap to the wall supports, four hold-down angles were placed near the top and bottom tracks.

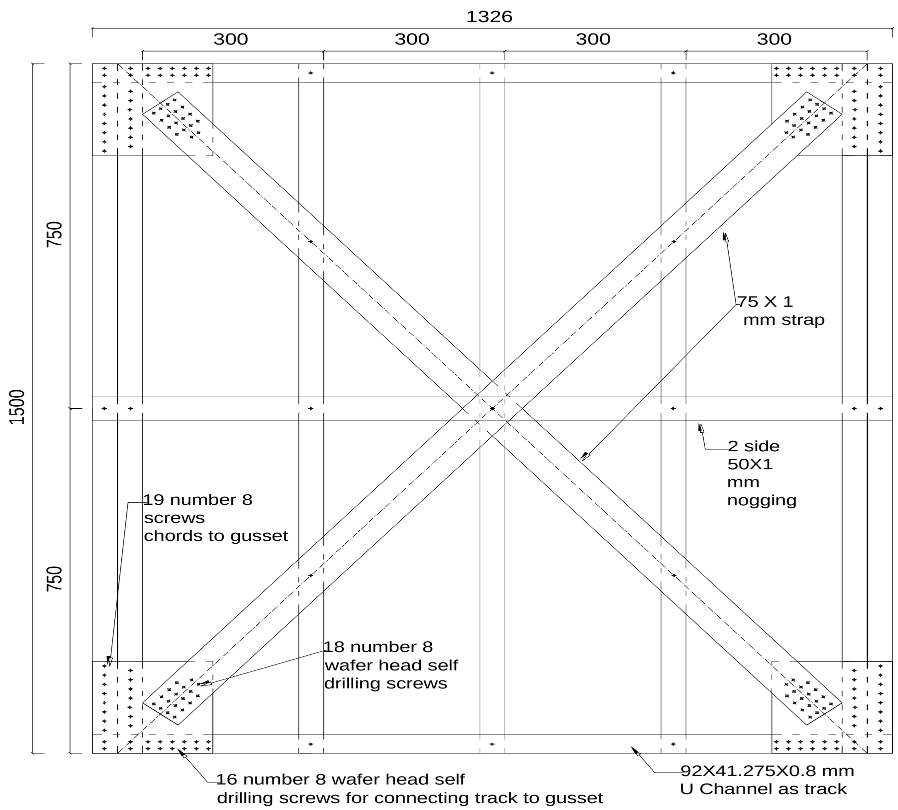

Figure 1. Prototype LSF braced frame

Table 2 Material properties derived from tension test

	#1	#2
0.2% proof stress MPa	336.8	330.4
F_{max} (UTS) MPa	416.3	415.3
strain at fracture	34.9%	39.1%
thickness	1.45	1.45
E-Modulus GPa	196	208.9

1 LVDT was used to measure the horizontal displacement of the top track and to measure the amount of imposed displacement and slip between the top track and the load beam. Two LVDTs were also installed at the bottom track to measure the amount of slip between the bottom track and the base beam and probable uplift on wall edges.

3.5 ***Loading***

Cyclic loading methodology followed Method B of ASTME2126-05 [5] standard, which was originally developed standard 16670.In the current study, the loading regime consisted of three full-cycles of 1.5, 3, 4.5, 6, 9, 12, 18, 24, 15, 30 and 45 mm (Fig. 2), unless failure or a significant decrease in the load resistance occurred earlier. The loading velocity was 3min/cycle which is in the range ofacceptable rates of displacement recommended by ASTME 2126-05[5].

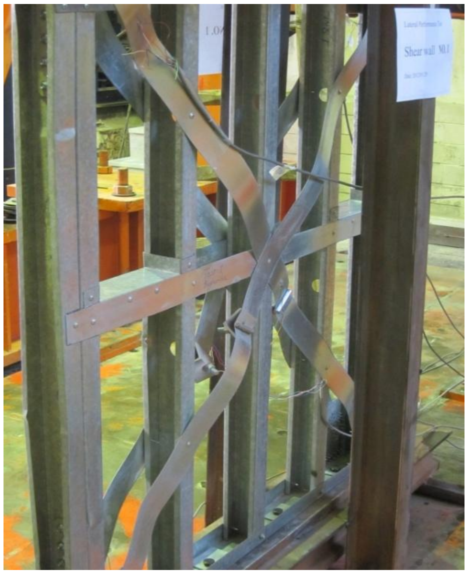

Figure 2. Loading protocol according to Method B of ASTM E2126-05 standard

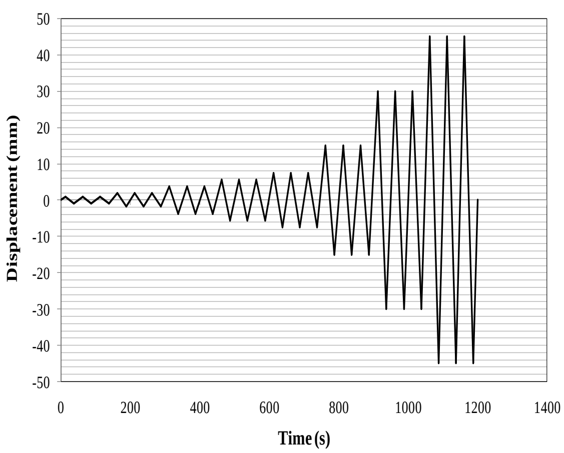

Figure 3. Buckling of straps and studs

EXPERIMENTAL RESULTS

All specimen exhibited linear behavior during the first nine cycles of testing. At the first half of Cycle 10, audible buckling sounds began and the magnitudeof the buckling waves became visible. The maximum base shear for frames was 29 kN which occurred at 10δy. Fig. 3 shows the buckling of the straps and end studs.

To achieve the final load bearing capacity of braced frame, one of cyclic tests continued until failure which occurred in 64 mm displacement (4.2% drift). Fractures developed at the straps in vicinity of tension unit. Also second frame continued to load monotonically (after cyclic test till 3% drift) to investigate the failure mode of failed frame. The failure of this frame initiated by local buckling of end studs which was buckled during cyclic test and overall instability of frame was occurred in displacement of 75 mm (5% drift).

The hysteresis for specimens is shown in Fig. 4. The overall behavior of frame was ductile and stable up to large drift levels, although significant pinching is apparent in the hysteretic loops.

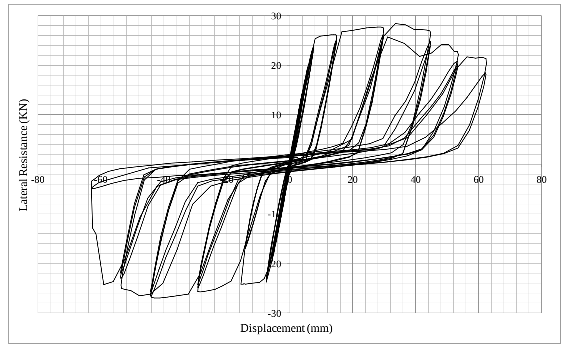

Figure 4. hysteresis behavior of LSF frame specimens

Table 3.Parametric study variables

parameters	description
strap angle	Two panel braced (68’)
	Three panel braced (59’)
	Four panel braced (51’)
	Five panel braced (45’)
Strap thickness	0.5 mm
	0.8 mm
	1.0 mm
	1.5 mm
Gravity load	Without gravity load
	10% stud capacity
	20% stud capacity
	30% stud capacity

3.6 *Finite Element Results*

This section presents the results of a series of finite element analyses undertaken to investigate the effects of some important parameters on behaviour of braced frame. Finite element analysis was employed for the full scaled model of a braced frame. Geometry of model including dimension and connections to base and actuator are proportionate to the experimental model. Also loading protocol and material properties are the same. To perform the analysis, a three-dimensional model was created and analyzed using the ABAQUS finite element program. Parameters studied in this research are summarized in table

Analysis results shows strength and stiffness areincreased by decreasing strap angle from 70 to 45.Stress distribution and summary of analysis results of various strap angles are summarized in table 4. Strength of frame with 5 panel bracing is twice the frame with two panel bracing. Also increase in frame stiffness for 5-panel bracing is about 400% in comparison to 2-panel bracing. Increase in frame strength from 2-panel bracing to 3-panel is 36%, from 3-panel to 4-panel is 24% and from 4-panel to 5-panel is 11%.Also, by increasing

Table 4.strap angle effect

	wall width (mm)	wall height (mm)	Aspect Ratio (h/w)	S_{max} (N)	Δ_{Smax} (mm)	$0.4S_{max}$ (N)	$0.4S_{max}$ (mm)	K_e (N/mm)	Unit shear capacity (KN/m)
5 panel bracing	3156.5	3000	0.95	106361	106.87	44305.4	7.16	6185.41	33.70
4 panel bracing	2556.5	3000	1.17	95612.3	138.75	35623.4	7.98	4466.26	37.40
3 panel bracing	1956.5	3000	1.53	77386.5	162.47	33299	12.69	2623.50	39.55
2 panel bracing	1356.5	3000	2.21	56792.2	126.643	21119.6	17.46	1209.83	41.87

Table 5.strap thickness effect

strap thickness	wall width (mm)	wall height (mm)	Aspect Ratio (h/w)	S_{max} (N)	Δ_{Smax} (mm)	$0.4S_{max}$ (N)	$0.4S_{max}$ (mm)	K_e (N/mm)	Unit shear capacity (KN/m)
1.5 mm thickness	2556.50	3000.00	1.17	95612.30	138.75	35623.40	7.98	4466.26	37.40
1 mm thickness	2556.50	3000.00	1.17	64599.90	106.12	23760.90	6.60	3601.76	25.27
0.8 mm thickness	2556.50	3000.00	1.17	52063.50	117.36	23354.20	7.15	3264.47	20.37
0.5 mm thickness	2556.50	3000.00	1.17	33819.80	166.98	12884.80	5.61	2297.21	13.23

3. strap inclination, axial load in end chords increase proportionally which can cause frame failure by chord local or overall buckling (based on stud configuration) prior to other failure modes. Also results indicate that strength and stiffness of frame increased by increasing strap thickness, as expected.

Behavior of frame investigated by neglecting and including axial load. Magnitude of axial load is considered 10%, 20% and 30% of stud's axial load bearing capacity according to AISI standard. Results shows stiffness and strength of frame not affected considerably by increasing gravitational loads (in analyzed domain) but post-peak behavior is influenced. Rate of strength reduction in post-peak region is increased by increasing gravity load level.

4 CONCLUSSION AND SUGGESTIONS

In this research, the behavior of strap braced frames studied experimentally and numerically. Experimental part consists of test on 3 strap braced LSF frames under cyclic loading and numerical part includes parametric study on effect of various parameters on cyclic behavior of braced frames e.g. strap angle, presence and magnitude of vertical load and strap thickness. Based on the experimental and numerical results, two types of failure (by assumption of avoiding any failure in strap to stud connection region) for wall specimens were bearing failure of straps (especiallyaround the drilling region for tension unit installation) and the buckling of studs. Also, The shear-resistance of braced walls is significant both in terms of rigidity and load bearing capacity, and can effectively resist lateral loads.The hysteretic behaviour is characterized by very significant pinching, and reduced energy dissipation.

5 REFERENCES

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