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Investigations on buckling behavior of intermittently fastened cold-formed steel built-up columns using spline finite strip method

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Abstract
In load-bearing cold-formed steel (CFS) framed wall systems, built-up columns are preferred over single CFS sections for their improved structural performance. In this study, a numerical formulation is presented to compute the elastic stability of isolated and compound wall studs, braced intermittently to the sheathing. These bracings can alter the buckling behavior of the compound columns altogether, especially in the distortional and global buckling modes. The present study is towards improving the design provisions of built-up columns presented in AISI-S100 (2016) which suggests adopting a modified global slenderness ratio. Although, this is intended to accommodate the loss of shear rigidity due to discrete fastener spacing, no guidance is provided to accommodate this effect on other buckling modes. In the literature, approximate methodologies have been reported, but comprehension of the composite behavior of built-up sections is still missing. In this paper, a numerical methodology using compound spline finite strip method is developed to compute the elastic buckling stress of built-up steel columns braced with and without sheathing. A compound model is generated by adding the stiffness matrix of fasteners into system global stiffness matrix where stiffness matrix of the fasteners is computed by adopting a three-dimensional beam model with adjustable geometrical properties and stiffness of wall system is added to the model with the help of translational and rotational springs. All the results are compared with FE based software ABAQUS and results are found to be in good agreement. A clarity is brought out in this paper between the effects of restraints provided by the presence of wall sheathing on the overall performance of built-up wall studs in comparison to the unsheathed ones.

1. Introduction

In the modern construction industry, load-bearing cold-formed steel (CFS) structural systems are gaining popularity due to their high strength to weight ratio and the ease of construction. In these structural systems, CFS members are assembled in specific frame configurations with discretely connected to the wall panels. The frame components will be subjected to high in-plane stress, and there will be demand of higher axial rigidity from the members. So, built-up CFS members are

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generally preferred in the frame system over the single CFS members as these sections have high axial and flexural rigidity. These built-up sections can be formed by connecting two or more single CFS sections with different orientations, depending upon the desired performance and required connection arrangements. These sections can be connected by use of self-tapping screws or bolts with or without spacers, and additional plates. For wall stud applications, built-up I sections are generally adopted, which are formed by connecting two CFS channel sections back-to-back in doubly symmetric shape which enhances the axial and flexural capacity of member. Since CFS sections are made of thin sheets, these sections under compression may undergo local, distortional or global buckling before yielding. For built-up sections, the presence of discrete fasteners can influence the formation of buckling modes and subsequently affect the critical buckling stress of these modes. In CFS wall frame systems, the presence of wall panels will provide additional out-of-plane restraints to these CFS members (single and built-up), which will influence the overall performance of these members.

In recent years, research work on built-up CFS members has increased, and for the design of such members, design standards (e.g. AISI-S100) are not comprehensive. AISI-S100 (2016) suggests to adopt a modified global slenderness ratio for computation of elastic minor axis buckling stress for built-up sections. Although this is intended to accommodate the loss of shear rigidity due to discrete fastener spacing, no guidance is provided to extend this effect on other buckling modes. Many researchers have presented different approaches towards assessing the stability behaviour of built-up CFS members through experimental and numerical studies, some of these studies are presented here. Experimental studies by Stone and LaBoube (2005) on back-to-back connected channel sections with discrete fasteners found that modified slenderness ratio will lead to conservative prediction of global buckling strength. In experimental study by Young and Chen (2008), built-up “box” section made of flange to flange connected web stiffened channel sections were used to evaluate the strength prediction using the Direct Strength method (DSM). The effect of modified slenderness ratio on strength prediction as given in AISI-S100 is studied by Whittle and Ramseyer (2009). In this experimental study, built-up closed sections formed by face to face welded lipped channel sections was adopted, and for these sections, conservative strength prediction was observed. Zhang and Young (2012) did series of tests on open I section formed by back to back connecting edge and web stiffened channel sections. Piyawat et al. (2013) did experimental and numerical study on I and box sections made by lipped channel sections sufficiently connected using weld and fasteners. Framatico et al. (2015) studied the composite action generated by screw fasteners on global buckling behaviour of built-up columns using semi-analytical screw fastener element. Series of compression tests on hollow flange built-up sections were performed by Kesawan et al. (2017) with different fastener spacing. Dar et al. (2018) studied the behaviour of built-up laced columns by series of tests. The built-up section was formed by four equal leg angle sections with different slenderness and width to thickness ratio. Roy et al. (2018) did study on cold-formed steel I section with varying thickness, spacing and screw spacing.

A numerical framework based upon classical finite strip method (FSM) is an established ideal framework for the analysis of thin-walled steel structures. CUFSM, an FSM based software developed by Ádány and Schafer (2006a), is used extensively for computation of buckling stress for single sections. Georgieva et al. (2012) using CUFSM, modelled the built-up sections with rigid constraints at fastener locations, to compute the elastic buckling stress and corresponding buckling modes. By extending application of CUFSM for critical buckling stress evaluation of built-up sections, Young and Chen (2008) and Zhang and Young (2012) developed different section models with node-constraints, and different thickness at junctions. Fratamico et al. (2015) developed a semi-analytical model for built-up members by incorporating stiffness of 2D fastener elements for computing of critical global buckling stress for CFS columns. These methods are approximate approach for computation of critical buckling stress of built-up CFS members. To accommodate the real behavior of stiffeners, a compound strip method was developed by Puckett (1991), which incorporates the stiffness of supporting element in global system stiffness matrix. In recent work, Abbasi et al. (2018) using compound finite strip method, developed framework which includes finite strip method approach for modelling the channel sections and compound strip approach to incorporate effect of fasteners.

Hence, there is need for a computational tool that can incorporate the effect of discrete fasteners and also, the effect of wall panel system on the behavior of CFS members. Experimental studies performed by Vieira et al. (2013) on sheathed wall panels under compression provide the spring stiffness model for wall stud members. In this study, the compound spline finite strip method (CSFSM) is developed to perform elastic buckling analysis for built-up CFS members with incorporating effect of wall panels using translation and rotational springs. This framework will incorporate the effect of discrete fasteners by compound methodology, and spline functions will help in incorporating the appropriate boundary condition and discontinuities in longitudinal direction.

2. Compound Spline Finite Strip Method (CSFSM)

For a thin-walled member, section discretization is formed by generating ‘n’ strips in transverse direction and ‘m’ sections along longitudinal direction. Each strip is divided in ‘m’ equal sections on each longitudinal edge, and additional section knots are defined at both ends of each node line for local amendment of splines at boundaries.

For a typical plate strip, generalized displacement field at mid surface in local coordinates **d** (x, y) is given by the displacement functions at its nodal lines. In this study, Hermitian interpolation functions for flexural displacements and Lagrangian interpolation functions for membrane displacements are adopted for transverse direction. For longitudinal direction, B3 cubic spline is adopted, which is defined over four sections, and is twice differential.
A generalized displacement field at mid surface is as follows,

$$\mathbf{d}\,(\mathrm{x},\,\mathrm{y}) = \{u,\, v,\, w\}^{\mathrm{T}} = [N_x]\,[\phi_y]\,\{\delta\} \tag{1}$$

where, $[N_x]$ is the matrix of transverse shape functions, $[\phi_y]$ is the matrix of spline functions in longitudinal direction and $\{\delta\} = \{\boldsymbol{u}_\mathbf{i},\, \boldsymbol{v}_\mathbf{i},\, \boldsymbol{w}_\mathbf{i},\; \boldsymbol{\theta}_\mathbf{i}\,,\, \boldsymbol{u}_\mathbf{j},\; \boldsymbol{v}_\mathbf{j},\; \boldsymbol{w}_\mathbf{j},\; \boldsymbol{\theta}_\mathbf{j}\}^{\mathrm{T}}$ is displacement vector of strip.

$$[N_x][\phi_y] = \begin{bmatrix} N_{ui}\boldsymbol{\phi}_{\boldsymbol{ui}} & 0 & 0 & 0 & N_{uj}\boldsymbol{\phi}_{\boldsymbol{uj}} & 0 & 0 & 0 \\ 0 & N_{vi}\boldsymbol{\phi}_{\boldsymbol{vi}} & 0 & 0 & 0 & N_{vj}\boldsymbol{\phi}_{\boldsymbol{vj}} & 0 & 0 \\ 0 & 0 & N_{wi}\boldsymbol{\phi}_{\boldsymbol{wi}} & N_{\theta i}\boldsymbol{\phi}_{\boldsymbol{\theta i}} & 0 & 0 & N_{wj}\boldsymbol{\phi}_{\boldsymbol{wj}} & N_{\theta j}\boldsymbol{\phi}_{\boldsymbol{\theta j}} \end{bmatrix} \tag{2}$$

in which,

$\boldsymbol{\phi} = \{\phi_{-1}, \phi_0, \ldots\; \phi_k, \ldots\; \phi_m,\; \phi_{m+1}\}$

$N_{ui} = N_{vi} = 1 - \left(\frac{x}{b}\right),$ $\qquad$ $N_{uj} = N_{vj} = \left(\frac{x}{b}\right)$

$N_{wi} = 1 - 3\left(\frac{x}{b}\right)^2 + 2\left(\frac{x}{b}\right)^3,$ $\qquad$ $N_{\theta i} = x\left(1 - 2\left(\frac{x}{b}\right) + \left(\frac{x}{b}\right)^2\right),$

$N_{wj} = 3\left(\frac{x}{b}\right)^2 - 2\left(\frac{x}{b}\right)^3,$ $\qquad$ $N_{\theta j} = x\left(\left(\frac{x}{b}\right)^2 - \left(\frac{x}{b}\right)\right),$

Fasteners are modelled as a three-dimensional beam element with two end nodes, b_i and b_j with six degrees of freedom per node (three translation and three rotation) as shown in Fig. (1). Symmetric stiffness matrix $[K_b^L]$ in local coordinate system of beam is given as,

$$[K_b^L] = \begin{bmatrix} [K_{ii}] & [K_{ij}] \\ [K_{ji}] & [K_{jj}] \end{bmatrix} \tag{3}$$

Displacement vector for beam $\{\delta_b^L\}$ in local coordinate system is given as,

$$\{\delta_b^L\} = \{u_b^i, v_b^i, w_b^i, \theta_{bx}^i, \theta_{by}^i, \theta_{bz}^i, u_b^j, v_b^j, w_b^j, \theta_{bx}^j, \theta_{by}^j, \theta_{bz}^j\}^{\mathrm{T}} \tag{4}$$

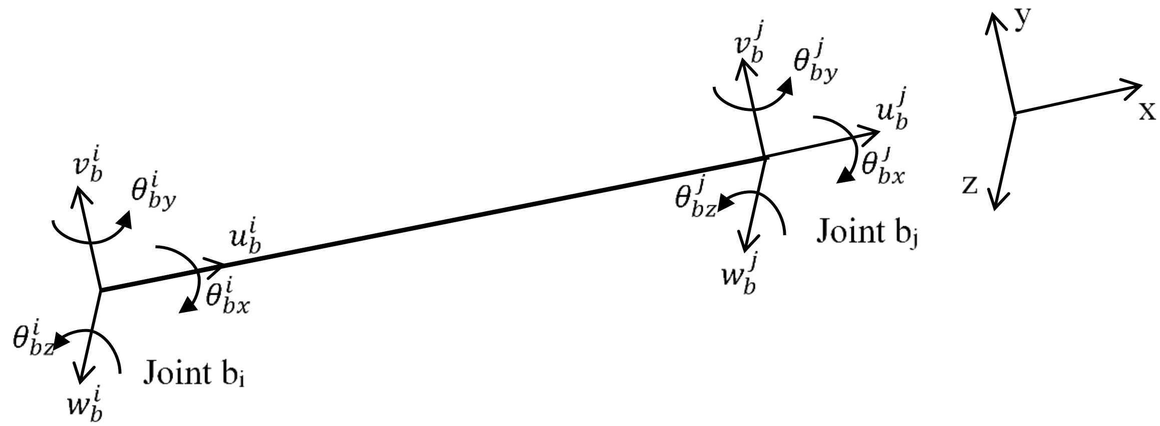

Figure 1: Three-dimensional beam element in local axis

$$[K_{ii}] = \begin{bmatrix} \frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\ 0 & 0 & \frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\ 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\ 0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\ 0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} \end{bmatrix}$$

$$[K_{ij}] = \begin{bmatrix} -\frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\ 0 & 0 & -\frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\ 0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 \\ 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\ 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} \end{bmatrix}$$

$$[K_{jj}] = \begin{bmatrix} \frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} \\ 0 & 0 & \frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\ 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\ 0 & 0 & \frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\ 0 & -\frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} \end{bmatrix}$$

The beam stiffness matrix is added to the global stiffness matrix by making appropriate transformation of axes and interpolating the beam displacement vector to the plate's displacement vector with the relationship given below.

$$\Pi_b = \frac{1}{2}\{\delta_b^G\}^T[K_b^G]\{\delta_b^G\} \tag{5}$$

$$\begin{Bmatrix} \{\delta_b^i\} \\ \{\delta_b^j\} \end{Bmatrix} = \begin{bmatrix} [Tr_{b_iq}] & \mathbf{0} \\ \mathbf{0} & [Tr_{b_jr}] \end{bmatrix} \begin{Bmatrix} \{\delta_q\} \\ \{\delta_r\} \end{Bmatrix} \tag{6}$$

$$[Tr_{ii}] = \begin{bmatrix} N_{ui}\boldsymbol{\phi}_{ui} & & & & N_{uj}\boldsymbol{\phi}_{uj} & & & \\ & N_{vi}\boldsymbol{\phi}_{vi} & & & & N_{vj}\boldsymbol{\phi}_{vj} & & \\ & & N_{wi}\boldsymbol{\phi}_{wi} & N_{\theta i}\boldsymbol{\phi}_{\theta i} & & & N_{wj}\boldsymbol{\phi}_{wj} & N_{\theta j}\boldsymbol{\phi}_{\theta j} \\ & & N_{wi}\boldsymbol{\phi}'_{wi} & N_{\theta i}\boldsymbol{\phi}'_{\theta i} & & & N_{wj}\boldsymbol{\phi}'_{wj} & N_{\theta j}\boldsymbol{\phi}'_{\theta j} \\ & & N'_{wi}\boldsymbol{\phi}_{wi} & N'_{\theta i}\boldsymbol{\phi}_{\theta i} & & & N'_{wj}\boldsymbol{\phi}_{wj} & N'_{\theta j}\boldsymbol{\phi}_{\theta j} \\ 0 & & & & 0 & & & \end{bmatrix} \tag{7}$$

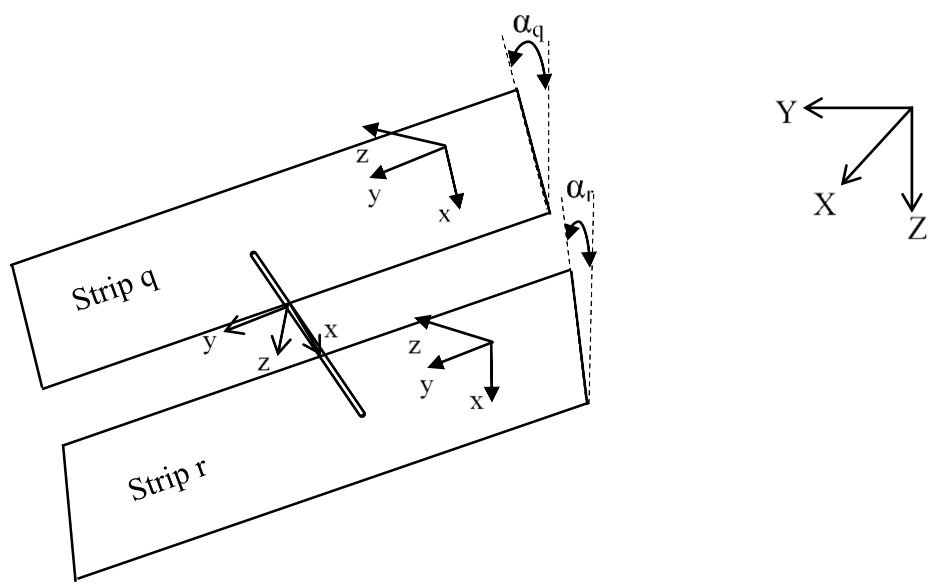

Figure 2: Compound plate strip in global axis

3. Numerical Study

In this study, to investigate the buckling behavior of built-up columns, different numerical models are developed. A constrained numerical model is formed such as an individual buckling mode can be captured and subsequently the effect of built-up formation and wall panels on these modes can be studied. To verify these constrained models, CUFSM (Ádány and Schafer (2006)) with constrained modes is used in this study. These constrained models are then extended to built-up sections after verifying these for single section. To further investigate the buckling behavior for wall panel systems using above discussed CSFSM, sheathed and unsheathed wall studs are studied. Numerical model generated by CSFSM is also compared with finite element software ABAQUS for sensitivity studies.

3.1 Constrained models

The constrained models are generated for the lipped channel section such as all three buckling modes i.e. Local, Distortional, and Global can be identified by their specific deformed configurations. The constraining model for allowing only local buckling is as shown in Fig. (4), where lateral and transverse displacements of the folded corner node lines are constrained such that only intermediate nodes can deform in out of plane direction. For distortional buckling, width to thickness ratio of individual element is selected such as critical local buckling stress will be higher than the critical distortional buckling stress, and for constraining the global buckling modes, folded corner node lines of web are constrained for lateral and transverse displacements, as shown in Fig. (4). For allowing only the global buckling mode, all folded corner node lines are constrained in transverse direction, and appropriate length of member and width to thickness ratio of elements are selected to avoid local buckling mode. A detailed discussion on these constrained models are given in Anil and Kalyanaraman (2017). For the verification of these constrained models, results from cFSM (Ádány and Schafer (2006a)) are used and presented in the Fig. (5) below. A lipped channel section (80x70x10x2) with yield stress of 500 MPa is used for the analysis. Section is selected such as its elastic local buckling stress is at least 1.5 times more than the other buckling modes. The selection of cross-section using this criterion is due to the limitation of the constraint models to restrain local buckling for computation of other buckling modes. The local buckling mode did appear in constrained distortional, and constrained global buckling modes in the initial length segment, but it did not influence the critical buckling stress values, as shown in Fig. (5). After verification of current constrained models, these models are extended for built-up sections in next section.

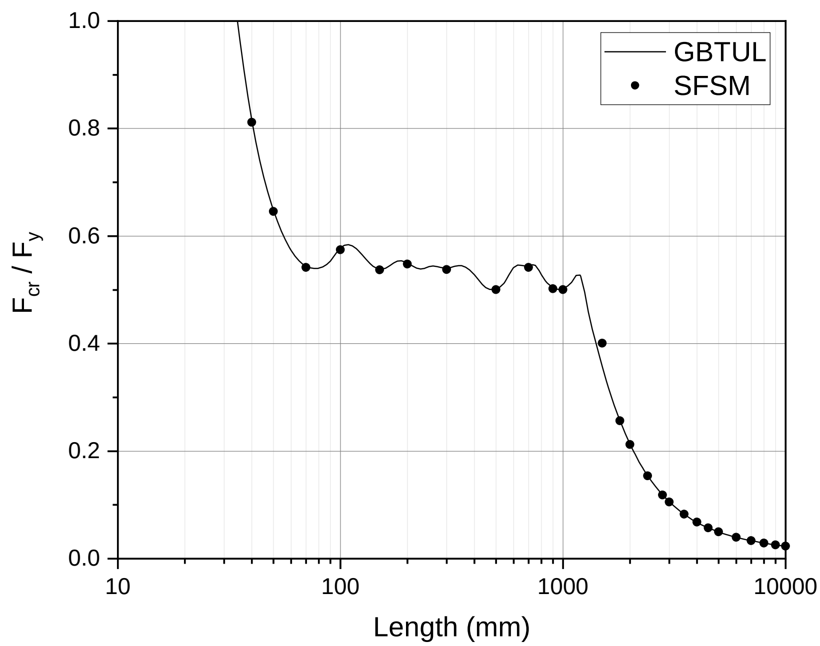

Figure 3: Verification of SFSM model output with GBTUL output for lipped channel section (80x70x10x2)

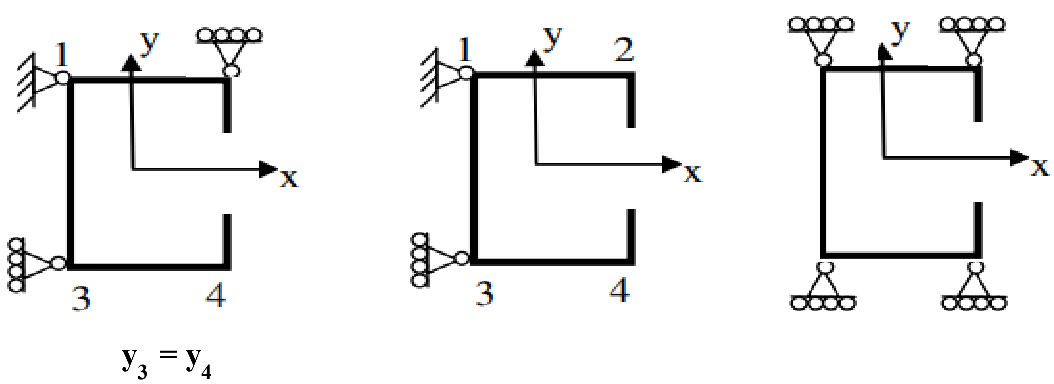

Figure 4: Constrained models for Local, Distortional, and Global buckling modes for lipped channel section

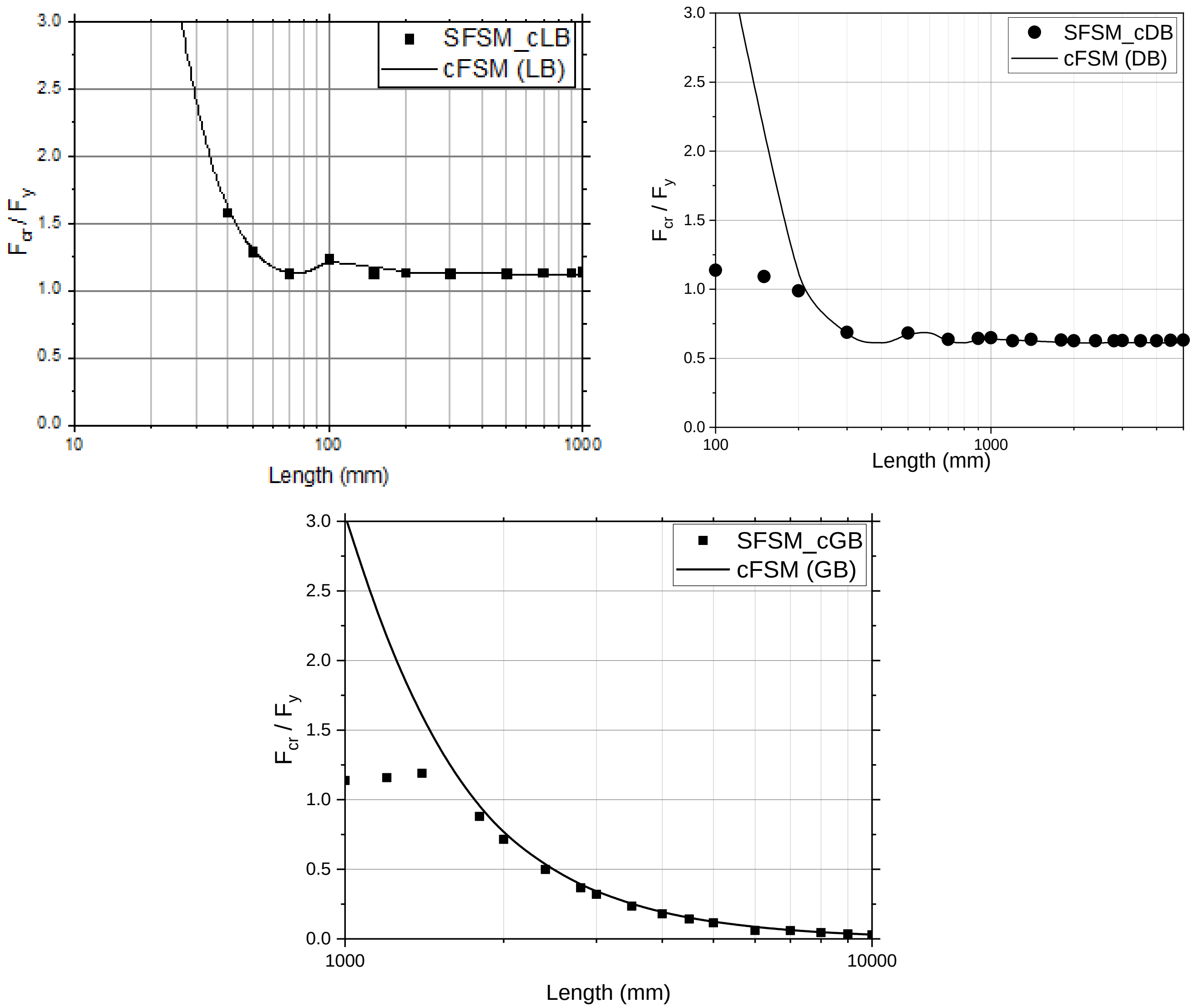

Figure 5: Verification of constrained models with cFSM for Local, Distortional, and Global buckling modes

3.2 Verification of CSFSM for built-up section

For verification of CSFSM for built-up sections, results obtained from ABAQUS are used. For a specific spacing of fasteners (s = Length / 3) and simply-supported boundary conditions with both ends warping free, and clamped-clamped boundary condition with both ends warping restrained are adopted for the validation. In ABAQUS, three-dimensional wire element (B3) is selected as fastener and shell edge load is applied to both ends with constraining longitudinal displacements at half length of the member (U3 @ L/2 = 0). At both ends, simply-supported boundary condition is formed by restraining U1, U2, and U6 displacements (U1 = U2 = U6 = 0), and fixed end is formed by keeping only U3 free with warping restraint condition at both ends. Results obtained from both CSFSM and ABAQUS are shown in Fig. (7) and Fig. (8) for built-up section formed by back to back connected lipped channel section given in Table 1.

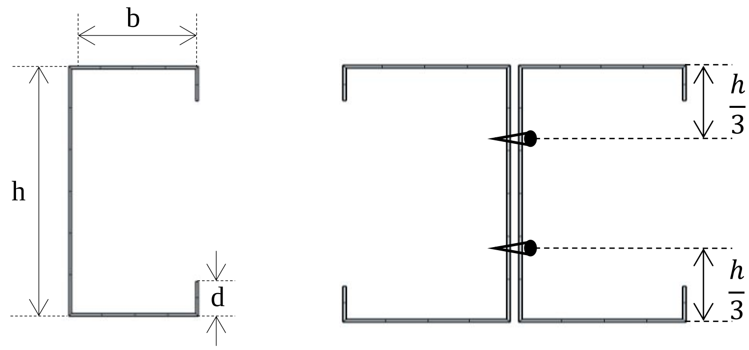

Figure 6: Lipped channel section and back-to-back connected built-up opens section

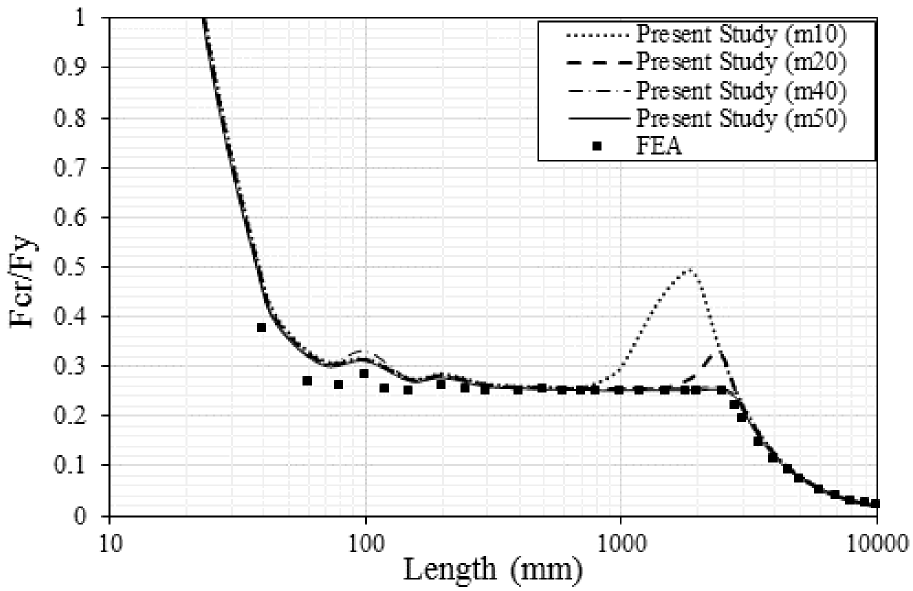

Figure 7: Verification of CSFSM (s = L/3) with ABAQUS for simply-supported boundary condition

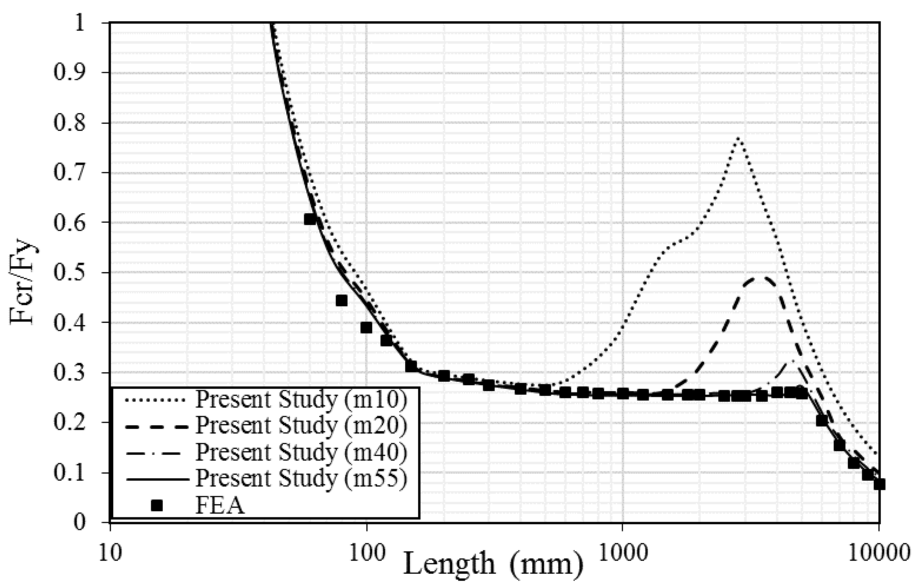

Figure 8: Verification of CSFSM (s = L/3) with ABAQUS for clamped-clamped boundary condition

Table 1: Geometrical and material properties of built-up section (back to back connected LC section)

Specimen	h (mm)	b (mm)	d (mm)	t (mm)	E (MPa)	F_y (MPa)	ν
Lipped channel	90	48	12	1.0	2.1×10^5	500	0.3

To model wall panel system, stiffness of wall panels will be added by help of translation and rotational springs (in Table 2) as suggested by Vieira et al. (2013) in the above mentioned CSFSM for built-up section.

Table 2: Wall panel stiffness for spring model as per Vieira et. al. (2013)

Spring	K_x (N/mm/mm)	K_y (N/mm/mm)	K_ϕ ((N-mm/rad)/mm)
Stiffness	3.185	0.3172	313

4. Investigation on stability behavior

4.1 For built-up section

The compound action generated by built-up formation can alter the buckling behavior compared to buckling behavior of single section. The presence of discrete fasteners will influence the deformation of CFS sections especially in global buckling mode. To comprehend the compound action on specific buckling modes, constrained models discussed above are adopted. For different fastener spacing (s = L/3 and L/5), critical buckling stress is compared with single section and composite section (by forming 2t thickness at joints). Results are also compared with modified slenderness ratio given in AISI-S100 for minor axis flexural buckling mode. Although AISI-S100 suggest the use of end fastener group (EFG) for built-up columns, but effect of EFG is not considered in this study for simplicity purpose.

Table 3: Geometrical and material properties of built-up section (back to back connected LC section)

Specimen	h (mm)	b (mm)	d (mm)	t (mm)	E (MPa)	F_y (MPa)	ν
Lipped channel	80	70	10	2.0	2.1×10^5	500	0.3

As discussed before, the CFS section is selected, such as the critical local buckling stress is at least 1.5 times the critical distortional and global buckling stress. All the results computed through these constrained models for built-up CFS section with different fastener spacing is presented in Table 4. From the results it can be observed that cross-sectional buckling modes (local and distortional) behavior do not get much affected by presence of discrete fastener in back-to-back connected I section. The minor axis buckling stress will increase with reduction in fastener spacing and after a specific fastener spacing (s = L/5 for this section), built-up section behaves similar to a fully composite section. All the results discussed are for simply-supported boundary condition only. To check the composite deformation behavior for built-up sections, tie constraints are applied between the both ends of beam element. These tie constraints are applied to the fastener's ends for both translation and rotational displacements. Only 5% maximum increment in critical buckling stress is found by applying specific tie constraints to the fastener ends in this study, which represents that the above discussed formulations are enough to predict the appropriate deformations in built-up sections.

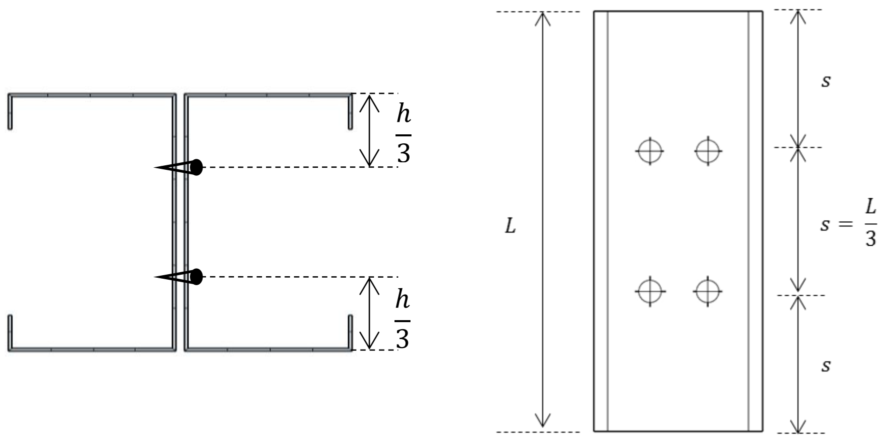

Figure 9: Back-to-back connected built-up open section and screw spacing in longitudinal direction

Table 4: Results of constrained buckling mode for built-up section

Simply-supported	spacing	Critical Buckling stress (in MPa)		
		F_{cr} (single)	F_{cr} (BU)	% increment
Constrained Local buckling	s = L/3	560	560.5	**0.1**
	s = L/5		561.1	**0.2**
Constrained Distortional buckling	s = L/3	312.5	314.2	**0.54**
	s = L/5		316.25	**1.2**
Constrained Global buckling (@L = 2400 mm)	s = L/3	249.13	345.48	**38.74**
	s = L/5		434	**75**
Constrained Global buckling (@L = 6000 mm)	s = L/3	30.24	56.85	**88**
	s = L/5		71.72	**137.16**

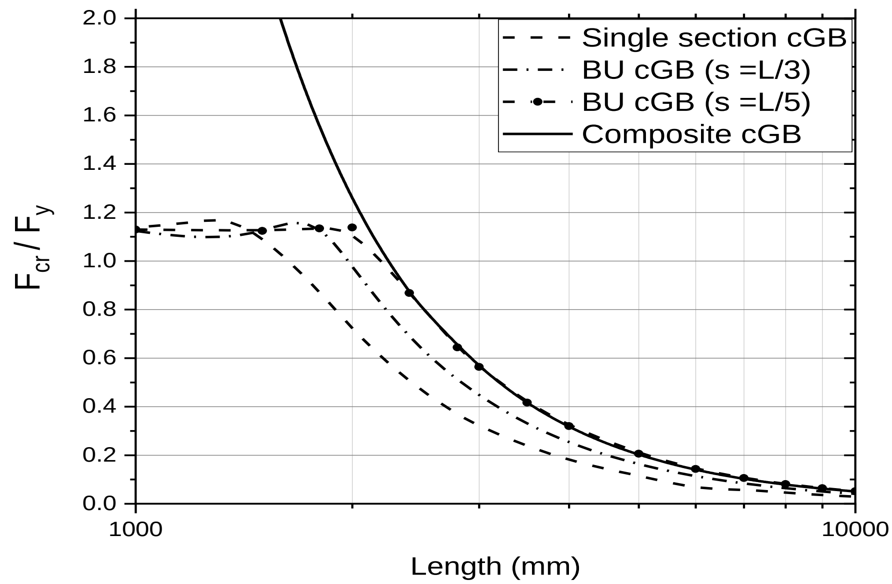

Figure 10: Effect of fastener spacing on critical minor axis buckling stress (CSFSM outputs)

4.2 Modified slenderness ratio

AISI-S100-16 suggest to adopt a modified slenderness ratio for built-up section buckling in minor axis. This modified slenderness ratio will account for the loss of shear rigidity in longitudinal direction.

$$\left(\frac{KL}{r}\right)_{ms} = \sqrt{\left({KL}/{r}\right)_o^{\ 2} + \left({s}/{r_{yc}}\right)^2}$$

For which, $$\left({s}/{r_{yc}}\right) \leq 0.5 \times \left({KL}/{r}\right)_o \qquad (8)$$

Results obtained from above numerical study is compared with the AISI prediction, and comparison is presented in Fig. (11).

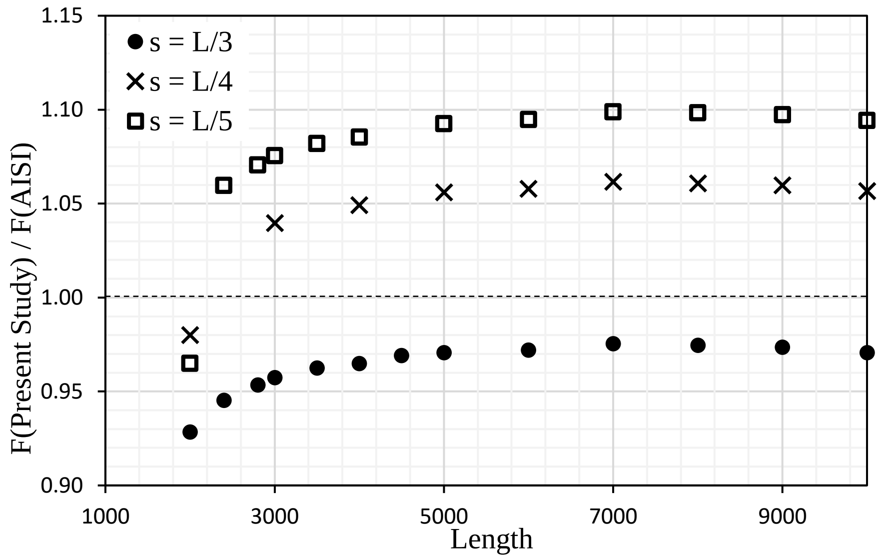

Figure 11: Comparison of AISI prediction and CSFSM results for different fastener spacing for built-up section

4.3 Sheathed and unsheathed wall studs

Built-up sections in wall frame system are sheathed by wall panels i.e. OSB or gypsum boards. These wall panels will provide additional restraints to the out-of-plane deformations and increase the buckling capacity of these wall studs. Numerical model for these systems is already discussed in previous section. By applying specific constraints to these wall studs, effect of wall panel on different buckling modes can be studied. In this section, a comparison is drawn between buckling behavior of sheathed wall studs and unsheathed wall studs for a specific fastener spacing (s = L/3).

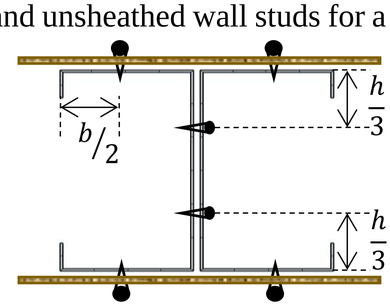

Figure 12: A typical sheathed wall stud

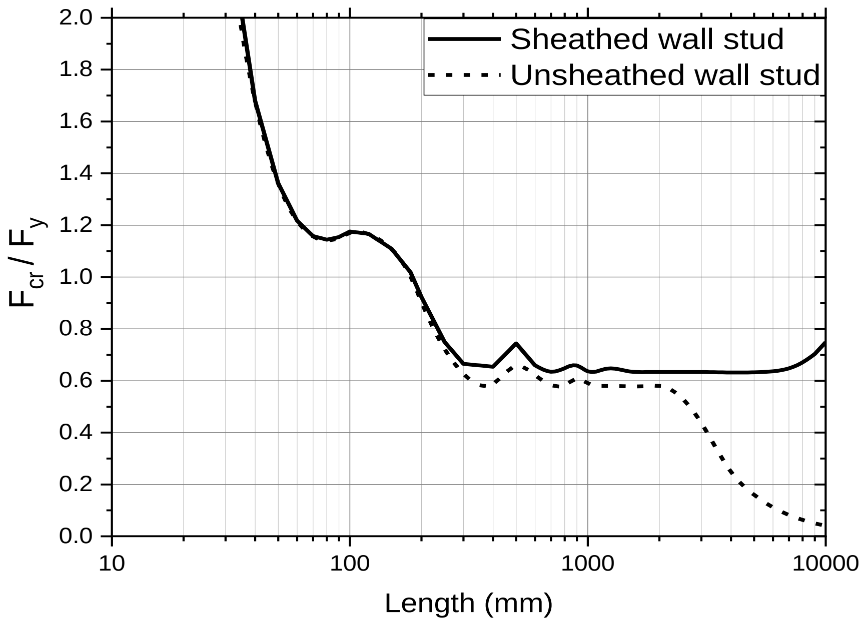

Figure 13: Effect of sheathing on wall stud with fastener spacing s = L/3

Table 5: Results of constrained buckling mode sheathed and un-sheathed wall stud

Simply-supported	**Critical Buckling stress (in MPa)**		
	F_{cr} (Unsheathed)	F_{cr} (Sheathed)	% increment
Constrained Local buckling	560.5	560.5	**0**
Constrained Distortional buckling	314.2	348	**10.75**
Constrained Global buckling (@L = 2400 mm)	345.48	Eliminated	**--**

5. Discussion

The effect of discrete fastener spacing on the buckling behavior of built-up CFS sections is presented. By applying specially formed constrained models, the elastic critical buckling stress of individual buckling mode are computed. The increment of buckling stress from single section to back-to-back connected built-up unsheathed column is found only in global buckling mode. Local and distortional buckling stress do not get much affected by the presence of discrete fastener system as fasteners are present in the web of the built-up section. For global buckling mode, fasteners create a partial composite behavior and for a specific fastener spacing, built-up section behaves as a fully composite section. This study also provides an exposure to different constrained buckling models for the application ranging from single to built-up sections. CFS columns can undergo flexural-torsional buckling, but this buckling mode does not generally occur in bi-symmetric built-up columns so it is not discussed in this study.

The buckling stress prediction by the use of modified slenderness ratio found to be lower than the actual buckling stress with reduction in fastener spacing. It is also found that modified slenderness ratio will predict higher buckling stress near the minimum fastener spacing suggested by the code. For sheathed wall studs, OSB are able to restrict the global buckling mode effectively. Their effect on distortional buckling is also studied, and about 10.75 % increment in distortional buckling stress is found. Wall sheathing do not affect the local buckling mode as the wavelength of this mode is very small compared to the fastener spacing provided in this study.

6. Conclusions

The compound spline finite strip method (CSFSM) is presented in this study for the stability assessment of built-up CFS columns with different applications. The versatility of CSFSM is presented to capture the elastic critical buckling stress for different buckling modes with discrete fastener spacing and boundary conditions. The presence of fasteners will affect the global buckling capacity of open built-up section CFS columns compared to the other buckling modes, which is computed by applying special constrained models. For global buckling mode, buckling stress generated by modified slenderness ratio is also compared with the CSFSM results, and code predictions are found to be lower than the actual buckling stress values about 10%. CSFSM is also extended to incorporate the effect of wall sheathing on different buckling modes, and results are compared with the unsheathed wall stud results. In conclusion, the versatility and accuracy of CSFSM can help in understanding the complex behavior of built-up sections, which will provide a significant contribution for the industrial applications.

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