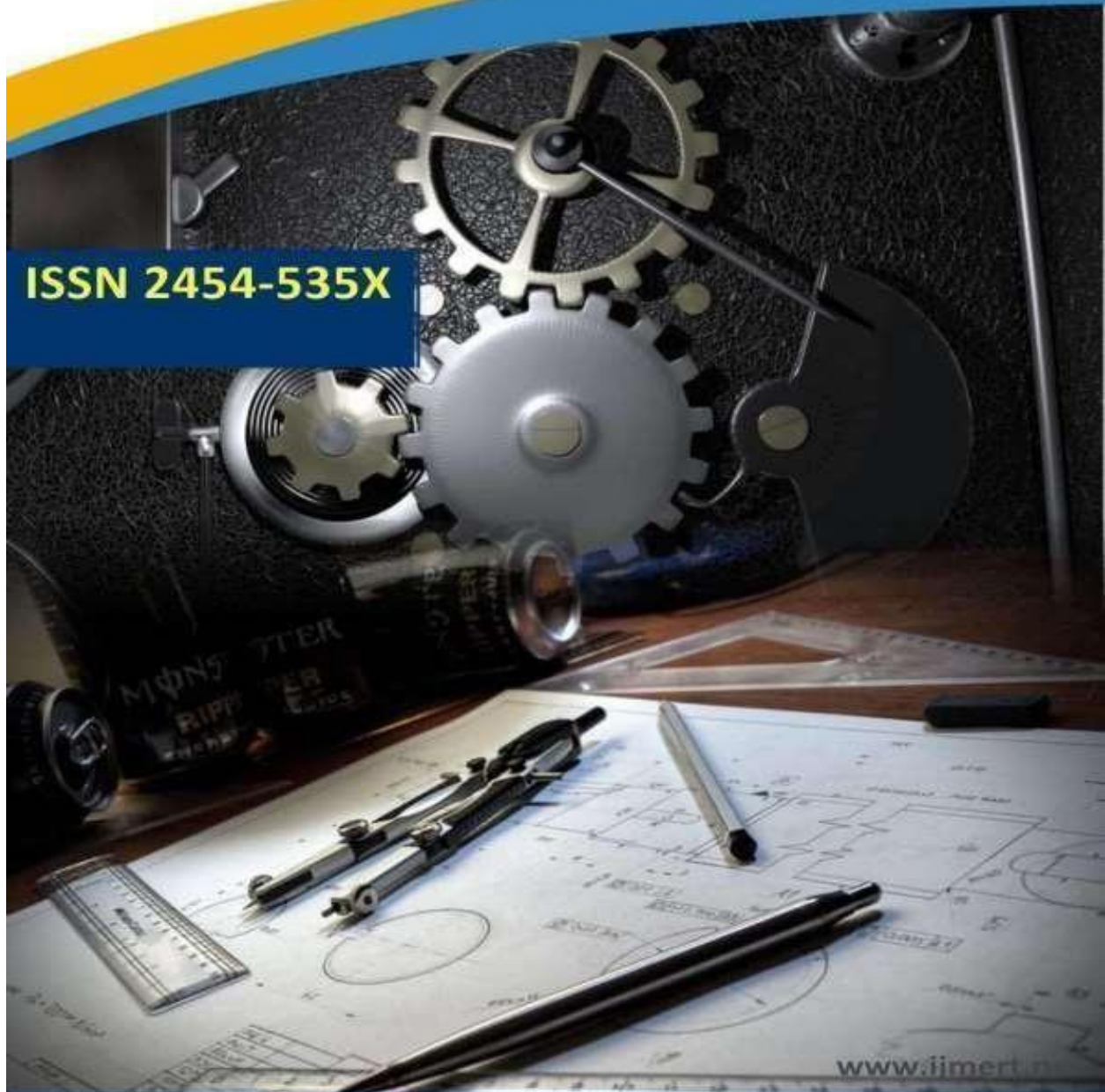




International Journal of Mechanical Engineering Research and Technology

ISSN 2454-535X



www.ijmert.net

Email ID: info.ijmert@gmail.com or editor@ijmert.net



Exploration of Ultra-Lightweight Aggregate Concrete with Minimal Nano-Si Clay

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Abstract

Cold-formed steel channel sections have been widely applied in structural buildings. This type of section is then added stiffeners in the web to form the new section called SupaCee. The capacities of these sections have been investigated due to shear actions paralleling their webs. Shear forces are assumed to be resisted by the web, but the presence of the flanges and lips also have specific impacts on the shear capacities of these sections. This paper, therefore, investigates the effects of the flange widths and lip lengths on the shear capacities of the channel and SupaCee sections. Also, the shear capacities of SupaCee sections are studied to illustrate their strength improvements compared to those of channel sections. Shear capacities of the investigated sections are determined according to AS/NZS 4600:2018. The study demonstrated the innovation of SupaCee sections in shear strength improvements in comparison with those of channel sections.

Keywords: Shear capacities; Cold-formed steel; Channel sections; SupaCee sections.

Introduction Cold-formed steel channel sections have become a common product in structural buildings with numerous applications [1]. They can be subjected to compression, bending or shear. In terms of compression or bending, buckling modes such as local, distortional, flexural, or flexural-torsional buckling have been investigated in many research studies and are deeply understood [1]. In the case of shear, shear buckling of channel section was investigated with the consideration of the web alone, but the flanges and the lips were ignored in the behavior. There was not any consistent theory for shear buckling of full thin-wall sections. The channel sections have then added web stiffeners to increase the stabilities. These such sections termed as SupaCee sections have a variety of advantages compared to the traditional channel ones, as discussed in Pham and Vu [2]. The recent

development of the DSM method for thin-wall sections in shear required the elastic buckling loads of the whole section in pure shear. Pham and Hancock [3-6] carried out a series of the channel and SupaCee section beams under shear to provide deep understandings of their strengths and behaviors. Also, Hancock and Pham [7,8] used the complex Semi-Analytical Finite Strip Method proposed by Plank and Wittrick [9] to develop the signature curve for channel sections under shear actions with the assumption of unrestraint at end conditions. Pham and Hancock [10] used a spline finite strip analysis to investigate the shear buckling of whole channel sections restrained at their ends. The spline finite strip analysis was developed by Lau and Hancock [11]. To reduce computer resources in analysis, Hancock and Pham [12] developed a new version of the semi-analytical finite strip analysis called reSAFSM that allows considering restrained ends in the analysis of thin-walled sections under shear actions. Channel sections with intermediate web stiffeners have been also investigated by Pham [13-14] using Semi-Analytical Finite Strip Method. This method was subsequently incorporated into the Thin-Wall-2 [15] in the analysis of the buckling loads under shear [16]. Thin-Wall-2 has been allowed to use for elastic buckling analysis of thin-wall sections according to the AS/NZS 4600-2018 [17]. The paper, therefore, is aimed to investigate the shear capacities of the channel and SupaCee sections with the variations of dimensions of the flanges and lips. The effects of the flanges and lips on the elastic shear buckling loads of thin-walled channel sections can be accounted for as presented in Appendix D3, but the intermediate web stiffeners are not included. Thin-Wall-2 software program [15], therefore, can be used

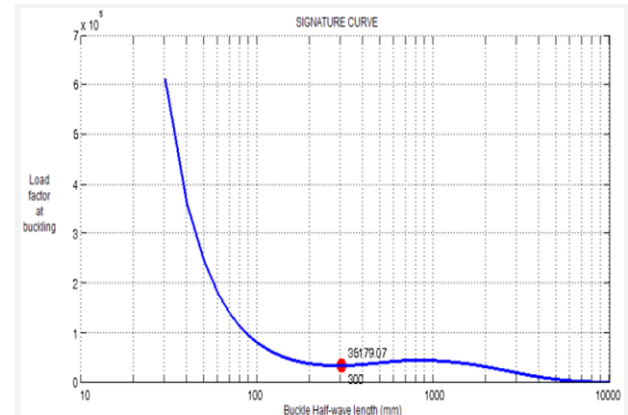
for the elastic shear buckling analyses in this investigation. The shear capacities of commercial SupaCee sections are also investigated to illustrate their innovation in strength improvements based on comparing the shear capacities between SupaCee and channel sections. The investigated sections are commercial sections provided by BlueScope Lysaght [18]. The THIN-WALL-2 software program [15] is used for elastic buckling analysis under shear actions, and the shear capacities are determined according to the AS/NZS 4600: 2018 [17].

Determination of the Shear Capacities of ColdFormed Steel Section

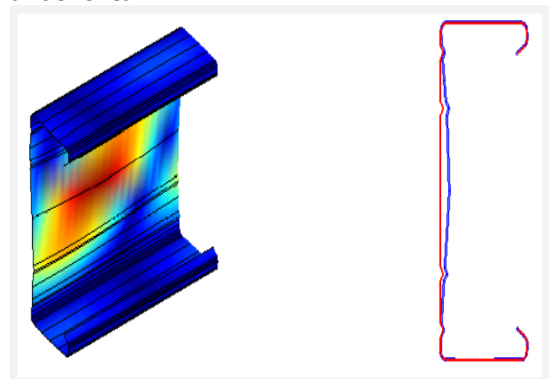
The nominal shear capacity of beams without transverse web stiffeners can be calculated determined according to AS/NZS 4600-2018 [17] as follows:

$$V_v = \begin{cases} V_y & \text{for } \lambda_y \leq 0.815 \\ 0.815 \sqrt{V_{cr} V_y} & \text{for } 0.815 < \lambda_y \leq 1.227 \\ V_{cr} & \text{for } \lambda_y > 1.227 \end{cases}$$

where V_y , V_{cr} are the yield shear force and the elastic shear buckling force of the section; λ_v is the non-dimensional slenderness, $\lambda_v = \sqrt{V_y / V_{cr}}$. The yield shear force V_y , can be calculated as $0.6 V_f A_w$, where A_w is the area of the web element; V_f is the design yield stress. The elastic shear buckling force V_{cr} can be determined according to Appendix D, AS/NZS 4600-2018 [17] or a rational elastic buckling analysis. THIN-WALL-2 software program [15] will be used for this elastic buckling analysis in this investigation. This software program was developed at the University of Sydney using the finite strip method. One of the outputs of buckling analysis is a signature curve performing the relationship between the elastic buckling stress and the half-wavelength of each buckling mode. This program can be used for buckling analysis under compression, bending, shear, localized loading or combined actions. (Figure 1 (a)) shows the signature curve of a channel section under the shear actions paralleling the web. The elastic shear buckling stress is the minimum point in the curve with the buckling mode demonstrated in (Figure 1(b)).



a) The signature curve of a channel section under shear



The illustrations of shear buckling mode

Figure 1: Elastic shear buckling analysis.

Effects of Flanges and Lips on the Shear Capacities of Channel and SupaCee Sections

The geometry of the unlipped, lipped channel and SupaCee sections are demonstrated in (Figure 2). The section depths (D) are 250 mm, the flanges (B) vary from 0.1 to 0.9 times of the depth (D). The sectional thicknesses (t) are 1.5 mm, 1.9 mm and 2.4 mm, and the inner radii at corners (r_1 or r_2) are 5 mm. The elastic shear buckling stresses are determined with the support of the THINWALL-2 software program [15]. The buckling stresses are listed in (Table 1) with the variation of the dimensions of the flanges and the lips. The shear capacities are then calculated with the design yield stress V_f of 450 MPa, as presented in Section 2. The nominal shear



capacities are listed in (Table 2) and demonstrated in (Figure 3).

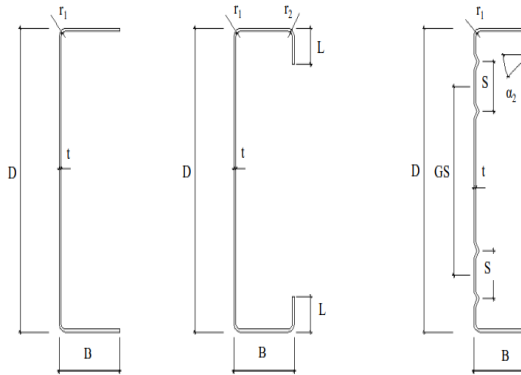
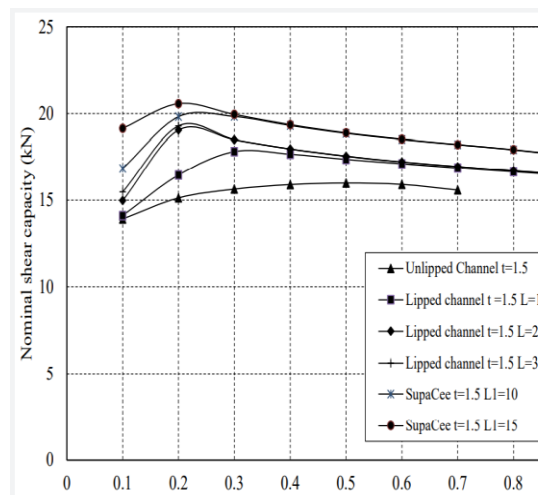


Figure 2: Nomenclature for investigated sections

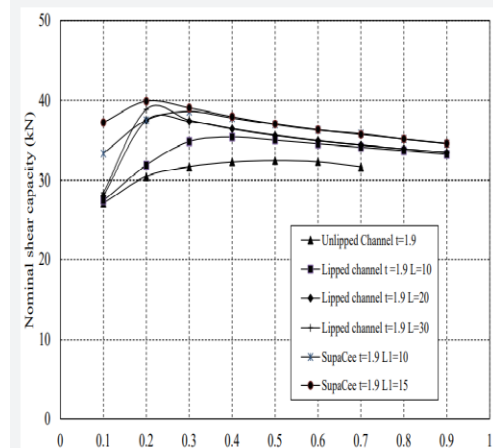


The ratio B/D

Figure 3: Nominal shear capacities of investigated sections with the thickness of 1.5 mm

Table 1: Elastic shear buckling stresses of the investigated sections.

Sections	t	L or L1=L2	Elastic buckling stress (MPa) with the variation of the ratio B/D								
			0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Unlipped channel	1.5	0	39.14	42.57	43.99	44.73	44.97	44.75	43.85	41.62	37.09
	1.9	0	60.35	67.91	70.53	71.86	72.27	71.93	70.48	66.86	59.57
	2.4	0	97.04	107.15	112.34	114.85	115.59	115.02	112.75	106.81	95.08
Unlipped channel	1.5	10	39.7	46.31	50.13	49.71	48.88	48.12	47.46	46.83	46.23
		20	42.14	53.59	52.01	50.54	49.37	48.42	47.67	47.01	46.36
		30	43.55	54.25	52.08	50.54	49.41	48.44	47.68	47	46.34
	1.9	10	61.1	71	77.6	78.86	78	76.98	76.03	75.05	74.05
		20	62.44	83.54	83.3	81.15	79.29	77.82	76.62	75.55	74.52
		30	63.34	86.62	83.64	81.27	79.45	77.89	76.66	75.57	74.52
	2.4	10	97.75	108.89	119.03	123.43	123.44	122.25	120.93	119.42	117.45
		20	98.5	124.18	131.54	129.15	126.57	124.34	122.53	120.83	119.21
		30	99.24	134.57	133.43	129.94	127.05	124.63	122.67	120.91	119.26
SupaCee	1.5	10	47.36	55.74	55.79	54.33	53.07	52.05	51.2	50.4	49.38
		15	53.87	57.86	56.13	54.45	53.14	52.11	51.24	50.45	49.44
	1.9	10	74.3	83.64	86.04	84.24	82.39	80.83	79.84	78.27	77.02
		15	83	88.88	87.04	84.61	82.57	80.96	79.58	78.32	77.05
	2.4	10	93.45	128.71	132.56	130.95	128.57	126.24	124.23	122.27	120.35
		15	103.96	134.98	135	131.7	128.94	126.64	124.46	122.45	120.49



The ratio B/D

Figure 4: Nominal shear capacities of investigated sections with the thickness of 1.9 mm.

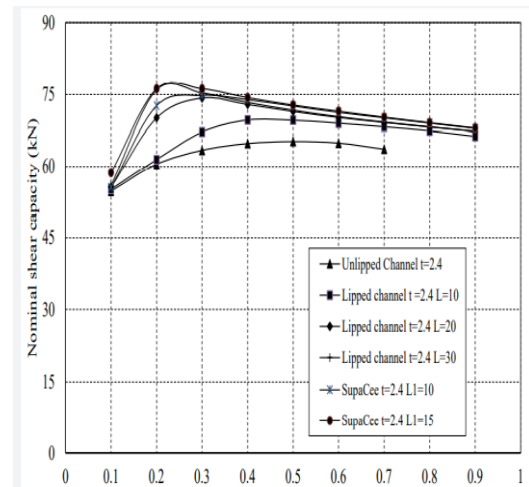
Based on the results in (Table 2), the shear forces are maximum at the ratio B/D of 0.5 for unlipped channel sections, whereas the maximum of shear forces are obtained at the lower ratio B/D varying from 0.2 to 0.4 depending on the lip lengths for lipped channel or SupaCee sections. In terms of lipped channel and SupaCee sections, as the ratio B/D increases from 0.1 to 0.2, the shear force goes up rapidly. This illustrates the significant contribution of the flange on the shear capacities of the channel sections. The ratio B/D subsequently increases, the shear



capacities improve slowly to the maximum values, subsequently reducing gradually as the flange width increase to 0.9. These results can be explained due to the effects of flange slenderness (Figures (4&5)). With the small flange, there is very little effect of flange slenderness on the shear buckling capacity. This effect is significant when the flange dimensions increase resulting in the reduction of the shear capacities. In terms of the unlippped channel section, as the increase of the ratio B/D, the shear capacities have a slow increase trend to the maximum values, and then have a gradual reduction. When the ratio B/D increases to 0.8 and 0.9, shear buckling occurs in the flanges (Figure 6), this leads to the significant reductions of elastic buckling stresses. The lips are then added, shear buckling is prevented in the flanges, and the elastic shear buckling stresses are significantly improved as presented in (Table 1)

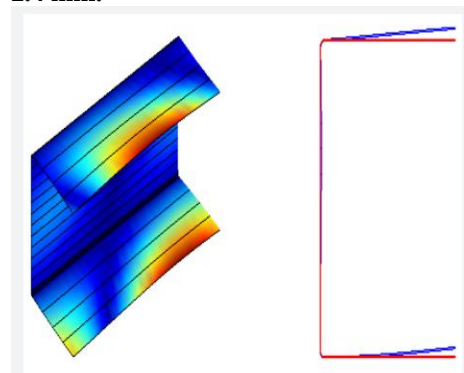
Table 2: Nominal shear capacities of the investigated sections.

Sections	t	L or L1= L2	Nominal shear capacity (kN) with the variation of the flange width B/D							
Unlippped channel			0.1	0.2	0.3	0.4	0.5	0.6	0.7	
	1.5	0	13.91	15.13	15.64	15.9	15.99	15.91	15	
	1.9	0	27.08	30.48	31.65	32.25	32.43	32.28	31	
	2.4	0	54.78	60.48	63.41	64.83	65.25	64.93	63	
Lipped channel	1.5	10	14.11	16.46	17.82	17.67	17.37	17.11	16	
		20	14.98	19.05	18.49	17.97	17.55	17.21	16	
		30	15.48	19.29	18.51	17.97	17.56	17.22	16	
	1.9	10	27.42	31.86	34.83	35.39	35	34.55	34	
		20	28.02	37.49	37.38	36.42	35.58	34.92	34	
		30	28.43	38.87	37.54	36.47	35.66	34.96	34	
	2.4	10	55.18	61.47	67.19	69.67	69.62	69.01	68	
		20	55.6	70.1	74.25	72.9	71.45	70.19	69	
		30	56.02	75.96	75.32	73.35	71.72	70.35	69	
	SupaCee	1.5	10	16.84	19.82	19.83	19.31	18.86	18.51	18
			15	19.15	20.57	19.95	19.36	18.89	18.53	18
		1.9	10	33.34	37.54	38.61	37.81	36.97	36.27	35
15			37.25	39.89	39.06	37.97	37.06	36.33	35	
2.4		10	52.75	72.65	74.83	73.92	72.58	71.26	70	
		15	58.68	76.19	76.2	74.34	72.78	71.49	70	



The ratio B/D

Figure 5: Nominal shear capacities of investigated sections with the thickness of 2.4 mm.

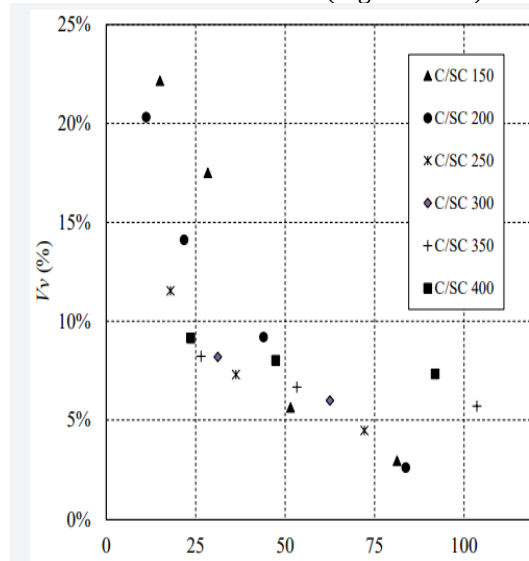


Comparison of Shear Capacities of Channel and SupaCee Sections

The channel and SupaCee sections for this investigation are taken from the catalogue provided by BlueScope Lysaght [18]. Their dimensions are presented in (Table 3) with the nomenclature demonstrated in (Figure 2). The elastic shear buckling stresses are determined using the Thin-Wall-2 software program [15] and are listed in (Table 3). These buckling stresses are then used to determine shear capacities of the investigated sections according to AS/NZS 4600-2018 [17] as presented in Section 2. The design yield stress y_f of 450 MPa is used for this investigation. Shear capacities of channel and SupaCee are summarized in (Table 3). The results of shear capacities are plotted in percentage diagrams, where the



shear capacities of channel sections are shown in the horizontal axis and the vertical axis is for the shear capacity deviations (in %) between SupaCee and channel sections, as illustrated in (Figure 7).



Nominal shear capacity of channel sections (kN)

Figure 7: The nominal shear capacity deviation between investigated sections.

The SupaCee sections have demonstrated their innovation in shear capacities compared to those of channel sections due to the effects of the intermediate web stiffeners with the increase of shear capacities reaching 22%. The web stiffeners become more beneficial effects with the smaller thicknesses in all investigated sections. This conclusion can be seen as the strength improvements of the SC250 section decrease from 11.54% to 4.48% when the thicknesses increase from 1.5mm to 2.4mm as presented in (Table 4). This trend is also observed in the other sections. For small sections (SC150 and SC200 sections), the shear strength improvements are more noticeable for the small section. This result is illustrated as the higher strength improvements of SC150 section compared to those of SC200 section in almost investigated thicknesses. For large sections (see SC250 to SC400 sections), the strength improvements become more significant as the increase of web slenderness. This conclusion is based on the increasing trend of strength improvements from 7.29% to 9.14% corresponding to the increase

of web slenderness from SC25019 to SC40019 sections. This trend is also seen for the other thicknesses.

Table 3: The nominal dimensions of channel and SupaCee sections.

Sections	t	D	B	L1	L2	L	GS	S	$\alpha 1$	$\alpha 2$
SC/C15012	1.2	152	64	7.5	7.5	14.5	64	42	5	35
SC/C15015	1.5	152	64	7.5	7.5	14.5	64	42	5	35
SC/C15019	1.9	152	64	7.5	7.5	14.5	64	42	5	35
SC/C15024	2.4	152	64	7.5	7.5	14.5	64	42	5	35
SC/C20012	1.2	203	76	10	10	19.5	115	42	5	35
SC/C20015	1.5	203	76	10	10	19.5	115	42	5	35
SC/C20019	1.9	203	76	10	10	19.5	115	42	5	35
SC/C20024	2.4	203	76	10	10	19.5	115	42	5	35
SC/C25015	1.5	254	76	11	11	21.5	166	42	5	35
SC/C25019	1.9	254	76	11	11	21.5	166	42	5	35
SC/C25024	2.4	254	76	11	11	21.5	166	42	5	35
SC/C30019	1.9	300	96	14	14	27.5	212	42	5	35
SC/C30024	2.4	300	96	14	14	27.5	212	42	5	35
SC/C30030	3	300	96	14	14	27.5	212	42	5	35
SC/C35019	1.9	350	125	15	15	30	262	42	5	35
SC/C35024	2.4	350	125	15	15	30	262	42	5	35
SC/C35030	3	350	125	15	15	30	262	42	5	35
SC/C40019	1.9	400	125	15	15	30	312	42	5	35
SC/C40024	2.4	400	125	15	15	30	312	42	5	35
SC/C40030	3	400	125	15	15	30	312	42	5	35

Note: the inner radius $r1 = r2 = 5\text{mm}$; t, D, B, L1, L2, GS, S (mm); $\alpha 1$, $\alpha 2$ (°)

Table 4: The elastic shear buckling stress and nominal shear capacity of the channel and SupaCee sections.

Sections	Elastic shear buckling stress (MPa)		Nominal shear capacity (kN)		
	Lipped channel	SupaCee	Lipped channel	SupaCee	Δ (%)
15012	90.87	111.01	15.00	18.33	22.16%
15015	138.12	162.3	28.38	33.35	17.51%
15019	220.97	246.57	51.52	54.42	5.63%
15024	349.92	370.84	81.29	83.68	2.95%
20012	49.55	59.62	11.15	13.42	20.32%
20015	77.43	88.36	21.72	24.78	14.12%
20019	124.22	135.64	43.95	47.99	9.19%
20024	197.83	208.23	83.72	85.89	2.59%
25015	50.43	56.25	17.93	20.00	11.54%
25019	80.75	86.64	36.24	38.88	7.29%
25024	127.8	133.52	72.14	75.37	4.48%
30019	57.29	61.98	31.15	33.7	8.19%
30024	91.3	96.76	62.49	66.23	5.98%
30030	142.15	148.8	121.11	126.78	4.68%



35019	41.47	44.88	26.49	28.67	8.22%
35024	66.21	70.62	53.26	56.81	6.66%
35030	103.36	109.25	103.57	109.47	5.70%
40019	32.15	35.09	23.59	25.75	9.14%
40024	51.22	55.33	47.35	51.15	8.02%
40030	79.78	85.63	91.91	98.65	7.33%

Note: Δ (%) is the nominal shear capacity deviation between SupaCee and Lipped channel sections (in %)

Conclusion

The paper investigated the effects of flange widths and lip lengths on the shear capacities of unlipped channel, lipped channel and SupaCee sections. The investigated results have demonstrated the role of the flanges and lips on the shear capacities with the significant increase of shear forces as the ratio of B/D increase from 0.1 to 0.2, but then observe a gradual reduction due to the effects of flange slenderness. Also, the lips can prevent the shear buckling from occurring in the flanges with the large ratio of B/D. The paper subsequently investigated the innovation in shear capacities of SupaCee sections compared to those of traditional channel sections with significant shear strength improvements.

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