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FLEXURAL CAPACITIES OF COLD-FORMED STEEL CHANNEL AND SUPACEE SECTIONS ABOUT THE WEAK-AXIS

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ABSTRACT: Cold-formed steel structures have been progressively used in structural buildings in the forms of the typical channel and Zed sections. The channel sections under weak-axis bending can be found in various situations, especially under biaxial bending. The flexural capacities about the weak-axis, therefore, have specific impacts on the flexural capacities of the channels. The unsymmetrical feature of this channel section about the weak-axis results in a variety of behaviors and strengths of cold-formed steel channel beams with the change of moment directions. SupaCee - a new form of the channel section – made by adding stiffeners in the web of the channel section to increase the stability of the sectional web is also considered in the investigation. This paper, therefore, is aimed to investigate the behaviors and sectional capacities of the channel and SupaCee sections under the weak-axis bending. The considered sections are taken as the availably commercial sections in the market. The sectional capacities are determined using an innovative method namely the Direct Strength Method as regulated in the Australian/New Zealand Standard AS/NZS 4600:2018. The bending behaviours of the investigated sections are observed and analysed; the obtained strength results are the basis for the evaluation of sectional capacities of the channel and SupaCee sections under variations of moment directions. It was found that capacities of the channel and SupaCee sections under the weak-axis bending can be governed by local or distortional buckling depending on the moment directions, whereas the capacities of distortional failures are higher than those of local failures. Also, the innovative strengths of SupaCee sections under the weak-axis bending are not demonstrated in comparison with these such strengths of channel sections.

Keywords: Flexural capacities, Cold-formed steel, Channel sections, SupaCee sections, Weak-axis

1. INTRODUCTION

Cold-formed steel structures have been commonly applied in structural buildings due to their advantages compared to traditional steel structures [1]. These structures can be used for single-story industrial, commercial and agricultural buildings. They also can be applied for mid-rise construction buildings from four to twelve storeys. Cold-formed sections are seen as chord and web members in the space frames. More details about their applications are reported in Yu et al [1].

In the design, the effective width method is found to become cumbersome in the design due to their complicated designs for complex section shapes ([2-3]). A new design method, therefore, called the Direct Strength Method (DSM) was developed by Schafer and Pekoz [4-6] to solve these drawbacks. This method can directly predict the capacities of cold-formed steel members based on the elastic buckling analyses for the cross-sections. These buckling analyses can be carried out using numerical software programs such as CUFSM [7] or THIN-WALL-2 ([8-9]). The procedure for the design of this DSM method was presented in Pham and Vu [10].

Research studies on cold-formed steel structures under bending have been available in the literature. These studies investigated the flexural capacities of cold-formed steel members in the major axis ([6], [11-16]) or in the minor axis ([17-18]) by the developments of experimental and/or numerical studies. Channel has been seen as the common section in the applications. SupaCee is seen as the form of the channel section with the addition of stiffeners in the web. Flexure about the weak axis of the channel and SupaCee sections is also observed in various cases, particularly in biaxial bending. The biaxial bending has been considered in the design, as regulated in Clause 3.5, Australian/New Zealand AS/NZS 4600:2018 [19]. The behaviour and strength of channel and SupaCee sections under the weak-axis bending are varied with the variation of bending directions due to the unsymmetrical characteristic in the weak axis of these sections [20]. Other recent research results on cold-formed steel structures were also found in publications of Sani *et al* [21] or Setyowulan *et al* [22].

The previous studies focus on the evaluation of the current design guidelines, followed by the modifications or improvements of design equations. Meanwhile, the investigation of sectional capacities of channel or SupaCee sections bent about the weak-axis with the variation of bending directions remain limited. This paper, therefore, focuses on investigating the behaviors and sectional capacities of the channel and SupaCee sections under the weak axis bending. The investigated sections are the availably commercial sections provided by BlueScope Lysaght [23], and the material properties are followed the Australian Standard AS 1397 [24]. The flexural capacities of the considered sections are determined according to the Australian/New Zealand Standard AS/NZS 4600:2018 [19] using the Direct Strength Method (DSM). Based on the obtained results, the behaviors are analysed, and the evaluation of flexural capacities of cold-formed steel channel and SupaCee sections under the weak axis bending is reported.

2. RESEARCH SIGNIFICANCE

The behaviors of investigated sections were analysed with a variety of bending orientations due to the unsymmetric sectional characteristics of channel sections. It is found that the buckling failures are governed by local buckling or distortional buckling depending on the bending orientations. Also, moment capacities of channel and SupaCee sections under the weak-axis are determined and analyses to find out the beneficial and detrimental moment capacities of such sections. In addition, the comparisons of moment capacities between channel and SupaCee sections about the weak-axis are carried out to demonstrate whether or not the innovative strengths of SupaCee sections. It reveals that the strength improvements are not illustrated for SupaCee sections under bending about the weak-axis.

3. FLEXURAL CAPACITIES OF COLD-FORMED STEEL SECTIONS USING THE DSM

Only sectional capacities are considered in this paper; it means that the global buckling moment (M_{be}) can be taken as the yield moment (M_y), as presented in Pham and Vu [10]. The DSM is applied to determine the flexural capacities of these sections based on the elastic buckling moments including the elastic local buckling moment (M_{ol}) and the elastic distortional buckling moment (M_{od}). These elastic bucking moments can be determined by using the software program THIN-WALL-2 ([8-9]). The flexural capacities are the lesser nominal strengths in local buckling (M_{bl}) and distortional buckling (M_{bd}), as follows:

$$M_s = Min(M_{bl}; M_{bd}) \tag{1}$$

Local buckling moment:

If $\lambda_l \leq 0.776$: $M_{bl} = M_y$ (2)

If λ_l>0.776:

$$M_{bl} = \left[1 - 0.15\left(\frac{M_{ol}}{M_y}\right)^{0.4}\right]\left(\frac{M_{ol}}{M_y}\right)^{0.4} M_y \tag{3}$$

Distortional buckling moment:

If $\lambda_d \leq 0.673$:

$$M_{bd} = M_y \tag{4}$$

If λ_d>0.673:

$$M_{bd} = \left[1 - 0.22\left(\frac{M_{od}}{M_y}\right)^{0.5}\right]\left(\frac{M_{od}}{M_y}\right)^{0.5} M_y \tag{5}$$

where $\lambda_l = \sqrt{M_y/M_{ol}}$; $\lambda_d = \sqrt{M_y/M_{od}}$; M_y is the yield moment; M_{ol} and M_{od} are the elastic local and distortional buckling moments respectively and are determined as presented in Section 4.

4. ELASTIC BUCKLING ANALYSES

Channel and SupaCee sections used for the investigation are taken from the catalogue provided by BlueScope Lysaght [23], as presented in Table 1 and illustrated in Fig.1. The labelling is based on the nominal depth and the thickness of the investigated sections. For example, “SC/C15024” is included: “SC/C” is interpreted as SupaCee or channel sections; “150” indicates the nominal depth of this section; “24” shows the thickness of 2.4mm. Elastic buckling analyses are carried out with the support of the THIN-WALL-2 software program ([8-9]) to obtain sectional buckling stresses. They are local buckling and distortional buckling stresses with the consideration of bending directions about the weak axis, as presented in Table 2, where the bending moment directions are illustrated in Fig. 2. The material properties regulated in Australian Standard AS1397 [24]; the grade G450 will be used in this investigation and include Young’s Modulus E =200 GPa; f_y = 450 MPa.

For the negative moment direction, the lip areas are in tension and the sectional webs are in compression; this leads to the occurrence of the local buckling in the web as demonstrated in Fig. 3(a). Distortional buckling modes are not observed in this case. In terms of the positive moment sign, the webs are in tension whereas the compression is observed in the lips and the flange areas near the corners between the lips and flanges. Both local and distortional buckling modes are seen in this situation although local buckling modes are found in the flange areas instead of normally observed in the sectional webs (see Figs 3(b) and 3(c)). These sectional behaviors are obtained for both channel and SupaCee sections.

Under the action of negative moments, elastic local buckling stresses are achieved as listed in Table 2. The presence of the stiffeners in the web of SupaCee sections helps these such sections to have much higher local buckling stresses compared to those of channel sections. The effectiveness of these stiffeners is significant for small sectional dimensions and thicknesses.

In the positive moment direction, both local and distortional buckling stresses of SupaCee sections are also found to be higher than those of channel sections. Local buckling stresses are seen to be much higher than distortional buckling stresses. It means that it is hard to occur the local buckling modes, or the failure modes will be governed by distortional buckling in this moment direction. This will be illustrated in Section 4.

These elastic buckling stresses are subsequently utilized for the determination of flexural capacities about the weak-axis, as presented in Section 5.

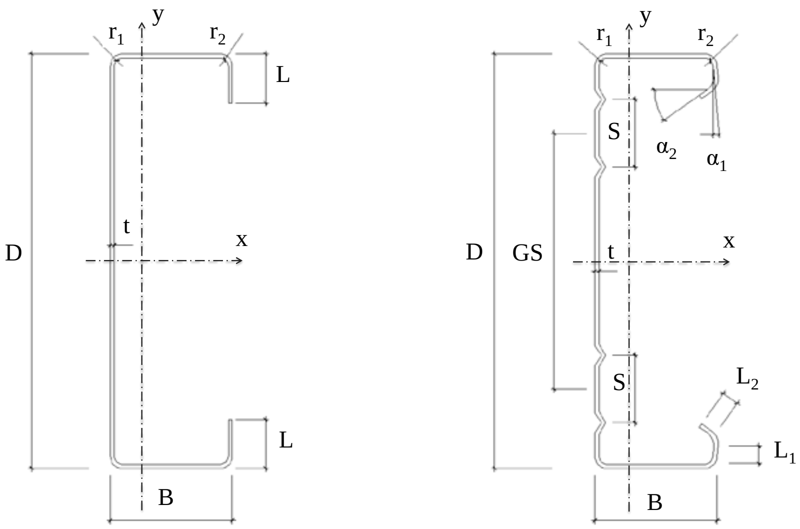
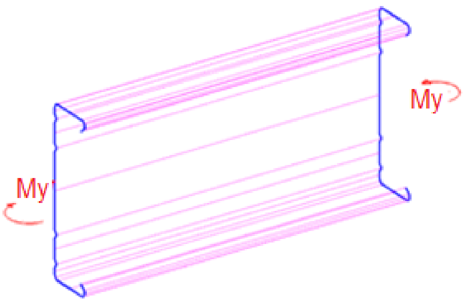


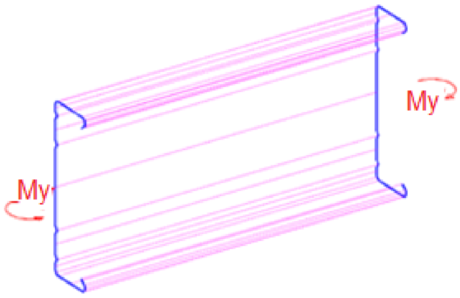
Fig.1 Nomenclature for channel and SupaCee sections

Table 1 The nominal dimensions of channel and SupaCee sections

Sections	t	D	B	L_1	L_2	L	GS	S	α_1	α_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	3.0	300	96	14	14	27.5	212	42	5	35
SC/C35019	1.9	350	125	15	15	30.0	262	42	5	35
SC/C35024	2.4	350	125	15	15	30.0	262	42	5	35
SC/C35030	3.0	125	125	15	15	30.0	262	42	5	35
SC/C40019	1.9	400	125	15	15	30.0	312	42	5	35
SC/C40024	2.4	400	125	15	15	30.0	312	42	5	35
SC/C40030	3.0	400	125	15	15	30.0	312	42	5	35



a) Negative



b) Positive

Fig.2 The illustrations of bending directions

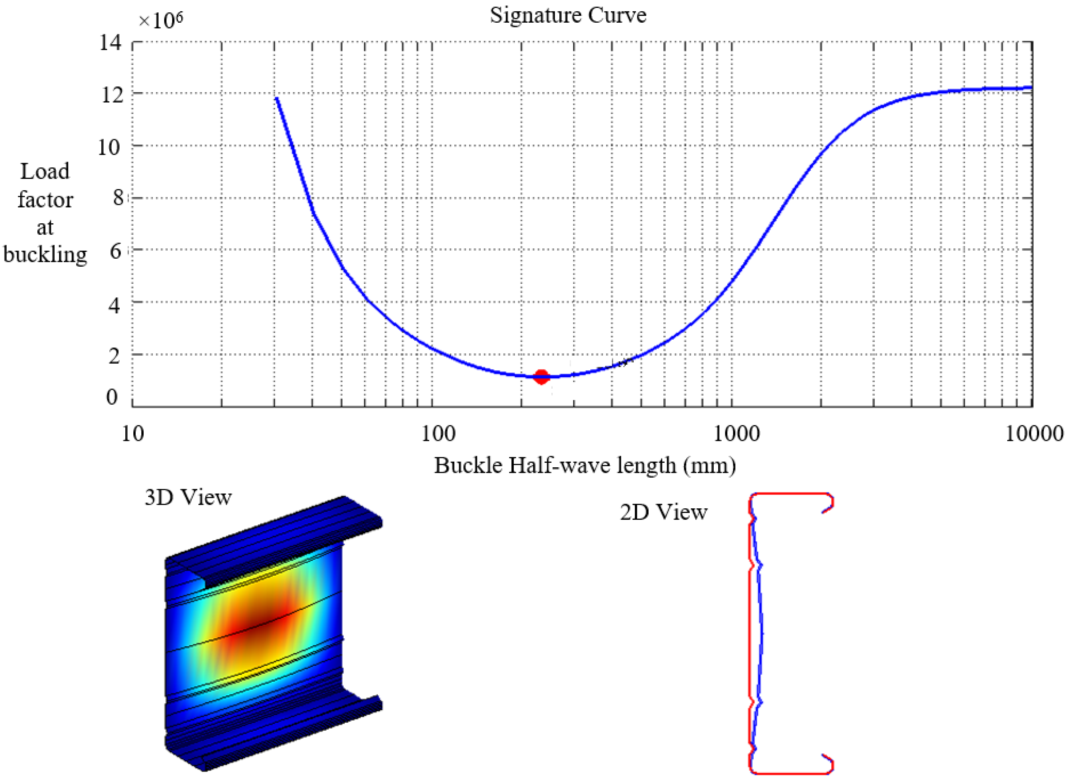
Table 2 Sectional buckling stresses of channel and SupaCee sections under bending about the weak-axis (Unit: MPa)

Sections	f_{ol} (MPa) – M(-)			f_{ol} (MPa) - M(+)			f_{od} (MPa) – M(+)		
	C	SC	%	C	SC	%	C	SC	%
15012	70.25	134.27	91.13%	908.65	1225.13	34.83%	319.23	379.58	18.90%
15015	106.71	179.98	68.66%	1404.69	1660.37	18.20%	417.06	453.42	8.72%
15019	171.16	253.23	47.95%	2240.34	2444.27	9.10%	551.21	605.35	9.82%
15024	275.77	366.66	32.96%	3561.08	3465.05	-2.70%	736.77	788.51	7.02%
20012	37.91	64.96	71.35%	553.05	793.12	43.41%	281.21	325.59	15.78%
20015	59.09	89.39	51.28%	859.22	1111.41	29.35%	362.21	423.67	16.97%
20019	94.86	127.28	34.18%	1388.22	1618.31	16.57%	479.09	563.96	17.71%
20024	150.53	187.84	24.79%	2208.02	2370.23	7.35%	627.87	750.72	19.57%
25015	38.15	51.35	34.60%	753.33	1114.47	47.94%	393.92	479.47	21.72%
25019	61.55	74.87	21.64%	1211.71	1536.89	26.84%	516.66	604.03	16.91%
25024	95.98	110.91	15.56%	1951.47	2245.01	15.04%	682.62	807.68	18.32%
30019	43.81	50.72	15.77%	734.01	1030.92	40.45%	395.68	437.12	10.47%
30024	70.97	78.69	10.88%	1158.88	1481.14	27.81%	504.85	579.39	14.76%
30030	105.09	114.53	8.98%	1849.66	2147.32	16.09%	663.25	769.31	15.99%
35019	32.46	34.83	7.30%	505.28	639.87	26.64%	254.17	267.87	5.39%
35024	51.14	52.82	3.29%	814.13	927.11	13.88%	333.97	349.83	4.75%
35030	81.22	81.92	0.86%	1251.56	1343.47	7.34%	423.92	459.11	8.30%
40019	24.02	27.15	13.03%	487.45	613.82	25.92%	252.28	266.96	5.82%
40024	40.13	40.72	1.47%	779.42	914.61	17.34%	329.17	357.75	8.68%
40030	62.29	62.08	-0.34%	1238.83	1327.42	7.15%	432.81	468.92	8.34%

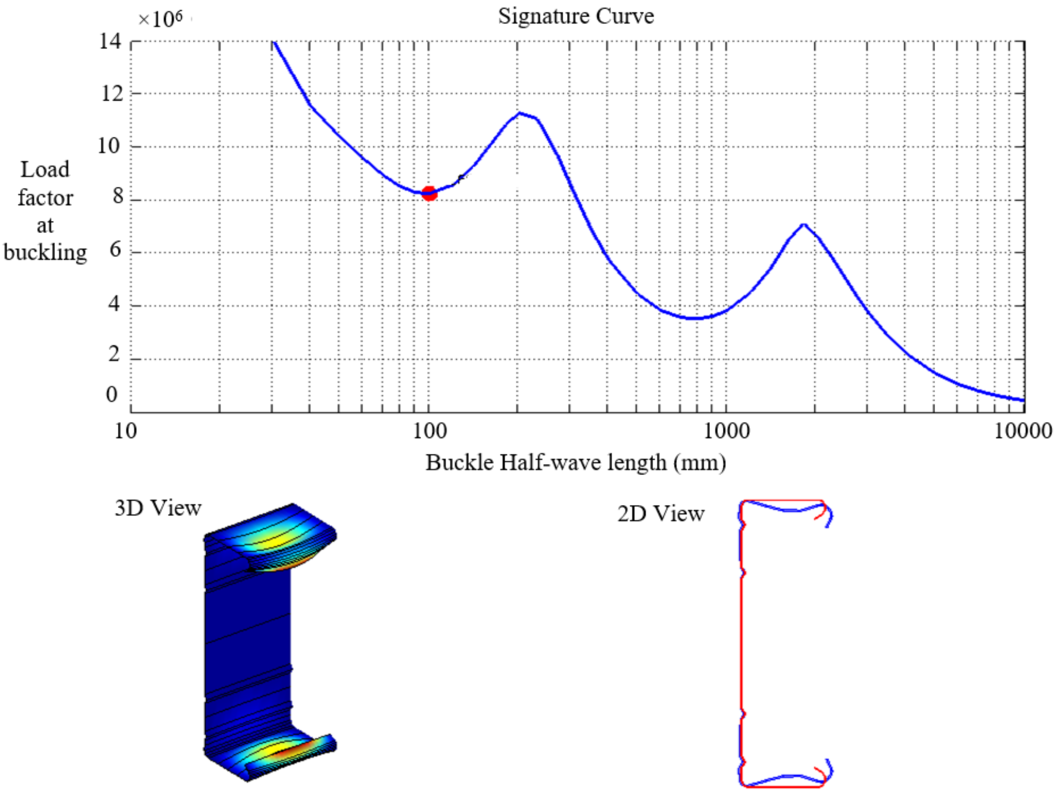
Note: f_{ol} and f_{od} are the elastic local and distortional buckling stresses, unit: MPa

5. COMPARISONS OF SECTIONAL CAPACITIES BETWEEN CHANNEL AND SUPACEE SECTIONS

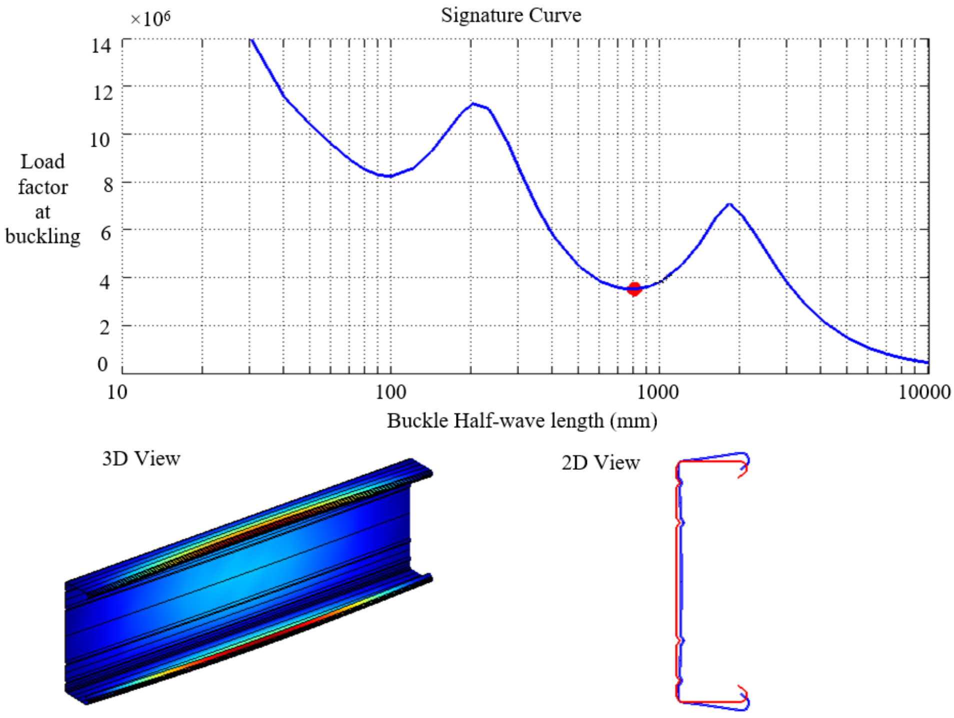
The sectional capacities can be achieved by using full bracings for beams, as presented in Pham [25]. The bracing members are attached to the web to avoid the global buckling modes, as illustrated in Fig. 4. The flexural capacities for both channel and SupaCee sections are determined using the Direct Strength Method as presented in Section 3. The obtained results of these such sections under bending about the weak-axis are listed in Table 3. It is found that the flexural capacities of the investigated sections about the weak-axis are governed by local buckling modes for the negative moment direction and by distortional buckling modes for the positive moment direction.



a) The local buckling mode under the bending in the negative direction



b) The local buckling mode under the bending in the positive direction



c) The distortional buckling mode under the bending in the positive direction

Fig.3 The behaviors of the investigated sections with the variation of bending directions

Table 3 Flexural capacities of the channel and SupaCee sections about the weak-axis (Unit: kNm)

Sections	M_y		$M^{(-)}$		$M^{(+)}$		$M^{(+)}/M^{(-)}$	
	C	SupaCee	C	SupaCee	C	SupaCee	C	SupaCee
15012	1.841	1.390	0.813	0.777	1.263	1.018	1.553	1.310
15015	2.256	1.913	1.162	1.188	1.712	1.496	1.474	1.259
15019	2.776	2.411	1.694	1.687	2.324	2.082	1.372	1.234
15024	3.389	3.024	2.443	2.401	3.116	2.838	1.276	1.182
20012	2.868	2.343	1.007	1.006	1.873	1.620	1.861	1.611
20015	3.523	2.887	1.460	1.393	2.537	2.203	1.738	1.581
20019	4.360	3.586	2.151	1.968	3.478	3.026	1.617	1.537
20024	5.349	4.420	3.118	2.787	4.677	4.087	1.500	1.466
25015	3.789	2.918	1.333	1.148	2.815	2.328	2.112	2.029
25019	4.694	3.854	1.975	1.743	3.844	3.327	1.947	1.909
25024	5.765	4.755	2.856	2.483	5.176	4.493	1.812	1.809
30019	7.748	6.608	2.871	2.587	5.767	5.100	2.008	1.972
30024	9.573	8.194	4.245	3.774	7.777	6.976	1.832	1.848
30030	11.654	10.016	5.968	5.291	10.370	9.329	1.738	1.763
35019	12.300	10.826	4.072	3.680	7.715	6.935	1.895	1.884
35024	15.266	13.482	5.994	5.358	10.659	9.581	1.778	1.788
35030	18.688	16.561	8.709	7.743	14.265	13.011	1.638	1.680
40019	12.450	10.983	3.677	3.398	7.786	7.026	2.118	2.068
40024	15.456	13.680	5.542	4.932	10.732	9.805	1.936	1.988
40030	17.651	16.809	7.459	7.094	13.576	13.305	1.820	1.876

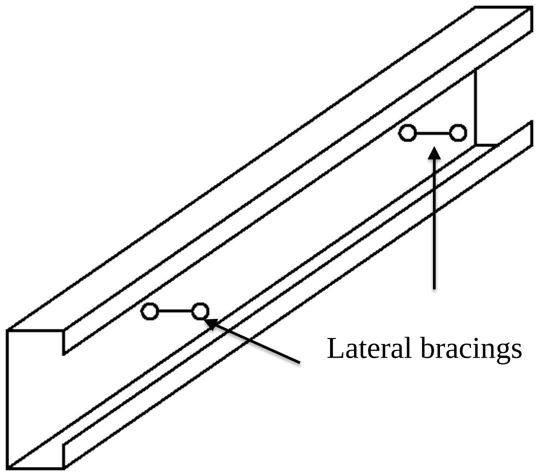


Fig.4 The model configuration

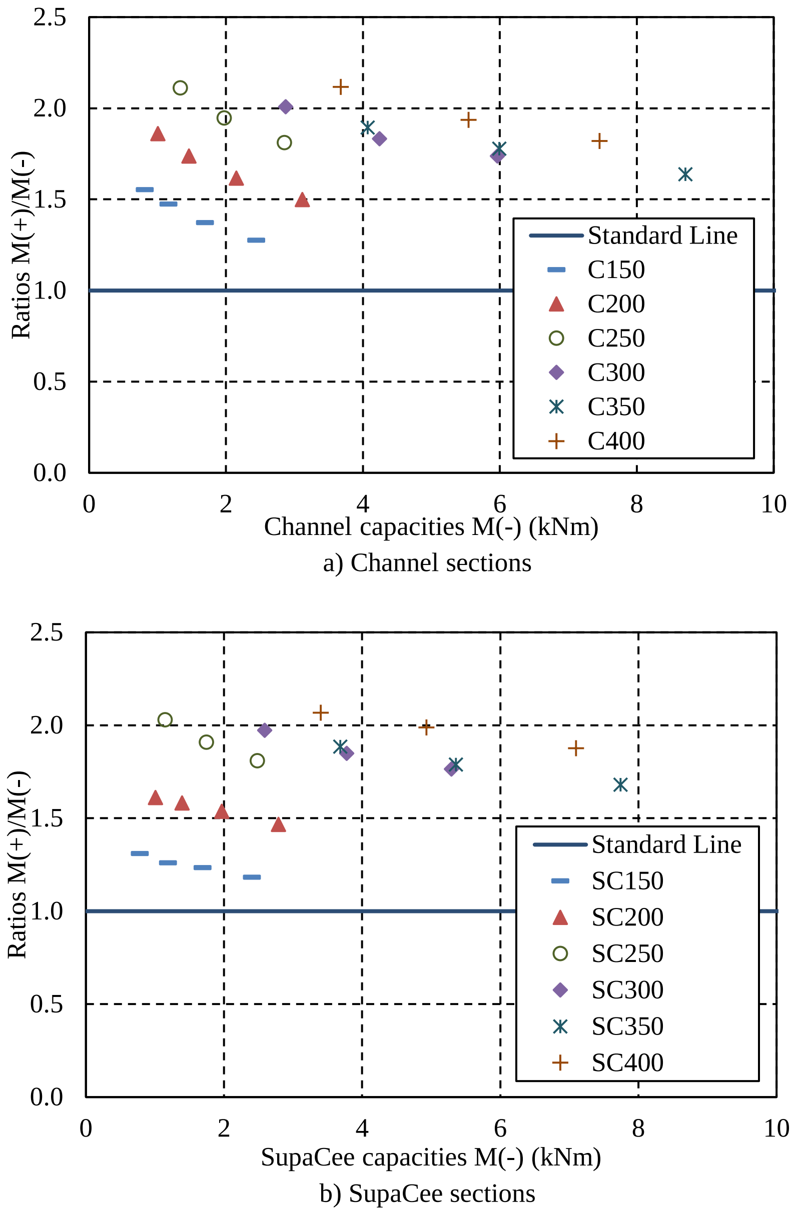


Fig.5 The ratios $M^{(+)}/M^{(-)}$ for channel and SupaCee sections

Although the SupaCee sections have illustrated their strength improvements under the strong-axis bending in comparison with the channel sections, their advantages have not been demonstrated for bending about the weak-axis. Even the capacities of the former sections are lower than those of the later ones, as shown in Table 3. This is explained as a result of the reductions of yield moment (M_y) of SupaCee sections compared to those of the channel sections (see Table 3) due to the significant low second moment of area about the weak-axis (I_y), as discussed in Pham and Vu [10] and Pham [25]. Table 3 also shows that the flexural capacities in the positive moment direction are beneficial compared to those in the negative direction, and this direction, therefore, is recommended for the design. In comparison with the negative moment direction, the positive direction allows the flexural capacities of these such sections to significantly increase, as demonstrated in Fig. 5, in which the horizontal axis is for the flexural capacities of the investigated sections in the negative direction and the vertical one is for the flexural capacity ratios between two directions.

Fig. 5 shows that the ratios $M^{(+)}/M^{(-)}$ undergo a downward trend with the increase in the sectional thicknesses for both channel and SupaCee sections. For example, this ratio is 1.873 for C20012, but is only 1.500 for C20024. This can be explained that the sectional webs become more stable with the increase in sectional thicknesses. Also, the presence of stiffeners in the web of SupaCee sections helps such sections to be more stable due to local buckling; this results in the lower ratios of $M^{(+)}/M^{(-)}$ for these SupaCee sections in comparison with those of channel sections, especially for small sectional dimensions, as shown in Table 3.

6. CONCLUSION

An investigation of the behaviors and flexural capacities of the channel and SupaCee sections about the weak-axis under the variation of moment directions has been presented. The investigated sections were the availably commercial sections in the market, and their capacities were determined using the Direct Strength Method as regulated in the Australian/New Zealand Standard AS/NZS 4600:2018 with the support of the THIN-WALL-2 software program in the elastic buckling analyses. Based on the obtained results, several remarks are drawn as follows:

- The behaviors of the channel and SupaCee sections are varied with the change of bending orientations.
- The flexural capacities are governed by local buckling modes for the negative direction whereas they are distortional buckling modes for the positive direction.
- The sectional capacities of the channel and SupaCee sections are beneficial in the positive bending direction.
- The improved strengths of SupaCee sections under the weak-axis bending are not demonstrated compared to such strengths of the channel sections.

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