Shear Capacity Analysis of Welded Steel I-Girders with Corrugated Webs based on First Yield

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Abstract

Steel I beams or girders with sinusoidal corrugated profile webs have become popular in the recent development of the steel structural designs, since corrugated-web beams (CWBs) can provide better performance in terms of less deformation and more stability against buckling failure. It is verified in previous research that CWBs can be considered as an alternative to replace normal beams in the structural designs with their numerous favourable features. Since CWBs are being used as the main structural elements, it is apparent that some essential practical properties of this type of beams should be studied, where the prediction of the shear capacity is one of the most significant design aspects that should be accurately investigated. Calculations to the design formulas from other standards and several finite element simulations have been carried out to compare the differences in obtained results and to find an adequate approach to calculate the shear capacity of CWBs for the Australian civil engineering community. Ultimate Limit State design theory has been utilised in conjunction with AS4100 (2020) along with linear analysis in SAP2000. By comparing the results of the theoretical calculations and numerical simulations, it has been concluded that the highly formed equations presented by EN 1993-1-5 (2006) and Hancock et al. (2017) could well estimate the shear capacity constraining requirements and rules in accordance with Australian standards, which can be adequately used in Australian structural design fields.

Keywords: *Steel Structures, Steel Beams, Steel Corrugated Web Beams; Shear Capacity of steel beams; SAP2000; Ultimate Limit State Design, Structural design, Load Carrying Capacity, Buckling*

1. Introduction and Background

Corrugated-web beams and girders (CWBs) represent a new constructional system emerged in different structural designs, which offer an intelligent solution to reduce the need of web stiffeners for the post-loading performance problems associated with conventional flat-web beams (Barakat et al 2018; Divaha & Joanna 2018). This type of structural members can provide high resistance to loads before buckling, due to the corrugated-web profile, which makes corrugated-web beams more attractive for researchers and designers. The nature of corrugation, such as trapezoidal or sinusoidal shapes, has been proven to increase the capacities under flexural and shear forces of the steel beams with corrugation (Fisher & Sherman 1971; Abbas et al. 2006; Kuchta 2007; Elchalakani et al. 2018), where the stability of the beams is also enhanced compared to the normal welded beams. Since there is no need to implement web stiffeners and considering lighter beam features, corrugated-web beams have been utilised as main bearing elements in large building constructions and for girder segments in highway or railway bridge designs (Ashrawi et al. 2016; Li et al. 2019). In addition, material properties and characteristics significantly influence the behaviour and performance of structures (Tabatabaiefar et al. 2012; Fatahi & Tabatabaiefar 2014; Tabatabaiefar & Clifton 2016).

Abbas et al. (2007) investigated the flexural strength of the beams with corrugated webs in both theoretical calculations and Finite Element (FE) simulations. They suggested that CWBs had less deflection and higher flexural capacity than the ordinary beams, while the CWBs also performed better in fatigue resistance. Deng et al. (2017) performed several tests to understand the bending behaviour of the corrugated-web beams. After seven investigations for CWBs with different sizes, they concluded that the nature of corrugation did affect the properties of the beams, consisting of lesser girder displacements and strength increment. According to Inaam & Upadhyay (2019), it was verified that the performance of corrugated-web girders was better than the normal beams, in which CWBs had improved stability against shear buckling, lighter weight, and long service life. Zhang et al. (2020) mentioned that the corrugation profile in the corrugated-web beams could significantly reduce the usage of steel materials in the bridge girders. Lee et al. (2019) pointed out that it was possible to save up to 30% of the beam weight with similar mechanical properties to the conventional beams, since the thickness of the webs of the CWBs was thinner without using web stiffeners to reinforce under required design loads. According to Wu et al. (2020), the corrugation in the webs could enhance the steel girder’s strengths and reduce the costs of fabrication and transportation of the beams. Similarly, Lin et at. (2018) carried out beam optimisation for CWBs in comparison to the flat-web beams. In their studies, the optimisation included material saving of up to 20% while maintaining the same flexural and shear strengths compared with the corresponding parent traditional beams. Dmitrieva et al. (2019) carried out 10 sets of experiments with different sizes of CWBs to examine the flexural stress distribution. They concluded that the stress level of CWBs were 4-12% smaller than the ordinary beams, while the deflection was also

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less due to being more rigid than the traditional flat-web beams. All the above-mentioned information of beams with corrugated webs verified that CWBs could replace conventional beams in the real-world designs with less deflection, stronger stability against buckling, and lower material cost.

Since CWBs are actively used in different design fields, some essential properties including post-buckling strength, deflections, and shear capacities of corrugated-web beams need to be investigated. Beams are the significant components to support floors and the loads will be transmitted to the foundation by the beam-column connections (Ingkiriwang & Far 2018; Walsh et al. 2018; Haydar et al. 2018, Far 2019). Therefore, different aspects of strength of structural beams or girders should be clearly determined to eliminate the potential failure of the structures. Shear strength of CWBs has been continuously studied in recent decades, which is one of the most important properties for structural members (Barakat et al. 2018; Far et al. 2017; Saleh et al. 2018).

Due to numerous favourable properties of the beams with corrugated profile, CWBs have been used as main structural elements by some Australian civil engineering community without detailed approach to calculate the shear capacity. Consequently, an acceptable methodology for estimating the shear capacity of corrugated-web beams is highly required to enable designers in Australian regions to utilise this kind of beams, since there are not detailed equations for shear strength computation for sinusoidal corrugated-web beams in AS 4100(1998). This research has been conducted to validate whether the equation combination from EN 1993-1-5 (2006) and Hancock et al. (2017) can be used to estimate the shear capacity of CWBs based on the first yield regarding the rules and limitations provided by Australian Standards. As a result, a detailed approach to compute the shear capacity would be suggested to benefit the Australian engineers and designers in the convenience of applying the CWBs to the structural designs.

2. Theoretical Background

To precisely estimate the shear capacity of the webs, many researchers have created different relationships to reasonably predict the shear strength. Hancock et al. (2017) carried out a stress analysis to CWBs subjected to vertical shear forces in FE simulation, and they proved that the shear stress is uniform over the webs' depth. After comparing the results in their parametric studies, the authors stated that to estimate the shear strength of CWBs, local shear buckling force should be selected rather than using the global shear buckling force, where global shear buckling force was 8578 kN and local shear buckling force was only 671 kN in their examples. EN1993-1-5 (2006), the standard of steel structures – plated structural elements in European Union provides Equations 1 to 3 to determine the shear capacity V_v of CWBs as follows:

$$V_v = V_Y \qquad \text{for} \qquad \lambda_v \leq 0.25 \tag{1}$$

$$V_v = \frac{1.15V_Y}{0.9 + \lambda_v} \qquad \text{for} \qquad \lambda_v > 0.25 \tag{2}$$

where, V_L is the shear buckling load from Equation 3, V_Y is the shear yield force from Equation (3),

$$V_Y = \tau A_W \tag{3}$$

where, τ is equal to $\frac{F_y}{\sqrt{3}}$, F_y is the minimum yielding strength of the beam flange or the web, A_W is the web cross sectional area, and λ_v is calculated by Equation (4),

$$\lambda_v = \sqrt{\frac{V_Y}{V_L}} \tag{4}$$

$$V_L = k_L \frac{\pi^2 E A_W}{12(1-v^2)(\frac{w}{t})^2} \tag{5}$$

where, E is the Young's modulus, v is the Poisson's ratio, w is equal to half of the corrugation length, t is the web thickness, and k_L is computed from Equation (6) for simply supported condition, where h is the depth of the webs.

$$k_L = 5.34 + 4(\frac{w}{h})^2 \tag{6}$$

According to Hancock (2017), the shear capacity determined from equations stated by EN1993-1-5 (2006) has been underestimated, where the data did not fit well with the shear test results.

Hancock & Pham (2012) performed several tests to validate their proposed Equations 7 to 8 with shear buckling force from Equation (5) for the shear strength of corrugated-web beams. After comparing the theoretical results with results from shear tests, the shear capacity from the proposed Equations 6 to 7 has been overestimated with a high coefficient of variation, which could not be considered as conservative designs.

$$V_v = 0.815\sqrt{V_L V_Y} \qquad \text{for} \qquad \lambda_v \leq 1.227 \tag{7}$$

$$V_v = V_L \qquad \text{for} \qquad \lambda_v > 1.227 \tag{8}$$

Other researchers (e.g. Easley 1975; Yi et al. 2008; Abbas et al. 2006) have carried out functional studies to validate the results from shear strength equations with the results from FE simulations and shear tests. However, due to inaccurate determination of k_L or β value, being a reduction factor in their proposed equations, the shear capacity was unexpectedly underestimated or overestimated with a high coefficient of variation in their parametric investigations (Hancock et al. 2017). Sause & Braxtan (2011) pointed out that some of those researchers made inaccurate assumptions regarding the boundary conditions, which should be precisely determined in order to obtain accurate results. The above-mentioned researchers carried out functional investigations to analyse the shear capacity of CWBs. However, accurate results do not seem to be obtained due to inaccurate settings in calculating the shear resistance (Barakat et al. 2018).

In this study, the main objective is to find reasonably appropriate equations to calculate the shear capacity of CWBs for Australian civil engineering community. Equations from EN 1993-1-5 (2006) have been selected as supplementary guidelines by this study to perform a functional numerical investigation. According to several researchers (e.g. Hancock et al. 2017; Barakat et al. 2018), the proposed equations to calculate the shear strength for CWBs with trapezoidal corrugation are reasonably conservative since the highly established relationships of equations could well predict the shear capacity of beams with corrugated webs. Hence, to calculate the shear capacity for CWBs with sinusoidal corrugation, this study will combine equations from EN 1993-1-5 (2006) and Hancock et al. (2017) to achieve this goal. Equation (5) stated by EN 1993-1-5 (2006) will be used as a starting point to precisely estimate the local shear buckling load, which will be utilised in the following Equations 8 and 9 (Hancock et al. 2017) to generate the required shear capacity.

$$V_v = V_y \qquad \text{for} \qquad \lambda_v \leq 0.561 \qquad (9)$$

$$V_v=[1\text{-}0.25(\frac{V_L}{V_y})^{0.6}](\frac{V_L}{V_y})^{0.6}V_y \qquad \text{for} \qquad \lambda_v > 0.561 \qquad (10)$$

where V_L is the shear buckling load from Equation (5), and V_Y is the shear yield force from Equation (3). Hence, the above-mentioned highly structured design equations will be utilised to calculate the shear capacity of CWBs, which will be used to compare with the results generated from finite element modellings via strictly implementing the material properties and other rules stated in Australian Standards. In addition, Hot Rolled and Structural Steel Products property Tables (2018) have been used to provide all the essential information of CWBs' material properties and beam features. Moreover, AS/NZS 1170.1 (2002) was utilised to precisely determine the factors of loads combination, modification factors of design loads, and factors for buckling check.

3. Methodology

According to Lin et al. (2018), CWBs with the corrugation angle of 30° and the corrugation length of 400mm had better mechanical performances against other different corrugation sizes, in which this selected corrugation size will be utilised to replace the flat webs in WBs. A sample demonstration of CWB numerical model is shown in Figure 1 to illustrate the geometry details of the numerical simulation in this study, where the fundamental details of the cross-sectional geometry will be the same as the values listed in the Hot Rolled and Structural Steel Products property tables (2018). In Figure 1, the value of w being half of the corrugation length and the value of h being the beam depth will be used in Equation (3) to estimate the local shear buckling force. The top flange, being the compression flange, is fully restrained and then the lateral torsional buckling is prevented. Before performing the analysis of shear behaviour of CWBs, it is necessary to carry out the elastic buckling analysis to ensure the safety conditions of the webs against the web buckling, since the original flat webs have been replaced with corrugated webs. As stated in AS/NZS 1170.1 (2002), all buckling factors should be greater than 1.0 based on each CWB's design load combination for strength analysis to indicate the safe conditions of the web. If the buckling factor of a CWB is found to be less than 1, the web of that particular CWB will fail due to web buckling, which consist of lateral-torsional buckling, flexural-torsional buckling, global buckling and local buckling (Computers and Structures 2020).

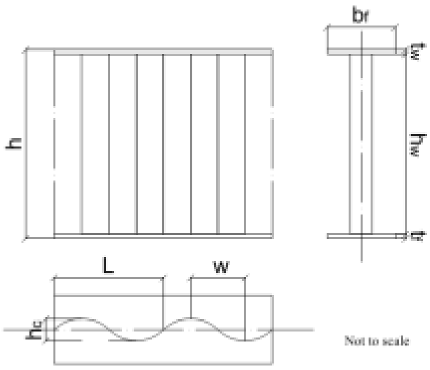


Figure 1. A sample elevation of a CWB.

To investigate the shear capacity of CWBs with sinusoidal corrugation, a comprehensive numerical investigation has been performed using SAP2000 non-linear finite element analysis software (Computers and Structures 2020), in which the shear capacities obtained from computer-based simulation will be compared with results from the theoretical calculations using Equations (5, 9 & 10) stated by EN 1993-1-5 (2006) and Hancock et al. (2017).

3.1 Numerical Simulation Assumptions

This study has made the following assumptions to carry out appropriate analysis using SAP2000 FE simulations, and a representative illustration of meshed model is shown in Figure 2, where the top flange will be loaded with uniformly distributed load. The SAP2000 software displays the distributed load as the green label in each meshed area to present the area load shown in Figure 2.

- The beam length of 5 metres, being the middle length of 3-7 metres, is commonly used as the main structural elements in Australian buliding industries, and the supporting condions of CWBs were simply supported.
- All loads are modelled as a constant pressure to precisely represent the maximum uniformly distributed load to the compression flanges, where the critical top flanges were fully restrained against lateral tortional buckling.
- All elements of CWBs were meshed using the FE simulation standard shell elements featured by SAP2000, and Figures 2 and 3 have depicted details of a typical FE model.
- To prevent the twisting of the beams, two 10-mm-thick stiffner plates were applied at both ends of each CWB as illustrated in Figure 3. Pin and roller supports were modelled by constraining the nodes along the stiffner's mid-depth. To eliminate rigid-body deformation along the beam's axis, the same stiffener nodes were also restricted at only one end of the CWBs in the beam's longitudinal direction.

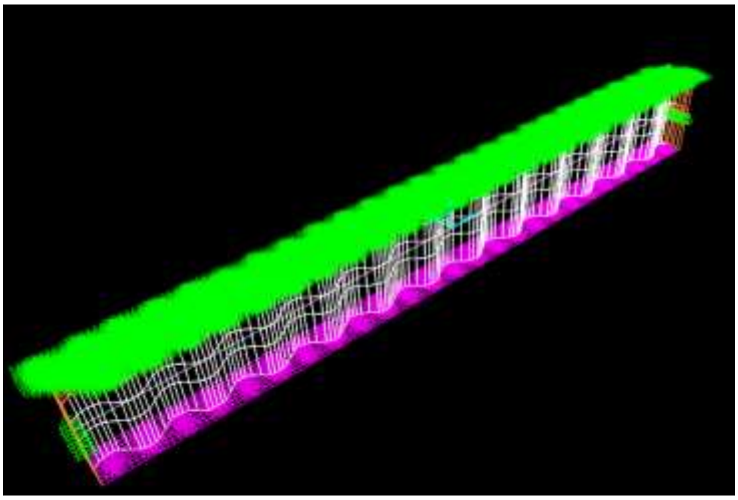


Figure 2. Illustration of a 3-D beam model with end stiffeners subjected to a UDL

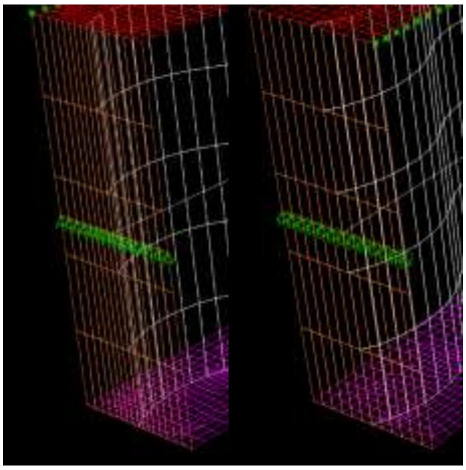
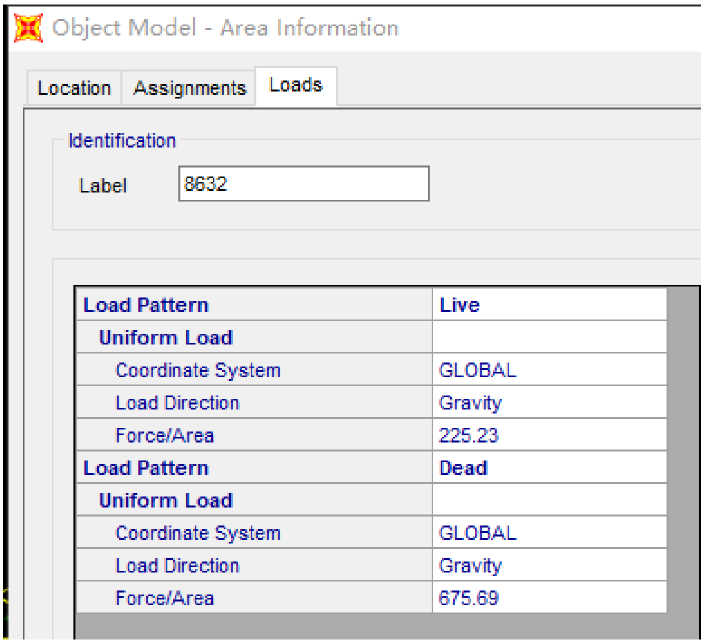


Figure 3. Details of pin supports and roller supports at beam-ends

3.2 Design and Analysis Parameters

Many researchers (e.g. Abbas et al. 2007; Deng et al. 2017; Lin et at. 2018) have pointed that the corrugation nature will enhance the bending and shear strengths of CWBs. To initiate the primary loading that each CWB can safely carry, the uniformly distributed load (UDL) ω^* is defined as the maximum UDL for each CWB to reach the maximum allowable stress on the first yield. According to AS4100 (2020), the maximum allowable flexural stress is 0.9 f_y and that for shear resistance is 0.6 f_y. A trial and error process will be carried out to find the maximum bending moment that each CWB could safely resist, where this process will be stopped as one of the stress level approaches the corresponding stress limitation. Once the maximum bending moment is found, the corresponding maximum UDL ω^* that the each CWB could safely carry will be recorded, and then the maximum shear force for each CWB could be obtained.

Concerning the load inputs to the FE simulations in SAP2000, according to AS/NZS 1170.1 (2002), the primary design load is equal to 1.2DL + 1.5LL, where DL is the dead load and LL is the live load. By Assuming the calculated ω^* can properly represent the design action combination for bending strength and DL =3LL from practical suggestion from Australian civil engineering communities, the force inputs to SAP2000 can be expressed as DL= ω^*/ 1.7 and LL = ω^* / 5.1, and a typical example is depicted in Figure 4.



Label 8632

Load Pattern	Live
Uniform Load	
Coordinate System	GLOBAL
Load Direction	Gravity
Force/Area	225.23
Load Pattern	Dead
Uniform Load	
Coordinate System	GLOBAL
Load Direction	Gravity
Force/Area	675.69

Figure 4. Inputs of dead load and live load

To further demonstrate the applied methodology in this paper, a detailed flowchart is illustrated in Figure 5.

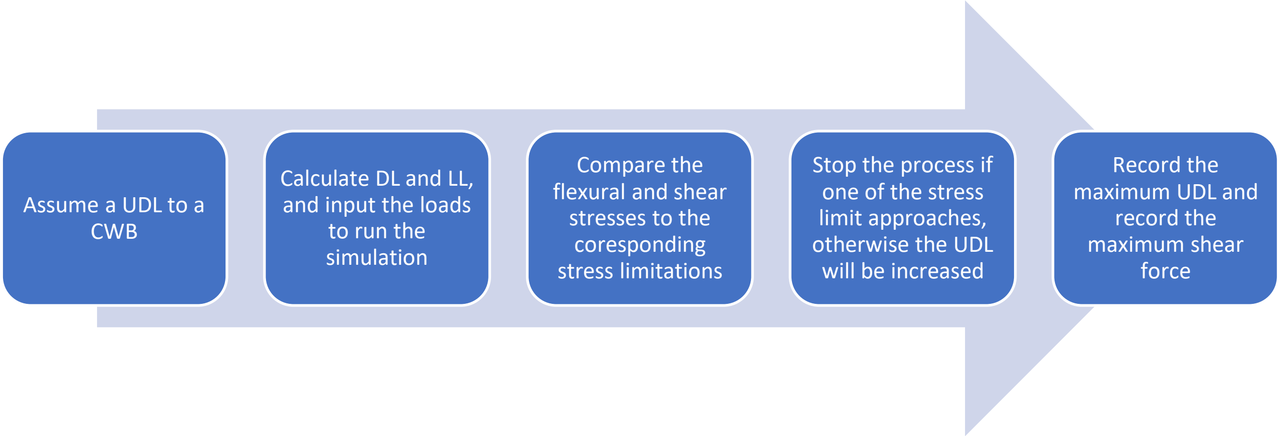


Figure 5. The methodology flowchart

In this study, two different structural steel grades, being 300PLUS-300 and 300PLUS-280, have been used to model the CWBs, and the mass density of structural steel equates to 7849 kg/m^3. Other essential material properties as required by above-mentioned equations are depicted in Table 1.

Table 1. Illustrations of Material types of WB beams.

	Grade	*f_y (MPa)*	*v*	*E (MPa)*
700WB115	300PLUS-300	300	0.25	200000
800WB122	300PLUS-300	300	0.25	200000
900WB175	300PLUS-300	300	0.25	200000
1000WB215	300PLUS-300	300	0.25	200000
1200WB249	300PLUS-280	280	0.25	200000

4. Validation of the Developed Numerical Model

Many researchers (e.g. Martins et al. 2012; Calenzani et al. 2012; Oliveira et al. 2016) have carried out numerical and functional studies on different behaviours of beams with corrugated webs. To validate the accuracy of the FE simulation models featured by SAP2000 in this study, the numerical results generated from those models have been compared against the results of practical experiments by Martins et al. (2012). Martins et al. (2012) performed parametric experiments on three full-scale composite connections for CWBs, containing PSS 600×150×12.5×2.0 for specimens 1 and 2 and PSS 600×150×8/ 12.5×2.0 for specimen 3. Considering the similar features in beams' geometry to the developed CWBs' models in this study, the specimen 1 has been selected for functional numerical verification, in which the same FE method with shell elements used in this study was implemented to the tested beam to generate essential results for comparison. The results from finite element analysis using the same approach adopted to the CWB models in this study have been verified against the load-deformation curve published by Martins et al. (2012) in Figure 6.

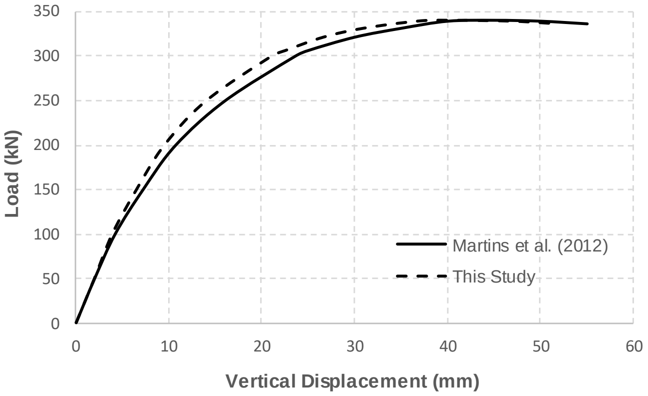


Figure 6. Load-deflection curves estimated by the numerical model developed in this study with the experimental data reported by Martins et al. (2012).

As apparently depicted by Figure 6, the trends and the reuslts of the parametric and functional responses, obtained from the developed FE models in SAP2000 in this study, shows good agreement and consistency with the practical results published by Martins et al. (2012). Consequently, the developed numerical model in this study can be considered as conservative models to represent the real physical and mechanical behaviours of structural steel I girders with corrugated webs. The accuracy of the developed SAP2000 FE models has been validated by the good agreement between the functional numerical predictions in this study and the tested results by Martins et al. (2012). As a result, predictions give high degrees of confidence in the practical use of the developed finite element model.

5. Results

In this study, 5 different welded beams from each category of structural steel sections in the Hot Rolled and Structural Steel Products property Tables (2018) are chosen to carry out the investigations, where the original flanges of these five WBs will be welded with new corrugated webs to form new CWBs. Hence, the new designations are named as 700CWB15, 800CWB122, 900CWB175, 1000CWB215, and 1200CWB249. For 700CWB115 and 800CWB122 simulations, the beams will be remodelled with thickness of 7mm, 8mm, 9mm and 10mm. For 900CWB175 model simulations, the tested web thicknesses are 9mm, 10mm, 11mm, and 12mm, while the web thicknesses are 13mm, 14mm, 15mm, and 16mm for 1000CWB215 and 1200CWB249. All necessary values of beam features and mechanical properties of each CWB are summarised in Table 2 to be utilised in the shear force calculations.

Regarding the theoretical analysis, it starts with Equation (5) to calculate the shear buckling force. The parameter k_L is calculated using Equation (6), and then all shear buckling forces can be generated by Equation (5) and shown in Table 3. The shear yielding force V_y is estimated by the multiplication of the average web shear stress τ and the cross sectional area of the web. After that, the determination factor λ_v is calculated from Equation (4). Since all values of λ_v are greater than 0.561 given in Table 3, the nominal shear capacity V_v of each corrugated-web beam should be determined using Equation (9) as stated in Section 2. According to AS4100 (2020), the nominal shear capacity of each CWB from Equation (9) should all multiply by 0.9 to take the uncertainties and inherent variabilities in material properties or geometry into account and all nominal shear capacities are tabulated in Table 3.

Table 2. Essential properties of Corrugated-web beams

	τ (MPa)	w (mm)	t (mm)	h (mm)	Aw (mm^2)	k_L
700CWB115	173.21	200	7	660	4620	5.91
	173.21	200	8	660	5280	5.91
	173.21	200	9	660	5940	5.91
	173.21	200	10	660	6600	5.91
800CWB122	173.21	200	7	760	5320	5.77
	173.21	200	8	760	6080	5.77
	173.21	200	9	760	6840	5.77
	173.21	200	10	760	7600	5.77
900CWB175	173.21	200	9	860	7740	5.83
	173.21	200	10	860	8600	5.83
	173.21	200	11	860	9460	5.83
	173.21	200	12	860	10320	5.83
1000CWB215	173.21	200	13	960	12480	5.73
	173.21	200	14	960	13440	5.73
	173.21	200	15	960	14400	5.73
	173.21	200	16	960	15360	5.73
1200CWB249	161.66	200	13	1120	14560	5.58
	161.66	200	14	1120	15680	5.58
	161.66	200	15	1120	16800	5.58
	161.66	200	16	1120	17920	5.58

Table 3. Shear force calculations of CWBs.

	V_L (kN)	V_y (kN)	λ	V_v (kN)
700CWB115	2245	800.2	0.597	716.5
	1927	914.5	0.689	784.6
	1540	1028.9	0.817	803.9
	1248	1143.2	0.957	798.7
800CWB122	2621	921.5	0.593	885.7
	2347	1053.1	0.67	913.1
	2021	1184.8	0.766	942.3
	1658	1316.4	0.891	969.99
900CWB175	4400	1340.6	0.602	1432.8
	4200	1489.6	0.596	1459.5
	4250	1638.6	0.621	1499.8
	3262	1787.5	0.792	1534.6
1000CWB215	4850	2161.7	0.668	1876.7
	4350	2327.9	0.732	1939.7
	4050	2494.2	0.785	1998.5
	3694	2660.5	0.849	2028.1
1200CWB249	7025	2353.8	0.602	2205
	6455	2534.9	0.627	2246.3

	6054	2715.9	0.67	2355
	5524	2897	0.724	2426.2

Concerning the finite element analysis, CWBs are subjected to uniformly distributed loads to investigate the shear behaviours by using the finite element function in SAP2000. Before the shear investigations, the elastic buckling analysis need to be performed since the web geometries of CWBs have been changed. For each elastic buckling analysis of a CWB with different web thicknesses, SAP2000 will provide four buckling factors to check the safety of the web of each CWB corresponding to the four different buckling modes as mentioned in Section 3. The minimum valve among the four factors will be selected to compare with the limitation by AS/NZS 1170.1 (2002).

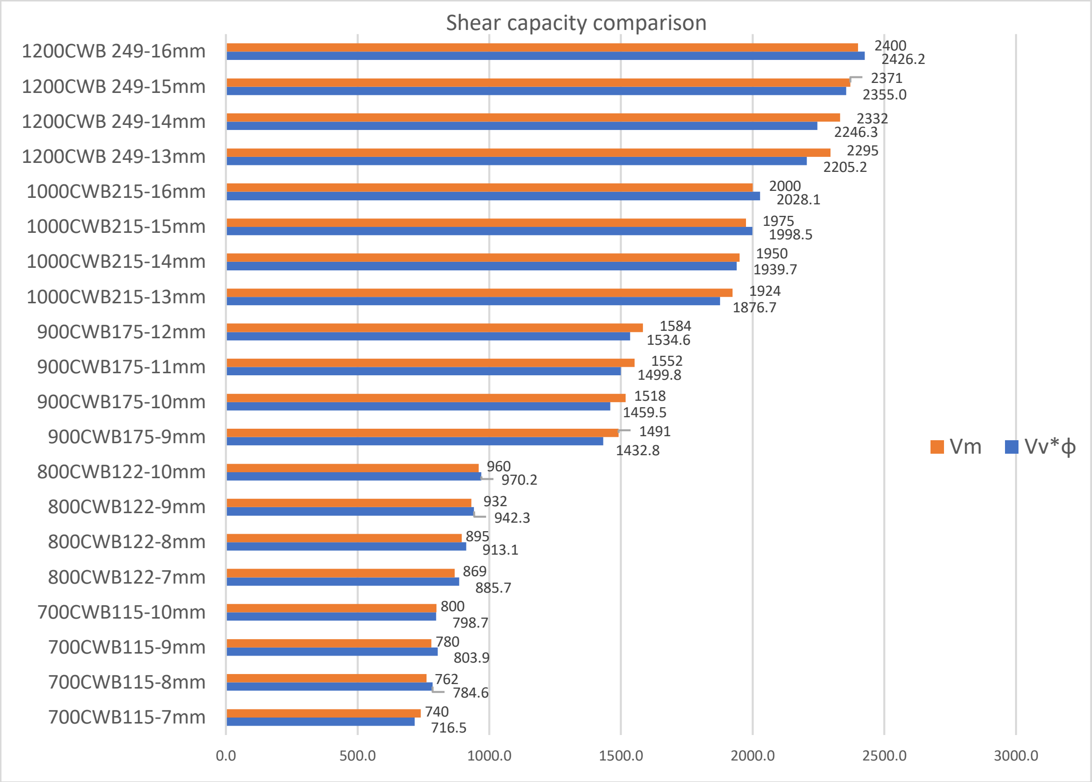
Table 4 has demonstrated that all buckling factors are higher than the minimum value of 1, which means that all webs with corrugated shape are adequate against the web buckling modes. After that, the maximum shear force that each CWB can safely carry is obtained and illustrated in Figure 7 for the comparisons to the theoretical values.

Table 4. Buckling factor check for CWBs.

	Buckling factors
700CWB115	3.5481
	4.5154
	4.9442
	6.7957
800CWB122	4.4525
	4.8841
	5.0157
	5.3619
900CWB175	5.8942
	6.0265
	6.3584
	6.4498
1000CWB215	5.5428
	5.8468
	6.0654
	6.3859
1200CWB249	8.7215
	8.9248
	9.2514
	9.7991

Figure 7 has summarised the shear capacity of CWBs both in FE models and the highly structured formulas. It is obviously that the estimated shear capacities with capacity factors are quite similar to those forces in the finite element analysis. For the tested CWBs with different web thicknesses, the capacity differences are located in the range of 1–3.3%, 1-2%, 3-4%, 1-2.6%, and 1-4% of the five groups respectively. The smallest differences are found in the 800CWB122 group, followed by the 1000CWB215 group, while the highest differences are shown in the 900CWB175. Despite the capacity results of 900CWB175 group in formula-based calculation are 3-4% less than those in FE models, which can be recognised as slightly underestimating the shear capacity for this grade of CWB with various web thicknesses. Considering the conservative requirements for the safety design, the 3-4% differences are within the acceptable tolerance to be used as the main load-carrying elements in the buildings. Overall, the theoretical results show good consistency with the simulation-based results in all five grades of corrugated-web beams.

Figure 7. Shear capacity comparisons.



CWBs have been validated to have many favourable properties containing low material cost, less deformations, better stability and stronger strengths by many researchers as mentioned in Section 1, and these advantages can assist CWBs to gain more attentions from engineers and designers from different design areas. In this study, the similar values in the comparisons reveal that the numerical approaches from EN 1993-1-5 (2006) and Hancock et al. (2017) are sufficient to estimate the conservative shear capacities for beams with sinusoidal-corrugation webs properly in conjunction with limitations and requirements in Australian standards, where the highly structured equations have high degree of reliability and applicability to predict the shear strength of CWBs for designers in the Australian civil communities.

6. Conclusions

In this parametric study, functionally theoretical calculations and finite element analysis have been performed to find out appropriate equations to estimate the shear capacity for steel I girders and beams with corrugated-profile webs profile webs based on the first yield. Ultimate Limit State design theory has been used in conjunction with AS4100 (2000) in this numerical study along with material and geometric non-linearity in the FE simulations in SAP2000. After finalising the two groups of data, the differences in the results are found between 1% to 4.2%, and the small percentages of differences could be considered to be reasonable and acceptable in the requirements of the conservative safety design. The highly developed design formulas can create more conveniences to Australian civil community to select this type of beams as an alternative to the traditional flat-web WBs in their varied designs, since there is not direct technique in Australian standards to compute the shear capacity to beams with sinusoidal-corrugation webs. By comparing the results both in formula-based approach and FE simulations, it is safe to state that this set of design equations can properly calculate and predict the shear capacity of the corrugated-web beams. In conclusion, this numerical approach mentioned by EN 1993-1-5 (2006) and Hancock et al. (2017) to estimate the shear capacity can be used, with acceptable accuracy, for practical designs in accordance with Australian standards with the following limitations:

- The highly structural equations could be applied to estimate the shear capacity for CWBs when the λ_v of each CWB is greater than 0.561, otherwise Equation (6) should be used to estimate the shear resistance.
- The shear capacity calculated in this paper is an instant strength based on the first yield. In the FE simulations, once the stress levels of each CWB approach the stress limitations given by AS4100 (2020), which is 0.9* f_y for the bending stress or 0.6* f_y for the shear stress, the maximum UDL that each CWB could resist will be recorded and the corresponding maximum shear force could be obtained.

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