



Stub column tests of thin-walled complex section with intermediate stiffeners

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ABSTRACT

A series of stub column tests on complex sections with intermediate stiffeners is presented in this paper. Initial geometric imperfections and material properties of the test specimens were measured. It is shown that the intermediate stiffeners could effectively enhance the local buckling stress of thin-walled sections. The test strengths are compared with the design strengths calculated using the direct strength method in the North American Specification and Australian/New Zealand Standard for cold-formed steel structures. It is shown that the direct strength method using finite strip method to obtain the buckling stresses is very conservative. Therefore, finite element method was used to predict the elastic buckling stresses. It is shown that the design strengths calculated using direct strength method based on the buckling stresses obtained from finite element analysis results generally agree with the test results well.

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1. Introduction

The use of thin-walled steel structural members has increased in building construction in recent years. In thin-walled steel structural members, individual elements are usually thin and the width-to-thickness ratios are large. These thin elements may buckle locally at a stress level lower than the yield point of steel when they are subject to compression. Therefore, unusual sectional configurations are often produced by cold-forming operations, and consequently favorable strength-to-weight ratios can be obtained [1]. When the width-to-thickness ratio of a stiffened compression element is relatively large, local buckling will reduce the full strength of the member. Intermediate web stiffeners are added to the compression element to enhance the local buckling stress [2]. However, the complex section also makes the design procedure of those sections complex [3,4].

The North American Specification [5,6] and Australian/New Zealand Standard [7] for cold-formed steel structures have design provisions for intermediate web stiffeners using effective width approach, however the design provisions are not applicable to the sections that were tested in this study. The advantage of using the direct strength method is that it can accommodate for unusual shape sections. However, the direct strength method developed by Schafer and Peköz [8] and Schafer [9] was based on open sections, such as the simple lipped channel, lipped channel with

web stiffeners, Z-section, hat section and rack upright section. Therefore, there is a need to investigate the appropriateness of the direct strength method on the type of cold-formed steel sections with intermediate web stiffeners.

The purpose of this paper is firstly to present a series of stub column tests on the cold-formed steel sections with intermediate web stiffeners. Secondly, the test strengths are compared with the design strengths obtained using the direct strength method in the North American Specification [5,6] and Australian/New Zealand Standard [7] for cold-formed steel structures. In the calculation of the direct strength method, local and distortional buckling stresses are required. In this study, two different methods, namely finite strip method and finite element method were used to obtain these stresses. The appropriateness of the direct strength method on the thin-walled steel stub columns with intermediate web stiffeners is investigated.

2. Experimental investigation

2.1. Test specimens

The test specimens of complex section were brake-pressed from structural steel sheets having nominal thickness of 2.0 mm. Each specimen was cut to a specified length of 400 mm, and both ends were milled flat by an electronic milling machine. The ends of the specimen were then welded to 10-mm-thick steel plates to ensure full contact between specimen and end bearings. Table 1

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Nomenclature

The following symbols are used in this paper

A	gross cross-section area
b_f	width of flange;
b_w	width of web;
E	Young's modulus;
f_{od}	elastic distortional buckling stress of cross-section;
f_{ol}	elastic local buckling stress of cross-section;
f_y	yield strength;
f_1, f_2, f_3, f_4, f_5	dimensions of intermediate web stiffeners;
L	length of column specimen;
P_{crd}	critical elastic distortional column buckling load;
P_{cre}	critical elastic column buckling load in flexural buckling;
P_{crl}	critical elastic local column buckling load;
P_{DSM}	nominal axial strength calculated using the direct strength method (unfactored design strength);
P_{DSM-FS}	P_{DSM} for buckling stresses obtained using finite strip method;

$P_{DSM-FS-M}$	P_{DSM} for buckling stresses obtained using modified equation;
$P_{DSM-FEA}$	P_{DSM} for buckling stresses obtained using finite element method;
P_{Exp}	experimental ultimate load (test strength);
P_{nd}	nominal axial strength for distortional buckling;
P_{ne}	nominal axial strength for flexural buckling;
P_{nl}	nominal axial strength for local buckling;
P_y	squash load;
r_i	inside corner radius at flanges of specimen;
t	plate thickness of specimen;
w_1, w_2, w_3, w_4, w_5	dimensions of intermediate web stiffeners;
λ	distortional buckling number of distortional half-waves along the length;
$\lambda_c, \lambda_d, \lambda_l$	non-dimensional slenderness used in direct strength method;
$\sigma_{0.2}$	0.2% proof yield stress; and
σ_u	ultimate tensile strength.

shows the measured cross-section dimensions of the test specimens, using the nomenclature defined in Fig. 1. The test specimens are labeled according to their cross-sections from Sections 1–4, as shown in Fig. 1.

The initial local imperfections of the test specimens were measured prior to testing. Initial local geometric imperfections were measured on each specimen. The imperfections were measured on all faces of the sections. The measurements were taken at mid-length of the specimens. A feeler gauge of 0.005 mm was used to measure the initial local geometric imperfections. The maximum value of local imperfection measurements is 0.25 mm.

2.2. Tensile coupon tests

Tensile coupon tests were conducted to obtain the material properties of the test specimens. The coupons were taken from the structural steel sheet and cold-formed specimens. For cold-formed specimen, the coupons were taken from the center of the web plate of Section 2, which is the center of element w_3 as shown in Fig. 1, in the longitudinal direction of the finished specimens belonging to the same batched as the column test specimens. The coupon dimensions conformed to the Australian Standard AS 1391 [10] for the tensile testing of metals using 12.5-mm-wide coupons. The coupons were also tested in accordance with the AS 1391 [10] in a displacement-controlled testing machine using friction grips. A calibrated extensometer of 50 mm gauge length was used to measure the longitudinal strain. A data acquisition

system was used to record the load the readings of strain at regular intervals during the tests. The values of Young's modulus (E), 0.2% proof stress ($\sigma_{0.2}$) and tensile strength (σ_u) are shown in Table 2. The typical stress–strain curves are shown in Fig. 2.

2.3. Test rig and operation

The test rig and the test set-up of the column tests are shown in Fig. 3. A hydraulic testing machine was used to apply compressive axial force to the column specimens. Two 10-mm-thick steel end plates were welded to the ends of the specimen. Three dial gauges were positioned on the top end plate of the specimen to measure the axial shortening of the column. In addition, seven strain gauges were also used to measure the strain of the column at mid-length. Four strain gauges were attached at the four corners and the other three strain gauges were attached at the middle of the web, as shown in Fig. 4. A data acquisition system was used to record the applied load and the readings of the strain at regular intervals during the tests.

2.4. Column test results

The test ultimate loads (P_{Exp}) and failure modes of the columns are shown in Table 3. Repeated tests were conducted for each section and the test results for the repeated tests are very close to their first test values, with differences ranging from 1.0% to 4.7%. The small differences between the repeated test values and their first test values demonstrated the reliability of the test results.

Table 1
Measured dimension of test specimens.

Section	Length (mm)	Thickness (mm)	Lip (mm)	Flange (mm)						Web (mm)					
	L	t	B_l	B_f	f_1	f_2	f_3	f_4	f_5	B_w	w_1	w_2	w_3	w_4	w_5
1A	401.0	1.98	14.9	149.6	–	–	–	–	–	149.5	–	–	–	–	–
1B	400.0	1.99	14.8	149.5	–	–	–	–	–	149.6	–	–	–	–	–
2A	400.0	1.98	15.0	150.0	–	–	–	–	–	151.0	40	22	40	22	40
2B	399.8	2.0	14.9	150.0	–	–	–	–	–	151.0	40	22	40	22	40
3A	400.5	2.0	15.0	149.3	40	22	40	22	40	151.1	–	–	–	–	–
3B	400.0	1.98	14.8	149.5	40	22	40	22	40	151.3	–	–	–	–	–
4A	399.5	2.0	–	150.2	40	22	40	22	40	151.4	40	22	40	22	40
4B	400.8	2.0	–	150.2	40	22	40	22	40	152.6	40	22	40	22	40

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