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Method Considered Distortional-local Interaction Buckling for Bearing Capacity of Channels with Complex Edge Stiffeners and Web Stiffeners under Axial Compression

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Abstract. Using the current direct strengths method to predict the bearing capacity of channels with complex edge stiffeners and stiffeners in the web, it will make the excessively conservative results to the test data for it couldn't account for the interaction between distortional and local buckling. In order to study the method for bearing capacity of channels with complex edge stiffeners and web stiffeners under axial compression, the paper revised the current direct strengths method and new proposals considered distortional and local interaction buckling were made. The proposed method was verified by the finite element analysis results and the test results. It shows that the member strength predicted by the proposed method is more accurate than the present method and agrees well with the test data. Furthermore, compared with the results of the finite element method and hand method, the hand method for calculating elastic buckling critical stress of web-stiffened lipped channels with complex edge stiffeners was validated.

1 Introduction

Cold-formed steel sections are commonly used in a variety of applications including residential construction. With the reduction in thickness and variation in sections, distortional buckling modes have become control actions in structural instabilities gradually. Effective width method is the common approach in current codes for all countries, but the process of calculation is too complicated and the influence of distortional buckling is not considered. Direct strength method (DSM) developed recently is able to handle both local and distortional effects and has simple but accurate calculation. However, its application to members affected by distortional-local interaction buckling is still under development. Widely accepted DSM for channels with complex edge stiffeners and web stiffeners is lacking.

In recent years, the study on calculation method of the stiffened members' bearing capacity has been carried out in China and abroad. But about channels with complex edge stiffeners and web stiffeners under axial compression, there is no well established method. The paper deals with the ultimate strength and design of pin-ended channel columns with complex edge

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stiffeners and web stiffeners under axial compression. The aim of this paper is to put forward a method considered distortional-local interaction buckling.

2 Current Direct Strength Method

The DSM provides an efficient approach to estimate the ultimate strength of cold-formed steel columns considered failing in local-global interactive and distortional-global interactive modes[1]. The formula for calculation is as follows.

$$P_{nl}=\begin{cases} P_{ne} & \lambda_l \le 0.776 \\ \left[1-0.15\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.4} P_{ne} & \lambda_l > 0.776 \end{cases} \tag{1}$$

where $\lambda_l = \sqrt{P_{ne}/P_{crl}}$; $P_{crl} = A\sigma_{crl}$;and σ_{crl} means local critical buckling stresses; P_{ne} means overall stability bearing capacity.

$$P_{nd}=\begin{cases} P_{ne} & \lambda_d \le 0.561 \\ \left[1-0.25\left(\frac{P_{crd}}{P_{ne}}\right)^{0.6}\right]\left(\frac{P_{crd}}{P_{ne}}\right)^{0.6} P_{ne} & \lambda_d > 0.561 \end{cases} \tag{2}$$

where $\lambda_d = \sqrt{P_{ne}/P_{crd}}$; $P_{crd} = A\sigma_{crd}$;σ_{crd} means distortional critical buckling stresses.

The column nominal strength is the lower of the local-global interactive and distortional-global interactive failure stresses.

The domestic method considered local-global interaction buckling [2] is determined by

$$P_{nl}=\begin{cases} P_{ne} & \lambda_l \le 0.847 \\ \left[1-0.10\left(\frac{P_{crl}}{P_{ne}}\right)^{0.36}\right]\left(\frac{P_{crl}}{P_{ne}}\right)^{0.36} P_{ne} & \lambda_l > 0.847 \end{cases} \tag{3}$$

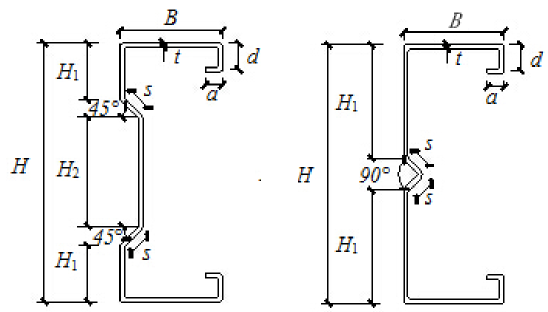
The domestic method considered distortional-global interaction buckling is identical to Eq. 2, but the integral stability coefficient of specimen is determined by domestic code.

The current method only considered local-global interactive and distortional-global interactive buckling, but the buckling mode of specimen with web stiffener mostly is interaction of local, distortional and overall buckling modes. The formula proposed by Yap [3] is suitable for fixed-ended lipped channel columns, but for pin-ended complex lipped channel it is necessary to study the direct strength method of the bearing capacity of channels with complex edge stiffeners and web stiffeners under axial compression.

3 The Elastic Buckling Stress of Channels with Complex Edge Stiffeners and Web Stiffeners

The elastic buckling stress is essential for the calculation of direct strength method. The finite strip program of CUFSM was used to calculate the elastic buckling stress of channel columns with complex edge stiffeners and web stiffeners under axial compression. The results of the finite strip and hand methods were compared with each other, and the hand method of elastic buckling critical stress was validated. The buckling stress of channels with complex edge stiffeners and interactive V type stiffeners has been studied by Wang Chungang [4] and with complex edge stiffeners and interactive ∑ type stiffeners was studied in this paper.

The cross section forms used for analysis are shown in Fig.1. There are three kind of specimen length(L=1m, 2m, 3m); two kind of thickness(t=1mm, 2mm); two kind of web height(H=180mm 、 220mm); $E=2.06\times10^5$MPa; υ=0.3; f_y=345MPa; the flange width B=90mm, the first lip width d=25mm, the second lip width a=15mm. In the specimen label, C2 means channels with complex edge stiffeners and interactive ∑ type stiffeners and C3 means with complex edge stiffeners and interactive V type stiffeners. L and the number then represents effective length; the letter s and h means H=180mm, H=220mm respectively; the number 1 and 2 means t=1mm, t=2mm; the letter a to e in C2 section means H_1/H_2=0.5, 1.0, 1.5, 2.0, 3.0 and a, b in C3 section means s=20mm, 26mm.



a) C2 b) C3

Fig. 1 Cross section form and geometric parameters definition of test specimen

4 The local buckling stress

The hand method of elastic local buckling stress proposed by Schafer [5] is suited for channels with interactive V type stiffeners. As shown in Table 1, the results of hand method coincided with the analysis results approximately, and the elastic local buckling critical stress of channels with ∑ type section is also predicted by this simplified formula.

Table 1 The Elastic Local Buckling Critical Stress Of Channels With Σ Type Section

Specimen	Schafer	CUSFM	$\sigma_{crl}/\sigma_{crl}'$
	σ_{crl}/MPa	σ_{crl}'/MPa	
C2L1000s1a	124.95	132.25	0.945
C2L1000s2a	499.81	521.39	0.959
C2L1000h1a	118.03	121.67	0.970
C2L1000h2a	472.12	475.29	0.993
C2L1000s1b	116.34	128.12	0.908

C2L1000s2b	465.35	514.23	0.905
C2L1000h1b	108.63	125.59	0.865
C2L1000h2b	434.52	500.23	0.869
C2L1000s1c	118.64	128.97	0.920
C2L1000s2c	450.15	509.95	0.883
C2L1000h1c	112.27	125.54	0.894
C2L1000h2c	449.08	496.67	0.904
C2L1000s1d	124.20	128.27	0.968
C2L1000s2d	496.79	507.24	0.979
C2L1000h1d	118.37	123.80	0.956
C2L1000h2d	473.48	489.79	0.967
C2L1000s1e	131.69	127.36	1.034
C2L1000s2e	526.78	503.72	1.046
C2L1000h1e	126.73	120.83	1.049
C2L1000h2e	506.41	476.41	1.063
Average			0.954
StDev			0.061

Table 2 The Elastic Distortional Buckling Critical Stress Of Channels With Σ Type Section

Specimen	Hancock	CUSFM	$\sigma_{crd}/\sigma_{crd}'$
	σ_{crd}/MPa	σ_{crd}' /MPa	
C2L1000s1a	134.57	138.80	0.970
C2L1000s2a	291.64	288.24	1.012
C2L1000h1a	117.76	114.22	1.031
C2L1000h2a	254.04	237.84	1.068
C2L1000s1b	134.57	138.37	0.973
C2L1000s2b	291.64	287.35	1.015
C2L1000h1b	117.76	114.58	1.028
C2L1000h2b	254.04	238.49	1.065
C2L1000s1c	134.57	137.56	0.978
C2L1000s2c	291.64	285.55	1.021
C2L1000h1c	117.76	113.64	1.036
C2L1000h2c	254.04	236.57	1.074
C2L1000s1d	134.57	136.91	0.983
C2L1000s2d	291.64	284.13	1.026
C2L1000h1d	117.76	112.73	1.045
C2L1000h2d	254.04	234.71	1.082
C2L1000s1e	134.57	136.04	0.989
C2L1000s2e	291.64	282.20	1.033
C2L1000h1e	117.76	111.42	1.057
Average			1.029
StDev			0.037

5 The distortional buckling stress

It is found that the influence of the interactive V type stiffener on the distortional stress of the section is very small. The formula proposed by Hancock [6] is suited for channels with interactive V type stiffeners. The comparison result of distortional stress of channels with Σ type section calculated by hand method and software analysis is shown in Table 2.

6 The Global Buckling Stress

Setting up the middle stiffeners doesn't have a significant effect on the overall stability. The method of global buckling stress was introduced in literature [7].

6.1 Proposed Design Method for bearing capacity of channels with complex edge stiffeners and web stiffeners under axial compression

As shown in Table 3. Using present direct strengths method to predict the bearing capacity of channels with complex edge stiffeners and stiffeners in the web, it will make the excessively conservative results to the test data.

In order to consider the enhancement of bearing capacity by stiffening, the magnification factor has been introduced into P_{nd}. $\sqrt{P_{uf}/P_{nd}}$ is used as ordinate and P_{nl}/P_{crd} is used as abscissa. The results are showed in Fig2. It's obvious that regularities of distribution seem to be linear. The fitting equation is: $y = 0.04527x+1.12599$, recommended formula: $y=0.045x+1.1$.

Table 3 The Results Of The Present Dsm Contrast To The Experimental Results

Specimen	P_{ut}/kN	P_{nl}/kN	P_{nd}/kN	P_n/kN	P_{ut}/P_n
C2L700b	296.25	327.14	210.35	210.35	1.408
C3L700a	296.67	311.83	203.13	203.13	1.460
C3L700b	294.14	312.56	205.08	205.08	1.434
C2L1250a	302.72	303.82	201.85	201.85	1.500
C3L1250a	255.47	296.89	196.64	196.64	1.299
C3L1250b	275.80	296.99	196.25	196.25	1.405
C2L1800a	215.75	269.85	189.70	189.70	1.137
C2L1800b	271.34	267.75	188.28	188.28	1.441
C3L1800a	243.38	273.76	184.42	184.42	1.320
C3L1800b	236.62	272.78	184.73	184.73	1.281
Average					1.415
StDev					0.147

Table 4 Proposed Method Contrast To Test Results

Specimen	P_{ut}/kN	P_m/kN	P_{ut}/P_m
C2L700a	351.06	304.09	1.154
C2L700b	296.25	302.65	0.979
C3L700a	296.67	292.84	1.013
C3L700b	294.14	295.06	0.997
C2L1250a	302.72	291.50	1.038
C2L1250b	330.54	291.83	1.133

C3L1250a	255.47	283.50	0.901
C3L1250b	275.8	283.06	0.974
C2L1800a	215.75	277.52	0.777
C2L1800b	271.34	276.25	0.982
C3L1800a	243.38	270.39	0.900
C3L1800b	236.62	270.96	0.873
Average			0.977
StDev			0.106

Table 5 Proposed Method Contrast To Fea Results

Specimen	P_u/kN	P_m/kN	P_u/P_m
C2L1000s1a	97.15	95.11	1.021
C2L2000s1a	76.87	85.95	0.894
C2L1000h2a	280.15	268.59	1.043
C2L2000h1a	85.66	90.14	0.950
C2L2000h2a	253.51	241.77	1.049
C2L3000h2a	183.05	179.52	1.020
C2L1000s1b	96.47	94.71	1.019
C2L2000s2b	254.55	238.04	1.069
C2L1000h2b	283.45	269.37	1.052
C2L2000h1b	87.26	91.84	0.950
C2L2000h2b	256.58	243.52	1.054
C2L3000h1b	78.13	74.22	1.053
C2L3000h2b	186.41	183.88	1.014
C2L1000s1c	96.47	94.50	1.021
C2L2000s1c	74.77	85.95	0.870
C2L2000s2c	210.78	238.95	0.882
C2L1000h1c	106.57	99.93	1.066
C2L1000h2c	285.23	269.07	1.060
C2L2000h1c	86.12	91.76	0.939
C2L2000h2c	255.62	243.78	1.049
C2L3000h1c	78.86	74.43	1.060
C2L3000h2c	187.12	186.03	1.006
C3L1000h1a	103.52	96.13	1.077
C3L1000h2a	279.66	264.80	1.056
C3L2000h1a	87.39	87.71	0.996
C3L1000s1a	93.89	93.49	1.004
C3L1000s2d	281.26	265.14	1.061
C3L1000h2d	230.43	267.74	0.861
Average			1.007
StDev			0.065

The proposed design methods for bearing capacity are as follows:

$$P_{\text{n}l\text{d}} = \gamma P_{\text{nd}} \tag{4}$$

where $\gamma = (0.045\lambda_{l\text{d}}^2 + 1.1)^2$; $\lambda_{l\text{d}} = \sqrt{P_{\text{n}l} / P_{\text{crd}}}$;$P_{\text{n}l}$ and P_{nd} are obtained from Eq. 2 and Eq. 3.

The column nominal strength (P_n) is the lower of $P_{\text{n}l}$ and $P_{\text{n}l\text{d}}$.

In order to validate the accuracy of proposed method, the proposed method is verified by the finite element analysis results and the test results from literature [8]. As shown in Table 4 and Table 5. The contrast results are in good agreement.

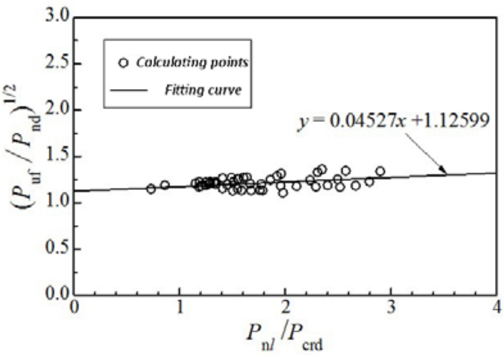


Fig.2 Curve fit

7 Summary

(1) The hand methods of the elastic local and distortional buckling stress are also suited for the channels with complex edge stiffeners and web stiffeners.

(2) The ultimate bearing capacity of the members can be improved effectively after stiffening and the failure mode mainly are distortional or distortional-local interactive buckling. The result of the present direct strength method is often inaccurate and conservative.

(3) Based on the current DSM, a method considered distortional-local interaction buckling for bearing capacity of channels with complex edge stiffeners and web stiffeners under axial compression was proposed and verified by the finite element analysis results and the test results.

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