

Stability Behavior of Perforated Lipped Channel Columns

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Abstract. Taking the cold-formed thin-walled perforated lipped channels with simple edge stiffeners and complex edge stiffeners as research objects. The influence of perforated parameters, such as hole width, hole height, hole shape and hole spacing, on axial compressive bearing capacity and buckling mode of these two types of lipped channels were studied by finite element analysis. It shows that the change of hole width, hole shape and hole spacing may change the buckling mode, but influence little on ultimate bearing capacity within a reasonable perforated range; However, it indicates that the ultimate bearing capacity decreased obviously with the opening height increased. The suggestions on reasonable hole shape and hole size were put forward. Furthermore, combined the direct strength method of lipped perforated channels under axial compression abroad with the relevant specification of our country, the direct strength method of lipped perforated channel columns for our country were put forward also. Then, the methods mentioned above were extended to calculate the ultimate bearing capacity of perforated channels with complex edge stiffeners under axial compression, and the validity of the formulas was verified.

1 Introduction

Cold formed thin-walled steel is widely used in all kinds of industrial and civil buildings for its flexible cross section form and efficient structural characteristics. In order to facilitate the installation of circuit system and pipeline facilities, holes are usually set up on the web of cold-formed thin-walled steel members in practical engineering application. But the existence of holes can affect the stability and bearing capacity of the members, even change the buckling modes. And the calculation method of bearing capacity becomes more complicated. The current direct strength method (DSM) is no longer suitable for the perforated members. Therefore, it is necessary to carry out the relevant research on cold-formed thin-walled perforated lipped channels under axial load.

For perforated lipped channels and complex lipped channels pin-ended columns, the influence of perforated parameters on bearing capacity and buckling mode has been studied. And combined the direct strength method of perforated common lipped channels under axial compression abroad with the relevant specification of our country, the direct strength method of perforated common lipped channel columns for our country were put forward in this paper. Then the methods mentioned above were extended to calculate the ultimate bearing capacity of

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perforated channels with complex edge stiffeners under axial compression, and the validity of the formulas was verified.

2 The Influence Factors of Stability Performance by Finite Element Parametric Analysis

The accuracy of simulating method has been validated by preliminary study [1]. The paper uses the same finite element analysis method to study the influence of hole width, hole height, hole shape and hole spacing on bearing capacity and buckling mode of lipped and complex lipped perforated channels. The reasonable hole shape and hole size are put forward.

There are 50 lipped perforated channels and 58 complex lipped perforated channels. The cross section forms used for analysis are showed in Fig.1. In the specimen label, L and the number then represents effective length; Ja and the number then means the serial number of lipped perforated channels and Jb means complex lipped channels (Table 1); the letter b and then means the width of hole; the letter h and then means the height of hole. When there is a single hole in the web, the hole in the specimen length 1/2; there are two holes, the holes in the specimen length 1/3. The hole spacing l means the distance between the center of holes. The web holes sizes parameters are showed in Fig2.

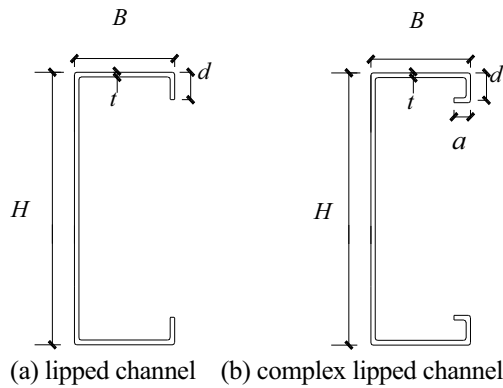


Fig.1 Cross section of specimen

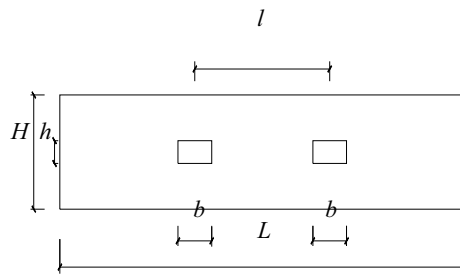


Fig.2 Web holes sizes parameters

Table1 Cross Section Numbers Of Specimen

Specimen	H/mm	B/mm	d/mm	a/mm	t/mm
Ja1	200	90	25	—	2
Ja2	200	120	25	—	2
Ja3	200	120	25	—	2.5
Ja4	160	70	20	—	2
Ja5	160	90	20	—	3
Ja6	180	70	20	—	2
Ja7	180	90	20	—	2
Ja8	180	120	20	—	1
Ja9	220	120	25	—	2
Ja10	220	150	25	—	2
Jb1	200	90	25	15	2
Jb2	200	120	25	15	2
Jb3	200	120	25	15	2.5
Jb4	200	100	25	15	2
Jb5	200	180	25	15	2
Jb6	160	70	20	10	2
Jb7	160	90	20	10	2
Jb8	150	150	25	15	2
Jb9	150	150	25	15	3
Jb10	120	120	20	10	2
Jb11	120	120	20	10	3
Jb12	220	120	25	15	2
Jb13	250	220	30	20	2
Jb14	300	280	35	15	2

2.1 The hole width

The results of finite element analysis are showed in Table 2. The bearing capacity of specimen decreases with the increase of hole width, but the amplitude is very weak. From Table 2, it's obvious that the influence of the width of hole on the buckling mode of members is very small. It is suggested that the hole width of the cold-formed channel under axial compression is 110mm.

2.2 The hole height

As shown in Table 3. The ultimate bearing capacity of the member is obviously decreased with the increase of the height of the hole and the influence of the hole height on the stability of the bearing capacity is large.

In order to find a more economical and reasonable hole height range, the ratio of bearing capacity of specimen (P_u) and net section strength carrying capacity (P_{ynet}) is used as ordinate and the ratio of the height of hole (h) and the height of web (H) is used as abscissa. $P_{ynet} = f_y \times A_{net}$, f_y means yield strength, A_{net} means net cross-sectional area. The results are showed in Fig3. It is suggested that hole height should be 30-40 percent of the height of web.

2.3 The hole shape

The bearing capacities of perforated channel under axial compression with different hole shapes are showed in Table 4. It's showed that the influence of hole shape on bearing capacity is small. But considered concentration of stress and opening technology, it's suggested that elliptical hole is better than rectangular hole.

2.4 The hole spacing

The ultimate bearing capacity of the axial compression members with different hole spacing is shown in Table 5. The influence of hole spacing on bearing capacity is small. Referred to the relevant codes, the minimum height of specimen is not less than 1200mm for members with two holes.

Table2 Bearing Capacity Of Perforated Lipped Channel With Different Hole Width

Specimen	P_u /kN	Specimen	P_u /kN
L700Ja7b40h40	165.48	L700Jb1b70h60	175.89
L700Ja7b70h40	164.47	L700Jb1b100h60	174.14
L700Ja7b100h40	163.07	L700Jb1b40h80	170.48
L700Ja1b40h40	169.55	L700Jb1b70h80	168.85
L700Ja1b70h40	170.82	L700Jb1b100h80	166.37
L700Ja1b100h40	169.95	L1200Jb7b60h40	174.92
L900Ja10b60h60	184.45	L1200Jb7b90h40	172.57
L900Ja10b80h60	183.34	L1200Jb7b70h60	159.71
L900Ja10b100h60	182.84	L1200Jb7b100h60	158.39
L700Jb1b40h40	181.46	L1200Jb1b60h40	176.02
L700Jb1b70h40	181.59	L1200Jb1b90h40	175.43
L700Jb1b100h40	180.29	L1200Jb1b70h60	167.48
L700Jb1b40h60	176.57	L1200Jb1b100h60	166.46

Table 3 Bearing Capacity Of Perforated Channel With Different Hole Shapes

Specimen	Shapes	P_u /kN
L700Ja1b100h40	Rectangular	169.95
L700Ja1b100h40	Elliptical	171.27
L700Ja1b100h60	Rectangular	162.56
L700Ja1b100h60	Elliptical	163.28
L700Jb1b100h40	Rectangular	180.29
L700Jb1b100h40	Elliptical	181.69
L700Jb1b100h60	Rectangular	174.14
L700Jb1b100h60	Elliptical	173.37

Table 4 Bearing Capacity Of Perforated Members With Different Hole Spacing

Specimen	l /mm	P_u / kN
L1500Ja6b100h40	600	100.19
L1500Ja6b100h40	700	96.99
L1500Ja6b100h40	800	99.09
L1500Jb4b100h40	600	109.66
L1500Jb4b100h40	700	111.32
L1500Jb4b100h40	800	115.49
L1500Jb12b100h40	600	125.36
L1500Jb12b100h40	700	123.53
L1500Jb12b100h40	800	128.40

Table 5 Bearing Capacity Of Perforated Lipped Channel With Different Hole Heights

Specimen	P_u /kN	Decreased percentage
L700Jb1b110h20	183.47	0.97
L700Jb1b110h30	181.21	2.19
L700Jb1b110h40	177.99	3.92
L700Jb1b110h50	175.44	5.30
L700Jb1b110h60	172.79	6.73
L700Jb1b110h70	167.81	9.42
L700Jb1b110h80	162.87	12.09
L700Jb1b110h100	154.40	16.66
L700Jb2b110h20	198.63	0.80
L700Jb2b110h30	197.34	1.45
L700Jb2b110h40	195.02	2.61
L700Jb2b110h50	191.45	4.39
L700Jb2b110h60	187.94	6.14
L700Jb2b110h70	184.37	7.93
L700Jb2b110h80	180.78	9.72
L700Jb2b110h100	176.29	11.96
L1600Jb1b110h20	171.77	0.60
L1600Jb1b110h30	170.55	1.30
L1600Jb1b110h40	168.14	2.70
L1600Jb1b110h50	165.33	4.32
L1600Jb1b110h60	162.63	5.89
L1600Jb1b110h70	159.86	7.49
L1600Jb1b110h80	157.11	9.08
L1600Jb1b110h100	147.78	14.48
L1600Jb3b110h20	302.19	1.02
L1600Jb3b110h30	296.17	2.99
L1600Jb3b110h40	292.81	4.09

L1600Jb3b110h50	288.13	5.62
L1600Jb3b110h60	283.22	7.23
L1600Jb3b110h70	279.05	8.60
L1600Jb3b110h80	274.43	10.11
L1600Jb3b110h100	267.65	12.33

Note: decreased percentage means compared with members with no hole.

3 The Direct Strength Method for Perforated Lipped Channel Columns

3.1 Elastic buckling stress of axial compression members

Based on a large number of finite strip analysis, the simplified calculation method of elastic critical stress of lipped perforated channels are presented by literature [2]. To maintain the local elastic buckling stress and global buckling stress of the members same as members with no hole. And for the elastic distortion buckling stress, actual thickness of the web is replaced by discounting web thickness. The following is reduction method. The contrast between the results of finite element analysis and the simplified method is listed in Table 6. And the simplified method is validated.

$$t_{web, hole} = \left(1 - \frac{b}{L}\right) t_{web} \tag{1}$$

Where b means the width of hole, L means the length of specimen, t_{web} means actual web thickness.

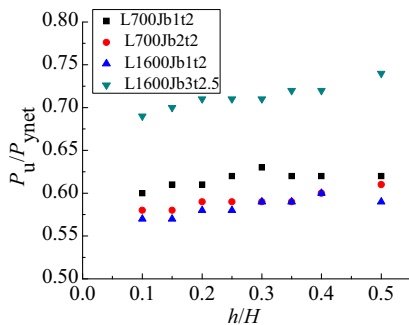


Fig. 3 Relationship of P_u/P_{ynet} and h/H

Table 6 Distortional Buckling Stress Calculation Results By Simplified Thickness Reduction Method

Specimen	Calculation results $\sigma_{cr,cal}$ /MPa	Simulation results $\sigma_{cr,sim}$ /MPa
L900Ja10b80h60	79.50	86.41
L900Ja10b100h60	79.50	86.47
L800Ja5b100h40	313.79	339.40
L700Jb1b40h40	102.66	116.05
L1200Jb10b110h40	191.72	177.37

3.2 The DSM for lipped perforated channels under axial compression

Moens had put forward a reasonable method for lipped perforated channels under axial compression [3]. The method not only considers the fact that nominal capacity for local-global interaction buckling is not more than the net section bearing capacity, but also is more detailed to segment the calculation formula of distortion.

Referred to the method above, combined with the domestic modified DSM for members with no holes, the domestic DSM for lipped perforated channels under axial compression is proposed. The formula is as follows.

The proposed nominal axial capacity for the interaction of local-overall buckling P_{nl} is as follows:

$$P_{nl} = \begin{cases} P_{ne} & \lambda_l \leq 0.847 \\ \left[1 - 0.10 \left(\frac{P_{crf}}{P_{ne}} \right)^{0.36} \right] \left(\frac{P_{crf}}{P_{ne}} \right)^{0.36} N_{ne} & \lambda_l > 0.847 \end{cases} \quad (2)$$

And $P_{nl} \leq P_{ynet}$

The proposed nominal capacity for the interaction of distortional-overall buckling P_{nd} is as follows:

$$P_{nd} = \begin{cases} P_{ynet} & \lambda_d \leq \lambda_{d1} \\ P_{ynet} - \left(\frac{P_{ynet} - P_{d2}}{\lambda_{d2} - \lambda_{d1}} \right) (\lambda_d - \lambda_{d1}) & \lambda_{d1} < \lambda_d \leq \lambda_{d2} \\ \left[1 - 0.25 \left(\frac{P_{crd}}{P_{ne}} \right)^{0.6} \right] \left(\frac{P_{crd}}{P_{ne}} \right)^{0.6} P_{ne} & \lambda_{d2} < \lambda_d \end{cases} \quad (3)$$

Where $\lambda_{d1} = 0.561(P_{ynet}/P_{ne})$

$$\lambda_{d2} = 0.561[14(P_{ne}/P_{ynet})^{0.4} - 13] \quad (4)$$

$$P_{d2} = \left(1 - 0.25 \left(\frac{I}{I_{d2}} \right)^{1.2} \right) \left(\frac{I}{I_{d2}} \right)^{1.2} P_{ne} \quad (6)$$

The ultimate bearing capacity of the mentioned specimen above is calculated by the formula proposed. The comparison between the results and the simulation results are shown in Table 7. The other results were found in the literature [4]. The contrast results are in good agreement.

3.3 The Direct Strength Method for Complex Lipped Perforated Channel Columns

The proposed method above is suited for lipped perforated channel columns. In order to study the DSM for complex lipped perforated channel columns, the ultimate bearing capacities of complex lipped perforated channels were calculated using the method above and compared with the results of finite element simulation. As shown in Table 8. The method for lipped perforated channels to solve the ultimate bearing capacity of complex lipped perforated channel is still applicable.

Table 7 Results Of Lipped Perforated Channels Under Axial Compression By Dsm

Specimen	P_E /kN	P_D /kN	Buckling modes	P_D / P_E
L700Ja7b40h40	165.48	153.99	D	0.93
L700Ja7b70h40	164.47	149.96	D	0.91
L700Ja7b100h40	163.07	145.82	D	0.89
L700Ja1b40h40	169.55	169.94	D	1.00
L700Ja1b70h40	170.82	167.93	D	0.98
L700Ja1b100h40	169.95	163.42	D	0.96
L1600Ja1b110h20	162.56	158.02	D	0.97
L1600Ja1b110h30	161.02	158.02	D	0.98
L1600Ja1b110h40	159.48	158.02	L	0.99
L1600Ja1b110h50	156.83	158.02	D	1.01
L1600Ja1b110h60	154.24	158.02	D	1.02
L1600Ja1b110h70	151.52	158.02	D	1.04
L1600Ja1b110h80	148.80	158.02	D	1.06
L1600Ja1b110h100	135.26	158.02	D	1.17
Average	—	—	—	0.994
StDev	—	—	—	0.069

Notes: L means local buckling, D means distortional buckling.

Table 8 Results Of Complex Lipped Perforated Channels Under Axial Compression By Dsm

Specimen	P_E /kN	P_D /kN	Buckling modes	P_D / P_E
L700Jb1b40h40	181.46	184.43	L	1.02
L700Jb1b40h70	181.59	184.43	L	1.02
L700Jb1b40h100	180.29	184.43	L	1.02
L1600Jb1b110h20	171.77	172.5	L	1.00
L1600Jb1b110h30	170.55	172.5	L	1.01
L1600Jb1b110h40	168.14	172.5	L	1.03
L1200Jb8b110h40	181.53	182.68	D	1.01
L1200Jb8b110h60	170.18	182.68	D	1.07
L1200Jb8b110h80	165.36	182.68	D	1.10
L1200Jb9b110h40	357.74	340.19	D	0.95
L1200Jb9b110h60	327.92	340.19	D	1.04

L1200Jb9b110h80	316.52	340.19	D	1.07
L1200Jb10b110h30	174.16	160.06	D	0.92
L1200Jb10b110h40	164.51	160.06	D	0.97
L1200Jb10b110h50	159.55	160.06	D	1.00
Average	—	—	—	1.015
StDev	—	—	—	0.046

4 Summary

(1) The influence of the width of hole, hole shape and hole spacing on the buckling mode of members is very small. It is suggested that the hole width of the cold-formed channel is 110mm.

(2) The influence of the hole height on the stability of the bearing capacity is large. Hole height should be 30-40 percent of the height of web.

(3) Based on the domestic modified DSM, a method for lipped perforated channels under axial compression is proposed and verified by the finite element analysis results. The method is also suited for complex lipped perforated channels.

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