



International Specialty Conference on Cold-Formed Steel Structures

(1992) - 11th International Specialty Conference on Cold-Formed Steel Structures

Oct 20th, 12:00 AM

Experimental Investigations of I-beams

Shang-Jian Chen

Shan-Feng Fang

Follow this and additional works at: <https://scholarsmine.mst.edu/isccss>



Part of the [Structural Engineering Commons](#)

Recommended Citation

Chen, Shang-Jian and Fang, Shan-Feng, "Experimental Investigations of I-beams" (1992). *International Specialty Conference on Cold-Formed Steel Structures*. 1.

<https://scholarsmine.mst.edu/isccss/11iccfss/11iccfss-session3/1>

This Article - Conference proceedings is brought to you for free and open access by Scholars' Mine. It has been accepted for inclusion in International Specialty Conference on Cold-Formed Steel Structures by an authorized administrator of Scholars' Mine. This work is protected by U. S. Copyright Law. Unauthorized use including reproduction for redistribution requires the permission of the copyright holder. For more information, please contact scholarsmine@mst.edu.

EXPERIMENTAL INVESTIGATIONS OF I-BEAMS

Shang-Jian Chen¹ and Shan-Feng Fang²

SUMMARY

I-beams made of cold-formed thin-walled channels, back to back, can be connected by resistance spot welding or arc-welding. Both stability and ultimate strength of these beams are different for welding method. The stability can be increased provided several battens are attached on the open sections of these beams.

1. EXPERIMENTAL INVESTIGATIONS OF I-BEAMS MADE OF COLD-FORMED CHANNELS BY DIFFERENT WELDING METHOD

1.1 INTRODUCTION

The symmetric I-beams made of cold-formed thin-walled channels, back to back, are connected by resistance spot welding (RSW). It is a section often used in practice engineering. See Fig 1. The writers have investigated a number of standards of cold-formed thin-walled steel structures concerning RSW dealt only with the strength of RSW, in other words, the strength of RSW is not collapsed before the members were collapsed or buckled, but disregarding whether the dif-

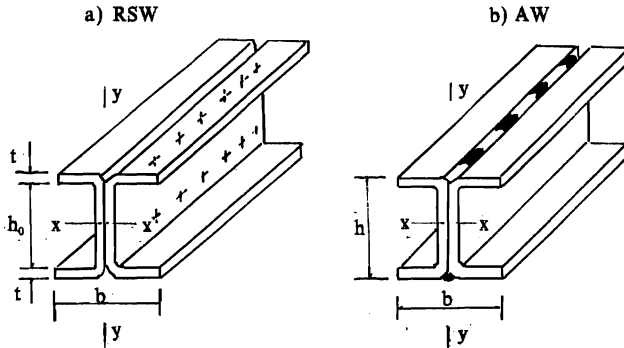


Fig. 1 I-beams made of cold-formed thin-walled channels

1. Lecturer, Wuhan University of Hydro-Electric Engineering, Hubei, China.
2. Professor, Wuhan University of Hydro-Electric Engineering, Hubei, China.

ferent welding method affects on structural load-carrying capacity or not. The analysis of this problem has not yet presented, the purpose of this section is to analyse the strength and the buckling behaviour of I-beam when we utilize different welding method (RSW or AW). So we have carried out twelve beams test (strength and stability) in Wuhan University of Hydro-Electric Engineering and proposed the approximate expressions of calculating the torsion constant I_x of beams connected by different method in consideration of stability.

1.2 TESTING INVESTIGATION

Experiments have confirmed that both the stability and ultimate strength of beams connected by RSW is lower than that of beams joined by AW. First let us see that the stability of these beams is compared with different welding method. Length of beam $L=11.81\text{ft}$ (3.6m), depth of beam $h=6-3/8$ in. (160mm), flange width $b=2-3/4$ in. (70mm), flange thickness $t=1/10$ in. (2.5mm), distance of welding spot is 4 in. (100mm) and $3-1/8$ (80mm) along direction of beam depth and beam length respectively. Experiment results see Table 1.

TEST MOMENT : FT - KIP (KN - M)

TABLE 1

welding method	number of beam	M_{or1}	welding method	number of beam	M_{or2}	M_{or2}/M_{or1}
	A1-1	2.16 (2.93)		A2-1	2.75 (3.73)	1.27
RSW	A1-2	2.146 (2.91)	AW	A2-2	2.69 (3.65)	1.25
	A1-3	2.095 (2.84)		A2-3	2.72 (3.69)	1.30

From Table 1, the critical moment of beams by AW is 25% higher than that of beams by RSW when the section of beams and other conditions are completely the same except welding method. Why reason is? It is possible that the torsion constant I_x is direct reason, because the thickness of web is twice as the thickness of flange as the two channels, back to back, are connected. When using AW, the torsion constant I_{x1} is the following.

$$I_{x1} = \frac{2bt^3}{3} + \frac{h_0(2t)^3}{3} \quad (1)$$

when using RSW, the I_{x2} can be approximately written

$$I_{x2} = \frac{2bt^3}{3} + \frac{2(h_0-d)t^3}{3} + \frac{k_1d(2t)^3}{3} \quad (2)$$

The d is distance from welding spot to welding spot along direction of beam depth, k_1 is effective highness factor, effective highness in calculation of torsion constant is k_1d , we have obtained $k_1=0.65$ by test.

For doubly symmetrical I-beams, the critical moment is

$$M_{cr} = \xi_1 \frac{\pi^2 EI_y}{(kL)^2} \left(\xi_2 a_y + \sqrt{(\xi_2 a_y)^2 + \frac{I_w}{I_y} \left(1 + \frac{GI_k (kL)^2}{\pi^2 EI_w} \right)} \right) \quad (3)$$

in which coefficients ξ_1 and ξ_2 are equal to 1.13 and 0.45 for the beam simply supported and subjected to the uniformly distributed transverse load, E is the modulus of elasticity, I_y denotes the moment of inertia of the cross section about the y -axis, k is a coefficient and equal to 1 for the condition of simple support, L is the distance between points of support against lateral bending and twisting, I_w denotes the torsion warping constant, G is the modulus of rigidity, I_k is the torsion constant, a_y refers to the distance from shear center to the point of application of transverse load (positive when load is below shear center and negative otherwise).

Substituting the corresponding values, in which I_k is computed by using equation (1) or (2), into equation (3) respectively, the calculated values of critical moment are satisfactory in agreement with the testing results.

The strength of beam is also different for welding method, the size of beam cross section is the same as before, length of beams $L=3.28$ ft (1m). The strength of beam joined by AW is approximately 10% higher than that of beam connected by RSW, why to cause the difference? It can be illustrated that the beam joined by RSW is not enough to develop plasticity in collapse because the deformation of this beam occurs very readily, specially the outstanding flanges prone to local buckling. But the beam connected by AW is enough to develop plasticity almost up to forming plastic hinge due to the strengthened effect of welding seams, which can improve the supporting condition and increase the stability of compression flange. Besides, the welding seams far apart from the neutral axis of cross section are also beneficial to the load-carrying capacity of the beam

1.3 CONCLUSIONS AND SUGGESTION

Basen on the experimental investigation for the strength and stability of the I-beam using different welding method, we have gotten below two points.

(1) The symmetric I-beam made of cold-formed thin-walled channels, back to back, are joined by different welding method, the strength and stability of beam joined by RSW is lower than that of beam connected by AW. It is worthy to notice and study further.

(2) The torsion constant I_k can be approximately calculated by formula (1) or (2) respectively for evaluating critical moment. The design of I-beam made of thin-walled cold-formed channels joined by AW can be considered plastic development when the load is dead load.

2. EXPERIMENTAL INVESTIGATION OF COLD-FORMED THIN-WALLED I-BEAM WITH BATTENS

2.1 INTRODUCTION

Stability can be increased for centrally or eccentrically load columns of thin-walled open cross-section with battens, the experimental investigation of this problem has been carried out at Hunan University and theory is confirmed by test. Stability can be also increased for arbitrary loaded beam of thin-walled open cross-sections with battens and it is possible to transform the mode of failure from torsional-flexural buckling to in-plane collapse, provided the spacing of the battens is close enough to prevent beams from warping and twisting. The critical moment is how to calculate if this beam has been added to battens, which is a question to be solved, the purpose of this paper is to analyse the buckling behaviour of doubly symmetric thin-walled I-beams with battens for raising the load-carrying capacity of these beams.

Experimental investigation of this problem has been carried out at Wuhan University of Hydro-Electric Engineering, we used that the symmetric I-beams made of cold-formed thin-walled channels, back to back, were connected by RSW and 9 specimens have been tested. The Rayleigh-Ritz method is applied to determine the critical moments. The final critical moment equation is relatively simple for practical use, the results of tests are satisfactory in agreement with predictions of theory.

2.2 GENERAL EQUATION FOR LATERAL BUCKLING STRENGTH OF BEAMS WITH BATTENS

Consider a doubly symmetric beam bent about a principal axis, If transverse loads are applied, assume that their line of action lie in a plane that contains a principle axis through the shear center and the centroid.

The potential energy of such a beam as buckling can be expressed

$$\pi = \frac{1}{2} \int_0^L [EI_y u''^2 + EI_w \theta''^2 + GI_x \theta'^2 + 2M\theta u'' + qa\theta^2] dz \quad (4)$$

In which u is the displacement parallel to the initial position of the x -axis and θ is the rotation of the cross section, E is modulus of elasticity, G is shear modulus, I_y is inertial moment to y -axis, I_x is torsion constant, I_w is warping constant, M is moment, q is transverse load, a , refers to the distance from shear centre to point of application of transverse load (positive when load is below shear centre; otherwise negative). In order to obtain a simple expression for critical moment equation, the deformation components u and θ can be approximated by suitably chosen

functions, these functions are selected in such a manner.

Assume these functions

$$\begin{aligned} u &= A f_1(z) \\ \theta &= B f_2(z) \end{aligned} \quad (5)$$

In which A, B are undetermined parameters, $f_1(z)$, $f_2(z)$ satisfy the geometric boundary conditions at both ends.

In order to calculate conveniently, make the following substitutions, $M = M_{cr} (4/L^2)(Lz - z^2)$ and $q = M_{cr} (8/L^2)$, in which M_{cr} is the maximum value of the bending moment in the beam.

Applying the Reyleigh - Ritz method, the critical buckling load can be determined. Set $\pi = 0$.

Eq(4) becomes:

$$\begin{aligned} & \left(\int_0^L z(L-z) f_2(z) f_1''(z) dz \right)^2 M_{cr}^2 - \int_0^L EI_1 f_1''^2(z) dz \int_0^L \frac{L^2}{2} a_1 f_2^2(z) dz M_{cr} \\ & - \frac{L^4}{16} \int_0^L EI_1 f_1''^2(z) dz \int_0^L (EI_w f_2''^2(z) + GI_k f_2'^2(z)) dz = 0 \end{aligned} \quad (7)$$

Letting

$$\xi_1 = \frac{\int_0^L f_1''^2(z) dz}{-\int_0^L z(L-z) f_2(z) f_1''(z) dz} \quad (8)$$

$$\xi_2 = \left(\frac{L}{2} \right)^2 \frac{\int_0^L f_2^2(z) dz}{-\int_0^L z(L-z) f_2(z) f_1''(z) dz} \quad (9)$$

$$\xi = \frac{I_w}{I_y} \left(\frac{u_b}{u_w} \right)^2 + \frac{GI_k L^2}{\pi^2 EI_y} \quad (10)$$

$$\eta = \xi_2 a_1 \quad (11)$$

And solving equation (7) for M_{cr} , one obtains the equation :

$$M_{cr} = \frac{\pi^2 EI_y}{L^2} \xi_1 (\eta + \sqrt{\eta^2 + \xi}) \quad (12)$$

The values of ξ_1 , ξ_2 depend on u , θ and the distribution of moment M , the function that describes u and θ depend on the boundary conditions and on loading conditions, but is usually not affected greatly by the beam cross section and length. L is the distance between points of support against lateral bending and twisting, I_k is the torsion constant (RSW), u_b is lateral bending restrained coefficients, u_w is warping restrained coefficients, where $u_w = 2/m$, m is the number of segments subdivided by battens.

Here assumed the functions of deformation

$$f_1(z) = \sin \frac{\pi z}{l}$$

$$f_2(z) = \left\{ \sin \frac{i-1}{m} \pi + \sin \frac{\pi}{2m} \cos \frac{2i-1}{2m} \pi \left[1 + (-1)^i \cos \frac{\pi z}{a} \right] \right\} \quad (13)$$

($i=1, \dots, m$)

Satisfy the following boundary conditions at both end and constrained condition of batten plates.

$$\begin{aligned} f_1(z) = f_2(z) = 0 \\ f_1''(z) = f_2''(z) = 0 \end{aligned} \quad \text{at } z=0, L$$

at the batten plates

$$f_2'(z) = 0 \quad z=ia$$

Here a is spacing of batten plates (centre-to-centre), substituting the assumed deformation functions given by equation (13) into (8), (9) obtain those coefficient values in calculating critical moment of beams with battens, these value are given in table 2.

COEFFICIENT VALUES FOR CRITICAL MOMENT

TABLE 2

number of battens m	moment distributed coefficient ξ_1	loading condition coef- ficient ξ_2	side bending coefficient μ_b
2	1.307	0.397	1
4	1.457	0.243	1
6	1.459	0.183	1

Letting Table 2 coefficient values into equation (11) get the critical moment given by table 3.

2.3 EXPERIMENTAL INVESTIGATION

The sections of beam are given by Fig 2a, the section size is the same as above, battened segments see Fig 2b. The symmetric I-beams made of cold-formed thin-walled channels, back to back, are connected by resistance spot welding, the numbers of batten are even number. M_{cr} shows the critical moment of unbattened beams, M_{cr2} is the critical moment of beam with battened segment $a=L/2$, M_{cr4} is the critical moment of beam with battened segment $a=L/4$. Test results see table 3.

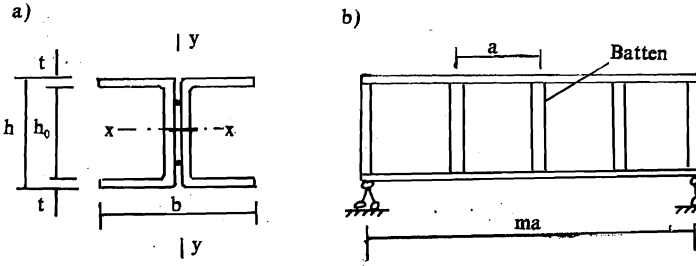


Fig. 2

THE CRITICAL MOMENT OF BEAM WITH BATTEN

TABLE 3

number of beam	Experiment ft · kip (kN · M)			compare		
	M'_{cr0}	M'_{cr2}	M'_{cr4}	M'_{cr2}/M'_{cr0}	M'_{cr4}/M'_{cr0}	M'_{cr4}/M'_{cr2}
1	2.16 (2.93)	2.626 (3.56)	4.168 (5.65)	1.22	1.93	1.59
2	2.146 (2.91)	2.663 (3.61)	4.286 (5.81)	1.24	2.00	1.61
3	2.095 (2.84)	2.567 (3.48)	4.322 (5.86)	1.23	2.06	1.68
number of beam	Experiment ft · kip (kN · M)			compare		
	M_{cr0}	M_{cr2}	M_{cr4}	M_{cr0}/M_{cr0}	M_{cr2}/M_{cr2}	M_{cr4}/M_{cr4}
1				1.04	1.056	0.95
2	2.073 (2.81)	2.486 (3.37)	4.396 (5.96)	1.036	1.07	0.97
3				1.01	1.03	0.98

we can know from table 3, the critical moment of beam with battens can be raised 1.22 and 1.9 times larger than that of the unbattened beam when battened segments are $a=L/2$ and $a=L/4$, the critical moment of test is closed to the critical moment of theory.

2.4 CONCLUSIONS

(1) The elastic buckling equation of battened beam is obtained by the Rayleigh-Ritz method, the ξ_1 , ξ_2 coefficients incorporate the effect of batten plate to critical moment.

(2) The stability of I-beams made of the cold-formed thin-walled channels with battens can be increased, the theory results are firm by test.

APPENDIX I -- REFERENCES

1. J. W. Clark, M. ASCE, and H. N. Hill, F. ASCE, Lateral buckling of beams, ASCE. Vol. 127 Part II (1962).
2. Charles, G. Salmon, John, E. Johnson, Steel Structures Design and Behavior, 2d edition. (1980).
3. Shi-Ji Wang, Torsional-Flexural Buckling of Open Thin-walled Columns with Battens Thin-walled Structures, (1985).
4. Shan-Feng Fang, Theoretical and Experimental Investigations of stability for cold-formed Thin-walled I-Beams, Proceedings of Colloquium on Steel structural stability and Fatigue, ISSF, CSCS, Beijing, CHINA, (1991).

APPENDIX II -- NOTATION

- a = spacing of batten plates (centre-to-centre)
 a_y = distance from shear centre to point of application of transverse load (positive when load is below shear centre, negative otherwise)
 b = flange width of symmetrical I-Section
 d = distance from welding spot to welding spot along direction of beam depth
 E = modulus of elasticity
 G = modulus of rigidity
 h = depth of beam
 I_x = moment of inertia of beam cross section about x-axis
 I_y = moment of inertia of beam cross section about y-axis
 I_t = torsion constant
 I_w = torsion warping constant
 K = coefficient

K_y = effective height factor

L = distance between point of support against lateral bending and twisting

m = number of segments subdivided by battens

M = bending moment at any point in a beam

M_{cr} = maximum value of M for a given beam

q = transverse load on a unit length of beam

t = thickness of compression flange

u, v = displacements of the shear centre in the x and y direction respectively

x = coordinate through centroid normal to axis of beam and normal to plane of bending

y = coordinate through centroid normal to axis of beam and parallel to plane of bending, positive downward

z = coordinate along centroidal axis of beam

θ = rotation of cross section

ξ_1 = coefficient depends on the conditions of loading and support etc.

ξ_2 = coefficient depends on the conditions of loading and support etc.

