A Comparative Study of Overall Stability Calculation of Bending Members by Specifications for Design of Steel Structures Between China and USA

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Abstract: For the issues of overall stability design of bending members in the three specifications for design of steel structures GB 50017-2003, GB 50017-201X(exposure draft) and AISC 360-10, we compared the detailed differences between the three specifications mainly from the aspect of calculation principle of the critical moment M_{cr} and stability design formulas. The differences can be compared and obtained by applying the design methods to practical problems of stability design of bending members. On the other hand, it can provide some references for the subsequent revision of Chinese code for design of steel structures.

Keywords: Flexural-torsional buckling; critical moment; equivalent moment factor; specifications between China and USA.

1. INTRODUCTION

For the bending beam in the plane, when the moment of the beam $M < M_{cr}$ (M_{cr} is called the critical moment), the beam produces only bending deformation in the plane of moment, with no lateral deformation. Even at this time there is outside accidental lateral disturbance force on the beam, bringing a certain degree of lateral displacement and torsion. But when the disturbance force disappears, the beam can still return to the original state of stable equilibrium. This phenomenon is called the overall stability of the beam. When $M \geq M_{cr}$, the beam will suddenly occur lateral bending and torsion under the action of a small lateral disturbance force. Besides, the torsion deformation does not disappear even by removing the lateral disturbance force. The beam lost carrying capacity with the increase of moment. This phenomenon is overall unstability, also called lateral-torsional buckling of the beam [1].

For the biaxial symmetry and uniform bending charpy in Fig. (**1**), the critical moment is:

$$M_{cr} = \frac{\pi}{l}\sqrt{EI_y GI_t\left(1+\frac{\pi^2 EI_\omega}{GI_t l^2}\right)} \tag{1}$$

For the biaxial symmetry and non-uniform bending charpy(the end moment M_1 and M_2 is not equal) in Fig. (**2**), the critical moment is:

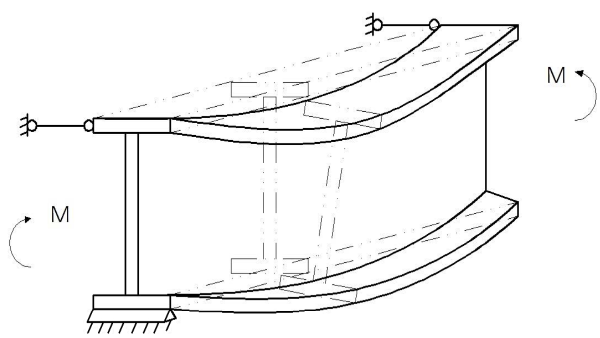

Fig. (1). Flexural-torsional buckling of beam.

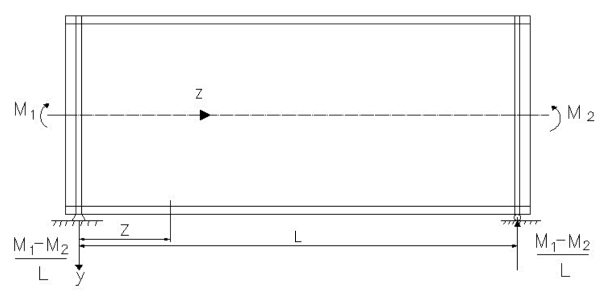

Fig. (2). Bending beam with unequal end moment.

$$M_{cr} = \beta_b \frac{\pi}{l}\sqrt{EI_y GI_t\left(1+\frac{\pi^2 EI_\omega}{GI_t l^2}\right)} \tag{2}$$

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Here β_b is the equivalent moment factor of bending members.

The current specification for steel structures of China is GB 50017-2003 [2], having been used for 10 years. In recent years, the relevant departments have been committed to the revision of new specification. Then GB 50017-201X (exposure draft) [3] has been released in June 2012. The draft has passed the expert group discussions and it is being approved by the higher authorities now. The current specification for steel structures in USA is AISC 360-10 Specification for Structural Steel Buildings [4], which was being revised on the basis of AISC 360-05. For the calculation method of overall stability of bending members in the three specifications, we have made a detailed comparison in the following content.

2. THE COMPARISON OF CRITICAL MOMENT M_{cr} AND EQUIVALENT MOMENT FACTOR β_b BETWEEN GB 50017-2003 AND GB 50017-201X

Chinese code has been revised for the calculation method of overall stability factor φ_b with respect to the overall stability design of flexural members. GB 50017-201X(exposure draft), which is being approved, is not only revised for the calculation method of overall stability factor φ_b, but also has changed in the overall stability design formula compared with GB 50017-2003. From TJ 17-74 to GB 50017-2003, the equivalent moment factor β_b has been using the lower limit (formula 3) in equivalent moment factor β_b curve of hinged non-uniform flexural members, which was studied by M. G. Salvadori [5] in 1956. The revised overall stability formula in GB 50017-201X is not related to β_b

$$\beta_b = 1.75 - 1.05\frac{M_2}{M_1} + 0.3\left(\frac{M_2}{M_1}\right)^2 \le 2.3 \tag{3}$$

Here, M_1 and M_2 are the end moments. When they cause the member to generate curvature distortion in the same direction in the moment plane, they take the same sign, and $M_1 \ge M_2$; when they cause the member to generate curvature distortion in different direction, they take the opposite sign, and $|M_1| \ge |M_2|$.

Besides, Professor Tong Genshu [6] proposes that the following formula may also be used:

$$\beta_b = 1.84 - 0.84\sin(0.5\pi M_2/M_1) \tag{4}$$

In GB 50017-2003 Appendix B and Table B, another calculation method of charpy equivalent moment factor β_b for the H-beam and the I-beam with uniform section is given. The formula $\varepsilon = l_1 t_1 / b_1 h$, here l_1 is the lateral free length of compression flange, b_1 and t_1 are the width and thickness of the compression flange, h is the section height.

The elastic flexural-torsional buckling calculation of bending members in GB 50017-2003 is based on the formula of critical moment M_{cr} which is under concentrated transverse loads [7].

$$M_{cr} = \beta_1 \frac{\pi^2 EI_y}{l_y^2}\left[\beta_2 a + \beta_3 \beta_y + \sqrt{(\beta_2 a + \beta_3 \beta_y)^2 + \frac{I_\omega}{I_y}\left(1 + \frac{GI_t l_w^2}{\pi^2 EI_w}\right)}\right] \tag{5}$$

Here the correction factor $\beta_1 = \beta_3 = 1.0$, $\beta_2 = 0$, so the stability factor of flexural-torsional buckling is $\varphi_{0b} = M_{0cr}/(W_x f_y)$, then:

$$\varphi_{0b} = \frac{\pi^2 EI_y}{l^2 W_x f_y}\left[\beta_y + \sqrt{\beta_y^2 + \frac{I_\omega}{I_y}\left(1 + \frac{GI_t l^2}{\pi^2 EI_w}\right)}\right]$$

We can get this by simplifying and substituting:

$$\varphi_{0b} = \frac{4320Ah}{\lambda_y{}^2 W_x}\left[\eta_b + \sqrt{1 + \left(\frac{\lambda_y t_1}{4.4h}\right)^2}\right]\frac{235}{f_y}$$

At last the stability factor of elastic flexural-torsional buckling is this:

$$\varphi_b = \beta_b \varphi_{0b} = \beta_b \frac{4320Ah}{\lambda_y{}^2 W_x}\left[\eta_b + \sqrt{1 + \left(\frac{\lambda_y t_1}{4.4h}\right)^2}\right]\frac{235}{f_y} \tag{6}$$

Besides, when $\varphi_b \ge 0.6$, there need for a correction:

$$\varphi_b' = 1.07 - 0.282/\varphi_b \tag{7}$$

The overall stability design formula in GB 50017-2003 is:

$$M_x \le \varphi_b W_x f \tag{8}$$

But in GB 50017-201X(exposure draft), it makes modification in overall stability design formula based on formula(8):

$$M_x \le \varphi_b \gamma_x f W_x \tag{9}$$

It can be seen that the new overall stability design formula(9) has a section plasticity development factor γ_x compared with formula(8). For the I-section and box section, we take $\gamma_x = 1.05$.

The overall stability factor φ_b in GB 50017-201X is very different from GB 50017-2003. The new formula of overall stability factor φ_b is:

$$\varphi_b = \frac{1}{\left(1 - \lambda_{b0}^{2n} + \lambda_b^{2n}\right)^{1/n}} \le 1.0 \tag{10}$$

Here, n and λ_{b0} are determined by the formula in Fig. (**3**). λ_b is determined by the following formula:

$$\lambda_b = \sqrt{\frac{\gamma_x W_x f_y}{M_{cr}}}$$

M_{cr} is the elastic buckling critical moment of charpy, cantilever beam or continuous beam. The formula is:

	n	λ_{b0}	λ_{b0}
		charpy	bearing linear change moment
hot rolled	$2.5\sqrt[3]{\frac{b_1}{h}}$	0.4	$0.65-0.25\frac{M_2}{M_1}$
welding	$1.8\sqrt[3]{\frac{b_1}{h}}$	0.3	$0.55-0.25\frac{M_2}{M_1}$

Fig. (3). The formula of n and λ_{b0}.

$$M_{cr}=C_1\frac{\pi^2EI_y}{l^2}[-C_2a+C_3\beta_x+\sqrt{(-C_2a+C_3\beta_x)^2+\frac{I_\omega}{I_y}(1+\frac{l^2GJ}{\pi^2EI_\omega})}]$$

C_1 C_2 C_3 are determined by the Table E.0.1-2 in the appendix. β_x is the section asymmetry parameter. When the section is biaxial symmetry, $\beta_x=0$.

For a long time, our country does not distinguish the overall stability factor between welding beams and rolled beams. However, their overall stability factors are not the same in practical experiments. So GB 50017-201X refers to the research achievements of UK, Japan and other countries in this respect, and it distinguishes the overall stability factor between welding beams and rolled beams for the first time.

It can be seen that the overall stability design thinking of GB 50017-2003 and GB 50017-201X is the same: translating critical moment into overall stability factor φ_b and using φ_b into overall stability design formula. GB 50017-201X has changed in the determination of φ_b and overall stability design formula. Therefore the determination of overall stability factor φ_b is the core.

3. CRITICAL MOMENT M_{cr} AND EQUIVALENT MOMENT FACTOR β_b IN AISC 360-10 SPECIFICATION FOR STRUCTURAL STEEL BUILDINGS

The calculation of equivalent moment factor β_b in AISC 360-10 is totally different from our country's GB 50017-2003 and GB 50017-201X. It was based on the moment distribution map of unbraced length beam segment [8] (Fig. **4**), which was proposed by P. A. Kirby and D. A. Nethercot in 1979. Later AISC 360-10 got the formula of β_b on the basis of making corrections on the first formula proposed by P. A. Kirby and D. A. Nethercot. The formula of β_b in AISC 360-10 is:

$$\beta_b=\frac{12.5M_{\max}}{2.5M_{\max}+3M_A+4M_B+3M_C}\le 3.0 \qquad (11)$$

Here, $M_{\max}$ is absolute value of maximum moment in the unbraced segment; M_A is absolute value of moment at quarter point of the unbraced segment; M_B is the absolute value of moment at centerline of the unbraced segment; M_C is absolute value of moment at three-quarter point of the unbraced segment.

For the doubly symmetric compact I-shaped members and channels bent about their major axis, having compact webs and compact flanges, AISC 360-10 gives the following formula of critical moment M_{cr}. It divides the lateral-torsional buckling into three different states on the basis of three kinds of relationships between L_b, L_p and L_r [9]:

(1) when $L_b\le L_p$, the limit state of lateral-torsional buckling does not apply. At this point it means the same with 4.2.1 in GB 50017-2003 and 7.2.1 in GB 50017-201X.

(2) when $L_p<L_b\le L_r$,

$$M_{cr}=\beta_b\left[M_p-\left(M_p-0.7F_yS_x\right)\left(\frac{L_b-L_p}{L_r-L_p}\right)\right]\le M_p,$$

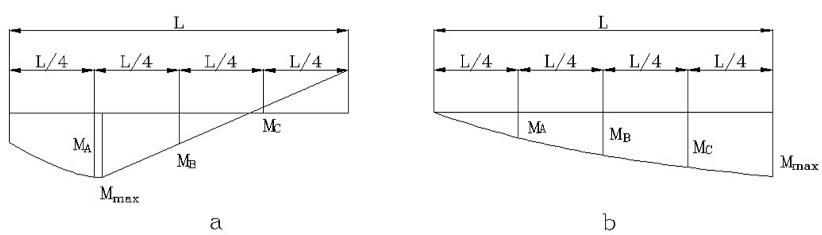

Fig. (4). Moment distribution map of unbraced length beam segment.

that is to take the smaller one between $\beta_b\left[M_p-\left(M_p-0.7F_yS_x\right)\left(\frac{L_b-L_p}{L_r-L_p}\right)\right]$ and M_p;

(3) when $L_b > L_r$, $M_{cr} = F_{cr}S_x \le M_p$;

Here, $$F_{cr}=\frac{\beta_b\pi^2E}{\left(\frac{L_b}{r_{ts}}\right)^2}\sqrt{1+0.078\frac{J_C}{S_xh_0}\left(\frac{L_b}{r_{ts}}\right)^2},$$

$$L_p=1.76r_y\sqrt{\frac{E}{F_y}},$$

$$L_r=1.95r_{ts}\frac{E}{0.7F_y}\sqrt{\frac{J_C}{S_xh_0}}\sqrt{1+\sqrt{1+6.76\left(\frac{0.7F_y}{E}\frac{S_xh_0}{J_C}\right)^2}},$$

$$r_{ts}^2=\frac{\sqrt{I_yC_w}}{S_x}$$

The overall stability design formula of bending members in AISC 360-10 is:

$$M_x \le \phi_b M_{cr} \tag{12}$$

Here, $\phi_b = 0.9$.

According to formula(12), it can be seen that critical moment M_{cr} is used for overall stability design formula directly. So the determination of critical moment M_{cr} is the core of overall stability design. On this point it is obviously different from our country's GB 50017-2003 and GB 50017-201X.

4. THE COMPARISON BETWEEN THE THREE SPECIFICATIONS IN THE ACTUAL DESIGN

For example, there is an I-shaped beam having compact webs and compact flanges, simply supported at both ends, in Fig. (**5**). We calculate the design value of critical moment by respectively using GB 50017-201X, GB 50017-2003 and AISC 360-10. Here, the steel model is Q235, f_y=235MPa, the design strength f=215MPa, E=206000MPa, G=79000-MPa. We separately do the calculation for the two kinds of cross section in Fig. (**6**).

1. For the doubly symmetric cross section

The parameters of the beam section obtained by calcula-tion

are: $A=128cm^2$, $I_x = 99096.2cm^4$, $W_x = 2984.8cm^3$, $W_{px} = 3322.9cm^3$, $I_t = 47.8cm^4$, $I_y = 6553.6cm^4$, $r_y = 7.16cm$, $I_w = 6964904cm^6$, $l_y = 450cm$, $\lambda_y = 62.8$, $M_{px} = 780.9KN.m$.

(1) GB 50017-201X

The calculation of overall stability factor φ_b:

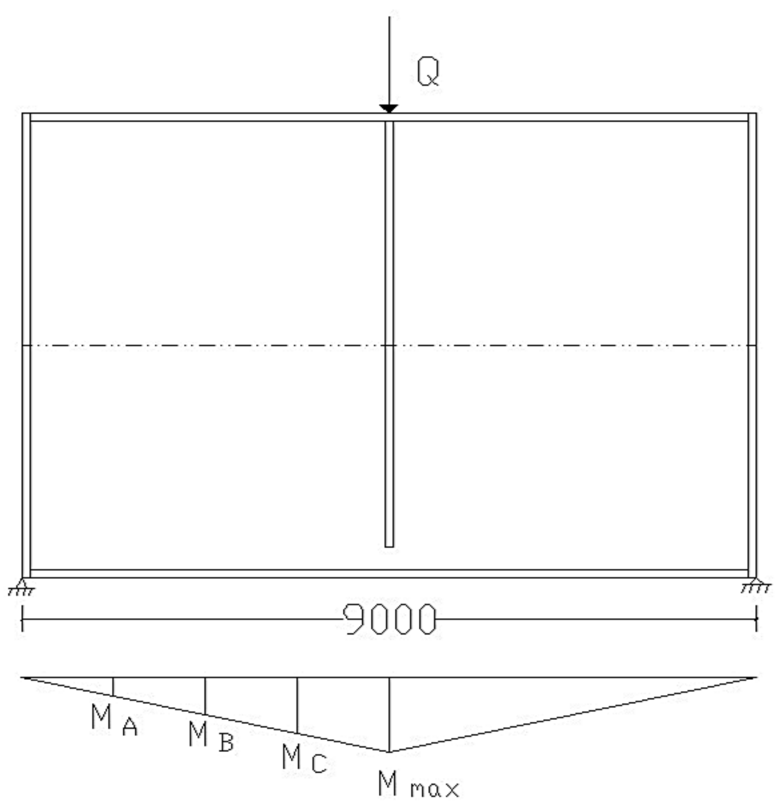

Fig. (5). The I-shaped beam.

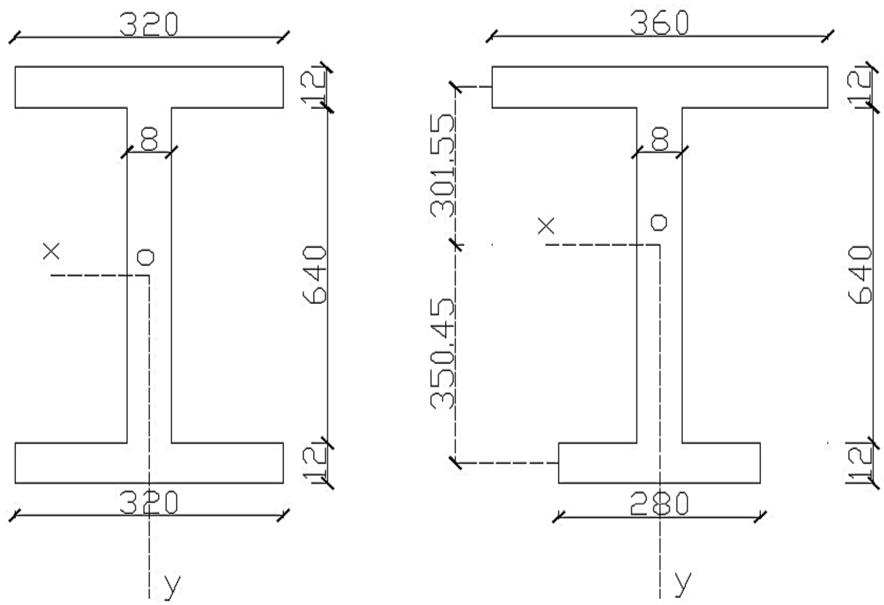

Fig. (6). Doubly symmetric and singly symmetric I-shaped cross section.

a. if it is rolled beam, according to the formula in Fig. (**3**),

$$n = 2.5\sqrt[3]{\frac{b_1}{h}} = 2.5\times\sqrt[3]{\frac{320}{652}} = 1.972\,,\ \lambda_{b0} = 0.4$$

According to the Table E.0.1-2 in Appendix E in GB 50017-201X, $C_1 = 1.75$, $C_2 = 0$, $C_3 = 1$, $\beta_x = 0$, so:

$$M_{cr} = 1.75\frac{\pi^2 EI_y}{l^2}\sqrt{\frac{I_w}{I_y}\left(1+\frac{l^2 GI_t}{\pi^2 EI_w}\right)} = 3854KN\cdot m$$

$$\lambda_b = \sqrt{\frac{\gamma_x W_x f_y}{M_{cr}}} = 0.437\,,\ \varphi_b = \frac{1}{\left(1-\lambda_{b0}^{2n}+\lambda_b^{2n}\right)^{1/n}} = 0.994$$

Substituting into the formula(9), the design value of critical moment is:

$$M_x \le \varphi_b\gamma_x fW_x = 0.994\times1.05\times215MPa\times2984.8cm^3 = 670KN\cdot m$$

b. if it is welding beam, then, $n = 1.8\sqrt[3]{\frac{b_1}{h}} = 1.8\times\sqrt[3]{\frac{320}{652}} = 1.42$,

$\lambda_{b0} = 0.3$

$M_{cr} = 3854KN\cdot m$, $\lambda_b = 0.437$ is the same with rolled beam.

$$\varphi_b = \frac{1}{\left(1-\lambda_{b0}^{2n}+\lambda_b^{2n}\right)^{1/n}} = 0.958$$

The design value of critical moment is:

$$M_x \le \varphi_b\gamma_x fW_x = 0.958\times1.05\times215MPa\times2984.8cm^3 = 645.6KN\cdot m$$

So, it can be seen that the overall stability factor φ_b of welding beams is lower than rolled beams. Thus, the design value of critical moment of welding beams is lower than rolled beams.

(2) GB 50017-2003

According to the Table **B**.**1** in Appendix B in GB 50017-2003, we take the equivalent moment factor $\beta_b = 1.75$; It can also get $\beta_b = 1.75$ by formula(3) because the end moment M_1 and M_2 are both zero. Substituting into the formula(6):

$$\varphi_b = \beta_b\frac{4320Ah}{\lambda_y{}^2 W_x}\left[\eta_b+\sqrt{1+\left(\frac{\lambda_y t_1}{4.4h}\right)^2}\right]\frac{235}{f_y} = 5.637 > 0.6\,,$$

$$\varphi_b' = 1.07 - \frac{0.282}{\varphi_b} = 1.0$$

The design value of critical moment is:

$$M_x \le \varphi_b' W_x f = 1.0\times2984.8cm^3\times215MPa = 641.7KN\cdot m$$

(3) AISC 360-10

We can get $M_A : M_B : M_C : M_{MAX} = 1:2:3:4$ according to the moment distribution map in Fig. (**5**), then substituting into the formula(11), so $\beta_b = 1.667$.

$$L_b = 450cm\,,\ L_p = 1.76r_y\sqrt{\frac{E}{F_y}} = 373.1cm\,,$$

$$r_{ts} = \sqrt{\frac{\sqrt{I_y I_w}}{W_x}} = 8.46cm$$

$$L_r = 1.95r_{ts}\frac{E}{0.7F_y}\sqrt{\frac{J_C}{S_x h_0}}\sqrt{1+\sqrt{1+6.76\left(\frac{0.7F_y}{E}\frac{S_x h_0}{J_C}\right)^2}} = 997.8cm$$

Because $L_p < L_b \le L_r$, so the formula of critical moment is:

$$M_{cr}=\beta_b\left[M_p-\left(M_p-0.7F_yS_x\right)\left(\frac{L_b-L_p}{L_r-L_p}\right)\right]=1242.1KN\cdot m>M_{px}=780.9KN\cdot m$$

Because when $L_p<L_b\le L_r$, $M_{cr}\le M_{px}$, so $M_{cr}=780.9KN\cdot m$

Substituting into the formula (12):

$$M_x\le\phi_bM_{cr}=0.9\times780.9KN\cdot m=702.8KN\cdot m$$

So the design value of critical moment is $702.8KN\cdot m$.

2. For the singly symmetric cross section

The parameters of the beam section obtained by calculation are: $A=128cm^2$, $I_x=98331cm^4$, $W_x=2758.6cm^3$, $W_{px}=3304.2cm^3$, $I_t=47.8cm^4$, $I_y=6860.8cm^4$, $r_y=7.32cm$, $I_w=6346029cm^6$, $l_y=450cm$, $\lambda_y=61.5$, $M_{px}=776.5KN.m$.

(1) GB 50017-201X

The calculation of overall stability factor φ_b:

a. if it is rolled beam, according to the formula in Fig. (**3**),

$$n=2.5\sqrt[3]{\frac{b_1}{h}}=2.5\times\sqrt[3]{\frac{360}{652}}=2.05,\ \lambda_{b0}=0.4$$

According to the Table E.0.1-2 in Appendix E in GB 50017-201X, $C_1=1.75$, $C_2=0$, $C_3=1$,

We get $\beta_x=10.96cm$, so formula E.0.1-1 becomes:

$$M_{cr}=1.75\frac{\pi^2EI_y}{l^2}\left[\beta_x+\sqrt{\beta_x^2+\frac{I_w}{I_y}\left(1+\frac{l^2GI_t}{\pi^2EI_w}\right)}\right]=5318.5KN\cdot m$$

$$\lambda_b=\sqrt{\frac{\gamma_xW_xf_y}{M_{cr}}}=0.358,\ \varphi_b=\frac{1}{\left(1-\lambda_{b0}^{2n}+\lambda_b^{2n}\right)^{1/n}}=1.0$$

Substituting into the formula(9), the design value of critical moment is:

$$M_x\le\varphi_b\gamma_xfW_x=1.0\times1.05\times215MPa\times2758.6cm^3=622.8KN\cdot m$$

b. if it is welding beam, then, $n=1.8\sqrt[3]{\frac{b_1}{h}}=1.8\times\sqrt[3]{\frac{360}{652}}=1.48$, $\lambda_{b0}=0.3$

$M_{cr}=5318.5KN\cdot m$, $\lambda_b=0.358$ is the same with rolled beam.

$$\varphi_b=\frac{1}{\left(1-\lambda_{b0}^{2n}+\lambda_b^{2n}\right)^{1/n}}=0.987$$

The design value of critical moment is:

$$M_x\le\varphi_b\gamma_xfW_x=0.987\times1.05\times215MPa\times2758.6cm^3=614.7KN\cdot m$$

Also, it can be seen that the overall stability factor φ_b of welding beams is lower than rolled beams. Thus, the design value of critical moment of welding beams is lower than rolled beams.

(2) GB 50017-2003

According to B.1-1 in Appendix B in GB 50017-2003, we can get $\eta_b=0.288$. Then substituting into the formula(6):

$$\varphi_b=\beta_b\frac{4320Ah}{\lambda_y{}^2W_x}\left[\eta_b+\sqrt{1+\left(\frac{\lambda_yt_1}{4.4h}\right)^2}\right]\frac{235}{f_y}=8.13>0.6,$$

$$\varphi_b'=1.07-\frac{0.282}{\varphi_b}=1.0$$

The design value of critical moment is:

$$M_x\le\varphi_b'W_xf=1.0\times2758.6cm^3\times215MPa=593KN\cdot m$$

(3) AISC 360-10

Also $\beta_b=1.667$.

$$L_b=450cm,\ L_p=1.76r_y\sqrt{\frac{E}{F_y}}=381.4cm,$$

$$r_{ts}=\sqrt{\frac{\sqrt{I_yI_w}}{W_x}}=8.7cm$$

$$L_r=1.95r_{ts}\frac{E}{0.7F_y}\sqrt{\frac{J_C}{S_xh_0}}\sqrt{1+\sqrt{1+6.76\left(\frac{0.7F_y}{E}\frac{S_xh_0}{J_C}\right)^2}}=1029.6cm$$

Because $L_p<L_b\le L_r$, so the formula of critical moment is:

$$M_{cr}=\beta_b\left[M_p-\left(M_p-0.7F_yS_x\right)\left(\frac{L_b-L_p}{L_r-L_p}\right)\right]=1240.6KN\cdot m>M_{px}=776.5KN\cdot m$$

Because when $L_p<L_b\le L_r$, $M_{cr}\le M_{px}$, so $M_{cr}=776.5KN\cdot m$

Substituting into the formula(12):

$$M_x\le\phi_bM_{cr}=0.9\times776.5KN\cdot m=698.9KN\cdot m$$

So the design value of critical moment is $698.9KN\cdot m$.

CONCLUSIONS

We can draw the following conclusions from the example in Fig. (**5**):

(1) From the aspect of calculation thought, the specifications between China and USA are different. GB 50017-2003 and GB 50017-201X first translate the critical moment M_{cr} into overall stability factor φ_b, then doing the overall stability design by φ_b; while in AISC 360-10 critical moment M_{cr} is used for overall stability design directly.

(2) For the determination of equivalent moment factor β_b, GB 50017-2003 has been using the lower limit (formula 3) in equivalent moment factor β_b curve of hinged non-uniform flexural members which was got by M. G. Salvadori in 1956 and the Table B.1 in Appendix B based on the formula. The overall stability design formula of GB 50017-201X does not involve the calculation of β_b after changes. AISC 360-10 got the formula of β_b (formula 11) by the moment distribution map of unbraced length beam segment which was proposed by P. A. Kirby and D. A. Nethercot in 1979 and making some corrections afterwards. So it can be clearly seen that the determination thought and calculation formula of β_b are different between the three specifications.

(3) This is distinctly different that GB 50017-2003 and GB 50017-201X use the design strength f while AISC 360-10 uses the yield strength f_y in overall stability design formula.

(4) In the process of overall stability design, GB 50017-2003 and GB 50017-201X uses the elastic resistance moment of section W_x; however, AISC 360-10 not only uses the elastic resistance moment of section W_x but also uses the plastic resistance moment of section W_{px} morely.

(5) GB 50017-2003 does not distinguish the overall stability factor φ_b between welding beams and rolled beams. The formula of φ_b mainly refers to the test data of rolled beams in GB 50017-2003. AISC 360-10 also does not distinguish welding beams and rolled beams in overall stability design. However, GB 50017-201X distinguishes the overall stability factor between welding beams and rolled beams by referring to the research achievements of UK and Japan in this respect. In the example of Fig. (**5**), firstly for the doubly symmetric cross section, the design value of critical moment is 641.7 $KN \cdot m$ by GB 50017-2003; while in GB 50017-201X it is 670 $KN \cdot m$ (rolled) and 645.6 $KN \cdot m$ (welding); then for the singly symmetric cross section, the design value of critical moment is 593 $KN \cdot m$ by GB 50017-2003; while in GB 50017-201X it is 622.8 $KN \cdot m$ (rolled) and 614.7 $KN \cdot m$ (welding). So it can be seen that the design value of critical moment by GB 50017-201X is slightly increased compared with GB 50017-2003 and the difference is very small. Besides, in GB 50017-201X the design value of critical moment of welding beams is lower than rolled beams because the overall stability factor φ_b of welding beams is lower than rolled beams. In addition, the design value of critical moment by AISC 360-10 are 702.8 $KN \cdot m$ and 698.9 $KN \cdot m$ for the doubly symmetric and singly symmetric cross section, so it can draw the conclusion that the design value of critical moment by GB 50017-2003 and GB 50017-201X is conservative and safe compared with AISC 360-10.

CONFLICTS OF INTEREST

The author(s) confirm that this article content has no conflicts of interest.

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