Structural Analysis & Design Software

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网络课堂

RFEM 6
欧标EC9
铝合金结构设计

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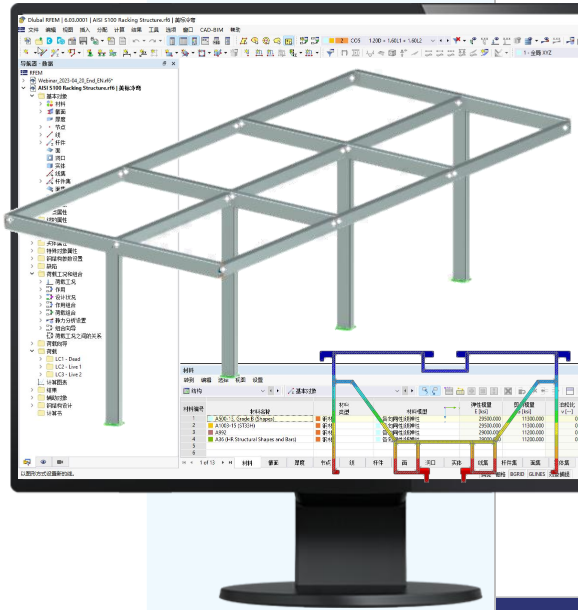

主要内容

RFEM 6进行铝合金结构设计优势

1.Rsection可以快速建立任意形状截面

2.**自定义任意截面也能进行截面等级判断、有效截面特性计算、截面强度和构件稳定验算**

3.可以考虑多种缺陷模拟方法（构件缺陷、层侧移缺陷、屈曲模态缺陷、组合缺陷等）

4.**可以通过直接分析法、二阶法、计算长度系数法验算构件稳定**

5.**横向扭转屈曲验算：基于特征值法求解M_{cr}**，通用性更大

6.腹板抗剪屈曲验算：可以定义横向加劲肋考虑拉力场有利贡献

7.中文使用环境下生成多种其他语言计算报告

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规范解读-内力分析

5.2 Global analysis

5.2.1 Effects of deformed geometry of the structure

(1) The internal forces and moments may generally be determined using either:

- first-order analysis, using the initial geometry of the structure or
- second-order analysis, taking into account the influence of the deformation of the structure.

(2)P The effects of the deformed geometry (second-order effects) shall be considered if they increase the action effects significantly or modify significantly the structural behaviour.

(3) First order analysis may be used for the structure, if the increase of the relevant internal forces or moments or any other change of structural behaviour caused by deformations can be neglected. This condition may be assumed to be fulfilled, if the following criterion is satisfied:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \qquad (5.1)$$

是否需要考虑二阶效应?

根据结构刚度来判断

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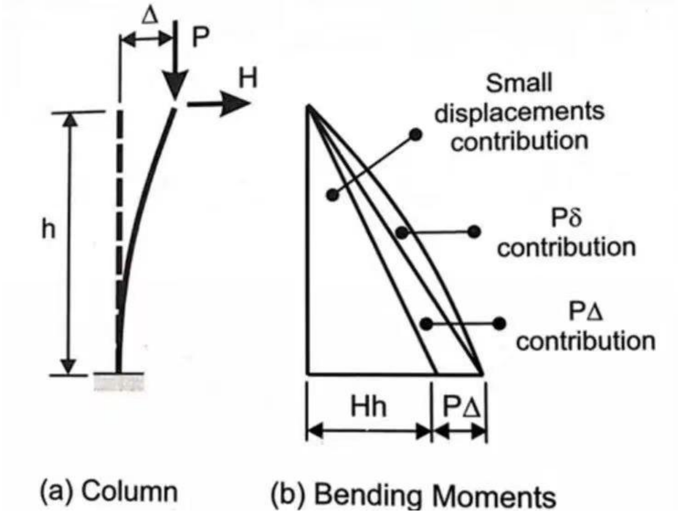
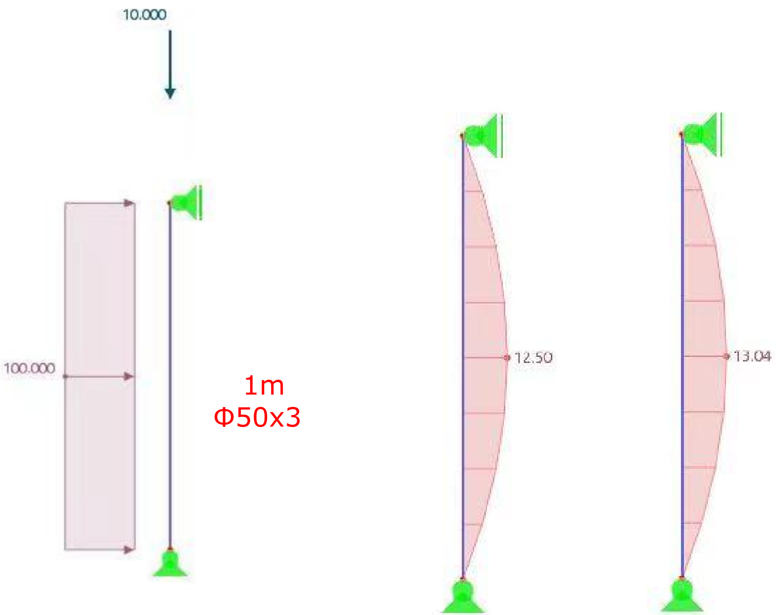
规范解读-内力分析





p-δ效应：放大系数1.0432

（杆件中间没有网格节点也能考虑，更不需要打断杆件）

规范解读-内力分析

(2) The verification of the stability of frames or their parts should be carried out considering imperfections and second order effects.

(3) According to the type of frame and the global analysis, second order effects and imperfections may be accounted for by one of the following methods:

a) both totally by the global analysis,

b) partially by the global analysis and partially through individual stability checks of members according to 6.3,

c) for basic cases by individual stability checks of equivalent members according to 6.3 using appropriate buckling lengths according to the global buckling mode of the structure.

方法a)：二阶效应和缺陷都在分析中考虑

方法b)：部分因素在分析中考虑，部分因素在构件验算中考虑

方法c)：根据屈曲模态获得构件的屈曲长度，进而采用等效杆件法验算。

如何考虑结构和构件的稳定?
根据结构类型和分析方法来判断

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规范解读-内力分析

(5) In accordance with 5.2.2(3) a) and b) the stability of individual members should be checked according to the following:

a) If second order effects in individual members and relevant member imperfections (see 5.3.4) are totally accounted for in the global analysis of the structure, no individual stability check for the members according to 6.3 is necessary.

b) If second order effects in individual members or certain individual member imperfections (e.g. member imperfections for flexural and/or lateral torsional buckling, see 5.3.4) are not totally accounted for in the global analysis, the individual stability of members should be checked according to the relevant criteria in 6.3 for the effects not included in the global analysis. This verification should take account of end moments and forces from the global analysis of the structure, including global second order effects and global imperfections (see 5.3.2) where relevant and may be based on a buckling length equal to the system length, see Figure 5.1 (d), (e), (f) and (g).

(6) Where the stability of a frame is assessed by a check with the equivalent column method according to 6.3 the buckling length values should be based on a global buckling mode of the frame accounting for the stiffness behaviour of members and joints, the presence of plastic hinges and the distribution of compressive forces under the design loads. In this case internal forces to be used in resistance checks are calculated according to first order theory without considering imperfections, see Figure 5.1 (a), (b) and (c).

分析阶段考虑了的因素，

验算阶段不再考虑！

分析阶段没考虑到的因素，

验算时需要考虑！

方法a)：分析阶段考虑了杆件的二阶效应和杆件缺陷，构件验算无需稳定验算（比较难操作）

方法b)：分析阶段考虑整体二阶效应和整体缺陷，构件稳定验算只需按系统长度进行。（比较好操作）

方法c)：分析按照一阶，无需缺陷，构件稳定验算时有效长度按照屈曲模态确定(适用于简单模型)

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规范解读-内力分析

5.3.2 Imperfections for global analysis of frames

(1) The assumed shape of global imperfections and local imperfections may be derived from the elastic buckling mode of a structure in the plane of buckling considered.

(2) Both in and out of plane buckling including torsional buckling with symmetric and asymmetric buckling shapes should be taken into account in the most unfavourable direction and form.

(3) For frames sensitive to buckling in a sway mode the effect of imperfections should be allowed for in frame analysis by means of an equivalent imperfection in the form of an initial sway imperfection and individual bow imperfections of members. The imperfections may be determined from:

a) global initial sway imperfections, see Figure 5.1(d):

$$\phi = \phi_0 \alpha_h \alpha_m \qquad (5.2)$$

where:

ϕ_0 is the basic value: $\phi_0 = 1/200$

α_h is the reduction factor for height h applicable to columns:

$$\alpha_h = \frac{2}{\sqrt{h}} \text{ but } \frac{2}{3} \le \alpha_h \le 1{,}0$$

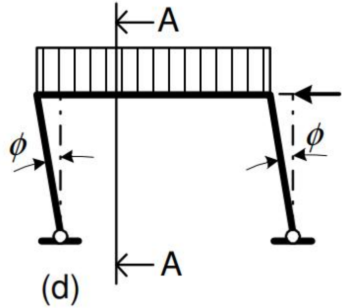
h is the height of the structure in meters

α_m is the reduction factor for the number of columns in a row: $\alpha_m = \sqrt{0{,}5\left(1+\frac{1}{m}\right)}$

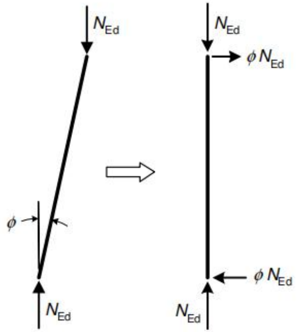
m is the number of columns in a row including only those columns which carry a vertical load N_{Ed} not less than 50% of the average value of the column in the vertical plane considered.

1.一般来说可以采用弹性屈曲模态

2.侧移敏感结构，可以采用等效缺陷



(d)



initial sway imperfections

缺陷怎么考虑?
根据结构类型来判断

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规范解读-内力分析

b) relative initial local bow imperfections of members for flexural buckling

$$e_0 / L \quad (5.3)$$

where L is the member length

NOTE The values e_0/L may be chosen in the National Annex. Recommended values are given in Table 5.1.

Table 5.1 - Design values of initial bow imperfection e_0 / L

Buckling class acc. to Table 3.2	elastic analysis e_0/L	plastic analysis e_0/L
A	1/300	1/250
B	1/200	1/150

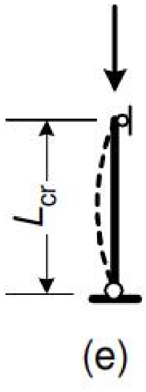
5.3.4 Member imperfections

(1) The effects of imperfections of members described in 5.3.1(1) are incorporated within the formulas given for buckling resistance for members, see section 6.3.1.

(2) Where the stability of members is accounted for by second order analysis according to 5.2.2(5)a) for compression members imperfections $e_{0,d}$ according to 5.3.2(3)b) or 5.3.2(5) or (6) should be considered.

(3) For a second order analysis taking account of lateral torsional buckling of a member in bending the imperfections may be adopted as $ke_{0,d}$, where $e_{0,d}$ is the equivalent initial bow imperfection of the weak axis of the profile considered. In general an additional torsional imperfection need not to be allowed for.

NOTE The National Annex may choose the value of k. The value $k = 0,5$ is recommended.



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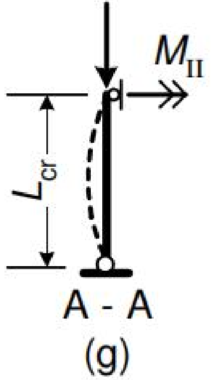


横向扭转屈曲

缺陷怎么考虑?
根据结构类型来判断

规范解读：构件验算

1.截面分类

1类：可以形成塑性铰，具有较好的转动能力

2类：可以形成塑性铰，由于板件局部屈曲，仅具有有限的转动能力

3类：截面最大应力可以达到名义屈服强度fo,但是板件局部屈曲的发生限值了全截面塑性的发展

4类：截面最大应力达到名义屈服强度fo之前,就有板件发生局部屈曲

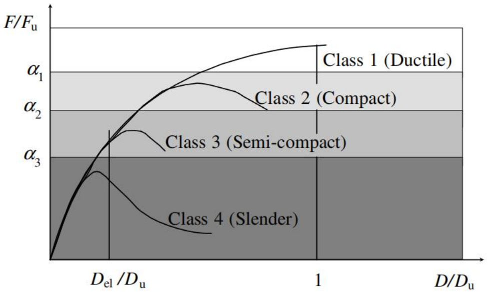


Figure F.1 - Classification of cross-sections

规范解读：构件验算

1.截面分类

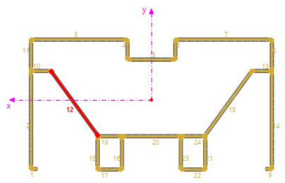
关于截面 RSECTION 中间水槽（简化） 的信息

截面属性 | 应力点 | 板件 | EN 1993 | DIN | 2020-11 | 板件 | EN 1999 | DIN | 2021-03

坐标 | c/t 比值

板件编号	长度 c [mm]	厚度 t [mm]	比值 c/t [--]
1	2.0	1.5	1.333
2	42.6	1.5	28.421
3	42.0	1.5	28.000
4	7.5	1.5	5.000
5	20.0	1.5	13.333
6	7.5	1.5	5.000
7	42.0	1.5	28.000
8	12.6	1.5	8.412
9	2.0	1.5	1.333
10	7.9	1.5	5.259
11	12.6	1.5	8.412
12	35.4	1.5	23.594
13	7.9	1.5	5.259
14	42.6	1.5	28.421
15	35.4	1.5	23.594
16	13.5	1.5	9.000
17	9.5	1.5	6.333
18	13.5	1.5	9.000
19	9.5	1.5	6.333
20	25.0	1.5	16.667
21	13.5	1.5	9.000
22	9.5	1.5	6.333
23	13.5	1.5	9.000
24	9.5	1.5	6.333

RSECTION 中间水槽（简化）



关闭

截面等级

Section classification for major axis bending		Class 4	
Section classification for minor axis bending		Class 4	

截面等级：4级

Effective Sections

Major axis bending | Effective section considering only reduced thickness $\rho_c t$

Results for iteration	No.	2	--		
板件编号 1 | 不受压					
板件编号 2 | 等级 1					
板件编号 3 | 等级 4					
板件编号 4 | 等级 1					
板件编号 5 | 等级 2					
板件编号 6 | 等级 1					
板件编号 7 | 等级 4					
板件编号 8 | 等级 1					
板件编号 9 | 不受压					
板件编号 10 | 等级 1					
板件编号 11 | 等级 1					
板件编号 12 | 等级 1					
平板 | 无加劲 | 内部 | 材料屈曲类型 A | 不带焊缝					
宽度	b	35.4	mm		
厚度	t	1.5	mm		
系数 $\sqrt{(250 / f_o)}$	ε	1.021	--		表 6.2
等级 1 长细比限值	β_1	11.227	--		表 6.2
等级 2 长细比限值	β_2	16.330	--		表 6.2
等级 3 长细比限值	β_3	22.454	--		表 6.2
始端应力	σ_A	-20.258	N/mm²	< 0	
末端应力	σ_B	21.800	N/mm²	≥ 0	
应力比	ψ	-1.076	--		6.1.4.3
Stress gradient	η	0.385	--		式 6.4 或 6.5
长细比参数	β	9.092	--	≤ β_1	式 6.3
组件分级		等级 1			6.1.4.4(1)
板件编号 13 | 等级 1					
板件编号 14 | 等级 1					
板件编号 15 | 等级 1					
板件编号 16 | 不受压					
板件编号 17 | 不受压					
板件编号 18 | 不受压					
板件编号 19 | 不受压					
板件编号 20 | 不受压					
板件编号 21 | 不受压					
板件编号 22 | 不受压					
板件编号 23 | 不受压					
板件编号 24 | 不受压					
Effective section properties					
Shift of centroid in x-axis	Δ_x	0.0	mm		
Shift of centroid in y-axis	zz	0.6	mm		
主轴的方向角	α	0.00	度		
Effective elastic section modulus using reduced thickness $\rho_c t$	$W_{eff,x}$	8.82	cm³		6.2.5.1

板件等级计算过程

有效截面特性

重要参数：b

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规范解读：构件验算

1.截面分类

6.1.4.4 Classification of cross-section parts

(1) The classification of parts of cross-sections is linked to the values of the slenderness parameter β as follows:

Parts in beams

$\beta \le \beta_1$: class 1

$\beta_1 < \beta \le \beta_2$: class 2

$\beta_2 < \beta \le \beta_3$: class 3

$\beta_3 < \beta$: class 4

Parts in struts

$\beta \le \beta_2$: class 1 or 2

$\beta_2 < \beta \le \beta_3$: class 3

$\beta_3 < \beta$: class 4

(2) Values of β_1, β_2 and β_3 are given in Table 6.2.

$$\rho_c = 1{,}0 \quad \text{if } \beta \le \beta_3$$

$$\rho_c = \frac{C_1}{(\beta / \varepsilon)} - \frac{C_2}{(\beta / \varepsilon)^2} \quad \text{if } \beta > \beta_3$$

Table 6.2 - Slenderness parameters β_1/ε, β_2/ε and β_3/ε

Material classification according to Table 3.2	Internal part			Outstand part		
	β_1/ε	β_2/ε	β_3/ε	β_1/ε	β_2/ε	β_3/ε
Class A, without welds	11	16	22	3	4,5	6
Class A, with welds	9	13	18	2,5	4	5
Class B, without welds	13	16,5	18	3,5	4,5	5
Class B, with welds	10	13,5	15	3	3,5	4
$\varepsilon = \sqrt{250/f_o}$, f_o in N/mm^2						

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规范解读：构件验算

2.杆件受压-N-截面强度验算

6.2.4 Compression

(1)P The design value of the axial compression force N_{Ed} shall satisfy:

$$\frac{N_{Ed}}{N_{c,Rd}} \leq 1,0 \qquad (6.20)$$

(2) The design resistance for uniform compression $N_{c,Rd}$ should be taken as the lesser of $N_{u,Rd}$ and $N_{c,Rd}$ where :

a) in sections with unfilled holes $N_{u,Rd} = A_{net} f_u / \gamma_{M2}$ (6.21)

b) other sections $N_{c,Rd} = A_{eff} f_o / \gamma_{M1}$ (6.22)

in which:

A_{net} is the net section area, with deductions for unfilled holes and HAZ softening if necessary. See 6.2.2.2. For holes located in reduced thickness regions the deduction may be based on the reduced thickness, instead of the full thickness.

A_{eff} is the effective section area based on reduced thickness allowing for local buckling and HAZ softening but ignoring unfilled holes.

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规范解读：构件验算

2.杆件受压-N-构件稳定验算

6.3.1.1 Buckling Resistance

(1)P A compression member shall be verified against both flexural and torsional or torsional-flexural buckling as follows:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1{,}0 \qquad (6.48)$$

where:

N_{Ed} is the design value of the compression force

$N_{b,Rd}$ is the design buckling resistance of the compression member

$$N_{b,Rd} = \kappa \chi A_{eff} f_o / \gamma_{M1} \qquad (6.49)$$

where:

χ is the reduction factor for the relevant buckling mode as given in 6.3.1.2.

κ is a factor to allow for the weakening effects of welding. For longitudinally welded member κ is given in Table 6.5 for flexural buckling and $\kappa = 1$ for torsional and torsional-flexural buckling. In case of transversally welded member $\kappa = \omega_x$ according to 6.3.3.3.

A_{eff} is the effective area allowing for local buckling for class 4 cross-section. For torsional and torsional-flexural buckling see Table 6.7.

$A_{eff} = A$ for class 1, 2 or 3 cross-section

重要参数：χ

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规范解读：构件验算

2.杆件受压-N-构件稳定验算

重要参数：$\bar{\lambda}$

6.3.1.2 Buckling curves

(1) For axial compression in members the value of χ for the appropriate value of $\bar{\lambda}$ should be determined from the relevant buckling curve according to:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \quad \text{but } \chi < 1{,}0 \qquad (6.50)$$

where:

$$\phi = 0{,}5(1 + \alpha(\bar{\lambda} - \bar{\lambda}_0) + \bar{\lambda}^2)$$

$$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_o}{N_{cr}}} \qquad (6.51)$$

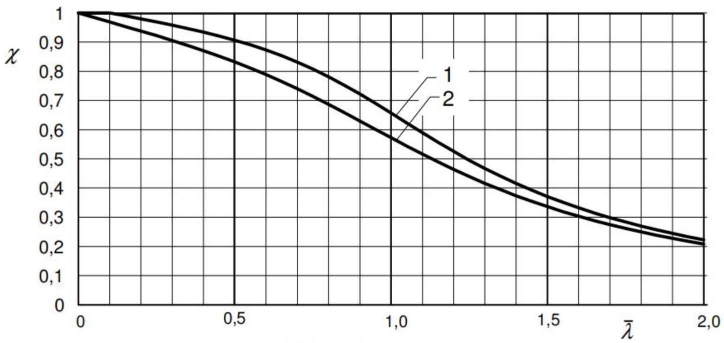
α is an imperfection factor

$\bar{\lambda}_0$ is the limit of the horizontal plateau

N_{cr} is the elastic critical force for the relevant buckling mode based on the gross cross-sectional properties

Table 6.6 - Values of α and $\bar{\lambda}_0$ for flexural buckling

Material buckling class according to Table 3.2	α	$\bar{\lambda}_0$
Class A	0,20	0,10
Class B	0,32	0,00



1 Class A material,
2 Class B material

Figure 6.11 - Reduction factor χ for flexural buckling

(4) For slenderness $\bar{\lambda} \le \bar{\lambda}_0$ or for $N_{Ed} \le \bar{\lambda}_0^2 N_{cr}$ the buckling effects may be ignored and only cross-sectional check apply.

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规范解读：构件验算

2.杆件受压-N-构件稳定验算

6.3.1.3 Slenderness for flexural buckling

(1) The relative slenderness $\bar{\lambda}$ is given by:

$$\bar{\lambda} = \sqrt{\frac{A_{\mathrm{eff}}\, f_{\mathrm{o}}}{N_{\mathrm{cr}}}} = \frac{L_{\mathrm{cr}}}{i}\,\frac{1}{\pi}\sqrt{\frac{A_{\mathrm{eff}}}{A}\,\frac{f_{\mathrm{o}}}{E}} \qquad (6.52)$$

where:

L_{cr} is the buckling length in the buckling plane considered

(2) The buckling length L_{cr} should be taken as kL, where L is the length between points of lateral support; for a cantilever strut, L is its length. The value of k, the buckling length factor for struts, should be assessed from a knowledge of the end conditions; Table 6.8 gives guidance.

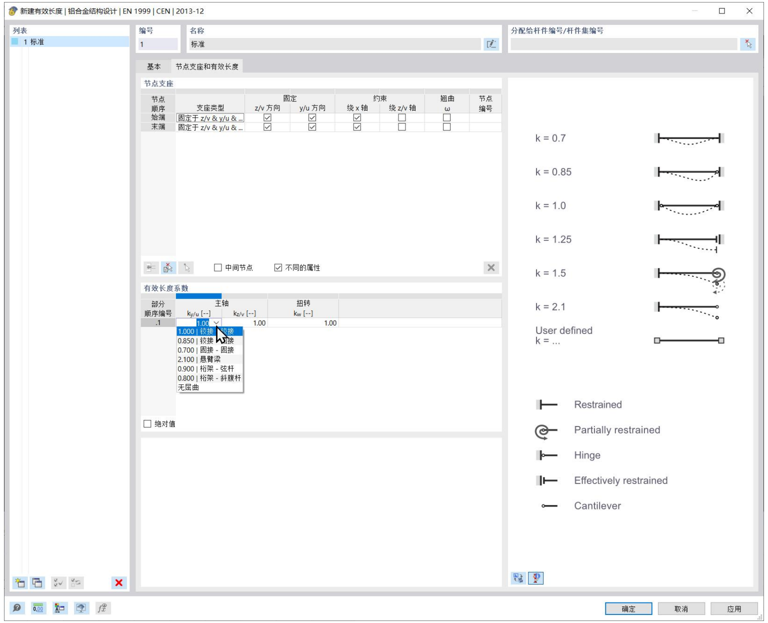
NOTE The buckling length factors k are increased compared to the theoretical value for fixed ends to allow for various deformations in the connection between different structural parts.

Table 6.8 - Buckling length factor *k* for struts

End conditions	*k*
1. Held in position and restrained in direction at both ends	0,7
2. Held in position at both ends and restrained in direction at one end	0,85
3. Held in position at both ends, but not restrained in direction	1,0
4. Held in position at one end, and restrained in direction at both ends	1,25
5. Held in position and restrained in direction at one end, and partially restrained in direction but not held in position at the other end	1,5
6. Held in position and restrained in direction at one end, but not held in position or restrained at the other end	2,0

重要参数：k

默认取1.0，因此最好添加整体侧移缺陷。按照方法b进行稳定验算。如果没有考虑缺陷，按照c方法（计算长度系数法）的话，需要根据屈曲模态修改k值



规范解读：构件验算

3.杆件受弯-M-截面强度验算

6.2.5 Bending moment

6.2.5.1 Basis

(1)P The design value of the bending moment M_{Ed} at each cross section shall satisfy

$$\frac{M_{Ed}}{M_{Rd}} \le 1{,}0 \qquad (6.23)$$

(2) The design resistance for bending about one principal axis of a cross section M_{Rd} is determined as the lesser of $M_{u,Rd}$ and $M_{c,Rd}$ where:

$$M_{u,Rd} = W_{net} f_u / \gamma_{M2} \quad \text{in a net section and} \qquad (6.24)$$

$$M_{c,Rd} = \alpha W_{el} f_o / \gamma_{M1} \quad \text{at each cross-section} \qquad (6.25)$$

Table 6.4 - Values of shape factor α

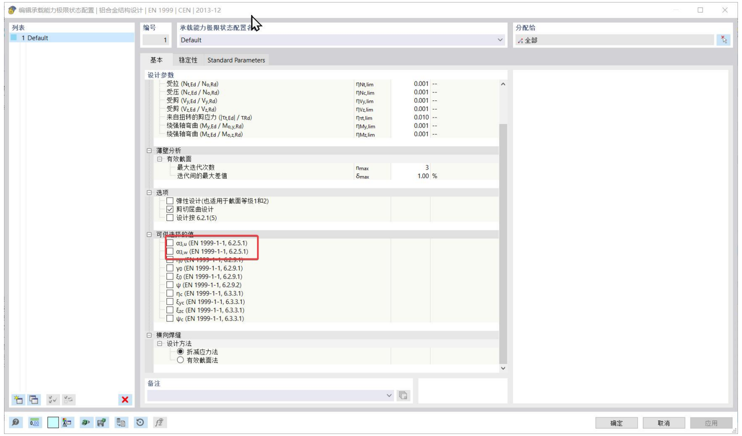
Cross-section class	Without welds	With longitudinal welds
1	W_{pl} / W_{el} *)	$W_{pl,haz} / W_{el}$ *)
2	W_{pl} / W_{el}	$W_{pl,haz} / W_{el}$
3	$\alpha_{3,u}$	$\alpha_{3,w}$
4	W_{eff} / W_{el}	$W_{eff,haz} / W_{el}$
*) NOTE These formulae are on the conservative side. For more refined value, recommendations are given in Annex F		

$\alpha_{3,u}$ =1 or may alternatively be taken as:

$$\alpha_{3,u} = \left[1 + \left(\frac{\beta_3 - \beta}{\beta_3 - \beta_2}\right)\left(\frac{W_{pl}}{W_{el}} - 1\right)\right]$$

$\alpha_{3,w} = W_{el,haz} / W_{el}$ or may alternatively be taken as:

$$\alpha_{3,w} = \left[\frac{W_{el,haz}}{W_{el}} + \left(\frac{\beta_3 - \beta}{\beta_3 - \beta_2}\right)\left(\frac{W_{pl,haz} - W_{el,haz}}{W_{el}}\right)\right]$$



$a_{3,u}$,$a_{3,w}$默认偏保守取1.0，也可以手动指定

规范解读：构件验算

3.杆件受弯-M-杆件稳定验算

6.3.2.1 Buckling resistance

NOTE Lateral torsional buckling need not be checked in any of the following circumstances:

a) bending takes place about the minor principal axis and at the same time the load application is not over the shear centre;

b) the member is fully restrained against lateral movement throughout its length;

c) the relative slenderness $\overline{\lambda}_{LT}$ (see 6.3.2.3) between points of effective lateral restraint is less than 0,4.

(1)P A laterally unrestrained member subject to mayor axis bending shall be verified against lateral-torsional buckling as follows:

$$\frac{M_{Ed}}{M_{b,Rd}} \leq 1{,}0 \qquad (6.54)$$

where:

M_{Ed} is the design value of the bending moment

$M_{b,Rd}$ is the design buckling resistance moment.

(2) The design buckling resistance moment of laterally un-restrained member should be taken as:

$$M_{b,Rd} = \chi_{LT} \alpha W_{el,y} f_o / \gamma_{M1} \qquad (6.55)$$

where:

$W_{el,y}$ is the elastic section modulus of the gross section, without reduction for HAZ softening, local buckling or holes.

α is taken from Table 6.4 subject to the limitation $\alpha \leq W_{pl,y} / W_{el,y}$.

χ_{LT} is the reduction factor for lateral torsional buckling (see 6.3.2.2).

重要参数：χ_{LT}

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规范解读：构件验算

3.杆件受弯-M-杆件稳定验算

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \quad \text{but } \chi_{LT} \le 1 \qquad (6.56)$$

where:

$$\phi_{LT} = 0,5\left[1 + \alpha_{LT}(\bar{\lambda}_{LT} - \bar{\lambda}_{0,LT}) + \bar{\lambda}_{LT}^2\right] \qquad (6.57)$$

α_{LT} is an imperfection factor

$\bar{\lambda}_{LT}$ is the relative slenderness

$\bar{\lambda}_{0,LT}$ is the limit of the horizontal plateau

M_{cr} is the elastic critical moment for lateral-torsional buckling.

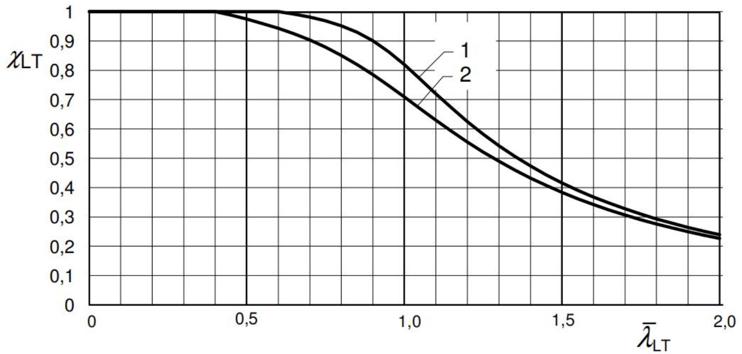
(2) The value of α_{LT} and $\bar{\lambda}_{0,LT}$ should be taken as:

$\alpha_{LT} = 0{,}10$ and $\bar{\lambda}_{0,LT} = 0{,}6$ for class 1 and 2 cross-sections

$\alpha_{LT} = 0{,}20$ and $\bar{\lambda}_{0,LT} = 0{,}4$ for class 3 and 4 cross-sections.

(3) Values of the reduction factor χ_{LT} for the appropriate relative slenderness $\bar{\lambda}_{LT}$ may be obtained from Figure 6.13

(4) For slenderness $\bar{\lambda}_{LT} \le \bar{\lambda}_{0,LT}$ or for $M_{Ed} \le \bar{\lambda}_{0,LT}^2 M_{cr}$ the buckling effects may be ignored and only cross-sectional check apply.



1 Class 1 and 2 cross sections,
2 Class 3 and 4 cross sections

Figure 6.13 - Reduction factor for lateral-torsional buckling

重要参数：$\overline{\lambda_{LT}}$

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规范解读：构件验算

3.杆件受弯-M-杆件稳定验算

6.3.2.3 Slenderness

(1) The relative slenderness parameter $\bar{\lambda}_{LT}$ should be determined from

$$\bar{\lambda}_{LT} = \sqrt{\frac{\alpha W_{el,y} f_o}{M_{cr}}} \tag{6.58}$$

where:

α is taken from Table 6.4 subject to the limitation $\alpha \le W_{pl,y} / W_{el,y}$.
M_{cr} is the elastic critical moment for lateral-torsional buckling.

(2) M_{cr} is based on gross cross sectional properties and takes into account the loading conditions, the real moment distribution and the lateral restraints.

NOTE Expressions for M_{cr} for certain sections and boundary conditions are given in Annex I.1 and approximate values of $\bar{\lambda}_{LT}$ for certain I-sections and channels are given in Annex I.2.

I.1 Elastic critical moment and slenderness

I.1.1 Basis

(1) The elastic critical moment for lateral-torsional buckling of a beam of uniform symmetrical cross-section with equal flanges, under standard conditions of restraint at each end and subject to uniform moment in plane going through the shear centre is given by:

1 2 3

$$M_{cr} = \frac{\pi^2 EI_z}{L^2}\sqrt{\frac{L^2 GI_t}{\pi^2 EI_z} + \frac{I_w}{I_z}} = \frac{\pi\sqrt{EI_z GI_t}}{L}\sqrt{1 + \frac{\pi^2 EI_w}{L^2 GI_t}} \tag{I.1}$$

where:

$$G = \frac{E}{2(1+\nu)}$$

I_t is the torsion constant
I_w is the warping constant
I_z is the second moment of area about the minor axis
L is the length of the beam between points that have lateral restraint
ν is the Poisson ratio

(2) The standard conditions of restraint at each end are:

- restrained against lateral movement, free to rotate on plan ($k_z = 1$);
- restrained against rotation about the longitudinal axis, free to warp ($k_w = 1$);
- restrained against movement in plane of loading, free to rotate in this plane ($k_y = 1$).

重要参数：M_{cr}

规范附录I的公式仅适用于均匀对称截面，均布弯矩，两端有抗扭约束的简支梁

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规范解读：构件验算

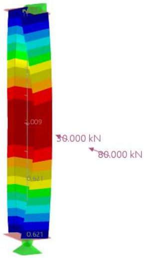
3.杆件受弯-M-杆件稳定验算

稳定性计算

Lateral-torsional buckling acc. to 6.3.2.1

$$\alpha = \frac{W_{eff,y}}{W_{el,y}} = \frac{190.20\ \mathrm{cm}^3}{234.43\ \mathrm{cm}^3} = 0.811$$

6.2.5, Tab. 6.4

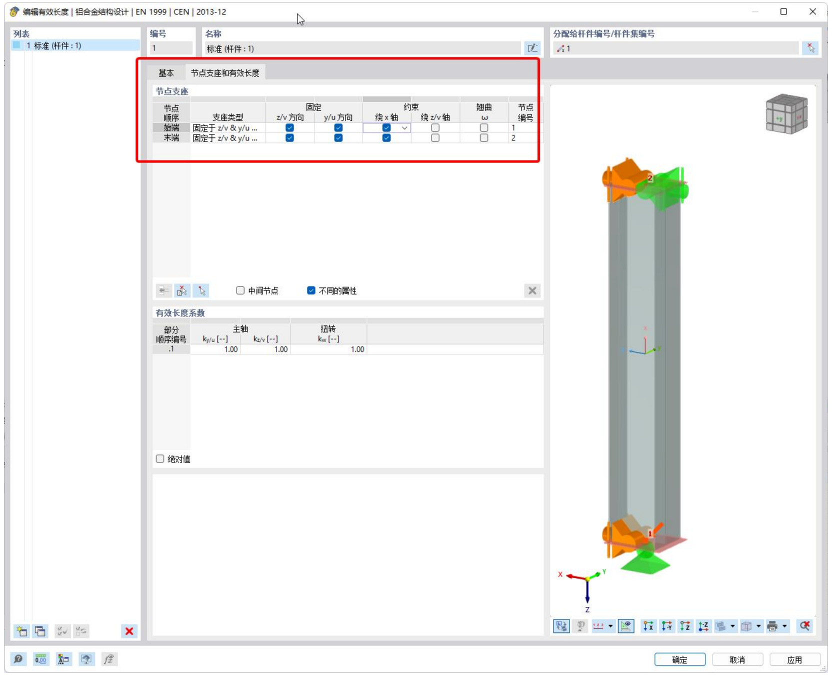


$$M_{cr} = \alpha_{cr} \cdot M_{y,Ed,max} = 4.99 \cdot 41.26\ \mathrm{kNm} = 206.01\ \mathrm{kNm}$$

6.3.2.2(1)

$$\bar{\lambda}_{LT} = \sqrt{\frac{\alpha \cdot W_{el,y} \cdot f_o}{M_{cr}}} = \sqrt{\frac{0.811 \cdot 234.43\ \mathrm{cm}^3 \cdot 260.000\ \mathrm{N/mm}^2}{206.01\ \mathrm{kNm}}} = 0.490$$

6.3.2.3(1), Eq. 6.58



重要参数：M_{cr}

规范附录I的公式仅适用于均匀对称截面，均布弯矩，两端有抗扭约束的简支梁

规范解读：构件验算

4.杆件受剪-V-截面强度验算

6.2.6 Shear

(1)P The design value of the shear force V_{Ed} at each cross-section shall satisfy:

$$\frac{V_{Ed}}{V_{Rd}} \leq 1{,}0$$

where:

V_{Rd} is the design shear resistance of the cross-section.

截面抗剪承载力与腹板高厚比相关，太大的话需要考虑抗剪屈曲！

(2) For non-slender sections, $h_w / t_w < 39\varepsilon$, see 6.5.5(2)

a) non-slender plate ($\beta \leq 39\varepsilon$):

$$V_{Rd} = A_{net} f_o / (\sqrt{3}\, \gamma_{M1})$$

b) slender plate ($\beta > 39\varepsilon$):

Values of V_{Rd} for both yielding and buckling should be checked. For the yielding check use a) above for non-slender plates. For the buckling check:

$$V_{Rd} = v_1 bt\, f_o / (\sqrt{3}\gamma_{M1}) \qquad (6.89)$$

where:

$$v_1 = 17 t\varepsilon \sqrt{k_\tau} / b \text{ but not more than } v_1 = k_\tau \frac{430 t^2 \varepsilon^2}{b^2}$$

$$k_\tau = 5{,}34 + 4{,}00 (b/a)^2 \quad \text{if} \quad a/b \geq 1$$

$$k_\tau = 4{,}00 + 5{,}34 (b/a)^2 \quad \text{if} \quad a/b < 1$$

NOTE These expressions do not take advantage of tension field action, but if it is known that the edge supports for the plate are capable of sustaining a tension field, the treatment given in 6.7.3 can be employed.

（6.89抗剪屈曲承载力没有考虑拉应力场的有效作用）

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规范解读：构件验算

4.杆件受剪-V-截面强度验算（添加横向加劲肋后，考虑拉立场有利贡献）

(4) The contribution from the web to the design resistance for shear should be taken as:

$$V_{Rd} = \rho_v t_w h_w \frac{f_o}{\sqrt{3} \cdot \gamma_{M1}}$$

where ρ_v is the factor for shear buckling obtained from Table 6.13 or Figure 6.28.

(5) The slenderness parameter λ_w is

$$\lambda_w = \frac{0{,}81}{\sqrt{k_\tau}} \frac{b_w}{t_w} \sqrt{\frac{f_o}{E}}$$

Table 6.13 - Factor ρ_v for shear buckling

Ranges of λ_w	Rigid end post	Non-rigid end post
$\lambda_w \leq 0{,}83/\eta$	η	η
$0{,}83/\eta < \lambda_w < 0{,}937$	$0{,}83/\lambda_w$	$0{,}83/\lambda_w$
$0{,}937 \leq \lambda_w$	$2{,}3/(1{,}66+\lambda_w)$	$0{,}83/\lambda_w$

$\eta = 0{,}7 + 0{,}35 f_{aw} / f_{ow}$ but not more than 1,2 where f_{ow} is the strength for overall yielding and f_{aw} is the ultimate strength of the web material.

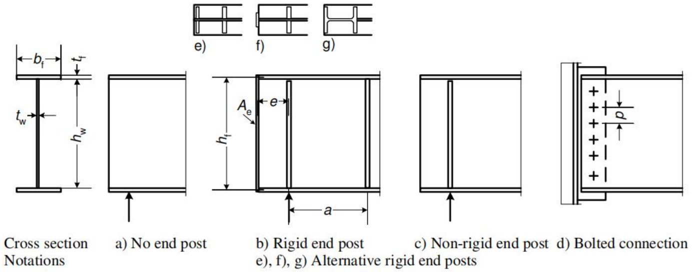
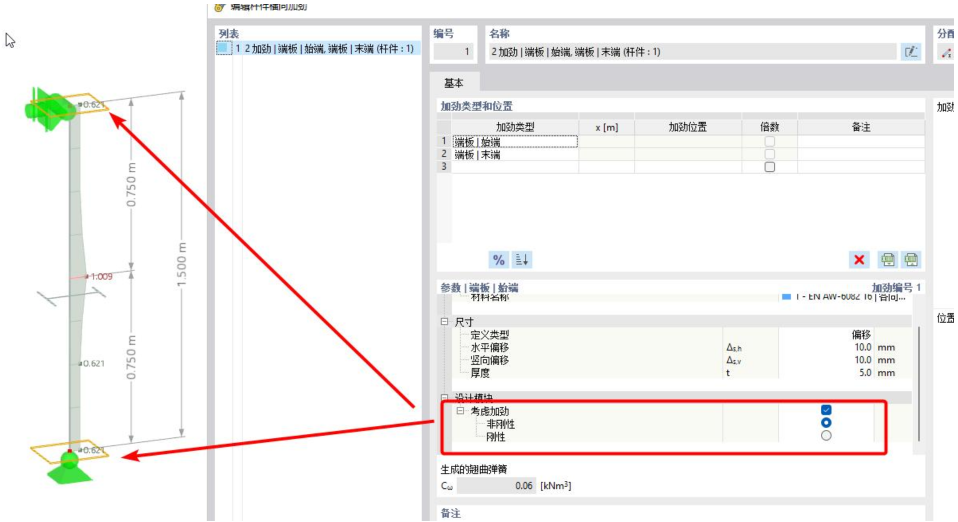


Figure 6.27 - End-stiffeners

规范解读：构件验算

4.杆件受剪-V-截面强度验算（添加横向加劲肋后,考虑拉立场有利贡献）



$$k_\tau = 5.34 + 4 \cdot \left(\frac{b_w}{a}\right)^2 = 5.34 + 4 \cdot \left(\frac{220.0\,\text{mm}}{1.500\,\text{m}}\right)^2 = 5.426$$ 6.7.4.2(7)

$$\lambda_{lim} = \left(\frac{1.02}{\eta}\right) \cdot \sqrt{k_\tau \cdot \frac{E}{f_{o,w}}} = \left(\frac{1.02}{1.117}\right) \cdot \sqrt{5.426 \cdot \frac{70000.0\,\text{N/mm}^2}{260.000\,\text{N/mm}^2}} = 34.892$$ 6.7.4.2(2)

$\lambda > \lambda_{lim}$

Acc. to 6.7.4.2(2), shear buckling has to be considered.

$$V_{z,Rd} = A_{v,z} \cdot \frac{f_{o,w}}{\sqrt{3} \cdot \gamma_{M1}} = 9.12\,\text{cm}^2 \cdot \frac{260.000\,\text{N/mm}^2}{\sqrt{3} \cdot 1.10} = 124.456\,\text{kN}$$ 6.2.6(2), Eq. 6.29

$$\lambda_w = \frac{0.81}{\sqrt{k_\tau}} \cdot \frac{b_w}{t_w} \cdot \sqrt{\frac{f_{o,w}}{E}} = \frac{0.81}{\sqrt{5.426}} \cdot \frac{220.0\,\text{mm}}{4.0\,\text{mm}} \cdot \sqrt{\frac{260.000\,\text{N/mm}^2}{70000.0\,\text{N/mm}^2}} = 1.166$$ 6.7.4.2, Eq. 6.126

$$\rho_v = \frac{0.83}{\lambda_w} = \frac{0.83}{1.166} = 0.712$$ 6.7.4.1(3), Tab. 6.13

$$V_{z,w,Rd} = \rho_v \cdot t_w \cdot h_w \cdot \frac{f_{o,w}}{\sqrt{3} \cdot \gamma_{M1}} = 0.712 \cdot 4.0\,\text{mm} \cdot 228.0\,\text{mm} \cdot \frac{260.000\,\text{N/mm}^2}{\sqrt{3} \cdot 1.10} = 88.624\,\text{kN}$$ 6.7.4.2, Eq. 6.125

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规范解读：构件验算

5.构件受弯剪-M/V-截面强度验算

6.2.8 Bending and shear

(1) Where a shear force is present allowance should be made for its effect on the moment resistance.

(2) If the shear force V_{Ed} is less than half the shear resistance V_{Rd} its effect on the moment resistance may be neglected except where shear buckling reduces the section resistance, see 6.7.6.

(3) Otherwise the reduced moment resistance should be taken as the design resistance of the cross-section, calculated using a reduced strength

$$f_{o,V} = f_o\left(1-(2V_{Ed}/V_{Rd}-1)^2\right) \quad (6.38)$$

where V_{Rd} is obtained from 6.2.6.

剪力设计值V_{Ed}大于$0.5V_{Rd}$时，需要对抗弯承载力进行折减！

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规范解读：构件验算

6.构件受压弯-N/M-截面强度验算

6.2.9 Bending and axial force

6.2.9.1 Open cross-sections

(1) For doubly symmetric cross-sections (except solid sections, see 6.2.9.2) the following two criterions should be satisfied:

$$\left(\frac{N_{Ed}}{\omega_0 N_{Rd}}\right)^{\xi_0}+\frac{M_{y,Ed}}{\omega_0 M_{y,Rd}}\leq 1{,}00 \qquad (6.40)$$

$$\left(\frac{N_{Ed}}{\omega_0\, N_{Rd}}\right)^{\eta_0}+\left(\frac{M_{y,Ed}}{\omega_0\, M_{y,Rd}}\right)^{\gamma_0}+\left(\frac{M_{z,Ed}}{\omega_0\, M_{z,Rd}}\right)^{\xi_0}\leq 1{,}00 \qquad (6.41)$$

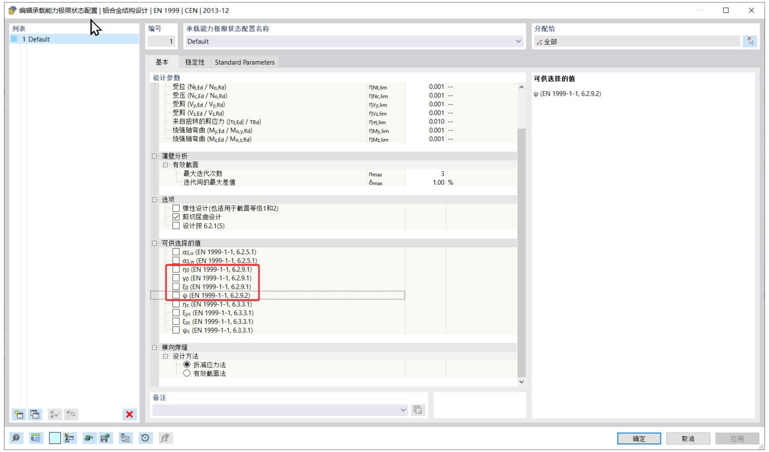
6.2.9.2 Hollow sections and solid cross-sections

(1) Hollow sections and solid cross-sections should satisfy the following criterion:

$$\left(\frac{N_{Ed}}{\omega_0 N_{Rd}}\right)^{\psi}+\left[\left(\frac{M_{y,Ed}}{\omega_0 M_{y,Rd}}\right)^{1,7}+\left(\frac{M_{z,Ed}}{\omega_0 M_{z,Rd}}\right)^{1,7}\right]^{0,6}\leq 1{,}00 \qquad (6.43)$$

where $\psi = 1{,}3$ for hollow sections and $\psi = 2$ for solid cross-sections. Alternatively ψ may be taken as $\alpha_y \alpha_z$ but $1 \leq \psi \leq 1{,}3$ for hollow sections and $1 \leq \psi \leq 2$ for solid cross-sections.

$\omega_{0:}$热影响区折减系数，默认取1.0



默认：

$\eta_0 = \xi_0 = \gamma_0 = 1.0$

Ψ=1.3（管截面）/2.0(实心截面）

规范解读：构件验算

6.构件受压弯-N/M-构件稳定验算

6.3.3 Members in bending and axial compression

(1) Unless second order analysis is carried out using the imperfections as given in 5.3.2, the stability of uniform members should be checked as given in the following clause, where a distinction is made for:

– members that are not susceptible to torsional deformations, e.g. circular hollow sections or sections restrained from torsion (flexural buckling only);
– members that are susceptible to torsional deformations, e.g. members with open cross-sections not restrained from torsion (lateral-torsional buckling or flexural buckling).

不易扭转变形的构件（圆管截面/有扭转约束开口截面）：仅需**弯曲屈曲**验算。

易扭转变形构件（没有扭转约束的开口截面）：**横向扭转屈曲**验算和**弯曲屈曲**验算。

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规范解读：构件验算

6.构件受压弯-N/M-构件稳定验算-弯曲屈曲

6.3.3.1 Flexural buckling

(1) For a member with open doubly symmetric cross-section (solid sections, see (2)), one of the following criterions should be satisfied:

- For major axis (y-axis) bending:

$$\left(\frac{N_{Ed}}{\chi_y \omega_x N_{Rd}}\right)^{\xi_{yc}} + \frac{M_{y,Ed}}{\omega_0 M_{y,Rd}} \leq 1{,}00 \qquad (6.59)$$

- For minor axis (z-axis) bending:

$$\left(\frac{N_{Ed}}{\chi_z \omega_x N_{Rd}}\right)^{\eta_c} + \left(\frac{M_{z,Ed}}{\omega_0 M_{z,Rd}}\right)^{\xi_{zc}} \leq 1{,}00 \qquad (6.60)$$

(3) Hollow cross-sections and tubes should satisfy the following criterion:

$$\left(\frac{N_{Ed}}{\chi_{min} \omega_x N_{Rd}}\right)^{\psi_c} + \frac{1}{\omega_0}\left[\left(\frac{M_{y,Ed}}{M_{y,Rd}}\right)^{1,7} + \left(\frac{M_{z,Ed}}{M_{z,Rd}}\right)^{1,7}\right]^{0,6} \leq 1{,}00 \qquad (6.62)$$

默认：

$\eta_c = \xi_{yc} = \xi_{zc} = 0.8$

$\omega_0 = \omega_c = 1.0$

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规范解读：构件验算

6.构件受压弯-N/M-构件稳定验算-横向扭转屈曲

6.3.3.2 Lateral-torsional buckling

(1) Members with open cross-section symmetrical about major axis, centrally symmetric or doubly symmetric cross-section, the following criterion should satisfy:

$$\left(\frac{N_{Ed}}{\chi_z \omega_x N_{Rd}}\right)^{\eta_c} + \left(\frac{M_{y,Ed}}{\chi_{LT} \omega_{xLT} M_{y,Rd}}\right)^{\gamma_c} + \left(\frac{M_{z,Ed}}{\omega_0 M_{z,Rd}}\right)^{\xi_{zc}} \leq 1{,}00 \quad (6.63)$$

默认：

$\eta_c = \xi_{zc} = 0.8$

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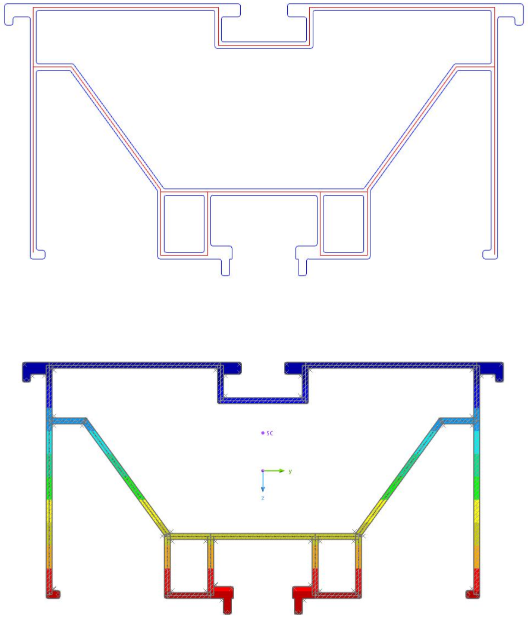
软件操作-操作流程



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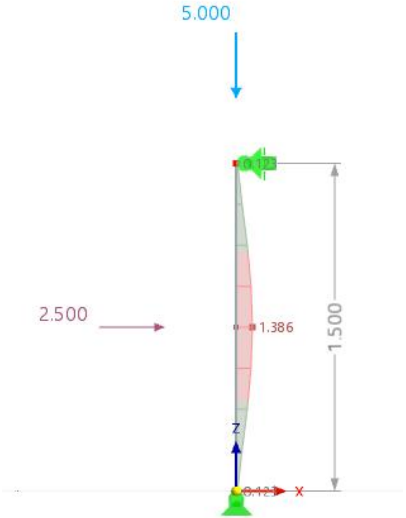

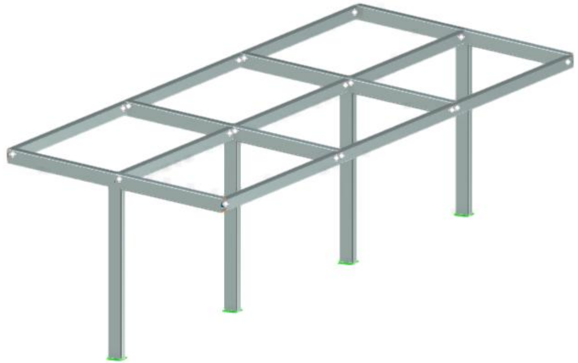

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