Structural Analysis & Design Software

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网络课堂

RFEM 6
美标ADM 2020
铝合金结构设计

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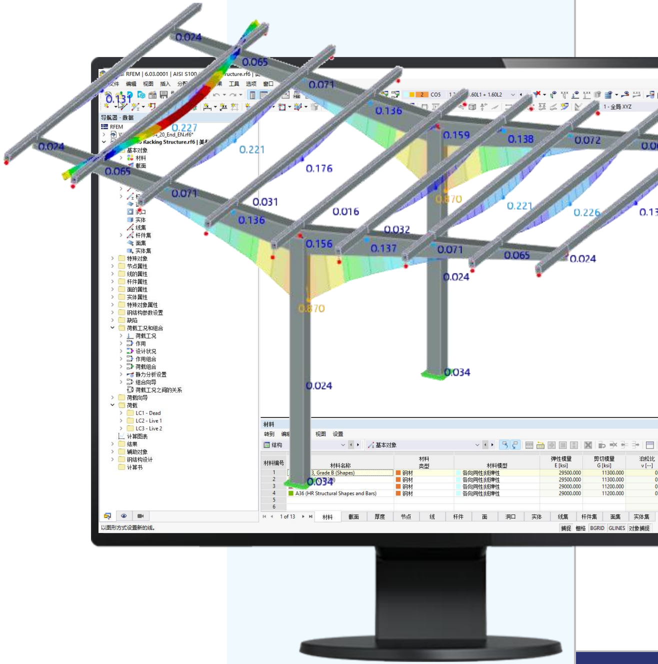


主要内容

规范解读-C章：稳定设计

杆件和节点设计所需的内力应该用考虑了以下因素的弹性分析来确定：

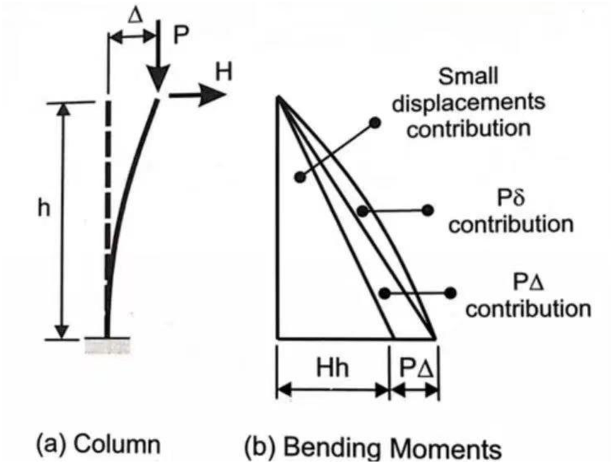
□ 要考虑结构的弯曲/剪切/轴向变形，其他组件和节点的变形
□ 二阶效应（P-Δ和P-δ）
□ 几何缺陷
□ 刚度折减（截面局部塑性/残余应力）
□ 强度和刚度的不确定性

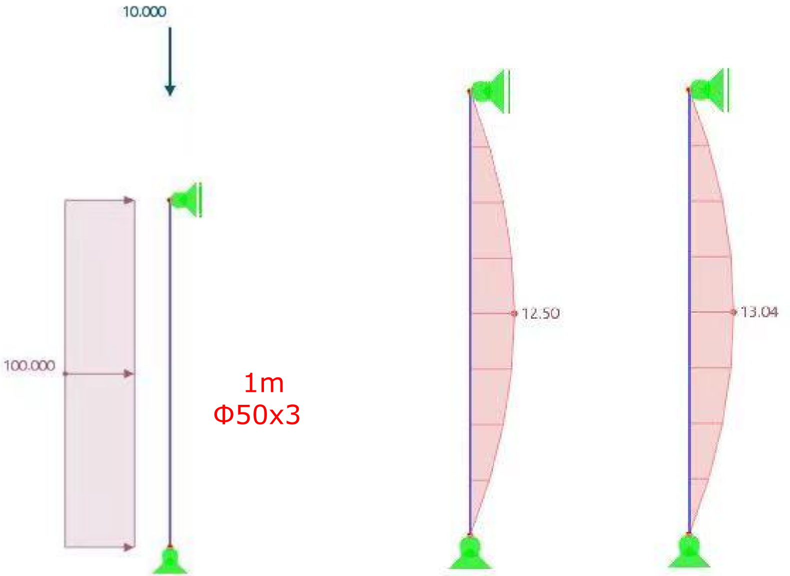
与AISC 360-16的要求基本相同。

规范解读-C章：稳定设计

二阶效应：

手算时，单工况分开
实际中，多工况同时作用



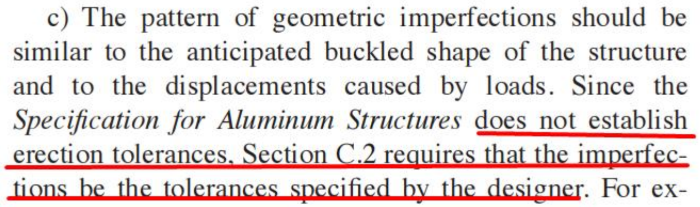


p-δ效应：放大系数1.0432

（杆件中间没有网格节点也能考虑，更不需要打断杆件）

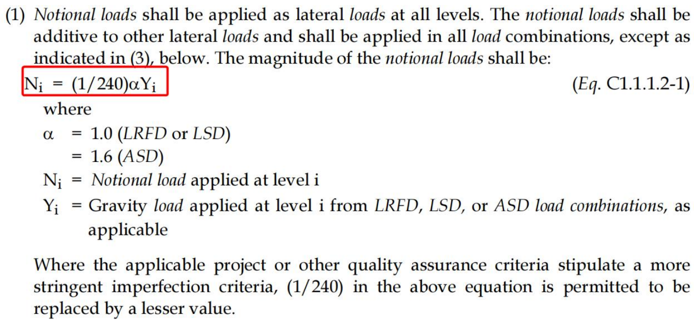
规范解读-C章：稳定设计

几何缺陷：ADM/AISI/AISC 不同之处：



c) The pattern of geometric imperfections should be similar to the anticipated buckled shape of the structure and to the displacements caused by loads. Since the *Specification for Aluminum Structures* does not establish erection tolerances, Section C.2 requires that the imperfections be the tolerances specified by the designer. For ex-

ADM



(1) *Notional loads* shall be applied as lateral *loads* at all levels. The *notional loads* shall be additive to other lateral *loads* and shall be applied in all *load* combinations, except as indicated in (3), below. The magnitude of the *notional loads* shall be:

$$\boxed{N_i = (1/240)\alpha Y_i} \qquad (Eq.\ C1.1.1.2\text{-}1)$$

where

α = 1.0 (*LRFD* or *LSD*)

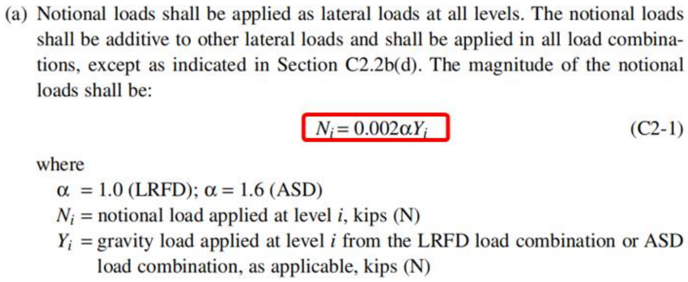
= 1.6 (*ASD*)

N_i = *Notional load* applied at level i

Y_i = Gravity *load* applied at level i from *LRFD*, *LSD*, or *ASD load combinations*, as applicable

Where the applicable project or other quality assurance criteria stipulate a more stringent imperfection criteria, (1/240) in the above equation is permitted to be replaced by a lesser value.

AISI



(a) Notional loads shall be applied as lateral loads at all levels. The notional loads shall be additive to other lateral loads and shall be applied in all load combinations, except as indicated in Section C2.2b(d). The magnitude of the notional loads shall be:

$$\boxed{N_i = 0.002\alpha Y_i} \qquad (C2\text{-}1)$$

where

α = 1.0 (LRFD); α = 1.6 (ASD)

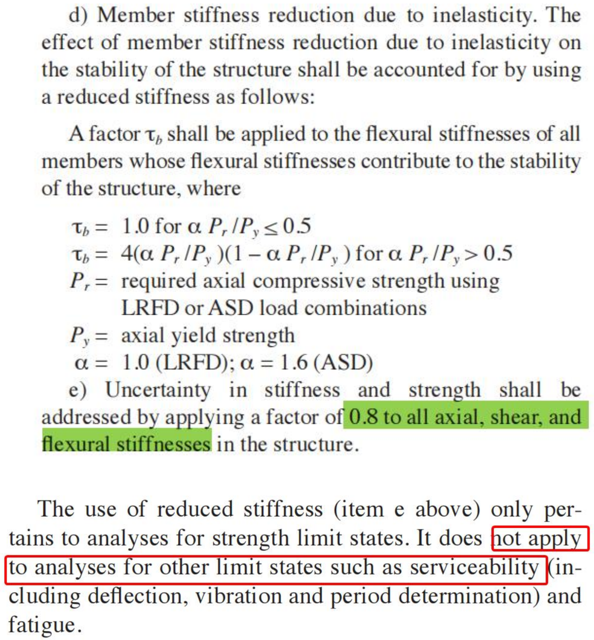
N_i = notional load applied at level i, kips (N)

Y_i = gravity load applied at level i from the LRFD load combination or ASD load combination, as applicable, kips (N)

AISC

规范解读-C章：稳定设计

刚度折减：ADM/AISI/AISC 不同之处：



d) Member stiffness reduction due to inelasticity. The effect of member stiffness reduction due to inelasticity on the stability of the structure shall be accounted for by using a reduced stiffness as follows:

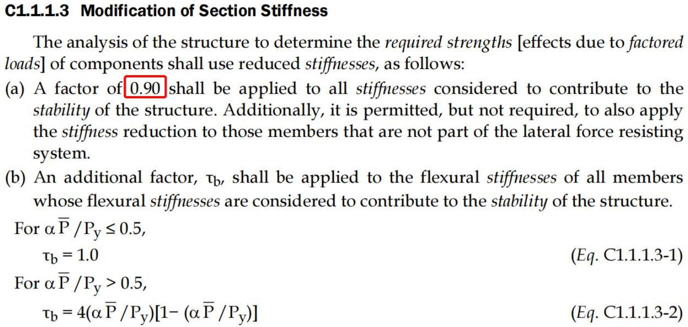
A factor τ_b shall be applied to the flexural stiffnesses of all members whose flexural stiffnesses contribute to the stability of the structure, where

τ_b = 1.0 for $\alpha P_r/P_y \le 0.5$
τ_b = $4(\alpha P_r/P_y)(1-\alpha P_r/P_y)$ for $\alpha P_r/P_y > 0.5$
P_r = required axial compressive strength using LRFD or ASD load combinations
P_y = axial yield strength
α = 1.0 (LRFD); α = 1.6 (ASD)

e) Uncertainty in stiffness and strength shall be addressed by applying a factor of 0.8 to all axial, shear, and flexural stiffnesses in the structure.

The use of reduced stiffness (item e above) only pertains to analyses for strength limit states. It does not apply to analyses for other limit states such as serviceability (including deflection, vibration and period determination) and fatigue.

ADM



C1.1.1.3 Modification of Section Stiffness

The analysis of the structure to determine the *required strengths* [effects due to *factored loads*] of components shall use reduced *stiffnesses*, as follows:

(a) A factor of 0.90 shall be applied to all *stiffnesses* considered to contribute to the *stability* of the structure. Additionally, it is permitted, but not required, to also apply the *stiffness* reduction to those members that are not part of the lateral force resisting system.

(b) An additional factor, τ_b, shall be applied to the flexural *stiffnesses* of all members whose flexural *stiffnesses* are considered to contribute to the *stability* of the structure.

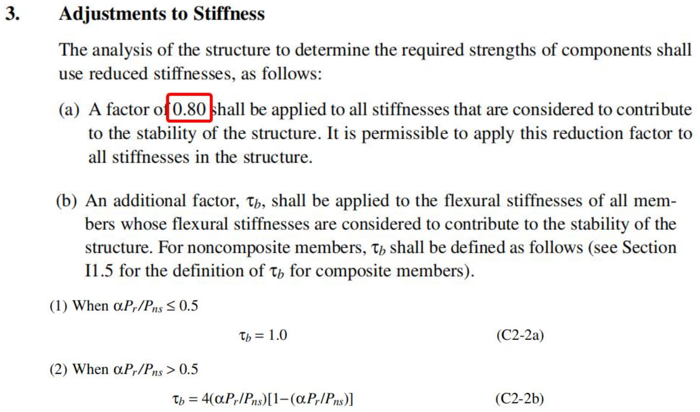
For $\alpha\overline{P}/P_y \le 0.5$,

$$\tau_b = 1.0 \qquad (Eq.\ C1.1.1.3\text{-}1)$$

For $\alpha\overline{P}/P_y > 0.5$,

$$\tau_b = 4(\alpha\overline{P}/P_y)[1-(\alpha\overline{P}/P_y)] \qquad (Eq.\ C1.1.1.3\text{-}2)$$

AISI



3. Adjustments to Stiffness

The analysis of the structure to determine the required strengths of components shall use reduced stiffnesses, as follows:

(a) A factor of 0.80 shall be applied to all stiffnesses that are considered to contribute to the stability of the structure. It is permissible to apply this reduction factor to all stiffnesses in the structure.

(b) An additional factor, τ_b, shall be applied to the flexural stiffnesses of all members whose flexural stiffnesses are considered to contribute to the stability of the structure. For noncomposite members, τ_b shall be defined as follows (see Section I1.5 for the definition of τ_b for composite members).

(1) When $\alpha P_r/P_{ns} \le 0.5$

$$\tau_b = 1.0 \qquad (C2\text{-}2a)$$

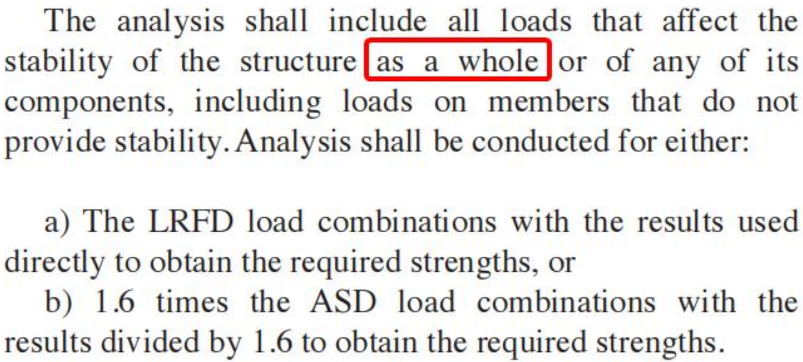
(2) When $\alpha P_r/P_{ns} > 0.5$

$$\tau_b = 4(\alpha P_r/P_{ns})[1-(\alpha P_r/P_{ns})] \qquad (C2\text{-}2b)$$

AISC

规范解读-C章：稳定设计

荷载组合：



The analysis shall include all loads that affect the stability of the structure as a whole or of any of its components, including loads on members that do not provide stability. Analysis shall be conducted for either:

a) The LRFD load combinations with the results used directly to obtain the required strengths, or

b) 1.6 times the ASD load combinations with the results divided by 1.6 to obtain the required strengths.

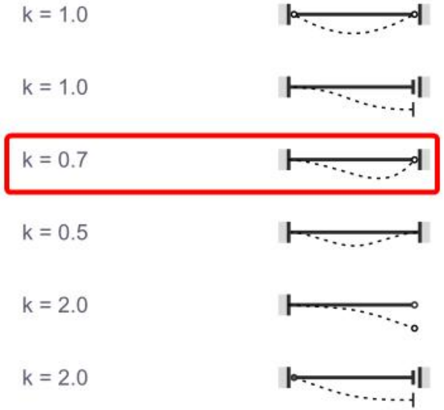
ADM

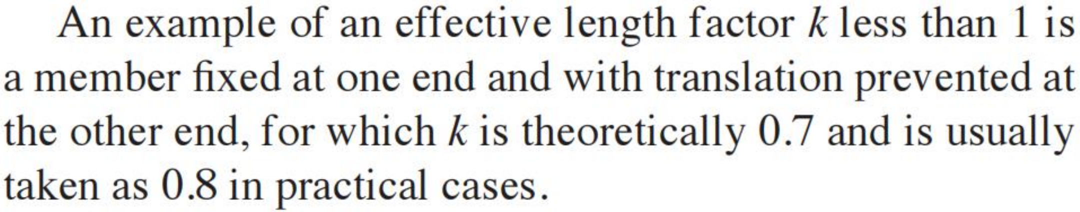
规范解读-C章：稳定设计

计算可用强度（承载力设计值）：

1.构件弯曲屈曲计算长度系数可取1.0，经过**合理分析的话也可以小于1.0**

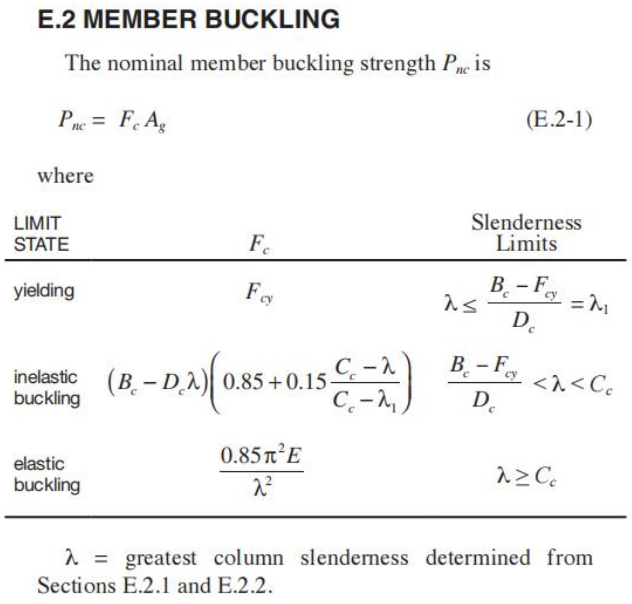
2.计算长度系数取1.0的只是弯曲屈曲验算，而扭转屈曲/弯曲扭转屈曲的计算长度系数仍需按照边界条件取（例如悬臂轴压柱：Ky=Kz=1.0,Kt=2.0)。




An example of an effective length factor *k* less than 1 is a member fixed at one end and with translation prevented at the other end, for which *k* is theoretically 0.7 and is usually taken as 0.8 in practical cases.

规范解读-E章：受压构件

杆件屈曲/局部屈曲/杆件屈曲-局部屈曲相互作用：



E.2 MEMBER BUCKLING

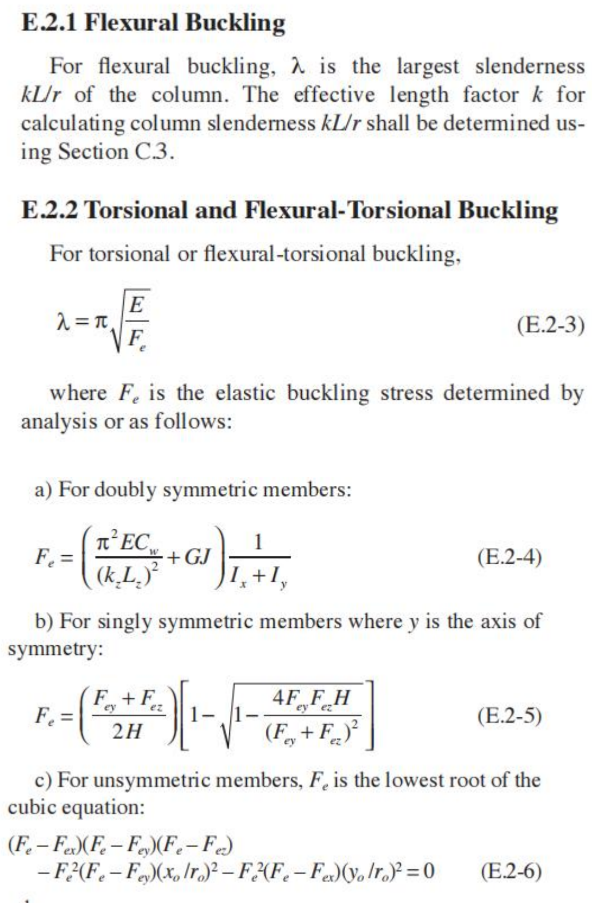
The nominal member buckling strength P_{nc} is

$$P_{nc} = F_c A_g \qquad \text{(E.2-1)}$$

where

LIMIT STATE	F_c	Slenderness Limits
yielding	F_{cy}	$\lambda \le \dfrac{B_c - F_{cy}}{D_c} = \lambda_1$
inelastic buckling	$(B_c - D_c\lambda)\left(0.85 + 0.15\dfrac{C_c - \lambda}{C_c - \lambda_1}\right)$	$\dfrac{B_c - F_{cy}}{D_c} < \lambda < C_c$
elastic buckling	$\dfrac{0.85\pi^2 E}{\lambda^2}$	$\lambda \ge C_c$

λ = greatest column slenderness determined from Sections E.2.1 and E.2.2.



E.2.1 Flexural Buckling

For flexural buckling, λ is the largest slenderness kL/r of the column. The effective length factor k for calculating column slenderness kL/r shall be determined using Section C.3.

E.2.2 Torsional and Flexural-Torsional Buckling

For torsional or flexural-torsional buckling,

$$\lambda = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(E.2-3)}$$

where F_e is the elastic buckling stress determined by analysis or as follows:

a) For doubly symmetric members:

$$F_e = \left(\frac{\pi^2 E C_w}{(k_z L_z)^2} + GJ\right)\frac{1}{I_x + I_y} \qquad \text{(E.2-4)}$$

b) For singly symmetric members where y is the axis of symmetry:

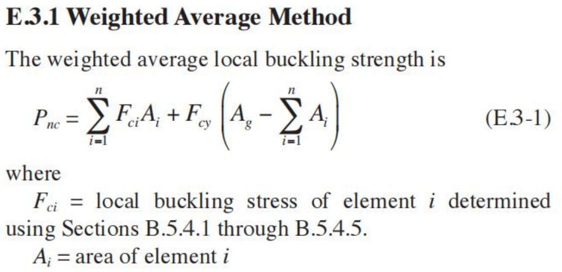
$$F_e = \left(\frac{F_{ey} + F_{ez}}{2H}\right)\left[1 - \sqrt{1 - \frac{4F_{ey}F_{ez}H}{(F_{ey} + F_{ez})^2}}\right] \qquad \text{(E.2-5)}$$

c) For unsymmetric members, F_e is the lowest root of the cubic equation:

$$\begin{aligned}&(F_e - F_{ex})(F_e - F_{ey})(F_e - F_{ez})\\ &\quad - F_e^2(F_e - F_{ey})(x_o/r_o)^2 - F_e^2(F_e - F_{ex})(y_o/r_o)^2 = 0\end{aligned} \qquad \text{(E.2-6)}$$

规范解读-E章：受压构件

杆件屈曲/**局部屈曲**/杆件屈曲-局部屈曲相互作用：



E.3.1 Weighted Average Method

The weighted average local buckling strength is

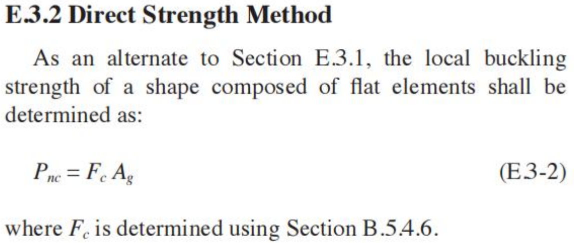
$$P_{nc} = \sum_{i=1}^{n} F_{ci} A_i + F_{cy}\left(A_g - \sum_{i=1}^{n} A_i\right) \qquad \text{(E3-1)}$$

where

F_{ci} = local buckling stress of element i determined using Sections B.5.4.1 through B.5.4.5.

A_i = area of element i

加权平均法：需要计算多个板件的屈曲应力Fci！



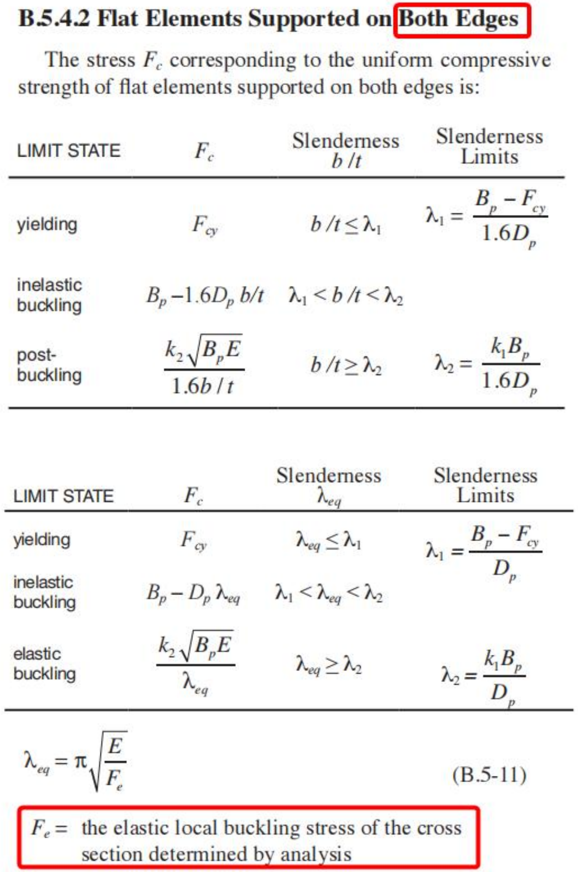
E.3.2 Direct Strength Method

As an alternate to Section E.3.1, the local buckling strength of a shape composed of flat elements shall be determined as:

$$P_{nc} = F_c A_g \qquad \text{(E3-2)}$$

where F_c is determined using Section B.5.4.6.

直接强度法：有限条带法获得最低阶弹性屈曲应力，从而获得毛截面的屈曲应力Fc！



B.5.4.2 Flat Elements Supported on Both Edges

The stress F_c corresponding to the uniform compressive strength of flat elements supported on both edges is:

LIMIT STATE	F_c	Slenderness b/t	Slenderness Limits
yielding	F_{cy}	$b/t \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{1.6D_p}$
inelastic buckling	$B_p - 1.6D_p\, b/t$	$\lambda_1 < b/t < \lambda_2$	
post-buckling	$\dfrac{k_2\sqrt{B_p E}}{1.6b/t}$	$b/t \ge \lambda_2$	$\lambda_2 = \dfrac{k_1 B_p}{1.6D_p}$

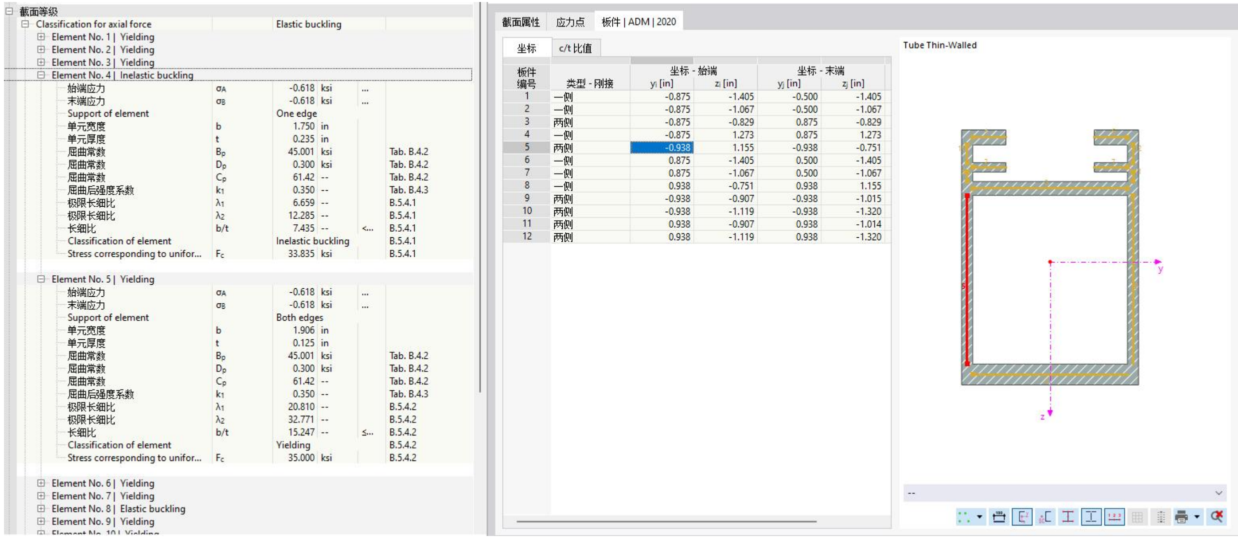
LIMIT STATE	F_c	Slenderness λ_{eq}	Slenderness Limits
yielding	F_{cy}	$\lambda_{eq} \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{D_p}$
inelastic buckling	$B_p - D_p\lambda_{eq}$	$\lambda_1 < \lambda_{eq} < \lambda_2$	
elastic buckling	$\dfrac{k_2\sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$	$\lambda_2 = \dfrac{k_1 B_p}{D_p}$

$$\lambda_{eq} = \pi\sqrt{\frac{E}{F_e}} \qquad \text{(B.5-11)}$$

F_e = the elastic local buckling stress of the cross section determined by analysis

规范解读-E章：受压构件

杆件屈曲/**局部屈曲**/杆件屈曲-局部屈曲相互作用：



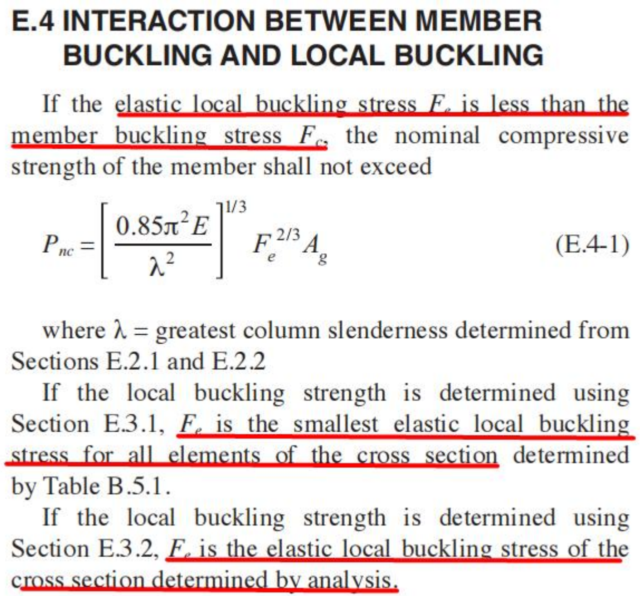
截面等级					
Classification for axial force		Elastic buckling			
Element No. 1 | Yielding					
Element No. 2 | Yielding					
Element No. 3 | Yielding					
Element No. 4 | Inelastic buckling					
始端应力	σ_A	-0.618	ksi	...	
末端应力	σ_B	-0.618	ksi	...	
Support of element		One edge			
单元宽度	b	1.750	in		
单元厚度	t	0.235	in		
屈曲常数	B_p	45.001	ksi		Tab. B.4.2
屈曲常数	D_p	0.300	ksi		Tab. B.4.2
屈曲常数	C_p	61.42	--		Tab. B.4.2
屈曲后强度系数	k_1	0.350	--		Tab. B.4.3
极限长细比	λ_1	6.659	--		B.5.4.1
极限长细比	λ_2	12.285	--		B.5.4.1
长细比	b/t	7.435	--	<...	B.5.4.1
Classification of element		Inelastic buckling			B.5.4.1
Stress corresponding to unifor...	F_c	33.835	ksi		B.5.4.1
Element No. 5 | Yielding					
始端应力	σ_A	-0.618	ksi	...	
末端应力	σ_B	-0.618	ksi	...	
Support of element		Both edges			
单元宽度	b	1.906	in		
单元厚度	t	0.125	in		
屈曲常数	B_p	45.001	ksi		Tab. B.4.2
屈曲常数	D_p	0.300	ksi		Tab. B.4.2
屈曲常数	C_p	61.42	--		Tab. B.4.2
屈曲后强度系数	k_1	0.350	--		Tab. B.4.3
极限长细比	λ_1	20.810	--		B.5.4.2
极限长细比	λ_2	32.771	--		B.5.4.2
长细比	b/t	15.247	--	≤...	B.5.4.2
Classification of element		Yielding			B.5.4.2
Stress corresponding to unifor...	F_c	35.000	ksi		B.5.4.2
Element No. 6 | Yielding					
Element No. 7 | Yielding					
Element No. 8 | Elastic buckling					
Element No. 9 | Yielding					
Element No. 10 | Yielding					

板件编号	类型 - 刚接	坐标 - 始端		坐标 - 末端	
		y_i [in]	z_i [in]	y_j [in]	z_j [in]
1	一侧	-0.875	-1.405	-0.500	-1.405
2	一侧	-0.875	-1.067	-0.500	-1.067
3	两侧	-0.875	-0.829	0.875	-0.829
4	一侧	-0.875	1.273	0.875	1.273
5	两侧	-0.938	1.155	-0.938	-0.751
6	一侧	0.875	-1.405	0.500	-1.405
7	一侧	0.875	-1.067	0.500	-1.067
8	一侧	0.938	-0.751	0.938	1.155
9	两侧	-0.938	-0.907	-0.938	-1.015
10	两侧	-0.938	-1.119	-0.938	-1.320
11	两侧	0.938	-0.907	0.938	-1.014
12	两侧	0.938	-1.119	0.938	-1.320

自定义任意截面，只有定义了"板件"才能按照规范计算局部屈曲承载力。

规范解读-E章：受压构件

杆件屈曲/局部屈曲/**杆件屈曲-局部屈曲相互作用**：



E.4 INTERACTION BETWEEN MEMBER BUCKLING AND LOCAL BUCKLING

If the elastic local buckling stress F_e is less than the member buckling stress F_c, the nominal compressive strength of the member shall not exceed

$$P_{nc} = \left[\frac{0.85\pi^2 E}{\lambda^2}\right]^{1/3} F_e^{2/3} A_g \qquad \text{(E.4-1)}$$

where λ = greatest column slenderness determined from Sections E.2.1 and E.2.2

If the local buckling strength is determined using Section E.3.1, F_e is the smallest elastic local buckling stress for all elements of the cross section determined by Table B.5.1.

If the local buckling strength is determined using Section E.3.2, F_e is the elastic local buckling stress of the cross section determined by analysis.

如果板件的弹性屈曲应力Fe小于杆件的屈曲应力Fc,就得考虑局部屈曲对杆件屈曲的削弱。

Fe的取值跟局部屈曲计算方法有关。

规范解读-F章：受弯构件

局部屈曲/横向扭转屈曲/局部屈曲-横向扭转屈曲相互作用:

F. 3 LOCAL BUCKLING

The nominal flexural strength for the limit state of local buckling $M_n = M_{nlb}$ shall be determined by Section F.3.1, F.3.2, or F.3.3. Local buckling is not a limit state for wire, rod, or bar.

F.3.1 Weighted Average Method

The nominal flexural strength for local buckling M_{nlb} shall be determined as

$$M_{nlb} = F_c I_f / c_{cf} + F_b I_w / c_{cw} \tag{F.3-1}$$

where

F_c = stress corresponding to the strength of an element in uniform compression determined using Sections B.5.4.1 through B.5.4.6. The strength of stiffened elements shall not exceed the strength of an intermediate stiffener or an edge stiffener.

F_b = stress corresponding to the strength of an element in flexural compression determined using Sections B.5.5.1 through B.5.5.5.

c_{cf} = distance from the centerline of a uniform compression element to the cross section's neutral axis

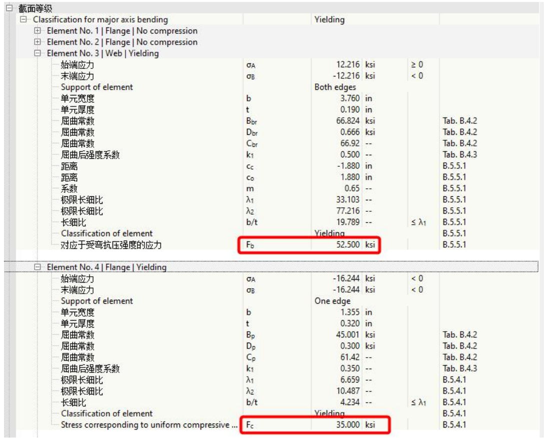
c_{cw} = distance from a flexural compression element's extreme compression fiber to the cross section's neutral axis

I_f = moment of inertia of the uniform stress elements about the cross section's neutral axis. These elements include the elements in uniform compression and the elements in uniform tension and their edge or intermediate stiffeners.

I_w = moment of inertia of the flexural compression elements about the cross section's neutral axis. These elements include the elements in flexure and their intermediate stiffeners.

方法1：加权平均法

(所有板件局部屈曲承载力之和)

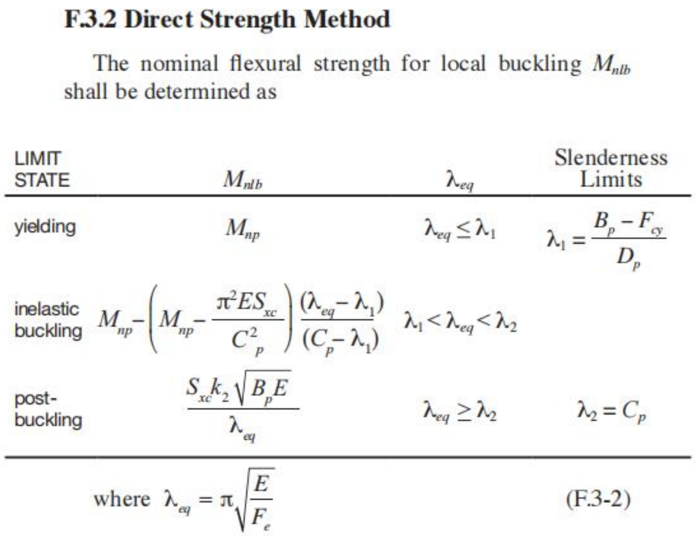


截面等级					
Classification for major axis bending		Yielding			
Element No. 1 | Flange | No compression					
Element No. 2 | Flange | No compression					
Element No. 3 | Web | Yielding					
始端应力	σ_A	12.216	ksi	≥ 0	
末端应力	σ_B	-12.216	ksi	< 0	
Support of element		Both edges			
单元宽度	b	3.760	in		
单元厚度	t	0.190	in		
屈曲常数	B_{br}	66.824	ksi		Tab. B.4.2
屈曲常数	D_{br}	0.666	ksi		Tab. B.4.2
屈曲常数	C_{br}	66.92	--		Tab. B.4.2
屈曲后强度系数	k_1	0.500	--		Tab. B.4.3
距离	c_c	-1.880	in		B.5.5.1
距离	c_o	1.880	in		B.5.5.1
系数	m	0.65	--		B.5.5.1
极限长细比	λ_1	33.103	--		B.5.5.1
极限长细比	λ_2	77.216	--		B.5.5.1
长细比	b/t	19.789	--	≤ λ_1	B.5.5.1
Classification of element		Yielding			B.5.5.1
对应于受弯抗压强度的应力	F_b	52.500	ksi		B.5.5.1
Element No. 4 | Flange | Yielding					
始端应力	σ_A	-16.244	ksi	< 0	
末端应力	σ_B	-16.244	ksi	< 0	
Support of element		One edge			
单元宽度	b	1.355	in		
单元厚度	t	0.320	in		
屈曲常数	B_p	45.001	ksi		Tab. B.4.2
屈曲常数	D_p	0.300	ksi		Tab. B.4.2
屈曲常数	C_p	61.42	--		Tab. B.4.2
屈曲后强度系数	k_1	0.350	--		Tab. B.4.3
极限长细比	λ_1	6.659	--		B.5.4.1
极限长细比	λ_2	10.487	--		B.5.4.1
长细比	b/t	4.234	--	≤ λ_1	B.5.4.1
Classification of element		Yielding			B.5.4.1
Stress corresponding to uniform compressive ...	F_c	35.000	ksi		B.5.4.1

$$
\begin{aligned}
M_{nlb,y} &= F_c \cdot \frac{I_{yf}}{c_{cf}} + F_b \cdot \frac{I_{yw}}{c_{cw}} \\
&= 35.000\,\text{ksi} \cdot \frac{12.284\,\text{in}^4}{2.340\,\text{in}} + 52.500\,\text{ksi} \cdot \frac{1.616\,\text{in}^4}{2.180\,\text{in}} \\
&= 18.55\,\text{kipft}
\end{aligned}
$$

规范解读-F章：受弯构件

局部屈曲/横向扭转屈曲/局部屈曲-横向扭转屈曲相互作用:

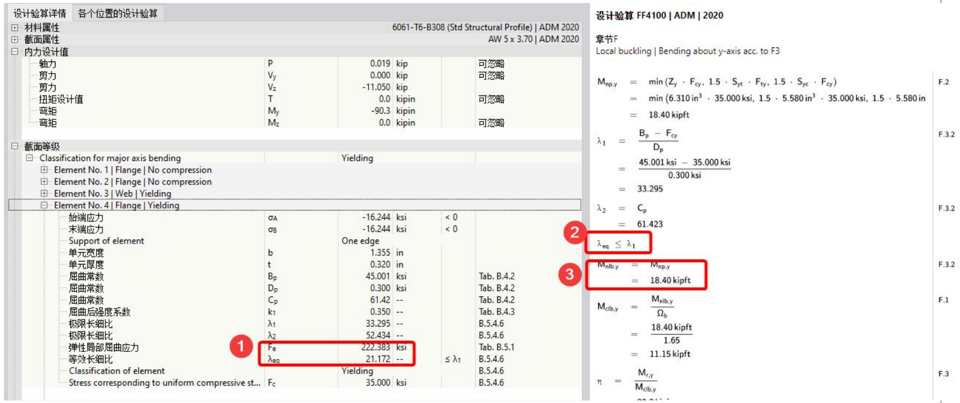


F.3.2 Direct Strength Method

The nominal flexural strength for local buckling M_{nlb} shall be determined as

LIMIT STATE	M_{nlb}	λ_{eq}	Slenderness Limits
yielding	M_{np}	$\lambda_{eq} \le \lambda_1$	$\lambda_1 = \dfrac{B_p - F_{cy}}{D_p}$
inelastic buckling	$M_{np} - \left(M_{np} - \dfrac{\pi^2 E S_{xc}}{C_p^2}\right)\dfrac{(\lambda_{eq} - \lambda_1)}{(C_p - \lambda_1)}$	$\lambda_1 < \lambda_{eq} < \lambda_2$	
post-buckling	$\dfrac{S_{xc} k_2 \sqrt{B_p E}}{\lambda_{eq}}$	$\lambda_{eq} \ge \lambda_2$	$\lambda_2 = C_p$

where $\lambda_{eq} = \pi\sqrt{\dfrac{E}{F_e}}$ (F.3-2)



设计验算详情 | 各个位置的设计验算

⊞ 材料属性		6061-T6-B308 (Std Structural Profile) | ADM 2020			
⊞ 截面属性		AW 5 x 3.70 | ADM 2020			
⊟ 内力设计值					
轴力	P	0.019	kip		可忽略
剪力	V_y	0.000	kip		可忽略
剪力	V_z	-11.050	kip		
扭矩设计值	T	0.0	kipin		可忽略
弯矩	M_y	-90.3	kipin		
弯矩	M_z	0.0	kipin		可忽略
⊟ 截面等级					
⊟ Classification for major axis bending		Yielding			
⊞ Element No. 1 | Flange | No compression					
⊞ Element No. 2 | Flange | No compression					
⊞ Element No. 3 | Web | Yielding					
⊟ Element No. 4 | Flange | Yielding					
始端应力	σ_A	-16.244	ksi	< 0	
末端应力	σ_B	-16.244	ksi	< 0	
Support of element		One edge			
单元宽度	b	1.355	in		
单元厚度	t	0.320	in		
屈曲常数	B_p	45.001	ksi		Tab. B.4.2
屈曲常数	D_p	0.300	ksi		Tab. B.4.2
屈曲常数	C_p	61.42	--		Tab. B.4.2
屈曲后强度系数	k_1	0.350	--		Tab. B.4.3
极限长细比	λ_1	33.295	--		B.5.4.6
极限长细比	λ_2	52.434	--		B.5.4.6
弹性局部屈曲应力	F_e	222.383	ksi		Tab. B.5.1
等效长细比	λ_{eq}	21.172	--	$\le \lambda_1$	B.5.4.6
Classification of element		Yielding			B.5.4.6
Stress corresponding to uniform compressive st...	F_c	35.000	ksi		B.5.4.6

设计验算 FF4100 | ADM | 2020

章节F
Local buckling | Bending about y-axis acc. to F3

$$M_{np,y} = \min(Z_y \cdot F_{cy},\ 1.5 \cdot S_{yt} \cdot F_{ty},\ 1.5 \cdot S_{yc} \cdot F_{cy}) \qquad \text{F.2}$$
$$= \min(6.310\,\text{in}^3 \cdot 35.000\,\text{ksi},\ 1.5 \cdot 5.580\,\text{in}^3 \cdot 35.000\,\text{ksi},\ 1.5 \cdot 5.580\,\text{in}$$
$$= 18.40\,\text{kipft}$$

$$\lambda_1 = \frac{B_p - F_{cy}}{D_p} \qquad \text{F.3.2}$$
$$= \frac{45.001\,\text{ksi} - 35.000\,\text{ksi}}{0.300\,\text{ksi}}$$
$$= 33.295$$

$$\lambda_2 = C_p \qquad \text{F.3.2}$$
$$= 61.423$$

② $\lambda_{eq} \le \lambda_1$

③
$$M_{nlb,y} = M_{np,y} \qquad \text{F.3.2}$$
$$= 18.40\,\text{kipft}$$

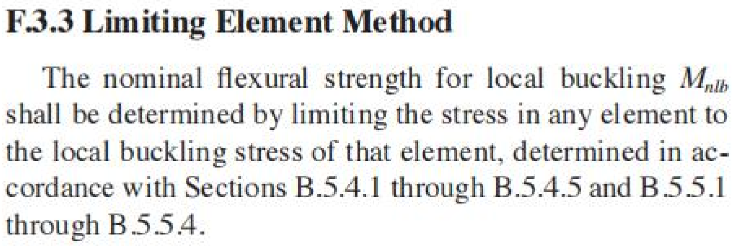
$$M_{clb,y} = \frac{M_{nlb,y}}{\Omega_b} \qquad \text{F.1}$$
$$= \frac{18.40\,\text{kipft}}{1.65}$$
$$= 11.15\,\text{kipft}$$

$$\eta = \frac{M_{r,y}}{M_{clb,y}} \qquad \text{F.3}$$

方法2：直接强度法
(更精确的考虑板件的支座条件)

规范解读-F章：受弯构件

局部屈曲/横向扭转屈曲/局部屈曲-横向扭转屈曲相互作用:

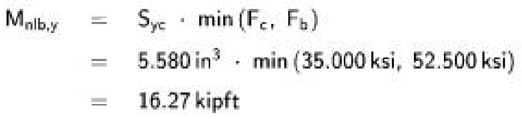


F.3.3 Limiting Element Method

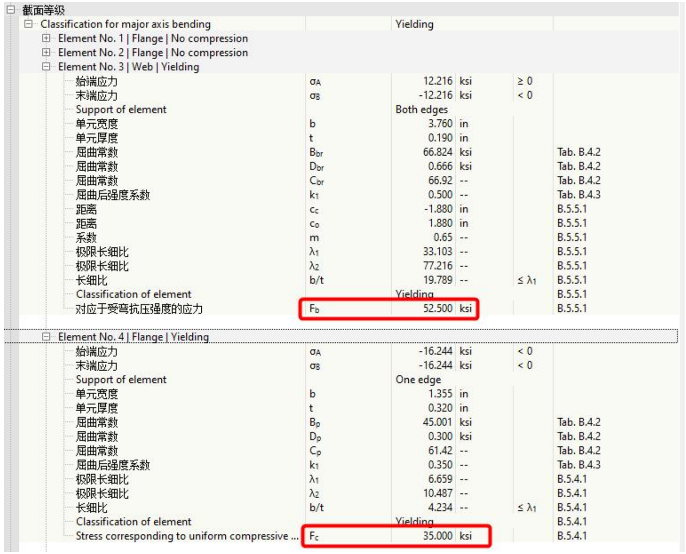
The nominal flexural strength for local buckling M_{nlb} shall be determined by limiting the stress in any element to the local buckling stress of that element, determined in accordance with Sections B.5.4.1 through B.5.4.5 and B.5.5.1 through B.5.5.4.

方法3：限值板件（应力）法

(只要有一个板件屈曲就认为截面屈曲)



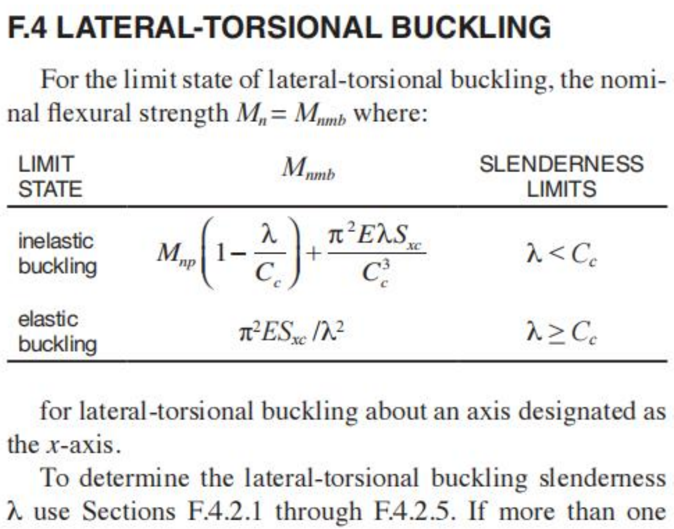
$$M_{nlb,y} = S_{yc} \cdot \min(F_c, F_b)$$
$$= 5.580\,\text{in}^3 \cdot \min(35.000\,\text{ksi},\ 52.500\,\text{ksi})$$
$$= 16.27\,\text{kipft}$$



截面等级					
Classification for major axis bending		Yielding			
Element No. 1 | Flange | No compression					
Element No. 2 | Flange | No compression					
Element No. 3 | Web | Yielding					
始端应力	σ_A	12.216	ksi	≥ 0	
末端应力	σ_B	-12.216	ksi	< 0	
Support of element		Both edges			
单元宽度	b	3.760	in		
单元厚度	t	0.190	in		
屈曲常数	B_{br}	66.824	ksi		Tab. B.4.2
屈曲常数	D_{br}	0.666	ksi		Tab. B.4.2
屈曲常数	C_{br}	66.92	--		Tab. B.4.2
屈曲后强度系数	k_1	0.500	--		Tab. B.4.3
距离	c_c	-1.880	in		B.5.5.1
距离	c_o	1.880	in		B.5.5.1
系数	m	0.65	--		B.5.5.1
极限长细比	λ_1	33.103	--		B.5.5.1
极限长细比	λ_2	77.216	--		B.5.5.1
长细比	b/t	19.789	--	$\le \lambda_1$	B.5.5.1
Classification of element		Yielding			B.5.5.1
对应于受弯抗压强度的应力	F_b	52.500	ksi		B.5.5.1
Element No. 4 | Flange | Yielding					
始端应力	σ_A	-16.244	ksi	< 0	
末端应力	σ_B	-16.244	ksi	< 0	
Support of element		One edge			
单元宽度	b	1.355	in		
单元厚度	t	0.320	in		
屈曲常数	B_p	45.001	ksi		Tab. B.4.2
屈曲常数	D_p	0.300	ksi		Tab. B.4.2
屈曲常数	C_p	61.42	--		Tab. B.4.2
屈曲后强度系数	k_1	0.350	--		Tab. B.4.3
极限长细比	λ_1	6.659	--		B.5.4.1
极限长细比	λ_2	10.487	--		B.5.4.1
长细比	b/t	4.234	--	$\le \lambda_1$	B.5.4.1
Classification of element		Yielding			B.5.4.1
Stress corresponding to uniform compressive ...	F_c	35.000	ksi		B.5.4.1

规范解读-F章：受弯构件

局部屈曲/**横向扭转屈曲**/局部屈曲-横向扭转屈曲相互作用:



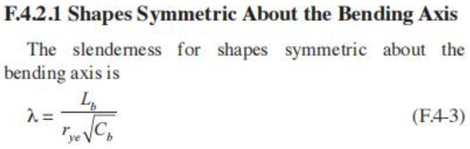
F.4 LATERAL-TORSIONAL BUCKLING

For the limit state of lateral-torsional buckling, the nominal flexural strength $M_n = M_{nmb}$ where:

LIMIT STATE	M_{nmb}	SLENDERNESS LIMITS
inelastic buckling	$M_{np}\left(1-\frac{\lambda}{C_c}\right)+\frac{\pi^2 E\lambda S_{xc}}{C_c^3}$	$\lambda < C_c$
elastic buckling	$\pi^2 E S_{xc}/\lambda^2$	$\lambda \geq C_c$

for lateral-torsional buckling about an axis designated as the *x*-axis.

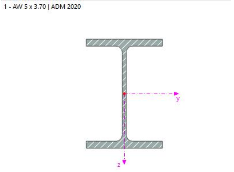
To determine the lateral-torsional buckling slenderness λ use Sections F.4.2.1 through F.4.2.5. If more than one

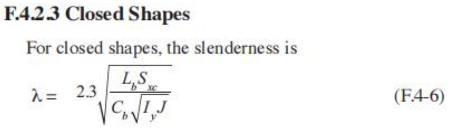


F.4.2.1 Shapes Symmetric About the Bending Axis

The slenderness for shapes symmetric about the bending axis is

$$\lambda = \frac{L_b}{r_{ye}\sqrt{C_b}} \quad \text{(F.4-3)}$$

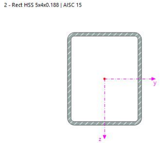


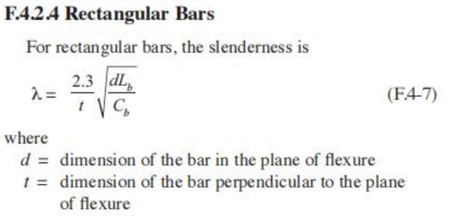


F.4.2.3 Closed Shapes

For closed shapes, the slenderness is

$$\lambda = 2.3\sqrt{\frac{L_b S_{xc}}{C_b\sqrt{I_y J}}} \quad \text{(F.4-6)}$$





F.4.2.4 Rectangular Bars

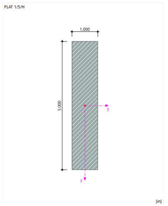
For rectangular bars, the slenderness is

$$\lambda = \frac{2.3}{t}\sqrt{\frac{dL_b}{C_b}} \quad \text{(F.4-7)}$$

where

d = dimension of the bar in the plane of flexure

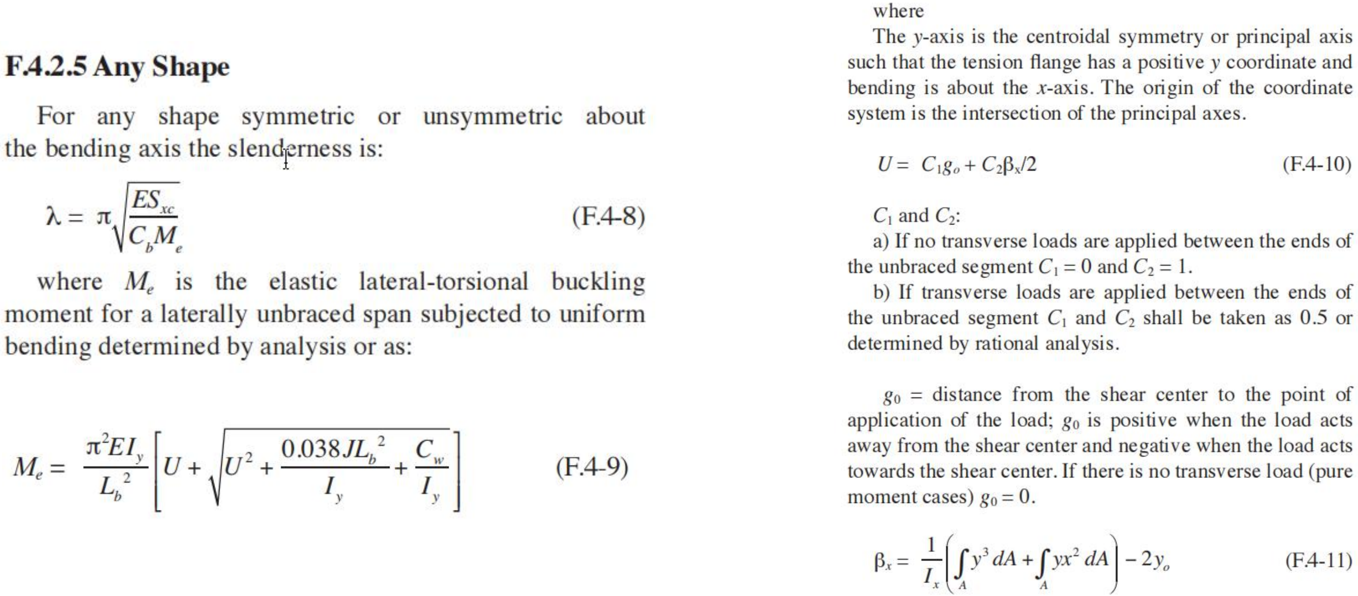
t = dimension of the bar perpendicular to the plane of flexure



均由F4.2.5通用公式推导而来

规范解读-F章：受弯构件

局部屈曲/**横向扭转屈曲**/局部屈曲-横向扭转屈曲相互作用:



F.4.2.5 Any Shape

For any shape symmetric or unsymmetric about the bending axis the slenderness is:

$$\lambda = \pi\sqrt{\frac{ES_{xc}}{C_b M_e}} \qquad \text{(F.4-8)}$$

where M_e is the elastic lateral-torsional buckling moment for a laterally unbraced span subjected to uniform bending determined by analysis or as:

$$M_e = \frac{\pi^2 EI_y}{L_b^2}\left[U + \sqrt{U^2 + \frac{0.038JL_b^2}{I_y} + \frac{C_w}{I_y}}\right] \qquad \text{(F.4-9)}$$

where

The y-axis is the centroidal symmetry or principal axis such that the tension flange has a positive y coordinate and bending is about the x-axis. The origin of the coordinate system is the intersection of the principal axes.

$$U = C_1 g_o + C_2\beta_x/2 \qquad \text{(F.4-10)}$$

C_1 and C_2:

a) If no transverse loads are applied between the ends of the unbraced segment $C_1 = 0$ and $C_2 = 1$.

b) If transverse loads are applied between the ends of the unbraced segment C_1 and C_2 shall be taken as 0.5 or determined by rational analysis.

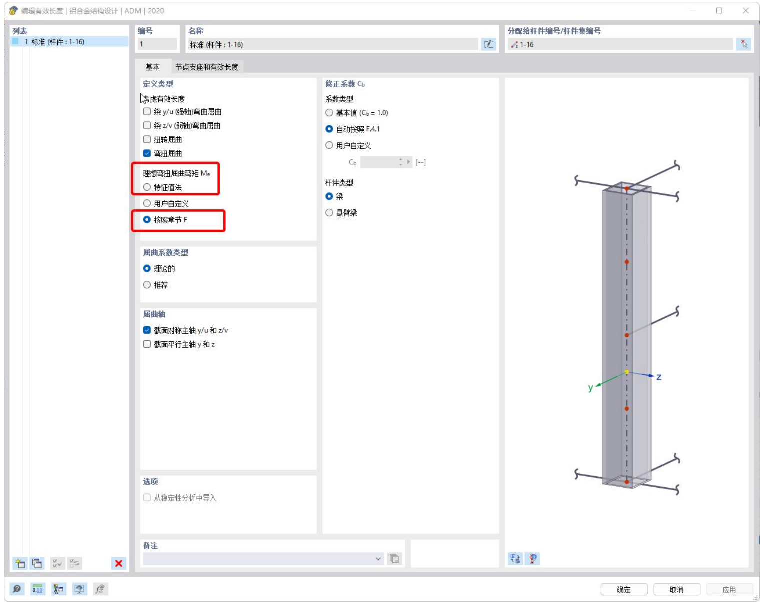
g_0 = distance from the shear center to the point of application of the load; g_0 is positive when the load acts away from the shear center and negative when the load acts towards the shear center. If there is no transverse load (pure moment cases) $g_0 = 0$.

$$\beta_x = \frac{1}{I_x}\left(\int_A y^3\,dA + \int_A yx^2\,dA\right) - 2y_o \qquad \text{(F.4-11)}$$

采用解析公式计算λ时，结果跟杆件弯矩分布/荷载作用点/支座边界有很大关系（Cb和U的计算）。采用杆系/板壳有限元进行屈曲分析可更精确的考虑这些因素（大部分软件的杆系屈曲分析不能获得LTB模态）

规范解读-F章：受弯构件

局部屈曲/**横向扭转屈曲**/局部屈曲-横向扭转屈曲相互作用：



编辑有效长度 | 铝合金结构设计 | ADM | 2020

列表
1 标准 (杆件 : 1-16)

编号: 1
名称: 标准 (杆件 : 1-16)
分配给杆件编号/杆件集编号: 1-16

基本 | 节点支座和有效长度

定义类型
考虑有效长度
☐ 绕 y/u (强轴)弯曲屈曲
☐ 绕 z/v (弱轴)弯曲屈曲
☐ 扭转屈曲
☑ 弯扭屈曲

理想弯扭屈曲弯矩 M_e
○ 特征值法
○ 用户自定义
● 按照章节 F

屈曲系数类型
● 理论的
○ 推荐

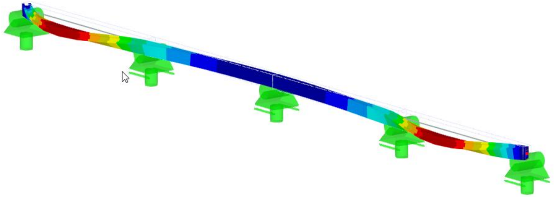
屈曲轴
☑ 截面对称主轴 y/u 和 z/v
☐ 截面平行主轴 y 和 z

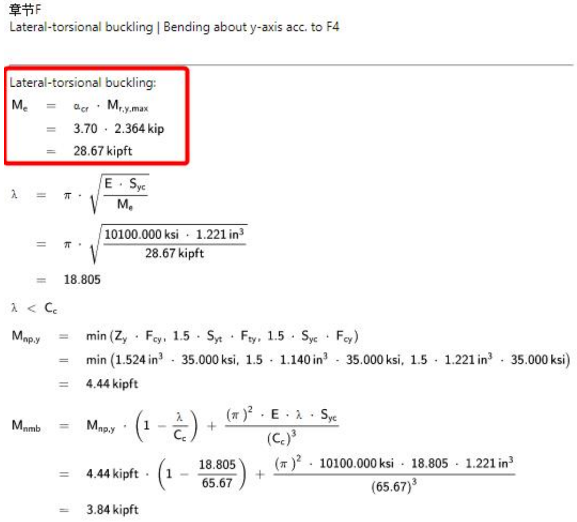
选项
☐ 从稳定性分析中导入

备注

修正系数 C_b
系数类型
○ 基本值 (C_b = 1.0)
● 自动按照 F.4.1
○ 用户自定义
C_b [--]

杆件类型
● 梁
○ 悬臂梁





章节F
Lateral-torsional buckling | Bending about y-axis acc. to F4

Lateral-torsional buckling:

$$M_e = \alpha_{cr} \cdot M_{r,y,max} = 3.70 \cdot 2.364\ \text{kip} = 28.67\ \text{kipft}$$

$$\lambda = \pi \cdot \sqrt{\frac{E \cdot S_{yc}}{M_e}} = \pi \cdot \sqrt{\frac{10100.000\ \text{ksi} \cdot 1.221\ \text{in}^3}{28.67\ \text{kipft}}} = 18.805$$

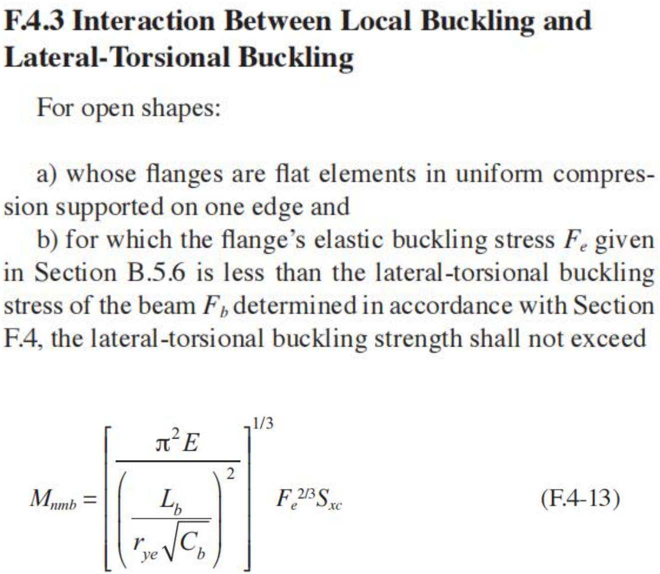
$\lambda < C_c$

$$M_{np,y} = \min(Z_y \cdot F_{cy},\ 1.5 \cdot S_{yt} \cdot F_{ty},\ 1.5 \cdot S_{yc} \cdot F_{cy}) = \min(1.524\ \text{in}^3 \cdot 35.000\ \text{ksi},\ 1.5 \cdot 1.140\ \text{in}^3 \cdot 35.000\ \text{ksi},\ 1.5 \cdot 1.221\ \text{in}^3 \cdot 35.000\ \text{ksi}) = 4.44\ \text{kipft}$$

$$M_{nmb} = M_{np,y} \cdot \left(1 - \frac{\lambda}{C_c}\right) + \frac{(\pi)^2 \cdot E \cdot \lambda \cdot S_{yc}}{(C_c)^3} = 4.44\ \text{kipft} \cdot \left(1 - \frac{18.805}{65.67}\right) + \frac{(\pi)^2 \cdot 10100.000\ \text{ksi} \cdot 18.805 \cdot 1.221\ \text{in}^3}{(65.67)^3} = 3.84\ \text{kipft}$$

规范解读-F章：受弯构件

局部屈曲/横向扭转屈曲/**局部屈曲-横向扭转屈曲相互作用：**



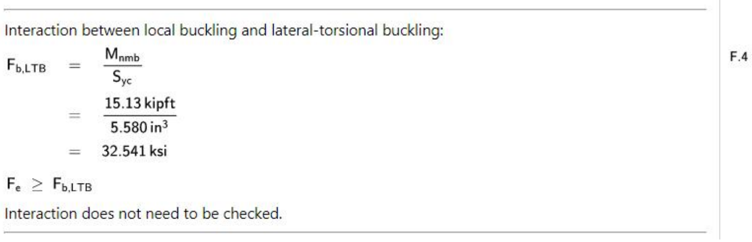
F.4.3 Interaction Between Local Buckling and Lateral-Torsional Buckling

For open shapes:

a) whose flanges are flat elements in uniform compression supported on one edge and

b) for which the flange's elastic buckling stress F_e given in Section B.5.6 is less than the lateral-torsional buckling stress of the beam F_b determined in accordance with Section F.4, the lateral-torsional buckling strength shall not exceed

$$M_{nmb} = \left[\frac{\pi^2 E}{\left(\frac{L_b}{r_{ye}\sqrt{C_b}}\right)^2}\right]^{1/3} F_e^{2/3} S_{xc} \qquad \text{(F.4-13)}$$

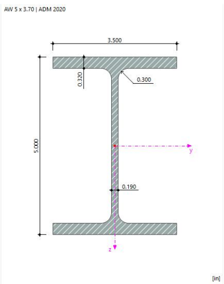


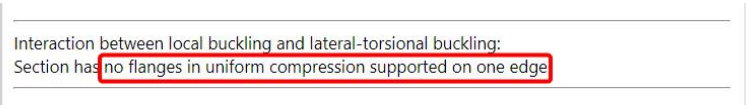
Interaction between local buckling and lateral-torsional buckling:

$$F_{b,LTB} = \frac{M_{nmb}}{S_{yc}} = \frac{15.13\ \text{kipft}}{5.580\ \text{in}^3} = 32.541\ \text{ksi}$$

$F_e \geq F_{b,LTB}$

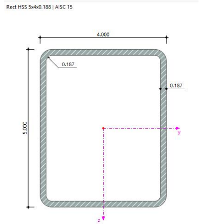
Interaction does not need to be checked.





Interaction between local buckling and lateral-torsional buckling:

Section has no flanges in uniform compression supported on one edge



软件操作-操作流程

自定义截面

(RSECTION导入Dxf)

分析参数

(二阶效应/几何缺陷/刚度折减)

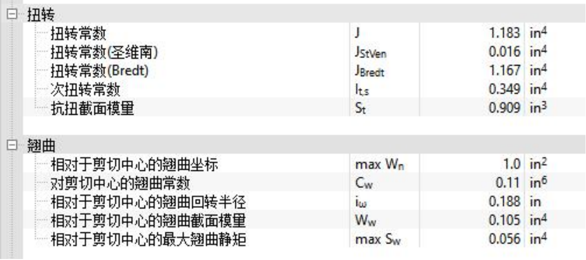
设计参数

(k/ULS/SLS验算配置)

软件操作-Rsection

薄壁分析：

- 薄壁截面（铝/钢/冷弯等）
- 使用解析法
- 沿厚度方向应力没有变化
- **扭转和翘曲特性只考虑板件的（忽略圆角的）**
- **必须定义板件（element）**

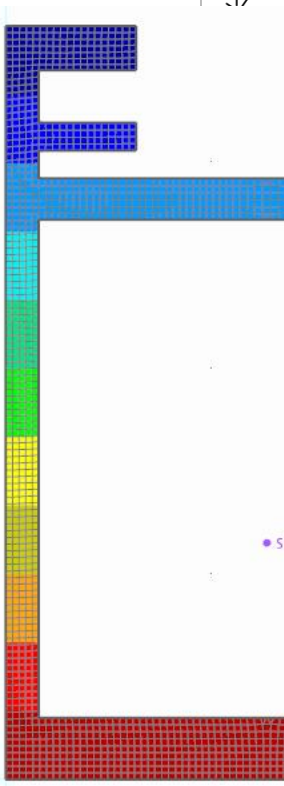


扭转			
扭转常数	J	1.183	in^4
扭转常数(圣维南)	J_{StVen}	0.016	in^4
扭转常数(Bredt)	J_{Bredt}	1.167	in^4
次扭转常数	$I_{t,s}$	0.349	in^4
抗扭截面模量	S_t	0.909	in^3
翘曲			
相对于剪切中心的翘曲坐标	$\max W_n$	1.0	in^2
对剪切中心的翘曲常数	C_w	0.11	in^6
相对于剪切中心的翘曲回转半径	i_ω	0.188	in
相对于剪切中心的翘曲截面模量	W_w	0.105	in^4
相对于剪切中心的最大翘曲静矩	$\max S_w$	0.056	in^4

有限元分析：

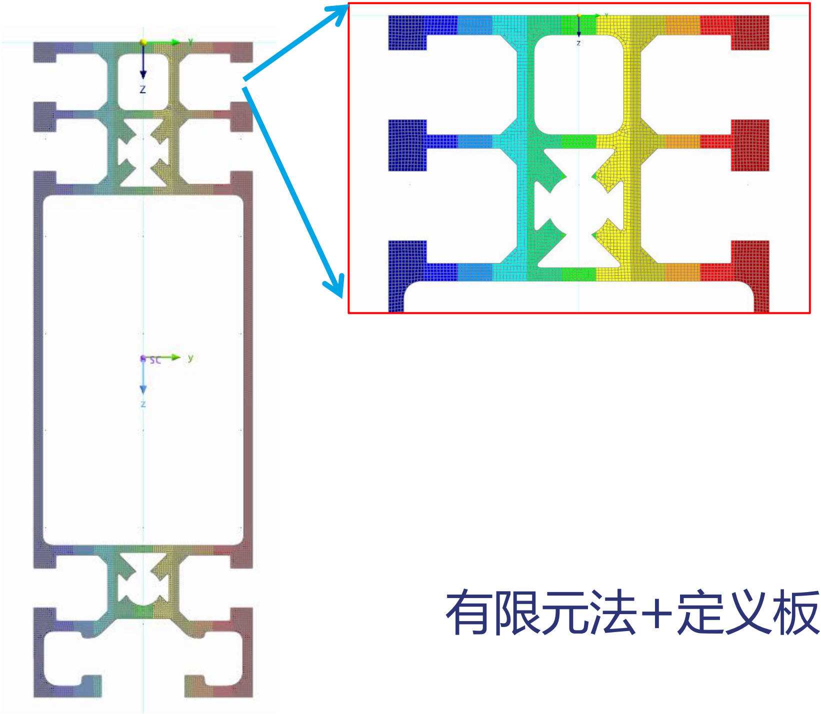
- 厚壁截面（混凝土/木等）
- 使用有限元法
- 沿厚度方向应力有变化
- **扭转和翘曲特性考虑全截面**
- 一般不用定义板件（element）

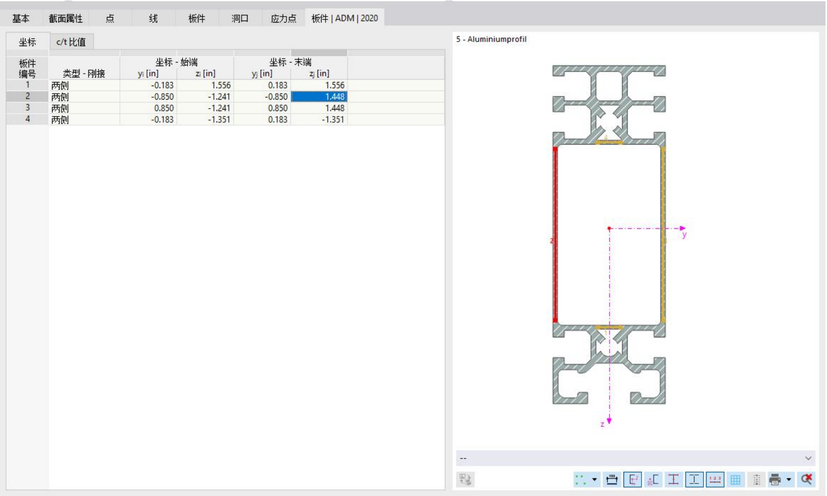
扭转			
扭转常数	J	1.224	in^4
抗扭截面模量	S_t	0.563	in^3
翘曲			
相对于剪切中心的翘曲坐标	$\max W_n$	1.0	in^2
对剪切中心的翘曲常数	C_w	0.10	in^6
相对于剪切中心的翘曲回转半径	i_ω	0.182	in
相对于剪切中心的翘曲截面模量	W_w	0.096	in^4



软件操作-Rsection

有限元分析：





板件编号	类型 - 刚接	坐标 - 始端		坐标 - 末端	
		y_i [in]	z_i [in]	y_j [in]	z_j [in]
1	两侧	-0.183	1.556	0.183	1.556
2	两侧	-0.850	-1.241	-0.850	1.448
3	两侧	0.850	-1.241	0.850	1.448
4	两侧	-0.183	-1.351	0.183	-1.351

有限元法+定义板件

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