Structural Analysis & Design Software

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网络课堂

RFEM 6
美标AISC360-16
钢结构设计（直接分析法）
实现方法

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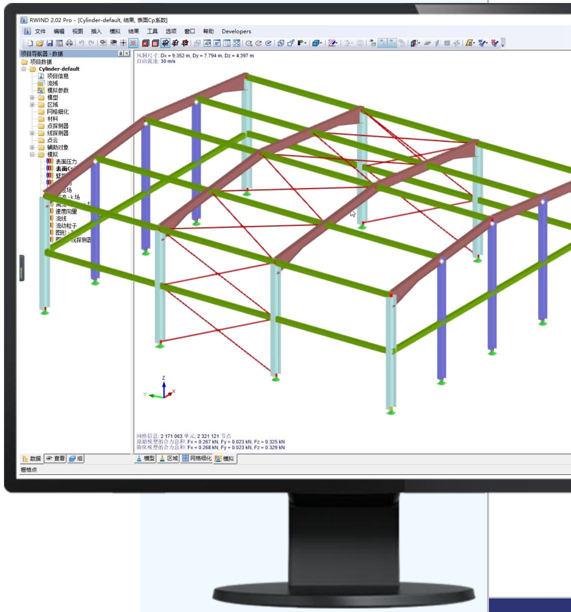

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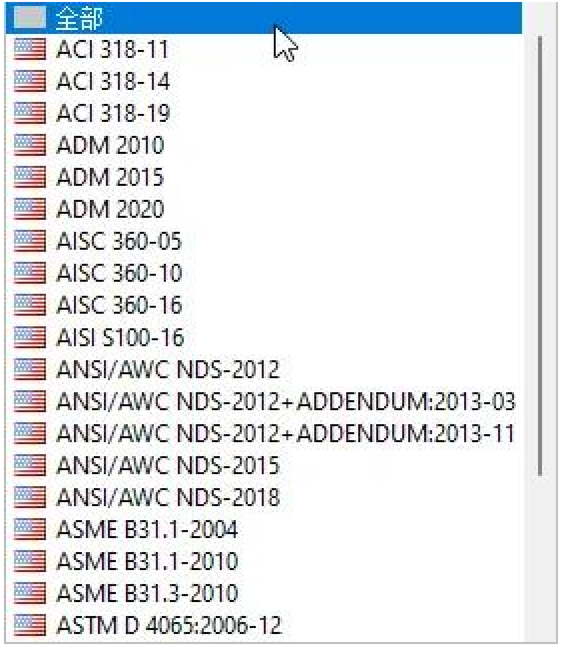
主要内容

01 **RFEM6进行美标结构设计优势**

02 AISC360-16关于稳定分析的条文解读

03 二阶效应/缺陷/刚度折减系数实现方法

RFEM6进行美标结构设计优势

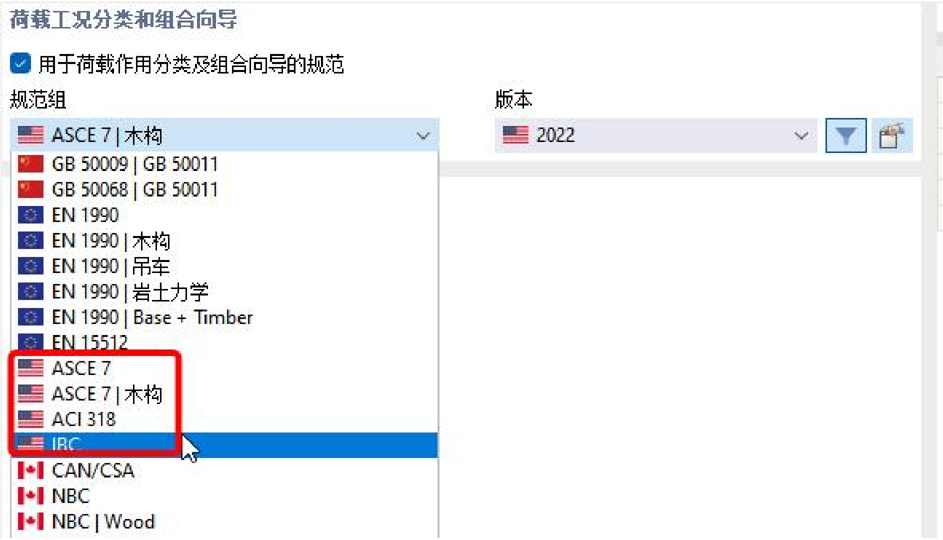


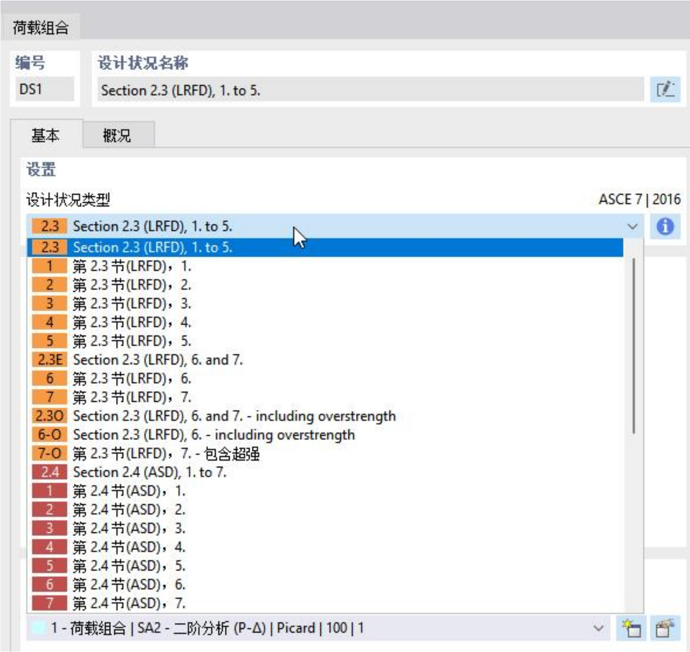
材料库

截面库

(钢/木/铝/砼/膜等)

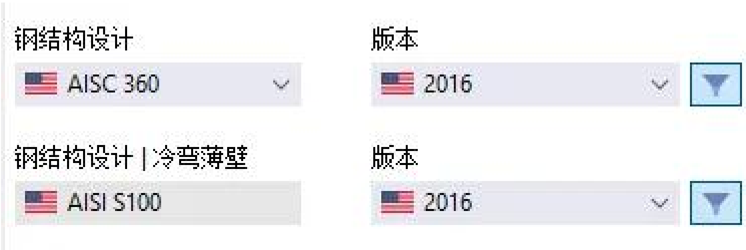
RFEM6进行美标结构设计优势

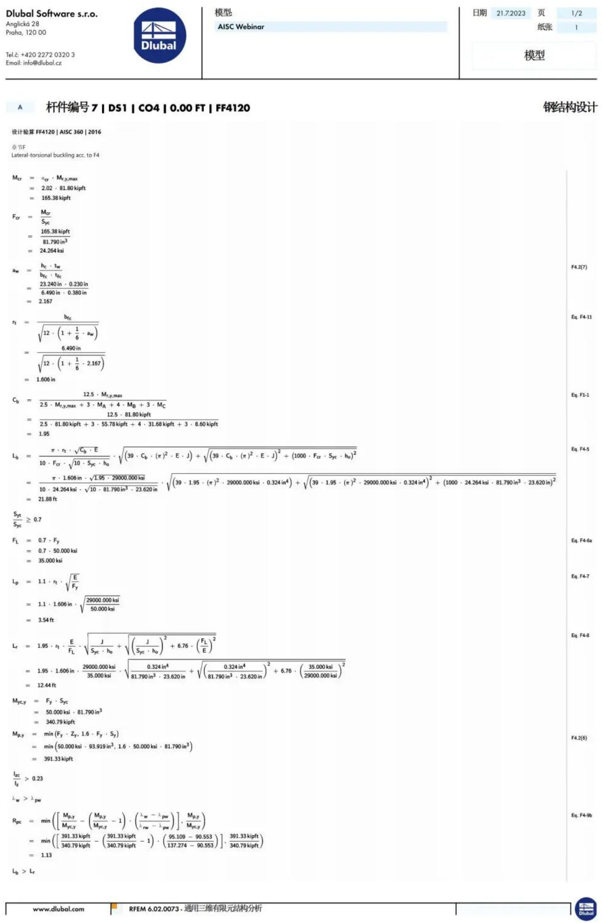




可以根据ASCE7(02/05/10/16版本）和ACI318(08/11/14/19版本)以及IBC(15/18/21版本）自动生成荷载组合(LRFD和ASD)

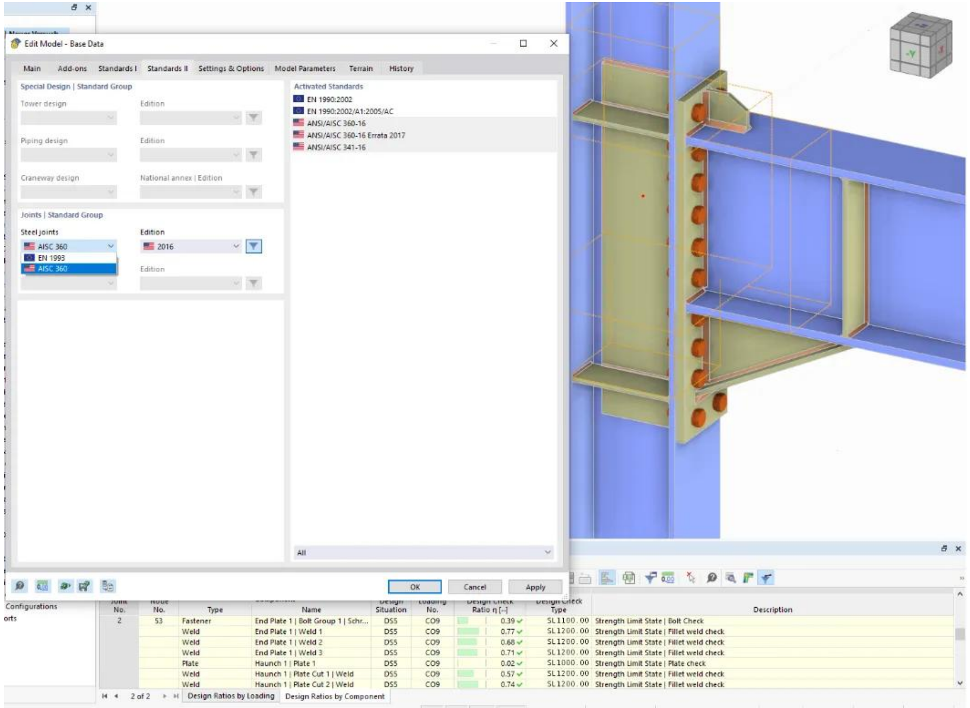
RFEM6进行美标结构设计优势





钢结构设计

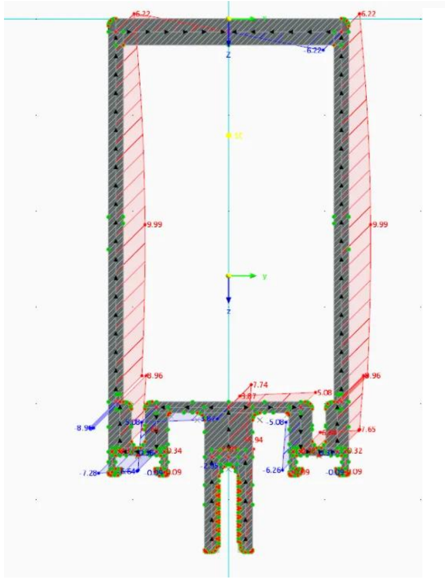
RFEM6进行美标结构设计优势

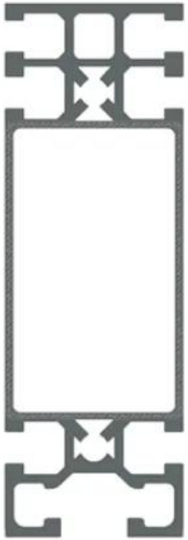


钢结构节点设计

节点模块可以根据ANSI/AISC 360-16进行基于抗力系数法（LRFD）和许用应力法(ASD)的验算。基于组件的参数化建模功能，可用基本组件创建各种节点类型。可以验算板件/焊缝/螺栓的强度和板件局部稳定。

RFEM6进行美标结构设计优势

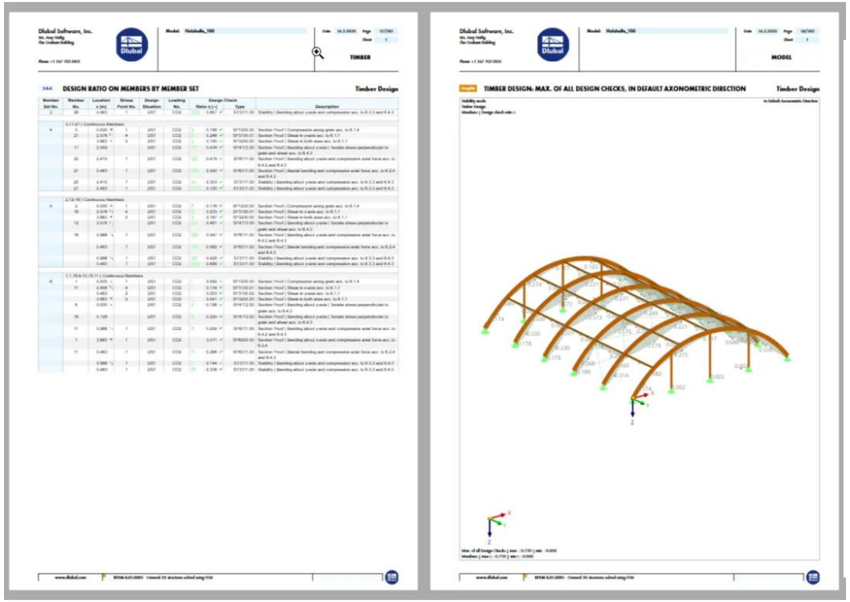


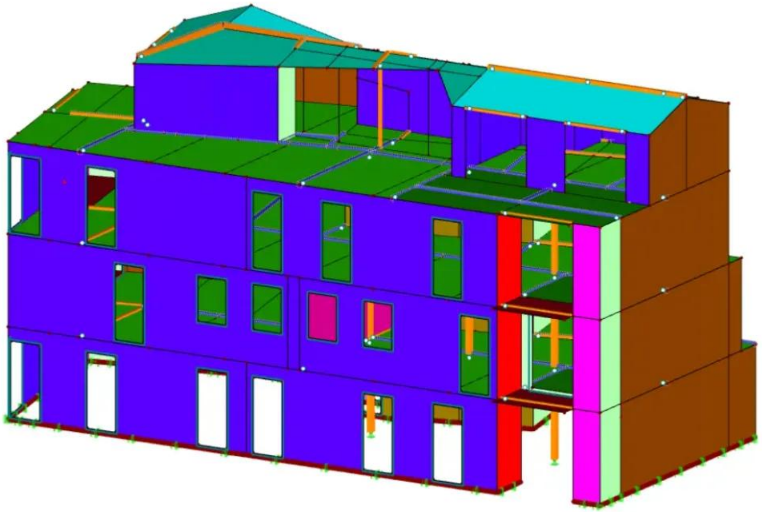


可以利用RSECTION生成任意形状铝合金截面

基于ADM-2020进行构件设计。

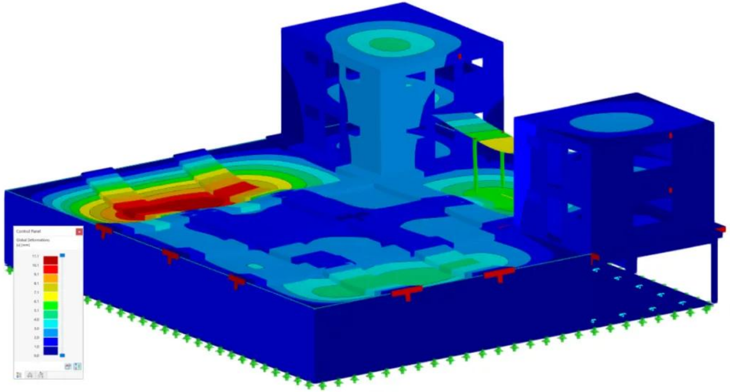
RFEM6进行美标结构设计优势

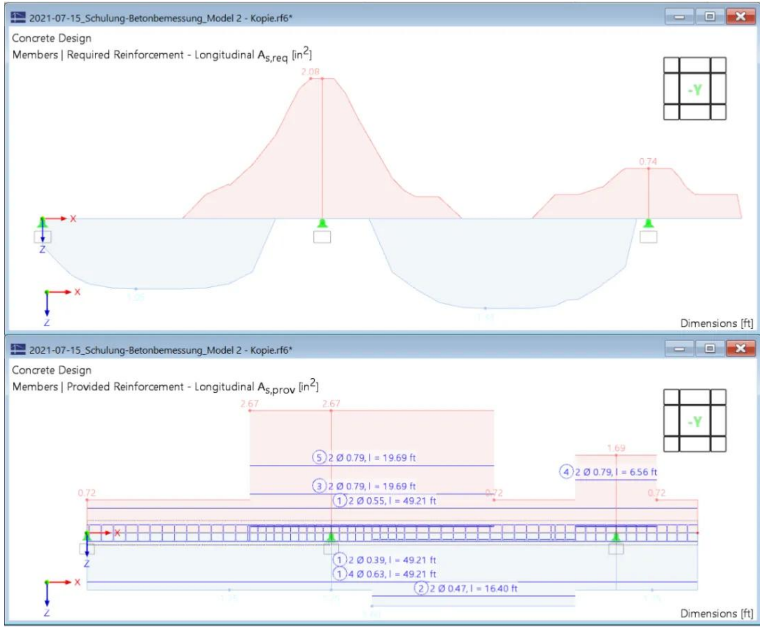




木结构设计(基于ANSI/AWC NDS进行木结构构件的结构强度/变形/防火验算。还可以进行正交胶合板/墙的设计。)

RFEM6进行美标结构设计优势





混凝土结构设计(可以按照IBC/ASCE考虑地震作用，基于ACI318进行杆件/柱/板/墙的设计。)

AISC360-16关于稳定分析的条文解读

应该提供两个层面的稳定设计：结构整体和构件。

无论采用什么稳定设计方法，都需要考虑以下因素：

- 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）
- 刚度折减（截面变形/局部屈曲/畸变屈曲）
- 强度和刚度的不确定性

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AISC360-16关于稳定分析的条文解读

□ 为什么要考虑结构的弯曲/剪切/轴向变形，其他组件和节点的变形？

1.单元简化：不同的力学模型考虑的自由度/变形不一样。**低估了内力成分。**

- 梁（考虑剪切变形/忽略剪切变形/忽略翘曲变形）
- 桁架（忽略弯曲和剪切变形）
- 刚性杆（忽略所有变形）

2.模型简化：忽略了其他构件的变形。**高估了承载力。**

- **单层网壳整体稳定（边界：框架/桩基）**。忽略支承结构的变形时，将得到过大的临界荷载系数。
- **无侧移框架柱压弯稳定**。忽略斜撑的轴向变形，得到过高的轴压稳定承载力。
- **有次梁提供侧向约束的主梁受弯整体稳定**。忽略次梁的轴向变形，得到过高的稳定承载力。

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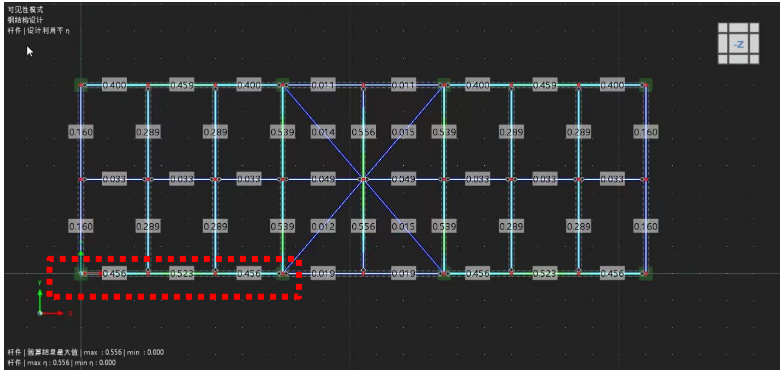
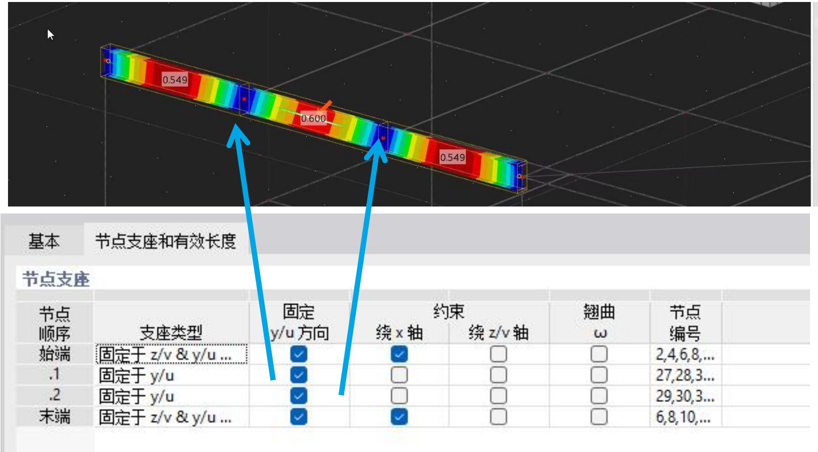
AISC360-16关于稳定分析的条文解读

□ 为什么要考虑结构的弯曲/剪切/轴向变形，其他组件和节点的变形?

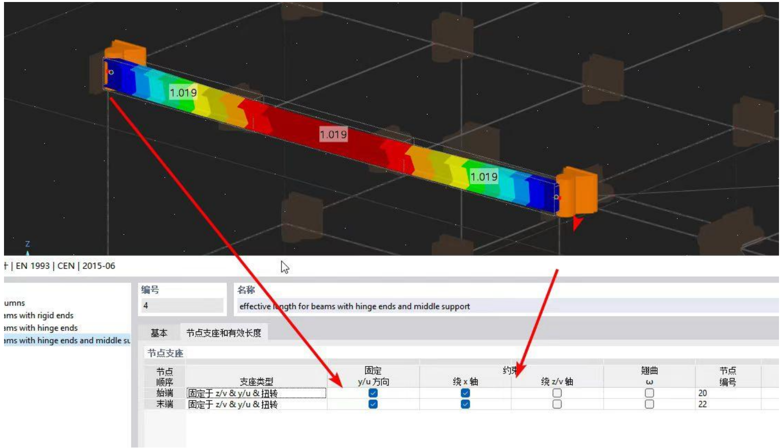


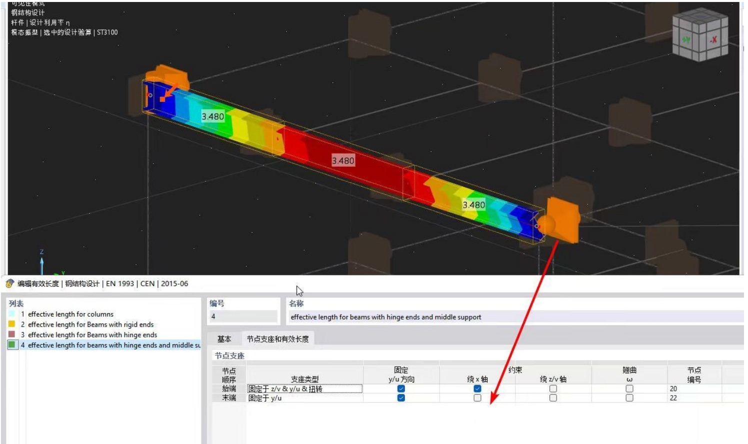


考虑次梁平动约束

AISC360-16关于稳定分析的条文解读

- 为什么要考虑结构的弯曲/剪切/轴向变形，其他组件和节点的变形?





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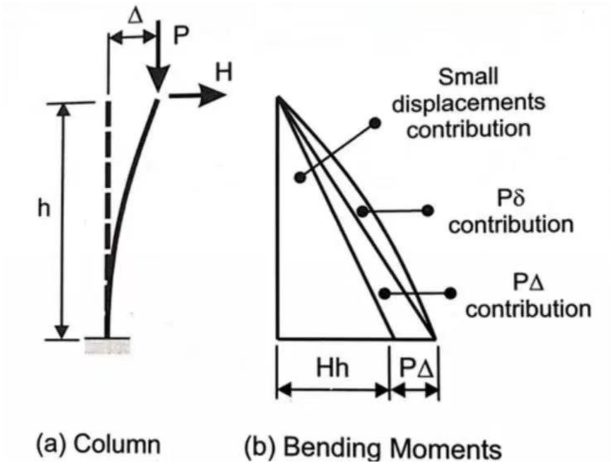
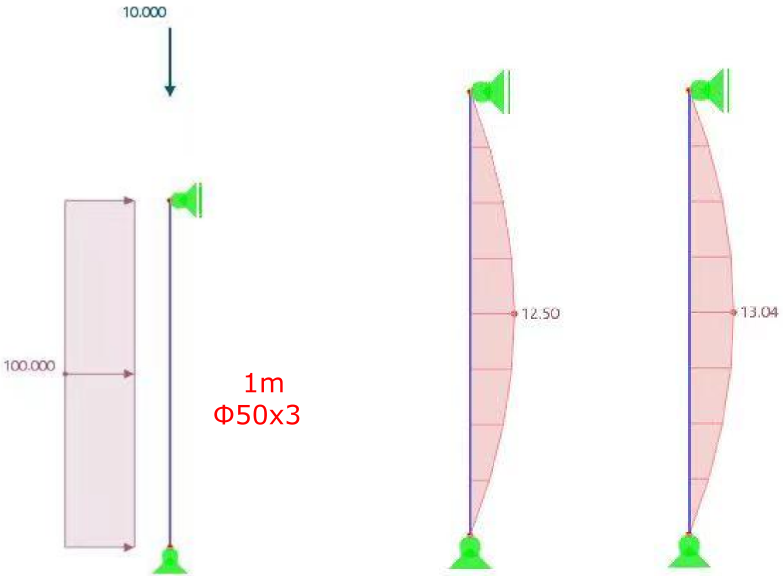
AISC360-16关于稳定分析的条文解读

- 为什么要考虑二阶效应？**否则低估内力大小**

手算时，单工况分开
实际中，多工况同时作用

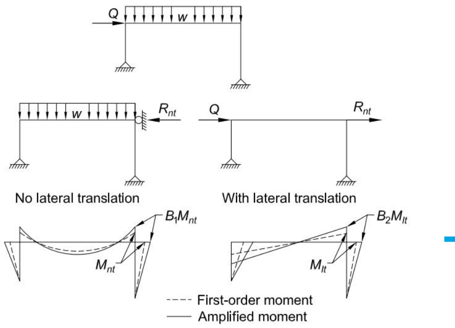




p-δ效应：放大系数1.0432
（杆件中间没有网格节点也能考虑，更不需要打断杆件）

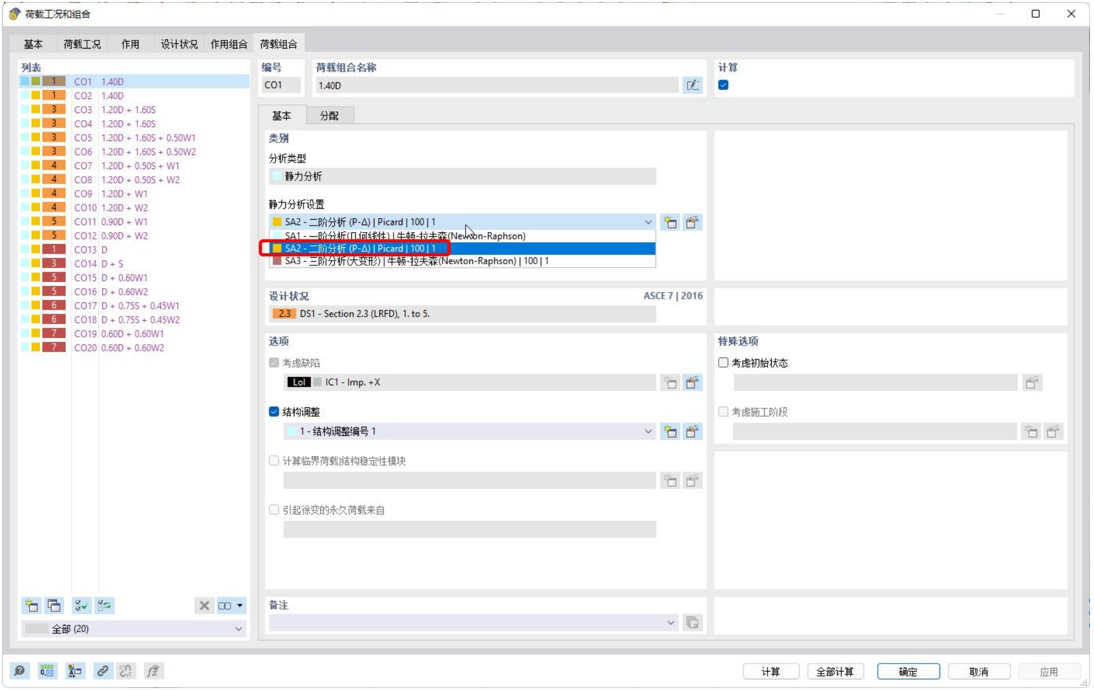
AISC360-16关于稳定分析的条文解读

☐ 如何考虑二阶效应?



$$M_r = B_1 M_{nt} + B_2 M_{lt}$$

$$P_r = P_{nt} + B_2 P_{lt}$$

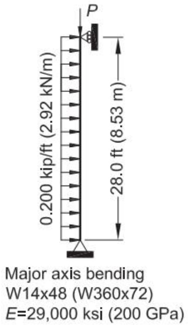


设计阶段考虑（近似）

分析阶段考虑（精确）

AISC360-16关于稳定分析的条文解读

□ 如何验证分析方法精确性？

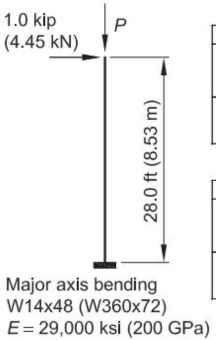


Axial Force, P (kips)	0	150	300	450
M_{mid} (kip-in.)	235 [235]	270 [269]	316 [313]	380 [375]
Δ_{mid} (in.)	0.202 [0.197]	0.230 [0.224]	0.269 [0.261]	0.322 [0.311]

Axial Force, P (kN)	0	667	1334	2001
M_{mid} (kN-m)	26.6 [26.6]	30.5 [30.4]	35.7 [35.4]	43.0 [42.4]
Δ_{mid} (mm)	5.13 [5.02]	5.86 [5.71]	6.84 [6.63]	8.21 [7.91]

Analyses include axial, flexural and shear deformations.
[Values in brackets] exclude shear deformations.

Fig. C-C2.2. Benchmark problem Case 1.



Axial Force, P (kips)	0	100	150	200
M_{base} (kip-in.)	336 [336]	470 [469]	601 [598]	856 [848]
Δ_{tip} (in.)	0.907 [0.901]	1.34 [1.33]	1.77 [1.75]	2.60 [2.56]

Axial Force, P (kN)	0	445	667	890
M_{base} (kN-m)	38.0 [38.0]	53.2 [53.1]	68.1 [67.7]	97.2 [96.2]
Δ_{tip} (mm)	23.1 [22.9]	34.2 [33.9]	45.1 [44.6]	66.6 [65.4]

Analyses include axial, flexural and shear deformations.
[Values in brackets] exclude shear deformations.

Fig. C-C2.3. Benchmark problem Case 2.

https://www.dlubal.com/zh/support-and-learning/support/knowledge-base/001759

AISC360-16 C章条文说明

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AISC360-16关于稳定分析的条文解读

- 为什么要考虑几何缺陷？**否则低估内力大小**　　材料缺陷/制造和安装误差等

> [redacted]. Initial imperfections in the structure, such as out-of-plumbness and material and fabrication tolerances, create additional destabilizing effects.

- 哪些情况不考虑缺陷？**正常使用状况不需要考虑**

> The Specification requirements for consideration of initial imperfections are intended to apply only to analyses for strength limit states. It is not necessary, in most cases, to consider initial imperfections in analyses for serviceability conditions such as drift, deflection and vibration.

AISC360-16关于稳定分析的条文解读

□ 如何考虑几何缺陷?

Initial imperfections may be accounted for in the direct analysis method through direct modeling (Section C2.2a) or the inclusion of notional loads (Section C2.2b).

两种方式：节点偏移/假想荷载（与国标直接分析法不同的是没有杆件局部缺陷）

In the development and calibration of the direct analysis method, initial geometric imperfections are conservatively assumed equal to the maximum material, fabrication and erection tolerances permitted in the AISC *Code of Standard Practice* (AISC, 2016a): a member out-of-straightness equal to $L/1{,}000$, where L is the member length between brace or framing points, and a frame out-of-plumbness equal to $H/500$, where H is the story height. The permitted out-of-plumbness may be smaller in some cases, as specified in the AISC *Code of Standard Practice*.

方式1：缺陷的大小保守的取为标准允许的最大偏差：层高H/500。

AISC360-16关于稳定分析的条文解读

如何考虑几何缺陷？

(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:

$$N_i = 0.002\alpha Y_i \tag{C2-1}$$

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)

方式2：重力荷载1/500

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AISC360-16关于稳定分析的条文解读

假想荷载跟其他工况怎么组合?

User Note: For most building structures, the requirement regarding notional load direction may be satisfied as follows: for load combinations that do not include lateral loading, consider two alternative orthogonal directions of notional load application, in a positive and a negative sense in each of the two directions, in the same direction at all levels; for load combinations that include lateral loading, apply all notional loads in the direction of the resultant of all lateral loads in the combination.

1.仅竖向荷载的组合:假想荷载考虑两个方向，每个方向考虑正负两种情况。

2.有水平荷载的组合：仅考虑与水平荷载相同方向的假想荷载。

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AISC360-16关于稳定分析的条文解读

□ 假想荷载跟其他工况怎么组合？

(d) For structures in which the ratio of maximum second-order drift to maximum first-order drift (both determined for LRFD load combinations or 1.6 times ASD load combinations, with stiffnesses adjusted as specified in Section C2.3) in all stories is equal to or less than 1.7, it is permissible to apply the notional load, N_i, only in gravity-only load combinations and not in combinations that include other lateral loads.

二阶计算得到的层间位移/一阶计算得到的层间位移≤1.7，假想荷载可以仅与竖向荷载组合而不与水平荷载组合。

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AISC360-16关于稳定分析的条文解读

- 为什么要考虑刚度折减?

Partial yielding accentuated by residual stresses in members can produce a general softening of the structure at the strength limit state that further creates additional destabilizing effects.

强度极限状态时，残余应力会导致构件部分屈服加剧，增加了结构失稳的可能性。

In these calibration studies, residual stresses in wide-flange shapes were assumed to have a maximum value of $0.3F_y$ in compression at the flange tips,

宽翼缘截面的残余应力高达0.3Fy

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AISC360-16关于稳定分析的条文解读

□ 如何折减?

(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.

> **User Note:** Applying the stiffness reduction to some members and not others can, in some cases, result in artificial distortion of the structure under load and possible unintended redistribution of forces. This can be avoided by applying the reduction to all members, including those that do not contribute to the stability of the structure.

1.所有杆件的所有刚度成分*0.8

(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

2.抗弯刚度*τ_b

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AISC360-16关于稳定分析的条文解读

☐ 如何折减?

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

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

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

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

where

α = 1.0 (LRFD); α = 1.6 (ASD)

P_r = required axial compressive strength using LRFD or ASD load combinations, kips (N)

P_{ns} = cross-section compressive strength; for nonslender-element sections, $P_{ns} = F_y A_g$, and for slender-element sections, $P_{ns} = F_y A_e$, where A_e is as defined in Section E7, kips (N)

(c) In structures to which Section C2.2b is applicable, in lieu of using $\tau_b < 1.0$ where $\alpha P_r/P_{ns} > 0.5$, it is permissible to use $\tau_b = 1.0$ for all noncomposite members if a notional load of $0.001\alpha Y_i$ [where Y_i is as defined in Section C2.2b(a)] is applied at all levels, in the direction specified in Section C2.2b(b), in all load combinations. These notional loads shall be added to those, if any, used to account for the effects of initial imperfections in the position of points of intersection of members and shall not be subject to the provisions of Section C2.2b(d).

轴压力较大时，τb的大小跟轴压力相关，而轴压力又跟刚度折减相关，因此需要迭代。

↓ 近似处理

τb=1.0，但是假想缺陷再增加0.001αYi,也即0.003αYi。

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AISC360-16关于稳定分析的条文解读

- 哪些状况不折减？

The use of reduced stiffness only pertains to analyses for strength and stability limit states. It does not apply to analyses for other stiffness-based conditions and criteria, such as for drift, deflection, vibration and period determination.

承载能力极限状态计算时考虑；
正常使用极限状态，振动及周期计算时不考虑。

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AISC360-16关于稳定分析的条文解读

□ 构件承载力计算参数？

C3. CALCULATION OF AVAILABLE STRENGTHS

For the direct analysis method of design, the available strengths of members and connections shall be calculated in accordance with the provisions of Chapters D through K, as applicable, with no further consideration of overall structure stability. The effective length for flexural buckling of all members shall be taken as the unbraced length unless a smaller value is justified by rational analysis.

Bracing intended to define the unbraced lengths of members shall have sufficient stiffness and strength to control member movement at the braced points.

E2. EFFECTIVE LENGTH

The effective length, L_c, for calculation of member slenderness, L_c/r, shall be determined in accordance with Chapter C or Appendix 7,

where

K = effective length factor

$L_c = KL$ = effective length of member, in. (mm)

L = laterally unbraced length of the member, in. (mm)

r = radius of gyration, in. (mm)

Lc=L，也即K=1.0进行轴压稳定验算。与国标不同的是，国标直接分析法中显式的引入了整体缺陷和构件缺陷，不在进行稳定验算。而美标直接分析法没有直接使用构件缺陷，还需要验算构件稳定。但是附录1的高级分析法考虑了杆件局部缺陷，轴压构件可以只考虑强度验算。

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AISC360-16关于稳定分析的条文解读

Appendix1:Dedign by Advanced Analysis?

APPENDIX 1

DESIGN BY ADVANCED ANALYSIS

This Appendix permits the use of more advanced methods of structural analysis to directly model system and member imperfections and/or allow for the redistribution of member and connection forces and moments as a result of localized yielding.

考虑杆件局部缺陷！

(c) In all cases, the analysis shall directly model the effects of initial imperfections due to both points of intersection of members displaced from their nominal locations (system imperfections), and initial out-of-straightness or offsets of members along their length (member imperfections). The magnitude of the initial displacements shall be the maximum amount considered in the design; the pattern of initial displacements shall be such that it provides the greatest destabilizing effect for the load combination being considered. The use of notional loads to represent either type of imperfection is not permitted

不允许使用假想荷载考虑缺陷！
（用位移描述杆件的缺陷）

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AISC360-16关于稳定分析的条文解读

Appendix1:Dedign by Advanced Analysis?

3. Calculation of Available Strengths

For design using a second-order elastic analysis that includes the direct modeling of system and member imperfections, the available strengths of members and connections shall be calculated in accordance with the provisions of Chapters D through K, as applicable, except as defined below, with no further consideration of overall structure stability.

The nominal compressive strength of members, P_n, may be taken as the cross-section compressive strength, F_yA_g, or as F_yA_e for members with slender elements, where A_e is defined in Section E7.

The nominal compressive strength, P_n, shall be determined based on the limit state of flexural buckling:

$$P_n = F_{cr} A_g \quad \text{(E3-1)}$$

The critical stress, F_{cr}, is determined as follows:

(a) When $\frac{L_c}{r} \le 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \le 2.25$)

$$F_{cr} = \left(0.658^{\frac{F_y}{F_e}}\right) F_y \quad \text{(E3-2)}$$

(b) When $\frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

$$F_{cr} = 0.877 F_e \quad \text{(E3-3)}$$

杆件轴压承载力Pn不再考虑屈曲。

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