

海外项目系列(I): 刚度折减那些事儿

彭志丰

随着“一带一路”的深入发展,中国设计师参与海外项目日益增多;随着新冠的有效控制,海外项目脚步逐步加快;为了使中国设计师能够快速胜任海外项目的设计,近期将结合盈建科欧美模块推出海外项目设计系列知识期刊。海外项目在有些设计理念与国内设计存在明显差别,第一期为“刚度折减那些事儿”,主要介绍海外项目中刚度折减。盈建科欧美模块支持中文和英文两种语言,语言可以自由切换,使英语不再是海外项目设计中的障碍。

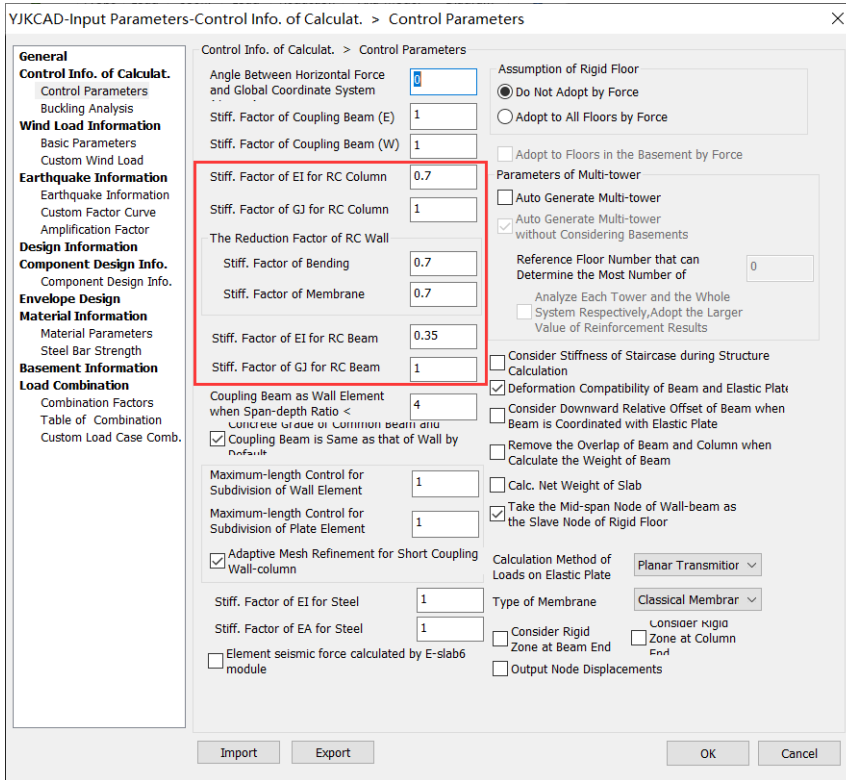


图 1. YJK 美标模块英文参数设置页

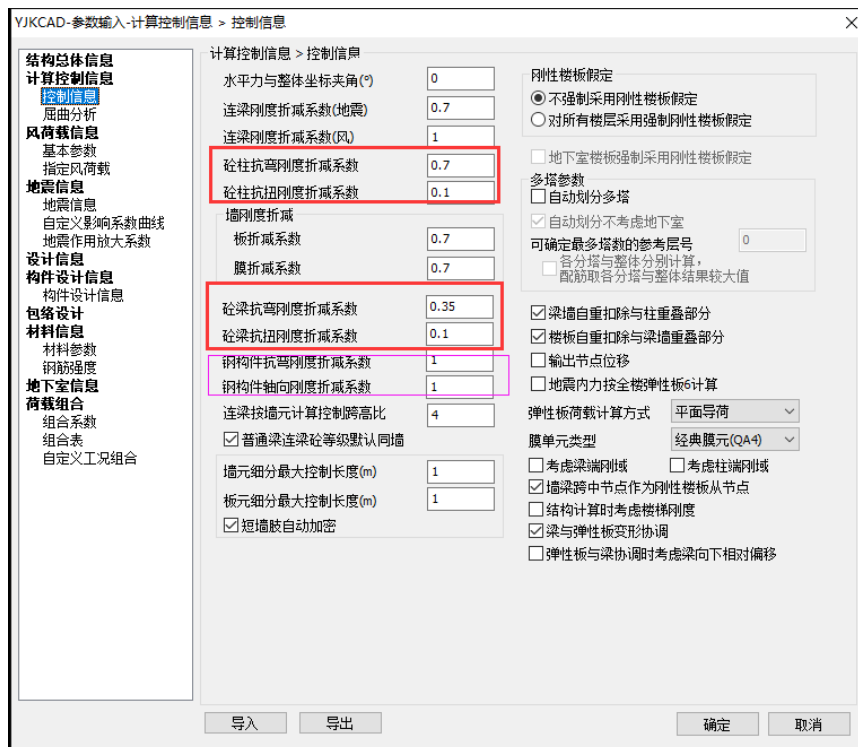


图 2. YJK 美标模块中文参数设置页

首先，我们先了解一下美标混凝土规范 ACI318-14 和美标钢结构规范 AISC360-10 中关于刚度折减的要求。ACI318-14 中 6.6.3.1 条明确规定：对墙进行 0.7 刚度折减，对柱进行 0.7 刚度折减，对梁进行 0.35 刚度折减，对板进行 0.25 刚度折减；6.6.3.1 适用于强度设计。AISC360-10 中 C2.3 条规定，对于直接分析法中的钢结构构件刚度进行 0.8 的折减，这个刚度折减项包含抗弯刚度与轴向刚度折减。AISC360-10 中表 C-C1.1 明确有效长度法不需要对钢结构构件刚度进行折减。

Table 6.6.3.1(a)—Moment of inertia and cross-sectional area permitted for elastic analysis at factored load level

Member and condition		Moment of Inertia	Cross-sectional area
Columns		$0.70I_g$	$1.0A_g$
Walls	Uncracked	$0.70I_g$	
	Cracked	$0.35I_g$	
Beams		$0.35I_g$	
Flat plates and flat slabs		$0.25I_g$	

图 3. 美标混凝土构件刚度折减 (Refer to ACI318-14 6.6.3.1)

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.

图 4. 美标钢结构直接分析法中刚度折减 (Refer to AISC 361-10 C2.3)

TABLE C-C1.1 Comparison of Basic Stability Requirements with Specific Provisions			
Basic Requirement in Section C1		Provision in Direct Analysis Method (DM)	Provision in Effective Length Method (ELM)
(1) Consider all deformations		C2.1(a). Consider all deformations	Same as DM (by reference to C2.1)
(2) Consider second-order effects (both $P-\Delta$ and $P-\delta$)		C2.1(b). Consider second-order effects ($P-\Delta$ and $P-\delta$) ^[b]	Same as DM (by reference to C2.1)
(3) Consider geometric imperfections <i>This includes joint-position imperfections^[a] (which affect structure response) and member imperfections (which affect structure response and member strength)</i>	Effect of system imperfections on structure response	C2.2a. Direct modeling or C2.2b. Notional loads	Same as DM, second option only (by reference to C2.2b) All these effects are considered by using $L_c = KL$ from a side-sway buckling analysis in the member strength check. Note that the differences between DM and ELM are: <ul style="list-style-type: none">• DM uses reduced stiffness in the analysis and $L_c = L$ in the member strength check• ELM uses full stiffness in the analysis and $L_c = KL$ from sidesway buckling analysis in the member strength check
	Effect of member imperfections on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of member imperfections on member strength	Included in member strength formulas, with $L_c = L$	
(4) Consider stiffness reduction due to inelasticity <i>This affects structure response and member strength</i>	Effect of stiffness reduction on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of stiffness reduction on member strength	Included in member strength formulas, with $L_c = L$	
(5) Consider uncertainty in strength and stiffness <i>This affects structure response and member strength</i>	Effect of stiffness/strength uncertainty on structure response	Included in the stiffness reduction specified in C2.3	
	Effect of stiffness/strength uncertainty on member strength	Included in member strength formulas, with $L_c = L$	

图 5. AISC360-10 中表 C-C1.1 中稳定性条款的比较

其次，我们了解一下欧标 EC8 关于刚度折减的要求。欧标 EC8 中 4.3.1 第 7 款中明确带裂缝工作的混凝土构件弯曲刚度可以折减 0.5。

EN 1998-1:2004 (E)

(5) For buildings conforming to the criteria for regularity in plan (see 4.2.3.2) or with the conditions presented in 4.3.3.1(8), the analysis may be performed using two planar models, one for each main direction.

(6) In concrete buildings, in composite steel-concrete buildings and in masonry buildings the stiffness of the load bearing elements should, in general, be evaluated taking into account the effect of cracking. Such stiffness should correspond to the initiation of yielding of the reinforcement. EC8 4.3.1

(7) Unless a more accurate analysis of the cracked elements is performed, the elastic flexural and shear stiffness properties of concrete and masonry elements may be taken to be equal to one-half of the corresponding stiffness of the uncracked elements.

(8) Infill walls which contribute significantly to the lateral stiffness and resistance of the building should be taken into account. See 4.3.6 for masonry infills of concrete, steel or composite frames.

图 6. EC8 规范 4.3.1 条关于刚度折减的规定

然后，我们了解一下沙标混凝土 SBC304 对刚度折减的要求；沙标 SBC304 中 10.11.1 条明确规定了混凝土构件刚度折减系数，沙标中混凝土构件刚度折减与美标中混凝土构件刚度折减系数相同，是因为沙标规范在编制过程中参考了美标。

10.11.1 The factored axial forces P_u the factored moments M_1 and M_2 at the ends of the column, and, where required, the relative lateral story deflections Δ_o shall be computed using an elastic first-order frame analysis with the section properties determined taking into account the influence of axial loads, the presence of cracked regions along the length of the member, and effects of duration of the loads. Alternatively, it shall be permitted to use the following properties for the members in the structure:

(a) Modulus of elasticity E_c from 8.5.1

(b) Moments of inertia

Beams $0.35 I_g$

Columns $0.70 I_g$

Walls -Uncracked $0.70 I_g$

-Cracked $0.35 I_g$

Flat plates and flat slabs $0.25 I_g$

SBC304

(c) Area $1.0 A_g$

The moments of inertia shall be divided by $(1 + \beta_d)$

(a) When sustained lateral loads act; or

(b) For stability checks made in accordance with Section 10.13.6.

图 7. 沙标 SBC304 中混凝土构件刚度折减

最后，我们了解一下埃标混凝土对刚度折减的要求。埃及标准 ECP201-2012 中 8.7.1 条第 3 款明确规定，剪力墙与柱子的刚度折减系数为 0.7，考虑板作用时候梁的刚度折减系数为 0.5，楼板的刚度折减系数为 0.25

3- In reinforced concrete and masonry buildings the stiffness of the load bearing elements should, in general be evaluated assuming un-cracked sections.

- Unless a more accurate analysis of the cracked elements is performed, the elastic flexural and shear stiffness properties of concrete and masonry elements may be taken equal to one-half of the corresponding stiffness of the un-cracked elements.

- In case of reinforced concrete elements, the actual stiffness (actual moment of inertia) shall be:

• Columns	$I_{eff} = 0.70 I_g$
• Shear walls	$I_{eff} = 0.70 I_g$
• Cracked Shear walls	$I_{eff} = 0.35 I_g$
• Beams (considering slab contribution)	$I_{eff} = 0.50 I_g$
• Flat Slab for all area	$I_{eff} = 0.25 I_g$
• No reduction in area	$A_{eff} = A_g$

where :

I_{eff} : Section stiffness considering cracking effect

I_g : Section stiffness neglecting cracking effect

A_g : Section area neglecting cracking effect

8.7.1

图 8. 埃及标准 ECP201-2012 中混凝土构件刚度折减

总结：在海外项目中，一般需要对构件的刚度折减，而国内仅仅对连梁刚度进行折减。国外工程师一般认为混凝土是带裂缝工作的，所以对混凝土构件进行刚度的折减。各国对混凝土构件刚度折减的趋势基本上一致，只是折减系数上略有不同。无论是对混凝土构件刚度折减，还是对钢结构刚度折减均可以在盈建科欧美模块中实现。