海外项目系列(II)：美标模块之抗震参数篇（1）

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。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。海外项目在某些设计理念与国内设计存在明显差别，第二期为“美标模块之抗震参数篇”，分为四部分，主要介绍美标模块抗震参数和某工程案例地震参数选取，以便用户快速掌握美标地震参数意义和确定流程。由于笔者英语水平有限，以免翻译错误，误导读者，本篇也将美标条文详细呈现，以便读者查阅。

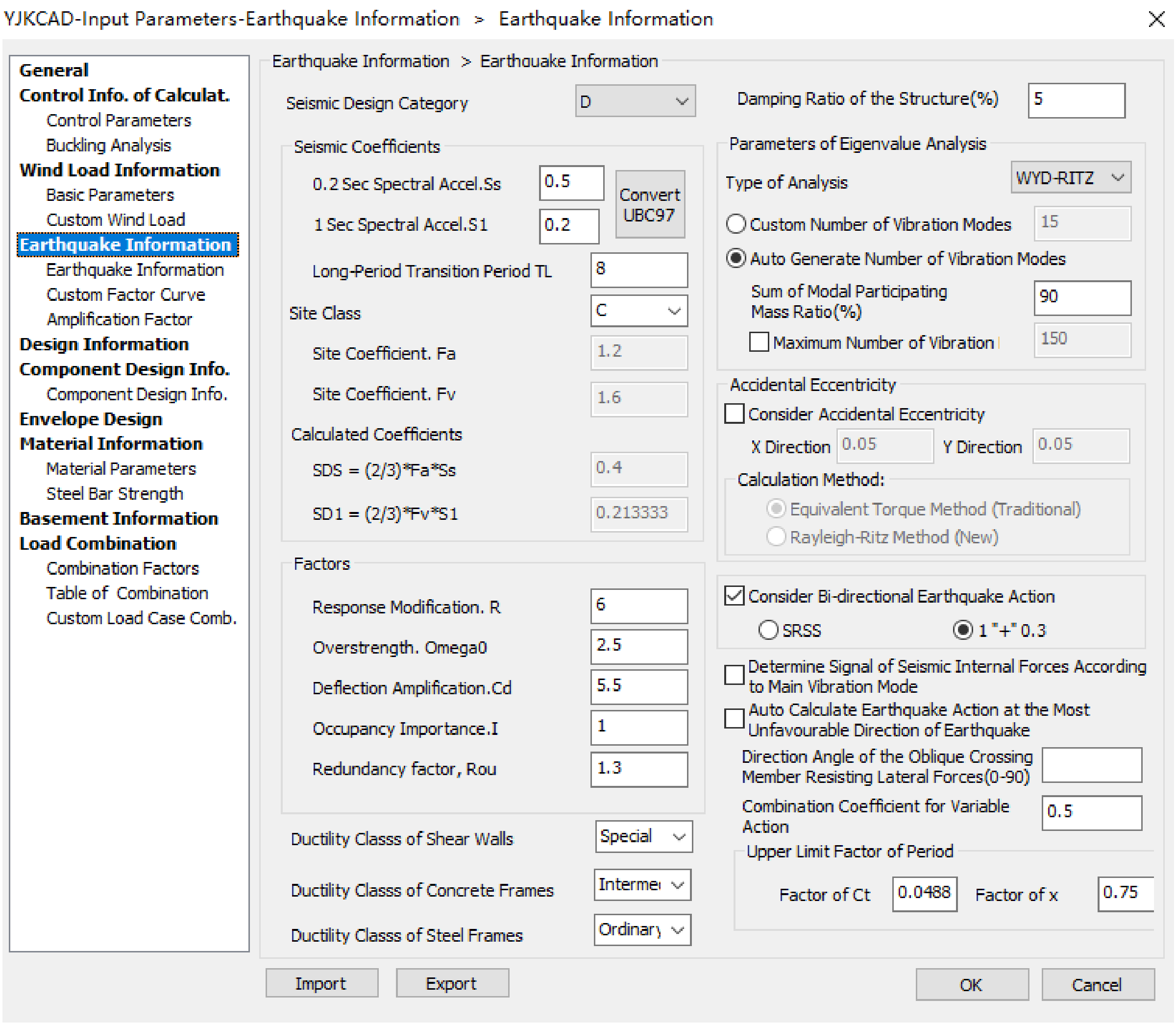

图 1. YJK 美标模块英文地震参数设置页

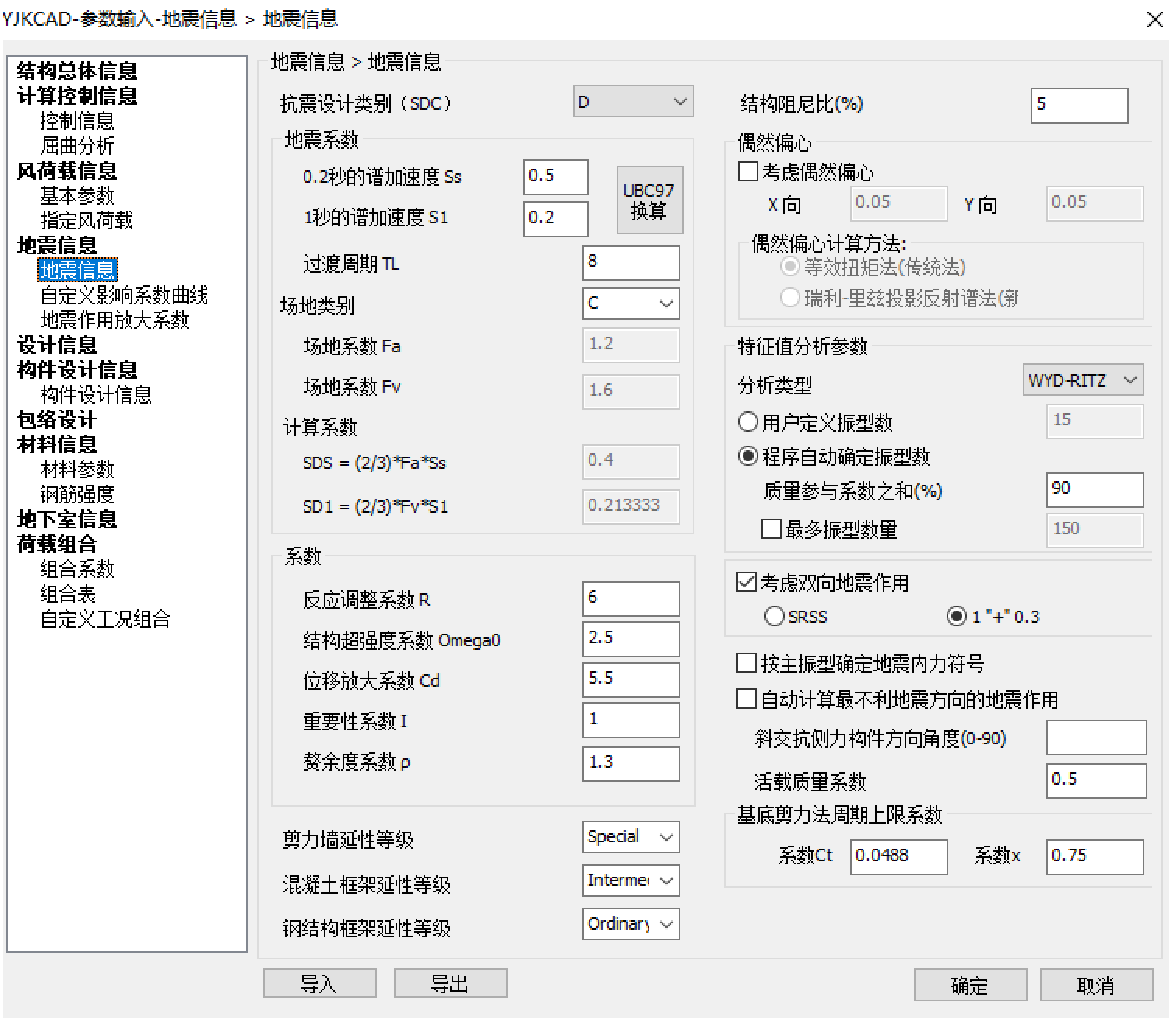

图 2. YJK 美标模块中文地震参数设置页

盈建科美标模块支持美标荷载 ASCE7-10、混凝土规范 ACI318-14、钢结构规范 AISC360-10、钢结构抗震规范 AISC341-10 等。

首先，我们根据 ASCE7-10 表 1.5-1（图 1）确定该建筑的安全等级，根据 ASCE7-10 表 1.5-2（图 2）确定其地震作用重要性系数。例如普通建筑的安全等级为Ⅱ，其地震作用的重要性系数为 1.0。

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent a low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	常见 II
Buildings and other structures, the failure of which could pose a substantial risk to human life. Buildings and other structures, not included in Risk Category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. Buildings and other structures not included in Risk Category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public if released.	III
Buildings and other structures designated as essential facilities. Buildings and other structures, the failure of which could pose a substantial hazard to the community. Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public if released.[a] Buildings and other structures required to maintain the functionality of other Risk Category IV structures.	最重要 IV

[a]Buildings and other structures containing toxic, highly toxic, or explosive substances shall be eligible for classification to a lower Risk Category if it can be demonstrated to the satisfaction of the authority having jurisdiction by a hazard assessment as described in Section 1.5.2 that a release of the substances is commensurate with the risk associated with that Risk Category.

图 3. 美标 ASCE7-10 表 1.5-1 建筑安全等级

Table 1.5-2 Importance Factors by Risk Category of Buildings and Other Structures for Snow, Ice, and Earthquake Loads[a]

Risk Category from Table 1.5-1	Snow Importance Factor, I_s	Ice Importance Factor—Thickness, I_i	Ice Importance Factor—Wind, I_w	Seismic Importance Factor, I_e
I	0.80	0.80	1.00	1.00
II	1.00	1.00	1.00	1.00
III	1.10	1.25	1.00	1.25
IV	1.20	1.25	1.00	1.50

[a]The component importance factor, I_p, applicable to earthquake loads, is not included in this table because it is dependent on the importance of the individual component rather than that of the building as a whole, or its occupancy. Refer to Section 13.1.3.

图 4. 美标 ASCE7-10 表 1.5-2 各种荷载作用重要性系数

其次，我们了解一下美标中的基本概念，如结构不规则的定义、地震分析方法中的等效侧向力法和反应谱法一些基本规定。结构平面不规则的规定详见图 5，结构竖向不规则的规定详见图 6。对于抗震设计类别为 E 和 F 建筑，不允许使用非常扭转不规则（type b）和楼层竖向刚度不规则（1a）、楼层竖向

承载力不规则（5a）、极端楼层竖向承载力不规则（5b）；对于抗震设计类别为 D 建筑，不允许使用极端楼层竖向承载力不规则（5b）（Refer to 12.3.3.1）。对于抗震设计类别为 D、E、F 建筑，属于特定平面不规则或者属于竖向抗侧力构件不连续时，地震作用应该放大 1.25 倍（Refer to 12.3.3.4）。

Table 12.3-1 Horizontal Structural Irregularities 水平不规则

Type	Description	Reference Section	Seismic Design Category Application
1a. 扭转不规则	**Torsional Irregularity:** Torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.2 times the average of the story drifts at the two ends of the structure. Torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	D, E, and F B, C, D, E, and F C, D, E, and F C, D, E, and F D, E, and F B, C, D, E, and F
1b. 非常扭转不规则	**Extreme Torsional Irregularity:** Extreme torsional irregularity is defined to exist where the maximum story drift, computed including accidental torsion with $A_x = 1.0$, at one end of the structure transverse to an axis is more than 1.4 times the average of the story drifts at the two ends of the structure. Extreme torsional irregularity requirements in the reference sections apply only to structures in which the diaphragms are rigid or semirigid.	12.3.3.1 12.3.3.4 12.7.3 12.8.4.3 12.12.1 Table 12.6-1 Section 16.2.2	E and F D B, C, and D C and D C and D D B, C, and D
2. 凹凸不规则	**Reentrant Corner Irregularity:** Reentrant corner irregularity is defined to exist where both plan projections of the structure beyond a reentrant corner are greater than 15% of the plan dimension of the structure in the given direction.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
3. 隔板不连续	**Diaphragm Discontinuity Irregularity:** Diaphragm discontinuity irregularity is defined to exist where there is a diaphragm with an abrupt discontinuity or variation in stiffness, including one having a cutout or open area greater than 50% of the gross enclosed diaphragm area, or a change in effective diaphragm stiffness of more than 50% from one story to the next.	12.3.3.4 Table 12.6-1	D, E, and F D, E, and F
4.	**Out-of-Plane Offset Irregularity:** Out-of-plane offset irregularity is defined to exist where there is a discontinuity in a lateral force-resistance path, such as an out-of-plane offset of at least one of the vertical elements.	12.3.3.3 12.3.3.4 12.7.3 Table 12.6-1 Section 16.2.2	B, C, D, E, and F D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F
5. 非平行体系不规则	**Nonparallel System Irregularity:** Nonparallel system irregularity is defined to exist where vertical lateral force-resisting elements are not parallel to the major orthogonal axes of the seismic force-resisting system.	12.5.3 12.7.3 Table 12.6-1 Section 16.2.2	C, D, E, and F B, C, D, E, and F D, E, and F B, C, D, E, and F

图 5. 结构水平不规则

Table 12.3-2 Vertical Structural Irregularities 结构竖向不规则

Type	Description	Reference Section	Seismic Design Category Application
1a.	**Stiffness-Soft Story Irregularity:** Stiffness-soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 70% of that in the story above or less than 80% of the average stiffness of the three stories above.	Table 12.6-1 楼层刚度不规则	D, E, and F
1b.	**Stiffness-Extreme Soft Story Irregularity:** Stiffness-extreme soft story irregularity is defined to exist where there is a story in which the lateral stiffness is less than 60% of that in the story above or less than 70% of the average stiffness of the three stories above.	12.3.3.1 Table 12.6-1 极端楼层刚度不规则	E and F D, E, and F
2.	**Weight (Mass) Irregularity:** Weight (mass) irregularity is defined to exist where the effective mass of any story is more than 150% of the effective mass of an adjacent story. A roof that is lighter than the floor below need not be considered.	Table 12.6-1 质量不规则	D, E, and F
3.	**Vertical Geometric Irregularity:** Vertical geometric irregularity is defined to exist where the horizontal dimension of the seismic force-resisting system in any story is more than 130% of that in an adjacent story.	Table 12.6-1 竖向几何不规则	D, E, and F
4.	**In-Plane Discontinuity in Vertical Lateral Force-Resisting Element Irregularity:** In-plane discontinuity in vertical lateral force-resisting elements irregularity is defined to exist where there is an in-plane offset of a vertical seismic force-resisting element resulting in overturning demands on a supporting beam, column, truss, or slab.	12.3.3.3 12.3.3.4 Table 12.6-1 竖向抗侧力构件在平面内不连续	B, C, D, E, and F D, E, and F D, E, and F
5a.	**Discontinuity in Lateral Strength–Weak Story Irregularity:** Discontinuity in lateral strength–weak story irregularity is defined to exist where the story lateral strength is less than 80% of that in the story above. The story lateral strength is the total lateral strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 Table 12.6-1 楼层承载力不规则	E and F D, E, and F
5b.	**Discontinuity in Lateral Strength–Extreme Weak Story Irregularity:** Discontinuity in lateral strength–extreme weak story irregularity is defined to exist where the story lateral strength is less than 65% of that in the story above. The story strength is the total strength of all seismic-resisting elements sharing the story shear for the direction under consideration.	12.3.3.1 12.3.3.2 Table 12.6-1 极端楼层承载力不规则	D, E, and F B and C D, E, and F

图 6. 结构竖向不规则

12.3.3.1 Prohibited Horizontal and Vertical Irregularities for Seismic Design Categories D through F

Structures assigned to Seismic Design Category E or F having horizontal irregularity Type 1b of Table 12.3-1 or vertical irregularities Type 1b, 5a, or 5b of Table 12.3-2 shall not be permitted. Structures assigned to Seismic Design Category D having vertical irregularity Type 5b of Table 12.3-2 shall not be permitted.

图 7. ASCE7-10 中 12.3.3.1 条款

12.3.3.4 Increase in Forces Due to Irregularities for Seismic Design Categories D through F

For structures assigned to Seismic Design Category D, E, or F and having a horizontal structural irregularity of Type 1a, 1b, 2, 3, or 4 in Table 12.3-1 or a vertical structural irregularity of Type 4 in Table 12.3-2, the design forces determined from Section 12.10.1.1 shall be increased 25 percent for the following elements of the seismic force-resisting system:

1. Connections of diaphragms to vertical elements and to collectors.
2. Collectors and their connections, including connections to vertical elements, of the seismic force-resisting system.

图 8.　ASCE7-10 中 12.3.3.4 条款

计算地震作用的方法包括等效侧向力法、反应谱法和时程分析法。等效侧向力法与我国的底部剪力法保持一致，但等效抗侧力法有一定的适用前提，详见图 9 地震作用分析方法。

Table 12.6-1 Permitted Analytical Procedures

Seismic Design Category	Structural Characteristics	等效侧向力 Equivalent Lateral Force Analysis, Section 12.8[a]	反应谱法 Modal Response Spectrum Analysis, Section 12.9[a]	时程分析法 Seismic Response History Procedures, Chapter 16[a]
B, C	All structures	P	P	P
D, E, F	Risk Category I or II buildings not exceeding 2 stories above the base	P	P	P
	Structures of light frame construction	P	P	P
	Structures with no structural irregularities and not exceeding 160 ft in structural height	P	P	P
	Structures exceeding 160 ft in structural height with no structural irregularities and with $T < 3.5T_s$	P	P	P
	Structures not exceeding 160 ft in structural height and having only horizontal irregularities of Type 2, 3, 4, or 5 in Table 12.3-1 or vertical irregularities of Type 4, 5a, or 5b in Table 12.3-2	P	P	P
	All other structures	NP	P	P

[a]P: Permitted; NP: Not Permitted; $T_s = S_{D1}/S_{DS}$.

图 9.　地震作用分析方法（a）

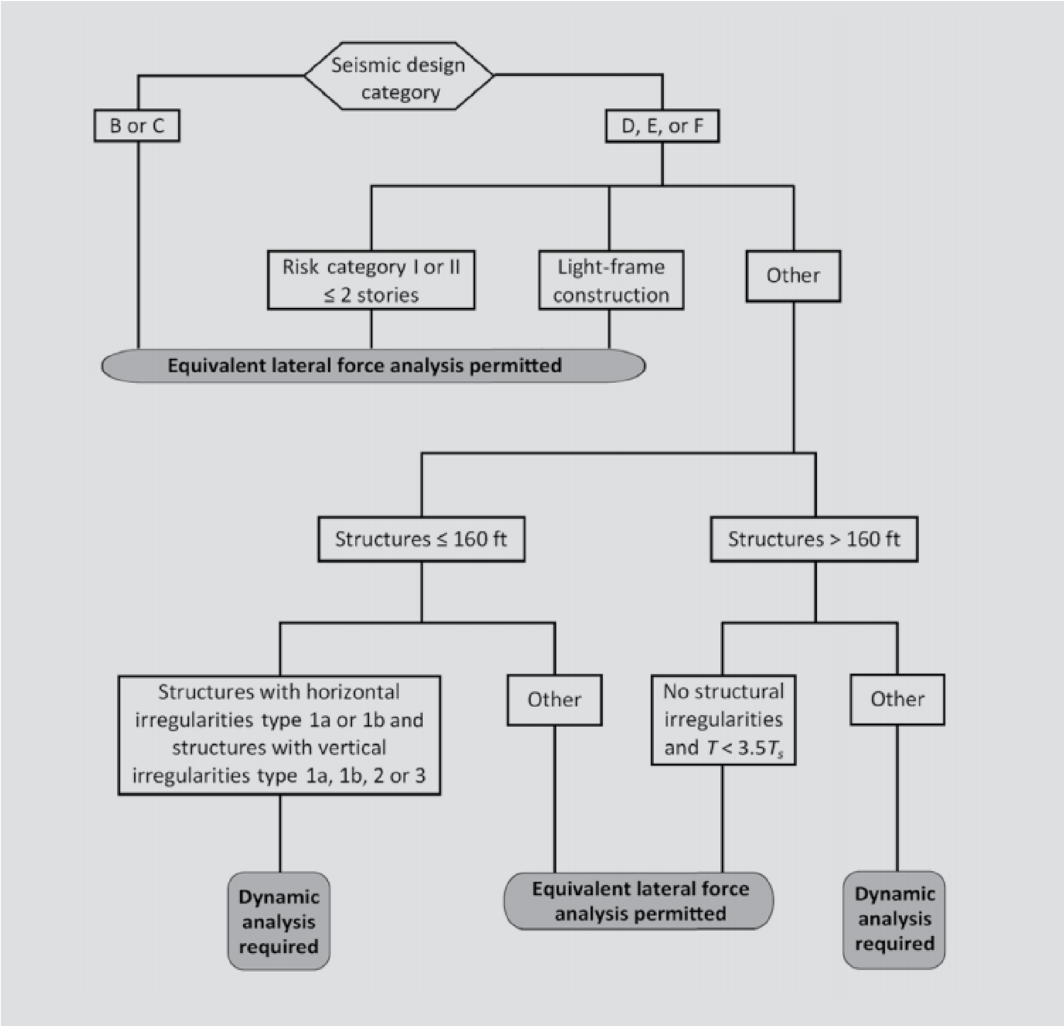

图 9. 地震作用分析方法（b）

注：《海外项目系列(Ⅱ)：美标模块之抗震参数篇》未完，精彩还在后面，请继续查阅。

海外项目系列(Ⅱ)：美标模块之抗震参数篇（2）

彭志丰

本篇接《海外项目系列(Ⅱ)：美标模块之抗震参数篇（1）》继续介绍美标中有关地震的参数，本篇主要介绍美标中的一些概念。

采用合理的分析方法确定结构周期 T，结构周期 T 不能超过计算周期上限系数 Cu 与估算结构基本周期 Ta 的乘积，计算周期上限系数 Cu 可根据表 12.8.1 查得，估算结构基本周期 Ta 可以通过 ASCE7-10 中公式 12.8-7 求得，注意表 12.8-2 中的括号数值用于米制单位。

计算周期上限系数Cu

Table 12.8-1 Coefficient for Upper Limit on Calculated Period

Design Spectral Response Acceleration Parameter at 1 *s*, S_{D1}	Coefficient C_u
≥ 0.4	1.4
0.3	1.4
0.2	1.5
0.15	1.6
≤ 0.1	1.7

图 10. 计算周期上限系数 Cu

12.8.2.1 Approximate Fundamental Period

The approximate fundamental period (T_a), in s, shall be determined from the following equation:

$$T_a = C_t h_n^x \qquad (12.8\text{-}7)$$

where h_n is the structural height as defined in Section 11.2 and the coefficients C_t and x are determined from Table 12.8-2.

Table 12.8-2 Values of Approximate Period Parameters C_t and x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1	0.03 (0.0731)[a]	0.75
Steel buckling-restrained braced frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a]Metric equivalents are shown in parentheses.

图 11. 估算结构基本周期公式 ASCE7-10　12.8-7 和表 12.8-2

等效抗侧力法关于地震基底剪力的求解详见公式 12.8.-1，地震系数 Cs 的求解详见公式 12.8-2，当 T>Ts 时，地震系数 Cs 上限与反应谱法中保持一致。（Refer to 12.8.1.1 and 11.4.5）；地震系数 Cs 的下限值 12.8-5 或公式 12.8-6 求出；地震系数 Cs 的下限值与国标中的最小剪重比的作用类似。

12.8 EQUIVALENT LATERAL FORCE PROCEDURE

12.8.1 Seismic Base Shear

The seismic base shear, V, in a given direction shall be determined in accordance with the following equation:

$$V = C_s W \qquad (12.8\text{-}1)$$

where

C_s = the seismic response coefficient determined in accordance with Section 12.8.1.1

W = the effective seismic weight per Section 12.7.2

12.8.1.1 Calculation of Seismic Response Coefficient

The seismic response coefficient, C_s, shall be determined in accordance with Eq. 12.8-2.

$$C_s = \frac{S_{DS}}{\left(\frac{R}{I_e}\right)} \qquad (12.8\text{-}2)$$

图 12. 地震系数 Cs 的求解公式

C_s shall not be less than

$$C_s = 0.044 S_{DS} I_e \geq 0.01 \qquad (12.8\text{-}5)$$

In addition, for structures located where S_1 is equal to or greater than $0.6g$, C_s shall not be less than

$$C_s = 0.5 S_1 / (R/I_e) \qquad (12.8\text{-}6)$$

where I_e and R are as defined in Section 12.8.1.1 and

S_{D1} = the design spectral response acceleration parameter at a period of 1.0 s, as determined from Section 11.4.4 or 11.4.7

T = the fundamental period of the structure(s) determined in Section 12.8.2

T_L = long-period transition period(s) determined in Section 11.4.5

S_1 = the mapped maximum considered earthquake spectral response acceleration parameter determined in accordance with Section 11.4.1 or 11.4.7

图 13. 地震系数 Cs 的下限值

盈建科美标模块等效侧向力法依据结构周期 T 按图 14 确定地震作用大小。

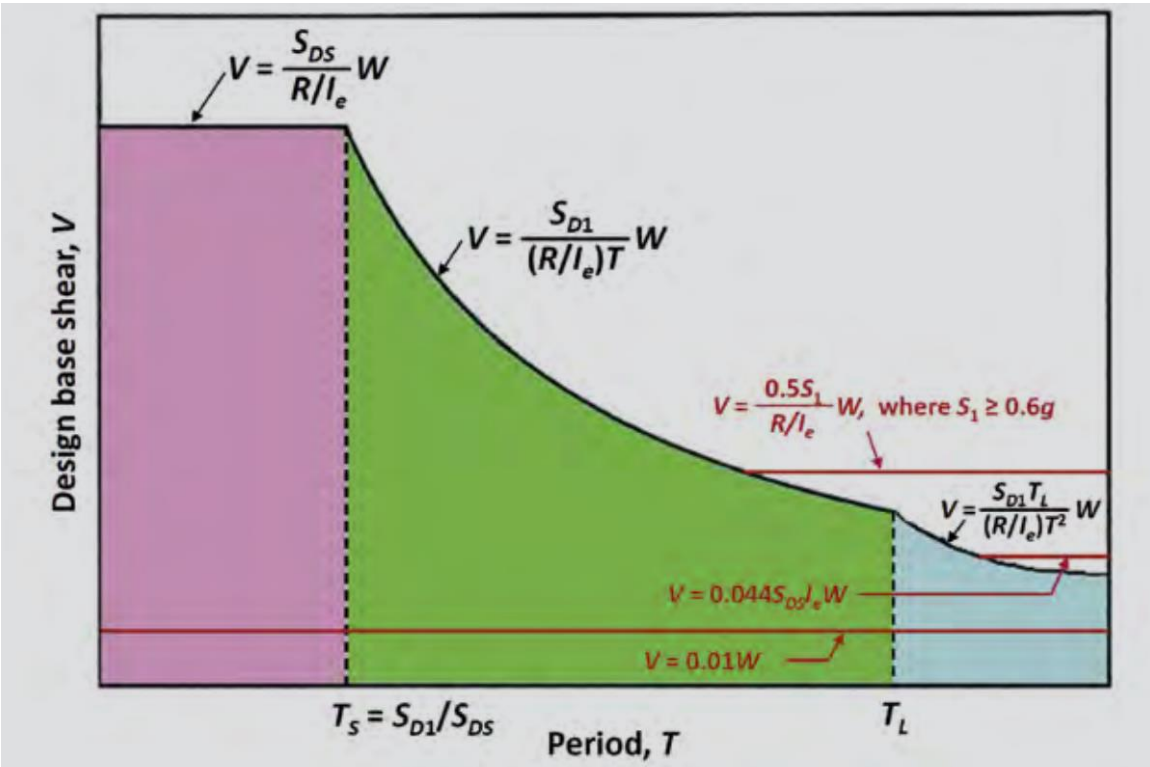

图 14. 盈建科美标模块等效侧向力法

阵型反应谱法要求每个方向的总质量系数不小于 90%（Refer to 12.9.1）。阵型反应谱法计算出的内力需要乘以 Ie/R，而阵型反应谱法计算出的位移角和位移需要乘以 Cd/R（Refer to 12.9.2）。阵型反应谱法计算的基底剪力不能小于 0.85 倍等效抗侧力法求得的剪力，当阵型反应谱法计算的基底剪力小于 0.85 倍等效抗侧力法求得的剪力，应将基底剪力放大至 0.85 倍等效抗侧力法求得的剪力（Refer to 12.9.4.1）。

盈建科美标模块不仅能够自动调整阵型反应谱法计算的地震效应与位移（位移角），而且也能自动根据等效侧向力法剪力来调整阵型反应谱法的地震剪力，不再需要用户手动进行调整。

12.9.2 Modal Response Parameters

The value for each force-related design parameter of interest, including story drifts, support forces, and individual member forces for each mode of response shall be computed using the properties of each mode and the response spectra defined in either Section 11.4.5 or 21.2 divided by the quantity R/I_e. The value for displacement and drift quantities shall be multiplied by the quantity C_d/I_e.

图 15. ASCE7-10 中 12.9.2 条款

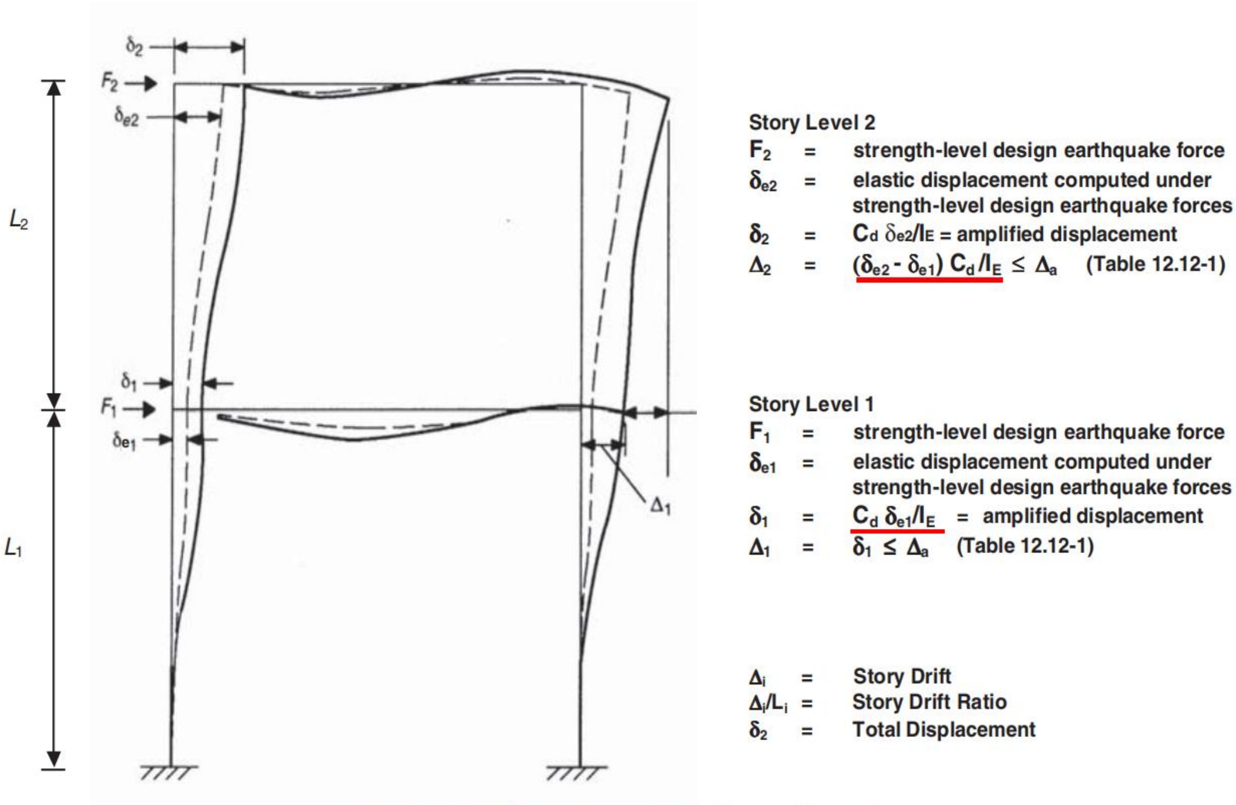

FIGURE 12.8-2 Story Drift Determination

图 16.　ASCE7-10 楼层相对位移

12.12.3 Structural Separation

All portions of the structure shall be designed and constructed to act as an integral unit in resisting seismic forces unless separated structurally by a distance sufficient to avoid damaging contact as set forth in this section.

Separations shall allow for the maximum inelastic response displacement (δ_M). δ_M shall be determined at critical locations with consideration for translational and torsional displacements of the structure including torsional amplifications, where applicable, using the following equation:

$$\delta_M = \frac{C_d \delta_{max}}{I_e} \qquad (12.12\text{-}1)$$

Where δ_{max} = maximum elastic displacement at the critical location.

图 17.　ASCE7-10 楼层位移计算公式

Table 12.12-1 Allowable Story Drift, $\Delta_a{}^{a,b}$ 地震位移限值

Structure	Risk Category 建筑安全等级 I or II	III	IV
Structures, other than masonry shear wall structures, 4 stories or less above the base as defined in Section 11.2, with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts.	$0.025h_{sx}{}^{c}$	$0.020h_{sx}$	$0.015h_{sx}$
Masonry cantilever shear wall structures[d]	$0.010h_{sx}$	$0.010h_{sx}$	$0.010h_{sx}$
Other masonry shear wall structures	$0.007h_{sx}$	$0.007h_{sx}$	$0.007h_{sx}$
All other structures	$0.020h_{sx}$	$0.015h_{sx}$	$0.010h_{sx}$

[a] h_{sx} is the story height below Level x.

[b] For seismic force-resisting systems comprised solely of moment frames in Seismic Design Categories D, E, and F, the allowable story drift shall comply with the requirements of Section 12.12.1.1.

[c] There shall be no drift limit for single-story structures with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate the story drifts. The structure separation requirement of Section 12.12.3 is not waived.

[d] Structures in which the basic structural system consists of masonry shear walls designed as vertical elements cantilevered from their base or foundation support which are so constructed that moment transfer between shear walls (coupling) is negligible.

图 18.　ASCE7-10 楼层相对位移限值

12.9.4.1 Scaling of Forces

Where the calculated fundamental period exceeds C_uT_a in a given direction, C_uT_a shall be used in lieu of T in that direction. Where the combined response for the modal base shear (V_t) is less than 85 percent of the calculated base shear (V) using the equivalent lateral force procedure, the forces shall be multiplied by $0.85\frac{V}{V_t}$:

where

V = the equivalent lateral force procedure base shear, calculated in accordance with this section and Section 12.8

图 19.　ASCE7-10 中 12.9.4.1 条款

竖向地震作用：竖向地震作用根据 ASCE7-10 中公式 12.4-4 确定，当短周期设计反应加速度参数小于 0.125 时候，可以忽略竖向地震作用。

12.4.2.2 Vertical Seismic Load Effect

The vertical seismic load effect, E_v, shall be determined in accordance with Eq. 12.4-4 as follows:

$$E_v = 0.2S_{DS}D \qquad (12.4\text{-}4)$$

where

S_{DS} = design spectral response acceleration parameter at short periods obtained from Section 11.4.4

D = effect of dead load

EXCEPTIONS: The vertical seismic load effect, E_v, is permitted to be taken as zero for either of the following conditions:

1. In Eqs. 12.4-1, 12.4-2, 12.4-5, and 12.4-6 where S_{DS} is equal to or less than 0.125.
2. In Eq. 12.4-2 where determining demands on the soil–structure interface of foundations.

图 20. 竖向地震力

双向地震作用：双向地震作用可按一个方向 100%地震作用加正交方向地震作用的 0.3 倍考虑。当抗震设计类别为 B 类时候，可以不考虑双向地震作用；当抗震设计类别为 C 类且建筑属于平面不规则中类型 5 时候，需要考虑双向地震作用；当抗震设计类别为 D、E、F 时，需要考虑双向地震。

12.5.3 Seismic Design Category C

Loading applied to structures assigned to Seismic Design Category C shall, as a minimum, conform to the requirements of Section 12.5.2 for Seismic Design Category B and the requirements of this section. Structures that have horizontal structural irregularity Type 5 in Table 12.3-1 shall use one of the following procedures:

a. **Orthogonal Combination Procedure.** The structure shall be analyzed using the equivalent lateral force analysis procedure of Section 12.8, the modal response spectrum analysis procedure of Section 12.9, or the linear response history procedure of Section 16.1, as permitted under Section 12.6, with the loading applied independently in any two orthogonal directions. The requirement of Section 12.5.1 is deemed satisfied if members and their foundations are designed for 100 percent of the forces for one direction plus 30 percent of the forces for the perpendicular direction. The combination requiring the maximum component strength shall be used.

图 21. 双向地震力

注：《海外项目系列(Ⅱ)：美标模块之抗震参数篇》未完，精彩还在后面，请继续查阅。

海外项目系列（Ⅱ）：美标模块之抗震参数篇（3）

彭志丰

本篇接《海外项目系列(Ⅱ)：美标模块之抗震参数篇（1）（2）》继续介绍美标中有关地震的参数，本篇主要介绍美标中的反应谱参数和抗震体系中的地震参数。

当了解完美标中地震一些总体要求后，然后，我们了解一下美标反应谱中的重要参数和结构体系中的重要参数。

ASCE7-10 提供场地加速度为 2475 年重现期基准场地 B 类 5%阻尼弹性谱值，长周期（1s）地震动反应谱加速度 S_1 和短周期（0.2s）地震动反应谱加速 S_S，可根据美标 ASCE7-10 中 22 章图 22 确定某地区相应的地震动反应谱加速度，或根据 USGS Web site 网站的地震设计图(2475 年重现期基准场地 B 类 5%阻尼弹性谱值)

（https://earthquake.usgs.gov/hazards/designmaps/pdfs/?code=NEHRP&edition=2003）确定；沙标是根据沙特荷载规范 SBC301 中图 9 确定其地区的地震动反应谱加速度。

根据场地土特性，参考 ASCE7-10 第 20 章将场地划分为 A，B，C，D，E，F 等六类，当地勘数据不充足时，场地类别可按照 D 类处理（Refer to ASCE7-10 11.4.2）。美标是以 B 类场地谱值为基准，其他场地谱值通过系数 Fa 和 Fv 进行换算。根据 ASCE7-10 中表 11.4.1 确定短周期反应谱的场地系数 Fa，根据 ASCE7-10 中表 11.4.2 确定长周期反应谱的场地系数 Fv。

Table 11.4-1 Site Coefficient, F_a 场地系数Fa

场地类别 Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_S.

Table 11.4-2 Site Coefficient, F_v 场地系数Fv

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_1.

图 22. ASCE7-10 场地系数 Fa 和 Fv

考虑场地调整 5%阻尼的短周期的场地反应谱加速度 SMS 根据公式 11.4-1 求出；考虑场地调整 5%阻尼的长周期的场地反应谱加速度 SM1 根据公式求 11.4-2 出。

11.4.3 Site Coefficients and Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameters

The MCE_R spectral response acceleration parameter for short periods (S_{MS}) and at 1 s (S_{M1}), adjusted for Site Class effects, shall be determined by Eqs. 11.4-1 and 11.4-2, respectively.

$$S_{MS} = F_a S_S \qquad (11.4\text{-}1)$$

$$S_{M1} = F_v S_1 \qquad (11.4\text{-}2)$$

where

S_S = the mapped MCE_R spectral response acceleration parameter at short periods as determined in accordance with Section 11.4.1, and

S_1 = the mapped MCE_R spectral response acceleration parameter at a period of 1 s as determined in accordance with Section 11.4.1

where site coefficients F_a and F_v are defined in Tables 11.4-1 and 11.4-2, respectively. Where the simplified design procedure of Section 12.14 is used, the value of F_a shall be determined in accordance with Section 12.14.8.1, and the values for F_v, S_{MS}, and S_{M1} need not be determined.

图 23. ASCE7-10 中考虑场地影响的场地反应谱加速度求解

短周期设计反应谱加速度 S_{DS} 根据公式 11.4-3 求出；长周期的设计反应谱加速度 S_{D1} 根据公式 11.4-4 求出。

11.4.4 Design Spectral Acceleration Parameters

Design earthquake spectral response acceleration parameter at short period, S_{DS}, and at 1 s period, S_{D1}, shall be determined from Eqs. 11.4-3 and 11.4-4, respectively. Where the alternate simplified design procedure of Section 12.14 is used, the value of S_{DS} shall be determined in accordance with Section 12.14.8.1, and the value for S_{D1} need not be determined.

$$S_{DS} = \frac{2}{3} S_{MS} \qquad (11.4\text{-}3)$$

$$S_{D1} = \frac{2}{3} S_{M1} \qquad (11.4\text{-}4)$$

图 24. ASCE7-10 中设计反应谱加速度求解公式

美标设计反应谱为“中震”弹性谱，该设计反应谱由直线上升段、水平段、曲线下降段 1 和曲线下降段 2 组成，美标设计反应谱如图 11.4-1 所示，控制参数为设计谱加速度 SD1、SDS 和转换长周期 TL。To 为 0.2 倍长周期设计反应谱值与短周期设计反应谱值比值，T_S 为长周期设计反应谱值与短周期设计反应谱值的比值，转换长周期 TL 可从 ASCE7-10 图 22-12 查得。

建筑抗震设计类 SDC 的确定，建筑抗震设计类别分为 A，B，C，D，E，F 等六类。当建筑安全等级为Ⅰ Ⅱ、III类且长周期地震动反应谱加速度 S1 大于等于 0.75 时为 E 类；当建筑安全等级为 Ⅳ长周期地震动反应谱加速度 S1 大于等于 0.75 时为 F 类;其他建筑的抗震等级根据 ASCE7-10 表 11.6-1 和表 11.6-2 确定，且按照从严原则确定抗震设计类别。

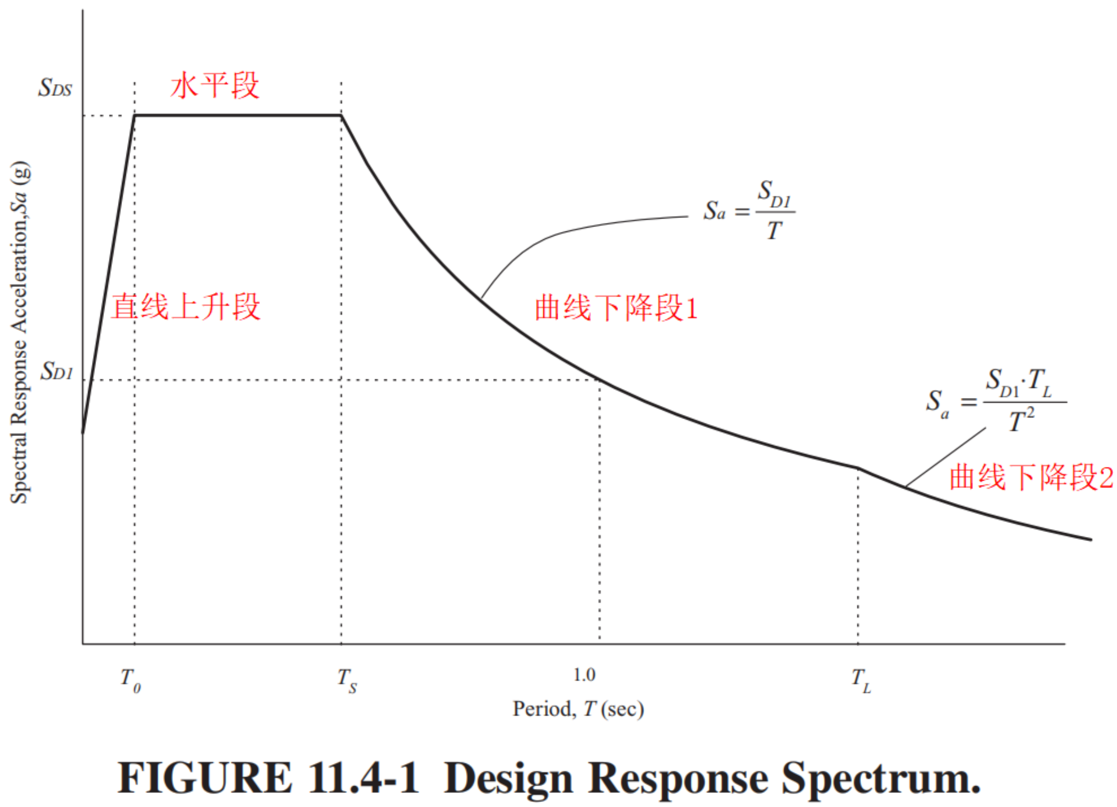

图 25.　ASCE7-10 中设计反应谱图

1. For periods less than T_0, the design spectral response acceleration, S_a, shall be taken as given by Eq. 11.4-5:

直线上升段$$S_a = S_{DS}\left(0.4 + 0.6\frac{T}{T_0}\right) \quad (11.4\text{-}5)$$

2. For periods greater than or equal to T_0 and less than or equal to T_S, the design spectral response acceleration, S_a, shall be taken equal to S_{DS}. 水平段
3. For periods greater than T_S, and less than or equal to T_L, the design spectral response acceleration, S_a, shall be taken as given by Eq. 11.4-6:

曲线下降段1 $$S_a = \frac{S_{D1}}{T} \quad (11.4\text{-}6)$$

4. For periods greater than T_L, S_a shall be taken as given by Eq. 11.4-7:

曲线下降段2 $$S_a = \frac{S_{D1}T_L}{T^2} \quad (11.4\text{-}7)$$

根据短周期反应加速度参数确定抗震设计类别

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

	Risk Category	
Value of S_{DS}	I or II or III	IV
$S_{DS} < 0.167$	A	A
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

图 26. ASCE7-10 抗震设计类别（a）

根据长周期反应加速度参数确定抗震设计类别

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

Value of S_{D1}	Risk Category	
	I or II or III	IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D

图 27. ASCE7-10 抗震设计类别（b）

根据抗震设计类别、建筑物高度和抗震体系确定反应设计参数，设计参数包含反应放大系数 R、结构超强系数Ω0、变形放大系数 Cd。R 表示延性，对地震力折减，R 越大表示延性越好，折减的地震力越大。当结构的延性越大，对结构的构造措施要求越严格；当结构的延性越小，对结构的构造措施要求越宽松。超强系数用于调整组合中地震作用的放大，仅仅用于结构局部区域的加强。变形放大系数用于将地震作用下的位移放大 Cd 倍。注意 ASCE7-10 中表 12.2-1 中结构高度 hn 为英制单位中的 feet，而不是米制单位中的米。

Table 12.2-1 Design Coefficients and Factors for Seismic Force-Resisting Systems

抗震体系 Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	响应修正系数 Response Modification Coefficient, R[a]	超强系数 Overstrength Factor, Ω_0[g]	变形放大系数 Deflection Amplification Factor, C_d[b]	高度限值 Structural System Limitations Including Structural Height, h_n (ft) 单位 Limits[c] 抗震设计类别 Seismic Design Category: B	C	D[d]	E[d]	F[e]
A. BEARING WALL SYSTEMS									
1. Special reinforced concrete shear walls[l, m]	14.2	5	2½	5	NL	NL	160	160	100
2. Ordinary reinforced concrete shear walls[l]	14.2	4	2½	4	NL	NL	NP	NP	NP
3. Detailed plain concrete shear walls[l]	14.2	2	2½	2	NL	NP	NP	NP	NP
4. Ordinary plain concrete shear walls[l]	14.2	1½	2½	1½	NL	NP	NP	NP	NP
5. Intermediate precast shear walls [l]	14.2	4	2½	4	NL	NL	40[k]	40[k]	40[k]
6. Ordinary precast shear walls[l]	14.2	3	2½	3	NL	NP	NP	NP	NP
7. Special reinforced masonry shear walls	14.4	5	2½	3½	NL	NL	160	160	100
8. Intermediate reinforced masonry shear walls	14.4	3½	2½	2¼	NL	NL	NP	NP	NP

图 28.　剪力墙抗震体系的抗震设计参数

超强系数：根据 ASCE7-10 中公式 12.4-7 可知，超强系数仅仅用于放大水平地震作用，不用于放大竖向地震作用。ASCE7-10 的 12.4.3.2 条明确了美标荷载分项系数法(LRFD)中有关超强系数放大地震作用的荷载组合。盈建科美标模块支持荷载分项系数法(LRFD)，暂不支持容许应力法（ASD）。

12.4.3.1 Horizontal Seismic Load Effect with Overstrength Factor

The horizontal seismic load effect with overstrength factor, E_{mh}, shall be determined in accordance with Eq. 12.4-7 as follows:

$$E_{mh} = \Omega_o Q_E \qquad (12.4\text{-}7)$$

where

Q_E = effects of horizontal seismic forces from V, F_{px}, or F_p as specified in Sections 12.8.1, 12.10, or 13.3.1. Where required by Section 12.5.3 or 12.5.4, such effects shall result from application of horizontal forces simultaneously in two directions at right angles to each other.

Ω_o = overstrength factor

12.4.3.2 Load Combinations with Overstrength Factor

Where the seismic load effect with overstrength factor, E_m, defined in Section 12.4.3, is combined with the effects of other loads as set forth in Chapter 2, the following seismic load combination for structures not subject to flood or atmospheric ice loads shall be used in lieu of the seismic load combinations in either Section 2.3.2 or 2.4.1:

Basic Combinations for Strength Design with Overstrength Factor (see Sections 2.3.2 and 2.2 for notation).

5. $(1.2 + 0.2S_{DS})D + \Omega_o Q_E + L + 0.2S$
7. $(0.9 - 0.2S_{DS})D + \Omega_o Q_E + 1.6H$

图 29. 有关超强系数的荷载组合

冗余度 ρ：冗余度用于将地震作用放大，用于将整个结构的地震力进行放大，超强系数仅仅用于结构局部地震力的放大。当抗震设计类别为 D、E、F 时，冗余度为 1.3（特殊情况除外，具体参见 ASCE7-10 中 13.3.4.2 节）；当抗

震设计类别为 B 或者 C 类时，冗余度系数为 1.0；位移计算或者考虑 P-Δ时，冗余度系数为 1.0。当考虑超强系数时候，冗余度系数取值为 1.0。

12.4.2.1 Horizontal Seismic Load Effect

The horizontal seismic load effect, E_h, shall be determined in accordance with Eq. 12.4-3 as follows:

$$E_h = \rho Q_E \qquad (12.4\text{-}3)$$

where

Q_E = effects of horizontal seismic forces from V or F_p. Where required by Section 12.5.3 or 12.5.4, such effects shall result from application of horizontal forces simultaneously in two directions at right angles to each other

ρ = redundancy factor, as defined in Section 12.3.4

Basic Combinations for Strength Design (see Sections 2.3.2 and 2.2 for notation).

5. $(1.2 + 0.2S_{DS})D + \rho Q_E + L + 0.2S$
6. $(0.9 - 0.2S_{DS})D + \rho Q_E + 1.6H$

图 30. 有关冗余度的荷载组合

12.3.4.1 Conditions Where Value of ρ is 1.0

The value of ρ is permitted to equal 1.0 for the following:

1. Structures assigned to Seismic Design Category B or C.

2. Drift calculation and P-delta effects.
3. Design of nonstructural components.
4. Design of nonbuilding structures that are not similar to buildings.
5. Design of collector elements, splices, and their connections for which the seismic load effects including overstrength factor of Section 12.4.3 are used.
6. Design of members or connections where the seismic load effects including overstrength factor of Section 12.4.3 are required for design.
7. Diaphragm loads determined using Eq. 12.10-1.
8. Structures with damping systems designed in accordance with Chapter 18.
9. Design of structural walls for out-of-plane forces, including their anchorage.

图 31. 冗余度取值为 1.0 的情况

注：《海外项目系列(Ⅱ)：美标模块之抗震参数篇》未完，精彩还在后面，请继续查阅。

海外项目系列（Ⅱ）：美标模块之抗震参数篇（4）

彭志丰

本篇接《海外项目系列(Ⅱ)：美标模块之抗震参数篇（1）（2）（3）》，本篇将结合沙特某工程确定美标地震中的具体参数，以便深入了解美标中地震作用的计算。本工程位于沙特地区中的吉达，项目地震设计参数检查表如表 1 。

表 1 沙特吉达某项目地震参数

XXX Project Structural Seismic Design Checklist			
City.	Jeddah, KINGDOM OF SAUDI ARABIA	Building Name	Main Building
No.	Seismic Design Step Description	Item to Provide	
1	Determine S_S & S_1 based on site coordinates	S_S=0.30g	
2		S_1=0.11g	
3	Site soil class	D	
4	Determine S_{D1}	S_{D1}=0.173067g	
5	Determine S_{DS}	S_{DS}=0.312g	
6	Determine seismic design category SDC	C	
7	Establish the building occupancy category	Ⅱ, I=1.0	
8	Fundamental period	T_a=0.46	
9	Determine T_s=S_{D1}/S_{DS}	T_s=0.55	
10	Identify types of horizontal irregularity	1a,2,3,5	
11	Identify types of vertical irregularity	N/A	
12	Confirm ELF procedure or modal response spectrum procedure	MRS	
13	Identify the proposed structural system	Intermediate reinforced concrete moment frames	
14	Determine the response modification factor	R=5.0	
15	Determine the deflection amplification factor	C_d=4.5	
16	Determine applicability of overstrength factor	Ω_0=3.0	
17	Determine redundancy factor	ρ=1.0	
18	Check if Ev is required	Y	
19	Seismic force orthogonal interaction effects considered?	Y	
20	Amplification of accidental torsional moment applicable?	Y	
21	Check 25% increase in forces of diaphragm to vertical elements?	N	

下面详细介绍美标地震参数确定流程。根据沙标 SBC301 中图 9.4.1 可查得 Ss=0.3g，S1=0.109g。

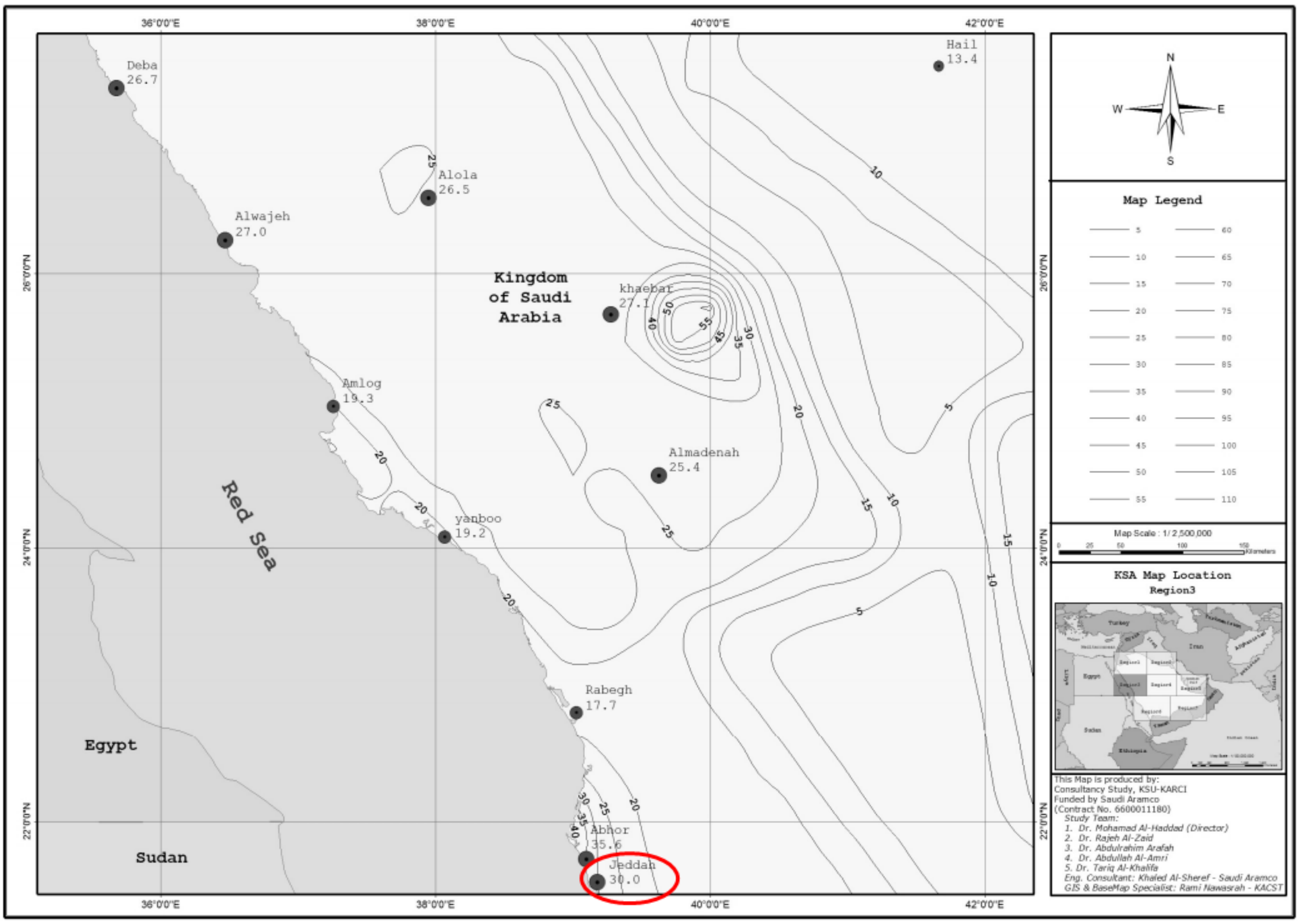

Figure 9.4.1(e): Maximum Considered Earthquake Ground Motion for the Kingdom of 0.2 SEC Spectral Response Acceleration (S_s in %g) (5 Percent of Critical Damping), Site Class B.

(Region 3)

图 32． Jeddah 地区的 Ss

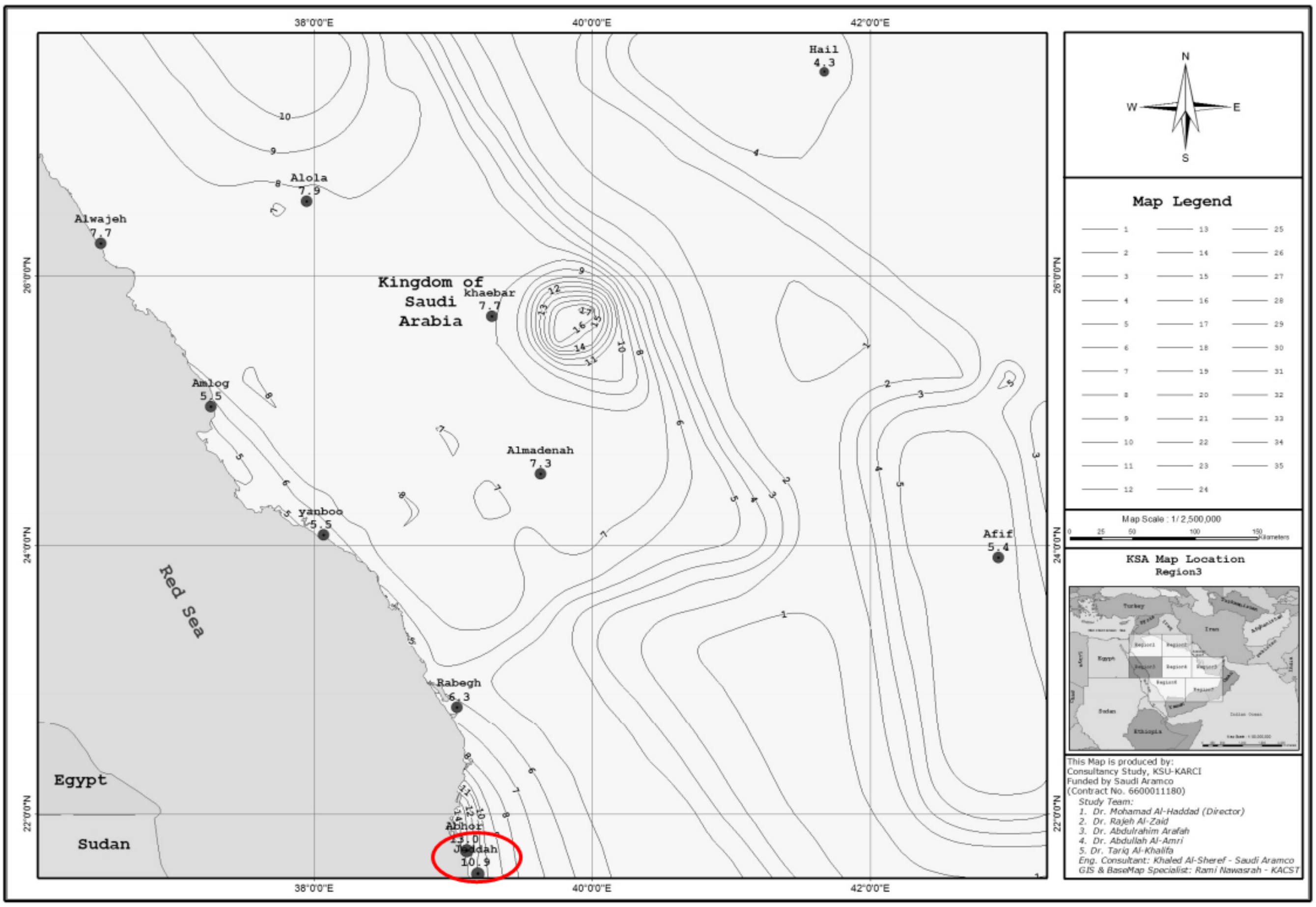

Figure 9.4.1(m): Maximum Considered Earthquake Ground Motion for the Kingdom of 1 SEC Spectral Response Acceleration (S_1 in %g) (5 Percent of Critical Damping), Site Class B.
(Region 3)

图 33. Jeddah 地区的 S1

Table 11.4-1 Site Coefficient, F_a 场地系数Fa

场地类别 Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at Short Period				
	$S_S \le 0.25$	$S_S = 0.5$	$S_S = 0.75$	$S_S = 1.0$	$S_S \ge 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_S.

Table 11.4-2 Site Coefficient, F_v 场地系数Fv

Site Class	Mapped Risk-Targeted Maximum Considered Earthquake (MCE_R) Spectral Response Acceleration Parameter at 1-s Period				
	$S_1 \le 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \ge 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See Section 11.4.7				

Note: Use straight-line interpolation for intermediate values of S_1.

图 34. ASCE7-10 场地系数 Fa 和 Fv

根据《海外项目系列(Ⅱ)：美标模块之抗震参数篇》的内容及相关公式，可计算以下有关地震参数。

$S_S = 0.30g$ (Refer to SBC301 Figure9.4.1(e))

$S_1 = 0.11g$ (Refer to SBC301 Figure9.4.1(m))

$Fa = 1.56$ (Refer to ASCE7-10 Table 11.4.1 Site Coefficient Fa)

$Fv = 2.36$ (Refer to ASCE7-10 Table 11.4.2 Site Coefficient Fv)

$S_{MS} = F_a \times S_S = 1.56 \times 0.3g = 0.468g$ (Refer to ASCE7-10 11.4-1)

$S_{M1} = F_v \times S_1 = 2.36 \times 0.11g = 0.2596g$ (Refer to ASCE7-10 11.4-2)

$S_{DS} = \frac{2}{3} S_{MS} = \frac{2}{3} F_a \times S_S = 0.312g$ (Refer to ASCE7-10 11.4-3)

$S_{M1} = \frac{2}{3} S_{M1} = \frac{2}{3} F_v \times S_1 = 0.173067g$ (Refer to ASCE7-10 11.4-4)

Seismic Design Category: B (Refer to ASCE7-10 Table 11.6.1)

Seismic Design Category: C (Refer to ASCE7-10 Table 11.6.2)

根据短周期反应加速度参数确定抗震设计类别

Table 11.6-1 Seismic Design Category Based on Short Period Response Acceleration Parameter

Value of S_{DS}	Risk Category I or II or III	Risk Category IV
$S_{DS} < 0.167$	A	A
$0.167 \le S_{DS} < 0.33$	B	C
$0.33 \le S_{DS} < 0.50$	C	D
$0.50 \le S_{DS}$	D	D

图 35.　ASCE7-10 抗震设计类别的确定（a）

根据长周期反应加速度参数确定抗震设计类别

Table 11.6-2 Seismic Design Category Based on 1-S Period Response Acceleration Parameter

Value of S_{D1}	Risk Category I or II or III	Risk Category IV
$S_{D1} < 0.067$	A	A
$0.067 \le S_{D1} < 0.133$	B	C
$0.133 \le S_{D1} < 0.20$	C	D
$0.20 \le S_{D1}$	D	D

图 36.　ASCE7-10 抗震设计类别的确定（b）

Table 12.2-1 (*Continued*)

Seismic Force-Resisting System	ASCE 7 Section Where Detailing Requirements Are Specified	反应放大系数 Response Modification Coefficient, R[a]	超强系数 Overstrength Factor, Ω_0[g]	变形放大系数 Deflection Amplification Factor, C_d[b]	Structural System Limitations Including Structural Height, h_n (ft) Limits[c] — Seismic Design Category: B	C	D[d]	E[d]	F[e]
C. MOMENT-RESISTING FRAME SYSTEMS									
1. Steel special moment frames	14.1 and 12.2.5.5	8	3	5½	NL	NL	NL	NL	NL
2. Steel special truss moment frames	14.1	7	3	5½	NL	NL	160	100	NP
3. Steel intermediate moment frames	12.2.5.7 and 14.1	4½	3	4	NL	NL	35[h]	NP[h]	NP[h]
4. Steel ordinary moment frames	12.2.5.6 and 14.1	3½	3	3	NL	NL	NP[i]	NP[i]	NP[i]
5. Special reinforced concrete moment frames[n]	12.2.5.5 and 14.2	8	3	5½	NL	NL	NL	NL	NL
6. Intermediate reinforced concrete moment frames	14.2	5	3	4½	NL	NL	NP	NP	NP
7. Ordinary reinforced concrete moment frames	14.2	3	3	2½	NL	NP	NP	NP	NP
8. Steel and concrete composite special moment frames	12.2.5.5 and 14.3	8	3	5½	NL	NL	NL	NL	NL

图 37. 抗弯框架结构体系的地震参数

Table 12.8-2 Values of Approximate Period Parameters C_t and x

Structure Type	C_t	x
Moment-resisting frame systems in which the frames resist 100% of the required seismic force and are not enclosed or adjoined by components that are more rigid and will prevent the frames from deflecting where subjected to seismic forces:		
Steel moment-resisting frames	0.028 (0.0724)[a]	0.8
Concrete moment-resisting frames	0.016 (0.0466)[a]	0.9
Steel eccentrically braced frames in accordance with Table 12.2-1 lines B1 or D1	0.03 (0.0731)[a]	0.75
Steel buckling-restrained braced frames	0.03 (0.0731)[a]	0.75
All other structural systems	0.02 (0.0488)[a]	0.75

[a]Metric equivalents are shown in parentheses.

图 38. 估算结构周期的有关参数

根据从严原则，该建筑的抗震设计类别为 C 类（Refer to ASCE7-10 11.6）。根据表 ASCE 7-10 表 12.2-1 中抗弯框架结构体系中，建筑抗震设计 C 类不受高度限制，该建筑可选择中等延性钢筋混凝土框架或者特殊延性钢筋混凝土框架（NL 表示不受限制，NP 表示不允许）。在结构体系既可以采用中等延性，又可以采用特殊延性时候，建议采用中等延性，因为中等延性钢筋混凝土框架不

需要验算节点核心区，而特殊延性钢筋混凝土框架需要验算节点核心区。中等延性钢筋混凝土框架体系相应的抗震参数为$R = 5$，$\Omega = 3$，$C_d = 4.5$（Refer to ASCE7-10 Table 12.2-1），$\rho = 1.0$（因为抗震设计类别为C类，冗余度可取1.0）。因为建筑的使用安全类别为II，所以地震作用重要性系数为1.0(Refer to ASCE7-10 Table 1.5-2)。因为该结构的抗侧力体系两个方向不正交，所以该建筑需要考虑双向地震作用。$C_t = 0.0466$，$x = 0.9$(Refer to ASCE7-10 Table 12.8-2)（注意盈建科美标模块建筑物高度单位为米制单位）。

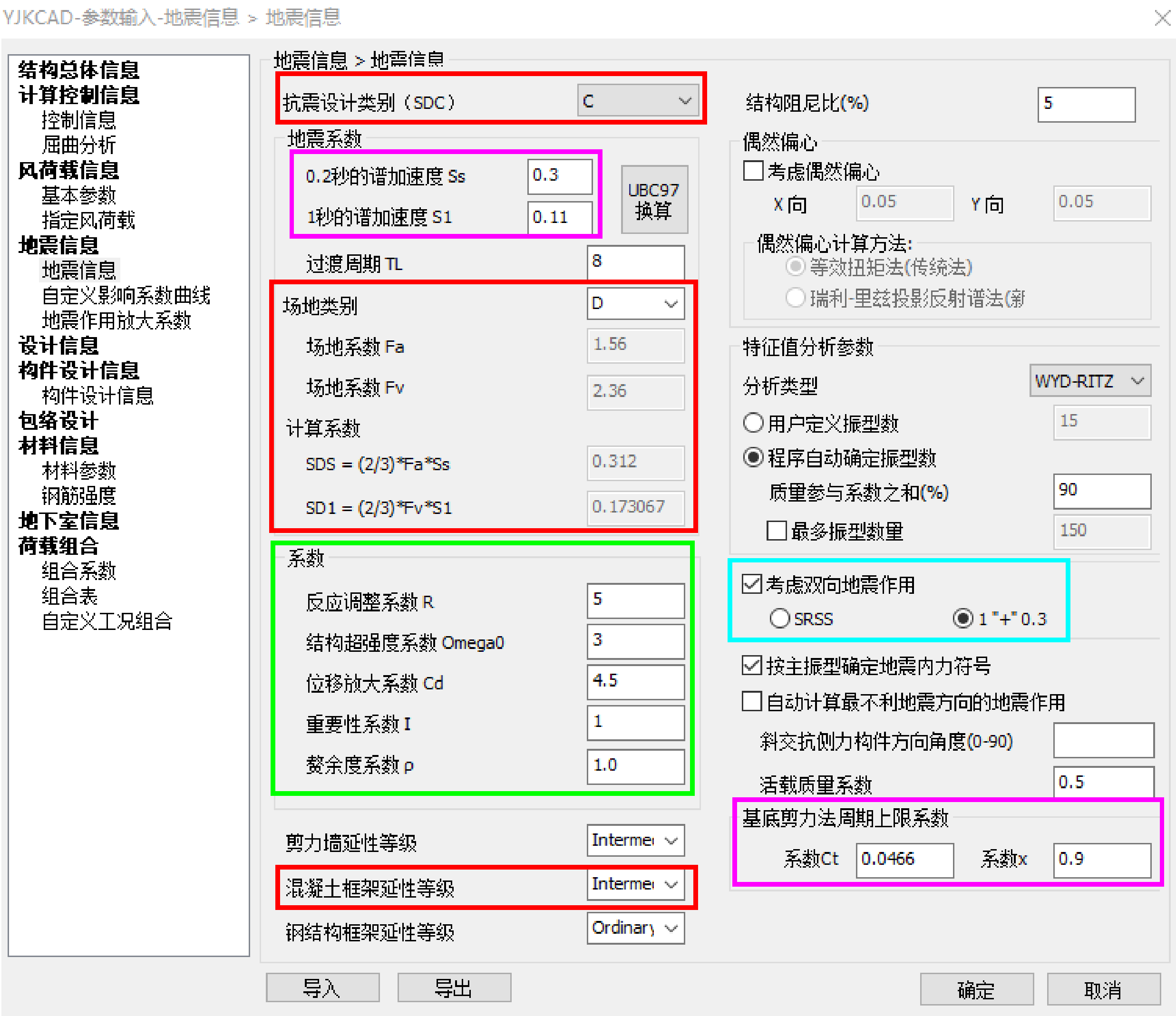

图 39. 沙特吉达项目在盈建科美标模块地震参数的设置

小注：《海外项目系列(II)：美标模块之抗震参数篇》全部介绍完毕，在此十分感谢刘建永老师老师的指导与帮助。