Title: **Comparative Study of Zhongnan Center Under Earthquake and Wind**

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Comparative Study of Zhongnan Center Under Earthquake and Wind
中南中心抗震及抗风设计的分析和对比

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A comparative study of seismic action and wind loading was conducted for the structural design of the Suzhou Zhongnan Center. The analysis parameters, design methodology and structural responses for both seismic action and wind loading were addressed and compared. The design parameters for the design of wind loading, such as the along-wind parameters, cross-wind parameters, damping ratio under different wind loading levels, and dynamic properties, are discussed. The design methodology, reference return period, base reactions for seismic action and wind loading were finally compared for the Suzhou Zhongnan Center project. The design parameters of the structural design for seismic action, wind loading and the comparative study results can be used as references for the structural design of other super- and megatall buildings.

本文对苏州中南中心大厦抗震及抗风设计的参数取值、设计方法和结构响应等进行了对比分析。首先对抗震设计参数，如设计反应谱、阻尼比和周期折减系数的取值进行了讨论。其次阐述了抗风设计参数，包括顺风向荷载参数、横风向荷载参数、阻尼比和动力特性等。论文最后对中南中心大厦抗震及抗风设计方法、荷载年限和基底反力等进行了对比分析。相关的参数取值和分析结果可供超高层建筑结构设计参考。

Introduction to the Structure of the Suzhou Zhongnan Center

The megaframe core wall structure is the main lateral resisting structural system of the Suzhou Zhongnan Center. The megaframe consists of eight supercolumns, four corner columns and nine belt trusses, which are located at the mechanical floors. The shape of the reinforced concrete core wall is square with a size of 34.1 m × 34.1 m. Four corners of the core wall are removed beginning at Zone 3 and proceeding upwards. Five outrigger truss levels are set up between the core wall and the megaframe, which are located in the mechanical floors of zones 2, 4, 6, 7 and 8. The structural system is shown in Figure 3.42.

Due to its megatall height and long structural period, the Suzhou Zhongnan Center is very sensitive to long-period ground motion. The lack of authentic long-period seismic records has meant that accepted design response spectra for long-period seismic motion have not been well-developed. Seismic action parameters of response spectra for period ranges longer than 6 seconds are not provided in Chinese code for the seismic design of buildings. The spectrum values of period range longer than 6 seconds in Shanghai's seismic design code are simply interpolated based on the values specified in the national Chinese code for period ranges below 6 seconds. For very important buildings, such as the Suzhou Zhongnan Center, it is required that both the site-specific spectrum and the code specified-design spectrum be investigated for the seismic design.

Located at the leading edge of the Yangtze River Delta, Suzhou has a typical subtropical marine monsoon climate. The typhoon season runs from the end of August to early September. The impact of typhoons should be considered in high-rise building design in Suzhou. With its height and large slenderness ratio, Suzhou Zhongnan Center is sensitive to both static and dynamic effects of wind loading. Due to its megatall height, wind loading is one of the controlling factors of the tower's structural design. Studies were thoroughly conducted to reveal the impact of the building profile on wind loading and the wind-induced building vibration at the building top. Design parameters for wind loading were obtained through careful comparison between code-based calculations and wind-tunnel tests.

引言

苏州中南中心的抗侧力体系运用了巨型框架-核心筒结构。巨型框架由8根巨柱、4根角柱以及位于设备层的9道环带桁架组成。钢筋混凝土核心筒的尺寸为34.1米×34.1米。核心筒从3区开始将角部削去。在巨型框架与核心筒之间设置了5道伸臂桁架，分别位于2区、4区和6~8区的设备层。图3.42为中南中心的结构体系。

由于超高的高度以及较长的自振周期，中南中心对长周期地震动是非常敏感的。目前，长周期地震动实测记录较少，国内外对长周期设计反应谱的研究尚不充分。国家建筑抗震设计规范的反应谱对周期超过6秒的情况未给出地震作用取值。上海市的建筑抗震设计规程中的反应谱周期范围虽然取为10秒，但6秒以上部分是根据国家抗震设计规范中的设计反应谱进行外推后获得的。因此，对于非常重要的建筑物，例如中南中心，进行抗震设计时，需要综合安评报告和规范规定，确定合理的地震作用参数。

苏州位于长江三角洲的前缘，属于典型的亚热带海洋性季风气候，8月底到9月上旬是台风的多发季节，易受台风的影响。所以台风的影响必须在中南中心的结构设计中予以考虑。由于高度较高和长细比较大，中南中心大厦对风荷载的静力和动力

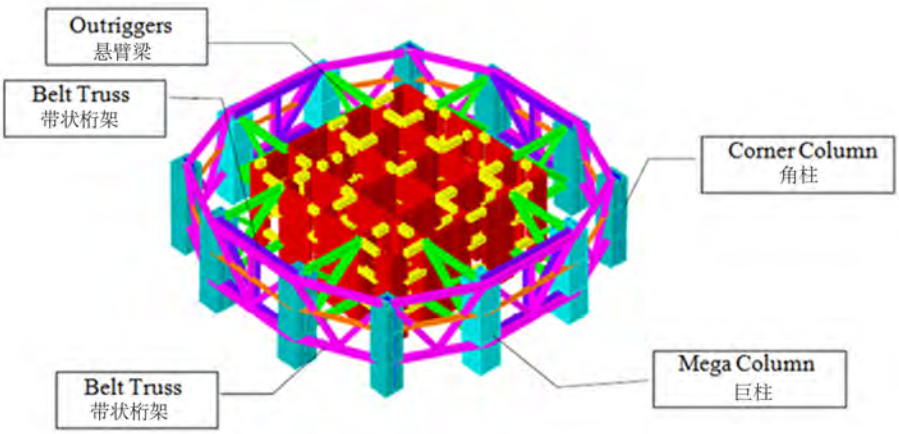

Figure 3.42. Structural system (Source: Guangjing Sha)
图3.42. 结构体系 (来源: 沙广璟)

The building seismic action and wind load are closely related to structural periods. The comparison between seismic and wind excitation spectra for multi-story and high-rise buildings with structural periods between 1 second and 10 seconds is shown in Figure 3.43. It can be seen that the dominant frequency of wind gusts is relatively low and lies in the frequency range of high-rise and supertall buildings. Commonly only the lowest mode of high-rise building will be excited by wind gusts, except for supertall buildings, which may consider the contribution of high modes. In contrast, the dominant excitation energy of earthquakes is in the frequency range of low-rise buildings or the higher modes of tall buildings, and therefore a large number of modes must generally be considered.

A comparative study was conducted for the structural design of Suzhou Zhongnan Center for seismic action and wind loading. The analysis parameters, design methodology and structural responses for both seismic action and wind loading were addressed and compared.

作用均较为敏感。由于其超高的高度，中南中心大厦的风荷载成为结构设计的主要控制因素之一。为了了解建筑形态对风荷载的影响，获得建筑顶部风致振动信息，进行了大量的风工程研究。中南中心大厦的抗风设计综合规范和风洞试验研究的结果确定了合理的风荷载参数。

地震作用及风荷载的取值均与结构周期密切相关。图3.43为当结构周期为1秒到10秒的高层和超高层建筑的地震及风反应谱对比。从中可知，风的主导频率较低且处于高层以及超高层建筑的频率范围内。通常超高层结构会考虑高阶振型的贡献，而对于高层建筑只有低阶振型会受到风的激励。相比之下，地震主要激励能量发生在低层建筑的频率范围或者高层建筑的高阶振型中，因此必须考虑大量的振型。

本文对地震以及风荷载下的中南中心结构设计做出对比，阐述并对比了地震以及风荷载下的分析参数、设计方法以及结构响应。

抗震设计参数

目前中南中心的抗震设计中，地震作用取值是按设计基准期50年确定。三个地震设计等级以各个设计基准期定义，分别为多遇地震、设防地震和罕遇地震。根据中国抗震规范对于设计基准期的定义，多遇地震为50年63%的超越概率，设防地震为10%的超越概率，罕遇地震为2~3%的超越概率。表3.22为不同设计基准下多遇地震、设防地震和罕遇地震的回归期。中南中心抗震设计以50年设计基准期进行设计。

常遇地震最大影响系数应按安评报告进行取值，而设计反应谱形状应按规范反应谱进行计算。对于设防地震以及罕遇地震，除了特征周期应根据安评报告，各地震参数都可以按规范取值。多遇地震、设防地震和罕遇地震的阻尼比分别取4.0%、4.0%和5.0%。而周期折减系数应分别取0.85、0.95和1.00。图3.44为中南中心塔楼的多遇地震反应谱。

型钢混凝土组合结构技术规程 (2002) 建议的结构阻尼比为4.0%。该阻尼比取值规定并未考虑荷载及作用类型，结构响应水平和结构高度等因素的影响。根据日本大量高层建筑现场实测的结果，Satake和Suda (2003) 发现随着建筑高度的增加，一阶振型阻尼比不断减小。需要注意的是，目前大部分的阻尼比现场实测均在脉动荷载条件下获得，对于比较高的荷载输入水平，如50年一遇的风荷载、多遇地震、设防地震和罕遇地震，

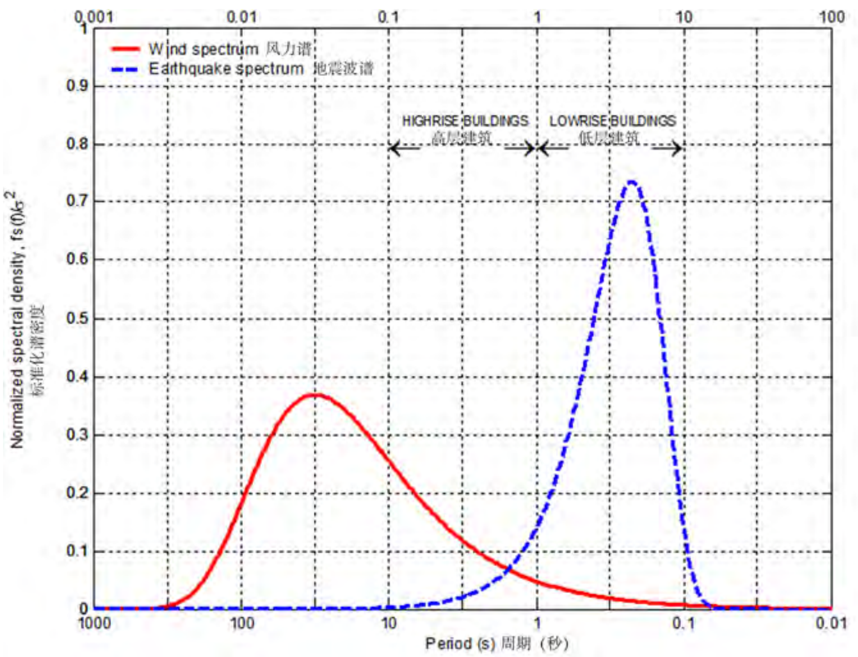

Figure 3.43. Comparison between seismic action and wind loading spectra for multi-story and high-rise buildings (Source: Guangjing Sha)
图3.43. 地震与风荷载下高层与超高层建筑反应谱对比 (来源: 沙广璟)

Design reference period (years) 设计参考周期 (年)	Design earthquake level 设计地震水平		
	Frequent earthquake 频繁地震	Moderate earthquake 中度地震	Rare earthquake 罕见地震
	(POE of 63.2%)	(POE of 10%)	(POE of 2% or 3%)
50	50	475	2475 (POE of 2%)
100	100	950	3283 (POE of 3%)

Table 3.22. Return periods for the design earthquake levels (Source: Guangjing Sha)
表3.22. 不同地震等级回归期 (来源: 沙广璟)

Seismic Design Parameters

In Chinese code, the design reference period is commonly taken as 50 years for structural design. Three design earthquake levels, "frequent," "moderate" and "rare", are defined for each design reference period. Under the specific design reference period set by the Chinese code, the probability of exceedance (POE) is 63.2% for the frequent earthquake, 10% for the moderate earthquake and 2 to 3% for the rare earthquake. The return periods for the frequent earthquake, moderate earthquake and rare earthquake under different design reference periods are listed in Table 3.22. A design reference period of 50 years is applied for the seismic design of the Suzhou Zhongnan Center.

由于结构响应水平较高，结构内在耗能能力增加，会使得阻尼比有所增加。中南中心大厦最终采用的不同地震作用水平下的阻尼比取值见表3.23。在不同阻尼比取值下对中南中心大厦地震作用基底反力进行了分析。分析结果表明，与3.5%阻尼比相比，4.0%阻尼比时的结构基底反力降低约4%，5.0%阻尼比时的结构基底反力降低约10%。

根据吕西林 (2001) 和李国强 (2000) 之前的研究，上海地区几座超高层建筑的实验得出的自振周期与计算所得的结果几乎一致。金茂大厦 (见表3.24) 的真实周期是在脉动荷载 (风波动以及小范围地面运动) 下进行测量的。在常遇地震以及设防地震荷载下，若考虑结构响应的增大以及结构的非线性，周期会进一步变长。

分析表明，在多遇地震作用下，与不考虑周期折减系数相比，当周期折减系数取0.9时，基底剪力和基底倾覆力矩增加约12%左右，周期折减系数对基底反力的影响较大。中南中心抗震分析中采用的周期折减系数取值见表3.25。

抗风设计参数

结构抗风设计通常假定结构在风荷载作用下处于弹性状态。在过去关于风灾的调查中，很少发现有风致结构破坏的例子。中国规范规定在刚度设计和强度设计中采取同样回归期水平 (50年或100年) 的风荷载。对舒适度设计则采用较小回归期水平 (10年) 的风荷载。然而在中国超高层建筑结构设计实践中，对刚度设计和强度设计实际采用不同回归期水平的风荷载。

目前在中南心大厦的结构设计中，强度设计采用了100年一遇的风荷载，相应的阻尼比采用3%。刚度设计则采用了50年一遇的风荷载，相应的阻尼比采用3%。舒适度验算考虑台风影响，采用1年一遇的风荷载，阻尼比取为1.0%。

根据中国高层结构设计规范，中南中心大厦体型系数可取为1.4，阻尼比为2%，属C类地貌。同济大学风洞实验室和中国建筑科

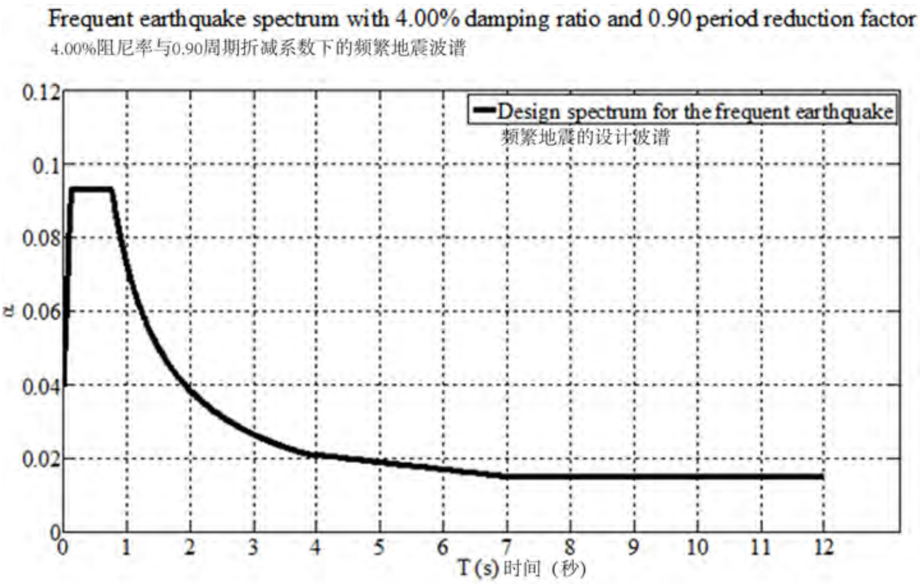

Figure 3.44. Design spectrum for the frequent earthquake of the Suzhou Zhongnan Center (Source: Guangjing Sha)
图3.44. 中南中心小震设计反应谱 (来源: 沙广璟)

Earthquake level 地震等级	Frequent earthquake 频繁地震	Moderate earthquake 中级地震	Rare earthquake 罕见地震
Damping ratio 阻尼率	4%	4%	5%

Table 3.23. The damping ratio of Suzhou Zhongnan Center (Source: Guangjing Sha)
表3.23. 中南中心阻尼比 (来源: 沙广璟)

For frequent earthquakes, the maximum value will be applied in design with the site-specific results. The shape of the design response spectrum can be equal to the code-based design spectrum. For the moderate and rare earthquakes, the code-based earthquake parameters can be applied, except for the characteristic period, which is governs the site-specific results. The damping ratios for the frequent, moderate and rare earthquakes are chosen as 4.0%, 4.0% and 5.0%. The corresponding period reduction factors are 0.85, 0.95 and 1.00. The Suzhou Zhongnan Center design spectra for the frequent earthquakes are shown in Figure 3.44.

According to the "Technical specification for concrete structures in tall buildings" (2002), the suggested damping ratio for composite structures is 4.0%. The influences of load types, structural response levels and structure height on the damping ratio value are not considered. According to a large number of site testing results in Japan, Satake and Suda (2003) determined that the damping ratio of the primary vibration decreases with the increase of the building height. It is worth pointing out that the damping ratio tests are mainly obtained from site measurements under ambient vibrations. For actions and loads of high amplitude, such as the 50-year return period wind load, frequent earthquake, moderate earthquake and rare earthquake, the damping ratio will increase with the increase of the energy dissipating, due to large structural responses. The design damping ratios of the Suzhou Zhongnan Center under different seismic levels are listed in Table 3.23. The base reaction results under different

学研究院对中南中心大厦进行风洞试验模拟塔楼所受的风荷载。表3.26分别为中国建筑科学研究院的风洞试验风荷载以及中国规范风荷载下塔楼基底反应的计算结果。

抗震及抗风设计方法对比

对于特别重要的建筑物，如中南中心大厦，通常在设计中考虑提高设计的安全性。增大地震作用通常采用提高抗震设计使用年限的方式，加强结构的抗震措施包括加强抗震构造措施以及内力放大系数。而提高结构的抗风安全性的方式通常采用提高风荷载水平的方式。与结构抗震设计方法不同的是，在进行结构抗风设计时，通常考虑结构处于弹性状态。由于目前的抗风设计方法不考虑结构在风荷载作用下的构件及结构延性要求，因此在抗风设计中未考虑相关措施，如抗震设计中的构造措施和内力调整。对于超高层建筑而言，由于横风向荷载效应显著，而且往往是控制性荷载，不作抗震设计的超高层建筑由于构件及结构整体的延性性能较差，在极端风荷载作用下可能出现灾难性的破坏。

中南中心大厦在进行强度设计时采用100年一遇的风荷载。在确定抗震设计使用年限时，通过地震作用与风荷载比较分析，

Mode 模式	Calculated values 计算值	Tested values[3] 测试值	Ratio 比值	Tested value [4] 测试值	Ratio 比值
1	6.523s	6.410s	0.983	6.301s	0.966
2	1.677s	1.653s	0.986	1.606s	0.958
3	0.774s	0.787s	1.017	0.754s	0.974

Table 3.24. Comparison between the tested and calculated periods of Jinmao tower (Source: Guangjing Sha)
表3.24. 金茂大厦计算与实测周期对比 (来源: 沙广璟)

Earthquake level 地震等级	Frequent earthquake 频繁地震	Moderate earthquake 中级地震	Rare earthquake 罕见地震
Period reduction factor 周期折减系数	0.85	0.95	1

Table 3.25. Period reduction factor (Source: Guangjing Sha)
表3.25. 周期折减系数 (来源: 沙广璟)

	Overall base shear(kN) 总基底剪力		Overturning moment(kN.m) 倾翻力矩	
Wind tunnel test (100 year) 风洞测试 (100年)	69,523	100%	26,712,412	100%
Chinese code 中国规范	73,123	105%	25,837,361	97%

Table 3.26. Base reaction comparison obtained from wind tunnel test and Chinese code (Source: Guangjing Sha)
表3.26. 风洞试验与规范风荷载下基地反力对比 (来源: 沙广璟)

damping ratios show that, compared with the base reactions obtained under damping ratio of 3.5%, the base reactions will be reduced by about 5% and 12%, if the damping ratios are set as 4% and 5% respectively.

Based on the previous study of Lv Xiling (2001) and Li Guoqiang (2000), the test periods of several towers in Shanghai are almost the same as the calculated periods. For example, the real periods of Jin Mao Tower (see Table 3.24) were measured under ambient vibration (wind fluctuation or small-amplitude ground motion). In frequent and moderate earthquakes, considering the increase of the structure response and the nonlinearity of the structure, the periods may become longer.

The analysis shows that the period reduction factor can affect the base reactions. Compared to the case with no period reduction, the base shear and overturning moment under frequent earthquakes will increase by about 12% with a period reduction factor of 0.9. The period reduction factors used in the Suzhou Zhongnan Center were listed in Table 3.25.

Wind Load Design Parameters

The buildings are generally assumed to be in an elastic state in the structural design for wind loading. Few wind-induced structure damage cases have been recorded in past storm damage investigations. Chinese code suggests that the same return period (50 years or 100 years) could be applied for the wind loads for both strength and stiffness design, while shorter return periods could be applied for human comfort design. In China, wind loads with different return periods are commonly applied for the strength and stiffness design of supertall buildings.

In the structural design of the Suzhou Zhongnan Center project, according to the specialists' suggestions, the 100-year return period wind load is applied for the strength design, and the corresponding damping ratio is 3%. The 50-year return period wind load is applied for the stiffness design, and the corresponding damping ratio is also 3%. The one-year return period wind load, reflecting the probable annual occurrence of a typhoon, is applied for the human comfort design, and the related damping ratio is 1.0%.

设计中考虑基底倾覆力矩的风荷载控制原则，采用50年设计基准期的地震作用取值依据。结构抗震安全性的提高主要通过提高重要构件抗震等级的方式来实现。由于超高层建筑结构的风荷载及其效应随高度迅速增加，成为结构设计中诸多方面的的主要控制因素，在确定地震作用水平时，应当考虑地震作用与风荷载的相对关系。表3.27列出了中南中心大厦在风荷载与多遇地震作用下基底反力的比较。由表中可知，风荷载作用下的基底反力均高于地震作用下的基底反力。

根据全国超限高层建筑抗震设防审查专家委员会的工作会议文件"超限高层建筑结构抗震性能目标的建议"，高度超过B级的超限高层建筑，应按"中震不屈服"或"中震弹性"的要求对关键构件进行复核。对于中南中心大厦，按"中震不屈服"的要求对关键构件进行复核。表7列出了超高层建筑在风荷载作用下的基底反力与中震地震作用下的基底反力比较。由表3.28可见，在中震地震作用下，结构的基底反力均低于100年一遇风荷载作用下的基底剪力。

值得注意的是，考虑结构构件承载力抗震调整系数，构件的抗震承载力设计值通常高于不考虑地震作用时构件的承载力。在

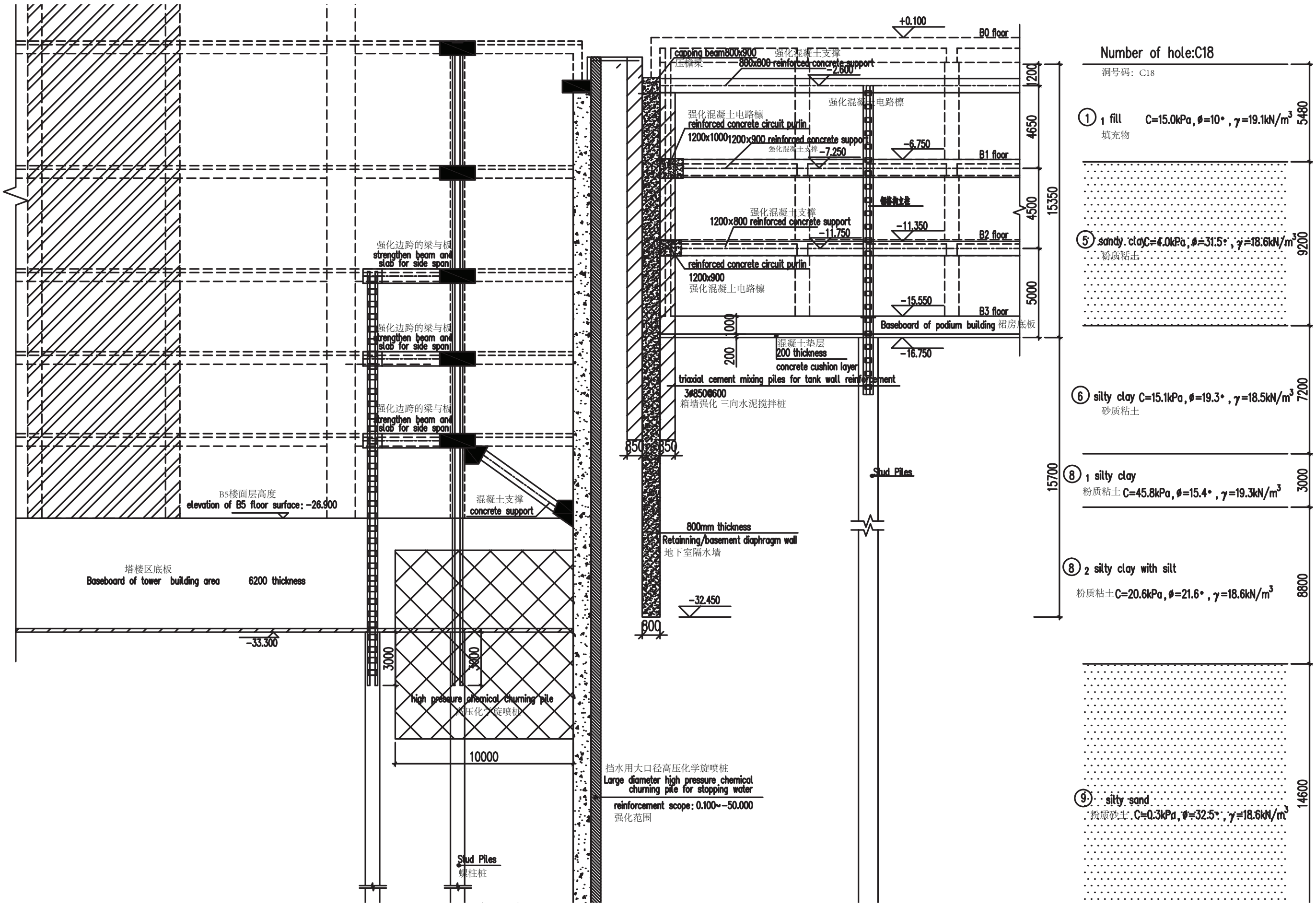

Figure 3.45. Detail, sectional view of envelope/basement diaphragm wall in the area with five underground floors (Source: Review plan of Suzhou Zhongnan Center project foundation pit supporting design)
图3.45. 细部详图 地下五层区"两墙合一"地下连续墙剖面图 (来源: 苏州中南中心项目地基基坑支撑设计审阅平面)

Based on the Chinese code for the design of high-rise structures, the parameters used in the wind load calculations of the Suzhou Zhongnan Center are as follows: The shape factor is set as 1.4, the damping ratio is set as 3% and the site exposure is type C. The Tongji University wind tunnel laboratory and China Academy of Building Research predicted the wind load of Suzhou Zhongnan Center with wind tunnel tests. Table 3.26 lists the overall base responses obtained from the wind tunnel test at the China Academy of Building Research compared to Chinese code.

Design Methodology Comparison Between Seismic Action and Wind Loading

For very important buildings, such as the Suzhou Zhongnan Center, a relatively high structural safety level is commonly specified.. The increase of seismic action can be reached by using earthquake action of longer return periods, and the increase of the seismic measures can be achieved by using high-level earthquake resisting measures and high internal force-amplification factors. However, there is only one way to improve the structural wind safety, and that is to increase the wind load applied in the structural design. Unlike seismic design, the structural design for wind loading assumes that the structure will remain elastic under wind load. The ductility of the whole structure and structural members are not required in current structural design practice for counteracting wind loading. Other measures to improve structural seismic safety, such as earthquake-resisting structural measures and adjustment of internal force-amplification factors, are also not considered in the structural design for wind loading. The cross wind is significant for a megatall building, and governs many aspects of the structural design. As the ductility of structure and members is poor, a catastrophic failure mode may occur for non-seismically-designed megatall buildings under extreme wind loading conditions.

	Base shear (kN) 基底剪力		Overturning moment (kN.m) 倾翻力矩	
Wind tunnel test (100 year) 风洞测试 (100年)	69,523	100%	26,712,412	100%
Frequent earthquake 常见地震	73,516	106%	18,969,555	71%

Table 3.27. Base reaction comparison between wind load and frequent earthquake (Source: Guangjing Sha)
表3.27. 风荷载与小震基地反力对比 (来源: 沙广璟)

	Base shear (kN) 基底剪力		Overturning moment (kN.m) 倾翻力矩	
Wind tunnel test (100 year) 风洞测试 (100年)	69,523	100%	26,712,412	100%
Moderate earthquake 中等地震	185,252	266%	50,973,509	191%

Table 3.28. Base reaction comparison between wind load and moderate earthquake (Source: Guangjing Sha)
表3.28. 风荷载与中震基地反力对比 (来源: 沙广璟)

The 100-year return period wind load is applied for the strength design of Suzhou Zhongnan Center project. Detailed comparative studies were conducted to obtain the optimized design working life of the Suzhou Zhongnan Center. By applying the wind control rule, a design reference period of 50 years was applied. The seismic safety of the structure was satisfied by improving the seismic safety level of critical structural members. Due to the rapid increase of wind loads and responses with building height, wind loading becomes a dominant governing factor for many aspects of the structural design for tall buildings. The relative relationship between seismic action and wind loading should be considered in the determining the earthquake level applied in the seismic design. Table 3.27 compares the base reaction of Suzhou Zhongnan Center under wind loading and frequent earthquakes. As shown in the table, the values of base reactions under wind loading are higher than the values under frequent earthquakes.

According to the guideline document "Suggestions on the seismic performance objectives for tall buildings beyond the scope of design codes" issued by the National Seismic Review Committee for Tall Buildings, for supertall buildings with structural height exceeding the B-level, the critical structural members are required to remain non-yielding or elastic under a moderate earthquake, which applies to the Suzhou Zhongnan Center. Table 3.28 compares the base reactions of the Suzhou Zhongnan Center obtained under wind load and moderate earthquake. Base reactions under moderate earthquakes are generally less than those under wind loads of a 100-year return period.

It should be noted that, by considering seismic adjustment coefficient of the structural member bearing capacity, the design values of the bearing capacity for seismically designed structural members may be higher than those of non-seismically-designed structural members. Thus, for those cases in which the seismic responses are higher than the wind responses, the design of certain structural members, such as the pile foundation, may also be controlled by the wind loading.

中震结构响应略高于风荷载作用下结构响应时，超高层建筑的构件设计 (如桩基础设计) 也会出现由风荷载控制的情况。

结论

本节讨论了中南中心大厦地震作用及风荷载参数取值，并就抗震设计与抗风设计的主要内容进行了对比分析。主要结论如下:

1. 在长周期段，常遇地震最大影响系数应按安评报告进行取值，而设计反应谱形状应按规范反应谱进行计算。对于设防地震以及罕遇地震，除了特征周期应根据安评报告，各地震参数都可以按规范取值。
2. 抗震分析的阻尼比取值，应考虑荷载的类型、结构响应水平和结构高度综合确定。对于较大的水平荷载输入，结构响应水平也相应较高，结构内在耗能能力增加，会使得阻尼比有所增加。
3. 超高层建筑的顺风向及横风向荷载效应显著。合理的风荷载参数可以结合规范取值和风洞试验研究获

Conclusions

In this chapter, the analysis parameters and structural design methodologies for seismic action and wind loading are addressed and compared. The following conclusions can be reached:

1. In the long-period range, the maximum value will be applied in design based on site-specific results. The shape of the design response spectrum can be set as the code-based design spectrum. For moderate and rare earthquakes, the code-based earthquake parameters can be applied, except for the characteristic period, which is determined by site-specific results.
2. The damping ratio applied for seismic analysis is related to the type of loads, structural response, height of the structure, etc. Large-amplitude actions and loads will induce high-level structural responses, which will in turn increase the energy-dissipating capacity and the damping ratio of the structure.
3. The along- and cross-wind loads and effects are significant for supertall buildings. Proper design parameters for wind loading can be obtained through careful comparison between code calculations and wind tunnel tests. Based on the investigation of damping ratios obtained from in-situ testing of tall and supertall buildings, low damping ratios could be employed in the structural design for wind loading.
4. The measures to improve seismic safety include the increase of seismic action and seismic measures, while the only available method for improving structural safety under wind is the increase of wind loading. A catastrophic failure mode may occur for non-seismically-designed supertall buildings under extreme wind loading conditions.
5. Although the structural responses due to wind loading are commonly higher than those due to frequent earthquakes, the structural responses due to seismic action may prevail if high seismic performance objectives were selected for important supertall buildings.

得。对较小的风荷载作用情况，其响应计算采用的结构阻尼比应考虑有所降低，具体数值可以参考同类超高层建筑的实测结果。

4. 提高结构抗震安全性的方式包括提高地震作用和加强抗震措施，而提高结构抗风安全性的方法通常仅通过提高风荷载水平实现。不作抗震设计的超高层建筑由于构件及结构整体的延性性能较差，在极端风荷载作用下可能出现灾难性的破坏。
5. 对于超高层建筑，风荷载结构响应通常高于多遇地震下的结构响应。但是对于重要超高层建筑，采用中震弹性设计的情况下，设防烈度地震下的结构响应会高于风荷载作用下的结构响应。

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