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Suzhou Zhongnan Center: Rising Above Engineering Challenges
苏州中南中心大厦: 攻克工程难题

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沈东，本科毕业于上海交通大学，并在美国檀香山大学获得工商管理硕士学位。他在房地产领域有多年的领导经验。从2012年起至今，沈东一直担任苏州中南中心经理层的常务副总。

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Abstract

Suzhou is only 30 minutes by train from Shanghai, but has a rich history and identity all its own, soon to be augmented by the Zhongnan Tower, a 700-meter structure that could become the world's tallest building outside the Middle East. The so-called "Venice of China" is moving into the 21st century, with the Zhongnan Tower anchoring a large urban development project, Suzhou Industrial Park.

Keywords: Suzhou Zhongnan Tower, Suzhou Zhongnan Center, Megatall, 7-Star Hotel, Suzhou Industrial Park

摘要

从苏州乘火车仅需30分钟便可抵达上海，但苏州这座城市拥有丰富的历史历史和独特的自我特征，而即将竣工的中南中心将进一步强化其特征，大楼具有700m高的结构，有可能成为中东地区以外世界上最高的建筑。中南中心的建设奠定了一个大型城市开发项目——苏州工业园区的发展，被称为"中国威尼斯"的苏州正在大步迈向二十一世纪。

关键词: 苏州中南中心，苏州中南中心，巨型结构，七星级酒店，苏州工业园

Introduction

The Suzhou Zhongnan Center is a building of virtually unprecedented scale and scope, even within China, the world's top market for tall buildings. Its extreme height, difficult soil conditions, and widely varied program require an advanced level of thinking beyond typical tall-building planning, design and construction. This paper establishes some of the base conditions and demonstrates how performance-based design approach was used to overcome challenges that building code and standard operating practice do not address. As such, Suzhou Zhongnan Center can serve not only as an awe-inspiring icon, but as an instruction book for future generations of tall builders.

Architecture

Site and Background

A confluence of factors makes Suzhou an ideal location for a megatall building. Though it is only 30 minutes from Shanghai by train, Suzhou is an independent city with an identity all its own. Its population is more than 10 million, and its canals and gardens make it a top tourism destination. Further, its industrial parks and new technology districts are transforming Suzhou into a world-class city.

引言

即使在中国这个全球最大的高层建筑市场，苏州中南中心的规模之大和影响范围之广几乎是前所未有的。其罕见的高度，严峻的土壤条件，以及广泛多样的项目程序需要超越普通高层建筑规划、设计和施工的固有逻辑，而进行超前的思考。本文设立了一些基本条件，并演示了如何采用基于性能的设计方法来克服建筑规范和标准没有解决的挑战。因此，苏州中南中心不仅能成为一个令人惊叹的模范建筑，而且能成为一本新一代高层建筑的指导册。

架构

基地和项目背景

一系列因素的汇合使苏州成为巨型高层建筑的理想建设地点。虽然从苏州乘火车仅需30分钟便可抵达上海，但苏州这座城市拥有丰富的历史历史和独特的自我特征。城市人口超过1000万，城中美丽的运河和古典园林使其成为一个顶级的旅游圣地。此外，工业园区和新技术区正在使苏州转变成一个世界级城市。

苏州中南中心建成后高729m高， 137层，总楼面面积375000m²。我们团队的目标是使它在周边街区环境中不仅成为一个标志性的结构，同时作为金融模式成功的方面也成为一份以绩效为基础的房地产资产。

The Suzhou Zhongnan Center will be a 729-meter tall building, containing 375,000 square meters of gross floor area across 137 floors. The object of our team is to make it not only an iconic structure, but a performance-based real estate asset, both in the sense of the broader community and in terms of its success as a financial model.

The project site is located just west of the Jinji Lake central business district (CBD), on 16,573 square meters of land adjacent to Century Plaza and Suzhou Center. Entrances along the podium edge correspond to the major program elements: the main entrance provides public access to the retail, hotel and office functions. An additional office drop-off lies along the south edge, while the north edge is reserved for the seven-star hotel and the apartment drop-off is along the west side.

Design Concept

The design of the tower is meant to reinforce local Jiangnan culture, referencing its pagodas and local artisinal springs, with the remainder of its geometry defined by its diversified program functions (see Figure 1). The podium lifts up its canopy in a welcoming "flying lantern" gesture, creating a public plaza at ground level. The transition from public to private occurs as one ascends.

The basement contains retail and food & beverage vendors, with connections to the adjacent mall and Metro station. Transportation and physical plant are accommodated in other B-level floors, of which there are five. Above ground there are nine zones, divided thus: Zone 1 supports retail, restaurant, entertainment and ballroom functions, up to level 7. Zone 2 includes offices and the entrance to the observatory elevator. Zone 3 contains service offices, while Zones 4 through 7 are devoted to luxury apartment. Near the top in zones 8 and 9, a seven-star hotel will also be one of the world's highest. At the very top is the observatory.

Façade

The design emphasis of the façade is on purity and simplicity. Constructed of a modular curtain wall, fully prefabricated in a factory, the glassy façade features an external vertical aluminum fin with darker glass at corners, framed by metal panels. The consistent look is broken only by the louver systems at mechanical floors. The podium attaches to the tower via a translucent façade, lit by fritted glass to the outside.

Performance-Based Design in Structural Engineering

The Zhongnan Center tower is notable for overcoming many structural design challenges, which are enumerated in greater detail in the Zhongnan Center Project Room Book. However, some highlights are worthy of mention here.

It was clear from the outset that basic building code would not provide sufficient enough guidance for a building of this height and scope. Therefore, the team undertook performance-based design to enhance and tailor the special design elements to match stakeholder objectives and ensure safe, economical construction. The performance-based design (PBD) approach provides a unified approach to designing buildings and delivers a predictable and satisfactory performance. It can also can lower cost while improving areas such as wind-induced serviceability design, life-cycle cost, material weight, and story drift reduction.

Wind Design

The PBD approach to wind design considers factors such as human comfort, building deflection, member strength and structural stability. The effects of wind on performance were measured on three levels at the Zhongnan Center, for return periods of five, 10 and 50 years.

Figure 1. Suzhou Jinji Lake CBD
图1 苏州金鸡湖CBD

该项目选址位于金鸡湖中央商务区 (CBD) 的西侧，基地面积16573 m²，毗邻世纪广场和苏州中心。沿着裙房的出入口对应主要项目元素: 为市民提供接到达零售，酒店和办公功能的主入口。另外一个办公室落客区位于地基南缘，而北缘保留给七星级酒店，公寓落客区沿西侧设置。

设计理念

中南中心的设计是为了加强当地的江南文化，引用其佛塔和当地繁荣的工艺文化，购物中心，用它通过其多元化的项目功能定义建筑几何体的其他部分。(见图1) 裙楼部分升起门厅雨棚，以一个欢迎的"飞灯笼"姿态，在地面上创造一个公共广场。当使用者乘电梯上升时可以体会到从公共到私人的过渡。

建筑地下空间功能包括零售和食品饮料商店，并连接到相邻的商场和地铁站。运输和物理设备被安置在其他五个地下层。地上有九个功能区，其划分如下: 从一层到七层1区为零售，餐饮，娱乐，宴会厅的功能; 2区包括办公室和入口处的天景观台电梯; 3区包含服务办公，4区到7区为豪华公寓。一个七星级酒店位在8区和9区顶部附近，也将是世界上最高的酒店之一。在最高层是景观台。

建筑立面

建筑立面设计重点是纯粹而简单。建筑立面构建了一个模块化的幕墙，由一家工厂完全预，通在边角使用深色玻璃并用金属板作框，玻璃状的建筑立面突出了外部垂直铝翅片。一致的外观仅在机械层由百叶系统打破。建筑附属的裙楼通过一个半透明立面同主楼相连，使用烧结玻璃作为外立面材料。

结构工程的性能优化设计

中南中心引人注目的是其克服了许多结构设计的挑战，对此的详细概述收录在中南中心项目记录书里。然而，在此一些亮点仍旧值得一提。

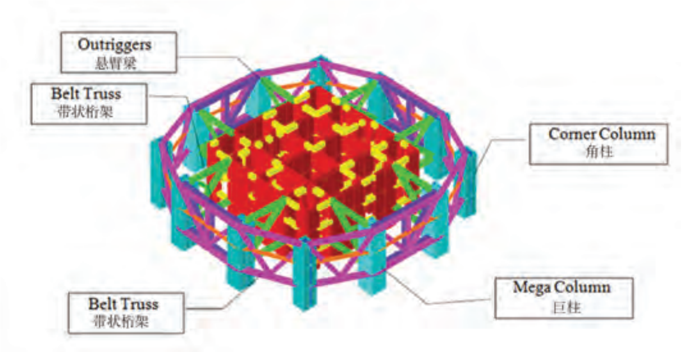

Figure 2. Structural system
图2. 结构体系

As a slender building with an aspect ratio of 8.7, the maximum wind accelerations for the top hotel room (598 meters) and the top apartment (463 meters) were determined to be too high for occupant comfort. The use of tuned mass and tuned sloshing dampers (TMDs, TSDs) at the tower crown and viscous dampers at the connection between outriggers and megacolumns, reduced these accelerations by 30%.

Seismic Design

Chinese code contains goals for performance states and expected damage at each level. Overall structural design is concerned with strength and stiffness criteria such as story drift and shear-weight ratio, whereas component design performance is measured by internal force and load capacity. Both were tested extensively in the design process of Zhongnan Center. The average maximum story drift of the building was determined to be within the code limit of 1/100 in case of a severe earthquake, which has a 50-year return period.

Seismic vs Wind Design Considerations

Due to the rapid increase of wind loads and responses with the building height, wind loading becomes a dominant governing factor for many aspects of the structural design for tall buildings, but for those in high seismic zones, such as Zhongnan Center, both conditions must be accommodated. A catastrophic failure mode may occur for non-seismically designed supertall buildings under extreme wind loading environment. Though seismic and wind reinforcements are generally complementary, the Zhongnan Center's final design was a careful compromise between the two objectives.

Critical Optimal Design Points

Rafts

Zhongnan Center used a raft foundation because the soil beneath was too silty and sandy, and contained too much water, to create a conventional bearing surface. The raft foundation was 6.3 meters thick, which was actually reduced from the original design thickness of 7 meters, after optimization exercises were undertaken.

Pile Foundation

With megatalls, interaction among superstructure, pile caps and soil is emphasized (this is normally ignored in conventional design). The length and dimension of piles can be adjusted to seek the optimal condition. The raft is supported by 719 bored piles of 1.1 meters' diameter and 110 meters length, with a bearing capacity of between 1,300 and 1,600 tons each. Extensive testing was undertaken to determine the correct dimensions of the piles.

Core and Columns

This building uses a 16-grid core, with eight megacolumns and four corner columns supporting as its main vertical load paths. High-zone

Figure 3. Geometry of the Zhongnan tower
图3. 中南中心立面图

从一开始，建筑超常的规模和高度便决定了建筑基本规范便无法为项目提供足够的指导。因此，设计团队进行了性能化设计，并定制专门的设计元素，以实现所有利益相关的目标，并确保安全和建设的经济性。基于性能的设计 (PBD) 方法提供了一种统一的方法来设计建筑，并提供一个可预测的，且令人满意的性能表现。同时可以降低成本，比如在这些方面进行性能改善: 风致可维护性设计，减少生命周期成本，控制建筑材料重量和层间位移。

抗风设计

这种抗风设计的PBD方法考虑的多个因素，如人体舒适度，建筑偏转，组件强度和结构稳定性。在中南中心项目中，在三个层面上在测量了风对性能的影响，以为5年，10至50年为重现期。作为一个形状修长的大楼，具有8.7的纵横比，顶层酒店房间 (598m高度) 和顶部公寓 (463米) 最大风速加速度被确定为太高了，而会是使用者的舒适性收到影响。在塔冠的调谐质量和调整晃动阻尼器 (TMDS，TSDS)，外伸桁架与超级柱子之间的连接采用粘滞阻尼器，降低了最大风速加速度的30%。

抗震设计

中国抗震规范包含对性能状态的目标，以及不同地震级别预期的损害。整体结构设计关注强度和刚度标准，如层间位移和剪切重量比，而组件设计性能是根据内力和承载力计算。这两者都在中南中心的设计过程中进行了广泛的测试。此外，在50年一遇的严

shear walls controlled by stiffness or shear strength under earthquakes, while the intersection of shear walls was embedded with steel to increase ductility and reduce potential tension stress in earthquakes. Core design criteria typically state that story drift is kept within 1/500, and that vibration periods are under 9.5 seconds. To achieve these goals, five basic layouts of the core and floorplates were studied. The selected scheme was chosen for superior lateral stiffness, best cost, and greatest flexibility for floor layouts.

Podium

The eight-story, 67-meter podium is separated from the tower by a seismic joint. It has large column spacing, which was required for retail and ballroom areas, where the maximum clear span is to be 41 meters. In some cases, megatrusses are hidden in ballroom partitions.

Outrigger Truss

These are typically installed in mechanical floors to reduce story drift for 300-meter-plus buildings. They connect the frame columns and core tubes, and have the advantage of enhancing overall lateral stiffness (see Figures 2 and 3). Their disadvantages are in the large member dimensions, long construction period, and large steel consumption. Thus, they must be optimized in order to form an efficient and cost-effective way to cut deformation and drift while preserving usable floor space.

For the Zhongnan Center project, the team used a sensitivity vector method (SVM) algorithm to obtain the favorable quantities and placements of outriggers under period and story drifts constraints, minimizing materials consumption. Member sizes were optimized using in-house developed structural optimization software. The original Zhongnan Center scheme had outriggers in each MEP zone, which kept vibration period suitably low but story drift at a subpar level. At least one outrigger was eliminated after testing three configurations, ultimately saving 2,032 tons of steel over the original design.

Belt Truss

This structural element acts as a transfer member for all secondary floor systems by engaging perimeter columns in resistance to lateral loads, decreasing pulling forces in megacolumns during wind or earthquakes. A U-type single belt truss and outrigger have nearly the same linear stiffness, about 3 to 4 times that of the megacolumn. Once again, the team used in-house developed structural optimization software to select the double-truss format over three other potential shapes for the Suzhou Zhongnan Center project. This included torsion stiffness, internal force and eccentricity analysis. The eight two-story belt trusses work in concert with the columns to form the perimeter megaframe, which also works with outriggers at upper zones to meet code-specified story drift ratios.

Floor Slab

Composite steel-concrete floors slabs are commonly used in buildings of more than 250 meters' height. As long as the thickness of the floor slab meets the minimum requirements, the composite slabs can meet the fire-resistance performance requirements of 1.5 hours under heat without fire protection. Two different types of composite floor were used at Zhongnan Center – a flat-profiled deck system, at a thickness of 125 millimeters on ordinary floors, and a steel-bar truss deck system of 200 millimeters' thickness on mechanical and refuge floors that needed more strength and lateral support. The composite floor system is also beneficial because it eliminates the need for formwork, and presents lighter weight for seismic loading.

重地震条件下，大楼平均最大层间位移被控制在为1/100以下。

地震与风的设计考虑

由于风荷载和反应随着建筑物高度上升而迅速增加，风荷载成为高层建筑结构设计很多方面的主导因素，但对于那些位于高烈度地震带的建筑，如中南中心，两个条件均必须加以考虑。极端风载环境下，非抗震设计的超高层建筑可能出现灾难性的失效情况。虽然抗震和风力加固措施一般都是互补的，在中南中心的最终设计方案则是在两个目标之间进行谨慎的折衷。

关键的优化设计要点

筏式设计

因为下方土壤下过于粉质和砂质，并且包含了太多的水，中南中心采用了筏式基础来创建一个传统的支撑面。筏板基础为6.3m厚，这实际上是7m的原设计通过优化设计将厚度减小的结果。

桩基础设计

随着超级高层建筑，上层建筑之间的相互作用，桩帽和土壤在设计中被强调 (这通常是传统设计中忽略的部分) 。桩的长度和尺寸可以调整，以寻求最佳的状态。木筏是由直径1.1m长度110m的719个钻孔桩支撑，以个桩支持1,300至1600吨的荷载。大量的测试是为了确定桩的正确尺寸。

核心筒和柱列设计

这栋建筑采用16网格核心筒，八个超级柱和四个角柱支撑作为其主要的垂直载荷路径。高层区域剪力墙由地震作用下的刚度或剪切强度控制，而剪力墙嵌入钢板以增加延展性，减少地震潜在的应力。核心筒设计标准通常规定，层间位移角保持在1/500之内，且振动周期在9.5s以内。为了实现这些目标，对其核心筒的五个基本布局和楼板进行了研究。所选择的方案具有最优的的侧向刚度，以及最佳的成本，并为地板布局提供最大的灵活性。

裙房设计

八层，67米长的讲台被从塔由地震联合分离。它有大柱间距，这是必需的零售和舞厅地区，那里的最大净跨度为41米。在某些情况下，megatrusses隐藏在舞厅分区。

伸臂桁架设计

伸臂桁架通常安装在机械层，以减少高度超过300m的建筑物的层间位移。它们连接框架柱和核心筒，并具有增强整体横向刚度的优点 (见图2和图3) 。其缺点为组件尺寸过大，建设周期长，钢材消耗量大。因此，它们必须进行优化，以形成一个有效并具有成本效益的方式来减少变形和侧移，并同时保证可使用面积。

对于中南中心项目，设计团队使用了灵敏度向量法 (SVM) 算法，以获得支架的最优数量和周期内桁架的位移，以最大限度地减少材料的消耗。室内组件尺寸通过结构优化软件进行优化。原中南中心在每个MEP区设计有伸臂，从而适当降低振动周期，但是层间位移则不符合要求。通过测试三种组合方案，至少有一个支腿可以被取消，最终达到节省2032吨钢材的目的。

带形桁架设计

这种结构元素充当所有二级地板系统的转换构建，联系周边柱列抵抗抗侧向载荷，减少风或地震时的拉力。一个U型单带桁架和伸臂具有几乎相同的线性刚度，其刚度约为超级柱列的3⊠4倍。再次，开发团队对室内组件尺寸通过结构优化软件，为苏州中南中心项目选择了其他三个可能形状的双桁架格式。这包括扭转刚度，内力和偏心分析。八个双层带形桁架与柱列协同工作形成的周边巨型框架，这也与在上部区域的外伸桁架协同，以使其满足规范规定的层间位移比。

楼板设计

钢 - 混凝土组合楼板通常用于250m以上高度的建筑物。只要楼板的厚度满足最低要求，在不做任何其他防火措施的情况下，组

The floor system is often up to 30% of a total tall building cost, and can be up to 50% of its weight. A minor change in the floor system has big effect on height, weight and cost of building overall. Taking a 60-story building as an example, each floor height increase of 30 centimeters will make the structural height increase 18 meters. At Zhongnan Center, the cost of open-trough profiled deck composition slabs is 7% less than the alternatives, and the weight of these slabs is 3% less than comparable alternatives.

Tower Crown

In addition to providing an aesthetically appealing terminus for the tower's tapering form, the tower crown also plays a critical role in the building's seismic and wind performance. It contains a 750-ton tuned mass damper and a 600-ton tuned sloshing damper (TSD) that also doubles as tank space for fire water.

Geotechnical and Subsurface Engineering

Geotechnical Conditions

Environmental conditions for the Zhongnan Center site are quite the opposite of its ideal cultural and economical conditions. The soil consists of sand and clay down to 120 meters below grade; bedrock is beyond practical reach. The water table was only 4.6 to 0.5 meters below grade, while the top of the mat foundation was no higher than 27 meters below grade. The tower would have sufficient weight to overcome buoyancy issues, but the podium needed to be engineered to counter uplift forces from groundwater. The overall foundation pit covers 26,260 square meters, and it is bound by pipes, aquifers, subways, and adjoining foundation excavation, occurring simultaneously, had to be protected.

Excavation Engineering Design

The foundation pit contains a five-floor and two-floor basement area adjacent to each other. The two-level underground area began excavation after the five-floor area was completed. The retaining walls were used as bracing and waterproofing structures during excavation; the 1,200-millimeter diaphragm walls were used as the permanent outside basement walls. The lateral support system consists of structural beams in the five-floor underground area, in place of lateral struts. The two-floor area uses diagonal and knee braces.

Protecting a Neighboring Excavation

Some special protection measures were required in order to protect the excavation of the Suzhou Center next door. The earth beneath the ground floor of the Suzhou Zhongnan Center could be excavated until the underground second floor of Suzhou Center's B-4 zone was completed and met the design strength required. Finite element analysis modeling (FEM) determined that the maximum lateral displacements of diaphragm walls between the two projects would be between 16.6 and 27.8 millimeters, and bottom plate heave would be limited to 5.4 to 6.9 millimeters, depending on location. The diaphragm wall between the two pits offered strong lateral stiffness and good integrity, and was constructed with a trench-cutting machine, helping to reduce the disturbance to the deep silt layer, those reducing the impact on the Suzhou Center.

Protecting the Metro Tunnel

Additional precautions were taken when constructing near the metro tunnel. Cement piles were sunk at each side of diaphragm wall to pre-reinforce the groove wall, so it did not collapse on the metro tunnel. To effectively control deformation of the foundation pit retaining structure and guarantee the safety of the subway tunnel, steel

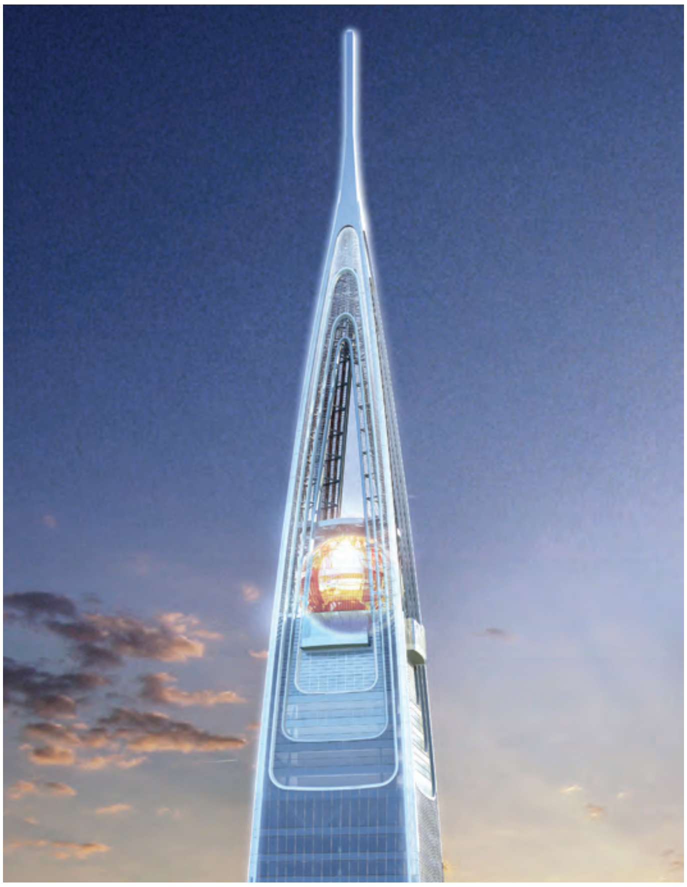

Figure 4. Tower crown rendering (Source: Gensler)
图4. 塔冠渲染图 (出自: Gensler)

合楼板可满足1.5小时的耐火性能要求。两种不同类型的复合地板在中南中心中使用——一台异型楼板系统，在普通楼层厚度为125毫米，在机械和避难层厚度为200毫米并使用钢筋桁架楼板系统，系统需要更多的强度和侧向支撑。复合楼板系统也是有利的，因为它消除了对模板的需要，并且呈现更轻的重量以抵抗地震载荷。

地板系统通常占高层建筑总成本的30%，并且可以是建筑总重量的50%。在地板系统中的微小变化对身高，体重和整体建设成本大的影响。以一个60层的大楼为例，30厘米每层高度增加将使结构高度增长18米。在中南中心，开放型槽异型甲板涂料板的成本比其它的少7%，而这些砖的重量比同类的替代品少3%。

塔冠

除了为塔的锥形形式提供了一个美观总站，塔冠也发挥了建筑物的抗震和抗风性能至关重要的作用。它包含一个750吨重的调谐质量阻尼器和一个600吨重的调整晃动阻尼器 (TSD) 也兼作消防水箱的空间。

岩土和地下工程

岩土工程条件

中南中心现场环境条件是其理想的文化和经济条件完全相反面。深至120m的土壤是沙子和粘土，基岩超出了使用范围。地下水位低于地下4.6m至0.5m，而筏板基础的顶部是不高于27米。该塔将有足够的重量来克服浮力的问题，但裙楼需要进行设计以克服地下水托力。整体基坑占地面积为26260平方米，它必将被同时出现管道，含水层，地铁和毗邻的基础开挖约束，并且必须受到保护。

基坑工程设计

基坑包含彼此相邻的一个五层和两层地下室区域。这两个层的地下

Figure 5. Site access diagram (Source: Gensler)
图5. 场地出入口图 (出自: Gensler)

supports were inserted to counter any axial forces. These were fitted with real-time monitoring devices. The maximum lateral displacement of the tunnel was between 3.07 and 3.90 millimeters, while uplift was kept to 1.31 millimeters.

Pile Foundations Loading Test

On supertall buildings in China, it is typical to use concrete-filled steel pipe piles, as was done at Jin Mao and Shanghai World Financial Center. But these piles perform poorly in deep, thick sand, and typically have a bearing capacity of 10,000 kN, whereas the bearing capacity at Zhongnan Center needed to be more than 15,000 kN per pile.

Bored pile formation techniques have improved since the early 2000s, so this is now a favorable approach. There has been little experience with constructing bored piles with bearing capacities such as was required to support the Suzhou Zhongnan Center. There are 13 layers of soil from 0 to 218 meters below grade, and the sandy, silty soil above 90 meters' depth was insufficient to bear piles. The 13th layer of soil, types 1 and 2, was determined to be sufficiently solid to serve as the bearing point, but this meant that an unusually deep and large bored pile would be necessary.

A static load test of piles with diameter of 1,100 mm showed that when a pile with 75 meters' effective length is supported on the 13-2 fine sand layer, the ultimate bearing capacity is more than 36,000 kN. When the pile with 65 meters' effective length is founded in the 13-1 silty sand layer, the ultimate bearing capacity is about 27,000 kN. Thus, all the bored piles were sufficient to support the Zhongnan Center comfortably.

MEP Design

The Zhongnan Center team also made intensive investments in the electromechanical and plumbing design of the building, in support of maximum safety and reliability, a high level of service, and attaining green certifications. As with the structural scheme, performance-based design (PBD) was again deployed.

室区域在五两层的地下室挖掘完成之后开始。开挖过程中挡土墙被用作支撑和防水结构;1200毫米的地下连续墙被用作永久外部地下室墙壁。侧向支撑系统包括在五层的地下区域的结构梁，代替横向支柱的。两层地下室区域采用对角线角撑。

保护邻近开挖策略

保护邻近施工的苏州中心，需要进行挖掘一些特殊的保护措施。苏州中南中心地面层下方的泥土可以在苏州中心的B-4区的地下二层挖掘完成时开始，并满足所需的设计强度。有限元分析建模 (FEM) 确定的两个项目之间的地下连续墙的最大侧向位移在16.6和27.8毫米之间，以及底板起伏将被限制在5.4到6.9毫米范围内，起伏大小视乎地点而变化。两个坑之间的隔墙提供了强大的侧向刚度和良好的整体性，并用沟槽切割机修建，有助于降低深淤泥层的干扰，这些都减少了本项目对苏州中心的影响。

保护地铁隧道策略

附近的地铁隧道施工时额外采取预防措施。沟壁两边水泥桩下沉以对地下连续墙进行预加固，所以也在地铁隧道处坍塌。为了有效地控制基坑支护结构变形，保证地铁隧道安全，钢支撑被插入以应对任何轴向力。这些都装上的实时监测装置。隧道的最大侧向位移在3.07到3.90毫米之间，而隆起保持1.31毫米的大小。

桩基荷载试验

在中国的超高层建筑，通常使用混凝土填充钢管桩，金茂和上海环球金融中心便是如此。但是，这些桩在深厚的沙层上表现不佳，通常只有10000 kN的承载能力，而中南中心需要的承载能力为每桩超过15000kN。

自21世纪初，钻孔灌注桩成形技术提高了，所以这种做法现在十分流行。目前已有的建设钻孔桩其承能力达到能够支持苏州中南中心的程度，其经验十分缺乏。地基有地下0m至218m以下的13层的土壤，另外地下90深度以内的沙质，淤泥质土不足以承受桩荷载。土壤中的第13层，1型和2，被确定为足够稳固以作为承载点，但是这意味着一个罕见深度和巨大的钻孔灌注桩是必要的。

1100毫米直径的桩静载试验结果表明，桩有效长度为75m通过13-2细砂层支撑，其极限承载力超过36,000kN。桩有效长度为65米通过13-1粉砂层通过，其极限承载力大约为27,000 kN。因此，所有钻孔桩足以支持整个中南中心的荷载。

MEP设计

中南中心团队也在建筑的机电和管道的设计方面进行了大量的资金投入，以达到最大的安全性和可靠性，高等级的服务水平，并实现绿色认证。与结构方案一起，再次部署性能化设计 (PBD) 。

消防及生命安全

工程师们采取了大量的主动和被动措施以确保消防安全。积极的措施包括前述的，基于塔冠的重力消防水箱/540立方米水调谐阻尼器晃动，在MEP楼层的压破消防水箱，在地下室的一个630立方米的消防水箱。暖通空调进气口和排气口分开设置，燃气泄漏探测器位于塔的供应管道处。应急照明电源系统连接到备用发电机，它可以提供长达三个小时连续供电。

高服务技术

中南中心最先进的方法并没有停止体制创新。整个电子系统由智能系统设计控制，包括通过直接数字控制 (DDC) 的一个楼宇管理系统 (BMS) 和MEP监测，可以在发生网络故障时独立运作。

集成的安全系统，包括数字监控，门禁控制，以及对重要区域的安全警报。每个功能区都有一个独立的安全系统。

Fire and Life Safety

The engineers undertook numerous active and passive measures to assure fire safety. Active measures included the aforementioned crown-based gravity fire service tank / tuned slosh damper with 540 cubic meters of water, pressure-break fire services tanks at MEP floors, and a 630 cubic-meter fire services tank in the basement. HVAC intakes and exhausts are separated, and gas leak detectors are located in the tower supply ducts. The emergency lighting power supply system is connected to generator backup, which can offer a continuous supply for up to three hours.

High-Service Technology

The state-of-the-art approach to Zhongnan Center did not stop at structural innovation. The entire electronic system is governed by intelligent systems design, consisting of a building management system (BMS) and MEP monitoring via direct digital control (DDC), which can operate independently in case of network malfunction.

Integrated security systems include digital surveillance, access control, and security alarms for critical areas. Each functional area has an independent security system.

The tower's electronic infrastructure is exceptionally robust. An emergency broadcast alarm system, keyed to fire compartments in public areas, plays background music during normal operations. A fiber backbone is provided to offices and luxury apartments, while hotel rooms have additional room control units for blinds, lighting, and heating/cooling. Internet protocol (IP)-based networks support the CCTV system, Power over Ethernet (PoE) switches, Category 6 fiber backbone, video management server, and digital storage. The low-voltage security alarm system includes event logging, security control room interface with the CCTV system.

Sustainability

The project's sustainable objectives include China Green Building Evaluation Standard 3-Star and USGBC LEED Gold. To achieve the desired level of sustainable performance and certification, significant demand reduction targets have been set. The annual cooling and heating load should be decreased by 3% compared with current Chinese code, while energy use by the MEP system should be decreased by 20%, and operational cost should be reduced by 16% compared with ASHRAE 90.1-2007.

The MEP system is aligned to the building's overall sustainability goals. As such, two high-efficiency energy centers act to reduce energy loss through transmission and heat exchange of chilled water through the tower's height. This also has the effect of lowering pipe working pressure and increasing reliability. The high-zone center serves the hotel, while the low-zone center serves the podium, retail and office spaces. The hotel, office and podium have separate chilled water plant rooms. Waste heat from the Suzhou Industrial Zone is recycled into direct-supply steam throughout the building.

Zhongnan Center stores ice for handling peak cooling loads in mid-summer and balancing day / night electricity demand. The stored ice can handle about 30% of the building's peak cooling load, and is mainly used for lower-level offices and the podium

The podium roof is at least 50% green, reducing heat island and storm runoff effects. Approximately 1,500 square meters of roof is covered with photovoltaics, which can generate 190 kW, or more than 250,000 kWh per annum.

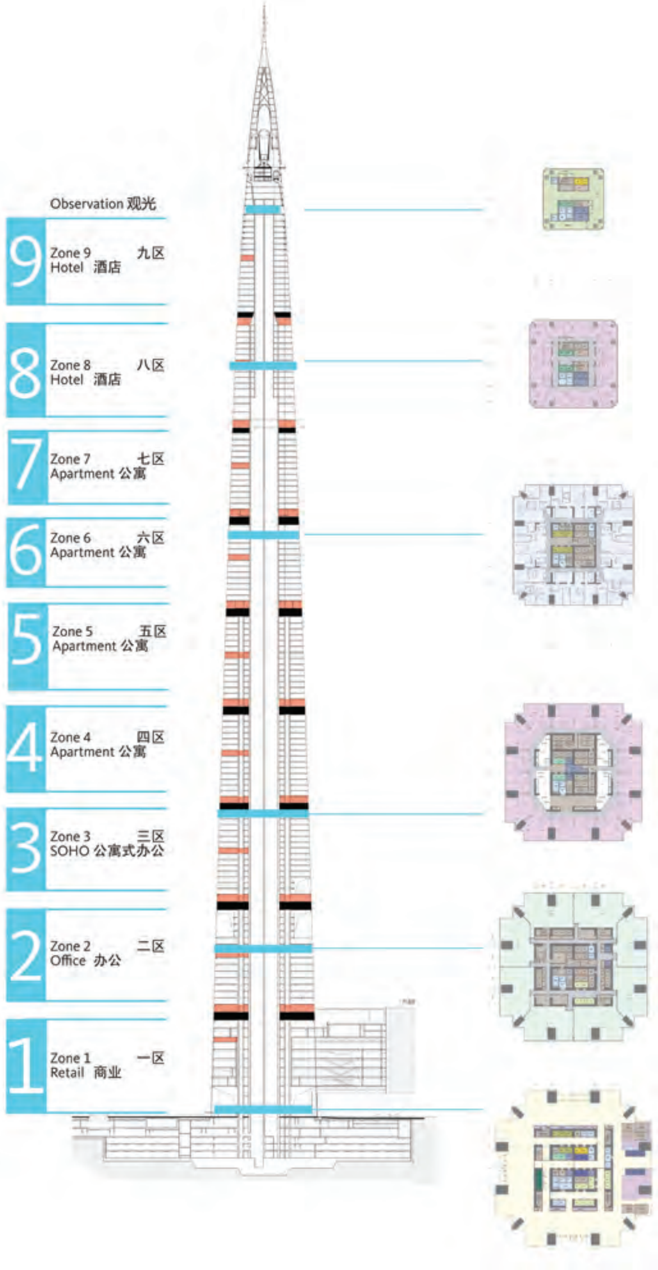

Figure 6. Diverse Vertical Community (Source: Gensler)
图6. 多样化的垂直社区 (出自: Gensler)

建筑的电子基础设施非常强大。紧急广播报警系统键入火车厢的公共区域，在正常操作期间播放背景音乐。光纤骨干网提供给写字楼和豪华公寓，而酒店客房内设有额外的单元控制百叶窗，照明以及加热/冷却设备。以互联网协议 (IP) 为基础的网络支持闭路电视监控 (CCTV) 系统，以太网供电 (PoE) 的交换机，6类光纤骨干网，视频管理服务器，以及数字存储。低电压安全报警系统包含事件日志记录，安全控制室接口和闭路电视监控 (CCTV) 系统。

可持续性

该项目的可持续发展目标，包括达到三星级中国绿色建筑评价标准和美国绿色建筑委员会LEED金级认证。为了实现可持续性能以及认证所需的水平，显著减少需求的目标已经确定。与目前中国规范相比，每年制冷和制热负荷应减少3%，而由MEP系统的能源使用应减少20%，并与ASHRAE90.1-2007相比运营成本要降低16%。

MEP系统与建筑的整体可持续发展目标相一致。因此，两个高效率的能源中心通过减少冷冻水传输的能量损失，并减少整个建筑

Vertical Transportation – Normal Service and Evacuation Design

As the Suzhou Zhongnan Center is expected to handle more than 20,000 occupants daily, there is a strong requirement for a high-performance and multi-functional elevator strategy. Passenger elevators operate at 1,650 kg capacity, while those devoted to the apartments carry 1,350 kg each. There are dedicated high-speed shuttles for service offices, apartments and hotel areas, a strategy that reduces core space usage, while making room for additional amenities. Sky lobbies provide amenity and view opportunities, adding economic value.

Normal Operations

Operation of the elevator system is governed and monitored by the BMS. Cars typically run in group automatic operation, in conjunction with a multiple-zone supervisory system. Cars automatically slow down and stop at floors in response to car and landing calls, with stops made in numerical sequence, irrespective of the order in which buttons are pressed. Through destination control, passengers can be assigned to specific elevators, using operating algorithms. This increases overall elevator performance and efficiency and building security, when used in conjunction with proximity cards.

Evacuation

In the event of a power outage, the system will identify the power available from the emergency generator network and allocate the use by priority as follows: fire service elevators, dedicated shuttles, passenger elevators, and non-fire freight and service. Primary objective is to first bring elevators throughout the building to a point where passengers can be off-loaded at nearest safe level during the power outage.

In a fire emergency, elevators will first return to the main floor via activation of lobby detectors and/or lobby recall switch. During or after a fire emergency, system will identify the power available from the emergency generator network and prioritize orderly evacuation of elevators serving that portion of the building prior to general elevator evacuation. Passenger elevators are evacuated first, followed by fire/service elevators, followed by non-fire freight and service elevators.

In the event of a power interruption before, during or after a building emergency, the system will identify the power available from the emergency generator network and apportion power as outlined in the emergency operation program. The Building Management System provides real-time database in non-volatile memory of individual car loading and status (i.e.: existing demands for operation of the elevator) during normal power operation, as a means to establish priorities during a power failure.

Conclusion

This paper has shown that the Suzhou Zhongnan Center tower is not just a high building; it is a high-performance building in every sense of the word. The mass of information summarized here and explored in greater detail in the Project Room Book, across measurements as minute as millimeters to massive as kilonewtons, demonstrates the immense effort of coordination that goes into such projects and the incredible attention to detail required of all practitioners. The author also believes that the paper demonstrates the validity of performance-based design as an alternative to assumptions based on extrapolations of code. As the tall-building industry and related technology inevitably move faster than many governments, it is valuable to have genuine case studies such as these for guideposts.

交换的热量损失。这也具有降低管道的工作压力并提高可靠性的效果。高层区域中心服务于酒店，而低层区域中心服务裙楼，零售和办公空间。酒店，写字楼及裙楼有单独的冷冻水机房。从苏州工业园区余热被回收利用与整个建筑的直供蒸汽。

中南中心为了处理盛夏峰值冷却负载并平衡昼/夜电力需求而存储冰。储存的冰可以应对约30%的建筑物的峰值冷负荷，主要用于低层区域的办公室和裙房

至少50%的裙房屋顶是绿色的，以减少热岛效应和暴雨径流的影响。约1500平方米屋顶上覆盖着太阳能发电设备，每年可产生190千瓦或超过25万千瓦时的电量。

垂直运输 - 日常服务及疏散设计

由于苏州中南中心预计每天接待超过20,000个住户，便产生了一个高性能多功能提升策略的强烈需求。客梯在1650公斤负荷下运行，而公寓电梯为1,350千克。设有专用的高速电梯服务。为写字楼，公寓和酒店区域采用一种特殊策略，以降低核心空间的使用，同时为额外设施腾出空间。天空大堂提供舒适的设施，并提供可能的景观视点，以增加经济价值。

日常运转

电梯系统的运行由BMS监督控制。电梯厢通常以组为单位自动操作运行，配合一个多区域监控系统使用。电梯厢能根据电梯厢和着陆指示自动减速并在楼板处停止，并根据楼层数字设计停靠方式，不论在哪个按钮被按下的顺序。通过目标控制，使用操作算法，乘客可以分流至特定的电梯。在与感应卡一起使用时，这种方式增加了电梯的整体性和效率，提升建筑安全，。

疏散

在停电的情况下，系统会识别应急发电机网络的可用电源，并按以下优先顺序分配使用: 消防电梯，专用班车，乘客电梯，以及非消防货梯和服务电梯。主要目标是在停电期间，首先把整个建筑物电梯停靠在在最近的安全水平的点，使用者可以安全撤出。

在火灾紧急情况下，电梯将首先通过激活大堂探测器或大堂召回开关返回到主楼层。期间或之后发生火灾紧急情况下，系统会识别应急发电机网络的可用电源，并优先考虑一般电梯服务的那部分建筑的电梯疏散。客梯先撤离，其次是消防/服务电梯，其次为非消防货运和服务电梯。

在大楼紧急事件期间或之后的断电情况下，系统会识别应急发电机网络的可用电源，并根据紧急应对程序分配电量。楼宇管理系统提供了单个电梯厢的荷载和使用状态的实时数据库 (即: 对电梯运行的现有需求) 通过使用正常功率运行的非易失性储存器作为在停电期间确定优先事项的一种手段。

结论

本文表明，苏州中南中心塔不仅是一幢高层建筑;并在每一个方面都具有高性能的建筑。本文对海量信息进行了汇总，并在项目记录册上进行更详细的探讨，测量值或为分钟，或为几毫米，大到以千牛为单位，这都展示了项目中团队协调的巨大努力，并要求所有从业者对细节令人难以置信的关注。笔者也认为，本文论证了性能化设计的有效性，可以作为基于规范的推断替代方式。不可避免地，高层建筑行业及相关技术的发展比许多国家的政府的反应更为迅速，因此，对这些世界地标进行真正的案例研究具有深刻的价值。