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Construction Technology and Management Innovation
工程施工技术和管理创新

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This project adopts a double glass curtain wall system. A vertical atrium is formed between internal and external curtain walls which cause the external curtain wall system to be operated in midair. The height of concrete rises more than 600 meters, the consumption of steel structure is up to 100,000 tons, and the total weight of the whole building is over 850,000 tons. An unsupported circular retaining wall system with an inner diameter of 121 meters, a damper with a quality of 1,000 tons, and a 6-meter-thick foundation slab are used. The narrow construction site, complex surrounding environment, difficult safety control, large time span, and a number of unsafe factors present large challenges to the construction technology and management of this project. The project can be completed successfully only through the innovation of construction technology and management.

本工程采用双层玻璃幕墙，内外幕墙之间形成垂直中庭，导致外幕墙系统呈凌空作业状态; 混凝土使用高度达600多米，钢结构用量达10万吨，整个建筑总重量超过85万吨; 还采用了内径121米无内支撑的圆形地墙围护体系、厚达6米的基础底板、最大质量1000吨的阻尼器等; 工程场地狭小、周边环境复杂、立体交叉多、安全管控难、时间跨度大以及不安全因素多等: 这些诸多特点给施工技术和项目管理提出了严峻挑战，只有通过施工技术和管理创新才能圆满完成本工程。

The Innovation of Construction Technology

Successful excavation of the unsupported circular foundation pit was an innovation in the construction of the building. First, the main building area was constructed in sequence, and then the unsupported circular underground continuous wall with an inner diameter of 121 meters was adopted as the retaining walls for pits (see Figure 5.7). The maximum digging depth of the foundation pit is 33.7 m. A combination of island excavation and basin excavation was used. This dealt with precipitation by successfully using 360,000 cubic meter artesian wells. The wall thickness is 1.2 meters with a depth of 50 meters into the silty, fine sand layer (commonly known as the monolithic sand layer), thus the trenching machine and slot milling machine were used for the construction of wall grooves.

Secondly, super deep bored piles were completed on the soft soil foundation. The Shanghai Tower is adjacent to the Jin Mao Tower and the Shanghai World Financial Center and conventional driven piles have too much impact on the surroundings, so the bored pile was adopted. This is the first time bored piles have been used on a tall building over 400 meters high in a soft soil foundation. The pile diameters of the main building is 1 meter with the maximum pile depth of 86.68 meters. Inserted into the piles is a 92 powder sand layer nearly 9 meters thick with a maximum bearing capacity of 10,000kN per pile. The bearing capacity of each pile is improved with post-grouting technology, grouting pressure and grouting quantity on the pile bottoms. Using this method, the pile test showed that the largest bearing capacity of single pile was up to 26,000 KN.

Advanced technology of compounding concrete ensures that the construction of concrete continuously breaks the world record. The thickness of foundation slabs of the main building is up to 6 meters, adopting the C50 concrete with a total volume of 60,000 m^3. Through scientifically making concrete and optimizing construction technology, 60,000 m^3 of continuously cast concrete was produce without cooling pipes, breaking the current world record (see Figure 5.8). This world record was achieved by using the advanced technique of compounding "high strength, high durability, high pumping, high flow, self-compacting" concrete.

施工技术创新

成功开挖了圆形无支撑基坑。主楼区域先行顺作施工，采用内径121米的无内支撑圆形地下连续墙作为基坑围护 (请见图5.7)，基坑最大挖深33.7米，采取岛盆结合方式挖土，配合承压井降水，成功挖土36万方。墙厚1.2米，地墙深50米，深入粉细砂层 (俗称铁板砂层)，故采用重斗成槽机和铣槽机进行成槽施工。

完成了软土地基超深钻孔灌注桩。毗邻金茂大厦、环球金融中心，打入桩对周边影响太大，故采取钻孔灌注桩形式，该方法在软土地基的400米以上超高层建筑中应用尚属首次。主楼桩径1米，最大桩深86.68米，插入〇92粉砂层近9米，单桩设计最大承载力10000千牛。通过桩端桩侧联合后注浆，采用注浆压力和注浆量双控原则，单桩承载力大幅提高，经试桩试验，单桩最大承载力达26000千牛。

先进的混凝土配制技术确保了混凝土施工不断刷新世界纪录。主楼基础底板厚达6米，采用C50混凝土，共计6万方。通过科学配制混凝土配合比和优化施工工艺，实现了不设冷却水管、一次连续浇捣6万方大体积混凝土，创造了世界房建领域的新纪录 (请见图5.8)。该记录的实现依靠先进的"高强度、高耐久性、高泵送、高流态、自密实"混凝土配制技术的运用。

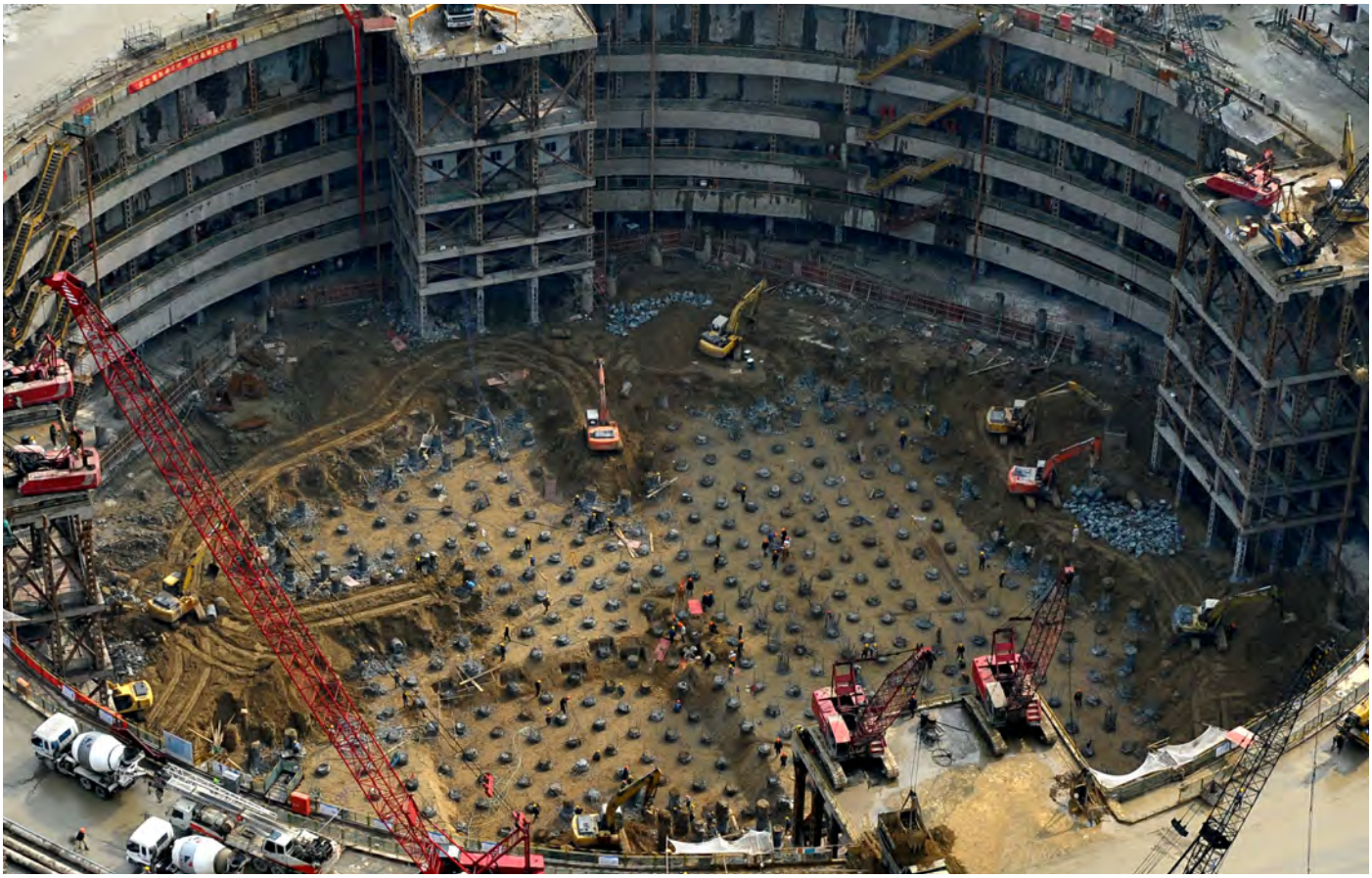

Figure 5.7. Unsupported circular foundation pit of 121 meters' diameter (Source: Shanghai Construction Group)
图5.7. 主楼121米直径无支撑圆形基坑 (来源: 上海建工集团)

Construction of the shear wall consisting of steel plate and concrete was completed. Shear walls with a large number of liner steel plates and outer-packed concrete have been used in the supertall building for the first time (see Figure 5.9). It can be divided into two forms: with one-layer steel plates and two-layer steel plates consisting of two kinds of concrete: C70 and C60. Before construction, construction technology, the construction process and the proportions for mixing the concrete was optimized. A shrinkage-reducing agent was added to improve the crack resistance of concrete. When pouring the concrete, the material was prepared at the same time on both sides of the steel plate to ensure that the concrete rises at a constant speed on both sides.

The innovative hydraulic jack-up steel platform and the template scaffold system used for the core are square with a plane size of 30 meters by 30 meters. It is divided into nine grids and uses the C60 concrete with a steel-framed structure inside. The core was constructed first, adopting a system that utilized a hydraulic jack-up steel platform and template scaffold (see Figure 5.10). The tools of modular design are convenient to deal with the three-times-changed core system,

成功完成了新型钢板混凝土组合剪力墙的施工技术。超高层建筑领域首次大量使用内衬钢板、外包混凝土的钢板-钢筋混凝土组合剪力墙 (请见图5.9)，分为内衬一层钢板和两层钢板两种形式，混凝土强度有C70、C60两种标号。施工前，优化施工工艺和施工流程，优化混凝土配合比，添加减缩剂，提高混凝土抗裂性; 混凝土浇筑时钢板两侧同时分皮下料，确保两侧混凝土等高匀速上升。

自主创新核心筒施工的液压顶升钢平台模板脚手体系。核心筒呈正方形，内部分成九个格，平面尺寸为30米乘30米，全部采用C60混凝土，内设劲性钢结构。核心筒先行施工，采用液压顶升钢平台模板脚手体系 (请见图5.10) ; 工具化模块化设计，方便应对核心筒3次体系变化、5次墙体收分及8个桁架层劲性钢结构吊装的影响; 封闭式构造设计，平台上方布置设备和材料堆放，下方施工作业，安全可靠。

电脑模拟预拼装技术在国内首次应用于建筑工程领域。本工程钢结构用量达10万吨以上，主楼有8个桁架层，由伸臂桁架、双拼环带桁架、径向楼面桁架、悬挑桁架及楼层钢梁组成，结构极其复杂。最大板厚达140毫米，单个构件最大重量近百吨。实物预拼装难度大，周期长，因此创新性地采用电脑模拟预拼装技术，完美地解决了此难题，且不受场地条件限制。

成功实现超大型动臂式塔吊外挂式布置和高空整体平移。结构施工阶段布置4台动臂式塔吊 (请见图5.11)，3台M1280D和1台ZSL2700，起重能力达2450吨以上。如此大的重型塔吊成功通过外挂方式布置，塔吊随结构施工自主向上爬升，每台塔吊爬升27次。随着核心筒墙体厚度的5次收分，塔吊实现了四次超高空整体平移，这尚属世界首次。

大量自制施工设备、设施等施工技术装备创新。外幕墙是柔性悬挂结构体系，处于全凌空作业状态。钢支撑施工时专门研发面积达2000平米的整体升降平台系统和极小半径只有8米的弯轨行走式小塔吊 (请见图5.12) ; 外幕墙板块施工时专门研发可斜向爬升的双层吊篮和利用永久擦窗机轨道的轨道式悬臂吊机; 中庭吊顶施工时专门设计了吊平台等等。这些施工设备和设施的创新均是为上海中心定向研发的。

成功实现外幕墙支座系统创新性研究。外幕墙系统属于扭转的柔性悬挂结构体系，需大量的高精度支座系统确保其结构稳定性和使用性。如此高精度的支座系统在幕墙领域甚至建筑工程领域都没有使用的先例，而且国际上也没有配套的成熟产品可用。专门组建

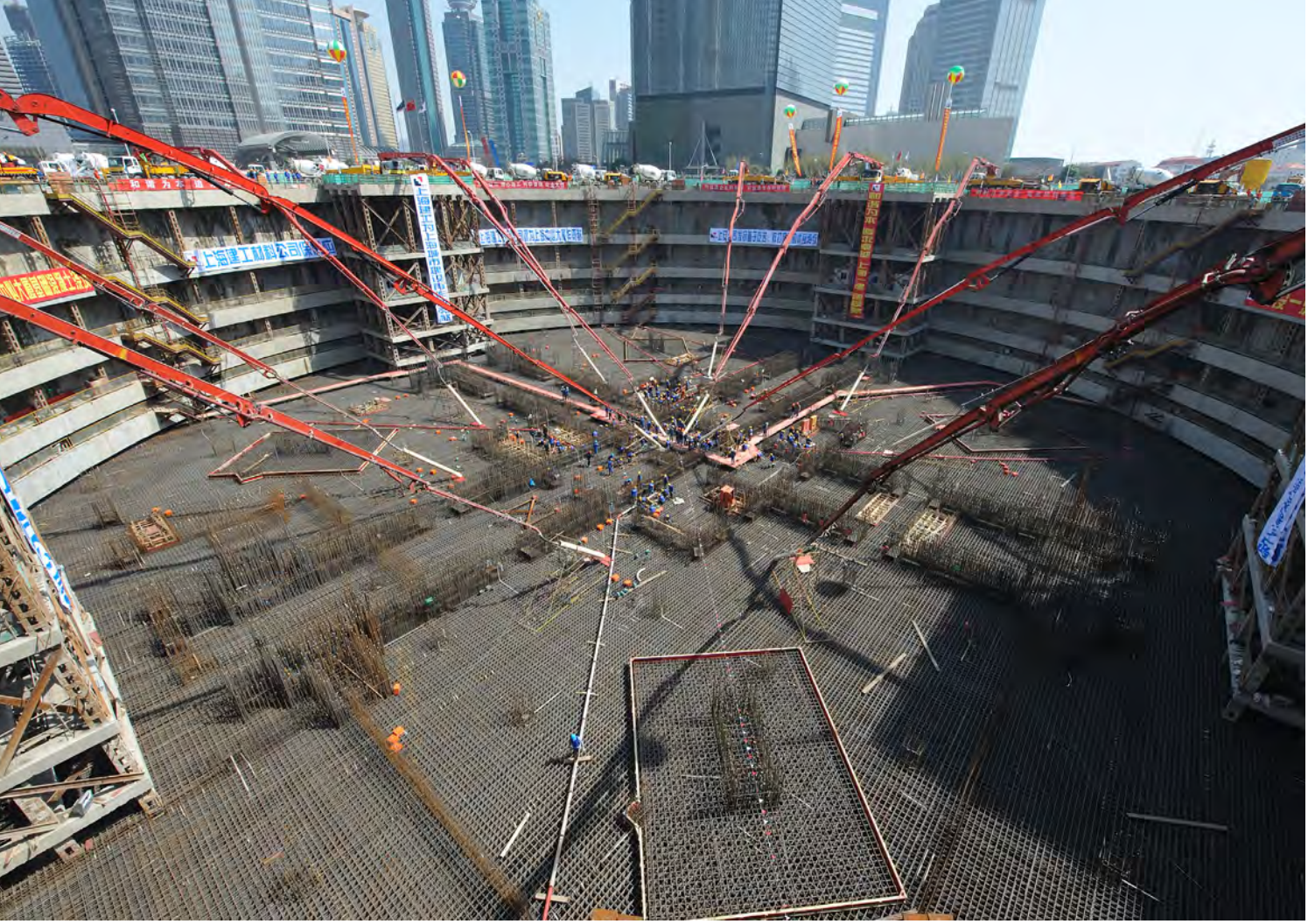

Figure 5.8. Concrete casting for the base slab of tower (Source: Shanghai Construction Group)
图5.8. 主楼大底板混凝土浇筑 (来源: 上海建工集团)

five-times-changed walls and the impact of lifting large steel structures. It is housed in an enclosed structure design to make it possible for equipment to be arranged and materials to be piled up on the platform. This makes the construction under the platform safe and reliable.

Computer simulation pre-assembling technology is used in the construction engineering field for the first time at the Shanghai Tower. In this project, more than 100,000 tons of steel will be consumed. The main building has eight trusses which consist of outrigger trusses, belt trusses, radial floor trusses, cantilever trusses, and steel floor girders. The structure is extremely complex with the maximum floor thickness of 140 mm and the maximum weight of individual components nearing 100 tons. Pre-assembly is difficult and takes a long time, so the innovative adoption of simulated pre-assembly solves these problems while not affecting conditions at the site.

Successful realization of outdoor-hanging arrangements and integral transitions at high altitudes required a whip-type tower crane. While constructing the structure, four tower cranes were arranged (see Figure

团队进行支座系统研发，历时一年多时间，圆满完成研发任务，并在工程中成功应用。

为实现重型机电设备吊装专门设计了移动式重型机电设备吊装平台，其中重型设备包括: 干式变压器、离心式冷水机组、板式换热器、空气处理机等。这不但解决了平台在楼层无法固定的问题，而且安全可靠，方便快捷。

电涡流调质阻尼器首次成功应用。阻尼器设置在塔楼125层的楼面上，重达1000吨，采用电涡流调质阻尼器，可以抵抗2500年一遇的罕遇地震。日常可以大幅减小大楼的摆动幅度，提高舒适度。电涡流系统和质量箱体分别安装，专门设计了质量箱体的搁置平台和同步升降系统，以确保阻尼器精确安装到位。

总承包管理创新

设计管理

专门成立设计协调部，全面负责原设计和专业深化设计出图的进度、协调和管理工作。由于原施工图出图深度不足，总包及专业单位配备了大量的深化设计人员，建立了深化设计五大专业协调平台，协调解决深化设计中遇到的各种问题与矛盾。原设计与深化设计出图比例达到1: 10。

进度管理

建立三级进度计划管理和监控体系，根据工况转换和施工进展，逐步对进度计划进行调整、升版; 采取"合同+行政措施"为主的资源配置机制和开设"绿色通道"为辅的资源快捷配置和保障机制，确保进度计划顺利实现各个节点的目标。

安全管理

安全是工程顺利开展的前提条件，建立安全责任分区负责管理制度，每区落实安全责任人。引入第三方安全评估和第三方消防安全巡视执法队，对工程的安全问题进行督查、执法; 建立消防灭火队，防患于未然。

完善立体交叉施工安全管理体系。建立立体交叉上报和公示制度，制订立体交叉施工安全技术管理方案和应急预案，明确立体交叉施工安全责任人，确保立体交叉施工安全。

技术管理

5.11), including 3 M1280D and 1 ZSL2700, the lifting capacity of which is more than 2450 tons. Large heavy cranes were arranged by out-door hanging. The cranes climbed upwards with the structure throughout the construction process, each crane climbing 27 floors in total. The fluctuating core wall thickness required 4 integral transitions of cranes at super-high attitudes – the first time in history in this has happened.

An expansive amount of innovative construction equipment and facilities were devised exclusively for Shanghai Tower. The external curtain wall is a flexible suspended structural system which needs to be operated in midair. For instance, during the construction of steel supports, a lift platform system and walking tower crane was specially researched and developed (see Figure 5.12). Also, when the external curtain wall plate is constructed, double hanging baskets that can climb at an angle and a cantilevered crane that used the track of a permanent window cleaning machine was developed. Furthermore, the lifting platform was specially developed and used to construct the atrium ceiling. All of these innovations were created specifically for the Shanghai Tower.

建立超高超限工程施工及验收标准。本工程超高超限，在很多方面已经超出了现有工程规范的覆盖范围。为使工程施工及验收有据可依，结合施工图纸、技术规格书及施工经验，专门编制了一系列针对本工程的施工及验收标准，并经相关专家反复论证，提交业主、监理及相关的政府监督指导部门批准后施行，如外幕墙支座系统施工及验收标准等。

建立台风特殊天气下的长效管理机制。周边高楼林立，特别是毗邻金茂大厦和环球金融中心两大世界级的摩天大厦，导致高空风场极其复杂。总包在深入调研上海最近10多年来的特殊天气资料及环球金融中心的风速监测资料后，进行分类整理、综

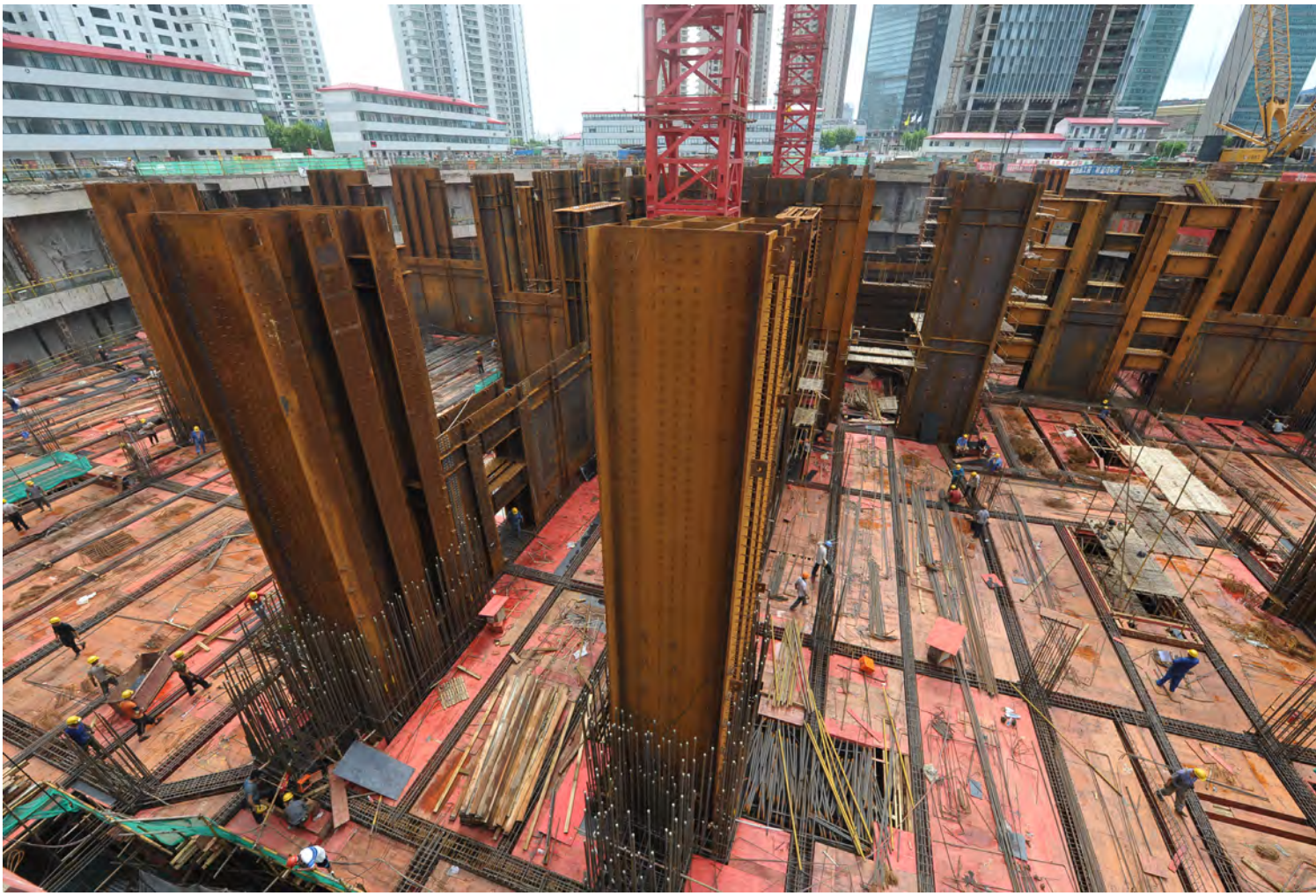

Figure 5.9. Steel - concrete composite shear wall (Source: Shanghai Construction Group)
图5.9. 钢板混凝土组合剪力墙 (来源: 上海建工集团)

Figure 5.10. Hydraulic jack-up steel platform and template scaffold system (Source: Shanghai Construction Group)
图5.10. 液压顶升钢平台模板脚手体系 (来源: 上海建工集团)

A torsion flexible suspension structure system was developed to support the external curtain wall. This required a large number of high precision supports to ensure structural stability. Such a high precision support system has not been used before for a curtain wall, even in the construction engineering field. A team was specially formed to develop the support system, and it spent more than one year completing the mission. The support system was successfully applied to the engineering of the Shanghai Tower.

A removable lifting platform was specially designed to lift heavy mechanical and electrical equipment, such as a dry type transformer, centrifugal water chillers, a plate heat exchanger, and an air processor. This not only solves the issues inherent with fixed platforms but is also is safe, reliable, convenient and quick.

A tuned mass damper (TMD) using eddy current damping was successfully applied for the first time. The TMD was set up on the 125 floor of the tower, weighing 1000 tons. Using Eddy Current Dampers, the tower can resist a 2500-year earthquake. It can significantly reduce the oscillation amplitude of the building, and improve the comfort in the daily lives of its users. The Eddy Current System and quality cases are installed respectively. The platform and synchronous lifting system of the quality case were specially designed to ensure that the damper was installed accurately.

Figure 5.11. Four heavy cranes arranged in the way of out-door hanging (Source: Shanghai Construction Group)
图5.11. 四台重型塔吊外挂式布置 (来源: 上海建工集团)

Innovation of General Management of General Construction Contractor

Design Management

A design-coordination department is responsible for the scheduling, coordination and management of the original design. Specialized designs were established for the Shanghai Tower. Since the original construction drawings were not thorough enough, general contractors and specialized companies were equipped with a large number of design employees. The detailed design platform consisting of five specialties

was established to resolve conflicts during the detailed design. The ratio between the original design and detailed design is up to 1:10.

Schedule Management

Three-level schedule management and monitoring systems were established. Based on the transformative working conditions and schedule of construction, the schedule itself can be modified and upgraded step by step. To ensure that every target can be achieved during the schedule, it was necessary to take the resource allocation mechanisms controlling the "contract-administration measures" first and the "green channel" second.

合分析，并结合每年的施工工况，制订了极端天气的应对措施方案、应急预案和管理机制。

质量管理

建立全专业全覆盖的质量考评体系。作为地标性建筑，我司也立志将上海中心打造成精品工程，因此加强了全过程的质量管控，建立了覆盖所有专业所有参建单位的

Figure 5.12. The walking tower crane and overall lift platform system (Source: Shanghai Construction Group)
图5.12. 行走式小塔吊和整体升降平台 (来源: 上海建工集团)

Figure 5.13. View of Shanghai Tower early in its construction in urban context (Source: Gensler)
图5.13. 从城市角度看上海中心大厦施工图景 (来源: 上海建工集团)

Safety Management

Safety is the precondition for the smooth progress of construction. It is therefore necessary to establish a management system which is divided by safety and responsibility. There should be a manager in every sector. To supervise safety and code compliance, a third-party safety assessment and the third-party fire safety enforcement team were introduced. The fire brigade was also established to impose a fire safeguard.

The safety management system of interchange construction was improved by establishing the interchange report and publicity system. In order to ensure the safety of the interchange construction, it was necessary to carry out the interchange construction safety management plan and create a contingency plan. This makes the safety manager of the interchange construction clear.

Technology Management

Set up the construction and acceptance criteria of the height-exceeded and over-limited project. This project is height-exceeded and over-limited because it is beyond the coverage of existing projects in many aspects. Combined with drawings, technical specifications and experience, a serial construction and acceptance criteria was worked out for this project to make construction and acceptance inevitable. The criteria, such as the construction and acceptance of external curtain wall bearing system, can be repeatedly implemented after verification by relevant experts and approval of the owners, supervisors, and relevant governmental departments.

Long-term management mechanisms should be set up in the event of extreme weather conditions such as a typhoon. The building is surrounded by many other tall buildings, such as the Jin Mao Tower and the World Financial Center. As a result, the wind at high-altitudes is extremely complex. General contractors carefully studied the special weather information of Shanghai in the last decades. The monitoring information of wind

千分制质量考评体系，每月召开质量例会，对各单位施工质量进行考评，表扬先进，曝光落后，确保项目质量。

建立公共资源统筹协调管理机制

塔吊、电梯和临水临电等公共资源是整个项目的生命线工程。建立公共资源提前申请审批机制，并综合现场的施工工况和进度要求，由总包统筹分配、协调管理，从而确保公共资源的高效利用 (见图5.13) 。

建立基于BIM技术的协调管理体系。

上海中心极其复杂的结构、繁多的机电系统、大量的深化设计，紧靠二维平面已经远远不能满足工程需求，BIM技术作为先进的技术和管理手段得到了深入、广泛的应用。总承包部成立BIM工作室，各专业分包成立BIM工作团队，分包BIM工作团队针对本专业的图纸深化、碰撞进行优化，在总包的协调下与相关专业合模，进行碰撞矛盾检查，上下协调，建立全方位的BIM管理体系。

基于网格化、信息化的协调管理机制。

speed around the World Financial Center in combination with the changing conditions every year helped create the contingency plans and management mechanisms for extreme weather events.

Quality Management

Throughout the development process, the company has had the ambition to make the Shanghai Tower as high quality as possible. Quality management was reinforced by a thousand-point quality assessment system evaluating every participant of the project. Quality meetings were held monthly to assess the construction quality of every participant. A reward system praised the outstanding contractors and consequences were handed out to the lagging contractors to ensure that the project retained its quality.

Establish a Coordination Management Mechanism of Public Resources

The tower crane, elevator and other public resources are the lifeline of the project. Applications to acquire public resources were established well in advance. Combining the construction conditions and schedule requirements through the general contractor ensured efficient use of these public resources. (See Figure 5.13)

Establish the Coordination Management System Based on BIM

Due to the complex structure, many mechanical and electrical systems, along with a large number of detailed designs, 2D planes are far from the needs of project. As an advanced technology, BIM was used widely in the Shanghai Tower construction. General contractors set up the BIM workshop while the subcontractors set up the BIM team to optimize and deepen drawings in their respective specialties. Under the general contractor's coordination, collision checks were completed between relevant specialties and a BIM management system was established.

Coordination Management Mechanism Based on Grid and Informatization

The large number of participating companies and workers proved perpetually challenging. Modern management measures were used and an innovative project management system based on grids and informatization was established. Each participant company was authorized to login and upload the files creating an environment of timeliness, accuracy and completeness. Also, engineering information is ensured, and efficiency was largely improved.

参建单位、专业及工人多，管理难度大。采取现代化的管理手段，建立了基于网格化、工程信息化的工程管理系统，各参建单位获得授权登录、上传，确保了工程信息的及时性、准确性和完整性，大大提高了工作效率。