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The Construction Supervision Process

施工监理的创新管理方式

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This chapter summarizes innovative management methods in the construction supervision process of Shanghai Tower, outlining the implementation process and application results. It includes key steps of the construction supervision process, acceptance criteria beyond specification, targeted inspection methods, safety management, sustainable building management, and BIM technology. Results prove that these innovative methods could satisfactorily meet the construction requirements of Shanghai Tower. Furthermore, these methods will provide a reference for other ultra high-rise buildings in the future.

This new landmark building in Shanghai has no parallel in history in the size of its engineering and architectural features. Additionally, it brought many challenges to the work personnel during the construction process. This article, from the perspective of supervision personnel, illustrates some innovative management practices used during the course of construction.

文章总结了上海中心大厦施工监理过程中若干创新管理方式，包括创新工作的提出、实施情况、应用效果等。具体内容有: 超高层施工监理关键工序、超规范的质量验收标准、针对性检查方式、安全监理模式、绿色建筑、BIM实施等。工程实际效果表明，这些创新手段较好的适应了上海中心工程推进需求，并将能够有助于今后类似超高层项目的工程咨询实施。

上海中心大厦作为上海市的新地标建筑，其工程规模和建筑特色史无前例，同时也给参与其中的各单位在工作方式方面众多挑战。本文从监理单位角度出发，阐述了在该工程施工监理过程中的一些创新管理做法。

The Innovation Comes from Challenges

The Challenges in Techniques

The construction process of the project required a broad range of engineering techniques. Furthermore, because the height of the building makes it the tallest in China, many technical aspects were beyond common practice. The main responsibility of supervision staff is to ensure quality results and accurate implementation at every step during construction. Therefore, the main challenge is identifying the essential elements of quality and controlling the key processes in this extraordinary project.

The Challenges in Management

For this project, management methods differ from normal engineering projects because of the numerous amount of involved subcontractors. Therefore, an innovation management model is required in order to achieve high quality results.

In addition to the routine work, there is the inevitable interface between the different technologies used in the project. For example, elevators need to be constructed within the core tube structure. For the sake of structural integrity, the structural steel personnel fabricated the elevator separator beams and completed the on-site installation. After the transfer procedures, elevator construction began. There are many other examples like this, and they took up a large part of daily technical coordination.

Innovation and Technical Measures – The Keys to Addressing Challenges

Identifying Key Processes in High-Rise Construction Supervision

Identifying and controlling critical processes are the key elements of quality management. This was done early in the project preparation period and 20 key main procedures were identified (see Table 5.3). These covered almost all of the engineering work, including the foundation, the main structure, curtain wall installation and decoration, etc.

As the project progressed, thorough screening of key procedures was very important. For aspects that exceeded current standards or had specific engineering difficulties or unusual

创新来源于挑战

上海中心的技术难度

本工程的建造过程基本涵盖了房屋建筑领域的所有分项工程内容。由于本工程建设总高度在国内属于首位，因此其中许多技术内容都超出了目前的常规。监理在现场主要的工作职责在于确保各分项内容质量的可靠实施，因此如何在这些超常规的工程中识别质量关键环节并进行控制，是面临的首要挑战。

上海中心的管理难度

本工程参与的分包单位众多，管理界面和工作方式也有别常规工程。需要考虑采取突破常规的管理模式，以顺利的实现工程进度、质量、投资等全方位目标。

除了常规协调工作外，不可避免的还有各技术之间的衔接。例如: 超高层核心筒内电梯施工，出于结构安全的考虑，电梯分隔梁由钢结构单位加工和现场吊装，完成移交手续后，电梯分包在此基础上进行专业施工。类似这样的例子还有许多，成为了日常技术协调中很大一部分内容。

创新的技术措施——攻坚克难的关键

超高层施工监理关键工序识别

我们首先将本工程的关键工序识别和控制作为质量管理的重点内容。早在工程准备

Figure 5.14. The Shanghai Tower under construction (Source: Gensler)
图5.14. 正在施工的上海中心 (来源: Gensler)

characteristics, we arranged further examination and identification. For many divisional working units, we updated the requirements and proposed specific evaluation criteria for components including the bored piles, the steel structure, the internal and external curtain wall and the supporting system, etc.

In addition, these key elements contain some requirements outside normal construction industry standards, such as: window coverings for the entire inner and outer curtain wall system, a large substation providing power for the building, a damper with the total weight up to 1,000 tons, a wind turbine group located at the height of 580 m, etc., all of which demanded a high level of technical performance and comprehensive evaluation of the strength and build ability of the construction elements.

Specific Inspection Methods

This section describes the innovative technology measures of key sub project procedures which were summarized above.

Inspection Method of Super-Deep Bored Grouting Piles

The main aspect of the pile foundation is that the pile diameter is large and the piles are

阶段，我们已经识别了20个主要的关键工序环节。(见表5.3) 涵盖了从地基基础、主体结构、幕墙围护、装饰装修等大部分的分部工程内容。

在工程进展过程中，我们对关键工序进行了深入地筛选，对于其中可能出现突破既有规范的内容，或是具有本工程难度和特点的内容，进行了深入探索和识别。在很多分项内容方面都提出或指定了特有的验收规范和要求，例如: 钻孔灌注桩验收规范、钢结构验收规范、内外幕墙及支撑体系验收规范等。

20 Main Procedures Required For Preliminary Indentifying 初步识别的20个主要关键工序			
Engineering Measurement 工程测量	Bored Grouting Pile 钻孔灌注桩	Diaphragm Wall 地下连续墙	Deep Foundation Excavation 深基坑
Mass Concrete 大体积混凝土	Concrete Construction 混凝土结构	Steel Construction 钢结构	Damper 阻尼器
Curtain Wall 幕墙	Installation & Decoration 装饰装修	Roof Protection & Anti-leaking 屋面与防渗漏	Water Supply & Drainage, Firework 给排水与消防
Ventilation & Air Condition 通风与空调	Construction Electricity 建筑电气	Intelligent Engineering 建筑智能化	Elevator 电梯
Outdoor General Engineering 室外总体	Large-size Equipment Hoisting 大型设备吊装	Construction Energy Conservation 建筑节能	Sustainable Engineering 绿色生态建筑技术

Table 5.3. Twenty Key Engineering Procedures
表5.3. 20关键工程流程

Figure 5.15. The heavy steel structure of the Shanghai Tower in it's early stages (Source: Antony Wood)
图5.15. 上海中心施工初期的重型钢结构 (来源: 安东尼·伍德)

very deep, with the deepest being 86 m into the ground. Controlling the verticality of the piles is the primary focus. Therefore, in addition to routine checks, we insisted that the inspection on the entire process be carried out as summarized below:

1. Inspection of the entire pile forming process required 24-hour uninterrupted monitoring. The proportion of sand in the mud had to be controlled in a certain range, or the wall of the pile may collapse. During this process, the weight of drilling mud was checked every 2 hours in order to ensure drilling verticality.
2. Since the project used post-grouting technology to improve the bearing capacity of the pile foundation, grouting was the key to quality control. The post-grouting quality control was refined in each step, including the grouting pipe connection, water pressure testing of the grouting pipe, and controlling the amount of grouting and grout pressure.

Inspection Method for Large Steel Structures

The total amount of steel structure in this project accumulated to more than 110,000 tons, which was provided by two domestic steel work factories. Because of the steel structure system that was adopted for the project, the number and size of components is very large, especially the trusses, the tower crown, and other key parts (see Figure 5.15). In the steel structure fabrication factory, inspection methods were very important and are summarized as follows:

3. It is important not only to inspect the components' processing quality, but to ensure that there were sufficient checking points to ensure the overall quality of the process. Therefore, the inspection of the quality management systems in the factories was important. In addition to routine evaluations, we also used ad-hoc inspections and statistical measurements, such as qualified welding procedures, to assess the quality of the steelwork machining and welds.
4. If all of the elements were pre-assembled in accordance with the general requirements, it would be difficult to reach the project schedule and cost requirements. Therefore, in this project, we used actual entity preassembly combined with BIM pre-assembly to control the precision of trusses and other key parts. The geometry of large steel components was modeled in 3D. This took advantage of the ability to model the steelwork by using the electronic analog of pre-assembled components in the BIM and it replaced the need for actual pre-assembly of the steelwork.

Inspection Method of Flexible Suspension Curtain Wall System

The double glass curtain wall of the building has a beautiful appearance, but it also brings extreme technical challenges. This can be seen in the outside curtain wall parts that require precision control from the curtain wall supporting system and curtain wall installation.

此外，还涉及到一些建筑行业之外的内容，比如: 覆盖整个内外幕墙体系的擦窗机，为大厦提供动力的大型变电站，总重量达到1000吨的阻尼器，位于580m高度的风力发电机组等。这些内容对各参建单位的技术水平和综合实力提出了很高的要求。

针对性的检查方式

本节主要就前节已经识别的突破常规的重点分项工程的创新技术措施进行阐述。

超深钻孔灌注桩的检查方式

本工程桩基最大的特点在于桩径大且超深，最深达到地面以下86m，需要重点控制桩基的垂直度。因此除了常规的检查内容之外，我们突破常规,采用了全过程监督检查方式:

1. 对成桩过程全过程检查，采用24小时不间断监控的方式，过程中每2小时检查1次成孔泥浆比重，确保成孔垂直度。
2. 由于本工程采用了后注浆工艺来提升桩基承载力，因此我们将其作为了质量控制的重点环节。对后注浆的质量控制细化到了各个环节: 注浆管的连接及下放、注浆管劈水试验、以及对注浆量和注浆压力进行控制。

大型钢结构的工厂检查方式

本工程钢结构总量超过11万吨，分别由2家国内钢结构加工厂加工。由于本工程采用劲性结构体系，因此构件数量和体型都十分庞大，尤其是桁架层、塔冠等重点部位(见图5.15)。在钢结构加工厂检查方面，采用了如下的针对性的检查方式:

3. 我们首先明确驻厂工作的重点，不仅仅是对构件加工质量的检查，更关键的是确保整个加工过程质量的总体平稳。因此我们注重对加工厂的质量管理体系进行检查: 除了常规驻厂外我们还采用不预先通知的飞行检查工作方式; 并采用焊缝合格率的统计指标等反映各加工点的质量。
4. 对于超大型钢结构的预拼装，如果全数按照一般规范要求进行工厂内预拼装，本工程进度和成本要求都难以达到。因此本工程中采用了实体预拼装结合BIM模型模

The installation of the curtain wall supporting ring beam required meeting the requirements of the plate connector construction schedule as well as requirements of the overall construction site schedule. Therefore, the method called "professional sub contractor – overall contractor-supervision" model was used. That is, the three parties respectively measure and double check their data and finally put their measured results into the BIM.

Inspection to Ensure the Sustainable Construction

In addition to conventional engineering objectives, the project also needed to achieve the standard of American LEED-CS Gold Standard and the Three-Star "double certification" standard of Green Building of China. Therefore, more than 30 green building technologies were used in the design. In order to achieve the "double certification" target, we identified some special technical improvements in the quality control points.

For example, the ground source heat pump differed from the conventional buried pipe approach. Different from normal ground source pump, we used a "pipe pile" as the source of ground source pump in this project. Therefore, the survival rate of the buried pipe is very important, because it is linked with the requirements of final energy savings.

Innovation Management – Guarantee of Efficient Operation

Safety Supervision Mode of Adjustments

Guarantee of Safety Technology

It is difficult to introduce safe production and non-hazardous construction processes without reasonable scientific and technical solutions. This is especially true for large projects, involving more breakthroughs in safety technology, such as the excavation of deep foundations, tall braced bents, etc. (see Figure 5.16) In the construction process, safety is highly inter-related with complete technical proposals, and they should be reviewed and demonstrated to comply with approved procedures.

拟预拼装的方式，进行桁架层等部位的安装精度控制。将加工好的大型钢构件的几何尺寸录入到三维模型中，用模型进行电子模拟预拼装以取代构件实体预拼装。

柔性悬挂幕墙体系的检查方式

本工程双层玻璃幕墙打造了建筑柔美的外形，同时也带来了极大的技术挑战。尤其外幕墙部分需要由幕墙支撑体系和幕墙板块安装进行精度控制。

幕墙支撑环梁的安装，既要满足板块转接件的施工进度要求，又要满足施工现场的总进度要求，因此采用了由"专业分包-总包-监理"的模式，三方分别复测数据，测量结果输入到BIM模型中。

保证绿色建筑效果的检查方式

本工程除常规工程目标外还需要达到美国LEED-CS金奖及中国绿色建筑三星级"双认证"标准。因此设计采用了多达30余项的绿色建筑技术。为达到"双认证"目标，我们对一些专项技术的控制重点进行了识别。

以地源热泵为例，区别于常规的地埋管做法，本工程采用了"桩埋管"方式。因此埋管的成活率对于最终节能要求是否能够达到十分关键。

创新的管理内容——平稳运行的保证

调整的安全监理模式

安全技术保证

安全生产文明施工，离不开科学合理的技术方案。特别是对于特大型项目，涉及到较多的安全技术突破，比如深基坑开挖、高大支撑排架等等 (见图5.16) 。在施工过程中，要做到安全，必须有完备的技术方案保证，并严格按程序进行审核和论证。

在现场，监理严格按批准同意的方案，督促施工单位落实各项安全生产文明施工的保证措施。不符合要求，不得投入使用，不得进行质量验收。比如钢筋隐蔽验收和模板验收，必须做到排架验收合格挂牌。要求做到方案怎么写，现场就怎么做，现场做不到，方案就得改，并经过验算和审核。这样做，督促施工单位必须重视方案的合理和科学，并重视技术交底和现场实施。

安全管理模式

Figure 5.16. The construction workers following safety procedures during the concrete pouring process (Source: Antony Wood)

图5.16. 施工人员按照安全程序浇筑混凝土 (来源: 安东尼·伍德)

During on-site management, supervisors must follow the approved procedures and coordinate with construction personnel to ensure production safety and safe construction practices. It was forbidden to use non-approved quality checking processes and to use any behaviors that were not aligned with the approved process. For example, in the acceptance process for concealed steelwork and templates, there must be an approved acceptance listing. The on-site implementation must strictly follow the approved construction proposal. If they were unable to be executed in accordance with approved procedures, then the proposal would be adjusted accordingly, after verification. It was a useful methodology to ask the construction units to consider their proposals in detail. They had to be reasonable and scientific. This methodology emphasized the importance of verification and on-site implementation.

Safety Management Model

Clarify that the main safety production responsibility is with the project leader:

- It is essential to ensure that the main responsibility for safety is with the project leader. When the project leader is committed to his responsibility and involved in onsite construction, the supervision and management of construction safety can be fully achieved. This brings awareness to the project team members at all levels. On-site management can be developed once they are aware that the project leader is the main person responsible for all onsite production safety.

Clarify the safety responsibilities for each role in the project.

- It is essential to follow the main principle that everyone must be committed to their responsibility in their position. Defining the safety responsibilities of the project leader, the general engineer, the functional head, and the relevant team members is essential. The goals of safety management should be achieved when everyone is clear about their responsibilities and that they can improve site safety from their own position.

Set up the management system for safety in construction for all levels of personnel:

- The accident control responsibility covers all levels of project members and it requires bottom-up management, so that everyone in the team is actively involved. It is also important to set up evaluation systems, such as specificity and measurability that ensure safety in construction. Secondly, timely tracking and periodic appraisal systems carried out by management must be implemented to ensure the continuous and consistent improvement of safety records. As a result, safety objectives should be achieved successfully and on schedule.

Innovative BIM Supervision Mode

Currently, BIM technology has been used in many large projects. For instance, it was used efficiently and developed in some specific process throughout the Shanghai Tower project. A series of BIM related technology and methods were developed and practiced, according to the characteristics of the supervision work.

Development of BIM Platform

In the development process for the BIM platform, the main factor was the management of important engineering information, such as quality, safety, progress, etc. Based on the existing engineering BIM, the concept of "data label" was introduced to associate the data in the model. The labels contain important information and data including engineering material, inspection, acceptance and solutions for specific problems. Furthermore, the label orientates the exact position of the element in the model. For the overall project, there is a summary list which is very clear and useful for early warnings of discrepancies.

落实项目负责人的安全生产责任制。

- 保证落实项目负责人的工作到位，一把手真正上岗到位了，才能对安全生产实行全员、全方位、全过程的管理和监督，才能形成"一把手是安全第一责任者为核心的各级安全生产责任制"。

做到安全生产层层有责

- 做到安全生产层层有责、按照"谁主管、谁负责"的原则，明确从一把手、总工程师到专责主管及其工作人员安全责任。做到层层把关，分兵把守，群防群治，群策群力，使安全生产处于受控在控状态。

层层签订安全生产责任状

- 层层签订安全生产责任状，建立起自下而上、分级控制事故，层层保护，一级对一级负责的保证体系。要将安全目标通过责任状的形式加以细化和量化，建立、完善实施细则和考核办法。通过实行过程跟踪和阶段考核，进行动态管理，确保安全记录与日俱进，安全形势日臻稳定．安全目标如期完成。

创新的BIM监理模式

在目前多数超大型项目均开展BIM技术应用的背景下，本工程也在多个专项工程中很好的推进了BIM工作。围绕监理工作的特点开发并实践了一系列与BIM相关的技术方法。

BIM工作平台开发

在该BIM信息平台的开发过程中，考虑的主要因素是工程的重要信息管理，例如质量、安全、进度等方面。基于既有的工程BIM模型，引入了"数据标签"的概念，将数据与模型进行关联。标签中能够包含各种重要信息，例如: 工程材料信息、检查验收信息、问题整改情况等。对于单个标签，可以详细的展示其中包含的具体质量信息，并能够具体的定位出在建筑模型中的精确位置。对于工程总体，具有非常直观的一览表功能，便于预警提醒。

此外，监理人员可以在工作平台中进行常规的工程管理流程操作。因为有了BIM模型的引入，使得一些常规工作能够更加直观、有序，提升管理效率。

BIM辅助现场技术

Figure 5.17. Shanghai Tower's impact on the Shanghai skyline creates an anchor for the many people travelling nearby. (Source: Gensler)
图5.17. 上海中心对上海天际线的改变吸引了许多来附近旅游的人（来源: Gensler）

Additionally, the supervisors can implement conventional engineering management processes on the BIM platform. With the application of BIM, we simplified the routine works and improved the efficiency of the project management.

BIM-Aided Technology

In the development of BIM platform, a series of BIM-aided technology for supervision was applied. We summarize two scanning modes for on-site management, 3D scanning and panoramic scanning.

- 3D laser scanning can accurately obtain the 3D geometry model of the object; it is very efficient and precise. Therefore, under certain conditions, 3D laser scanning measurement technology can be combined with physical measurement of key parts.
- Panoramic scanning technology is another tool to acquire the entire on-site model but it is different from the 3D scanning. The image in panoramic scanning is not high-precision, but it can record the construction site at specific times. This technology is very useful to rapidly review the on-site situation in quality management.

The Implementation Effect and Summary: Future Inspiration

The purpose of innovation is not only for achieving construction targets, it is also very important to inspire the project participants through the accumulation of engineering technology and management experience in innovative construction practices. By reviewing, recording, and refining this experience, we will achieve better application of innovations in similar projects in the future.

在进行BIM平台管理功能开发的同时，进行了一系列关于BIM应用技术的监理应用。在此介绍2种利于现场使用的扫描方式: 三维扫描和全景扫描。

- 三维激光扫描可以在现场精确的获得扫描对象的三维点云模型，具有高效率、高精度的特点。因此一定条件下可将该项技术与关键部位的实体测量相结合。
- 全景扫描技术是另外一种获取现场实体模型的工作方式。与三维扫描的区别在于，这种方式虽然没有极高的精度，但是可以最大程度的还原特定时间节点的施工现场。这样尤其可以在质量管理中起到较好的追溯作用。

实施效果与总结——对未来的启发

创新的目的不仅仅在于达成工程建设目标，更关键的是能够对参与者起到很好的思维启发作用。在本工程创新实践中积累的技术和管理经验，经过亲身经历者的进一步总结提炼，将能够在未来类似项目中得到更好的应用。