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Key Aspects of Construction Management
施工管理中的关键方面

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In general, construction management embraces topics such as programs, progress, quality control, and construction methods, all of which somehow correlate to each other. During the construction of the Ping An Finance Center, some experiences on construction management are worth sharing. This chapter thus discusses some aspects of construction, including a comparative study on excavation and lateral support (ELS), a study on improving tower crane performance, and a comparative study on the location of mega column construction joints. In the study on ELS, a lateral supporting system with and without a phasing wall is discussed. In the study of tower crane location, cranes mounted inside and outside the core-walls are discussed with their effects on construction effectiveness stated. For the mega columns, a discussion on two different locations of construction joints which affects construction is also given.

一般而言，施工管理包括项目进程，质量控制，施工方式等方面，这些方面都互相关联。在PAFC的施工中，一些施工管理的经验值得分享。本文介绍了施工中的几个方面，包括ELS的比较研究，塔式起重机改进的研究以及施工节点位置的对比研究。在ELS的研究中，讨论了包含隔水墙和不包含隔水墙的侧向支撑体系。对于塔式起重机位置的研究，讨论了位于核心筒内部和核心筒外部两种情况对于施工效率的影响。巨型柱方面，对于影响施工进度的两种不同方式的节点进行了讨论。

Introduction

The main tower is a framed structure with composite concrete core-walls surrounded by eight mega columns linking with steel beams and composite slabs / reinforced concrete slabs. There are seven bell trusses and four outriggers. The bell trusses are located about every thirteen stories and are spanning 1-2 stories-high each. The outriggers are typically spanning two stories. On the other hand, the podium structure is a reinforced concrete framed structure at nine stories.

The construction of the sub-structure was to be completed in September 2014, since sub-structure work began in November 2009. The sub-structure boundary was along the site boundary, namely the red line. The excavation over the sub-structure area was executed at once (i.e. without phasing), thus a lateral support system was spanning over the whole construction site. Over 350,000 m^3 was excavated in eleven months, (i.e. the excavation was completed in October 2010).

The construction sequence of the super-structure was as follows; core-walls, mega columns, steel beams, and then slabs in cycling. The construction of core-walls was five stories ahead of the construction of mega columns. Both core-walls and mega columns were in a hybrid system, i.e. structural steel members inside reinforced concrete. Similarly, the construction of mega columns was five stories leading from the installation of steel beams. Also, the installation of steel beams was five stories ahead from the installation of profiled sheeting in typical floors, and the installation of profiled sheeting was five stories leading from the construction of concrete decking. Therefore, there are a total of twenty stories between the construction of the core-walls and the construction of composite floors.

ELS

According to the specifications for estate surveying and mapping SZJG/T22-2006, basement areas designated as below-grade car parking and mechanical are classified as non-GFA accountable areas. Therefore, most of the complex developments have basement structures.

简介

主体塔楼为框架结构，复合混凝土的核心墙由8根巨型的柱子包围，两者之间通过钢梁和复合/钢筋混凝土楼板连接。共有7个带状桁架和4个悬臂。每隔13层有一个高1-2层的带状桁架。悬臂则一般都是2层高。而9层高的基座采用的是钢筋混凝土框架结构。

辅助结构的施工从2009年11月开始，于2014年九月完工。辅助结构的边界紧贴基地边界，也就是基地红线。辅助部分的地基是全部整体开挖的(没有分阶段)，因此整个施工场地内都布满侧向支撑系统。11个月内开挖土方量超过350,000立方(开挖与2010年10月结束)。

巨型结构的施工次序是由核心筒墙体，巨型柱子，钢梁最后到楼板的循环。核心筒墙体的施工比巨型柱子快5个楼层。核心筒墙体和巨型柱子都是由混凝土包裹结构性钢构件的复合系统。同样的，巨型柱子的施工比钢梁快5个楼层。钢梁的施工又比标准层压型钢板快5个楼层，压型钢板再比混凝土楼板快5个楼层。因此，施工的最快的核心墙体就比复合楼板快了整整20个楼层。

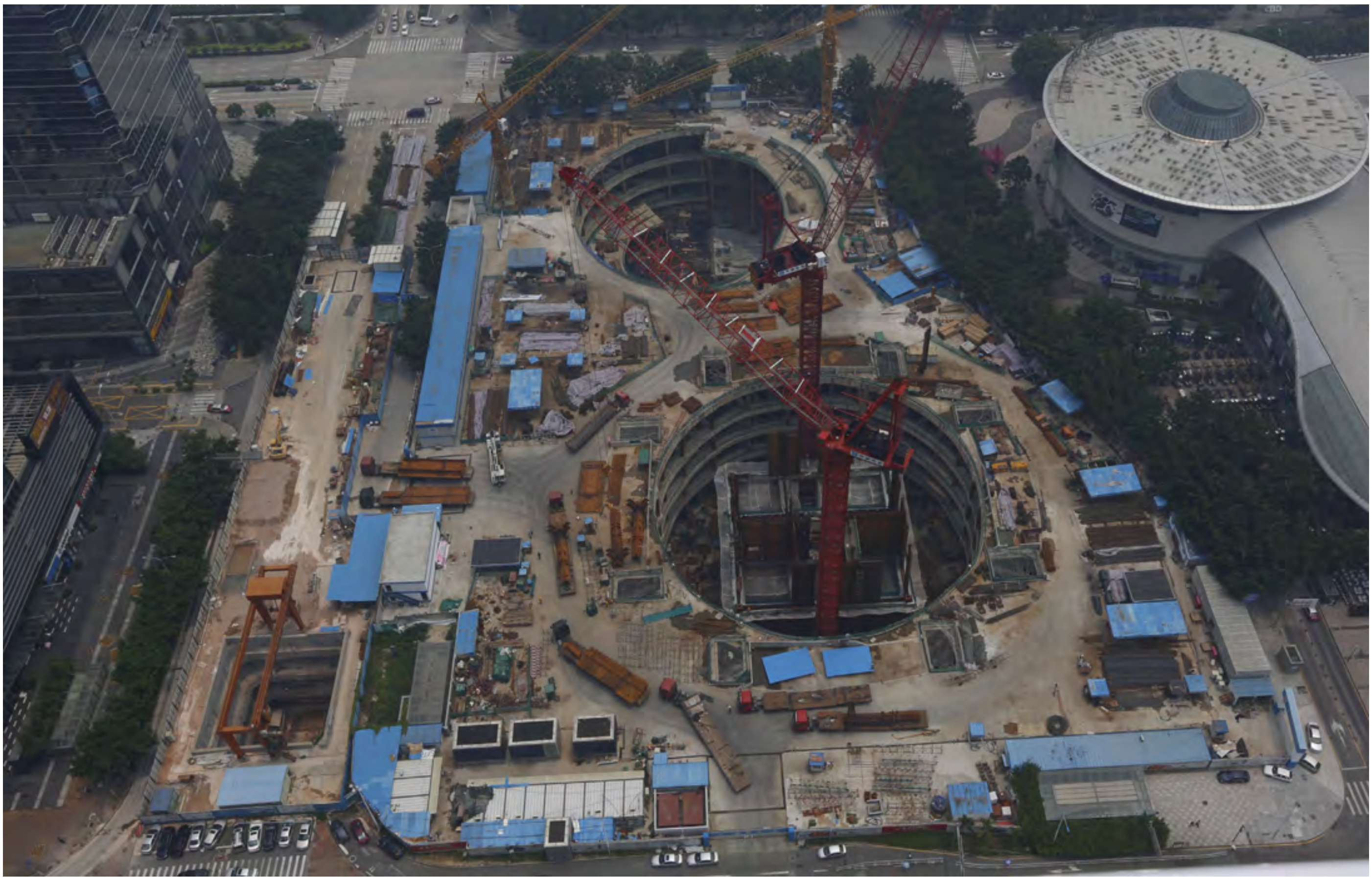

Figure 6.9. Completion of excavation at the site. (Source: Ping An)
图6.9. PAFC地基开挖完工 (来源: 平安)

Unavoidably, excavation is needed and a lateral supporting system is required in order to excavate safely.

There are some factors affecting the design of ELS (Excavation and Lateral Support) that will affect the subsequent construction sequences. Obviously, the design of ELS significantly depends upon a number of factors, including the soil type, excavation depth, and construction sequences, etc.

Based on the soil investigation report, two common lateral supporting systems would be adopted separately; the pile wall system and the diaphragm wall system. Each lateral system has its advantages and disadvantages. After a comparative study, the geotechnical consultant recommended adopting the pile wall system with main consideration on the local construction technique and the construction costs. Finally, the excavation was executed for the whole construction site area at once as shown in Figure 6.9.

Additionally, since excavation of the whole construction site was performed at once, this was allocated to a critical path. Reviewing the work done with reference to the critical path, we found that all events in the tower were critical, i.e. installation of the curtain wall, installation of MEP, etc. Therefore, completion of the main tower was the most critical. Having acquired experience,

开挖和侧向支撑

根据深圳经济特区技术规范 SZJG/T22-2006，作为停车或是设备用房的地下室面积是不计入建筑面积的。因此，大部分的综合体项目都会下挖地下室。为了保证开挖的安全性，就需要使用侧向支撑系统。

ELS (开挖和侧向支撑) 的设计会受到很多因素的影响而决定相应的施工顺序。很显然，ELS的设计受到比如土壤类型、开挖深度和施工顺序等因素的影响。

基于土壤调查报告，一般会在桩基墙体系统和隔水墙系统两种侧向支撑系统中选择一种。两者都有各自的优势和劣势。在比较研究后，考虑到当地施工条件和施工造价，岩土工程顾问推荐使用桩基墙体系统。最终，整个基地同时进行开挖，如图6.9所示。

此外，由于整个基地地基开挖是同期进行的，使得它也成为一个核心部分。如果在这个项目中评定那些部分是施工核心部分，我们发现塔楼的每一步都是核心，包括幕墙安装、设备安装等等。因此塔楼的施工是最为关键的。根据已有经验，我们计划加速主体塔楼的施工速度。既然裙房不属于核心部分，我们在塔楼周边设置好定位墙体后就搁置裙房的施工。这样就能减少核心部分的开挖时间。同时，也为主体塔楼的施工提供了一

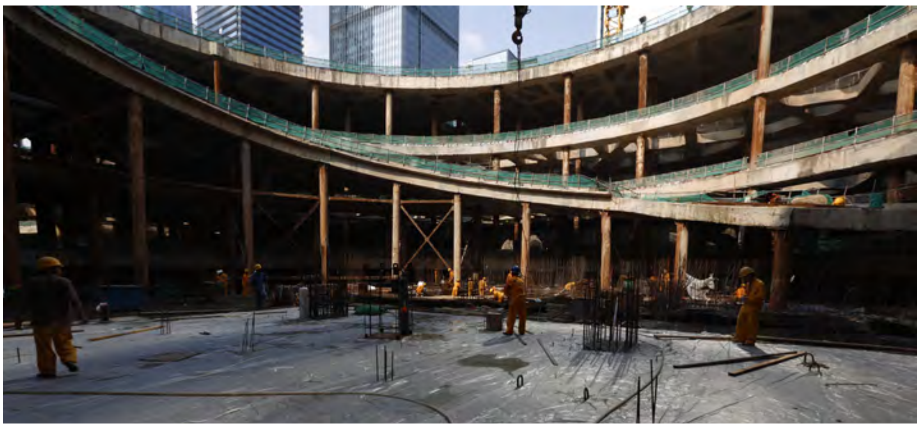

Figure 6.10. Early stages of foundation work. (Source: Ping An)
图6.10. 基础施工的早期阶段 (来源: 平安)

Figure 6.11. The structural support for the parking garage and weather proofing to prevent water leakage. (Source: Ping An)
图6.11. 停车场的结构支撑以及防渗水的耐候件（来源: 平安）

we should have planned to accelerate the construction of the main tower. Since the podium portion was not on the critical path, we should have discarded the construction of the podium portion by adding phasing wall surrounding the main tower footprint. The excavation period occupied on the critical path could be reduced. Meanwhile, a storage area for the construction of the main tower could be optimized. However, the construction costs could be increased. The excavation of the podium portion should be executed while the main tower would be constructed up to 10F.

Reviewing the quality of the lateral support, the pile wall system was found to have leakage between piles. This was because of the unevenness of the pile wall's verticality. Their verticality was difficult to control. For instance, one pile could be constructed to incline towards the construction site and the neighborhood piles could be constructed to incline outwards from the construction site, thus, leakage had occured between piles. The increased number of pile walls would increase the chances of leaking between pile walls. To prevent water leakage, a grout curtain was applied between two piles in addition to deep penetrating grout. It is presumed that if the diaphragm wall system was adopted, the work done on grouting would be reduced accordingly, as the number of gaps were significantly reduced. On the one hand, this would reduce the time it takes to repair leakages. On the other hand, the total cost of construction would be less than that of using a pile wall system.

Location of Tower Cranes

Tower cranes are normally mounted either inside the core-walls or outside the core-walls; both scenarios have advantages and disadvantages. In the PAFC project, the tower is 660m high, so it follows that the structural steel members could be very heavy. The maximum weight of a single segment could weigh up to 90 tons, i.e. a segment from an outrigger, therefore, the main contractor selected to adopt four tower cranes for material hoisting. Also, the main contractor decided to install four tower cranes at each side of the outer core-wall so that the loading capacity could be optimized (see Figure 6.12). As the tower cranes were sitting on supporting frames, the frames were mounted outside of the core-walls too. This meant that the installation

个储存空间。这样的缺点就是会增加施工造价。在塔楼建设到10层以上，就可以开始裙房部分的地基开挖。

在对侧向支撑体系的评估中发现，在桩基之间存在渗漏现象。这是由于桩基墙体垂直角度的不均匀导致的。墙体的垂直是非常难控制的，例如一个桩基可能会朝着施工方向倾斜而另外一个桩基又向着反方向倾斜，这样就导致了不同桩基间的渗漏。桩基墙体数目的增大会加重渗漏现象。为了阻止地下水渗漏，除了深渗透性水泥浆之外在两个桩基之间再增加一个水泥砂浆帘。据估算，如果使用了隔水墙系统的话，由于缝隙数量的减小，花在水泥灌浆上的工程量也能够相应的减小。此外，修护渗漏的时间也能够节省下来。工程的整体造价比起桩基系统要更低。

塔式起重机的位置

塔式起重机一般要么位于核心筒内部要么核心筒外部，两种都有各自的优势和劣势。在PAFC项目中塔楼高达660m，不难想象很多结构钢构件都会非常的重。单个构件 (比如悬臂的构件) 最大重量能够达到90吨，总承包商决定使用4个塔式起重机来吊装材料。同时选择将四个塔式起重机分别放在核心筒外侧的四面，这样保证荷载分配最为均衡 (见图6.12) 。由于塔式起

of steel beams outside the core-walls must be three stories underneath the supporting frames; the construction of one story took a week.

We could observe that there were some advantages and disadvantages between mounting tower cranes among the inside and outside of the core-walls. For tower cranes mounted inside the core-walls, the advantages include the following:

1. No obstacles outside the core-walls so that structures outside of the core-walls could be constructed earlier

Disadvantages include:

1. Loading capacity of the tower cranes are less than that those mounted outside the core-walls, as the moment arm is longer
2. It will be too late to construct the structures inside core-walls
3. Similarly, it will be too late to install the MEP inside core-walls, i.e. the installation of lifts
4. Materials cannot be transported using the lift shaft, as the lift shaft will be occupied by the tower cranes

重机放置在支撑框架上，框架在核心筒的外圈，这样就意味着核心筒外伸的钢桁架施工要比支撑框架慢3个楼层。每个楼层的施工时间为1个星期。

我们知道将塔式起重机放在核心筒内侧或是外侧都有优势及相应的劣势。对于放在内侧这种情况，优点包括:

1. 核心筒外侧结构没有障碍物而能够尽快施工

缺点包括:

1. 比起放在外侧的起重机，内侧的起重机由于力臂更长而荷载能力较小。
2. 核心筒内部结构的施工太滞后。

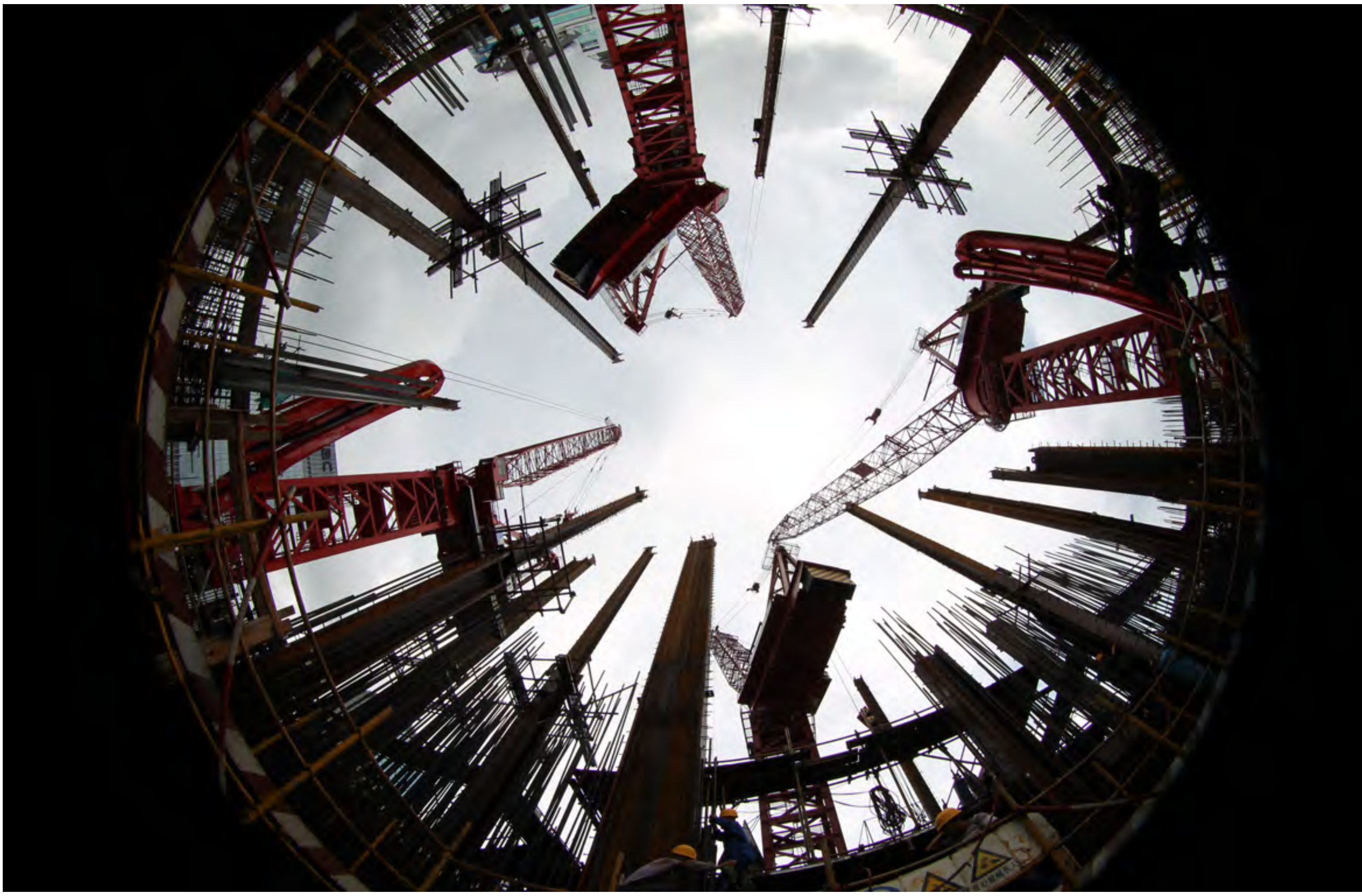

Figure 6.12. The four tower cranes at each side of the outer core-wall. (Source: Ping An)
图6.12. 位于核心筒外墙每一侧的四个塔吊 (来源: 平安)

For the tower cranes mounted outside the core-walls, the advantages and disadvantages are reversed.

Since construction of the basement already took a very long period to complete, i.e. five years, it occupied about half of the total construction period. Therefore, it was necessary to accelerate the construction at the superstructure stage in order to complete and handover the project as planned. Generally, in the construction of super-high rise buildings, the construction cycle per story would be four days. Hence, the first target was to accelerate the construction cycle per story from seven to four days.

By comparing the four-day and seven-day cycle, it was concluded that some extra time was spent on raising the tower crane itself. During the service status, a tower crane was supported by two sets of supporting frames, separately at toe level and at the middle level of the tower crane. When the tower crane was to rise up, one set of supporting frames was to be mounted at the top level of the tower crane. At this moment, the tower crane had three sets of supporting frames; the lowest set would be dismantled when the tower crane was raised up to a certain height. It was designed using the tower crane to dismantle the lowest supporting frame, so the tower crane was occupied for few days. It was then designed as a lifting system designated on dismantling the dummy supporting frame so that some time was saved from dismantling the lowest supporting frames by using the tower crane. It was analyzed that the middle supporting frame would take the mass majority of the tower crane and the top supporting frame would assist the stabilization of the tower crane during the rising up. Hence, the top supporting frame had dummy capacities. Based on this condition, the lifting system was designed to mount on the top supporting frame and therefore the construction cycle was reduced from a seven-day to four-day per story rate. The steel installation contractor obtained a patent for the lifting system.

Figure 6.13. Fixing of mega columns on site. (Source: Ping An)
图6.13. 现场巨型柱子的安装 (来源: 平安)

3. 同理，核心筒内部的设备也就是电梯的安装会非常滞后。
4. 材料不能通过电梯来运送，而只能由塔式起重机来运送。

对于将塔式起重机放在核心筒内部的情况，优点和缺点与上面相反。

由于地基的施工已经花了长达5年的时间，占据了总施工工期 的一半。因此，为了按时完成和交付项目就必须加速超上层结构的施工。一般来说，超高层建筑的施工中每个楼层的工期为4天。因此，第一个目标就是将每个楼层工期由7天缩至4天。

对比4天工期和7天工期的流程，我们会发现多余的时间有的是花在抬升塔式起重机本身上。在施工状态下，一个塔式起重机由2组支撑框架支撑，分别位于起重机底部和中部。当起重机抬升之后，在起重机的顶部又会再有一组支撑框架，这时一个起重机就会有三组支撑框架，但起重机上升到一定高度之后，最底部的支撑框架会被卸除。最底部框架的拆卸是由起重机来完成，因此起重机会被占用几天。然后我们设计了一个起吊系统来代替塔式起重机负责失效支撑框架的拆除。经过分析得知，中部的支撑框架承受塔式起重机的大部分重量，而上部的支撑框架主要负责在塔式起重机的上升中保持稳定性。因此，上部框架还有富余的荷载容量。基于这些情况， 将起吊系统放在上部框架上，将每个楼层的施工周期从7天缩至4天。起吊系统的钢材安装承包商为此申请了专利。

巨型柱子施工节点的位置

巨型柱子作为重要的垂直结构元素，将竖向荷载传递到地基。当巨型柱子与梁相连形成框架后还能保证建筑的稳定性。在设计阶段，所有的构件都是按照均匀等距来考虑的。然而现在的很多巨型钢材剖面已经无法通过热轧成型，他们只能由板材连接形成，一般是通过焊接来保证结构整体性。

Location of Construction Joints of Mega Columns

Mega columns are important vertical structural elements that transmit vertical loads to the foundation. The mega columns also provide stability for buildings when they connect to beams acting as frames. In the design stage, all elements are considered to be homogenous and isometric. Nowadays, however, giant steel sections cannot be hot rolled; therefore, they are unavoidably formed from plates in connections, e.g. commonly in welding to ensure structural integration.

At the beginning of construction, each segment of mega columns was three stories high in two pieces. The segments were connected with vertical joints on site. The advantage of this was to complete three stories for each erection; hence, the total number of erections could be minimized. It was recorded that the construction period was a seven-day cycle per story. With reference to experience acquired from previous projects, in general, the construction period could be as fast as a four-day cycle per story. This was based on the segment of mega columns in 1 or 1.5 stories per erection, without a vertical connection. It was then revised that the segment of mega columns were to be 1 to 1.5 stories, which was similar to other projects, so that the speed of construction had been decreased from seven to four days. On the other hand, the quality of welding was easier to achieve by comparing vertical welding against horizontal welding. Also, the safety precautions were easier to control and assure. For the vertical welding, a working platform must be spanned over three stories high, i.e. about 15 m. For horizontal welding—since the welding joints were at the same level—the working platform just needs to be provided at a certain height below the joints to be sufficient. Experience acquired shows that the stabilization of working platforms for horizontal welding was easier than that of vertical welding. Besides, based on the Safety Management Ordinance (2009), scaffolding spanning over 10 m must be passed by an expert review panel. Therefore, it is not only actual work done, but also makes the consent approval easier. Therefore, it could be concluded that the use of horizontal joints achieves a better performance than the use of vertical joints. Figure 6.13 shows the fixing of mega columns on site.

Concluding Remarks

A comparative study has been presented here on the experience acquired from the current adoption and theoretical understanding of ELS, locations of tower cranes, and locations of the construction joints of mega columns. For the ELS, it was concluded that the construction of a tower portion was on the critical path, and it was recommended to proceed into the excavation phase by phase so that the construction of the tower portion could be started earlier. Meanwhile, the retail portion could provide temporary storage for structural steel for the construction of the tower portion. It was concluded that there were some advantages and disadvantages no matter where the tower cranes were mounted. Locations of tower cranes are dependent upon project conditions. For the locations of the construction joints of mega columns, there is no doubt that the use of horizontal joints was better than the use of vertical joints.

在施工开始阶段，巨型柱子的每一个构件有3层楼高由两个部分构成。构件在现场通过垂直节点来连接。这样的优点是每次支模能完成3个楼层; 那么支模的总次数就能够减少。根据记录看来，这样每个楼层平均工期为7天。由之前项目的经验看来，每个楼层的平均工期是能够减少到4天的。这需要将巨型柱子每次支模的完成的高度控制在1-1.5层，不再进行垂直连接。这样施工速度从7天下降到了4天。此外，水平焊接和垂直焊接比起来，更容易控制焊接质量。同样，安全措施也更加易于控制和保证。垂直焊接需要有一个高达3个楼层也就是15m的脚手架，而水平焊接由于焊接 点都在同一个高度上，只需要在低于焊接的某一个高度有脚手架就可以。根据经验，保持水平焊接脚手架的稳定也比垂直焊接的要容易。此外，根据危险性较大的分部分项工程安全管理办法(2009)，跨度超过10m的脚手架都必须由专家审查小组进行审查，因此水平焊接不仅实际运作要好，审查流程也更为简单。总而言之，使用水平节点比起垂直节点各方面表现都要更好。图6.13是现场巨型柱子的安装。

总结

基于现项目进程中ELS、塔式起重机位置和CJ巨型柱子的位置几个方面上获得经验和理论理解的比较研究，我们知道: ELS方面，塔楼部分的施工是核心部分，因此推荐阶段性地进行地基开挖这样能早点开始塔楼部分的施工。同时裙房部分能够为塔楼部分施工中结构钢材提供一个临时性储存空间; 塔式起重机不论放在哪边都各有利弊。起重机的位置取决于哪一种选择能为项目带来更多的好处; 而对于巨型柱子施工节点的位置，毫无疑问水平节点远远优于垂直节点。

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