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Key Technologies for Super Tall Building Construction: Lotte World Tower

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Abstract

This paper addresses the key technologies for supertall building construction based on the Lotte World Tower project in Korea. First, the mega-mat foundation construction technologies are shown, including ultra-low heat concrete, heat of hydration control programs, and the logistics plan. Then, high strength concrete technologies of 50~80 MPa are introduced and discussed within the context of the highest pumping record in Korea at 514.25 meters. Structural design concepts of gravity load and lateral force resistance systems are introduced, along with surveying systems using GNSS and temporary installation plans of special heavy equipment like tower cranes, hoists, and high pressure concrete pumps. If it is possible to coordinate these key technologies and others, optimizing for the building's design and construction, supertall building construction can be successfully completed.

Keywords: Supertall building, Mat foundation construction, High strength concrete, Structural design, Logistic plan

1. Introduction

Skyscraper, super tall building in city is usually characterized as a landmark. Since Burj Khalifa was completed in 2010, which is the tallest building in the world as 828 m height (162 floors), many skyscrapers have been built around Middle East, China and Southeast Asia and skyscrapers' market in the world has increased consistently. For domestic cases in super tall buildings, most of them had been built as mixed-use apartments and the tallest one in Korea is the NEATT Tower (Incheon, 305 m). Lotte World Tower in Jamsil, Seoul will reach the goal of 555 m height/123 floors that is more than 100 floors, after completing the high-rise buildings that had been developed for 20 years, such as Dogok-dong project, Sangam project, etc. Lotte World Tower's structural framework has been completed on May in 2016 and interior finishing work is under construction.

For smooth construction, it is necessary to have experts who can manage technologies from material to maintenance, and apply them to the work. For example, 1) Material technology for high performance concrete and high-strength structural steel, 2) Construction technology for short construction cycle compared to scale, 3) Special equipment management skills such as tower crane, hoist and super high-pressure pump etc., 4) Structural technologies such as lateral load resisting system and column shortening analysis, 5) IT technologies such as PMIS, RFID, GPS system, 6) Design skills for complex use and special structure, 7) Highly advanced facilities and elevators, 8) Maintenance and Management for green energy technology. Therefore, it is necessary to develop and support those technologies.

In this article, construction technologies related with framework which are the key elements for building a skyscraper are introduced and discussed.

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2. Core Technologies for Super Tall Building Construction

The key element technologies of skyscrapers are construction of mega mat foundation delivering architectural load into the ground, structural system optimization, high-rise building measurement technology, and construction equipment technology, etc. Main features applied to Lotte World Tower are as follows.

2.1. Construction technology for the mega mat foundation

Mega mat foundation in Lotte World Tower delivers 750,000 tons of vertical loads to the ground. Also it is very important element because it secures the whole structural stability to maintain the structure's safety and usability resisting to lateral load.

Lotte World Tower's mat foundation is a super structure. The size of width and length is 71.7 m, 6.5 m thickness and total volume is 31,203 m^3 (Fig. 1). To secure structural integrity and construction period, it was casted by sin-

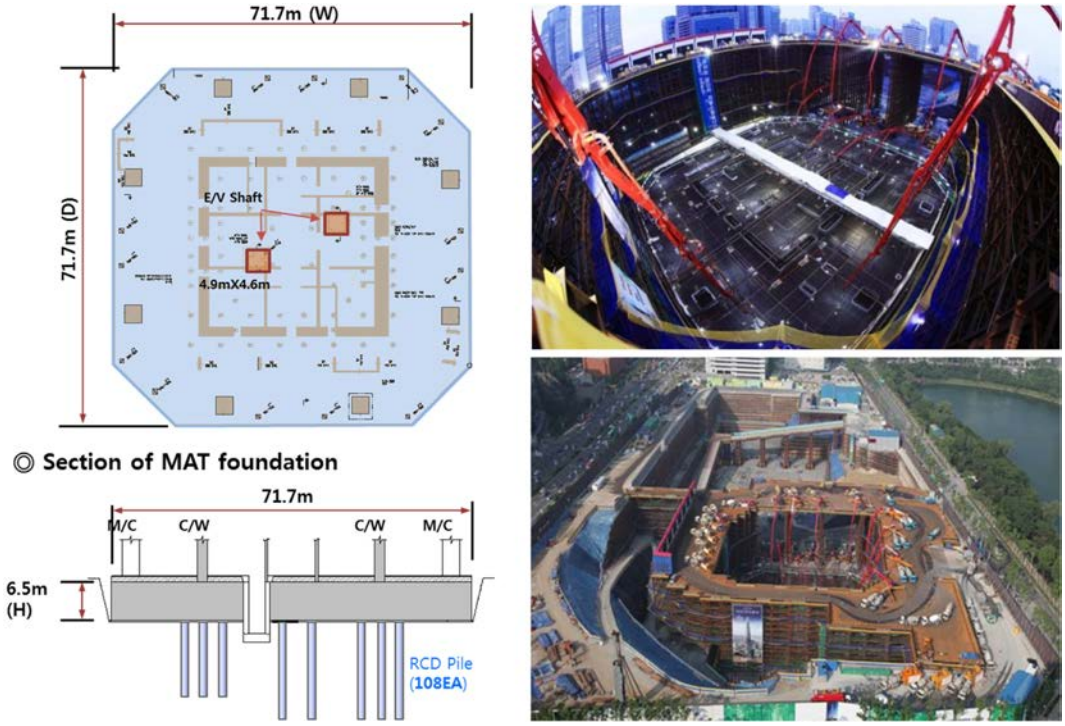


Figure 1. Lotte World Tower's Mat Foundation Size and Construction.

gle concrete placement. Steel rebar and couplers of 51 mm diameter were used and Bar-Chair system was applied to accommodate working condition under the 6.5 m thickness.. Also, High strength of 50 MPa and ultra-low heat concrete controlling hydration heat was self-developed (Patent Possession) and applied. The concrete's high quality construction was completed by preventing thermal cracks caused by the temperature difference between core and surface, through a lot of actual-sized mock-up experiments with hydration heat analysis and measurements.

In advance, two simulations for logistics were performed for perfect single pouring of concrete construction. According to the results of simulations, we used 5,300 trucks of ready-mixed concrete for 30 hours and completed placing concrete successfully. It was the largest scale in Korea and second largest scale in the world as skyscraper's mat foundation single pouring concrete.

2.2. High strength concrete technology

It is a vital to use high-strength concrete for skyscraper that requires high-speed construction and smaller cross-sectional structural members. Also, optimized concrete mix design and high level quality control for concrete engineering are essential to the construction management.

High-strength concretes that were used for Lotte World Tower's project are 50~80 MPa, presented as Table 1, and applied to mega-columns and core-walls for the vertical members, mat foundation, and flat slabs for the horizontal members according to floors.

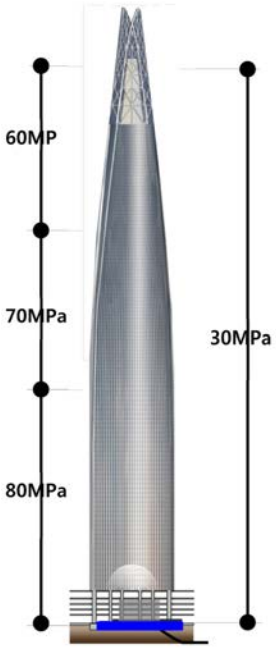
We finally optimized the mix proportions of concrete mix design from raw material analysis through lab trials as well as RMC (ready-mixed concrete) BP Test. After that, we did mock-up tests to perform quality control to satisfy 3 hours fire resisting capacity by using spalling resistance material for high-strength concrete, Poly-mix F (Patent possession). 80 MPa high-strength concrete was placed of total 77,255 m^3, which is the largest volumes for a sole project in Korea. Also low viscosity mix design and high-pressure pumping monitoring were performed consistently to secure high-pressure pumping performance so that it was reached the highest point 514.25 m at a time, which is the highest record in Korea (Fig. 2).

2.3. Structural design concept and maintenance system

Skyscraper's structural system could be classified as gravity resistance system and lateral force resistance system. Like Fig. 3, Lotte World Tower's gravity resistance system is consisted of core walls are located in the center up to 123th floor and 8 mega columns are located around perimeter and deck slab structure with steel beams. Core wall supports 60% of building loads and Mega columns support 40% of building loads (Fig. 4).

Also, lateral force resistance system is consist of outriggers and belt truss which were built on 39^{th}~44^{th} floors, 72^{nd}~76^{th} floors 104^{th}~107^{th} floors. Also, there are 671 measuring instruments such as tilt meter, an accelerometer, displacement meter and internal stress meter etc. installed to have real-time monitoring system during construction

Table 1. Summary of High Strength Concrete in Lotte World Tower



Floor (Height)	Vertical Members (MPa)			Horizontal Members (MPa)			
	Core Wall	Mega Column	Perimeter Column	Link Beam	Beam	Outer Slab	Core Slab
123F Roof (512.4m) ~ 78F(327.2m)	60	-	-	60	30	30	60
					50[1)]	50[1)]	30
77F(327.2m) ~ 76F(322.6m)	70			70	30	30	
75F(320.0m) ~ 45F(203.9m)		70					
44F(200.0m) ~ 1F(0.0m)	80	80		80			
1F(0.0m) ~ B5(-27.1m)			40				
B5(-27.1m) ~ B6(-31.6m)			80				
Foundation (-38.1m)	-			50 (SCC)			

1) 87F~102F: Hotel Flat Slab (50 MPa)

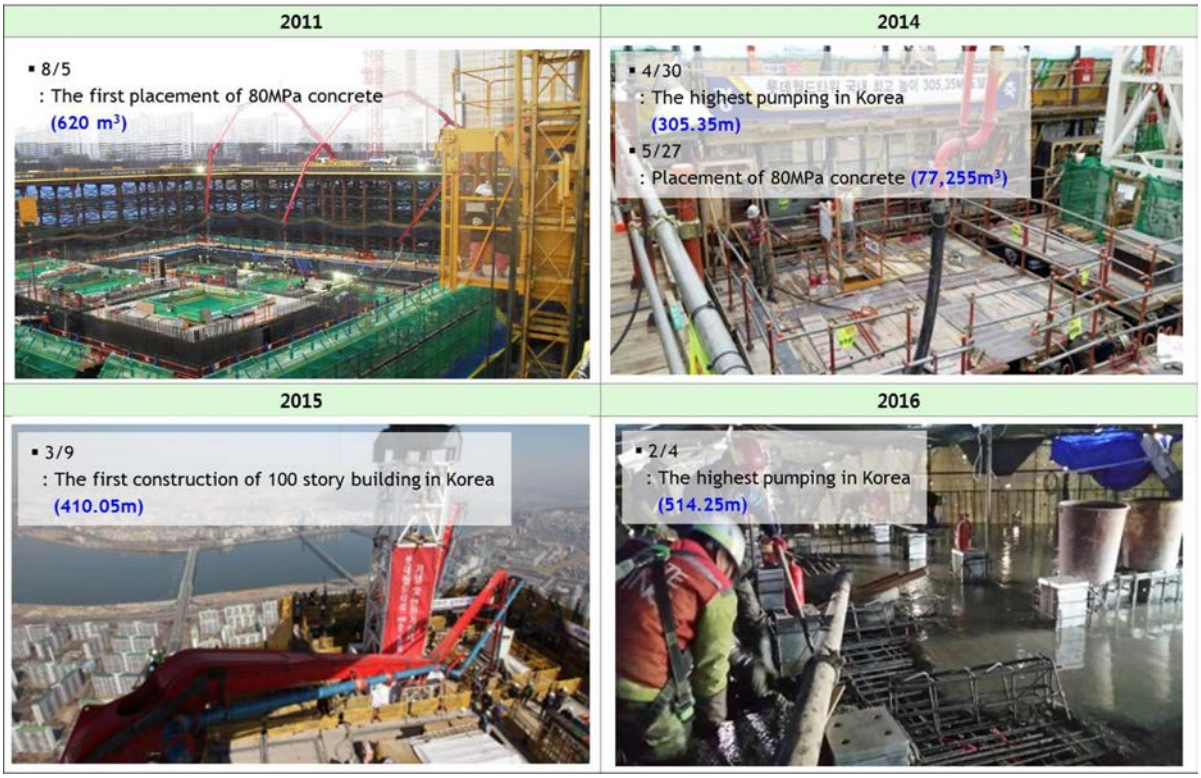


Figure 2. Major events of high strength concreting (2011~2016).

period or after its completion for skyscraper's structural stability, which is called as SHM (Structural Health Monitoring) System for measuring and analyzing structural response caused by wind load, earthquake, etc. The system is very important and essential technology that can maintain super structure safe condition.

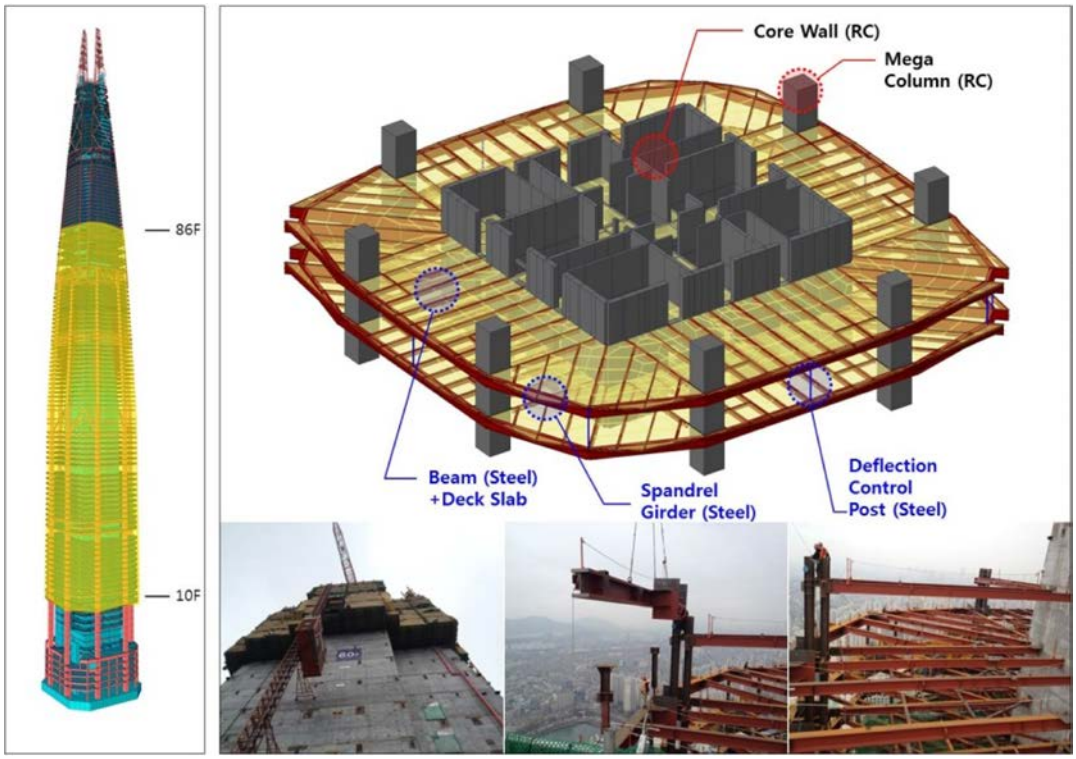


Figure 3. Lotte World Tower Gravity Resistance System and Construction.

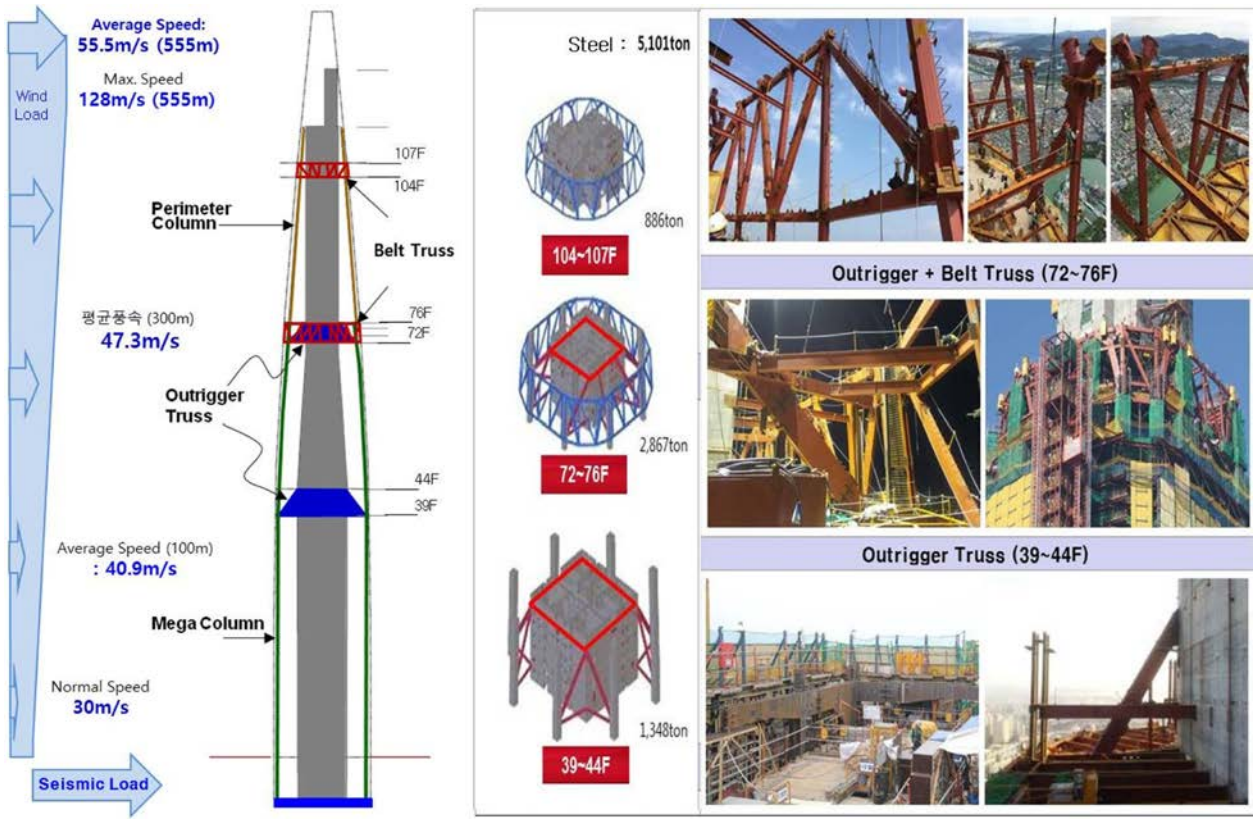


Figure 4. Lotte World Tower Lateral Force Resistance System and Construction.

2.4. Surveying technology in super tall building

It is very important to build vertically accurately in a super tall building construction. If the verticality of construction is wrong, the building cannot stand vertically and maintain the healthy condition. As a result, the building cannot resist a vertical and lateral load safely. The building becomes taller, surveying technology become more important.

Lotte World Tower uses a GNSS (Global Navigation Satellite Systems) by using over 3 rotating satellites around the earth. It allows to perform measurement without external environment such as climate change and time so that construction could be done in the righ time. Also, it improves degree of precision and accuracy and strictly manages straightness by monitoring the building's real-time movement. According to ACI specification standard, a guidance for straightness is intensified as 75 mm than 150 mm, but the actual construction was managed as 25 mm. Fig. 5 shows that receivers on top of the structure, receiving satellite signals to manage straightness and Lotte World Tower's GNSS concept diagrams.

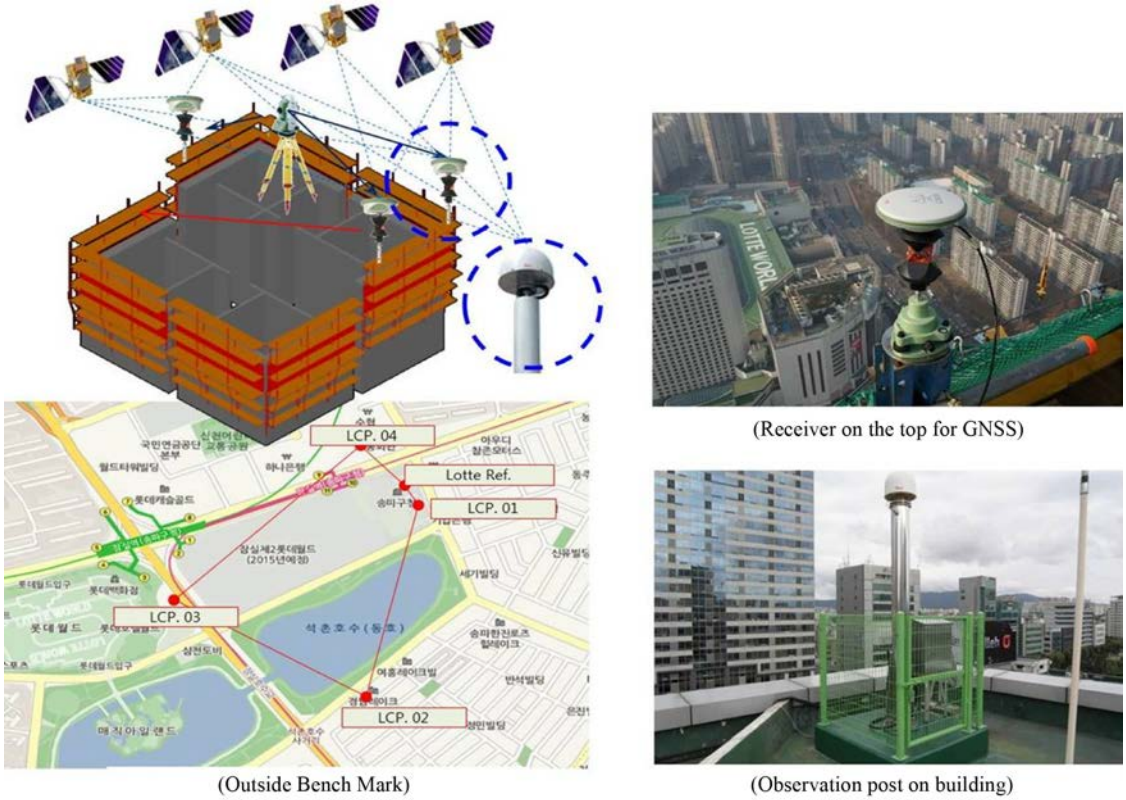
2.5. Special heavy equipment

For skyscraper construction, there are special equipment such as tower crane, hoist and high-pressure concrete pump. There are four luffing type tower cranes. Two of them can lift maximum 64 tons of things, and the others can lift 32 tons large construction material and equipment (Fig. 6).

Hoist is an essential transportation equipment for workers and materials in constructing a tall building. Hoist's plan should consider lifting load at the peak moment of construction site. The hoist is important machinery because it is in charge of lifting material and workers efficiently. Also elevators' operation plan for construction is an important method to moving them. Especially, we need to calculate the number of hoists and select its location and types, to minimize interference between the site condition and construction sequence. If common tower is used for the skyscraper, its demolition plan should be also considered. Lotte World Tower installed common tower to deal with facade slope and used 8 high-speed hoists up until 79 floors. At the top part of the building, 2nd common tower was used for lifting materials and workers, and shuttle hoist was installed for upper part of interior construction. At this point in time, common tower and hoists were all demolished except for 3rd hoist inside (Fig. 7).

It is necessary to install and operate high-pressure pumping, piping and CPB (Concrete Placing Boom) to do pumping high-performance concrete to more than 500 m height (which is delivered to the site by using ready-mixed concrete).

In case of high-pressure concrete pumps, the pipe should be selected after calculating its capacity based on maximum pumping height, expected pumping pressure and concrete



(Outside Bench Mark)

(Receiver on the top for GNSS)

(Observation post on building)

Figure 5. GNSS Surveying system in Lotte world tower.

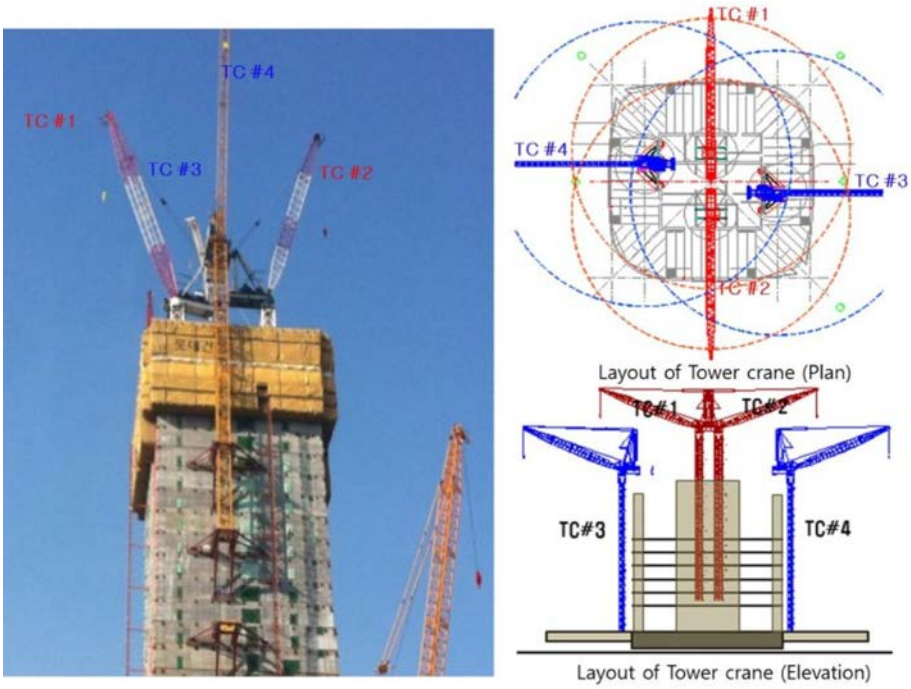


Figure 6. Tower Crane installation plan in Lotte World Tower.

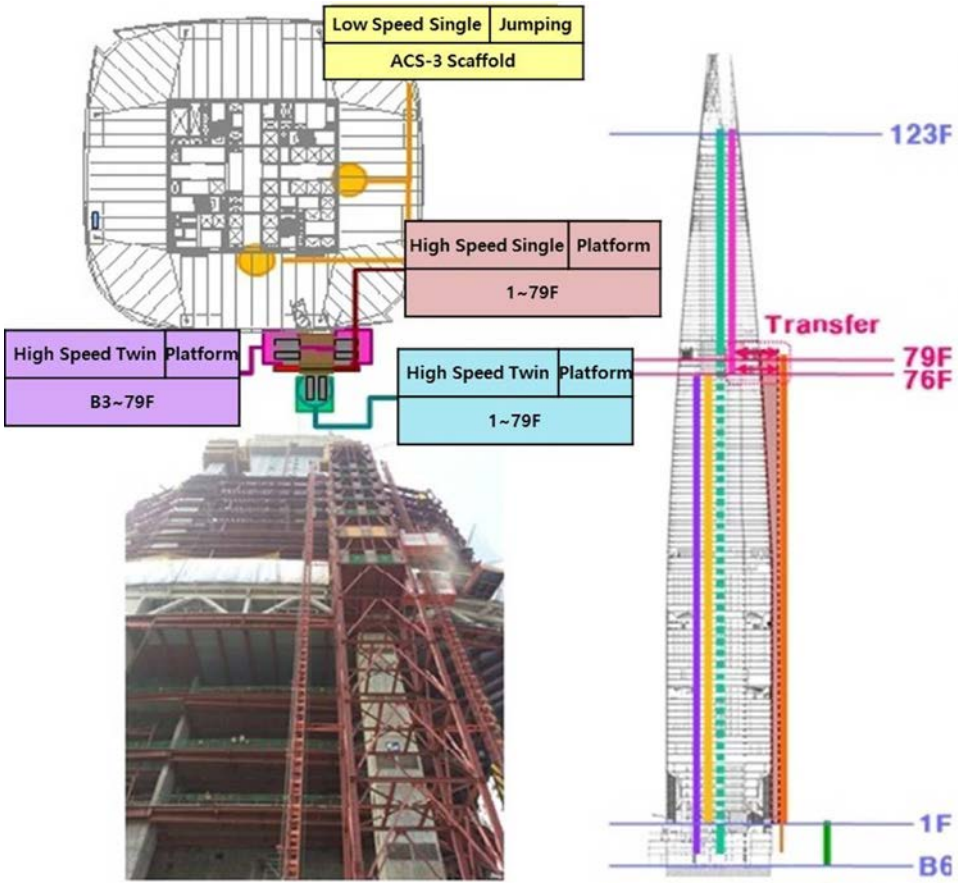


Figure 7. Hoist installation plan in Lotte world tower.

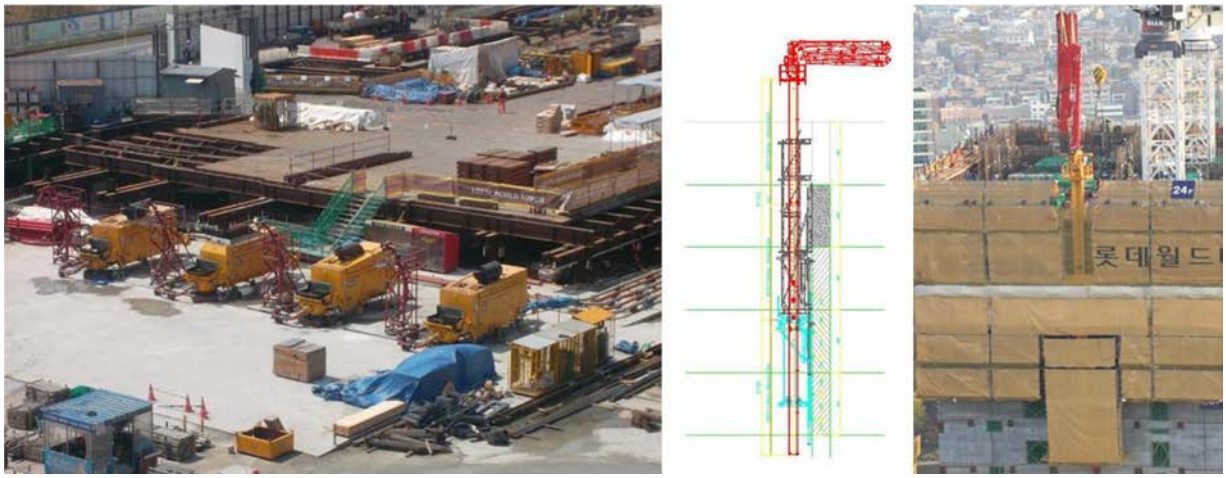


Figure 8. High pressure concrete pumps & CPB installation in Lotte world tower.

pumping volume per hour. High-pressure pumping diameter and thickness should be determined after considering high-pressure pumping load. Also, CPB (Concrete Placing Boom)'s types and locations should be selected based on concrete placing radius and changes of building plan. Lotte World Tower installed and operated 4 high-pressure pumps that have maximum 777 horsepower outputs, 7 high-pressure pipes, and 3 CPB according to construction period. Figs. 6~8 shows Lotte World Tower's tower crane, hoist and high-pressure equipment plan and installation perspective.

3. Conclusions

Besides these things, the key technologies of skyscrapers can be classified as RC (Reinforced Concrete) construction's essential elements such as a mold and steel works, construction plan, welding quality control for high strength steel, engineering for the special steel-frame works and construction method, optimized processing method for curtain wall system based on result analysis, a temporary construction plan, high-pressure concrete pumping technology, MEP (Mechanical, Electrical, Plumbing) and safety management system that are all specialized for skyscrapers.

Super Tall Building construction could be successfully completed if it is possible to coordinate various technologies optimizing for the building's design and construction, and applying them to business practice. These could be done with accumulating lots of construction data. As a result, our construction experience and accumulated technologies from Lotte World Tower, which is the tallest building in Korea, will contribute remarkably to improve Korea's skyscraper engineering and construction technologies.

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