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## Brief on the Construction Planning of the Burj Dubai Project, Dubai, UAE

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### Biography

Ahmad Abdelrazaq is Vice President and Executive Director of the Highrise Building and Structural Engineering Divisions at Samsung Corporation. Since joining Samsung in 2003, he has been involved in the construction planning and structural design of several local and international projects, including the Burj Dubai Project, the Samsung Seocho Project in Seoul Korea, and currently performing pre-construction services for the Y22 project in Seoul, Korea, and several major projects in the Middle East.

Prior to Joining Samsung, Mr. Abdelrazaq was Associate Partner and Senior Project Structural Engineer with Skidmore Owings and Merrill in Chicago, where he was engaged in all aspects of structural engineering works, from planning/feasibility studies to completed construction documents and construction administration. Mr. Abdelrazaq has extensive experience in the design of buildings ranging from low-rise to ultra high-rise, and long span structures. Some of the notable projects during his tenure at SOM included the Burj Dubai Project, Jin Mao Tower, Tower Palace III, LG Kangnam Tower, LG Art Center, Chicago Place, Hotel Vila Olympica, and the Millennium Park Project.

Presently Mr. Abdelrazaq serves also as a lecturer at Seoul National University, where he teaches a high rise building design course for graduate students. He also served as an adjunct professor at the Illinois Institute of Technology's School of Architecture, where his commitment to the development of innovative structural systems was reflected in his research on concrete/steel/composite structural systems, and the shaping of supertall buildings to control their dynamic response to wind excitations. He is also involved in a National Science Foundation grant project to monitor the response of high rise buildings to wind effects.

Mr. Abdelrazaq has published numerous papers on special engineering topics and lectures frequently at universities and international professional organizations. He pursues a collaborative approach to integrating the architectural and engineering design with construction methods, to achieve a unified and economical design.

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### Abstract

The Burj Dubai Project will be the tallest structure ever built by man; when completed the tower will be more than 700 meters tall and more than 160 floors. The early integration of aerodynamic shaping and wind engineering considerations played a major role in the architectural massing and design of this residential tower, where mitigating and taming the dynamic wind effects was one of the most important design criteria. While the focus of this paper will be on the construction planning of the tower, this paper will briefly present an overview of the structural system of the tower's design and construction, which are integrated from the early design concept.

**Keywords:** Burj Dubai, Planning, Engineering, Construction, Material

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### Introduction

The Burj Dubai Project is a multi-use development tower with a total floor area of 460,000 square meters that includes residential, hotel, commercial, office, entertainment, shopping, leisure, and parking facilities. The Burj Dubai project is designed to be the centerpiece of the large scale Burj Dubai Development that rises into the sky to an unprecedented height that exceeds 700 meters and that consists of more than 160 floors.

The Client of Burj Dubai Tower, Emaar Properties, is a major developer of lifestyle real estate in the Middle East. Turner International has been designated by the owner as the Construction Manager, and Samsung Joint Venture (consisting of Samsung, Korea base contractor; Besix, Belgium base contractor; and Arabtec, Dubai base contractor) as the General Contractor.

The design of Burj Dubai Tower is derived from geometries of the desert flower, which is indigenous to the region, and the patterning systems embodied in Islamic architecture.

The tower massing is organized around a central core with three wings. Each wing consists of four bays. At every seventh floor, one outer bay peels away as the structure spirals into the sky. Unlike many super-highrise buildings with deep floor plates, the Y-shape floor plans of Burj Dubai maximize views and



Figure 1: Burj Dubai Artist's Rendering

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\* The author was involved in the development of the structural systems of the Burj Dubai Project while at SOM, as the Senior Project Engineer.

provide tenants with plenty of natural light. The modular Y-shaped building, with a setback at every seventh floor, was part of the original design concept that allowed Skidmore, Owings and Merrill to win the invited design competition.

The tower superstructure of Burj Dubai is designed as an all reinforced concrete building with high performance concrete from the foundation level to level 156, and is topped with a structural steel braced frame from level 156 to the pinnacle.

The tower massing is also driven by wind engineering requirements to reduce dynamic wind excitation. As the tower spirals into the sky, the building's width and shape diminish, thus reducing wind dynamic effects, movement, and acceleration. Integrating wind engineering principals and requirements into the architectural design of the tower results in a stable dynamic response,, taming the powerful wind forces.

**Structural System Brief Description**

**Lateral Load Resisting System**

The tower's lateral load resisting system consists of high performance, reinforced concrete ductile core walls linked to the exterior reinforced concrete columns through a series of reinforced concrete shear wall panels at the mechanical levels.

The core walls vary in thickness from 1300mm to 500mm. The core walls are typically linked through a series of 800mm to 1100mm deep reinforced concrete or composite link beams at every level. Due to the limitation on the link beam depth, ductile composite link beams are provided in certain areas of the core wall system. These composite ductile link beams typically consist of steel shear plates, or structural steel built-up I-shaped beams, with shear studs embedded in the concrete section. The link beam width typically matches the adjacent core wall thickness.

At the top of the center reinforced concrete core wall, a very tall spire tops the building, making it the tallest tower in the world for all categories. The lateral load resisting system of the spire consists of a diagonal structural steel bracing system at level 156.

**Floor Framing System**

The residential and hotel floor framing system of the Tower consists of 200mm to 300mm two-way reinforced concrete flat plate slabs spanning approximately 9 meters between the exterior columns and the interior core wall. The floor framing system at the tips of the tower floor consists of a 225mm to 250mm two-way reinforced concrete flat plate system. The floor framing system within the interior core consists of a two way reinforced concrete flat plate system with beams.

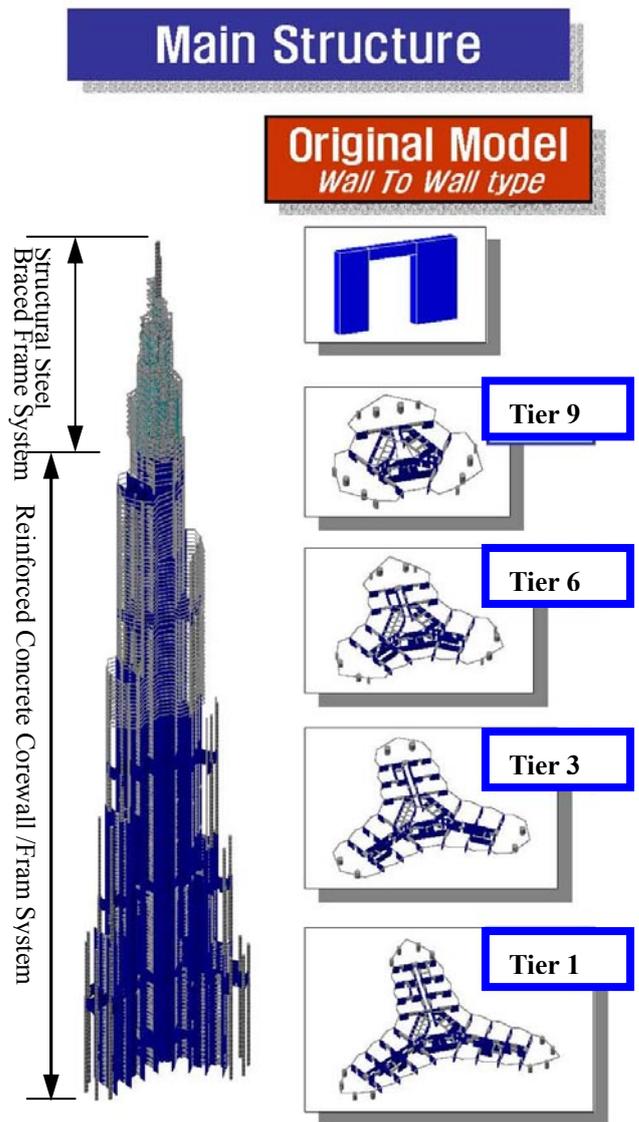


Figure 2: Lateral Load Resisting System

**Foundation System**

The Tower is founded on a 3700mm thick high performance reinforced concrete pile supported raft foundation at -7.55 DMD. The reinforced concrete raft foundation utilizes high performance Self Compacting Concrete (SCC) and is placed over a minimum 100mm blinding slab over waterproofing membrane, over at least 50mm blinding slab. The raft foundation bottom and all sides are protected with waterproofing membrane. See Figure 3 for the Raft Foundation System.

The piles are 1500mm diameter, high performance reinforced concrete bored piles, extending approximately 45 meters below the base of the raft. All piles utilize self compacting concrete (SCC) with w/c ratio not exceeding 0.30, placed in one continuous concrete pour using the tremie method. The final pile elevations are founded at -55 DMD to achieve the assumed pile capacities of 3000Tonnes.

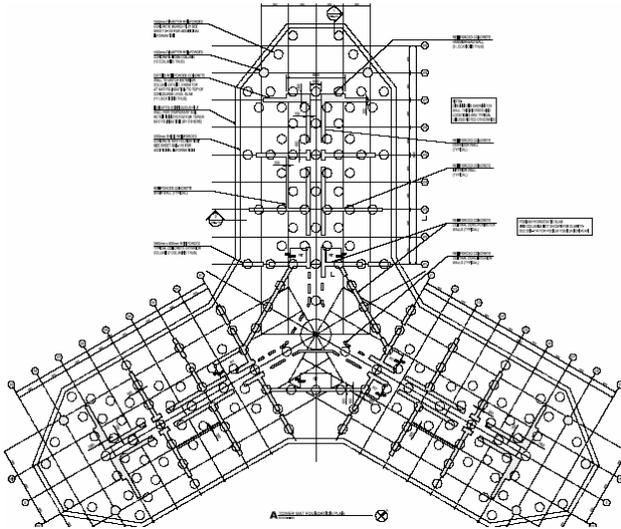


Figure 3: Raft Foundation System

A robust cathodic protection system for both the bored piles and the raft foundation system protects the foundation and the reinforced concrete raft against the severe and corrosive environment (chloride and sulfate) of the soil at the Burj Dubai site.

### Construction of the Tower Superstructure

Currently the tower is under construction and the foundation system (pile & raft) were completed in February 2005, including pile foundation and the raft foundation. The tower superstructure construction started in April 2005.



Figure 4: Tower Raft Foundation

The original construction program is very tight. To complete the project within 48 months, Samsung, Besix, Arabtech Joint Venture (SBAJV) established the following strategic approach:

- Achieve a three (3) day-cycle for structural works.
- Develop optimum transportation systems with large capacity high speed equipment.
- Utilize optimum formwork system to

accommodate various building shapes along the building height.

- Develop organized logistic plans throughout the construction period.
- Apply all high-rise construction technologies available at the time of construction.

Since the construction planning is extensive and cannot be covered in detail in this paper, only a brief summary of the major construction planning works will be covered in this paper.

### Planning for the Concrete Work

Prior to the construction of the tower, extensive concrete testing and quality control programs were put in place to ensure that all concrete works are done in agreement with all parties involved, including the supervision consultant (Hyder), the owner independent testing agency (IVTA), the concrete supplier (Unimix) top quality team, CTL, and Samsung Engineering and Construction Task force team. These programs started from the early development of the concrete mix design until the completion of all test and verification programs. The testing regimes included, but were not limited to the following programs:

- Trial mix designs for all concrete types needed for the project.
- Mechanical properties, including compressive strength, modulus of elasticity, and split tensile strength.
- Durability tests which included initial surface absorption test and 30 minute absorption test.
- Creep and shrinkage test program for all concrete mix design (see Figure 5 for testing setup).
- Water penetration tests and rapid chloride permeability test.
- Shrinkage test program for all concrete mix designs.
- Pump simulation test for all concrete mix design grades up to at least 600 meters (see Figure 6 for test setup).



Figure 5: Creep Test

- Heat of hydration analysis and tests, which include cube analysis and tests, and full scale

heat of hydration mock tests for all the massive concrete elements that have a dimension in excess of 1.0 meter. These tests are needed to confirm the construction sequence of these large elements and to develop curing plans that are appropriate for the project, considering major daily and seasonal temperature fluctuations. See Figure 7 for test setup.



Figure 6: Pump Simulation Test



Figure 7: Heat of Hydration Mockup Test

### Site Logistic Plan

The Burj Dubai site area is approximately 105,600m<sup>2</sup> and encompassing the tower, the office annex, the pool annex, and the parking areas, divided into three zones (Zone A, Zone B, and Zone C). The site logistic works and planning works are constantly evolving to

reflect current construction activities, lay-down areas, site traffic circulation, etc. Figure 8 below provides a snapshot of the site logistic plan after 14 months of construction.



Figure 8: Snap Shot of Site Logistic Plan (M+14)

### Technologies used to achieve 3-day cycle

The tower consists of more than 160 floors and is expected to be completed within a very tight schedule and 3-day cycle. Hence, the following key construction technologies were incorporated to achieve the 3-day cycle set for the concrete works:

- Auto Climbing formwork system (ACS)
- Rebar pre-fabrication
- High performance concrete suitable for providing high strength, high durability requirement, high modulus, and pumping
- Advanced concrete pumping technology
- Simple drop head formwork system that can be dismantled and assembled quickly with minimum labor requirements
- Column/Wall proceeding method, part of ACS formwork system

### Sequence of Construction and ACS

Figures 9 and 10 depict the construction sequence of the tower and show the auto climbing formwork system (ACS), designed by Doka. The ACS form work is divided into four sections consisting of the center core wall that is followed by the wing wall construction along each of the three tower wings. Figure 10 also demonstrates the following construction sequence:

- the center core wall construction is followed by the center core slab construction;
- the wing wall construction is followed by the wing flat plate slab construction; and
- the nose columns are followed by flat plate and flat slab construction at the nose area.

In addition, the core walls are tied to the nose columns through a series of multi-story outrigger walls at each of the mechanical levels.

The construction of these outrigger walls are complex and time consuming because of the congestion of reinforcing bars at the connection zones. Therefore, the reinforcing bars are now replaced with structural steel sections to help resolve the design forces more effectively at the joints, eliminated the reinforcing bar congestion issues, and most importantly ensuring the joint integrity. These levels were constructed at a later stage and taken out of the critical path.

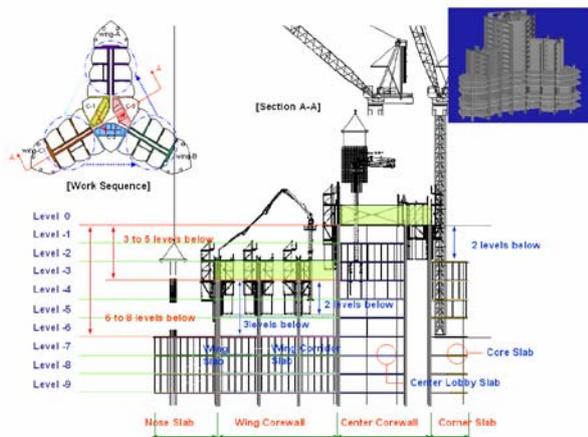


Figure 9: Sequence of Construction

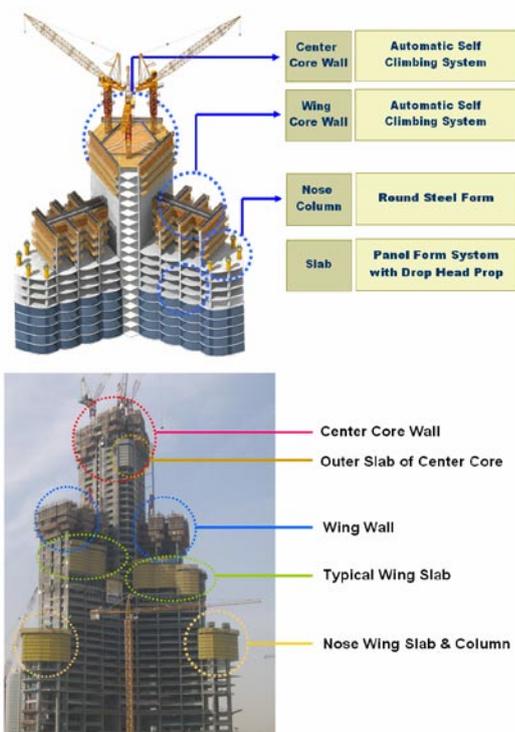


Figure 10: Sequence of Construction

### Rebar Pre-fabrication

Most of the reinforcing bars for the core walls, wing walls, and the nose columns were prefabricated at the ground level as shown in Figure 11. This rebar fabrication and pre-assembly method resulted in many quality control advantages and reduced the number of workers going up and down the tower. Moreover, whenever possible, the rebar was assembled in double story modules to speed up the vertical element construction time.



Figure 11: Rebar Prefabrication

### Composite Link Beams

In addition to connecting the vertical core wall elements rigidly for maximum strength and stiffness for the lateral load resisting system, the link beams are also used as means of transferring and equalizing the gravity loads between the vertical members (core-wall elements and nose columns). This equalizes stresses and strains between the members. Because the link beams are subject to large shears and bending moments, many of the link beams had to be composite (steel members encased in high strength concrete). Thus the steel beams imposed special demands on the cranes, pre-assembly and lifting methods. Figure 12 depicts the composite link beam pre-assembly and installation method.



Figure 12: Composite Link Beam Installation

### Slab Formwork System

Figure 13 shows a drop head system used for the slab construction. Meva Deck Drop Head slab formwork system was selected because of its installation simplicity, lightness, panel formwork material and strength, prop

strength and stiffness, system flexibility and suitability for the slab hanging geometry, and allowance for cambering where needed.

>Beam&Panel+Drop Head Prop Method  
>Aluminium Framed Panel with composite Plastic Sheet.



Figure 13: Typical Slab Formwork System

The slab shoring system consists of four levels of shores and one level of re-shore to control the maximum loads in the slabs at the lowest level. However, the shoring props at the upper-most slab were left undisturbed Figure 14 provides an outline of the slab construction methodology used.

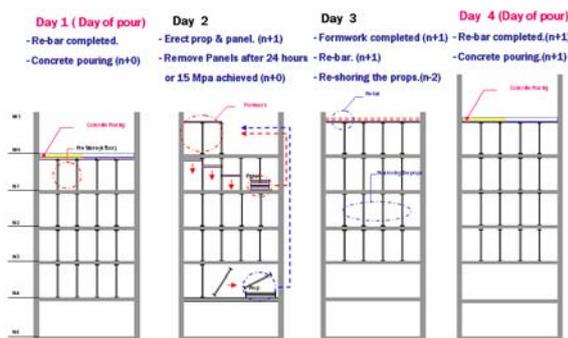


Figure 14: Outline of slab Construction Method.

### Concrete Pumping

The utilization of high strength concrete and concrete pumping technologies was critical in the construction of the project. See Table 1 for a summary of the concrete types used for both the vertical and horizontal members.

Table 1. Grade of Concrete in Tower

Table 1. Grade of Concrete in Tower		
Level	Concrete Grade	
	Vertical	Horizontal
L154~L156	C60/14	C50/20
L101~L126	C80/14	
B2~L101	C80A/20	

Direct concrete pumping and delivery methods

required considerations for the following:

- selecting an optimum concrete mix design with excellent flow characteristics to minimize/avoid blockages;
- choosing equipment that has enough capacity to deliver concrete to the highest level, more than 160 floors up;
- designing a pipe line that can be installed with maximum construction efficiency;
- selecting equipment and pipe line system that work well with the site's overall logistics and planning; and
- maintaining quality control of the pumping system and placement method by monitoring all components of the system and ensuring the concrete properties required.

A horizontal pump simulation test, shown in Figure 6, was performed, using over 600m of pipe length to confirm the pump capacity and evaluate the overall pressure losses in the pipes due to friction/connections/concrete type, etc. BSA-14000-SHP-D Putzmeister was utilized for all concrete grades. See also table 2 for a summary of the horizontal pump simulation system.

Table 2. Summary of Pumping Simulation

Table 2. Summary of Pumping Simulation (Horizontal line)	
Pumping Length	- 250m, 450m, 600m
Pipe Diameter	- 125mm (5inch)
Grade of Concrete	- C80A/2, C80/14, C60/14, C50/20
Pressure Measuring	- Hydraulic & Delivery Pressure, Strokes
Concrete Testing	- Flow, Temperature, Strength
Concrete Properties (/100m pumping)	- Flow loss: 25~30mm - Temp. increment: 0.8~1.0°C - Early Strength: 30%
Expected Con. Pressure (vertical - 6" pipe)	- C80A/20 (250m) : 151 bar - C80/14 (450m) : 170 bar - C60/14 (600m) : 209 bar - C50/20 (600m) : 199 bar

### Major Equipment

The process of selecting the right equipment to ensure delivery of materials and workers effectively and efficiently is an art in its own right. Selecting the optimal equipment and vertical transportation system for construction requires ongoing analysis and constant modifications due to the dynamic nature of the project during its construction life.

Since the project is more than 160 floors, close coordination of many overlapping activities of various trades, throughout the construction period, required careful planning, analysis, scheduling, and regular coordination. The process of selecting equipment for this project was extensive and cannot be adequately described in detail in this paper. Therefore, only a brief

summary of the equipment used for the project will be provided and it includes cranes, hoists, and concrete pumping equipment.

### Tower Cranes

Three high capacity self climbing luffing type tower cranes were optimally selected and located at the center core of the tower as shown in Figures 10 and 15. A summary of the tower crane specifications utilized for the project is shown in Figure 15.

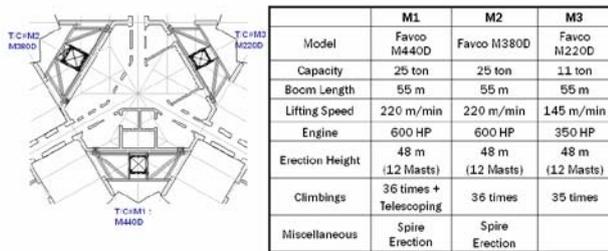


Figure 15: Tower Crane Types and Location.

### Tower Main Hoist

Figure 16 depicts the location of the main hoists and the hoist specifications. The hoists were installed in three different phases following the construction sequence of the tower. Additional Jump hoists were installed in accordance with the specifications shown in figure 16.

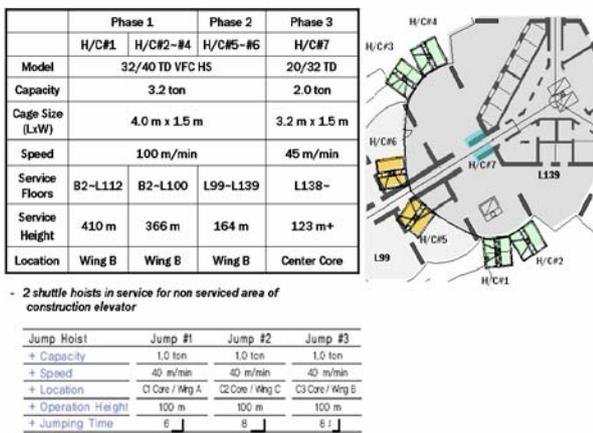


Figure 16: Tower Main Hoists System

### Concrete Pumping Equipment

While the horizontal concrete pump simulation test was very successful and indicative that re-pumping was not required, pumping the concrete vertically and under different environmental conditions could potentially present unexpected complications. Therefore, a secondary pump at level 124 was in place in case of an emergency situation.

Three major pumps were placed at the ground level as shown in Figure 17 and 4. Pumping line 1 situated at the center core, with pumping lines 2, 3 and 4 at the south, west, and east wings of the core. An additional

pumping line 5 was located at the center core area for emergency use. At the time of writing this paper, the secondary pump has not been used and most of the concrete has been pumped directly to the highest concrete elevation, that in excess of 585m.

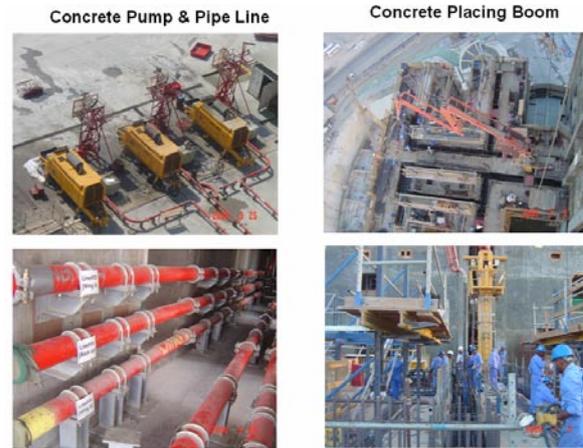
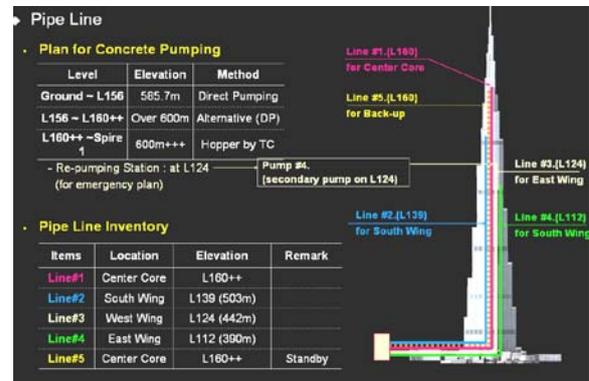


Figure 17: Tower Pump Equipment and Pipe Lines

### Spire Erection and Pinnacle Assembly and Lifting Method.

At Level 156, the reinforced concrete core wall will reach its highest point and serves as the foundation for the spire's structural steel works. The central pinnacle structure, which consists of 1200mm-2100mm diameter structural steel pipe, varies in thickness from 60mm at the lowest level to 30mm at the top.

The structural steel works above level 156 consists of the spire structure surrounding the central spine pinnacle structure, and provides the basis for its lateral support and stability. The spire structural system consists of an exterior diagonal braced frame system to provide for the lateral stability system. While the spire structural steel works is fabricated in Dubai, the pinnacle structure is procured and made in Korea and shipped to Dubai for final fabrications and assembly.

The erection of the spire and the pinnacle starts from level 156, and the erection of the spire was done in traditional steel construction method. However, the pinnacle pipe sections are stacked from level 156 and lifted to the final position from within the spire as shown

in Figure 18.

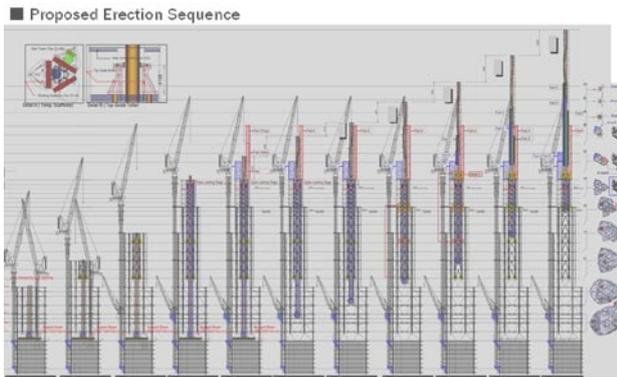


Figure 18: Spire & Pinnacle Erection and the Pinnacle Lift-up method.

The lift of the pinnacle will occur in three steps. After each lifting step, the cladding on the pinnacle will be completely installed. The sequence of the pinnacle installation is shown in Figure 19 and as follows:

- Erection of the spire structure
- Installation of the support beam
- Installation of the lifting block and assemblies
- Installation of the lifting equipment and assemblies
- Lifting the pinnacle in a three step process
- Installing cladding after each lift
- Completing lift of the pinnacle and all connection connections (gravity and lateral)
- Completion of the cladding installation

### Conclusion

At the turn of the century, concrete construction was at its infancy and nobody then could have dreamed of creating a building this tall using concrete. The Burj Dubai project demonstrates that tall building system development is always directly related to the latest developments in material technologies, structural engineering theories, wind engineering, seismic engineering, computer technologies, and construction methods. The Burj Dubai project capitalizes on advancements in these technologies, advancing the development of supertall buildings and the art of structural engineering.

As of today, the Burj Dubai is the tallest man made structure in the world in all categories, and it has become a catalyst for further development in highrise construction in the Middle East and throughout the world. The Burj Dubai project is another step forward in

meeting the technological challenges of future construction.

### □ Spire/Pinnacle Installation Sequence

- ❖ Erection of Spire
- ❖ Install Pinnacle Support Beam
- ❖ Install Pinnacle lifting block & Assembly
- ❖ Install Lifting Equipment and Assemblies
- ❖ Lifting the pinnacle in three step process
- ❖ Install cladding at pinnacle after each lift and prior to the next lift.
- ❖ Complete lifting, secure all connection (gravity and lateral)
- ❖ Complete cladding works

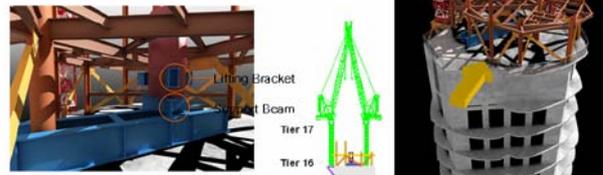


Figure 19: Spire and Pinnacle Erection



Figure 20: Construction Progress Photos