

Structural Engineering of World's Tallest Building Burj Khalifa (Dubai)

An Online Continuing Education Course for Engineers

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Structural Engineering of World's Tallest Building Burj Khalifa (Dubai)

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1. Introduction

Burj Khalifa, the 2717 feet (828 meters) skyscraper in Dubai, is the tallest building in the world and also the tallest freestanding structure in the world (Figure 1). For comparison, the second tallest building Taipei Financial Center (Taipei 101) in Taiwan is 1671 feet (509 meters) tall. The top floor of Burj Khalifa's reinforced concrete building (tower) is at 2,038 feet (621.3 meters), and above the building is a steel spire that houses some of the communication equipment. The building is utilized for retail, residential and office space as well as the Giorgio Armani Hotel. Seven double-story height mechanical floors house the electrical and mechanical equipment. These mechanical floors are located at every 30 or so stories. Communication equipments are located at the top four floors as well as in the steel spire.

Since people cannot reasonably be expected to walk down 160 floors in case of emergencies like a major fire, there are pressurized, air-conditioned refuge areas located approximately every 25 floors. Such refuge floors or refuge rooms are available in some other tall buildings too, for example the 88 story, 1483 feet tall Petronas Towers (Malaysia) and 101 story, 1671 feet tall Taipei Financial Center (Taiwan).

The building used 431,600 cubic yards (330,000 cubic meters) of concrete and 39,000 tons of steel rebar. The spire used more than 4,000 tons of structural steel. Work on Burj Khalifa started in January 2004 and it officially opened in January 2010. It took 22 million person-hours to construct Burj Khalifa.



Figure 1: Photograph of Burj Khalifa

Skidmore, Owings and Merrill (SOM) designed Burj Khalifa. Designing a complex building such as the Burj Khalifa involves many areas of structural engineering. We discuss here some of the structural analysis, design and construction aspects.

2. Architectural Description

The “Y-shaped” tower is composed of three “lobes (wings)” arranged around a hexagonal central core (Figures 2, 3). The Y-shaped floor plan allows occupants the maximum views outward without overlooking a neighboring unit. The wings contain the residential condominium units and hotel guest rooms, with the central core housing the elevators and mechanical equipment.

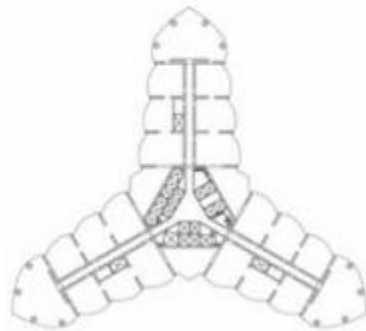


Figure 2: Plan View of the Tower



Figure 3: Photographic Plan View of Tower during Construction

As the tower rises, one wing at each tier sets back in an upward spiraling pattern, decreasing the cross section of the tower incrementally. There are 26 such setbacks. Only the central core remains at the top of the tower. On top of the tower is the steel spire. Floor plans at three elevations are shown in Figure 4 illustrating the incrementally decreasing cross section as the tower rises. Figure 1 also shows how the cross section decreases in a step-by-step fashion as the elevation increases.

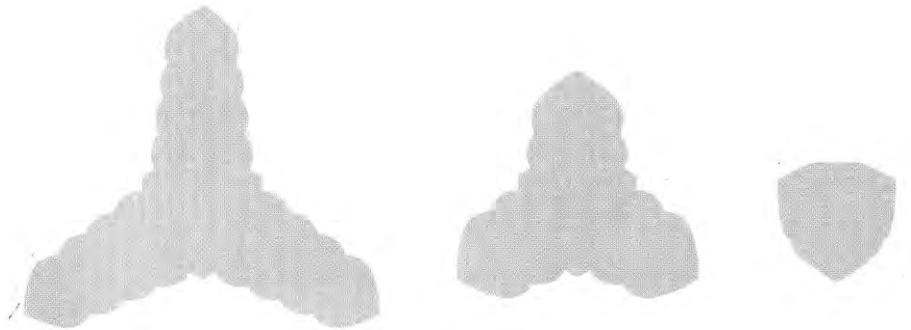


Figure 4: Floor Plan at Ground Level, at an Intermediate Elevation and at the Top of the Tower

3. Structural System

The structural system is described as a “buttressed core”. The three lobes (wings) have corridor walls extending from the hexagonal central core to near the end of each wing, terminating in thickened hammerhead walls. Each of the wings buttresses the others via the central core. The hexagonal core provides the torsional resistance of the structure, similar to a closed pipe. The corridor walls and hammerhead walls act like the webs and flanges of a vertical cantilever beam to resist wind shears and moments. There are a few perimeter columns at the end of each wing, supporting the flat plate floors. At mechanical floors, outrigger walls are provided to link the perimeter columns to the interior wall system, allowing the perimeter columns to participate in the lateral load resistance of the structure. Thus all of the “vertical concrete” is utilized to support both gravity and lateral loads.

4. Foundation

Foundation consists of pile-supported reinforced concrete mat. The mat is 3.7 meters (12.1 feet) thick, and was constructed in four separate pours (three wings and the center core) totaling 12500 cubic meters (16350 cubic yards) of concrete. Reinforcement was typically at 300mm (almost 12

inches) spacing in the mat and arranged such that every 10th bar in each direction was omitted, resulting in a series of 600mm x 600mm openings at regular intervals facilitating access and concrete placement.

There are almost 200 piles. These bored cast-in-place reinforced concrete piles are 1.5 meters diameter and 43 meters long (4.9 feet diameter and 141 feet long). Concrete mix for the piles had 25% fly ash and 7% silica fume. Each pile has a design capacity of 3000 metric tons (3300 tons). These friction piles are supported in the naturally cemented calcisiltite formations, developing an ultimate pile skin friction of 250 to 350 kPa (2.6 to 3.6 tons/sft). When the rebar cage was placed in the piles, special attention was paid to orient the rebar cage such that the mat bottom rebar could be threaded through the pile rebar cages without interruption.

Extensive site geotechnical investigation was conducted with dozens of boreholes. A three-dimensional foundation settlement analysis was carried out based on the results of the geotechnical investigation and pile load tests. Predicted maximum long-term settlement is 80mm (3.1"). In comparison, when the construction was at Level 135, the measured average foundation settlement was 30mm (1.2").

Chloride and sulfate concentrations in the groundwater are much lower than the concentrations in sea water (groundwater chloride concentration is only 0.05% to 0.6%). So durability of the mat and piles was enhanced by a waterproofing system. The concrete mix included specialized admixtures and corrosion inhibitors to the concrete. A cathodic protection system utilizing titanium mesh was also provided.

5. Design Codes and Standards

Reinforced concrete design was based on ACI 318-02 Building Code Requirements for Structural Concrete.

Structural steel design was based on AISC 360-05 Specification for Structural Steel Buildings (AISC), Load and Resistance Factor Design (LRFD) and Allowable Stress Design and Plastic Design (ASD).

6. Structural Analysis

The structure was analyzed using a commercially available structural analysis software. The analysis for gravity loads included P-Delta effect, creep and shrinkage. The analysis for wind loads included P-Delta effect. The analysis for seismic loads included P-Delta effect. The analysis for foundation mat and piles were included in the structural analysis model. The three-dimensional finite element model consisted of over 73500 elements and 75000 nodes.

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