Brief description of the Design and Construction of the Burj Dubai Project, Dubai, UAE

Ahmad K. Abdelrazaq, S.E.

Vice President/Executive Director, Samsung Corporation, Engineering and Construction Group

Abstract

The Burj Dubai Project will be the tallest structure ever built by man; when completed the tower will be more than 700 meter 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. This paper presents a brief overview of the structural system development and considerations of the tower and discusses the construction planning of the key structural components of the tower.

Keywords: Buttressed Core Wall System, High Performance Concrete, self compacting/consolidating concrete, raft foundation, wind engineering integration with the architectural massing, heat of hydration analysis, pump simulation test, creep and shrinkage test, concrete durability.

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 center piece of the large scale Burj Dubai Development that rises into the sky to an unprecedent height that exceeds 700 meters and that comprises of more than 160 floors.

The Client of Burj Dubai Tower, Emaar Properties is a globally acknowledged as one of the finest developers of lifestyle real estate in the Middle East Region. Turner International has been designated by the owner as the Construction Manager, and Samsung Joint Venture (consisting of Besix, Belgium Base Contractor, and Arabtec, Dubai base), 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.

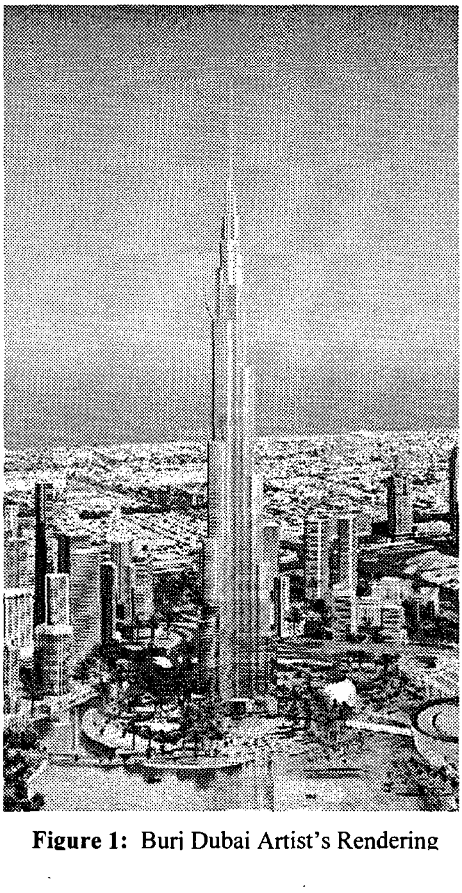

Figure 1: Burj Dubai Artist's Rendering

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

The tower massing is organized about the central core with three wings, with four bays, that peels off by one bay from each wing at every seven floors in a spiral as it rises into the sky. Unlike many super-highrise buildings, with deep floor plates, the Y-shape floor plans of Burj Dubai maximize the views of the Persian Gulf and provide plenty of natural light for its tenants. The modular Y-shaped building, with setback of the three wings, every 7 floors, was part of the original design concept that allowed Skidmore, Owings and Merrill to won 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 147 and is topped with an all structural steel structure from level 148 to the tip of the spire. The tower massing is also driven by the wind engineering requirements to reduce the dynamic wind excitation of the tower by reducing the building width and shape as the tower spirals up into the sky, thus reducing wind dynamic effects, movement, and acceleration. Integrating the wind engineering principals and requirements into the architectural design of tower resulted in very stable dynamic response of the structure against the strong wind effects, thus taming the powerful wind forces.

Structural System Considerations

Structural System Design Approach

The structural design process of the tower was formulated based on the following goals:

- Optimize the tower structural system for strength, stiffness, cost effectiveness, redundancy, and speed of construction.
- Manage and locate the gravity load resisting system so as to maximize its use in resisting the lateral loads while harmonizing with the architectural planning of a luxury residential and hotel tower.
- Incorporate the latest innovations in analysis, design, materials, and construction methods.
- Limit the building drift, acceleration, and torsional velocity to within the international accepted design criteria.
- Control the relative displacement between the vertical members, by equalizing their long term behavior.
- Control the dynamic response of the tower under wind loading by tuning the structural characteristics of the building to improve its dynamic behavior and to prevent lock-in vibration due to the vortex shedding. Favorable dynamic behavior of the tower was achieved by:

a) Varying the building shape along the height while continuing, without interruption, the building gravity and lateral load resisting system;

b) reducing the floor plan along the height.

Wind Engineering

Wind engineering is one of the primary concerns in the design of tall building design and planning. The shape of the Burj Dubai project is the result of direct strong and successful collaboration between SOM's architects and engineers to vary the shape of the building along its height from the early development of the design concept (competition stage), thereby minimizing the wind forces on the tower. The variation of the tower shape, and width, resulted in wind eddies around the perimeter of the tower that behaved differently and at different frequencies that are not organized along the building height.

From the beginning of the project, an extensive wind tunnel studies and testing regimes were established to develop a full understanding of the building wind behavior and response. Based on these extensive studies, target building periods and mode shapes were established to optimize the building dynamic response to the dynamic wind action.

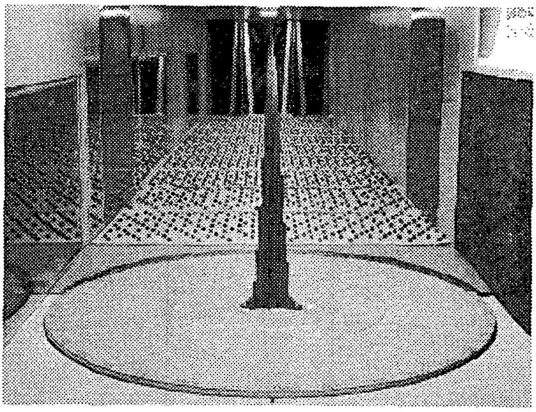

Figure 2: Wind Tunnel Study at RWDI

The wind tunnel studies included extensive studies of the Dubai wind climate studies which included both frequently and rare wind events, high frequency force balance models, aeroelastic models, pedestrian wind studies, and cladding studies. These extensive studies included the effects of frequent events to study the serviceability conditions of the tower and rare wind effects that are required to study the strength requirements of the tower.

Wind tunnel recommendation included combining the wind loads in the orthogonal direction and torsional moments simultaneously. 1.5% and 2% damping were assumed for serviceability and strength design.

Seismic Considerations

The Burj Dubai is located in an area with low to moderate seismic activities and the building is essentially founded pile foundation into the different sandstone layers. Site seismicity analysis was performed considering the effects of near and far earthquake records, plate tectonics, and the overall characteristics of the site. Based on these studies, response spectrum curves and time history records were provided for the seismic analysis of the tower.

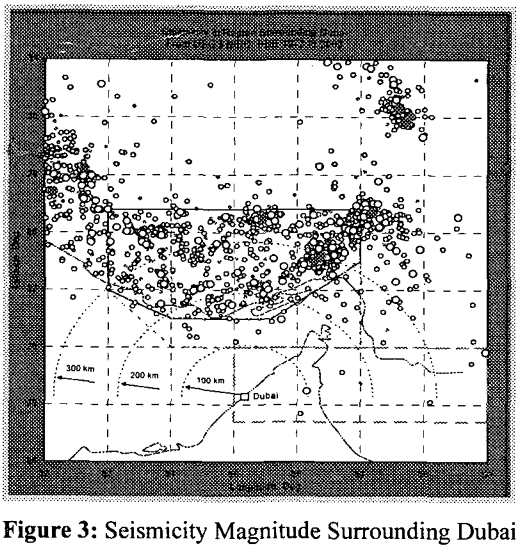

Figure 3: Seismicity Magnitude Surrounding Dubai

The seismic behavior and response of the tower was evaluated using the modal response spectrum analysis method and time history analysis. Since the building is very tall and flexible, the tower was controlled by wind design rather than seismic design except at the top of the building, where the whip lash effects generated forces that are slightly higher than the wind forces.

Foundation System Considerations

The selection of the foundation system of the tower is based on extensive geotechnical and seismic investigation programs that required mapping the entire site vertically and horizontally. In addition, the selection of the tower foundation system took into consideration the vast experience of high rise building construction in Dubai. Dubai soil and ground water conditions are very corrosive and have very high chloride and sulfate contents. This caused concerns and required a great deal of care in selecting the foundation systems, detailing, and durability requirements of the tower to overcome the high corrosive environment of the site. Therefore self compacting concrete with 0.3 water cement ratio was selected in order to provide high density and low permeability concrete for the pile foundation and raft foundation.

High Performance Concrete Considerations

Since concrete was considered are the primary materials to be used for the tower, an extensive program was developed to investigate the potential for using high performance concrete in the market by considering the skilled labor conditions, the readily available material, the capabilities of the concrete batch plants in producing consistently high performance concrete, and the sources of the raw materials.

Based on the above investigation program, it was clear that Dubai market has most of the materials needed to produce the high performance concrete needed for the project. In addition, based on discussion with both structural engineering professionals and concrete suppliers, it was re-assuring that most concrete suppliers and structural engineering community were very well equipped to deal to the corrosive environment of the site.

In addition, and extensive programs, research, and details were developed for the UAE corrosive conditions in general and for the Dubai in particular that were useful to incorporate into the project to protect the foundation system against the corrosive environment of the site.

Structural System Description

Lateral Load Resisting System

The lateral load resisting system of the Tower provides resistance to wind and seismic forces and consists of high performance, reinforced concrete ductile core walls from the foundation to the roof that are linked to the exterior high performance reinforced concrete columns through a series of high performance 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 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 and provides for the majority of the shear and moment resistance. 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 rises to the sky to make the building the tallest tower in the world for all categories. The lateral load resisting system of the spire consists of structural steel Mega-Bracing system that is founded at the top of the central reinforced concrete core wall system.

Floor Framing System

The typical residential and hotel floor framing system of the Tower consists typically 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 225mm to 250mm two-way reinforced concrete flat plate system. The floor framing system within the interior core consists also of two way reinforced concrete flat plate system with beams.

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 of 100mm blinding slab over waterproofing membrane, over at least 50mm

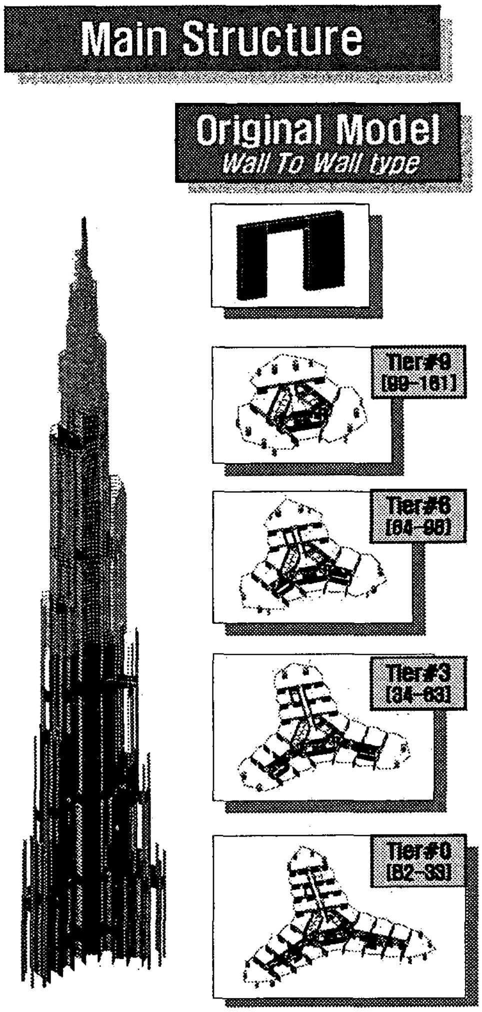

Figure 4: Structural Analysis Model for the Tower

blinding slab. The raft foundation bottom and all sides are protected with waterproofing membrane. See **Figure 5** for the Raft Foundation System.

The piles are typically 1500mm diameter, high performance reinforced concrete bored piles, extending approximately 45 meters below the base of the raft. All piles utilized self compacting concrete (SCC) with w/c ratio not exceeding 0.30, and 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.

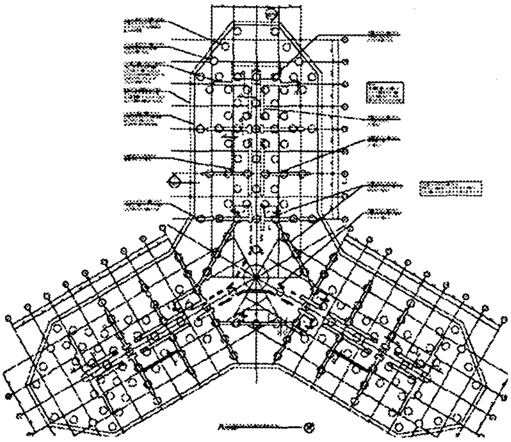

Figure 5: Raft Foundation System

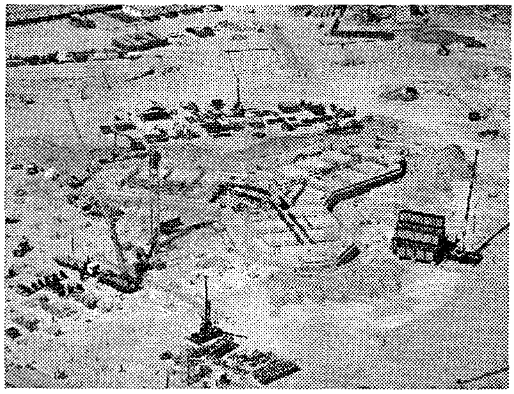

Figure 6: Tower Raft Foundation

A robust cathodic protection system is also provided for both the bored piles and the raft foundation system to protect the foundation and raft foundation systems against the severe and corrosive environment (chloride and sulfate) of the soil at the Burj Dubai site.

Construction of the Tower

Currently the tower is under construction and the foundation system, including pile foundation and the raft foundation have been completed and the tower superstructure is ready to start, See figure 6.

Prior to the construction of the tower, extensive concrete testing programs have been prepared, executed, and have been very successful in all aspects and they include but not limited to the following programs:

- ♦ Trial mix designs for all concrete types needed for the project.
- ♦ Mechanical properties, which included compressive strength, modulus of elasticity, split tensile strength.
- ♦ Durability tests which included initial surface absorption test, 30 minute absorption test.
- ♦ Creep and shrinkage test program for all concrete mix designs.

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.
- ♦ Heat of hydration analysis and tests, which included cube analysis and tests, and full scale heat of hydration mock tests for all the massive concrete elements that have a dimension in access 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.

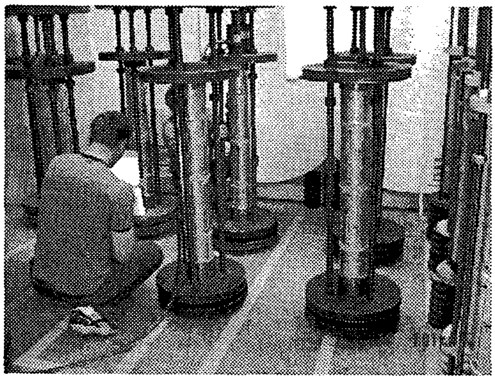

Figure 7: Creep test

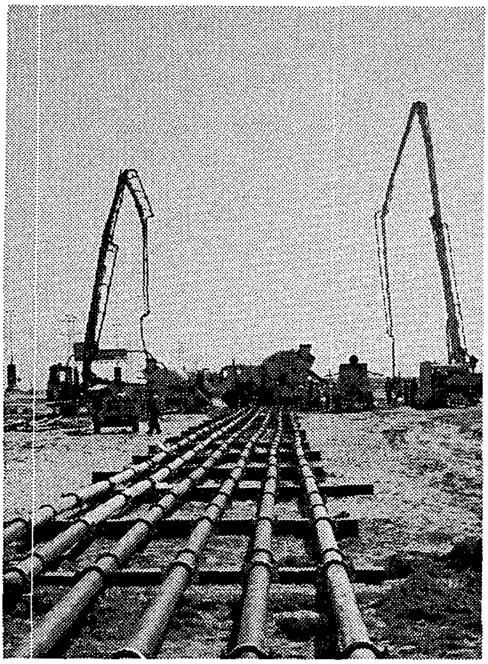

Figure 8: Pump simulation test

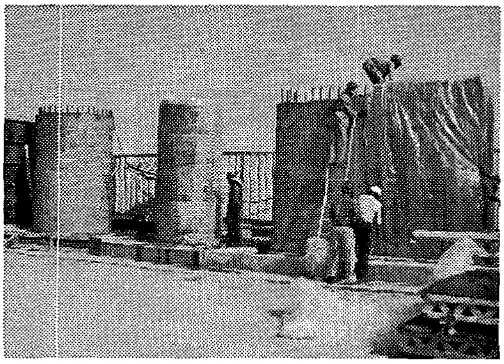

Figure 9: Heat of Hydration Mockup Test

Conclusion

While the wind behavior of supertall building is one of the most important design criteria to be considered, the gravity load management is also a critical design criteria that need to be addressed from the early design stage, during the development of the architectural and structural concept of tall building design. If the gravity load system is not managed properly, it would results in significant system inefficiencies and thus an additional cost to the project. The means and methods of mobilizing and redistributing the gravity load has its own inefficiencies and demands on the system, if not properly managed, it would result in structural system inefficiencies and construction complexities. The balance between the gravity load management and gravity load redistribution is a structural engineering art that requires in depth understanding of the behavior of the structural system from the early design process.

At the turn of the century, concrete construction was at it infancy and no body then could have dreamed of creating a building this tall using concrete. The Burj Dubai project presents a testimony that tall building system development is always directly related to the latest development in material technologies, structural engineering theories, wind engineering, seismic engineering, advancement in computer technologies, and construction methods. The Burj Dubai Project capitalizes on these technologies to result in the latest advancement in the development of supertall buildings and the art of structural engineering.

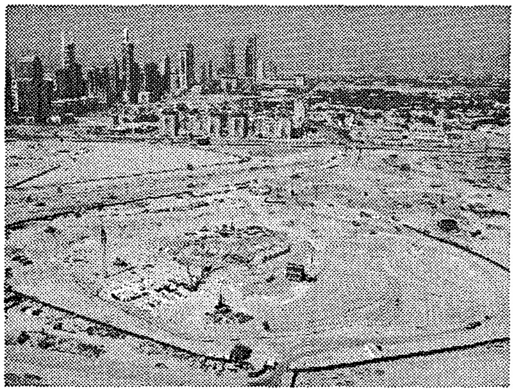

Figure 10: Burj Dubai Site as of March 2005