Structural Engineering of the 600 m Chicago Spire

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Summary

The Chicago Spire has a very innovative structural system that is a true integration of architecture and engineering. The spiral shape of the tower is ideal for improved wind performance and the composite structural frame has optimized the use of a concrete core and steel framing for one of the most significant tall buildings of this century. A unique circular outrigger system, that does not require thru core struts, and the use of high strength concrete all contribute to the feasibility of this future landmark. The engineering analysis included a sequential construction analysis of the building with time dependent material properties to account for the effects of elastic shortening, creep and shrinkage of the concrete.

Keywords: outriggers, high strength concrete, shortening, creep and shrinkage, high-rise.

1. Introduction

This paper describes the structural engineering of the 600 m Chicago Spire being developed by Shellbourne and designed by Santiago Calatrava. The architect of record for the project is Perkins & Will of Chicago and the engineer of record is Thornton Tomasetti. The building foundations are currently under construction and this will be the tallest building in North America upon completion. The building sits on a prominent location on the northern bank of the Chicago River's inlet from Lake Michigan. The east side of the site is bordered by Lake Shore Drive and the north side by Ogden Slip, a man-made inlet from Lake Michigan.

Figure 1: Architectural Rendering of Chicago Spire

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2. Building Overview

The building will be the tallest residential building in the world, containing approximately 1200 condominium units, various amenities, and 1400 parking spaces in 7 below grade levels. The residences will be among the most luxurious in the world, and therefore require high standards for occupant comfort relating to acoustics, floor motion and building motion. The building will also be the tallest in North America at its completion, surpassing the Sears Tower (also in Chicago) by 167 m. The aspect ratio of the building comparing the width of the structure at its base to its height is approximately 12.

3. Basics of Structure

The basement is one of the deepest in Chicago extending nearly 70' below grade. It will be constructed using the "top down" method and utilizing a perimeter slurry and secant pile wall system described in detail in the "Geotechnical Engineering of the 600m Chicago Spire" paper. The tower foundations are 10' diameter straight shaft caissons embedded into bedrock more than 100' below grade. These caissons are lined with over 1.5 inch thick steel plates and are filled with 10.5 ksi concrete. The allowable bearing pressure of 300 tons per square foot is the highest allowable bearing capacity on Chicago rock to date.

The tower of the Chicago Spire will be a reinforced concrete core with steel columns near the perimeter. The floor framing will be steel and composite deck floor framing. Although the curtain wall and perimeter slab edge are rotating and tapering on every floor, the tower vertical supports are straight on most floors with floor framing cantilevering out to the edge.

At the mechanical levels the columns step in and the core transitions to either a new thickness or a new shape. At these floors are outriggers that link the core to the perimeter columns. The circular core of the Chicago Spire presents a special challenge when detailing the attachment of the outriggers. There are very large shear forces between the top and bottom of the outrigger connections as the steel frame pushes back against the concrete core. Because the Spire core is circular and outriggers are arranged in all directions, the layout inside the core does not allow for multiple thick through-walls. Something is needed to link the shear and bending resistance and analysis showed that the concrete wall could not transfer that force through plate bending by itself. Therefore a continuous steel ring was designed around the core to transfer the lateral forces between the concrete core and steel systems.

4. Special Analyses

Some of the other special analyses done for this project include the intense analysis in RWDI's wind tunnel in Guelph, Ontario. The results of that analyses and some of the extraordinary studies done for this building are discussed in detail in the paper "Wind Engineering of the 600m Chicago Spire". The building will use an Active Mass Damper to provide comfort to the occupants. Also multiple methods of analyzing shortening were used to estimate the effects of creep and shrinkage on the system.