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Consultants Corner

Engineering for the future

Testing the Limits of High-Rise Construction

The world's tallest skyscraper opened on January 4, 2010 in Dubai, United Arab Emirates. With 162 floors and a height of 2,717 feet, Burj Khalifa surpasses the previous record holder, Taipei 101 of Taiwan, by more than 1,000 vertical feet.

Designing and constructing a building of such extraordinary height involved numerous technological challenges, particularly in view of the climate and soil conditions of the Persian Gulf. Support of the building was accomplished by constructing 192 concrete piles that extend 164 feet into the underlying sandy soil. With its slender silhouette, swaying of the structure due to wind stress was a significant design concern. During the design process, the building was rotated 120 degrees from its original position to accommodate the prevailing winds. At its tallest point, sway of the tower is estimated at 3.9 feet.

Like most modern skyscrapers, Burj Khalifa is built of reinforced concrete and composite construction materials rather than traditional steel. As construction progressed, the difficulties of pumping thousands of cubic yards of concrete to the required heights had to be overcome. Special mixes of concrete were developed that had both the necessary consistency to be pumped to extreme heights, and the ability to withstand the extreme stresses imposed by the massive weight of the building.

In addition, daytime temperatures in Dubai can reach 122˚F. High temperatures could cause the concrete to cure unevenly or too rapidly, possibly inducing cracks; therefore, ice was added to the concrete and it was poured at night when temperatures were lower and humidity was higher.

Even communication proved to be an issue. Once the height of the structure surpassed 30 stories, the basic walkie-talkies that had been used to communicate critical information experienced delays or lost reception entirely. They had to be replaced with walkie-talkies equipped with Radio over Internet Protocol (RoIP) technology.

Burj Khalifa in Dubai, UAE, the world's tallest building.

The debut of Burj Khalifa occurred amid a financial crisis that has left Dubai, after two decades of a booming economy and vast commercial expansion, mired in debt estimated at $26 billion. Dubai's faltering economy has been rejuvenated by the injection of billions of dollars in bailout funds by its oil-rich neighbor, Abu Dhabi. Despite the technological and economic obstacles faced, the opening of the $1.5 billion tower is a triumph of engineering, design and construction, illustrating the emergence of the Middle East and Asia in the field of high-rise design and technology.

Not all recent high-rise projects have

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Testing the Limits... *(continued from page 1)*

gone as well as Burj Khalifa. Take the Harmon Hotel & Spa, part of the six-building City Center project constructed at a cost of $8.5 billion in Las Vegas, Nevada. The building was designed as a cast-in-place reinforced concrete tower with 400 hotel/condominium units and 49 floors. The design of the structure required precise spacing of rebar; however, stirrup hooks (a rebar component of the beams) were placed incorrectly and extended above the floor slab in some areas. Workers simply cut off the stirrups with torches to prevent them from showing, but in doing so they compromised the structural integrity of the building.

"These and other construction mistakes were discovered during a spot check by the project structural engineers, despite 62 daily inspection reports indicating that the reinforcing steel had been properly installed."

These and other construction mistakes were discovered during a spot check by the project structural engineers, despite 62 daily inspection reports indicating that the reinforcing steel had been properly installed. The discovery shut down work on the project while engineers scrambled to redesign the structure. The project owner, MGM Mirage, announced that it would reduce the tower from 49 stories to 28 stories, losing 200 condominium units in the process. Project completion is projected for late this year, approximately one year later than the rest of the building complex. The project's testing and inspection firm was fined, charged with submitting false inspection reports and banned from seeking new work in the southern part of Nevada for an extended period.

A worst-case scenario of high-rise construction occurred on South Padre Island in Texas. Sales literature for the Ocean Towers condominium complex extolled the gorgeous views of the Gulf of Mexico that could be seen from the soon-to-be completed high rise. Advertised as the tallest and most luxurious building on the island, Ocean Towers was designed as a 31-story, 151-unit tower connected to a four-level parking garage.

Before it could be completed, however, soil settlement led to discernible tilting of the structure, leading locals to dub it the "leaning tower of South Padre." The problem appeared to be at the connection between the nearly 400-foot tower and the adjacent low-rise parking garage. Settlement estimated at over 14 inches resulted in cracks in columns, beams and pile caps.

The project owner, Ocean Tower LP, claims that the settlement was due to a "flawed engineering design" and is suing the structural engineering firm and their geotechnical consultant, claiming $125 million in damages. Ocean Tower alleges that the settlement was caused by a stratum of compressible clay (at depths of 120 to 190 feet below the surface) that the consultants failed to take into consideration.

After it was determined that remediation and completion of the tower would not be economically feasible, Ocean Tower elected to demolish the building. The implosion process was complicated by site conditions that included a high water table, an ecologically-sensitive dune environment, and sandy soils that tend to easily transmit vibrations to nearby buildings. The post-tensioned beams of the tower base were another concern, due to the potential danger of backlash of the highly-tensioned tendons in the beams. The building was successfully imploded in December 2009. At this time, the developer has no plans to rebuild.

Although today's challenging economic times create a greater pressure to control costs, these case studies demonstrate that a strong design team, adequate geotechnical investigation and competent quality assurance during construction are crucial to a successful project outcome. Even with these project elements in place, pushing the known boundaries of construction increases the potential for unanticipated occurrences. As technology continues to advance and test the previous limits of our experience, the old adage of "expect the unexpected" applies more than ever.

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