Leica Geosystems

Innovative Vertical Alignment System Keeps 432 Park Ave. Plumb

'Skyscrapers' is such an '80s term—1880s that is. In the 21st century, as high-rise buildings have reached previously unimaginable new heights, architects and city planners have been forced to find new terms, eventually settling on the fairly literal 'supertall' for buildings over 300 meters (984 feet) and the clunky-but-evocative 'megatall' for buildings over 600 meters (1968 feet)—only three buildings currently qualify, including Dubai's 829.8 meter (2,722 feet) Burj Khalifa.

But there are lots of supertalls, so many that subcategories are beginning to emerge, and the sexiest so far is 'superslim' a term being applied to a new crop of supertall buildings with very small footprints. New York City's 432 Park Avenue building is perhaps the best example now under construction; when completed in 2015 it will, at 426 meters (1,398 feet), be the 2nd or 3rd tallest tower in the United States (depending on how one defines One World Trade Center's crowning pinnacle) and easily the Western hemisphere's tallest residential building... and it will rise straight up from a perfectly square ("The purest geometric form," according to architect Rafael Viñoly) footprint measuring just 28.5 meters (93.5 feet) per side. That's about 814 sq. meters (8,760 sq. feet)—for comparison, the Burj Khalifa's footprint is about 8,000 sq. meters.

A building this tall and this skinny is very nearly in a class by itself, and calls for advanced construction techniques. One task in particular is simple in conception, but extremely challenging in practice: keeping the building plumb.

Working With Gravity

Many confounding factors affect supertall verticality and most are dynamic, changing from hour to hour. Some of the most important include thermal load (the differing expansion rates of sunlit and shaded sides of a building), wind pressure (remember, each side of the completed building will be like a giant, 131,000 sq. foot sail), and crane loading and movement during construction. More subtle factors include slight variations in concrete settling, and even the variations, within tolerance, of steel work. So Adam M. Cronin, lead surveyor for Roger and Sons Concrete on 432 Park Avenue, really needs to know— in realtime if possible—where the building is, compared to design, and how it's responding to various loads.

For conventional urban construction, even skyscrapers, this task is relatively simple. Ground level control is transferred to permanent marks on surrounding buildings, and those marks are used as references for formwork positioning, steel assembly, and other layout tasks. Sometimes, buildings are kept plumb with sightings through slab penetrations. But these methods won't work on a supertall. For one thing, they don't scale well—the need for vertical alignment information is so critical and urgent that optical measurements are simply not fast or accurate enough. It can take several hours, in typical ground reference systems, to take all needed measurements and perform calculations for a high altitude positional fix. More obviously, 432 Park Avenue will quickly rise well above nearby buildings, making nearby optical references useless. "We're literally in the clouds up here," Cronin points out. "Some days, we can't see the street or even other buildings."

So on this project, Cronin is using the most recent iteration of the Vertical Alignment System first developed by Leica Geosystems Engineered Solutions for use on the Burj Khalifa, and proven several times since, most notably on One World Trade Center. In essence, the system combines realtime data streams from several sources:

- GNSS positional data from four Leica receivers, posted near the corners of 432 Park Avenue's outer formwork platform (also known as the "cocoon"). The receivers monitor GPS and GLONASS, and the Brooklyn Pier and Holland Tunnel CORS stations.
- Continuously monitored optical data, derived from total station shots on 360º prisms mounted just beneath the GNSS receivers. This data gives feedback on the building's frame and shape, and the prisms are also used as resection points when doing layout and form positioning work. The prisms are 'active' control points; moving upward as construction progresses.
- Leica Nivel200 Series dual-axis inclinometers, which can measure displacement to +/-0.2" of arc, are installed in the building's basement, and at regular intervals of about 10-12 floors. "They make a big difference. Along with the GNSS, they're helping us to make great strides in vertical alignment control, especially when predicting the effects of the day to day construction and wind loads," Cronin says, referring to movement due to the weather, crane loads, concrete placement, cocoon jumping and so on. The system's inclinometers are sometimes left in place after construction to provide continuous monitoring.
- As construction progresses, a weather station will be added; "We're working with Leica Geosystems to tie in realtime wind and temperature information," Cronin explains. "To tie that in with the GNSS/RTK observations and tiltmeter data would be very helpful."

All this data is combined and processed in a customized implementation of Leica's advanced Spider network RTK solution. Among other tasks, Spider is able to automatically apply the complex transformation between 'ellipsoid normal' (vertical relative to the WGS84 ellipsoid) and 'gravity vertical' (vertical on the job site, better known as 'plumb'). In most construction applications, the difference between the two is immaterial, but at nearly 1,400 feet it could be inches... which would be potentially disastrous. "Fortunately, thanks to Spider, I don't have to think about that too much," Cronin says.

All results can be accessed continuously, and a 'solid solution' is provided each hour. So, on an hourly basis, Cronin can check the figures and be confident he knows exactly how the building is placed within two hundredths of a foot and, over time, he can develop a sense of how the various construction and weather loads affect verticality from day to day. If needed, he can make adjustments to form positioning to make corrections. It's a surprisingly speedy process; "We're completing a lift every three days," Cronin says. "And that's fast for this type of construction."

In sum, the Vertical Alignment System frees supertall construction surveyors from the need to tie to ground references. Building control is independent of ground control, and surveyors can generate precise coordinates as needed, compare these to design coordinates, and correct the building's vertical alignment incrementally to keep walls plumb.

"The Vertical Alignment System consists of consultation, training, installation and on-going management of the data," explained Leica Geosystems' Vice-President of Engineered Solutions Gerard Manley. "It's a modular system, and the components can be acquired based on the user's needs. We are seeing a definite trend in supertall construction, where BIM, realtime monitoring, and construction are all tightly integrated. As this trend develops, we are continuing to refine the Vertical Alignment System to be even more effective."

An Easy Transition

432 Park Avenue is Cronin's first opportunity to use a GNSS-based system on a major building construction, and he admits he was a little uncomfortable at first. "I didn't want to "flip the switch" too soon," he says. "Coming from a more traditional surveying background, it was important to me to test the system against ground references."

Fortunately, he was able to do just that for several months. Cronin essentially doubled up on verticality control during construction of the first 20 floors. That is, he started with ground control, and a network of prisms on nearby buildings, while also installing and using the Vertical Alignment System. "We compared results every floor," he explains. "And by the 20th floor, as I lost the ability to use references I was used to, I was already super confident—the GNSS system always checked out." In fact, as the building rises multipath issues are eliminated, and GNSS coordinates should become even more reliable.

Cronin has established some good routines for working with the Vertical Alignment System. For instance, he's learned to use overnight results as the basis for layout work; thermal loads are balanced then, and cranes aren't shifting a lot of weight around. He also prefers to do precise layout work in the quieter twilight hours, when the site is calmer and there is less movement in the structure. Still, he finds that he can get consistent results at any time of day; "As an exercise, we've performed the same positioning work at twilight and in the afternoon, and found that the differences were negligible, which surprised me. And even during the recent polar vortex weather, which was super cold, we always had good signal and good results. It's been a very reliable system."

Leica Geosystems has developed the current state of the art in high-rise construction control, and the Vertical Alignment System has proven its worth on the world's tallest buildings, including the Burj Khalifa, the tallest of all. For the first time, construction surveyors are no longer dependent on the ever receding ground for positional fixes; instead, continuously updating GNSS and inclinometer data, and optical readings give precise moment-to-moment coordinates on active control points, and help to keep the world's burgeoning class of supertalls and superslims standing tall, and perfectly straight.

So what's it like when your 'office' is a semi-exposed platform more than a 1,000 feet above the ground? "There's nothing better!" says Cronin. "We can see from Tappan Zee Bridge all the way downtown, and we have a bird's eye view of Central Park. It's not for everyone, but I surelike it." And with the security provided by excellent, realtime positional information, he likes it even more.

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