



Controlling Vertical Towers

by Joël van Cranenbroeck

There has been considerable interest in the construction of super high-rise and iconic buildings recently. From a surveying perspective, these towers present many challenges. The Burj Khalifa in Dubai and the Al Hamra tower in Kuwait, for example, have risen into territory previously uncharted: methods and processes normally used to control tall buildings have needed a re-think. Leica Geosystems' Core Wall Control Survey System (CWCS) delivers precise and reliable coordinates on demand that are not influenced by building movements.

In addition to being very tall, high-rise buildings are often quite slender and during construction there is usually a lot of movement of the building at upper levels due to wind loads, crane loads, construction sequence, and other factors. It is essential that a straight "element" be constructed that, theoretically, moves around its design center point due to varying loads and, if all conditions were neutral, would stand exactly vertical. This ideal situation is rarely achieved due to differential raft settlement, differential concrete shortening, and construction tolerances.

Structural movement creates several problems for correct set-out of control: at a particular instant in

time the surveyor needs to know exactly how much the building is offset from its design position and at the same time he must know the precise position at the instrument location. Construction vibrations in the building and building movement further complicate this situation, making it very difficult, if not impossible, to keep an instrument leveled up.

Leica Geosystems has developed and tested a surveying system, the Core Wall Control Survey System (CWCS), using networked GNSS (GPS and GLONASS) sensors combined with high precision inclination sensors and total stations to deliver precise and reliable coordinates on demand that are referenced to the design frame, where the construction was designed and projected, and that are not influenced by building movements. These coordinates are used to control the position of the climbing formwork systems located at the top of any vertical structure, such as a tall building under construction, as well as to monitor the dynamics and behavior of the structure implemented.

Active Control Points and Inclination Sensors

As on most construction sites, surveyors typically work around steel structures and obstructions and beneath or beside materials being lowered by crane. The working areas are congested with materials,



equipment, and people, and of course working at height requires a special regard for safety. Under these conditions surveying becomes difficult.

In time, surveying becomes very much a steering of the vertical alignment of every single wall element by making discrete corrections to the position of each, but with strict limitations placed on the amount of correction per rise. This needs to be done while the structure continues to move as usual. The optimum method for placing survey control for tall buildings needs much consideration. The use of conventional methods such as optical plumbing of control through slab penetrations is very limited for such structures.

Core walls are constructed in a sequence of several concrete pours. After each pour, three to four GNSS antennas combined with a GNSS permanent reference station and a total station are set up. The total station observes the geometry of the GNSS antennas by measuring angles and distances to the 360° collocated reflectors (Active Control Points). This information and the GNSS data are either post-processed at the survey office or calculated in real-time on site. The resulting coordinates are transferred to the total station to update its coordinates and orientation.



■ Burj Khalifa in Dubai (828 m)

Precise dual-axis inclination sensors are installed at ground level and at about every given number level above. The information from the inclination sensors is logged at the survey office and the exact amount in Δx and Δy that the building is offset from its vertical position is applied as corrections to the coordinates of the Active Control Points. The total station then observes the control points (nails set in the top of the concrete) to derive the corrections to be applied to the formwork structure. These coordinates are in relation to a continuous line of the building as defined by the control lines and therefore when the points are used to set the formwork for the next pour, the construction progresses as a straight element regardless of building movement.

From WGS to Gravity Vertical

All the results from GNSS surveying refer to an ellipsoidal normal as reference for the Z component (WGS84). Therefore a transformation is carried out to transform the results obtained by GNSS to the same local coordinate reference frame as the primary survey control network. If this transformation is limited to a single point, the difference between the gravity vertical (that could be visualized by a plumb line) and the ellipsoid normal (deflection of the vertical) will introduce a bias that will impact the vertical alignment of the construction. The transformation needed to get GNSS to provide coordinates and orientation for the total station is derived by using the coordinates of the reference frame and the coordinates obtained for the same marks with GNSS.

To summarize, GNSS receivers, automatic total stations, and precise inclinometers must all refer to the same reference frame, where the gravity vertical is the most sensitive component as the building's main axis reference.

Benefit

The real advantage is that the surveyor is able to continue to set control – even when the building has moved “off centre” – confident that he will construct a straight concrete structure. With the networked dual-axis precise inclination sensors he also obtains precise information about building movement.

The analysis isolates factors such as wind load, crane loads, and raft slab deformation and also relates movement to the construction sequence. This information is of great benefit in explaining to the client



what is actually happening to the structure. If there is a trend in any one direction it can be identified and an RFI (request for information) submitted for a correction based on reliable data obtained over a long period of time.

Another advantage is that the surveyor is able to get precise positions at the top of the formwork without the need of sighting external control marks, which become increasingly difficult to observe as the building rises. The control surveys are completed in a shorter time, improving productivity, and the instruments do not need to be leveled during the survey, which is an important consideration when the building is moving or there are vibrations.

A Tribute to Chief Surveyors and Structural Engineers

Doug Hayes, an Australian surveyor who worked on a number of large construction projects world-wide and was Chief Surveyor at Samsung Engineering & Construction, United Arab Emirates, immediately recognized the merit of Leica Geosystems' Core Wall Survey Control System proposal and largely contributed to the success of its implementation during the construction of Burj Khalifa in Dubai.

A short time after the installation of the CWCS in Dubai we were contacted about the Al Hamra tower project in Kuwait. The contractor was requesting a

similar system and a professional surveyor that would be able to drive it. Soang Hoon from South Korea was willing to accept the challenge and became Chief Surveyor for the contractor. Even though the system was similar to the one delivered for the Burj Khalifa, he made necessary adaptations and we learnt how tall buildings are different even if, from a surveying point of view, they have the same specifications.

A year after the installation in Kuwait, we were asked to provide a CWCS system for the Landmark tower in Abu Dhabi. This tower was again slightly different and the contractor had great interest in having the system run in real-time mode. Mohammed Haider, structural engineer for the contractor, oversees the system and has been an outstanding supporter.

In this article I tried to review the state of the art of an innovative surveying method to support the construction of outstanding vertical structures. The dedicated involvement of the surveyors and engineers in this process has contributed greatly to the sophistication of our system. In the near future we would not be surprised to receive requests for semi or fully automatic systems. After all, it is only the first step in a long journey. ■

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