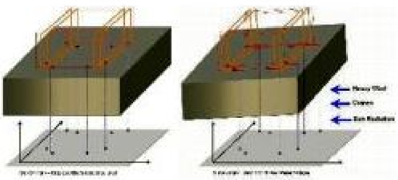
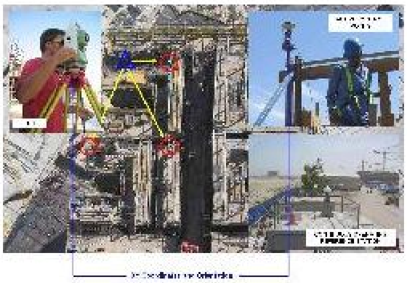
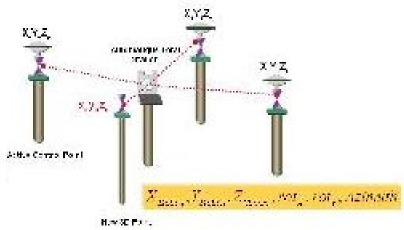
SURVEYING FOR HIGH-RISE STRUCTURES

Driving Vertical Towers







The construction of iconic towers such as the 828-metre high Burj Khalifa (formerly Burj Dubai), officially inaugurated on 4th January 2010 in Dubai, poses many challenges to surveyors. Tall towers may bend and sway in the wind, with cranes and other loads. Ideally, such motion should centre on the as-designed main axis, so that in the absence of load the tower stands precisely vertical, but deviations occur as a result of raft settlement, concrete shortening and construction tolerances. The author presents a new, patented measurement system capable of driving the highest towers in an exactly vertical direction.

To guarantee the precise upward thrust of a tower along the vertical during construction, complete control must be maintained of the position of each new element erected on top of the existing core walls. Such new elements, and hence formwork structures, must be precisely positioned with respect to the main axis of the design reference frame, which is defined as the vertical positioned in the centre of tower. This means that the position of the formwork structures at the top of the tower must be continuously measured during erection of the building.

Anomalies

The coordinates, computed from the measurements, should refer to the main axis very precisely and reliably. However, anomalies arise from movement due to wind, cranes, sun radiation and other loads, and vibrations within the tower (Figure 1). Conventional methods for monitoring tall towers, such as optical plumbing, are incapable of compensating for such anomalies, and this is an intolerable drawback when the towers are super high-rise, such as the Burj Khalifa in Dubai. To control such towers, Leica Geosystems developed and proof-tested a new measurement system based on GNSS (GPS and Glonass) combined with high-precision inclination sensors and total-stations. The surveying procedure, called Core Wall Control Survey System (CWCSS), has been applied to the Burj Khalifa in Dubai, UAE; the Al Hamra tower in Kuwait; the Landmark tower in Abu Dhabi; and other high-rise buildings around the world, and has been patented under International Publication Number WO 2007/080092 A1.

Active GCPS

Core walls are constructed bit by bit, one on top of the other. Each core wall element consists of several concrete pours. The placement of the formwork structure on top of existing core walls should be done very precisely, determined from the position of previously placed elements. For this purpose control points, materialised, for example, by nails, have to be set in the top of the concrete. The basic task of the surveyor is to determine the coordinates of these control points and to compute and stake out the position of the formwork structure in a design reference system based on the main axis of the tower. Basically, the work consists of measuring angles and distances with a high-grade total-station positioned on a ground control point (GCP). In the new CWCSS system the total-station remains the main instrument, providing as it does distances and angles to compute the coordinates of control points and any other mark or object in the structure. On most construction sites surveyors carry out their work in the midst of a tangle of steel and other obstructions, and beneath or beside materials lowered by cranes; working areas are congested with materials, equipment and men and, of course, working at height requires special safety measures. Under such conditions, GCPs on which the total-stations can be positioned are scarce. So the CWCSS system is based on positioning total-stations from measurements to three or four GNSS (GPS + Glonass) receivers to which 360° reflectors are attached beneath the antenna (Figure 2).

These act as active ground control points for setting up the total-station at any stage of construction (Figures 3 and 4). In Figure 3 the red circles indicate the positions of the control points, and the blue triangle that of the total-station. The GNSS antennas should be placed such that the lines of sight between antenna and satellites are not obstructed by constructions and buildings, while reflection and diffraction of the satellite signals should be carefully avoided. Because very precise coordinates can only be determined in differential GNSS mode, a continuously operating reference station has to be established, preferably located outside the construction venue (Figure 5).

Inclination Sensors

To determine the offset caused by movements of the tower, dual-axis precision inclination sensors, which measure the exact offset from the vertical of the tower, are installed at ground level and about every given number level above. Mounted on the core wall along a vertical line, these measure any variation in tilt of the main axis of the tower. The offsets calculated from these measurements are used to correct the coordinates of the control points as measured by the total-station, ensuring that the building is constructed as straight element, pointing precisely vertically, regardless of movement. To calibrate the inclination sensors, tilt values can be compared with measurements gained through vertical laser plummet beams passing through holes made on different levels, the method used for the Burj Khalifa, or using a motorised high-precision dual-axis inclination sensor, as for the new Ryiad Tower in Saudi Arabia.

Gravity Vertical

A network of marks made to identify GCPs and used to set up the total-stations must be established around the construction area to ensure a proper design reference frame to which all measurements can be referred. These marks need protecting and regular re-survey during the construction process (Figure 6). GNSS receivers, total-stations and inclinometers must all refer to the design reference frame. Since GNSS coordinates refer to the ellipsoidal WGS84 system, these will have to be transferred to the design reference frame. The vertical defined by gravity, as visualised by a plumb-line, differs from the ellipsoid normal. This introduces a bias which will affect vertical alignment of the construction. Applying corrections is of the utmost importance, since the gravity vertical, as the main reference for the main axis of the tower, is the most sensitive component.

Benefits

The CWCSS method enables the surveyor to continue his control measurements even when the building moves off centre, since the network of dual-axis inclination sensors provides continuous precise information on tilt variation. Combining tilt values with measurements from other instruments, such as wind-speed sensors and thermometers, enables derivation of a relationship between tilt and loads due to weather and other sources.

Establishment of such relationships provides valuable information for explaining the causes of movement and understanding the behaviour of the building. It also enables the identification of and compensation for systemic bending in one direction by adapting placement of elements on top of finalised parts during the construction phase. Precise positioning of formworks can thus be realised without the need to sight to external GCPs, a procedure which becomes increasingly difficult as erection of the building progresses. Control surveys can be completed within a short time span, improving productivity, and instruments do not need to be levelled, important in the presence of movement and vibration.

Concluding Remarks

CWCSS provides an effective method for determining coordinates of points during driving the highest buildings in a vertical direction. However, determination of the vertical component is very sensitive and should be checked and double-checked using conventional levelling procedures in addition to the CWCSS system. The network of inclination sensors can be kept operational after completion of the building for long-term monitoring of the behaviour of the tower. A GNSS antenna can also be kept running on the top of the tower to provide deflection information.