Controlling The Bow

by Vicki Speed

The Bow, with construction costs at an estimated 1.5 billion Canadian dollars, is the largest office space in Calgary and the tallest building in Canada outside of Toronto. During the construction of a skyscraper as complex as the Bow, the structure will temporarily lose its exact verticality and the building will tilt, contract, and expand. To ensure the functionality of such a complex and innovative design, MMM Geomatics, Ledcor Construction, and steel fabricators/erectors Supreme Walters Joint Venture, established an innovative "neutral" building control network that combined leading-edge technologies, advances in geomatics methodology, and rigorous quality control and quality assurance procedures to deliver precise real-time data.

In advance of construction, MMM, with help from long time survey equipment supplier, Spatial Technologies Inc., selected the right equipment to establish a comprehensive horizontal and vertical building control network that would allow precise survey layout both on and off the structure.

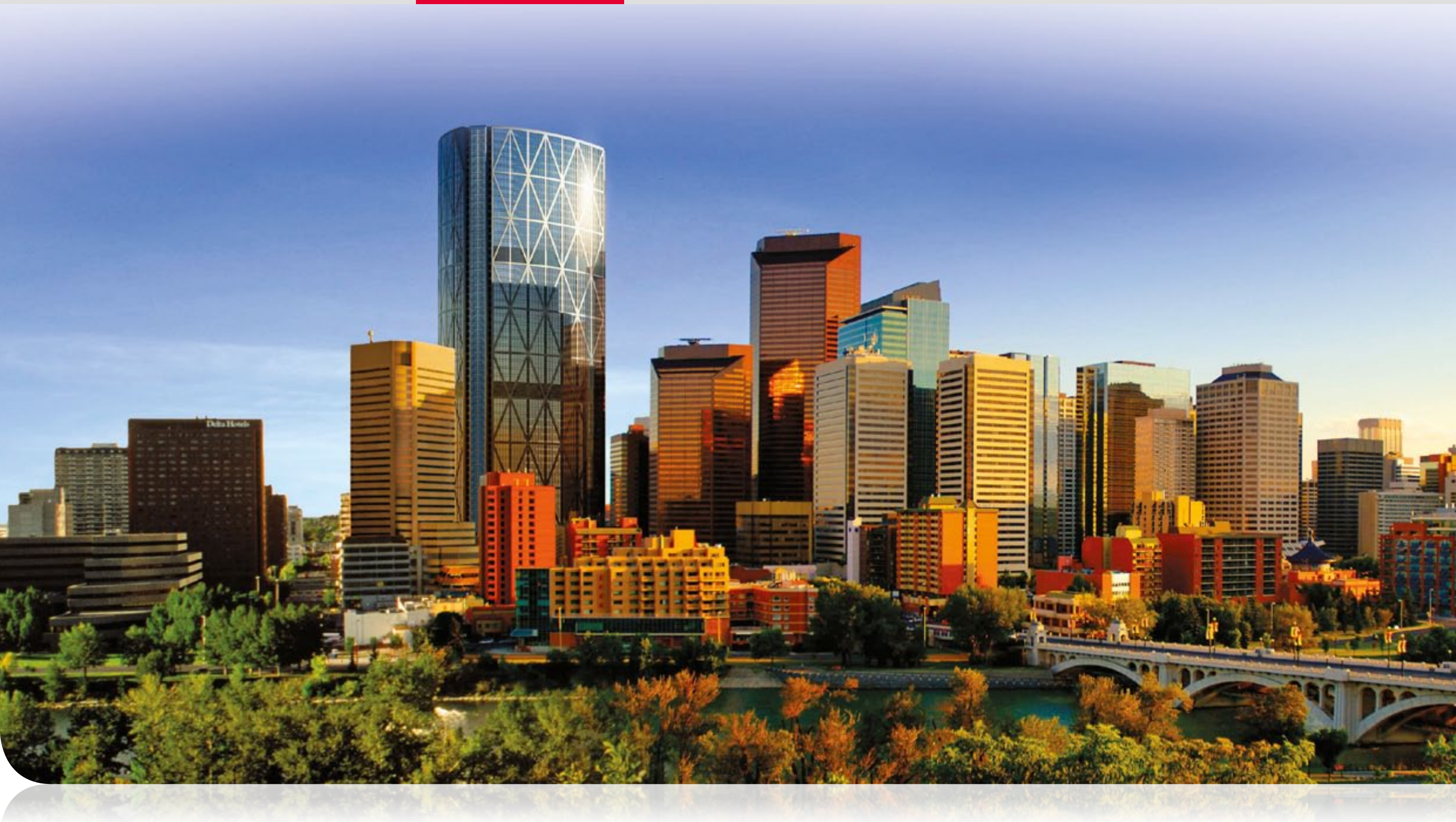
The primary level of horizontal control consisted of three external framework control stations. These reference stations were installed on solid infrastructure, such as bridge abutments, nearby and located at adequate distances from any development for maximum marker stability. The primary horizontal project control was established using a combination of conventional and static GPS observation techniques.

Real-time Response

Two continuously operating GPS reference stations were selected as well and acted as a reference for the external framework control. The GPS stations continuously streamed real-time kinematic data and constantly recorded raw GPS phase and code data for precise post-processing applications.

MMM further established an external rooftop control network that consisted of 12 Leica Geosystems professional 360 degree prisms, tribrachs, and carriers located on existing buildings near the site. GPS antennas were attached to the top of the prisms to allow for static GPS observations on these control markers. At three-month intervals, MMM performed a complete static GPS survey that involved simultaneous occupation of all rooftop prisms and framework control markers. In addition, conventional angles, distances, and spirit-leveled observations were combined with the GPS position differences in the network adjustment. After each survey, the network was re-adjusted and statistically significant coordinate updates, if any, were published.

Finally, MMM established a floor control system on each level of the structure as it was constructed. The floor control system included a series of at least six horizontal control stations, which were used for all



subsequent layouts on the floor, including building elements such as atrium steel, edge-of-slab, curtain wall, elevator shafts, and project gridlines. These stations were monumented on the ground floor concrete surface and subsequently transferred vertically to each floor via laser plummet and validated by an extensive survey and data quality control process via least squares adjustment.

MMM selected two Leica TCRP1201 and one Leica TS30 0.5" precision motorized total stations for all precise setting-out activities on site. The Leica TS30 was used for applications where stringent accuracy was required, including the establishment of floor control for subsequent use by all trades. The established control served as the primary horizontal reference for all future layout by all trades within the tower.

Displacement and Deviation

Perhaps the most innovative technique employed on the project was the use of a network of Leica Nivel220 inclination sensors to track and correct for any deviation from a neutral plumb state due to natural or man-made forces.

Natural forces that might impact the structure include wind, which creates building drag, and solar effects, which cause temperature-related variation in steel and concrete. Artificial forces, caused by differential raft slab settlement and crane loading, yielded unbalanced loading on the structure. The period of the building movements varied and consisted of a combination of short-term, daily, and seasonal durations.

Surveyors have used inclinometer instrumentation on some of the most innovative and complex skyscraper projects in the world. MMM worked closely with Spatial Technologies Inc., as well as other Leica Geosystems experts, to evaluate and test the Leica Nivel technology and conduct short surveyor training programs as needed, for use on the Bow project.

The Leica Nivel220 inclinometer is a two-axis high-precision tilt sensor with a resolution of 0.001 milliradians. The device uses an optoelectronic principle to accurately measure tilt and temperature in real time, and allows for continuous data logging. Inclination is measured from the true horizontal surface along the two orthogonal axes.

The MMM survey team continuously monitored, validated, and compared the inclinometer-derived building deviations to deviations determined using conventional survey measurements from external fixed control.

Rising Challenges

Continued monitoring of the structure, using the rooftop prism and framework control network, indicated that building movement started to gain significance at about level 36 of the tower. Once building displacement was proven to be greater than 20 mm in any direction, standard survey layout procedures were modified to account for the movement.

Real Time Kinematic (RTK) GPS techniques were employed to plumb the building columns above level 36. A major limiting factor and important source of error when using GPS techniques in urban environments is signal blockage and multipath from surrounding buildings. As the BOW's elevation increased, these effects were diminished as the building surpassed adjacent structures in height. In general, the layout using RTK GPS proved highly effective and accurate.

As the structure continuously deviated from a neutral plumb state due to natural and man-made forces, it was necessary to account and correct for this displacement. Observations indicated that building deviations from the plumb line exceeded 50 mm (2.0 in) at times. The inclinometer network allowed for the correction of this deviation.

GPS survey procedures employed to position the steel columns included the occupation of each column center using nominal RTK observation times of two minutes. Structural displacement from the building's neutral position was determined simultaneously using data from the inclinometer network. The inclinometer-determined displacements, during each two-minute GPS occupation, were then applied to the GPS positions to determine the actual movements of each column, thus accounting for the deviation of the structure from the vertical. ■

About the author:
Vicki Speed is a freelance writer based in Littleton, Colorado/USA. (vickispeed1@comcast.net)

The Bow

At 58-stories and 236 m (775 ft) high, the Bow skyscraper in downtown Calgary, Alberta is one of the tallest and most unique buildings in Canada, encompassing nearly two city blocks and 180,000 m² (1.9 million sq-ft) office and retail space. For the first time in a North American skyscraper, the structure incorporates a triangular diagrid system to create a crescent-shaped building design. The diagonal and vertical steel frame with triangular plates significantly reduces the overall steel weight, and the number and size of interior columns and thickness of the elevator shaft walls.

The Bow will be the headquarters of EnCana Corporation, North America's second largest natural gas producer. The skyscraper is owned by H&R REIT, designed by Foster + Partners with development driven by Matthews Development (Alberta), and built by Ledcor Construction Ltd.

More information at: www.the-bow.com