Supporting a DREAM DESIGN

BY MITCHELL G. WIMBUSH, PS

From coast to coast, a surveying firm supports the installation of a complex architectural structure using today's advanced technology.

It has been said that "if you can dream it, you can build it." The architects who came up with the design for the new Station Place Building in downtown Washington, D.C., must have been doing a lot of dreaming. The new home of the Securities and Exchange Commission (SEC) is a 1.6-million-square-foot, 10-story office development located next to the historic Union Station. It features a prominent glass atrium lobby—composed of a complex, double-curved cable net wall and skylight. Complex also describes the level of surveying applied to this unique structure.

The Design

Cable net structures, which use tensioned cables to form a grid to support glass panels, were first introduced in the United States in 1999 for the UBS Tower, a global financial firm's facility in downtown Chicago. Prior to the building of Station Place, cable net structures were flat or only curved in one plane. The architects for the Station Place Building—Kevin Roche, John Dinkeloo and Associates of Hamden, Conn., and Advanced Structures Inc. of Marina del Ray, Calif.—decided to do something different by making the front of the building and the skylight curve inward in one plane and outward in another plane, giving it a saddle-shaped design. Never before had this design been constructed anywhere in the world. The geometric complexity of this double-curved net added stability to the building but required an innovative survey approach for the installation. The fabricator/erector, Art Iron Inc. of Toledo, Ohio, knew it needed a surveying company with highly specialized skills to provide quality control for installation. Its search led it to Midwestern Consulting of Ann Arbor, Mich.

The author prepares a backsight for a control survey at the Station Place project site.

Midwestern Consulting is a civil engineering and land surveying company with a reputation for assisting with construction layout on complex structures. "Art Iron was referred to us because of our surveying support for lifting and installing the roof dome at Ford Field in Detroit," says Dan Bongiovanni, president of Midwestern Consulting. "When we met with Art Iron, I knew this would be the most complex project in my 30-plus years of surveying. At our first meeting with the team from Art Iron, we were not even sure what we were looking at in the plans."

The Challenge

Art Iron needed to obtain an accurate (within 1/8 inch) verification survey of the structures that would support the prefabricated cable net and truss. The front of the supporting structure consisted of one 90-foot-tall concrete super column and a 90-foot-tall column that served as a building corner. The sides of the building consisted of two 60-foot-long concrete box beams; the rear was a 60-foot-long concrete gutter truss. In each of these structures were a total of 74 3-foot-long embedded steel sleeves with 1-foot square plates that held the cables. Additionally, between the front columns sat a 1-foot diameter, triangular-shaped steel pipe truss. The grid of cables and the truss were manufactured in China and shipped to the United States. It was critical that when the truss was installed and the cables unwound from their spool that everything fit together the first time. The critical point that needed to be located for the cables was the center of the embed on the inside of the concrete structures. This point was at the end of the cables and controlled the x,y,z location of the cable. The challenge: this point was not visible. In order to accurately locate this point, we relied on our dependable laser scanning equipment.

The Solution

One of the obvious advantages of using laser scanning equipment is the ability to see a complete picture of the objects being surveyed. Traditional surveying techniques can be considered point-to-point surveys and result in only the minimal amount of points needed to make a drawing. When surveying with a laser scanner, thousands of points are gathered in a few minutes, producing a complete 3D representation—the point cloud. In order to find the center of an embed that was set inside a concrete column, we decided to scan and catalog all the embeds before they were installed.

The 3D Model

Because of the way the cable net curved, the embeds were different shapes. By using our Leica Geosystems HDS 2500 (Leica Geosystems HDS, San Ramon, Calif.) 3D laser scanner, we scanned each of the embeds and converted the point cloud data to 3D models using Leica's Cyclone software. Once the embeds were set in the concrete, we scanned the exposed face and used the 3D as-built model to derive the center of the unseen plate inside the column. Without the HDS 2500, we would not have had an accurate as-built of each embed and would have had to rely on a few points from a reflectorless total station; this would not have allowed us to confidently locate the interior point based on the exterior surface. With conventional equipment, we would also have spent a lot of time and effort accessing the inside of the concrete columns to actually see the hidden points. Fortunately, we were able to take our HDS 2500 to the site in Washington, D.C. on several occasions to scan the embeds after they were set in the supporting structures. It took just one or two days to scan the site, and even though our main interest was in the face of the embeds, we found that having a scan of the entire atrium area proved to be very useful as the project progressed.

Back in our office in Ann Arbor, Mich., we used AutoCAD 2004 (Autodesk, San Rafael, Calif.) to compare the proposed design to the constructed location of the embeds and gave the architect a spreadsheet showing the differences. This method proved to be efficient; most of the embeds were in the correct location. Only a few of the plates had to be slotted. The cable net could go up as planned and the next task was to correctly install the truss.

Midwestern Consulting's HDS2500 safely performs an as-built survey from the ground.

The Installation

The first critical part of the truss installation was the location of the truss bearing plates. The truss rested on these plates on top of the super columns. Art Iron needed a sketch showing where these plates were to be welded in relation to the constructed location of the concrete columns. Since we had this as-built information from scanning the embeds, a return visit to the site was not necessary. We made the requested sketches from the point cloud information we already had. Once these plates were welded down, the truss was ready to be lifted into place.

To quickly position the truss, we decided to rely on a target-based survey using our Leica TCRA 1103+ total station (Leica Geosystems, Norcross, Ga.) and 1' square reflective targets. We placed seven targets across the face of the truss and used the stakeout mode in the total station to provide real-time positions as Art Iron placed the truss on the super columns. "They wanted to get the truss off the crane as soon as possible," says Dax Bird, crew chief. "There was a lot of pressure to quickly get it in place. It was not like staking out a manhole or a curb line. The complex 3D geometry of this project required everything we had." Once the truss was in position, we checked it with a steel tape and told Art Iron where to make some slight adjustments. We then went back to Ann Arbor and waited for the node survey.

Dax Bird, Midwestern Consulting crew chief, monitors truss installation.

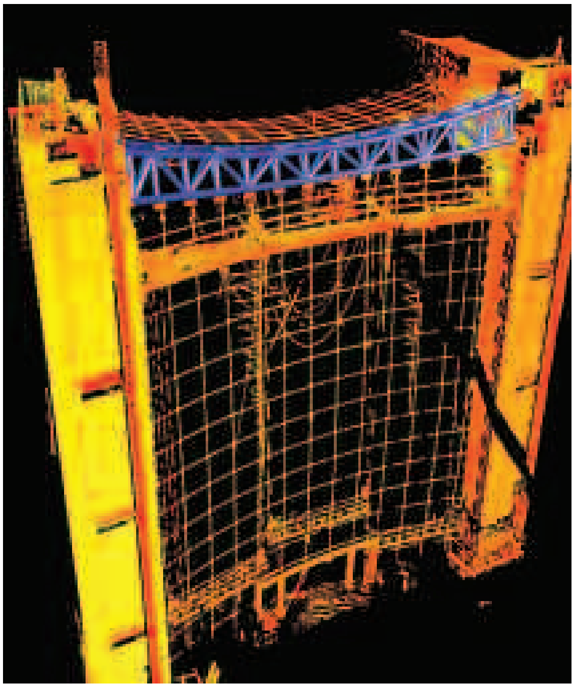
At the intersection of each of the net's 28-millimeter stainless steel cables were 3-inch square nodes that held a bracket that supported the 5-foot square glass panels. Once the truss was in place, the net was unwound from its spool and hung on the truss and columns. Next, the net was tensioned with hydraulic jacks in a precise sequence so as not to deform the net. Once all the cables were tensioned, we were ready to check the location of all 340 nodes. A field crew was sent to Washington, D.C. for three weeks to survey the nodes. Because the information was needed quickly, and because we only needed a single point on the center of the node, we used our reflectorless total station for this survey. The point could also be easily seen and measured using the optics in the total station. "Manipulation of the nodes was very tedious and challenging but ultimately rewarding once we achieved the necessary 1/8-inch accuracy," says Paul Kovacs, crew chief. The field crew shot the nodes and sent the data file late in the afternoon to our Ann Arbor office. There, we processed the data using AutoCAD LDD2004 and Star*net (Starplus Software Inc., Oakland, Calif.). We then sent a report to Advanced Structures Inc. in California who analyzed the data and returned it with revised coordinates of where the nodes should be. We E-mailed the new coordinates to our field crew the next morning so they could stake out the revised location of the nodes, allowing Art Iron to change the layout of the grid. The architect had to decide where to move each node because adjustments had to be made across the whole net and not locally, otherwise the glass would not fit. This process of relaying information back and forth went on for several weeks until finally the front wall and the skylight were completed and ready for glass.

The Benefits of Point Cloud Data

One of the most important benefits in using a laser scanner on this project was increased safety on the construction site; more of the surveying could be done from safe locations without the need for attaching targets to structures using scaffolding or cranes. And the extensive amount of accurate, reliable data generated by the scanner proved to be very valuable. In fact, many times during construction, the point cloud data proved to be more useful than originally intended. Since the project team was spread across the country from California to Washington, D.C., there were times when communication was difficult. If it is true that "a picture is worth a thousand words," we at

This top view of the truss shows the unique curved design of the SEC's Station Place.

This point cloud with modeled truss contains millions of points allowing for precise measurements anywhere on the building.



Midwestern say, "a point cloud is priceless." On several occasions we were able to explain conflicts or issues on the site by sending images of the point cloud to the project team. Often there were no photographs to rely on, and even if there were, we could not accurately utilize a photograph with multi-dimensions like we could a point cloud. Also, the point cloud helped us plan our future surveys. From our office in Ann Arbor, we could determine where to establish control points on the site in Washington, D.C. There was limited room on the site and the point cloud helped determine where there was a good line of sight to the necessary areas. This became critically important during the node survey because line of sight and incidence angles needed to be accounted for while shooting the nodes in reflectorless mode. Also, from our office we calculated the error due to non-normal incidence angles from each of the control points and realized that some of the nodes needed to be shot with a peanut prism.

The point cloud also proved valuable when discrepancies in dimensions across the building were found. We were able to go back through the succession of point clouds and document the subtle shifting of the building over time. It was not our initial intent to have a 3D record of the construction site over time, but by having detailed point clouds taken at different stages of the construction, we were able to show the client how the building was reacting under different loads.

The SEC's Station Place is a great example of how today's architecture is becoming more and more complex. Square, monochrome buildings are becoming less common as modern technology allows architects to design and build structures that previously only existed in one's imagination. To provide accurate surveys on these projects, surveyors can stop dreaming about future surveying tools, and start using them successfully now.

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