Engineering the tallest freestanding flagpole in North America required more than just looking at going big with a typical flagpole design.

TALL Order

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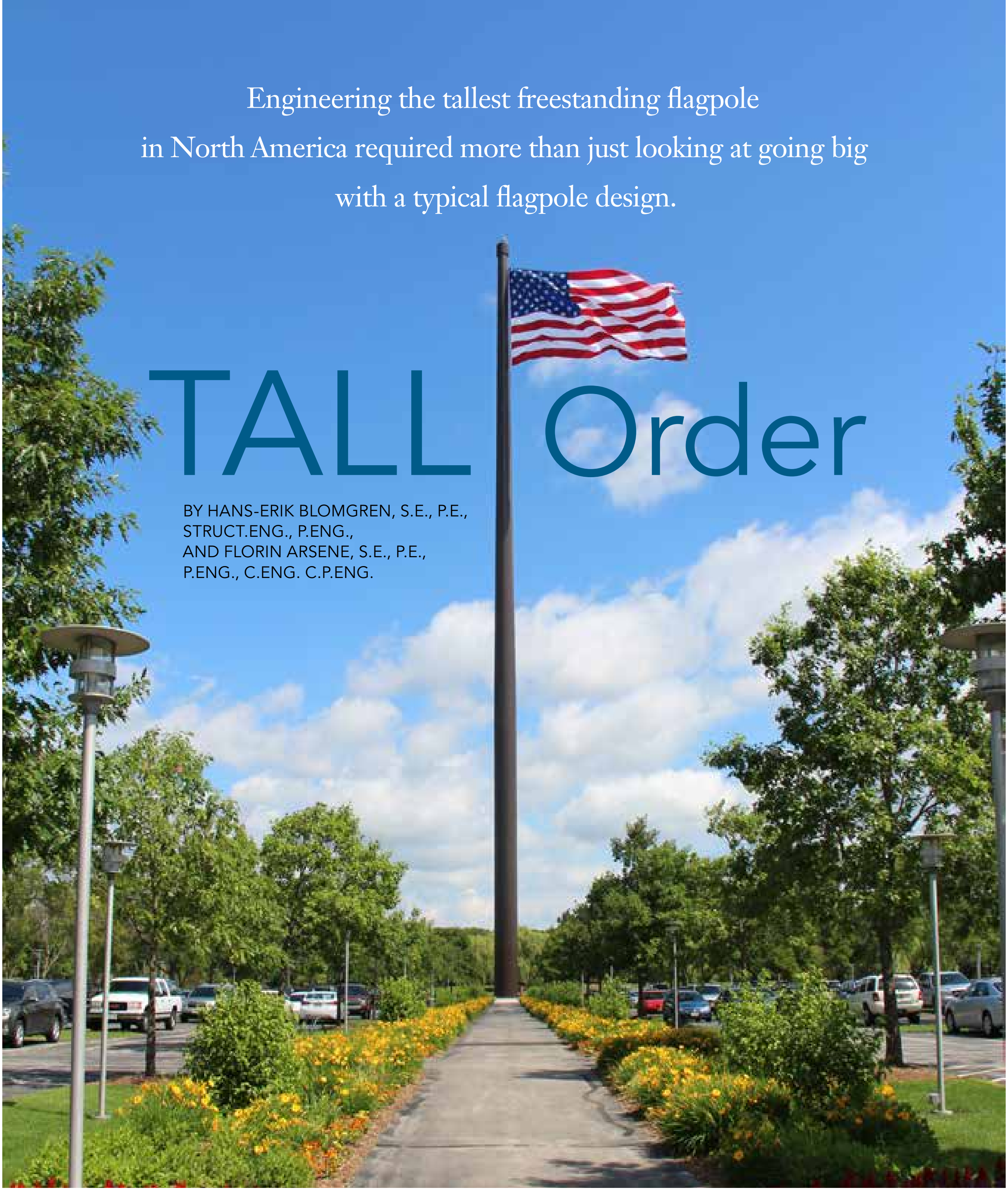

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Photos: ACUITY

▲ ACUITY's flagpole, at 400 ft tall, is the tallest freestanding flagpole on the continent.

IF THERE IS ONE THING that can reinforce the importance of the structural engineer's role in a project, it is arguably our ability to design efficient and functional structures of large or even immense scale—for example, designing the tallest freestanding flagpole on the continent.

Soaring to 400 ft tall, this flagpole was recently completed for ACUITY Insurance Company's headquarters in Sheboygan, Wis. Whereas flagpoles of standard heights are a common scene across the American landscape, the principles suitable for their design are not directly applicable to a flagpole that has been scaled up to such heights. This record-setting project provided an opportunity for the owner, engineer and contractor to work collaboratively to conceive and deliver the design criteria, analysis methods and construction requirements for a working flagpole of extremely large proportions.

Long, Tall, Sturdy

At the onset of design, the following key design criteria were agreed to for the given site conditions and owner requirements: The flagpole should stay functioning for at least 50 years; cold weather conditions had to be addressed, given the harsh winters typical to the area and; an accurate assessment of wind-induced effects in both the along and cross-wind directions had to be made.

In consultation with the owner, a Risk Category III, as defined by the *International Building Code*, was assigned to the project. This category calls for the primary overturning moment on the flagpole to be determined for a 120-mph basic wind speed with a recurrence interval of 1,700 years. To verify the wind and cold weather design conditions, CPP Wind Consultants carried out a detailed site-specific climate assessment study for the site. The study supplied information of the wind speed directional variation, looking at 16 wind directions at 22.5° intervals. In addition, the study recommended a design ice thickness of 1.9 in. concurrent with a basic wind speed of 40 mph, and a lowest anticipated service Temperature of -42 °F; this had implications on the specified steel components that could be used for the flagpole. Lastly, the study also supplied site-specific dynamic characteristics of the wind, such as turbulence intensity and length of scale.

Blowing in the Wind

At 400 ft, the flagpole is even taller than typical commercial wind turbine towers, which usually reach 300 ft. The fabrication for both structure types is similar, as is the controlling limit state: fatigue stresses. However, for wind turbines this vibration results from the rotating blades and heavy generator at the top of the mast. For the flagpole, the fatigue is derived from the aeroelastic effect of the wind-induced oscillations (vortex shedding) flowing around the cylindrical shape. The design methods used to assess these fatigue-inducing oscillations comes from standards published by the American Society of Mechanical Engineers (such as ASME STS-1-2011

▲ The flagpole is designed for at least a 50-year life.

▼ For the highest lifts, the crane was rigged with 177 ft of main boom and a 277-ft luffing jib.

➤ Starting at the bottom.

Steel Stacks) as well as the International Committee on Industrial Chimneys. In addition, a wind turbine tower is usually designed for a fatigue design life of only 20 years, 30 years fewer than the ACUITY flagpole's design life.

The flagpole structure is slender and flexible, having a natural period of vibration of four seconds. The ASCE 7 standard commonly used for building design provides a method of calculating a gust effect factor for dynamic sensitive structures to ensure that the maximum along-wind overturning moments and shear forces in the flagpole, at the design-level wind event, are accurately calculated. The ASCE 7 method is based on the natural frequency of the structure, damping ratio and the dynamic characteristics of the wind. However, this method has limitations as it only considers the first mode of vibration. Due to its slenderness, the flagpole has additional vibration modes that influence the dynamic response.

Therefore, special provisions outside of ASCE 7 were used to adequately address the dynamic response of the flagpole. This procedure, called the power spectral method, separates the response of the pole in a mean and a fluctuating component. The mean component is calculated by using a mean hourly wind speed. The fluctuating components are calculated as standard deviations and are divided into a quasi-static component and a series of narrow band responses. The total response consists of the mean response plus the standard deviation multiplied by a peak factor. The power spectral analysis considered the first three vibration modes. The results of the detailed power spectral analysis are about 15% higher than the gust factor method for dynamic sensitive structures in ASCE 7.

Upon determining the required size of the flagpole to resist the along-wind forces, the next design step involved performing a detailed assessment of the flagpole's susceptibility to be dynamically excited in the cross-wind direction due to the phenomenon called vortex shedding. It was determined that for wind speeds in the range of 10 mph to 35 mph, the first three modes of vibration would be excited in the cross-wind direction. The design required these motions to be suppressed because: The wind speed recurrence intervals are very low; the amplitude of motions would be visible to onlookers and; the many repeated cycles of vibration on the pole would cause metal fatigue failure well before the intended 50-year design life of the pole is achieved.

There are two rows of 72 radially arrayed 1½-in.-diameter threaded anchor rods.

The bottom two sections are straight 11-ft-diameter cylinders.

To adequately suppress the first three modes of cross-wind vibration, three supplemental tuned mass pendulum-type passive dampers are located within the flagpole. These dampers are sized to individually swing out-of-phase with the first three modes of vibration, which effectively increases the overall damping of the flagpole from 0.2% to 2.0% of critical damping. With these dampers in place, the engineer was able to calculate that the amplitude of vibrations are reduced by as much as a factor of 10 and that the cyclic steel stress magnitudes are reduced to be within the threshold fatigue limits defined in ANSI/AISC 360 *Specification for Structural Steel Buildings*.

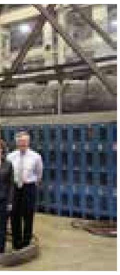
Gargantuan Six-Pack

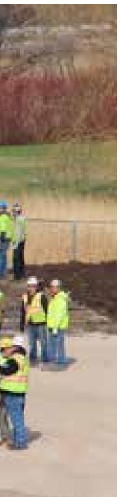
The structure consists of six tubular flanged sections that are connected by pre-tensioned high-strength bolts. The bottom two sections are straight 11-ft-diameter cylindrical

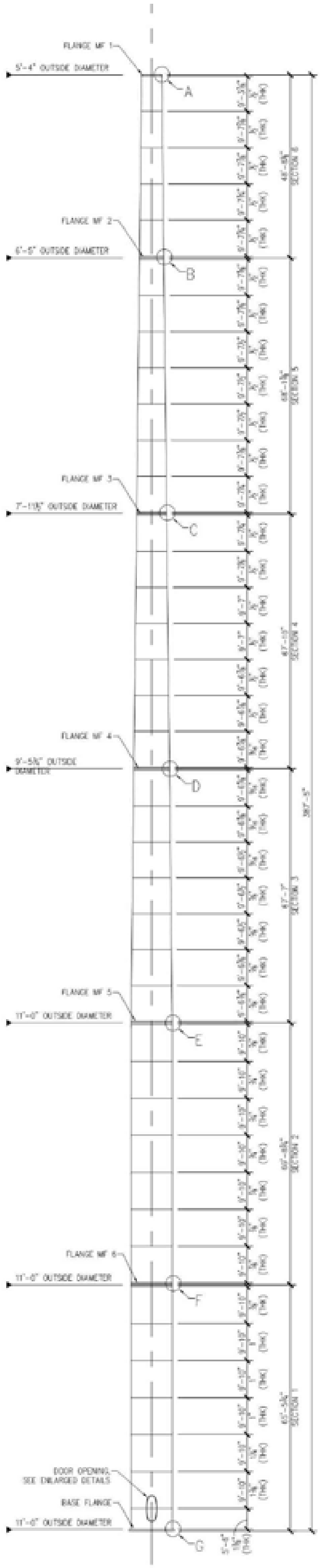
Special provisions outside of ASCE 7 were used to adequately address the dynamic response of the flagpole.

The structure consists of six tubular flanged sections.

The pole tapers from 11 ft in diameter at the bottom to less than 6 ft at the top.







cans. Above, the remaining four sections are tapered so that the top of the flagpole reduces to 5 ft, 4 in. in diameter. Each section is fabricated out of smaller 10-ft-wide rolled and welded steel plates. For the cylindrical sections, a 118-in. plate height was chosen with a 2-in. drop to allow for cutting and edge beveling. For the remaining tapered sections, the height is smaller than 118 in. as these sections require curved top and bottom cut edges.

The plates used for the tapered sections have variable height to minimize the steel drop. Each section is made complete by full-penetration welded, high-precision forged L-shaped circular flanges with a radial array of bolt holes for field connecting.

The flagpole is made from ASTM A572 Grade 50 steel that varies in thickness from 1½ in. at the base down to ½ in. at the top. The steel was specified to meet supplemental cold weather performance criteria, such as a Charpy V-Notch Impact Test of 20 ft-lb minimum at -40 °F. Flanges and door opening reinforcing were made from ASTM A707 Grade L2, Class 2 forgings with thicknesses up to 4½ in. This steel has a specified value Charpy V-Notch Impact Test 40 ft-lb minimum at minus 50 °F.

The pre-tensioned bolt assemblies used were DIN 6914 Class 10.9 in metric diameters ranging from M36 to M48, and the quantity of bolts at each flange ranged from 60 to 90. These high-strength bolts can be subject of hydrogen embrittlement failure; the maximum Rockwell Hardness was limited to 34 to mitigate this potential due to corrosion actions in service. To avoid the potential for hydrogen embrittlement during application of the corrosion protection coating, a zinc/aluminum coating—Dacromet—was used in lieu of hot-dip galvanizing. The anchor rods consist of two rows of 72 radially arrayed 1½-in.-diameter A320 Grade L7 pre-tensioned low-temperature service threaded rods embedded over 6 ft into the concrete foundation.

Mortenson Construction, using expertise from their wind energy construction group, provided a detailed erection plan. As a part of this plan, the engineer worked closely with the contractor to assess and mitigate the potential for wind-induced cross-wind motions of the partially erected flagpole considering the permanent tuned mass dampers were not yet in operation. The six flagpole sections were sequentially lifted into place by a Manitowoc 16000 crawler crane. The maximum section weight lifted was 59 tons. For the highest lifts, the crane was rigged with 177 ft of main boom and a 277-ft luffing jib.

Flying the Flag

The 60-ft by 120-ft flag weighs 350 lbs and is raised and lowered by a 10-hp winch system that is anchored to the concrete foundation at grade. A ½-in.-diameter high-strength cable inside the flagpole extends vertically to the top of the pole where it is carried over a series of sheaves and extends downward, protruding out of the top of the pole through a bronze bushing guide hole. From this point the cable is weighted at its base and restrained around the pole, with the flag tied to it at several connection points. Resting on the top flange of the top flagpole section is a 6-ft, 6-in.-diameter by 8-ft-tall steel truck assembly that supports the cable sheaves and can freely rotate on a lubricated slew bearing. This movable component of the flagpole ensures the cable and flag are allowed to weathervane with the prevailing winds.

This past June, more than 1,000 people attended the formal dedication of the flagpole, which serves as a memorial to United States Military Veterans. Visible from over nine miles away and located adjacent to Interstate 43, more than 45,000 people a day will be able to appreciate the monumental scale of the flagpole and what it symbolizes. ■

Owner
ACUITY Insurance Company

Technical Advisor
Arup

General Contractor
Mortenson Construction

Structural Engineer
Arsene Professional Engineers, Inc.

Flagpole Supplier
US Flag and Flagpole Supply