



Support Systems

What to Consider when Concreting Wind Turbine Foundations

By Charles Nmai

When spotting a wind turbine soaring in the sky, it's easy to keep focus on its blades turning in rhythm with the air. What is often overlooked is the structure that keeps these massive towers grounded and secure — a strong foundation built with specialized concrete. A towering wind turbine (which typically stretches 200 to 300 ft high) needs a strong support system from the very beginning to ensure that the turbine stays productive years after it's installed.

Specified compressive strengths for wind turbine foundations are typically in the range of 4,000 to 5,000 psi and can be achieved relatively easily. However, there is more to the design and construction of these foundations than compressive strength if they are to be functional throughout their designed service lives. Among the factors that can add to the challenge of concreting in these critical installations are: the mass of the foundation; the amount of reinforcement and its impact on concrete placement and consoli-

ation; the location of the installation; and the long-term durability of the concrete. By exploring the benefits of using chemical admixtures and innovative concrete technologies, contractors can produce green concrete mixtures that will facilitate concrete placement and consolidation, and enhance the overall durability of the concrete used in wind turbine foundations.

Warming Up

With section thicknesses ranging from 16 to 50 in. and greater, these foundations are essentially mass concrete placements. Therefore, the buildup of heat and peak temperature attained as the concrete hardens deserves consideration. Excessive heat development and dissipation may result in thermal contraction cracking shortly after the concrete hardens — compromising the structural integrity and durability of the foundation. Therefore, concrete mixtures

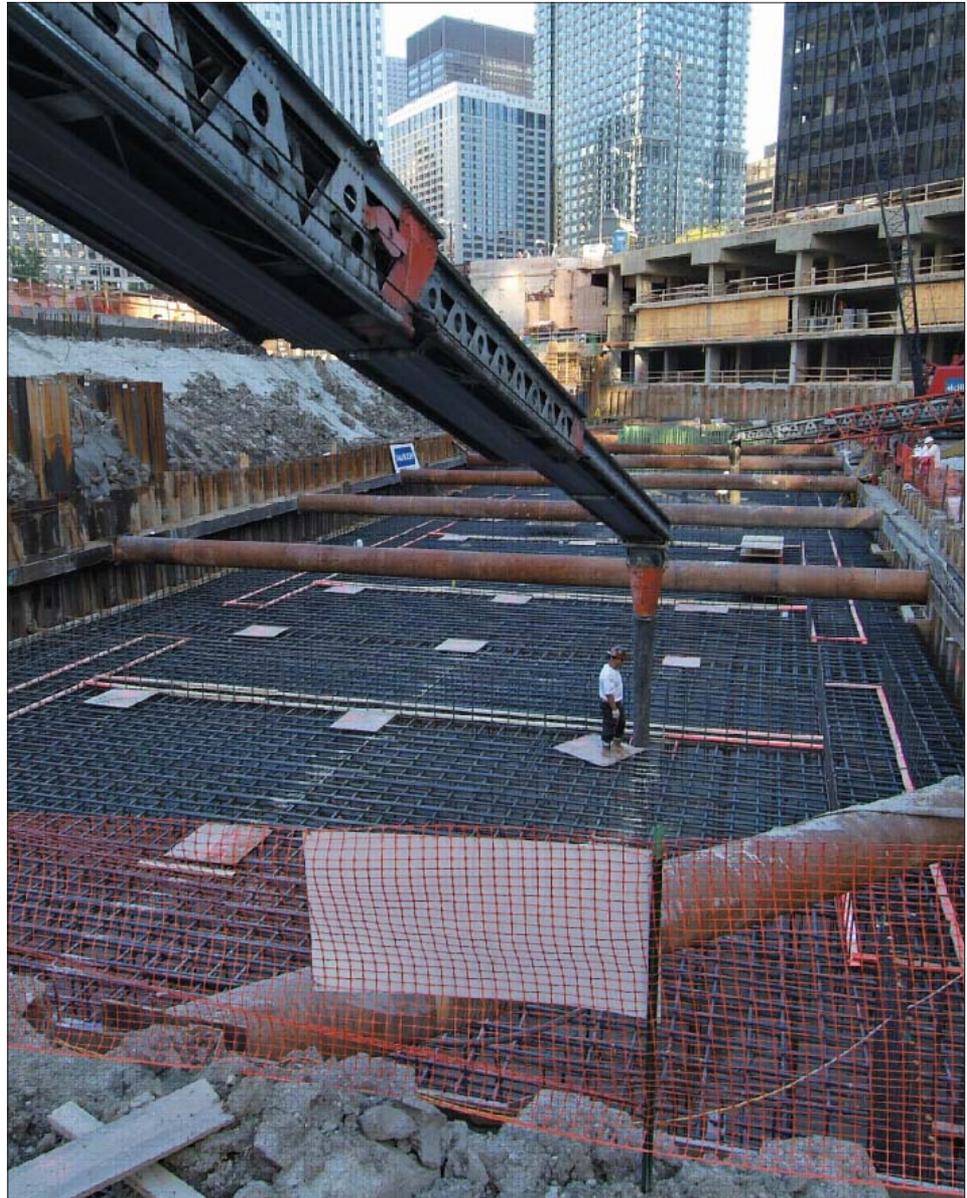
for mass concrete applications should be lean in Portland Cement content to reduce the amount of heat that is generated during hydration. This can be accomplished relatively easily while achieving specified compressive strengths by using supplementary cementitious materials (SCMs), such as fly ash, slag cement and metakaolin, in combination with the Portland Cement to ensure an adequate paste content for workability of the concrete mixture. Because time of set and early-age strength development can be impacted with these SCMs, water-reducing admixtures will be required to reduce the water-cementitious materials ratio (w/cm) and boost early-age strengths.

Increased levels of SCMs and a right blend of chemical admixtures can be used to proportion green concrete mixtures that are not only environmentally friendly, but also economical, using proprietary proportioning techniques. The ready-mixed concrete supplier, working in collaboration with a respected admixture manufacturer, should be able to work to develop an optimized concrete mixture for a specific wind farm project and provide a report that quantifies the economical and ecological benefits of the concrete. BASF's Green Senses Concrete Optimization and Eco-Efficiency Analysis programs are designed to accomplish these goals. In addition, as part of research funded by the Texas Department of Transportation, the Concrete Durability Center at the University of Texas developed a software program called ConcreteWorks to improve the constructability and durability of mass concrete bridge members, including concrete foundations. These software programs can be used to effectively proportion high-performance mass concrete mixtures for use in wind turbine foundations.

Placement and Consolidation

Concrete placement and consolidation difficulties may occur due to congestion of the reinforcement required to carry the vertical loads and to resist the overturning moments in wind turbine foundations. These concrete placement and consolidation difficulties can be overcome through the use of flowing concretes and, in particular, self-consolidating concrete (SCC). Flowing concretes are, by definition, cohesive concrete mixtures with slumps equal to or greater than 7 1/2 in. Because of the cohesiveness required, flowing concretes typically have low water contents or low water-cementitious material ratios (w/cm) and are made with high-range water-reducing admixtures (HRWRAs). Despite the high slump, a conventional-slump flowing concrete mixture will still require vibration for proper consolidation of the concrete.

SCC is a very high-performance flowing concrete mixture that is proportioned to have high fluidity and stability so that it consolidates under its self-weight without the need for mechanical vibration. It has been used very successfully in numerous projects including mass concrete elements in the Burj Khalifa, the world's tallest building,



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and the 10-ft thick mat foundation for the Trump International Hotel and Tower Chicago. Depending on the choice of admixtures and proportioning philosophy adopted, SCC can be produced with very minor changes to the proportions of the conventional mid- and high-slump concrete mixtures that are used in the casting of structural elements. However, some of the common techniques for proportioning SCC mixtures include the use of increased cementitious material contents and increases in the sand-to-aggregate ratios.

The choice of which proportioning technique to use is influenced by several factors, including the specific application, available materials and the recommendations of the admixture supplier. Depending on the concreting materi-

als and their proportions, a viscosity-modifying admixture (VMA) may be required to further enhance the stability of a SCC mixture. Exceptional stability in a SCC mixture is desired for proper flow and consolidation in elements with congested reinforcement.

The potential exists through the use of high-performance steel fiber-reinforced concrete (SFRC) to alleviate reinforcement congestion in wind turbine foundations. This can be achieved without compromising the structural integrity of the foundation through the addition of an appropriate amount of steel fibers in the concrete mixture to replace a portion of the steel bars. Essentially, the quantity of steel fiber is calculated using structural analysis programs to provide a moment capacity equal to or greater than the moment capacity of the steel bars that are to be replaced. SFRC is used extensively in applications such as slab-on-ground, shotcrete and tunneling.

The proximity of a wind farm to ready-mixed concrete plants is another factor that can impact decisions with respect to the concreting of wind turbine foundations. Depending on proximity, concrete for wind turbine foundations is either supplied by a ready-mixed concrete producer or produced onsite using a portable batch plant. When the concrete source is not conveniently located, hydration-control admixtures, also called extended-set control admixtures, and/or recently introduced workability retaining admixtures can be used to facilitate long-haul delivery of concrete. The workability retaining admixture is unique in the sense that it can be dosed to provide the degree of workability retention needed with only minimal, if any, impact on the time of setting the concrete or early-age strength development. These admixture technologies can potentially eliminate the need for portable batch plants for wind turbine foundations and thereby help to expedite wind farm construction.

Good Foundations Are Not Enough

Grout Is the Vital Link in Wind Turbine Foundations

By Patrick Watson

Well-designed and constructed foundations are critical to the successful operation of wind turbines. To assure long-term performance, the loads must be transferred from the tower to the foundation in a predictable and consistent manner. This is done with a bed of precision grout that serves as the vital link between the tower flange and the concrete foundation.

Properly specified, quality grout materials and knowledgeable installation are prerequisites to the long-term performance of wind turbine towers. Recent studies in Germany, where more than 20,000 wind energy systems are in place, have found that up to 30 percent are affected by foundation damage within the first three to five years. Causes of this damage include the high number of load changes (up to 7 million load changes per year). The loads must be transmitted through the anchors and through the grout bed that serves as the link to the foundation.

Some issues universal to all wind tower grouting include:

- The grout must be formulated to assure it flows into the entire grout bed space. If it can't be easily flowed to fill the space, even the best mechanical properties won't be of value.
- The grout must have a stable volume. Once the grout has filled the space between the tower flange and the foundation, it must keep that space filled without dangerous shrinkage or excessive expansion. Either of these will reduce the effective bearing capacity.
- The grout must have adequate strength to support the loads that will be placed upon it and to transfer those loads from the tower to the foundation. However, strength in and of itself is not enough. The loads are dynamic and include significant vibration. Grouts used for wind turbine towers should have vibration damping capability, as well as adequate compressive strengths. Accepted test methods have shown that carefully formulated epoxy based grouts installed in a professionally designed grout bed can provide these necessary properties. If cement-based grouts are selected for economic reasons, consider metallic aggregate based grouts for their high density and impact absorbing characteristics.

The installed grout is not just an extension of the concrete foundation; it is the vital link that is required for long-term successful wind turbine tower performance.

Patrick Watson is a technical service representative for BASF Construction Chemicals.



Grout and concrete work together to create a durable foundation for a wind turbine. To achieve long-term performance of wind turbine towers, quality grout materials and knowledgeable installation are a must.



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Staying Strong

Concrete durability is another aspect of wind turbine foundations that merits serious consideration. Reportedly, surface cracking in these foundations has been problematic, often requiring repair shortly after construction. The description of these surface cracks indicates that they are plastic cracks that form shortly after concrete placement. Plastic cracks can form when the rate of evaporation of water at the surface of the freshly placed concrete (bleed water) exceeds the rate at which the bleed water rises to the surface.

Subsequent drying of the concrete surface induces tensile stresses in the concrete that result in cracking because the concrete would not have developed any strength at that early age. This type of cracking is influenced by the concrete and ambient temperatures, relative humidity, wind speed and the bleeding characteristics of the concrete. For example, low humidity and a steady wind will produce favorable conditions for plastic shrinkage and plastic cracks. Plastic cracking can be significantly minimized by adding synthetic fibers to the concrete mixture or by applying an evaporation retarder to the concrete surface if conditions warrant it. In addition to reducing plastic cracks, synthetic fibers will also reduce cracking due to plastic settlement.

The durability of wind turbine foundations can be increased further through the use of specific durability-enhancing admixtures when necessary. For example, depending on the location, an air-entraining admixture may be required to develop an adequate air-void system within the concrete to increase its resistance to cyclic freezing and thawing. In marine applications or in areas with brackish water, corrosion-inhibiting admixtures and SCMs may be used to prevent or delay corrosion of the reinforcement.

If the wind farm location is in an area where aggregate sources include reactive materials, a lithium nitrate admixture, either singularly or in combination with appropriate amounts of effective SCMs, can be used to mitigate alkali-

silica reactivity (ASR). ASR is a destructive chemical reaction that once initiated is very difficult, if not impossible, to stop. It results in severe cracking of a concrete member within a few short years and overall loss of structural integrity. Therefore, it is imperative that the potential reactivity of the aggregate is known prior to construction of a foundation.

ASTM has standardized test methods for evaluation of the potential reactivity of aggregates with respect to ASR. They include ASTM C 1260, "Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)," ASTM C 1567, "Standard Test Method for Determining the

Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)," and ASTM C 1293, "Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction."

ASTM C 1260 and C 1567 are accelerated tests that take a little over two weeks to complete. They are severe and provide a rapid assessment of the potential reactivity of an aggregate relative to the C 1293 test, which takes a year to two years to complete. Project specifications should require information on the potential reactivity of aggregates and must provide options for ASR mitigation if the aggregates are deemed to be either reactive or potentially reactive.

Chemical admixtures and innovative concrete technologies can be used to produce green concrete mixtures that will facilitate concrete placement and consolidation, and enhance the long-term durability of wind turbine foundations. Self-consolidating concrete, synthetic and

steel fibers, hydration-control admixtures and the recently introduced workability retaining admixture appear to be technologies that can have immediate impact on the construction of wind turbine foundations. The use of highly durable, high-performance concrete mixtures and good construction practices can help achieve the design service lives of wind turbine foundations and keep them productive years after installation.

Charles Nmai, Ph.D., P.E., FACI, is manager of engineering services for BASF Construction Chemicals.



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