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Engineers tap increasingly innovative and sophisticated methods to design structures that can withstand the immense power of wind

BY SAMUEL GREENGARD

Modern buildings, bridges, outdoor shopping centers and stadiums are marvels of architecture and engineering. They alter skylines and create opportunities for people to live and work in entirely different ways than in the past.

Yet behind the iconic designs and the incredible economic benefits these structures provide, there's an important detail that's often overlooked: These structures must be engineered to withstand the forces of nature, especially wind.

"It's something that affects every structure on a daily basis," says Mark Chatten, wind engineer and principal at RWDI Consulting Engineers and Scientists in Toronto, Canada.

ENGINEERING

In extreme wind conditions such as a typhoon or hurricane, the stakes grow considerably—particularly for today's ultra-high-rise buildings. We all have been inundated with stories of recent and devastating hurricane wind speeds of 150 mph and more. As a result, architects and engineers turn to increasingly sophisticated methods to understand wind conditions and design structures for greater resiliency and comfort. They may alter the basic shape or use materials that are better suited for specific wind conditions, such as tuned mass dampers that absorb mechanical vibrations and shell components that temper noise from the wind.

Engineering wind-resilient structures and spaces is a complicated endeavor that relies on both human ingenuity and science. Projects must also mesh with other environmental factors, including falling snow and ice, snow loads and solar conditions. Consulting firms tap detailed climatological data, local wind data and more to grasp how wind affects a structure in a particular spot. But that's only a start.

Armed with a statistical wind model, these firms fabricate a scaled 3D model of a structure or even an entire community, and then equip these models with sensors and place them in a wind tunnel for extensive testing. "You subject the model to a 15-minute storm in just under a minute. You wind up with an understanding of how the shape, structure and materials on the building will handle wind," says David Banks, principal at CPP Wind Engineering & Air Quality Experts, Inc., Fort Collins, Colorado.

WINDS OF CHANGE

Designing and engineering for wind isn't a new concept. It has been used in one form or another for nearly half a century. In the 1960s, several pioneers in the field—including Alan Davenport, Jack Cermak and Peter Irwin—began using scaled models along with wind tunnels to better understand the physics of air currents and their effect on structures.

Before that, engineers had relied on manual calculations and best guesses to construct wind-resistant structures. That meant incorporating more steel and concrete. "It was a laborious process. The buildings—often incorporating heavy masonry claddings and heavy masonry interiors—required adequate lateral strength and stiffness to handle both vertical loads and wind impact," says Robert Sinn, principal at New York City-based structural engineering firm Thornton Tomasetti.

The 167-floor Jeddah Tower in Saudi Arabia will be the first structure to rise above 1 kilometer (0.621 miles)



Since then, the field has advanced remarkably. As buildings and towers have become taller and unconventional shapes have emerged, the impact of wind has become a much larger consideration in architecture and engineering. At the same time, many cities have introduced stricter building codes, design and engineering has moved from drafting boards to CAD and then to BIM, cost considerations have grown, and new types of building materials have emerged. No less important: data about wind has become more accessible. Today, wind consultants and engineers typically plug in climate data from nearby city or airport locations but also study how other buildings and local wind conditions affect a structure. For a bridge, this may include how nearby hills or river valleys impact surrounding air currents.



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TONY ROFAIL
WINDTECH
CONSULTANTS


When Windtech Consultants, a global wind engineering firm based in Sydney, Australia, conducted studies in Dubai for the 106-floor Marina 106 Tower, it pored over 30 years of wind speed records from the international airport. It also plugged in data from a variety of other locations and sources to validate findings.

“Some records may be faulty or incomplete, so it’s important to validate the measurements with nearby stations,” says Tony Rofail, director, Windtech Consultants.


In the case of Dubai, that meant comparing records between Sharjah International Airport and Dubai International Airport, roughly 20 kilometers apart. But it also meant examining other local data and understanding how strong local winds and storms would affect the structure. “It’s a very painstaking process, but you can’t get an accurate probabilistic model without it,” he says.




How a Wind Tunnel Works




1 Engineers assemble 3D-printed components of the building.




2 The scaled model is fitted with sensors to measure wind speeds, movements and pressures.




3 Wind engineers place the model in a wind tunnel, alone or with models of surrounding buildings.



4 The model is subjected to different wind conditions. A minute usually simulates about 15 to 30 minutes in the real world.



5 All the data is fed into software, where it is analyzed and presented in a report.



6 Architects and structural engineers use the data to optimize the design.

There's also the task of applying climate data and understanding local microclimate conditions.

"A structure located upstream a couple of hundred meters away can have a significant impact on the dynamic loading of a tall building, particularly if the two buildings are not located within a dense urban setting. A combination of structures in the area can alter the equation further," says Rofail. This might translate into a sway of a meter or less under normal circumstances. Depending on how the structure is designed, the sensation for humans could range from negligible to noticeable. "If people are living and working in a high-rise building and there is a significant sway once every five or 10 years, it's not a problem. If it's a monthly event, they're probably not going to find it acceptable," Chatten says.

Things are further complicated by viewing decks, pedestrian bridges linking structures, outdoor terraces, swimming pools and other spaces that may be included in a design. Banks points out that engineers must fully understand wind conditions before finalizing the design and building the structure. "A building owner or hotel may want an observation deck or a swimming pool in a particular place because it offers an awesome view. But if the location is extremely windy and unpleasant, people aren't going to use it," Banks says. Although there's some subjectivity involved in decisions, the issue may lead to an engineer redesigning, modifying or tweaking the space—or building screens or other structures to deflect or block the wind.

However, the biggest consideration is to ensure that a building or bridge is structurally sound—particularly for a major event such as a hurricane or typhoon. "The goal is to prevent the building from sustaining damage or collapsing," Chatten says. Furthermore, designers have gravitated to slender high-rise designs and tapped 3D CAD software to produce complex shapes for buildings. This means designing the structure for a 1-in-700-year windstorm—or adopting an even longer timeline. Consequently, wind consultants and structural engineers may rely on Monte Carlo simulations of hurricanes in computers to understand the most extreme weather scenarios.

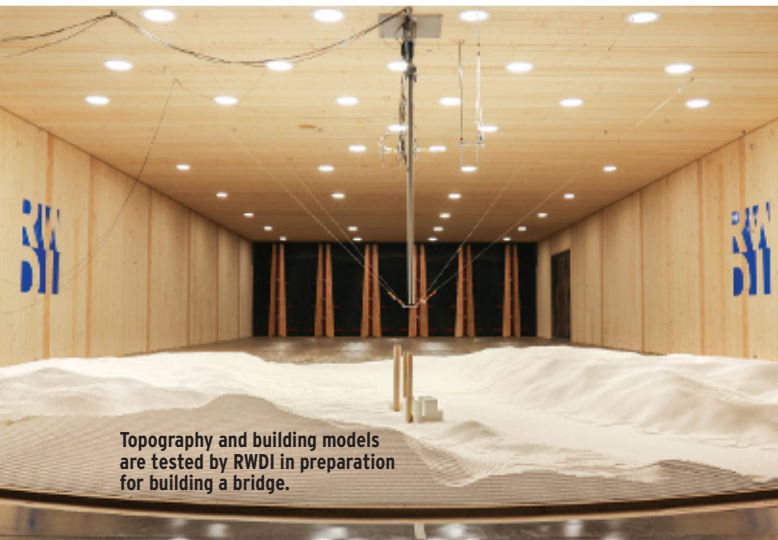
Rofail says that he sometimes generates timelines as long as 10,000 years. "Because the dynamics of structures can vary greatly depending on specific wind conditions—particularly lighter structures such as suspended or cable-stayed bridges—it's critical to examine a cross-section of conditions and scenarios," he says.

RIDING THE STORM OUT

Today's telecommunication towers, high-rise buildings and long-span bridge structures push the boundaries of architecture and engineering to new and once unimaginable limits. Burj Khalifa, the tallest building in the world, reaches more than 160 floors (828 meters) into the sky above Dubai. The 167-floor Jeddah Tower in Saudi Arabia, currently under construction and scheduled for completion after 2020, will be the first structure to rise above 1 kilometer. Typically, wind speeds and turbulence vary at different levels of structures—and the predominant wind direction may vary, depending on the location. In addition, the shape, orientation and cutouts in a building also play a major role in wind comfort and resiliency. RWDI, which handled the



An engineer at RWDI uses a specialized device to test and view air currents on a model of Shanghai Centre.



Topography and building models are tested by RWDI in preparation for building a bridge.

RWDI

wind testing for Burj Khalifa, modified the shape and orientation through wind studies and testing. “It is a very aerodynamically efficient building. The height would not have been possible without in-depth studies,” Chatten explains.

In fact, testing scaled models in wind tunnels has emerged as the primary method for understanding the effects of wind on

bridges and buildings. Once designers have developed a viable design, wind engineers use CAD software and a 3D printer to fabricate components for a model—roughly at a scale of 1:400. The days of laboriously assembling models from wood and Plexiglas have passed. The 3D model is assembled and equipped with pressure sensors, typically ranging from a few hundred to thousands, that together measure wind pressures across the entire envelope. The resulting data is fed into a computer, and proprietary software crunches the climate data and test data. The end result is a mathematical model of how the building will sway in the wind—and how it will fare under different conditions and scenarios.

If a structure looks sound and it fits desirable criteria, the structural engineers can proceed with the design. If the test shows that the building or bridge will sway excessively, the teams will change the natural frequency of the structure or make other necessary modifications to correct the underlying problem. Another model may go back in the wind tunnel for additional testing. Either way, when the testing has been completed and the software has crunched all the data, the consulting firm provides structural engineers a report with the wind loads. The wind



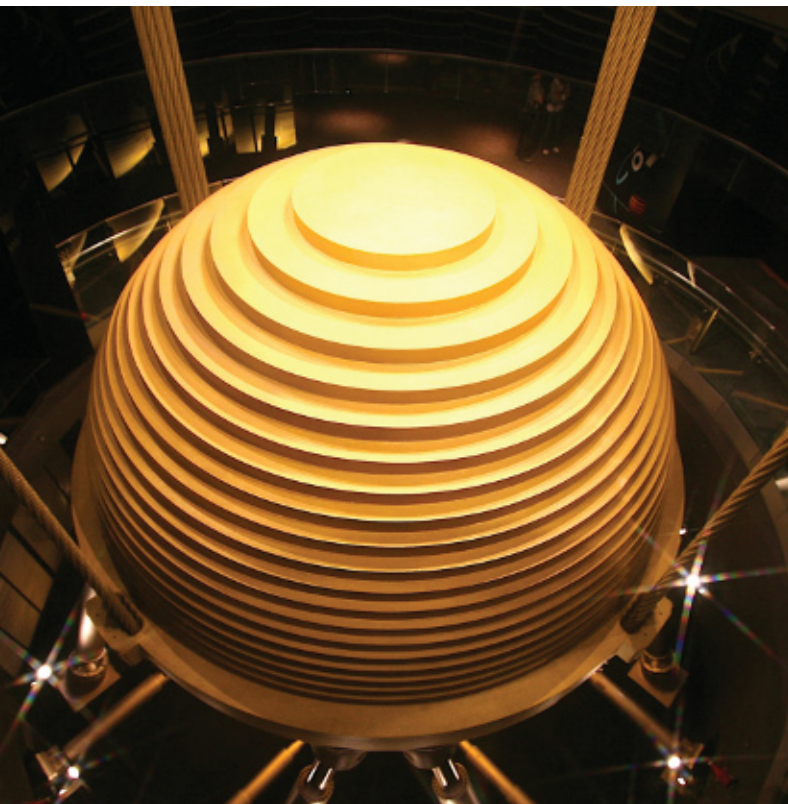
“If people are living and working in a high-rise building and there is a significant sway once every five or 10 years, it’s not a problem. If it’s a monthly event, they’re probably not going to find it acceptable.”

MARK CHATTEN | RWDI CONSULTING ENGINEERS AND SCIENTISTS



RWDI

The 1,667-foot-tall Taipei 101 tower (a 2006 EEA Grand Award Winner) uses a 727-ton tuned mass damper hanging from the 92nd floor to harmonically absorb wind motion



RWDI

tunnel test usually requires a few weeks of preparation, but the test itself lasts only a few hours. In some cases, engineers may conduct multiple tests to understand loads on the actual structure but also wind conditions for specific locations, including balconies and pedestrian areas. “It’s a very effective and accurate way to measure the effects of the wind,” Banks says.

Additionally, engineers might also turn to computer simulations and computational fluid dynamics to understand specific situations, such as internal airflows in a mall or the impact of mechanical vents in a particular place. However, Rofail points out that these methods haven’t advanced to the point where they are sufficiently reliable to be used on their own for overall wind engineering. A 40 percent to 70 percent variation often exists between computational fluid dynamics techniques and wind tunnel tests, he notes. “This pretty much wipes out any safety margin that would be incorporated in the design process,” he says.



“Testing has advanced remarkably. Today’s wind testing methods—which are used on virtually every building over roughly 400 feet—are producing truly incredible structures.”

ROBERT SINN
THORNTON
TOMASETTI

Of course, the end goal is a structure that can withstand the forces of nature and deliver maximum comfort. By knowing how wind and structure interact, a design team can increase the efficient use of materials, trim unnecessary costs and risks, and deliver a reliable design. “While it’s possible to toss unlimited concrete and steel at structures, the idea is to build something that is elegant and functional. It should fit the physical environment but also be adapted for that place. It isn’t just about designing to withstand anything. It’s about designing and engineering in the most effective way possible, which encompasses creative design, costs, environmental factors and safety,” says Banks.

SKY’S THE LIMIT

Not every large bridge and building requires sophisticated climatological data and extensive wind tunnel testing. Brent Wright, president of Wright Engineering in Columbus, Georgia, says industry standards that address wind design are adequate for building many structures. They provide basic information and guidelines about wind loads and construction standards. He typically consults the standards for constructing schools, offices and other buildings. This leads to the installation of shear walls, braced frames, different types of windows or other basic modifications. “Additionally, most buildings

simply require components to withstand uplift loading,” he says.

Yet, the wind engineering that goes into the tallest and most sophisticated structures is remarkable. For instance, the 1,667-foot-tall Taipei 101 tower, once the world’s tallest building, and a 2006 EEA Grand Award Winner featuring structural design by Thornton Tomasetti, uses a 727-ton tuned mass damper to harmonically absorb wind motion. The sphere is 18 feet in diameter and is suspended between the 87th and 92nd floors. It was actually tested during Typhoon Soudelor in 2009. When winds hit 145 mph, the giant orb swung more than 1 meter horizontally. The building did not sustain any major damage from the storm.

Make no mistake, wind engineering results in better architecture, engineering and construction methods. While it’s impossible to build a bridge or a building that is completely windproof, today’s methods maximize public safety while driving design excellence and cost savings. “Testing has advanced remarkably. Today’s wind testing methods—which are used on virtually every building over roughly 400 feet—are producing

Wind Testing the World’s Tallest Building

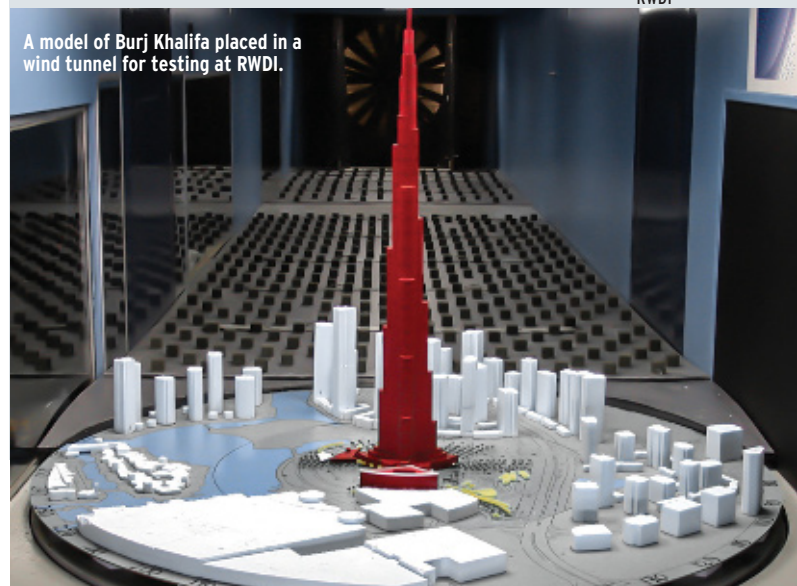
When Burj Khalifa was completed in 2010, it became the world’s tallest skyscraper, rising to a height of 828 meters (2,716.5 feet). The mixed-use structure—which includes a 304-room hotel, 900 apartments and office spaces—has emerged as one of the most identifiable buildings in the world.

Understanding wind loading and wind-induced motions was critical. The tall and slender shape of the building added to concerns. Although engineers had designed the core of the structure as a bundled tube and a Y-shaped design was selected to “confuse the wind,” extensive wind testing was required using 1:500 scale models and a 1:50 model for the top one-third of the building.

RWDI embarked on a series of wind tunnel tests at its Guelph, Ontario, facility. Teams used high-frequency force balance to understand crosswind effects of vortex shedding on the building. Along the way, designers changed the design of Burj Khalifa—including the number and spacing of the setbacks.

By overlaying wind tunnel tests with climate data, architects and engineers ultimately determined that it was best to reorient the tower to greatly minimize the effects of the wind. Using rigid-model force balance tests, full multi-degree-of-freedom aeroelastic model studies, measurements of localized pressures and pedestrian wind environment studies, they also found ways to minimize winds in pedestrian areas and observation decks.

RWDI



A model of Burj Khalifa placed in a wind tunnel for testing at RWDI.

truly incredible structures,” says Sinn, chief structural engineer for Jeddah Tower. This allows architects and engineers to move beyond box high-rises and simple bridges and introduce far more innovative and beneficial designs. ■

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