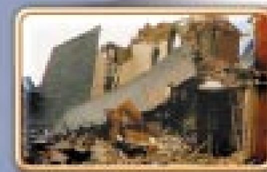
The death toll for the 1998 hurricane season topped 12,000, the deadliest year on record in this hemisphere.

Hurricanes are tropical storms with winds in excess of 74 miles per hour.



The Fujita Scale rates the intensity of a tornado by examining the damage caused by the storm after it passes over a man-made structure.

Every year about 1,000 tornadoes touch down in the U.S.

# The High Price of Wind

**One hundred million dollars a minute ... that's the amount of damage caused by Hurricane Andrew during its on-shore rampage. All totalled, it generated more direct and indirect economic losses than any other natural event in this country — in excess of $30 billion, not including the damage to offshore structures. But consider this: As devastating as Andrew was, if it had continued just 20 miles further north in Florida, the losses would have increased dramatically. Or if, instead of moving north, it had traveled as far west as New Orleans, the damage could easily have exceeded $100 billion. Think of the consequences — not only the damage to homes and other structures, but the loss of lives, the limits of the insurance industry's ability to sustain those losses, and the sheer time factor ... being able to rebuild before the next storm hits. The fact is that hurricanes and tornadoes are the deadliest types of natural disasters in terms of personal and property loss. With 75 percent of the U.S. population expected to live in coastal regions by 2010, it is likely they will remain the most destructive. Lessening the effects of high winds on homes, cityscapes, and bridges, as well as coastal structures and offshore installations is a problem that needs to be addressed before the price becomes too great to bear.**

## Battling the effects of strong winds

In the United States today, tornadoes and hurricanes kill more people and destroy more property than any other type of natural disaster. Economically, they are just as destructive, and the damage is not confined to one type of building or class of architecture. Wind related hazards impact structures old and new, high and low, on and offshore with the same fury. It is a daily struggle.

Modern unconventionally shaped structures with complex exterior geometry and innovative structural systems are sometimes more sensitive to high winds than buildings constructed 50 years ago, even though building codes have improved significantly. On the other hand, high-rise structures that meet the code for lateral drift requirements can still sway in strong winds. This movement may not be enough to cause structural damage, but it can adversely affect a building's occupants. Low-rise structures, bridges, and offshore platforms are also susceptible to wind.

Dr. Ahsan Kareem, Professor of Civil Engineering and Geological Sciences, is a leading researcher in dynamic fluid-structure interactions, structural safety, and the mitigation of natural hazards — specifically wind, waves, and earthquakes. One of his specialties is wind engineering, studying how structures react in the wind. Funded by the National Science Foundation, the Office of Naval

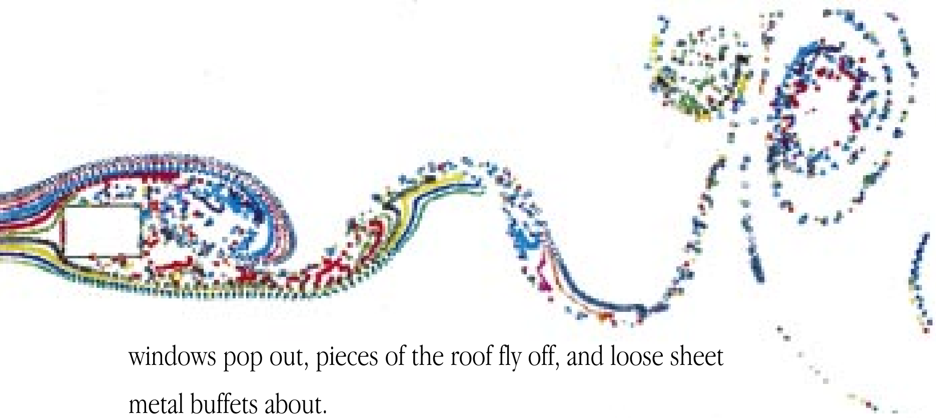
Research, Lockheed Martin, Texas Advanced Technologies, the American Institute for Steel Construction, and a host of major oil companies, Kareem's work has already brought about improvements in building codes and standards. For example, his research led to the revision of the ASCE7-95 Standard for Minimum Design of Loads on Buildings and Other Structures, which, in turn, helped create safer and more wind-resistant areas in the United States and the Caribbean and currently serves as a model for building codes around the world.

The threat of wind, however, is not confined to buildings. Wind also attacks bridges and offshore platforms, and its effects are varied. Movement in the wind may not affect a structure's integrity, but that motion can disrupt the daily function of the structure and its occupants. In extreme cases, elevators might be shut down or entire buildings closed. Understanding how wind flows around various structures and the type of damage that may result remains the best defense against the ravages of high winds and wind related disasters.

"One of the difficulties in studying wind, as well as the reason it's important to do so," said Kareem, "is its complex nature." Buildings, like humans, have skin and bones. They also come in different shapes and sizes, which determine how they react in extreme winds. The skeleton of a building is made up of beams and girders; this is where a structure gets its strength. Cladding, the skin of a building, protects its skeleton. Siding, shutters, glass panels, bricks, and sheet metal are examples of cladding. Unfortunately, cladding is the part of the building most affected by wind.

Skyscrapers can experience damage to cladding during intense winds. For instance, if the wind pressure exceeds design criteria, pieces of the cladding may break away. Even if the structure is built to high tolerances, it could still be impacted by windborne debris from other buildings designed or constructed to less stringent standards. When the cladding isn't anchored well ... if the building is old or materials are corroded ...

**Dr. Ahsan Kareem, Professor of Civil Engineering and Geological Sciences (right), and graduate student Swaroop K. Yalla use the computer controlled actuator system in Notre Dame's NatHaz Modeling Laboratory to study the dynamic effects of wind on structures. The equipment shown here tests a scale model of a tall building.**



With the help of high-speed computers, Kareem's group can generate virtual visualizations of wind flows around buildings of differing geometry. An integrated intelligent system coupled with Geographical Informational Systems (GIS), Global Positioning Systems (GPS), and a virtual computational environment will eventually provide a valuable tool for monitoring, in real-time, the potential for damage by wind as, or before, a storm hits. This system could be used to assist emergency response and recovery teams, as well as city planners.

windows pop out, pieces of the roof fly off, and loose sheet metal buffets about.

To help minimize this and other types of wind damage Dr. Kareem has pioneered several techniques to study wind. One of these is the use of wavelets, which serve as "mathematical microscopes" to paint a portrait revealing the minute details of how wind affects a structu and determine what causes structural damage. He also u: advanced statistical simulation and modeling, visualizations of wind flow around buildings of different shapes, and physical modeling. With the help of high-speed computers, he can monitor, in real-time, the actions of wind as it wraps around structures. He has also successfully developed numerical approaches as modeling tools and is collaborating with researchers from other universities to develop large-scale simulations of wind flow over residential areas and urban centers. Information from these studies will eventually provide city planners, architects, and builders a "virtual environment" so they can evaluate a variety of options before construction begins.

This is especially important considering some of the concerns that have risen about current structures. Due to increased competition, cost-control issues, and the availability of lightweight, high-strength materials, designers are under pressure to be more cost conscious and conserve the use of steel. As a result, they are making buildings lighter. Older structures, such as the Empire State Building, weigh about 25 pounds per cubic foot. Many newer buildings, high-rise and low-rise alike, average much less than that. They lack the bulk to withstand high winds.

These lightweight structures are literally attacked by the wind, and like a person walking down a sidewalk, the buildings are impacted from all sides. Pressure fluctuations on the face of a building in the direction of the oncoming wind push and pull the structure. Imbalances in the pressure distribution on a building's surface result in a twisting motion, and wind passing around a building generates swirling whirlpools. When this happens, a building's reaction is inevitable; it will sway and twist.

Long-span bridges are also sensitive to these buffeting actions, especially the whirlpools. In aeronautical terms this movement is called "flutter." Currently, Kareem is developing numerical and experimental procedures specifically for bridges that will help identify and overcome this phenomena.

"Any type of movement in a structure is potentially dangerous, but twisting is the worst motion, especially in office buildings," said Kareem. "It disrupts the human sense of balance causing a type of nausea associated with sea sickness. In some cases workers in tall buildings may lose several days of work due to wind generated motion sickness." Fortunately, a structure can be stabilized by using active, semi-active, or passive control systems to dampen the movement. These devices lessen structural damage while minimizing the motion felt by the building's occupants.

In addition to his other collaborations, Dr. Kareem is working with Dr. Jeffrey Kantor, Professor of Chemical Engineering and Associate Provost, to develop real-time intelligent control strategies for winds and earthquakes. Wind, wave, and earthquake loads are tested on campus in the NatHaz Modeling Laboratory, which represents the next generation of dynamic loading facilities because loads can be mimicked by a set of computer controlled actuators. Equipment in the Laboratory applies pressure at various points of a scale-model building to simulate loads, and the building's reactions are recorded. For instance, one of the current modeling studies tests a semi-active liquid damper. By manipulating the water motion in a tank on top of a building, movement can be reduced more than 50 percent.

"Experiments in NatHaz Modeling Laboratory are key," said Kareem. "However, to model details of wind effects on structures, scale models are used in wind tunnels." Traditionally operated for aeronautical applications, wind tunnels — like the one located in the Hessert Center for Aerospace Research — are becoming common tools for civil engineers. Kareem's research in the Hessert wind tunnel includes tests on a wide range of scale structures from the Nanjing Television Tower in the People's Republic of China to suspension bridges and offshore installations. Because offshore platforms are susceptible to both wind and wave interactions, studying the behavior of these structures also includes duplicating a variety of ocean conditions in order to determine safety and reliability measures and make them more suitable for deep-water operations.

With all of the research — with computer modeling and physical simulations — the fact remains: wind cannot be controlled. Nor can it be ignored. However, the havoc it creates can be managed. The more Dr. Kareem and other researchers monitor buildings, bridges, and offshore structures ... the more they study wind flow in urban and residential areas ... the better engineers, architects, and city planners will understand the enigmatic nature of wind related hazards. From that, safer design codes and construction practices, as well as more effective emergency preparedness plans for business and residential communities, can be developed. And, the less destructive the next high wind might be.

**Graduate student Fred L. Haan, Jr. readies a scale model of the 1,000-foot-high Nanjing Television Tower for testing in a wind tunnel at the Hessert Center for Aerospace Research. To investigate the tower's sway, Dr. Kareem modeled the effects of wind in the city of Nanjing, People's Republic of China. Based on those and other findings, a research team, including Dr. Kareem, designed an active damper system to help control the tower's movement.**