Signatures

Engineering Advances
at the University of Notre Dame

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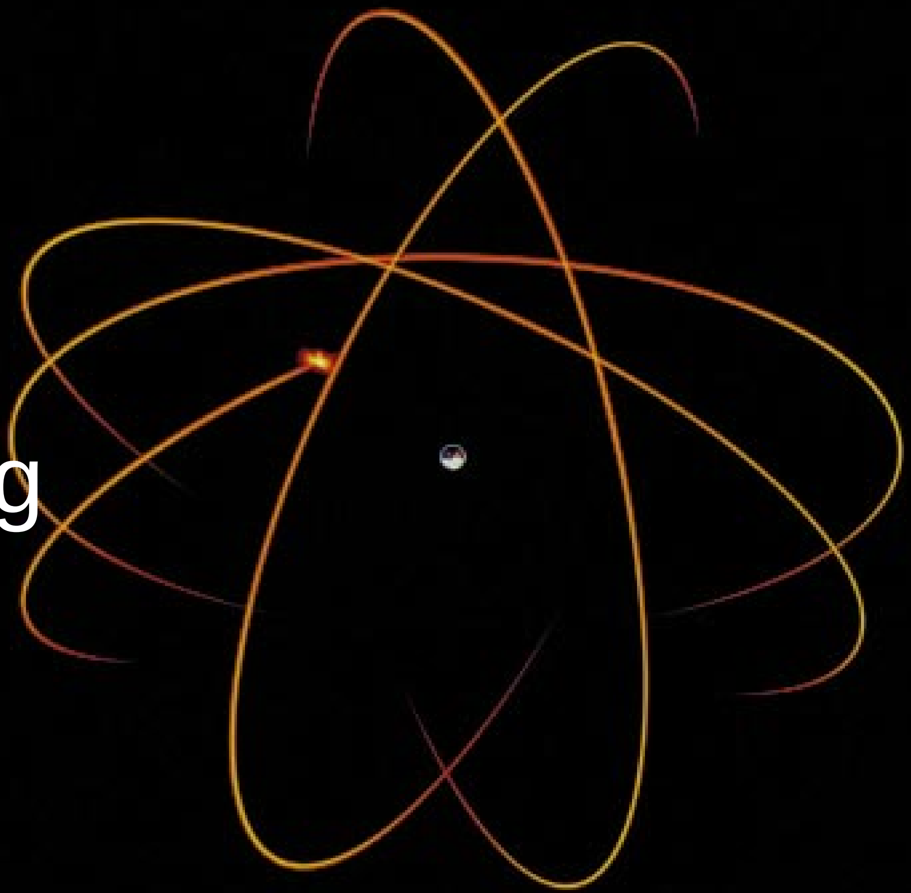
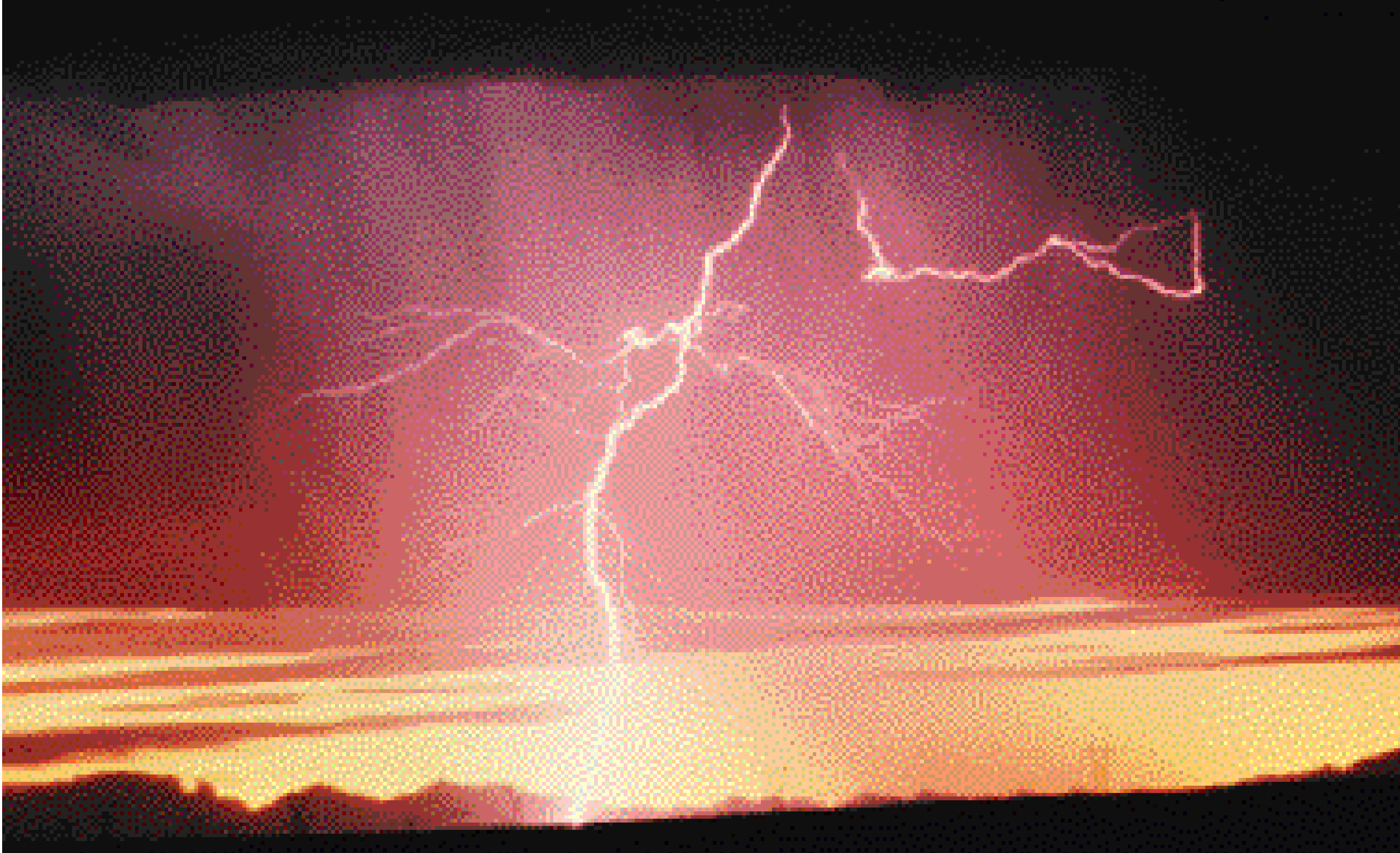
Mitigation:
Can We Curb the Effects of Natural Disasters?

Engineering and Minority YouthÑ
An Academic Initiative for the Future



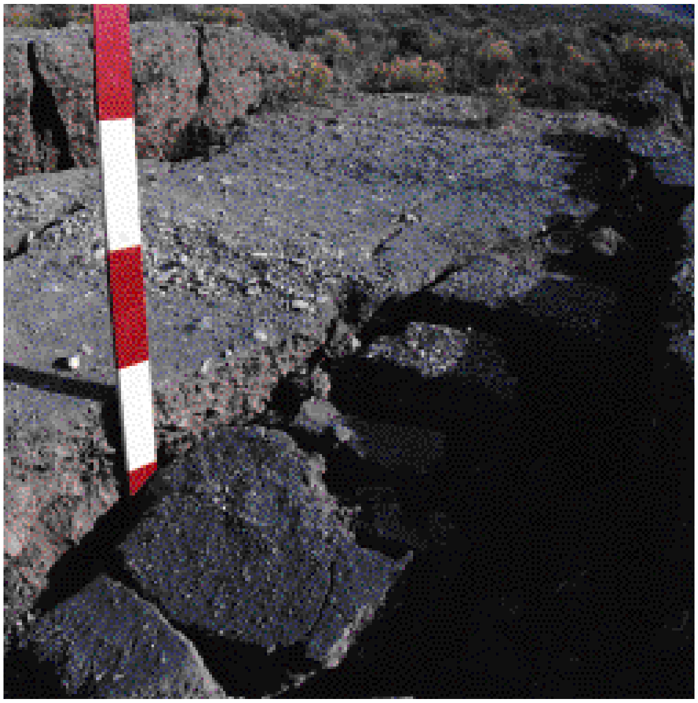
Quantum-Dot Cellular Automata .
Making Circuits Smaller, Faster, and Bett

"Acts of God" is a favorite phrase among insurance companies. It means no one can prevent certain natural events, like earthquakes, hurricanes, and tornadoes. These disasters devastate communities. Businesses are lost, and families destroyed. And while it is true that God devised the natural laws that govern weather, the earth's core, gravity, and other phenomena, it is just as true that He gave man the curiosity and intelligence to develop ways to lessen the havoc caused by natural hazards. Today, leading institutions like the University of Notre Dame, are studying ways to decrease the amount of damage brought about by these disasters. The findings, especially in the areas of earthquake and wind engineering, are encouraging ...



Movers & Shakers:

Natural Hazard Mitigation at the University of Notre Dame



A fault is a fracture in the earth's crust; most faults are the result of repeated movement over a long period of time. Surface rupture like this occurs when movement in a fault breaks through. Not all earthquakes result in surface rupture; however, the ground movement from the sudden shifting of an earthquake affects buildings and other structures.

Curbing the damage from earthquakes

There's a 100 percent chance of an earthquake today, a sudden slip in a fault when plates from the earth's crust shift and grind against one another. And, since the earth's plates are always moving, there will be an earthquake somewhere in the next 24 hours. The National Earthquake Information Center identifies about 35 earthquakes in the United States every day. That's anywhere from 12,000 to 14,000 quakes annually. Some are so light only very sensitive instruments can detect the ground motions — the "shaking." Others rattle windows, jar houses, and topple buildings.

For years government agencies, scientists, engineers, architects, and builders have studied the effects of quakes on buildings, looking for a way to curb the damage they cause. Scientists began recording information on earthquakes around 1880, but it was not until the 1940s that record-keeping instruments were installed in buildings. Over the next few decades as the number and size of buildings increased, so did the number of recording devices.

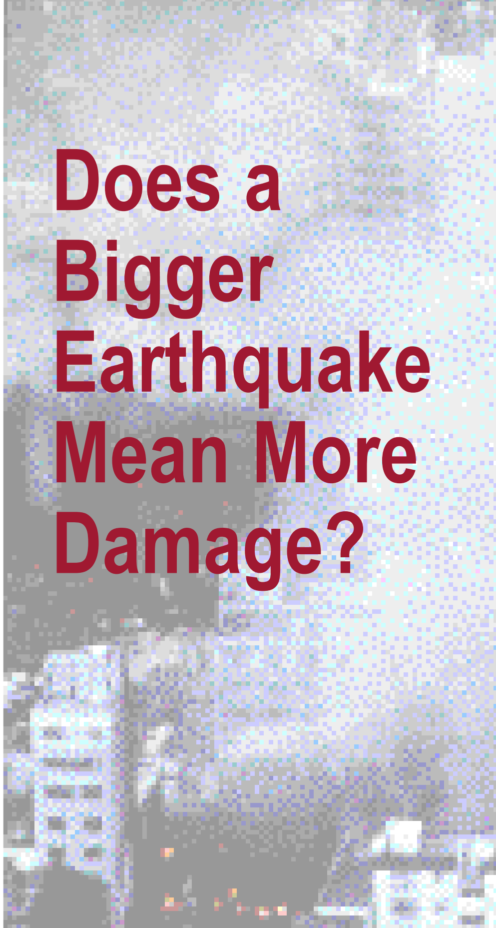
In 1977 the Earthquake Hazards Reduction Act, Public Law 95-124, established the National Earthquake Hazards Reduction Program (NEHRP). Its objectives were to analyze earthquakes, develop seismic design and construction standards for civil infrastructure, investigate the feasibility of earthquake prediction, prepare plans for mitigation and response activities, and educate the public about earthquakes and how to survive them. Four principal agencies are affiliated with NEHRP: the Federal Emergency Management Agency (FEMA), the United States Geological Survey (USGS), the National Institute of Standards and Technology (NIST) and the National Science Foundation (NSF).

It is the NSF that is funding a large portion of the research of Notre Dame's Dr. B. F. Spencer, Jr., Professor of Civil Engineering and Geological Sciences, and Dr. Michael K. Sain, Frank M. Freimann Professor of Electrical Engineering. Their approach is different than those previously considered. According to Professor Spencer, in order to survive large earthquakes, buildings have typically been designed to sustain damage. "That would be like your car breaking every time you go over a pothole. You wouldn't want that in your car; that's why automobile manufacturers use shock absorbers." Professors Spencer and Sain are working on a concept very similar to automotive shock absorbers, but for buildings and bridges. In the structural dynamics world, this is called "supplemental damping."

Much of the research in the last decade has been directed toward active and passive control systems. An active system physically applies force to a structure when the force-generating device (actuator) receives a signal and is activated. Although many active systems have been installed in buildings around the world, concerns do exist within the engineering community. Active systems are not currently cost effective. They are not as reliable as other systems, and the power requirements are high, a liability during a disaster such as an earthquake when power is often interrupted.

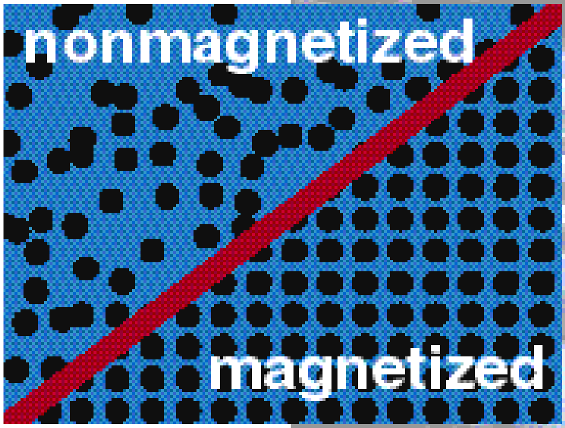
Passive dampers provide an alternative to active systems. They require no outside power source. However, they only react to the motion and forces of the building, dissipating energy in a fixed way. Passive dampers cannot adapt to changes in force or vibration.

Professors Spencer and Sain felt the solution lay somewhere between active and passive systems. "For controlling buildings during non-critical times, you want to have the dampers soft so there are no jerky movements. This helps protect the contents of the building," said Spencer. "During an earthquake you want increased damping." For example, during stable periods building occupants should experience the soft, cushy ride of a luxury car. The tight suspension and control of a sports car is sought during a catastrophic event. This additional control helps the building adapt more quickly to ground movements, keeping the structure and its occupants out of danger. Spencer and Sain have developed a shock absorber that uses an oil suspension of tiny iron particles, a magnetorheological (MR) fluid. The unique properties of the fluid are what attracted them to the possibilities of using it in their research.



Does a Bigger Earthquake Mean More Damage?

Jacob Rabinow, U.S. National Bureau of Standards, invented magnetorheological (MR) fluids and devices. He began working with them in the late 1940s, but his work was relatively unknown. It wasn't until recently that there has been a renewed interest in MR fluids. What's so unusual about them? They change from liquid to semi-solid when exposed to a magnetic field (below). When properly harnessed, this adaptability could help protect a building in the event of an earthquake.



Earthquakes create shock waves, much like exploding dynamite. For example, to release the same amount of energy or vibration of an earthquake with a magnitude of 4, you'd need to ignite six tons of explosives. This doesn't always mean death and destruction. Often earthquakes occur in remote areas with few buildings or people. Consider Alaska with roughly 4,000 earthquakes every year. Because it is less populated than other states, the damage is not always major. On the other hand, Alaska was also the state to record the largest quake in U.S. history. It happened on March 27, 1964, and had a magnitude of 9.2. The shaking lasted about seven minutes and raised and lowered the ground as much as two meters in some areas. A total of 115 people died, mostly due to the tsunami generated by the quake. The bottom line is that the destructive forces of an earthquake depend on a variety of factors: local geologic conditions, distance from the epicenter, how long the shaking lasts, population density, the number and type of buildings, and how well the area is prepared — adherence to strict building codes and disaster plans — to handle the effects of a quake.

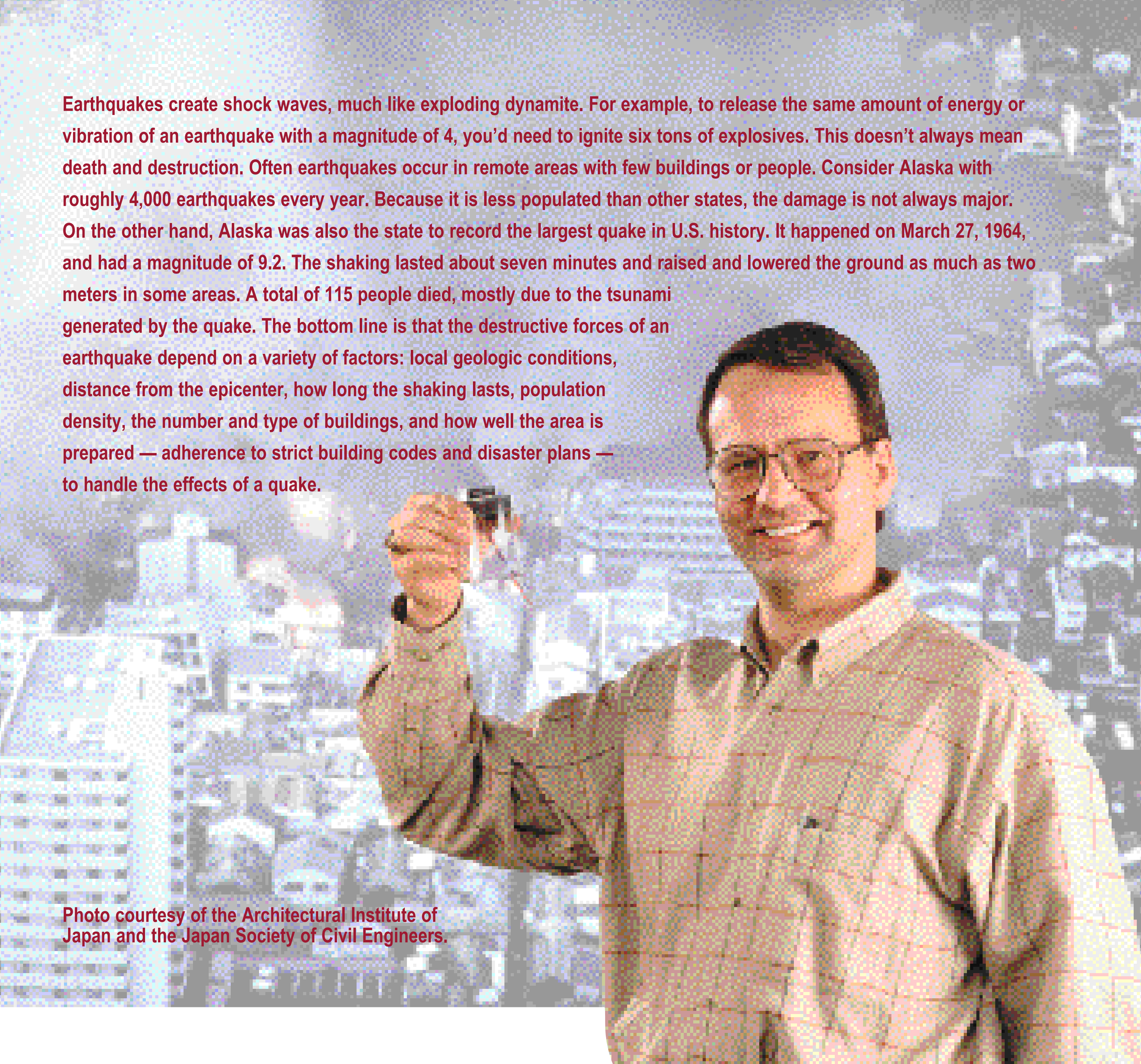


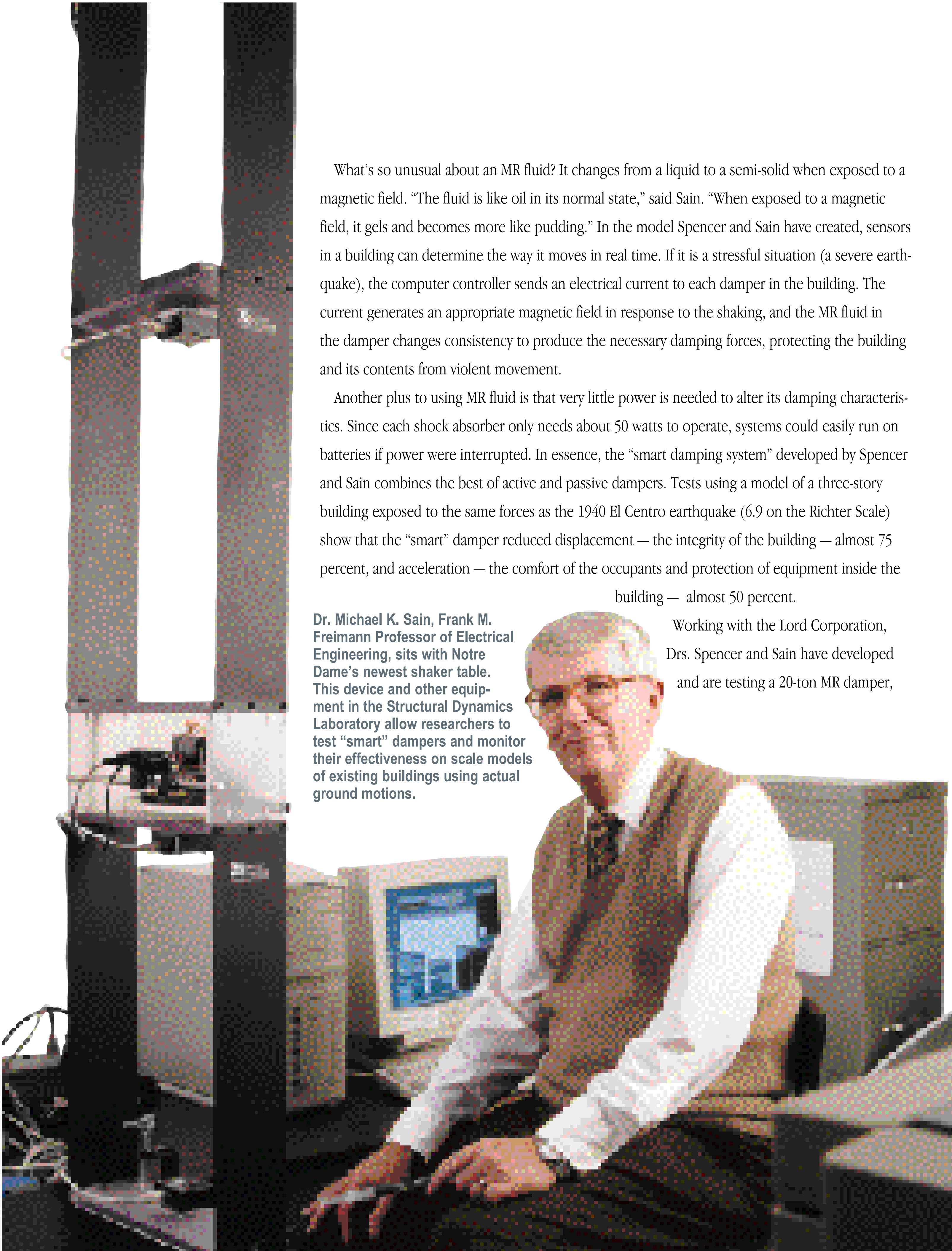
Photo courtesy of the Architectural Institute of Japan and the Japan Society of Civil Engineers.

MR fluid is a free-flowing suspension of micron-sized, iron particles in oil. Its normal viscosity (left) is that of a light motor oil. Dr. B. F. Spencer, Jr., Professor of Civil Engineering and Geological Sciences (right), demonstrates what happens when MR fluid is exposed to a magnetic field. It becomes more like pudding. This change occurs in milliseconds and needs very little power.

What's so unusual about an MR fluid? It changes from a liquid to a semi-solid when exposed to a magnetic field. "The fluid is like oil in its normal state," said Sain. "When exposed to a magnetic field, it gels and becomes more like pudding." In the model Spencer and Sain have created, sensors in a building can determine the way it moves in real time. If it is a stressful situation (a severe earthquake), the computer controller sends an electrical current to each damper in the building. The current generates an appropriate magnetic field in response to the shaking, and the MR fluid in the damper changes consistency to produce the necessary damping forces, protecting the building and its contents from violent movement.

Another plus to using MR fluid is that very little power is needed to alter its damping characteristics. Since each shock absorber only needs about 50 watts to operate, systems could easily run on batteries if power were interrupted. In essence, the "smart damping system" developed by Spencer and Sain combines the best of active and passive dampers. Tests using a model of a three-story building exposed to the same forces as the 1940 El Centro earthquake (6.9 on the Richter Scale) show that the "smart" damper reduced displacement — the integrity of the building — almost 75 percent, and acceleration — the comfort of the occupants and protection of equipment inside the building — almost 50 percent.

Working with the Lord Corporation, Drs. Spencer and Sain have developed and are testing a 20-ton MR damper,



Dr. Michael K. Sain, Frank M. Freimann Professor of Electrical Engineering, sits with Notre Dame's newest shaker table. This device and other equipment in the Structural Dynamics Laboratory allow researchers to test "smart" dampers and monitor their effectiveness on scale models of existing buildings using actual ground motions.

the largest ever constructed. Although not yet commercially available, its implications on public safety and cost savings for communities around the world are enormous.

Built in 1991, the Structural Dynamics & Control Earthquake Engineering Laboratory (SDC/EEL) houses a uniaxial earthquake simulator, a shaker table. Former Ph.D. candidate Shirley J. Dyke (left) was instrumental in developing the SDC/EEL with Drs. Spencer and Sain (not shown). Since receiving her doctoral degree, she has joined the faculty of Washington University in St. Louis, Missouri, as an Assistant Professor. More recently, Dyke was presented with the 1998 Presidential Early Career Award for Scientists and Engineers during a ceremony at the White House earlier this year. The award cited her work in mitigating structural damage from natural hazards.

Partnerships at Work in Natural Hazard Mitigation

Although this article focuses on Drs. Spencer and Sain, research within the Structural Dynamics & Control Earthquake Engineering Laboratory (SDC/EEL) involves scientists, faculty, students, government agencies like the National Science Foundation (NSF), and corporations from around the world. In fact, Notre Dame's efforts are often in tandem with Japanese researchers, because U.S.-Japan collaborations take advantage of the many synergies between the two leading countries in this field.

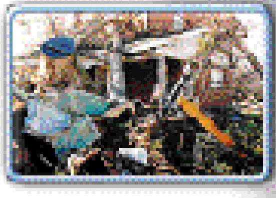
Personnel currently working in the SDC/EEL include: Dr. Erik A. Johnson, Visiting Research Assistant Professor of Civil Engineering and Geological Sciences; a visiting research student on leave from Nihon University, Yoshinori Satoh; Civil Engineering and Geological Sciences doctoral candidates Guangqiang Yang and Richard E. Christenson; Electrical Engineering doctoral candidates Gang Jin, Yun Chi, and Khanh Pham; and Greg Baker, a master's candidate in Civil Engineering and Geological Sciences. Each of these individuals is supported in part by SDC/EEL research funds. In addition a number of corporations and universities have sent engineers to Notre Dame to learn more about mitigating natural hazards. These researchers, who are supported by their sponsoring organizations, include: Hirokazu Yoshioka, a visiting scholar on leave from the Research and Development Institute at the Takenaka Corporation in Japan; visiting scholar Toshiyuki Suzuki, on leave from the Research Institute of Ishikawajima-Harima Heavy Industries (IHI) in Japan; Juan Carlos Ramallo, a visiting scholar from the Universidad Nacional de Tucuman, Argentina, who is being sponsored by the Argentinean government; post-doctoral research associate Dr. Y. Ohtori on leave from the Geotechnical & Earthquake Engineering Department at the Central Research Institute of Electric Power Industry (CRIEPI) in Japan; and Scott Burton, a Civil Engineering and Geological Sciences doctoral candidate on leave from General Electric Aircraft Engines in Cincinnati, Ohio.

Industrial partnerships and funding are also vital to the University's research in structural dynamics. Companies that provide partial financial support to this program include: the Lord Corporation in Cary, North Carolina, a leader in controllable fluid technology; one of the top five construction companies in Japan, the Takenaka Corporation; a leading heavy industry company in Japan, IHI; Sanwa Tekki, one of the largest Japanese manufacturers of high-capacity dampers; and Visteon, a division of Ford Motor Company responsible for the interiors/exteriors of Ford vehicles in Dearborn, Michigan.

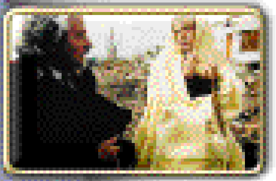
Government agencies also fund this research. They include the NSF, Earthquake Hazard Mitigation Program for Civil and Mechanical Systems; the Multidisciplinary Center for Earthquake Engineering Research (MCEER) in Buffalo, New York; and the NASA Indiana Space Grant Consortium.

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

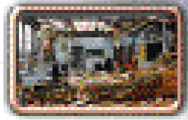
Hurricanes are tropical storms with winds in excess of 74 miles per hour.



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.

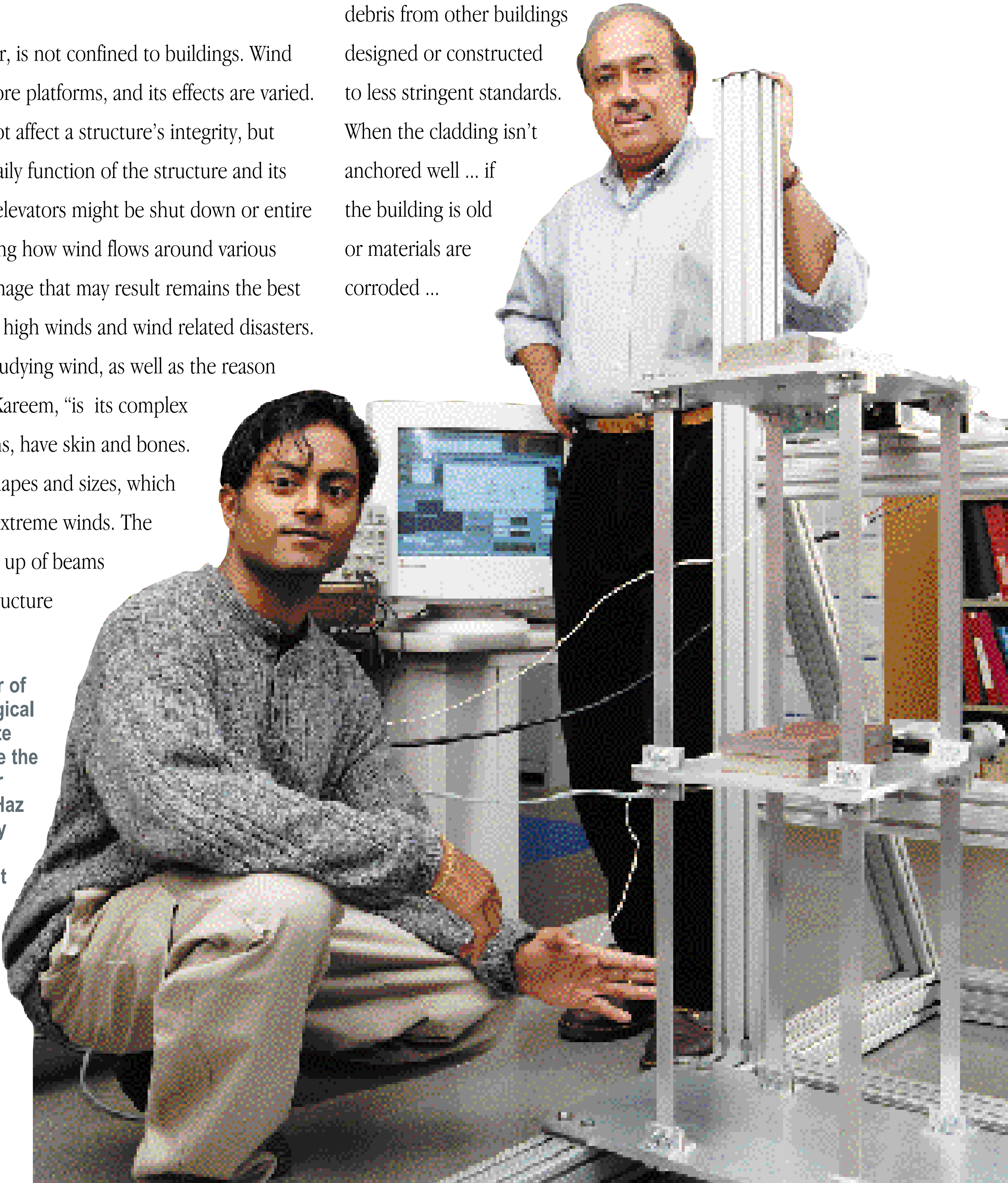
Dr. Ahsan Kareem, Professor of Civil Engineering and Geological Sciences, is a leading researcher in dynamic fluid-structure interactions, structural safety, and the mitigation of natural hazards — specifically wind, waves, and earthquakes. One of his specialties is wind engineering, studying how structures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

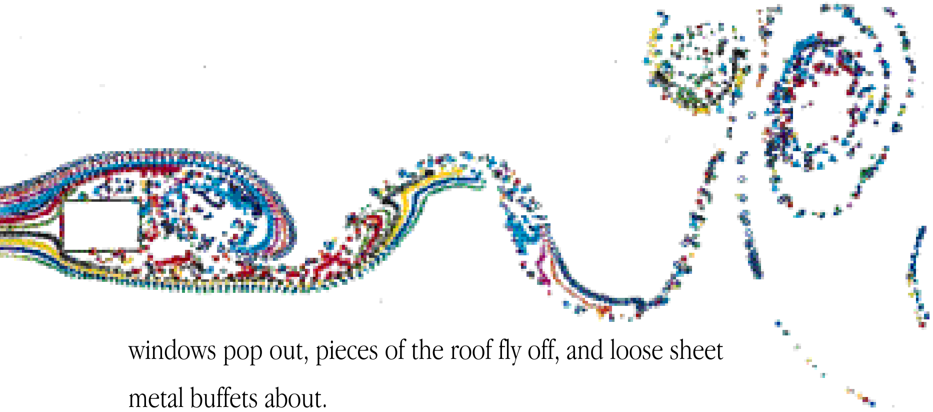
The threat of wind, however, is not confined to buildings. Wind also attacks bridges and offshore platforms, and its effects are varied. Movement in the wind may not affect a structure's integrity, but that motion can disrupt the daily function of the structure and its occupants. In extreme cases, elevators 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 structure and determine what causes structural damage. He also uses 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.