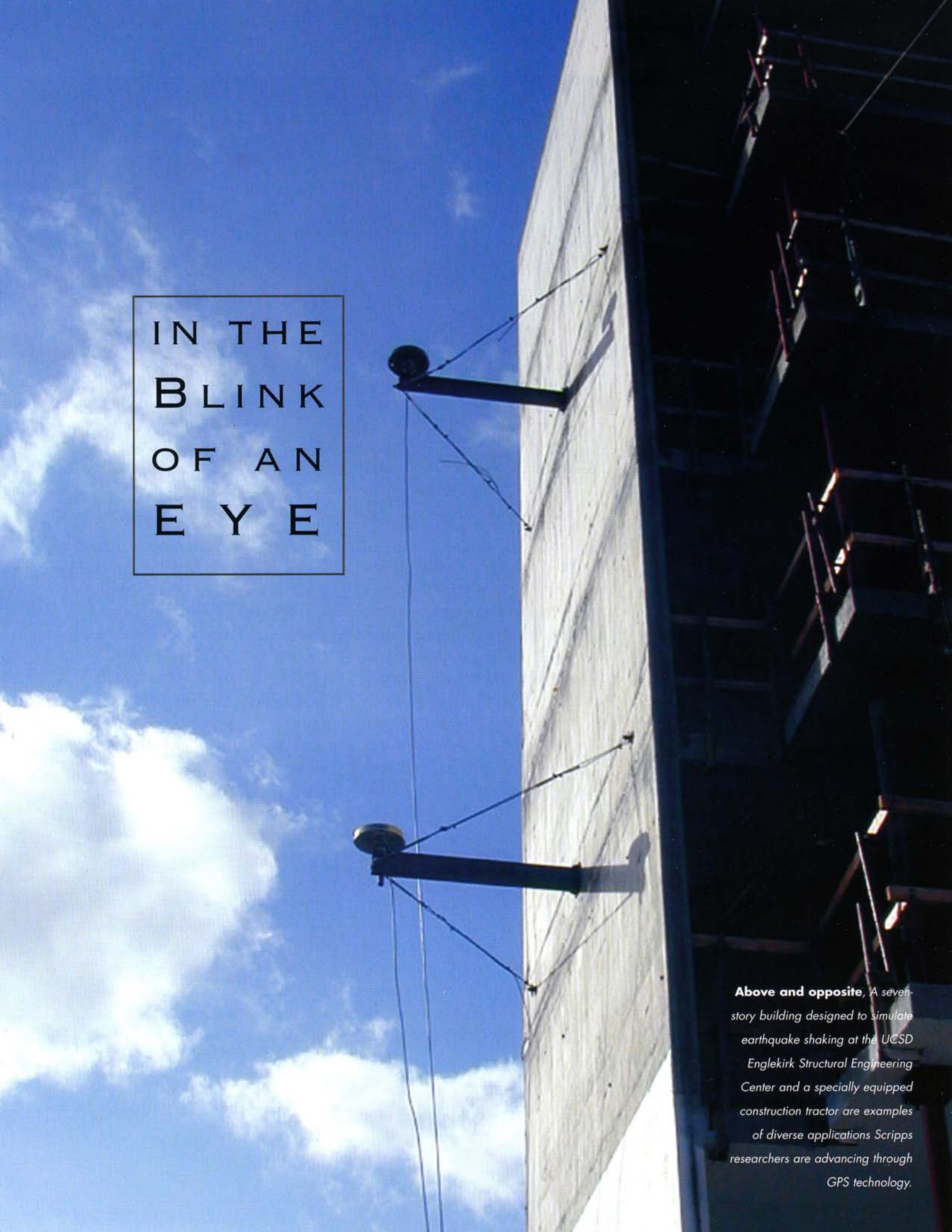
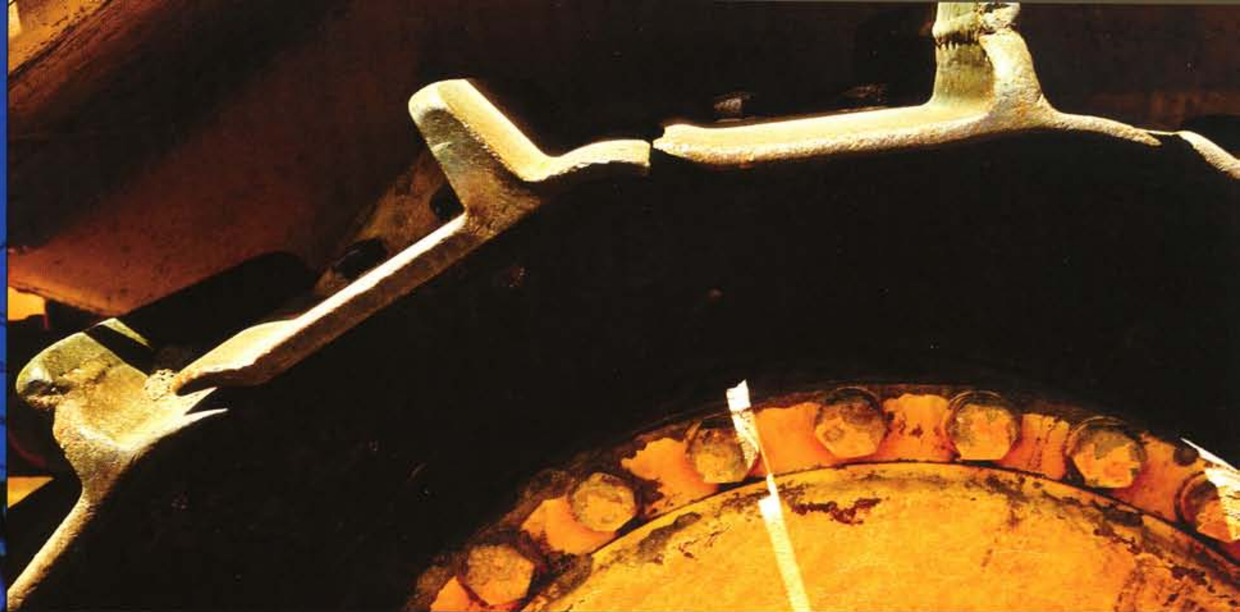
IN THE BLINK OF AN EYE



Above and opposite, *A seven-story building designed to simulate earthquake shaking at the UCSD Englekirk Structural Engineering Center and a specially equipped construction tractor are examples of diverse applications Scripps researchers are advancing through GPS technology.*



SCRIPPS SCIENTIST HELPS PIONEER GPS FOR EARTH STUDIES AND BEYOND

BY MARIO C. AGUILERA

THE SIGNAL COMES FROM SPACE. It's a radio wave traveling from a satellite in the sky above. Another just like it follows. One by one, a steady stream of waves reaches a receiver on Earth's surface. The signals are then relayed to a processing center at Scripps Institution of Oceanography and ultimately onto a computer display that reveals the precise geographic coordinates of a position on the ground.

From space to computer screen, it has all happened in one-twentieth of a second.

Most everyone these days is familiar with GPS (global positioning system) satellite technology—whether it's a crinkled, foldout road map being replaced by a GPS navigation system or a pocket compass giving way to the handheld GPS positioning device. This technology even appears in the blockbuster *The Da Vinci Code*, when the main character's movements are tracked with GPS inside the Louvre.

Scripps scientists are using GPS to gain new insights into earthquakes and how buildings and other human-made structures withstand them. Researchers are hoping that GPS-based studies will help lessen the tragic effects of natural catastrophes such as earthquakes and tsunamis. GPS technology has also helped transform the way scientists study the dynamics of how Earth moves and changes over time.

Many of the latest advancements related to GPS were only dreamed about 25 years ago. For Scripps's Yehuda Bock, who helped create many of these new avenues, it's all happening in the blink of an eye.

NINETEENTH-CENTURY MAPS FOR A TWENTY-FIRST CENTURY DISASTER

Geodesy is the study of the size and shape of Earth and the exact location of points on its surface. Since Aristotle's first attempts at calculating Earth's circumference, scholars have devised methods for mapping planetary features and determining geographic locations. In the late nineteenth century, groups from the Netherlands

Above, *San Diego County completed a real-time GPS network with this receiver installed in Descanso in spring 2006.*

Near left, *(left to right) Surveyor Norman Peet, Yehuda Bock, and surveyor Gabriel Mitchell check map coordinates against GPS readings at a surveying site.* **Below right**, *Peet evaluates GPS coordinates.* **Below left**, *Bock confers with Peet.*

created maps of their colonial territories in Indonesia. They used triangulation, in which locations of monuments on mountain peaks were referenced through a series of angles to plot map coordinates. Subsequent to an 1892 earthquake in the region, Dutch surveyor J. J. A. Müller noted a shift in the relative positions of monuments, indicating a movement of the earth.

One hundred years later, Bock and his colleagues visited the monument sites to conduct a GPS survey. Although some monuments had

crumbled or deteriorated, several remained intact. With GPS and Müller's historical recordings, they were able to calculate exactly how much the earth's crust had shifted along the Sumatran fault in the past century and to reestimate the magnitude of the 1892 earthquake.

Then the "big one" hit. A fault ruptured below the Indian Ocean floor on December 26, 2004, unleashing the massive 9.3 Sumatra-Andaman earthquake, one of the largest seismic events ever recorded. The giant megathrust fault ruptured across more than 1,600 kilometers (1,000 miles), triggering the devastating tsunami considered to be one of the worst natural disasters of our time.

Using GPS data collected since the quake, Bock and scientists from the California Institute of Technology, Rensselaer Polytechnic Institute, and Indonesia have developed new ideas of how and where giant earthquakes are most likely to occur. Areas that were once not considered at risk for massive earthquakes and tsunamis are now subjects of closer study.

"Before the Sumatra–Andaman event, this segment of the Sunda megathrust was not thought to produce great earthquakes," Bock said. "Our findings should concern Indonesian disaster planners about the segment adjacent to the densely populated island of Java. According to previous wisdom, that doesn't produce great quakes either."

Bock added that the megathrust in this region has the potential to produce a much more powerful quake than May's temblor in Yogyakarta that killed more than 6,000 people.

In the wake of the 2004 event, Bock has been working with scientists at the Pacific Geoscience Center in British Columbia, Canada, using real-time GPS as the foundation for a tsunami warning system in the Pacific Northwest fault region known as the Cascadia Subduction Zone.

"By measuring site displacements nearly instantaneously and comparing them to

likely earthquake scenarios, we should be able to provide early warning tsunami information," Bock said. "We estimate that it would take 15 minutes for a tsunami to hit Vancouver Island after a great Cascadia earthquake. Such a warning system should be extended to the U.S. portion of this active zone."

SHAKING THE FOUNDATION OF EARTHQUAKE STUDIES

In April 2006, hundreds of scientists gathered to mark the 100th anniversary of the disastrous 7.9 earthquake and subsequent fires that demolished San Francisco in 1906. Among the many presentations at the meeting of the Seismological Society of America, Bock and his collaborators unveiled yet another chapter in the evolving story of GPS technology and earthquake studies.

Right, *A GPS antenna mounted on a tractor is an example of how GPS technology is being used for a variety of real-time applications.* **Below right**, *In the early 1990s, Yehuda Bock, shown inspecting a GPS station, and his colleagues conducted GPS survey campaigns in Sumatra.* **Bottom right**, *Local guides and surveyors inspect a triangulation pillar in north Sumatra near Lake Toba.*

Earlier in the year, Bock and Scripps graduate student Fan Yang worked with Jose Restrepo and Marios Panagiotou at the University of California, San Diego's Jacobs School of Engineering to examine the effects of simulated earthquakes on a seven-story building outfitted with GPS sensors. The data showed details of how the building's concrete walls changed during simulations of various intensities. The changes were detected in real time at 50 times per second, giving the engineers a high-resolution picture of structural motion accurate to the millimeter.

"This is the level of resolution the engineers are interested in," Bock said. "Making this type of precise, direct measurement allows them to get a better sense of what's really going on with the building."

Bock has also journeyed to Israel and Jordan to study the Dead Sea Fault. He's traveled to the canals of Venice to measure sinking in the famed city's lagoons and to Sicily to monitor the Etna and Stromboli volcanoes.

He's worked with scientists at Columbia University to investigate the pressure that thousands of New York City Marathon runners put on the Verrazano–Narrows Bridge. (The studies documented a 30-centimeter [12-inch] dip in the bridge during the race.)

And while such research uses continue to grow, GPS applications outside of scientific research also have blossomed.

In the early 1990s, the same GPS advancements that Bock helped pioneer for earth science—developing software and related components to speed access and analysis of GPS data—began to garner attention from the surveying community.

Surveyors and scientists had collaborated for years in setting up GPS receiving stations, but it wasn't until the technology crossed the threshold of instantaneous results—real-time positioning feedback—that surveyors began capitalizing in earnest.

"After Yehuda created his software to accept one-second epochs, our relationships with Scripps and the federal government took off and enabled us to become the first county in the nation to become completely real-time. That's an amazing accomplishment," said former Orange County Surveyor John Canas.

REAL TIME FOR THE REAL WORLD

For the construction industry, surveyors are now able to furnish engineers and contractors with instant, highly accurate mapping information.

Yehuda Bock (left) and San Diego County surveyors assessed GPS readings of a road-widening project off Wildcat Canyon Road south of the Barona Indian Reservation.

"They can now make real-time decisions and save a countless amount of money, grief, and litigation in disputes," Canas said. "Problems can be solved right there in the field."

In the spring of 2006, the new San Diego County Real Time Network was completed. Virtually any trade that can benefit by knowing precisely where things are precisely and instantly will gain from the network.

"Whether it's storm water facilities, parks and recreation, agriculture, or shipping and navigation, we are planning to reach out and tell all of them that this GPS real-time resource is here for them to use," said San Diego County Surveyor Phil Giurbino, whose department was able to streamline its workforce with the new network. "The applications are actually limitless."

Having recognized the potential applications, Bock led the development of a resource center for helping outside organizations make use of GPS real-time networks. He had already established the Scripps Orbit and Permanent Array Center (SOPAC) in the early 1990s as a clearinghouse for precise GPS data for scientists. The Scripps-based California Spatial Reference Center (CSRC) was launched in 1999 offering precise information about the size, shape, and positions within the environment. Picture a GPS device planted on a tractor blade for strict details of where and how far to dig and you have an idea of what's called "precision construction." Other applications range from flood hazard assessments to intelligent transportation.

"Accuracy is a very prized commodity," said Greg Helmer, senior vice president of RBF Consulting in Irvine and former chairman of CSRC. "In some instances, real-time GPS is creating capabilities that simply were not possible before. We are able to understand our environment in ways that we couldn't even imagine."

There is even talk of use in law enforcement. Some envision GPS technology being used in ways akin to what's seen on television shows like *CSI*. For instance, it could help pinpoint positions of key elements of a crime or accident scene.

"Real-time GPS is touching everybody's lives," Canas said. "When GPS first became available to surveyors in the early '80s, it was a big black box and only a few scientists knew how to operate it and what it could do in terms of measurement accuracy and efficiency. Now everybody knows about GPS."

Above, *In 2006, researchers conducted ground-breaking studies of real-time GPS on this seven-story structure.* **Below**, *Yehuda Bock (right) observes the installment of GPS equipment, the final component of the new San Diego County Real Time Network, along a ridgeline in the Cleveland National Forest.*