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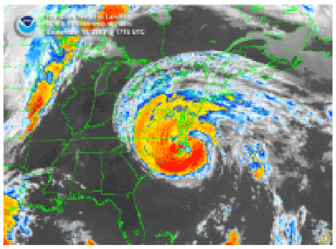

Hurricane Isabel, September 18, 2003 (www.ncdc.noaa.gov)

In this Issue:

The Height of Precision

Tracy Kijewski-Correa & Ahsan Kareem, University of Notre Dame

Even though the performance of tall buildings affects the safety and comfort of a large number of people in both residential and work environments, tall buildings are one of the few constructed facilities whose design relies solely upon analytical and scaled models, which, though based upon fundamental mechanics and years of research and experience, has yet to be fully validated in full-scale. As Chicago has been home to many important strides in the evolution of these structures, it is a fitting venue for full-scale investigations aimed at improving our understanding of these structures and thereby techniques for their design. The resulting Chicago Full-Scale Monitoring Program, being undertaken by the University of Notre Dame in conjunction with the Boundary Layer Wind Tunnel Laboratory (BLWTL) at the University of Western Ontario and Skidmore Owings and Merrill (SOM), represents the first systematic validation of tall building design in terms of accelerations and displacements, permitting an appropriate calibration of the design process and providing valuable information on the in-situ dynamic properties of tall buildings over a range of amplitudes. This program moves beyond the sole use of traditional accelerometers, incapable of capturing the quasi-static or background component of wind-induced response, supplementing them with a high precision GPS sensor pair. As a result, both the background and resonant components of full-scale structural displacements, collected in a pseudo-real-time framework, can be compared with wind tunnel predictions. This article briefly overviews the use of Global Positioning Systems (GPS) used in this project. A more detailed treatment of this topic was featured in the Sept. 2003 issue of GPS World, available electronically in the archives at www.gpsworld.com *(cont'd on p. 2).*

Update on Hurricane Isabel

(www.ncdc.noaa.gov & AAWE files)

A tropical wave moving off the shore of Africa developed into Tropical Storm Isabel in the far eastern Atlantic, near the Cape Verde Islands on September 6th, 2003. The next day, as it moved west-northwestward, Isabel developed an eye and reached hurricane strength on the 7th. Conditions were very favorable for Isabel's continued development with warm sea surface temperatures ahead of it, low shear and an impressive outflow pattern from the storm. Rapid intensification occurred over the next several days and Isabel became a category 5 hurricane on the 11th. *(cont'd on p.6)*

Though GPS had been successfully integrated into bridge monitoring programs around the world, the deployment of GPS in dense urban environments introduces a host of other concerns. Thus this deployment in Chicago allows the effectiveness of this technology to be validated in the most challenging of environments. In order to achieve the most precise tracking, two GPS sensors are installed in tandem, where the satellites tracked by a GPS receiver on the structure of interest (called the rover) and the tracking of the same satellites by a nearby stationary reference GPS receiver are used in the solution for GPS positions to cancel error terms associated with atmospheric delays and clock offsets. Leica MC500 GPS receivers were selected for this study, as they offered sub-centimeter resolution with the ability to capture displacements at 10 positions per second. As the system would ultimately be operated in a dense urban zone populated by reflective surfaces, a gold anodized choke ring antenna was incorporated to minimize the effects of multi-path errors induced by the delayed reception of reflected satellite transmissions, which remain the primary error source in urban areas.

As with any new sensing technology, calibrations are essential to assess the performance of the system before the full-scale deployment. In order to determine the accuracy of the sensor pair and identify the level of background noise, a series of nearly 40 static and dynamic calibration tests were conducted during the spring of 2002 in an open field in Indiana, sufficiently free from potential sources of multi-path error and with limited obstructions. The rover unit was firmly affixed to a portable, displacement-controlled shake table oriented in a Northerly direction permitting the introduction of a prescribed displacement time history. The North-South (N-S) GPS motions were then compared to the simulated displacement to assess dynamic tracking ability. In this configuration, each dynamic test also provided a running measure of the inherent background noise, as the East-West (E-W) displacements were always static. These static observations were used to assess the level of background noise in the system and the influence of geometric dilution of precision (GDOP) – a measure of the optimality of the satellite constellation overhead. The statistics of the displacements detected along this static direction in all the tests are summarized in Table 1. From the studies, root mean square (RMS) static accuracy in each test was found to be better than the Leica specifications, as shown by the example in Figure 1, and any peak inaccuracies were at the sub-centimeter level.

Table 1. Averaged statistics from static component of calibration tests.

Range	+/- 0.71 cm
Mean Value	~ 0.00 cm
Standard Deviation	0.22 cm

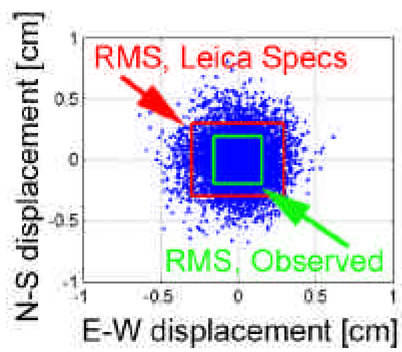

Figure 1. Example of static calibration test with RMS bounds.

In the dynamic calibration testing, satisfactory tracking, when quantified in terms of averaged measures like the standard deviation of the tracked displacements, was achieved consistently for motions above ±1 cm. However, instantaneous statistics like peak values are more difficult to capture, though they tend to be consistently identified for signals with amplitudes above ±2 cm. A sample of one of these experiments is shown in Figure 2, where the response of a tall building under wind loads is simulated. Note in this test, the tracking is quite good, even at lower amplitudes of motion, with the RMS error at 8% and error in peak values at 9%. Finally, it should be noted that all the calibration studies were conducted over short durations. Since GPS constructs its own models to correct for atmospheric delays, the accuracy improves as longer data sets are collected (45 minutes or more), therefore offering some additional improvement in tracking ability for the longer records customarily collected in full-scale.

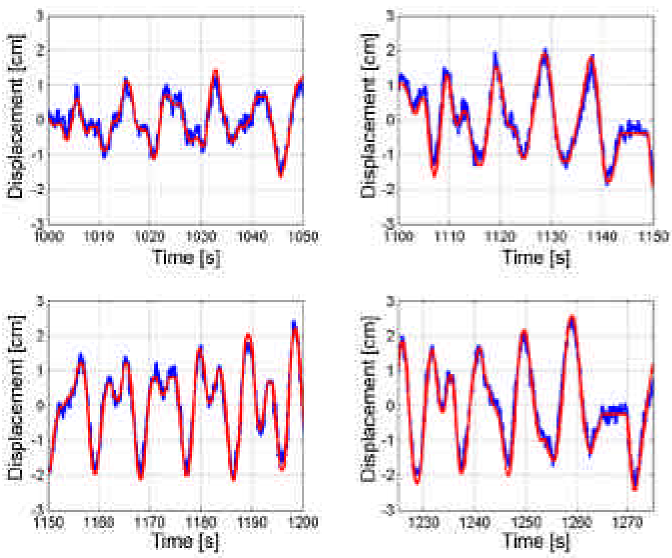

Figure 2. Snapshots of experimental verification of GPS dynamic tracking ability for simulated tall building response: simulated signal plotted atop the detected GPS displacements.

Following the experimental validation, the reference and rover equipment (shown in Figure 3) was installed in Chicago in September, 2002. The choke ring antennas, topped by protective radomes, were mounted on poles firmly affixed to the buildings' rooftops. The design of these antenna mounts was crucial, as flexible antenna mounts may lead to deceiving levels of tracked motion. At each site, ventilated enclosures installed at the highest mechanical floors in each building house the GPS receiver, laptop and back-up power supply. Based on the separation between the rover and the reference station in full-scale, the projected dynamic tracking accuracy is 7.6 mm (RMS).

To demonstrate the ability of GPS to monitor the static and dynamic displacements of this tall building in full-scale, a sample of data taken on January 7, 2003 is presented. The sample shown in Figure 4 was acquired between 15:00 and 15:30 CST. During the monitoring interval, the mean hourly wind speed at a meteorological station in Lake Michigan, just east of downtown Chicago, was approximately 13 m/s and approaching from the west-northwest with a mean wind angle of 290°. The data was filtered to separate the quasi-static or background components of the wind-induced response from their resonant counterpart, also shown in Figures 4a and 4b, for displacements along the Northerly (ΔN) and Easterly (ΔE) axes of the rover building, respectively. The background displacements are on the order of a few of centimeters, more pronounced along the softer N-S axis of the structure. Despite the resonant displacements along the E-W axis being beneath the resolution limits of the sensor, the fundamental frequency of the system is still accurately identified, in good agreement with the accelerometer data and finite element model predictions.

Performance Assessment in Urban Environments

The GPS pair has been in operation since September 2002, over which period its performance in full-scale has been evaluated. Such applications in dense urban environments raise a number of concerns, including potential RF interference. To date, there has

Figure 3. (left to right) GPS antenna installed at rover site in Chicago, GPS receiver cabinet on-site, GPS reference antenna.

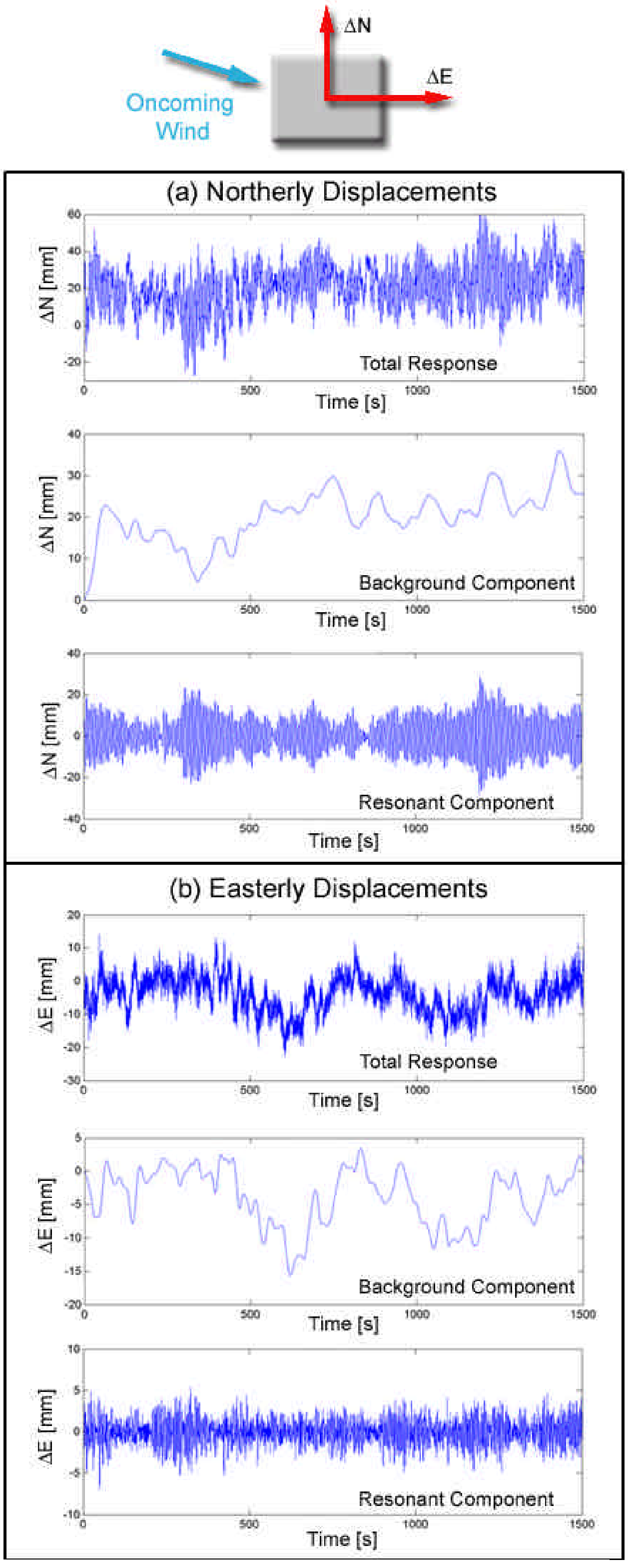

Figure 4. Sample of GPS sway displacements of tall building in Chicago under winds on January 7, 2003, decomposed into background and resonant components.

been no loss of tracking ability due to RF interference, though high periods of solar activity late in 2003 caused some signal loss. At times the ambiguity solution for GPS displacements cannot be achieved satisfactorily, leading to lesser reliability of displacement predictions reemphasizing the challenges of identifying a stationary, unshielded reference station in close proximity to the rover. In this study, position quality thresholds were also introduced to evaluate an effective noise threshold for the full-scale displacements in light of fluctuating satellite availability. These thresholds were on the order of 5-7 mm, whereas they are at times double in full-scale, partially attributed to the baseline separation between the reference and rover, though this situation does require motions of the building to be on the order of a few centimeters to be reasonably tracked.

Another issue that must be addressed in urban monitoring is multi-path interference, which can still be present even when choke ring antennas are used due to satellite signals reflected off of surfaces above the antenna. Thus the generation of full-scale baseline multi-path signatures and a series of controlled multi-path tests are currently underway to identify and effectively remove these systematic errors that may surface in GPS displacement data collected in this program. As the project progresses, multi-path errors will be more accurately identified and removed to allow the reliable correlation of GPS displacements against the predicted displacements of the structure under varying wind events.

Conclusions

The extensive experimental validations of the GPS system, conducted before moving to full-scale, affirmed that the system could track RMS displacements with sub-centimeter accuracy, though consistent tracking of peak displacement values required greater than centimeter-level motion. For this reason, the authors emphasize the need to calibrate and experimentally validate any GPS sensor before installation in full-scale so that the displacement tracking limitations and resolutions can be accurately benchmarked. As the accuracy of GPS continuously fluctuates throughout the day due to the position and availability of satellites, it is especially important to provide some reliability measure, e.g. the Position Quality Thresholds introduced in this study. Ultimately, the ongoing collection of GPS data and its assessment throughout this project will address the unique challenges facing applications in dense urban environments and provide a means to capture both the background and resonant components of response.

Acknowledgements

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Natural Catastrophes of 2003 - Excerpts from Report by Munich Re

(from Press Release)

Munich Re records and analyses all reports on natural hazard events that cause material or human losses anywhere in the world. Right up until the last days of the year, 2003 was marked by a series of severe natural hazard events, with the number of fatalities far exceeding the long-term average. In view of the deteriorating risk situation, the insurance industry must continue to act rigorously – for example, by agreeing on limits of liability and risk-adequate premiums.

The Results for 2003 in Detail

More than 50,000 people were killed in natural catastrophes worldwide, almost five times as many as in the previous year (11,000); such a high number of victims has only been recorded four times since 1980. The heat wave in Europe and the earthquake in Iran each claimed more than 20,000 lives.

The number of natural catastrophes recorded in 2003 was around 700 and thus at the same level as in the previous year.

Economic losses rose to over $60B (2002: $55B). These were mainly the result of tornadoes, heat waves, and forest fires – but also severe floods in Asia and Europe.

Insured losses increased to about $15B (previous year: $11.5B). The series of tornadoes in the Midwest of the United States in May alone cost insurers more than $3B.

The year 2003 was marked not only by natural catastrophes but also by other remarkable events: the power outages in the United States, the United Kingdom, Denmark, and Italy, for example; total losses involving two satellites; again numerous terrorist attacks; a major leak of poison gas in China shortly before the end of the year. However, the extent of the losses caused by these events was much smaller than that caused by the natural catastrophes and they claimed fewer lives.

Windstorms Govern the Insurers' Overall Balance

In 2003, windstorms and severe weather accounted for about a third of the approx. 700 events recorded but for 75% of all the insured losses caused by natural catastrophes.

The tornado series and the hailstorms that hit the US Midwest in April and May were particularly striking. They caused insured losses of some $5B. The loss caused by the series of tornadoes in May exceeded $3B, making it one of the ten most costly storms in insurance history. In the second half of September, Hurricane Isabel swept over the US East Coast and devastated more than 360,000 homes (economic loss: around $5B, of which $1.7B was insured).

Europe was largely spared severe storms this year. Even Calvann, the winter storm that struck France, Switzerland, and Germany at the beginning of January, caused only relatively moderate losses (economic losses: $1B, insured losses: $300M) in spite of wind speeds reaching 200 km/h.

Hot Summer: Extreme Event or the Norm in the Future?

The outstanding event of the past year in Europe was the extreme heat and drought of the summer. In Germany alone, the record temperatures from June to August corresponded to a 450-year event in climatological terms; if the atmosphere continues to warm up unchecked, such a heat wave could already become a mere twenty-year event by 2020. The heat affected a very large area (western and central Europe and large parts of the western Mediterranean region). Economic losses of approx. $13B constituted an extremely large amount. Nevertheless, the burden imposed on insurers by, for example, drought-related losses is relatively small because reduced yields in the agricultural sector as a result of dry weather are mostly not yet covered in the European Union.

Many countries in the world were ravaged by serious wildfires in 2003. Headlines were caused in particular by the forest fires in Australia, southwest Europe, Canada, and the United States. In October and November alone, thousands of homes fell victim to the flames in California, resulting in a bill of about $2B for the insurance industry, representing almost 60% of the economic losses.

In India, Bangladesh, and Pakistan, heat waves with temperatures of up to 50°C in May and June were followed by severe floods between June and September.

In China, the swollen waters of the Huai and Yangtze flooded 650,000 homes and caused an economic loss of almost $8B. Many places in southern France were under water at the beginning of December, when numerous rivers, including the Rhône, flooded their banks after extreme rainfall (causing insured losses of $1B and economic losses of around $1.5B).

Exceptional individual events of the past year like the heat wave again provided strong indications of climate change. They show that new types of weather risks and greater loss potentials must be reckoned with in the future. Stefan Heyd, responsible on Munich Re's Board of Management for corporate underwriting: "The insurance industry must prepare itself for increasing risks and losses. This requires above all transparency and a limitation of the risks. Prospective action also means adjustments in the premiums."

Increase in Weather Extremes Becoming More and More Distinct

Dr. Gerhard Berz, Head of Munich Re's Geo Risks Research Department: "We will have to get used to the fact that hot summers like the one we had in Europe this year must be expected more frequently in the future. It is possible that they will have become more or less the norm by the middle of the century. The summer of 2003 was a "summer of the future", so to speak. For many years we have been warning about the elevated danger of heat waves and the associated problems and risks. Warmer summers mean a rise in the intensity and frequency of severe weather events. A heated-up Mediterranean and a warm North Atlantic increase the risk that particularly strong low-pressure systems will form in autumn and winter with torrential rain and extreme wind speeds. This was confirmed by the devastating floods in southern France at the beginning of December and the intense low-pressure system called Jan over west and central Europe shortly before Christmas."

The discussed data are presented in tabular form on page 7.

Update on Hurricane Isabel

(cont'd from page 1)

Isabel weakened slightly on the 13th, but did not weaken considerably until overnight on the 15th/16th when westerly shear began to affect the storm. Isabel decreased in strength to a category 2 storm, and eventually came ashore along North Carolina's Outer Banks on September 18th with sustained winds of approximately 85 knots - a minimal category 2 storm.

Preliminary estimates of Isabel's precipitation indicate that interior Virginia bore the brunt of the rainfall from Hurricane Isabel. The rainfall from Isabel did not lead to widespread flooding throughout North Carolina and Virginia. However, the unusually high precipitation totals in the months that preceded Hurricane Isabel resulted in very wet soils, and the combination of the wet conditions and strong winds associated with the storm led to downed trees and power outages for millions of people in the mid-Atlantic and Northeast. Most of the flooding associated with storm *(see p. 8)*

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Ranking by number of fatalities

Date	Country/Region	Event	Fatalities
December 26	Iran	Earthquake	>22,000
July-August	Europe	Heat wave, drought	>20,000
May 21	Algeria	Earthquake, tsunamis	2,200
May-June	India, Bangladesh, Pakistan	Heat wave, drought	2,000
January	India, Bangladesh, Pakistan	Cold spell	1,800
June-September	India, Bangladesh, Pakistan, Nepal	Floods	1,400
Summer	China	Floods	800
May 18-19	Sri Lanka	Floods	300
February 24, 25, 26	China	Earthquake series	268
April 21-24	Bangladesh	Severe weather, hail	230

Ranking by economic losses

Date	Country/Region	Event	Fatalities	Economic losses $M	Insured losses $M
July-August	Europe	Heat wave, drought	>20,000	13,000	1)
Summer	China	Floods	800	8,000	1)
May 21	Algeria	Earthquake, tsuna-mis	2,200	5,000	1)
September 18-20	USA, Canada	Hurricane Isabel	40	5,000	1,685
September 11-13	South Korea, Japan	Typhoon Maemi	118	4,800	500
May 2-11	USA, Midwest	Tornadoes, severe weather	44	4,000	3,200
October-November	USA, California	Drought, forest fires	20	3,500	>2,000
April 4-8	USA, esp. Texas	Severe weather, hail	13	2,100	>1,600
December 2-4	France	Floods	7	1,500	1,000
January 2-3	Germany, Switzerland, France	Winter Storm Calvann	6	1,000	300

1) minor damage, figures impossible to estimate

Ranking by insured losses

Date	Country/Region	Event	Fatalities	Economic losses $M	Insured losses $M
May 2-11	USA, Midwest	Tornadoes, severe weather	44	4,000	3,200
October-November	USA, California	Drought, forest fires	20	3,500	>2,000
September 18-20	USA, East Coast. Canada	Hurricane Isabel	40	5,000	1,685
April 4-8	USA, esp. Texas	Severe weather, hail	13	2,100	>1,600
December 2-4	France	Floods	7	1,500	1,000
July 21-23	USA	Severe weather	7	800	600
January 13-25	USA	Winter storm	2	650	500
September 11-13	South Korea, Japan	Typhoon Maemi	118	4,800	500
November 12-14	USA	Severe weather	8	600	425
September 5-6	Bermuda	Hurricane Fabian	4	500	400

occurred at the coastal margin. Hurricane force winds and a storm surge of as much as 7-10 feet associated with Isabel led to a great deal of destruction at Cape Hatteras, NC, as well as along coastal Virginia and Maryland. Preliminary estimates suggest that 38 people died as a result of Isabel.

A six person damage investigation team was mobilized by AAWE. A two-person advance group was dispatched to North Carolina before landfall of Hurricane Isabel. The remaining members of the team were prepared for joining the advance group after the Isabel's landfall. Due to weakening of Isabel's before its landfall and relatively limited damage reported by the advance group, dispatching of this group was cancelled. A pictorial synopsis of the damage observed by this team is presented next.

Extensive damage due to falling trees

Failure of metal roof

Failure of built-up roof

Examples of roof failure in coastal areas

Damage due to water surge

Limited damage to well-protected beach houses

Typical failure of metal poles

Sand deposited on coastal roads due to water surge

Wind Engineering and Related Conferences - January 2004 Update

FIV2004 – 8th International Conference on Flow-induced Vibrations

Paris, France, July 5 - 9, 2004
http://laum.univ-lemans.fr/FIV2004/fiv2004_home.html
Contact: E. de Langre, Chairman FIV2004, Department of Mechanics, LadHyX, Ecole Polytechnique, 91128 Palaiseau, France
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Fifth International Colloquium on Bluff Body Aerodynamics & Applications (BBAA V)

Ottawa, Canada, July 11 - 15, 2004
http://www.bbaa5.org
Contact: BBAA V, Aerodynamics Laboratory, Institute for Aerospace Research, National Research Council Canada, Montreal Road Building M2, Ottawa, Ontario, Canada, K1A 0R6
Fax: (613) 957-4309
E-mail: bbaa5@nrc.gc.ca

2004 ASCE Structures Congress & Exposition - Building on the Past, Securing the Future

Nashville, TN, May 22 - 26, 2004
http://www.asce.org/conferences/structures2004/

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