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HURRICANE HUGO:
With Total Damage Over Ten Billion Dollars

*By Herbert S. Saffir, P.E.**


Miami Herald

ABSTRACT

Hurricane Hugo evolved off the west coast of Africa and crossed the Caribbean Sea making landfall in the U.S. on September 22, 1989 at Charleston, South Carolina. This paper reviews briefly the climatology of the storm, the ensuing damage and some lessons for the engineer and the building industry.

INTRODUCTION

The destruction that Hurricane Hugo (September 10-22, 1989) left from Guadelupe to Virginia was greater than damage in any past North American hurricane in history. Damage estimates at this time exceed ten billion dollars, both international and in the U.S.

Although not as strong as Hurricane Gilbert (1988), the populated areas around Charleston, South Carolina gave testimony to the strength of Hugo and, in some ways, to the deficiencies of long term planning and deficiencies of building code requirements. The storm increased from a Saffir-Simpson Category 2 hurricane to a Category 4 hurricane just before landfall in the U.S.

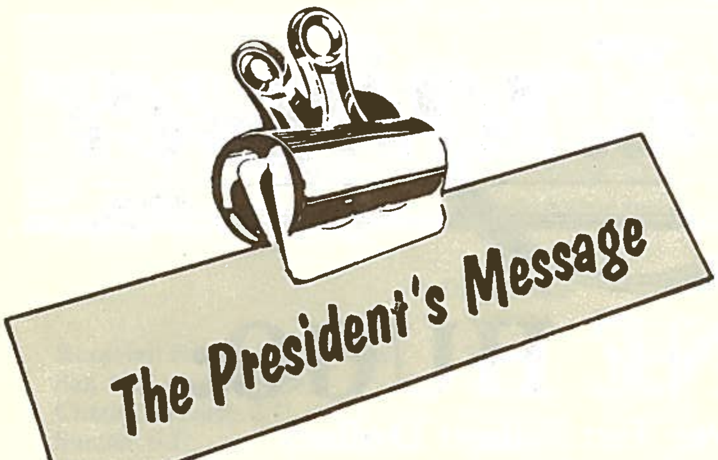
90% of the structures on the island of Montserrat had either complete damage or roofs taken off by Hugo. Montserrat is a British colony which will hold a referendum in 1990 on independence from the United Kingdom. A good building code is also needed.

Damage in the Caribbean Islands was extensive; on the island of Montserrat 90% of the homes had almost total structural failure or complete structural roof loss.

Total deaths caused by Hugo are estimated at 49, with 26 or more deaths on the mainland U.S., Puerto Rico and the Virgin Islands. This is in contrast to Hurricane Gilbert (1988) where deaths were few (except in Monterrey, Mexico where there were many flooding deaths).

The hurricane was a September Cape Verde storm, originating off the coast of Africa and traveling across the North Atlantic until it became a hurricane 1100 miles east of the Leeward Islands on September 13th. The eye went over Guadelupe and the storm continued on a west northwesterly path over the extreme eastern tip of Puerto Rico, and finally

(Continued on page 6)



by Kishor Mehta

This is my farewell message to the membership. Dr. Dale Perry, who has been elected President for a four-year term, takes office beginning 1990. During the last four years the Wind Engineering Research Countil (WERC) has made remarkable progress in making wind engineering research and application visible to the professional community and public at large. Opportunities, when presented, are used to promote the need for research and implementation of research results. The latest opportunities were the Hurricane Hugo incident of September 1989 and the Huntsville, Alabama tornado of November 15, 1989. The Committee on Natural Disasters (CND) of the National Research Council sent teams to Puerto Rico and South Carolina to survey hurricane damage and to Alabama to document tornado damage. An important aspect of these efforts was to present a briefing to the U.S. Senate Commerce Committee staff in Washington, DC on November 28, 1989. The congressional staff and the personnel of federal agencies were apprised of lessons learned from these windstorm damages and the research that should be pursued to mitigate damages. These activities help to focus attention on the effects of windstorms on society and to promote wind engineering research.

Wind engineering is a multi-disciplinary field that can tackle a variety of societal problems. Admittedly, the effects of severe windstorms are the most visible problem. Other areas where wind engineering can make a difference include building intake and exhaust systems, urban environment, natural ventilation, water evaporation, vehicle stability, and soil erosion, to name just a few. Researchers in many fields -- aeronautical, civil, agricultural, and mechanical engineering, atmospheric sciences, geology, mathematics, and others -- can contribute to advance wind engineering. WERC should welcome and encourage researchers in all fields to pursue wind engineering research.

As I say good-bye to the Presidency, I want to acknowledge the assistance of WERC Board Members and the Chairmen of the Standing Committees. These individuals made my tenure the most enjoyable and gratifying. I particularly want to acknowledge the work of two Secretary-Treasurers, Dr. Joseph E. Minor during 1986 and 1987 and Dr. James R. McDonald during 1988 and 1989, who kept the organization functioning and maintained its financial stability.

Japan Initiative

To improve professional relationships between American and Japanese engineers and institutions, the National Science Foundation has increased support for scientific research in Japan. The NSF will provide funds for scientists and engineers to conduct long-term (six months or more) research in Japan. It will provide support at the graduate, postgraduate, and senior levels to scientists and engineers to study the Japanese language and to help develop curricula and course materials for teaching Japanese to students. And the NSF will support visiting survey teams to report on specific disciplines with the goal of seeking opportunities for U.S. researchers to advance their work in Japan. Additionally, the NSF plays a coordination role in identifying American scientists and engineers who would qualify for long-term visits to Japan in three award programs established by the Japanese government in 1988.

Ph.D. Awards Up 13%

U.S. universities awarded a record 20,250 doctorates in engineering and science fields in 1988, according to a recent NSF survey.

The record was primarily fueled by foreign citizens, although there was an increase in U.S. recipients. The number of U.S. citizens receiving doctorates peaked at 15,000 in 1971; 12,850 were awarded in 1988.

The most growth occurred in engineering doctoral awards, which increased 13% over the 1987 level to reach an all-time high of 4,190 in 1988. Electrical and chemical engineering had substantial increases — 28% and 13%, respectively.

In engineering, foreign citizens accounted for 54% of all doctorates in 1988. However, for the third year, the percentage increase of U.S. citizens (14%) exceeded that of foreign citizens (11%),

GRANTS

Decade for Natural Disaster Reduction. "Support for Planning the U.S. Decade for Natural Disaster Reduction," National Science Foundation, $61,960, 12 months. Principal Investigator: *Riley Chung, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418, (202) 334-3312*

With this support from the National Science Foundation, the U.S. National Committee on the Decade for Natural Disaster Reduction, working with the Subcommittee on Natural Disaster Reduction of the Science Advisor's Committee on Earth Sciences of the National Research Council, will undertake three tasks: 1) clarify the need for a national Decade program and develop a Decade action plan; 2) prepare a report, presenting the committee's evaluations, conclusions, and recommendations, that can be used by the federal government and Congress to support this important national effort; and 3) serve as an effective link between the U.S. program and programs of other participating nations and the various participating organizations within the United Nations and elsewhere.

Hurricanes may Get Stronger

The names will be different, but more hurricanes with the powerful punches of Hugo and Gilbert may be prowling the Atlantic, Caribbean and Gulf of Mexico in the future.

"The probability of more intense hurricanes in the Atlantic region is greater in the next decade or two than it has been in the 1970s and '80s," says meteorologist William M. Gray of Colorado State University, who analyzes hurricane patterns.

Gray predicts a possible return of the more ferocious hurricanes of the '50s and '60s because of an apparent break in the periodic West African drought. Rainfall in the Sahel, typically associated with more intense hurricane activity, was above average in 1988 for the first time since 1969, he says. A second rainy summer this year indicates an end to the drought.

The most intense hurricanes, Gray explains, usually form at low latitudes from tropical disturbances moving westward from Africa. The well-watered conditions in the '50s and '60s produced 31 of the most severe kind (categories 4 and 5) in the 17 year period 1950 to 1967.

Hurricanes are classified by the Saffir-Simpson scale, the fiercest a No. 5, or catastrophic storm. The atmospheric pressure at its center drops drastically and its wind speed exceeds 155 mph.

In the drier 17-year period of 1970 to 1987, there were only 13 severe storms. In the '88 and '89 seasons (June through November) there have been five.

Last year's Gilbert, which left a wide swath of devastation across Jamaica and the Mexican Yucatan, was the mightiest hurricane on record in the Western Hemisphere. Its atmospheric pressure dropped to 888 millibars and its wind speed reached 200 mph (pressure and wind gusts measured by NOAA aircraft at 10,000 ft.)

This September's Hugo, which ripped through the Virgin Islands and Puerto Rico before clobbering South Carolina, had sustained winds of 150 mph and an atmospheric pressure of 918 millibars (27.1 inches). Officially a 4 on the Saffir-Simpson scale, it "may be a borderline 5," says meteorologist Mark Zimmer of the National Hurricane Center in Miami.

An Editorial Comment

After the Florida legislature weakened Florida state laws covering wind loads for residential construction away from coastlines, Hurricane Hugo paid a visit to the Carolinas, wreaking havoc on many inland areas. Hugo should demonstrate that legislators cannot -- by statute -- keep winds from affecting structures!

Our new WERC president, Dale Perry, has stressed the importance of WERC in publicizing potential danger from extreme winds, and has stated that our voice must be heard by decision-making bodies.

Herbert S. Saffir, P.E.,
Editor

The Art of Structural Engineering??

Structural Engineering is the art of molding materials, we do not wholly understand, into shapes we cannot precisely analyze, so as to withstand forces we cannot really assess, in such a way that the community-at-large has no reason to suspect the extent of our ignorance.

Anon, P.E.

Wind Conference At The University of Western Ontario

A wind engineering conference was held at The University of Western Ontario's Spencer Hall on campus in London, Ontario, Canada on August 15, 1989. Representatives from ACI, AISI, ASCE 7 (ANSI A58), BOCA, CUBC, ICBO, MBMA, SBCI, SEAOC, SEAOW, UWO, and WERC attended to hear presentations and participate in the conference discussion. Attendees received a conducted tour through UWO's closed loop Boundary Layer Wind Tunnel Laboratory recently constructed to provide additional facilities including wave action and remotely controlled terrain features. Presentations were made by Dr. Alan G. Davenport, Gill Harris, Eric Ho, Donald L. Johnson, Dr. Kishor C. Mehta, and Dr. David Surry.

An update on current research at UWO was given. Recent low-rise building research on the variability of parameters indicates some promise for simplification of wind engineering criteria in addition to providing support in verification of wind pressures recommended by earlier UWO wind research on low-rise buildings.

Gill Harris

Wind Profiling System Nears Installment

The first unit of a $16 million, 30-station network of wind profiling instruments designed to help improve short-range weather forecasting in the central United States has been accepted by the National Oceanic and Atmospheric Administration (NOAA). Manufacture of additional units by Unisys Corporation for installation in 16 states will begin immediately.

By 1991, when all units are in place, the profiler network should not only contribute to improved short range weather forecasting in the 16 states, but provide national forecasters with important wind information.

The ground based wind-profiling system has been under development for the past decade by a team of scientists from the laboratories at the Boulder, Colorado, facility.

Using an unattended clear-air Doppler radar, the profiler acquires wind speed and direction information at 72 different levels in a column of air up to a height of 10 miles as frequently as every six minutes. It is accurate to within two miles per hour for wind speed.

Presently, National Weather Service stations get winds aloft information by launching weather balloons once every 12 hours, and sometimes through interpreting satellite imagery of cloud movement.

A prototype profiler installation near Platteville, Colorado, where acceptance tests were conducted, automatically transmits the data it collects to a hub computer 40 miles away at the NOAA labratories in Boulder.

Additional installations will be brought on-line, at a rate of about two a month, beginning in November. They, too, will send wind readings to the Boulder hub, which will transmit the data to the National Weather Service for distribution to its field offices, to the National Meteorological Center in Camp Springs, Maryland, and to various research facilities.

Hurricane Warnings

Warming might increase storms

Federal scientists say the warming of the earth's atmosphere over the next 50 -100 years will raise sea levels and increase the number of killer storms such as Hurricane Hugo.

Experts on climate changes and sea levels spoke to about 100 people at a coastal issues workshop sponsored by the Enviromental Protection Agency.

The Southeast can expect "larger and more intense tropical storms and hurricanes" at a more frequent rate, said climatologist David Smith of the Southeast Regional Climate Center. Warmer global temperatures will heat the water of the Atlantic Ocean and Caribbean, generating more intense hurricanes, he said.

Wind Analysis Questioned on French Cable Stayed Bridge

Contractors' engineers checking French government design of the record-breaking Normandie cable stayed bridge say wind analysis of the structure is not good enough. They have asked for more tests to be carried out and warn that design changes could delay the start of construction by months.

Not true, says the bridge designer, Michel Virlogeux, head of large bridge design for the national transportation ministry's Service d'Etudes Techniques des Routes et Autoroutes (SETRA). Virlogeux claims that the 2,808-ft main span of the Normandie crossing has been subjected to an unprecedented array of wind tests.

The client, Le Havre Chamber of Commerce, signed a $5.3-million contract with a group of contractors to check conceptual designs and produce detailed drawings. It also gave the contractors, in two consortiums, letters of intent for building the bridge, estimated a $140 million.

A senior designer for one of the contractors says, "We have major technical problems on the bridge. We don't understand all the forces due to wind." He says the designers first disputed this, but two weeks ago they "told me I was probably right."

SETRA has made several changes to the bridge deck since the initial scheme in 1987, says Virlogeux. It smoothed the underside of the deck to ease fabrication, and deepened and widened it.

Contrary to French practice, government designers are taking full responsibility for wind design of the bridge. Normally, contractors check the conceptual scheme and produce detailed designs, for which they take responsibility. But the Normandie contractors had just four months to submit bids, not enough to analyze wind effects sufficiently, says Virlogeux.

Window Glass Research Program at Texas Tech

H. Scott Norville[1], P.E.

Window glass research at the Glass Research and Testing laboratories (GRTL) at Texas Tech University (TTU) is directed currently into the following areas: 1) basic window glass strength to resist uniform wind loadings, 2) improved window glass design methodologies, 3) the strength of laminated window glass units, 4) the strength of tempered window glass, 5) behavior of window glass under blast loadings, and 6) the behavior of structural glazing under long-term and dynamic loading. The following is a brief description of current and proposed work at GRTL.

GRTL began its work studies involving the strength and behavior of window glass lights. The most recent work concerning the strength of window glass lights is described in a report by J.W. Sligar and H. S. Norville entitled *The Strength of Weathered Window Glass Samples.* This report describes the acquisition of five weathered window glass light samples with a total of 138 lights from the San Antonio, Texas area. Each of the samples was approximately 20 years old. The report describes the testing of these samples to failure, the analysis of the failure data, and comparison of the failure strengths of the samples with existing thickness selection recommendations.

Paul Bove, a research associate in GRTL, is looking into improved techniques for selecting window glass thickness to resist uniform wind loadings. The simplest technique for selecting window glass thickness was that embodied in the first recommendations which related window glass area, uniform design loading, and thickness.

Under sponsorship from Monsanto, DuPont, and the National Science Foundation, investigations of laminated window glass life strength are continuing. Currently, no precise model exists to predict load-induced stresses in laminated window glass lights. C.V.G. Vallabhan is developing a model to accomplish such stress predictions. H.S. Norville is testing laminated window glass lights to determine their strengths in resisting uniform loadings. He is also performing a series of experiments aimed at measuring the shear strength of PVB interlayers used in most laminated glass lights.

[1]Director, Glass Research and Testing Laboratories, Texas Tech

Directors and Committee chairmen at the WERC Board meeting, Boulder, Colorado, July 15, 1989.

WIND TUNNEL FACILITIES IN NORTH AMERICA

This is a continuing list of wind tunnels available throughout the world.
Supplements will be provided in future issues of the WIND ENGINEER.

NAME	LOCATION	TYPE OF WORK	CONTACT
West Wind Laboratory	Carmel, California	Commercial Research	Jon D. Raggett 408-625-0106

Types Of Wind Storms

*by Robert H. Meroney**

Wind storms can be classified into several categories based on severity and physical origins. The types include tornadoes, hurricanes (cyclones or typhoons), and severe winds (thunderstorms, downbursts, and downslope winds).

Tornadoes are one of nature's most violent and frightening natural hazards. They appear suddenly, often with little warning and contain the most powerful of all winds. They form during synoptic situations involving large thunderstorm cells or squall lines ahead of a cold front where there is a strong surface temperature gradient coupled with strong shearing winds aloft. Fully developed tornadoes can have a variety of shapes varying from an ordinary funnel, wide at the top and narrow at the bottom, to cylinders whose diameter is constant between the cloud base and the ground. The tornado funnel one sees is a cloud of water droplets mixed with dust and other debris. The funnel translates along the ground with a speed of 5 to 65 mph, produces a maximum wind speed from 100-250 near the surface, and cuts a swath a few meters to kilometers width over a path length from a fraction of a kilometer to hundreds of kilometers long. The maximum mean annual observed number of tornadoes per year in the United States per 10,000 sq. miles is 10.4. About 10% of these will have wind speeds exceeding 150 mph. Although tornadoes can occur almost anywhere in the world, over 90% of observed tornadoes occur on the North American continent.

Hurricanes are typically longer lasting (average of nine days), and impact a larger surface area than tornadoes. A tropical cyclone is considered a hurricane if maximum wind speeds exceed 73 mph. Although tornadoes may occur almost anywhere, hurricanes generally originate between the 5 and 20 degree latitudes and impact islands and coastal regions. Tropical cyclones are characterized by three main features; a) strong winds circulating around a rain-free eye in an anticlockwise manner in the Northern hemisphere (vice versa in Southern hemisphere), b) high tides caused by the storm surge, and c) heavy rains. Typical tropical cyclones have a diameter of hundreds of miles, a depth of 9 to 12 miles, and move along the storm track at 5 to 50 mph. Winds spiral into the center at sea level and spiral out at upper levels. Hurricane-spawned tornadoes can occur anywhere but are most common in the northeast quadrant of hurricanes landfalling on the U.S. Gulf Coast. Latent heat released by condensation of water vapor from the warm ocean provides the energy source which intensifies and maintains the cyclone. The intensity of a tropical cyclone is measured in terms of central pressure at the core, i.e.. less than 29.0 in. of Hg (982 millibars) when winds exceed 73 mph. Tropical cyclones occur along the coasts of Australia and all the continents except South America.

Severe Winds can occur in all locations. Data associated with high variability storms such as hurricanes and tornadoes must be removed from an extreme wind time series to evaluate several wind effects. They are usually associated with storm fronts, winter gales, or downslope winds. Severe wind statistics are generally well behaved, have reasonably low annual variability and are well predicted by Fischer Type I or Weibell probability distributions. Often called "straight line" winds, they are not expected to swirl like tornadoes or tropical cyclones, and may show a strong directional dependence. These are the winds typically considered in most building codes (UBC, SBC, ANSI in United States).

**Professor, Fluid Mechanics and Wind Engineering, Colorado State University.*

NEW BOOKS

Of Interest to the Wind Engineering Community

Wind Engineering: A Handbook for Structural Engineers, by Henry Liu, Prentice-Hall Publishers* (*not yet published; now in final pre-publication form).

Design for Lateral Forces, by James Ambrose and Dimitry Vergun, John Wiley & Sons.

Building Structures, by James Ambrose, John Wiley & Sons.

Wind Effects on Civil Engineering Structures, by V. Kolousek, M. Pirner, O. Fischer, J. Naprstek, Elsevier Press.

(Continued from page 1)

made landfall at Sullivans Island near Charleston on September 22nd, 1989. The eye of the storm went over Sullivans Island and continued in a northwesterly direction across South Carolina weakening very slowly.

Some of the measured maximum surface wind speeds in miles per hour are as follows:

	One Minute Average	Peak Gust
Roosevelt Roads, Puerto Rico	92 mph	117 mph
San Juan, Puerto Rico	75 mph	90 mph
Charleston (city), S.C.	86 mph	105 mph
Sumter, S.C.	67 mph	109 mph
Charlotte, N.C.	60 mph	87 mph

BASIC TYPES OF STRUCTURAL DAMAGE OBSERVED

Puerto Rico: cladding; residential damage

In Puerto Rico, the major type of structural damage appeared to be extensive glass and window damage in high-rise condominiums. In Vieques Island, offshore of the main island of Puerto Rico, residential house damage was severe.

South Carolina: Cladding failures

Many buildings including schools, hospitals, condominiums, hotels and commercial structures had extensive roof and glass failures which led to serious rain damage. Most cladding did not appear to be designed for hurricane wind loads.

Residential failures on islands

On Sullivans Island, Isle of Palms, and Folly Beach - all adjacent to Charleston - one and two story residential construction was severely damaged or knocked out completely, often by a combination of wind and storm surge effects. Many of the beachfront structures had inadequate foundations, poor connection details to the foundation, or insufficient cladding strength above the foundation. Many piling foundations were visible, with the house several hundred feet away.

Folly Beach is a bulkheaded area; Sullivans Island and Isle of Palms have wide beaches with no structural bulkheads. Failures were extensive on all islands, especially on those areas within 500 feet of the water. There were a few exceptions to this; generally, everything on those islands within 500 feet of the water had major damage or complete loss.

Steel industrial buildings

Several large "pre-engineered" steel industrial buildings that had failed were inspected by the author. Failures involved extensive cladding damage, both sidewall and roof, and door damage. End bays failed on some rigid frame buildings, where the end bay was of post- and - beam construction. These buildings were subject to wind, not to tidal surge or wave action.

Charleston historic area

In Charleston's older historic area, a few older buildings partially collapsed, structurally. Most of the newer structures performed satisfactorily. Much glass, porch, chimney, facade and roof damage occurred in the old part of town.

Power lines

Electrical transmission and distribution lines fared poorly in Puerto Rico, the Virgin Islands, and South Carolina (and also in other Caribbean Islands not inspected by the author).

LESSONS FOR THE STRUCTURAL ENGINEER AND ARCHITECT IN HURRICANE PRONE AREAS

1. Building codes are minimum codes, not maximum codes. In some cases the design engineer or design professional must exceed the minimum requirements of the code, unless the building or its components are expendable.
2. Structures built in the area 1500 feet from high water - along the Atlantic Ocean or Gulf of Mexico - must be designed with wind and water action in mind. If directly on the oceanfront, wave action must be considered by either breakaway construction, or by open construction in those areas where waves can act. Waves can go higher than maximum tidal surge elevations.
3. Wind must be considered in the design of cladding, windows, glass, roofing, and other exterior portions of structures. Much of this is a "gray" area without either the engineer or architect concerned with these items. Some system of approval for building components must be established by code-enforcement agencies in hurricane-prone areas.
4. Utility companies must establish adequate hurricane-resistant criteria in design and planning for local distribution lines and area transmission lines.

**Principal, Herbert Saffir Consulting Engineers, Coral Gables, Florida and Chairman, ASCE Task Committee on Wind Damage Investigation.*

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