Katrina on Trial – Forensic Hindcasting The Most Costly Storm

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ABSTRACT

In addition to its massive physical impacts, Hurricane Katrina (August 23-30, 2012) engendered many disputes between policy holders and insurance companies over the agent and timing of damages to covered structures because most of the impacted properties had separate policies - each with exclusions - covering wind and flood damage. Thousands of lawsuits involving millions of dollars hinged on what became known as the “wind vs. flood” question. We resolved this question in an objective, unambiguous way through hindcasting of the storm conditions at high resolution and calculation of the structure’s response to the combined wind and hydrodynamic loads. Results for a representative property are presented to illustrate the procedures and results. Discussion covers subsequent evolution of the legal landscape with respect to the exclusion clause and dual causation in insurance policies. Recent court rulings appear to place the burden on the insurer to prove not only that *excluded damage* was, in fact, the result of the *excluded cause* but also that the damage from an excluded cause **preceded** damage from a covered cause.

INTRODUCTION

In addition to its massive physical impacts, Hurricane Katrina created a flood of lawsuits between policy holders and insurance companies. The typical coastal homeowner insurance policy is the so-called “wind-only” policy; it covers damage caused by wind and excludes coverage for damage caused by flood. Insurance coverage for flood damage can be purchased through a separate policy, usually one backed by the National Flood Insurance Program. However, much of the damage from hurricanes occurs in a zone where both wind and flood (in the form of storm surge) plays a role. The magnitude of Katrina combined with the geomorphology and development patterns of the northern Gulf coastline led to a record number of damaged structures - many without flood insurance because they were in areas not previously considered flood prone. Lack of a rigorous methodology for resolving the *wind vs. flood* conflict guaranteed a large number of these would result in lawsuits.

The standard procedure for allocating causation at a particular structure is fairly primitive: a) the flood line is established (usually by the adjuster), either from direct observation of the so-called “high water mark” on an inside wall or through transfer of an accepted surge elevation in the vicinity; b) damage below the high water mark is attributed to flood, damage above it to wind. Katrina produced hundreds of cases without even this basic level of evidence (such as "slab" cases, where nothing remained to examine but the concrete slab foundation), so another 'common sense' deduction became popular: c) "Peak winds occurred before the peak of the surge, so the wind destroyed it before the surge did." All of these primitive procedures are demonstrably false, as follows:

a) High water marks are like the ring left in a bathtub; they do not form until the water motion has essentially ceased and the water has begun to drain. They don't indicate the maximum dynamic level, including runup, the water may have reached during the peak of the storm, and they may be effected by localized seiching that can be influenced by many factors, even the geometry of a particular room. This is one reason high water marks measured within sight of each other can vary by several feet.

b) Wind damage may occur well below the peak surge elevation either before or after inundation occurred. Alternatively, wave forces – the largest forces, by far, generated in a hurricane – can damage structures at elevations well above the peak surge level. Uplift forces on the bottom of elevated structures, for example, can completely remove a structure from its pilings well before the surge level reaches the elevated floor level.

c) Damage occurs when forces exceed structural capacity, regardless of when the peak wind or surge level occurs. Some structures were completely demolished by hydrodynamic forces well before the surge, or the wind, peaked. Or winds from a different direction may damage a previously-inundated, undamaged structure that had been sheltered earlier in the storm cycle.

As the number of lawsuits climbed it became apparent that there was a need for more definitive determination of causation that could be applied to a large number of cases over the entire zone of impact in a short time frame and at a reasonable cost. This paper describes how we met that need through a combined numerical and analytical hindcast that was applied to over 60 properties representing a wide range of storm conditions, exposure, and structural type.

METHODOLOGY

The hindcast procedure consists of three main components or modules that are applied in series: 1) a hydrodynamic hindcast module that utilizes a suite of numerical models to produce the optimal time series of wind velocities, surge elevations, water current velocities and wave conditions; 2) a hydrodynamic force module that analytically calculates the site-specific time-varying wind, water current, hydrostatic, and wave forces on the wall, roof, and the underside of elevated structure surfaces; and 3) a structural response module that calculates the resulting stresses in structural members and identifies the time, location, and cause of failure to cladding, openings, and structural members as applicable to the structure under evaluation.

The process is best illustrated by example. The location of a typical property on an island forming the south boundary of the Rigolets, the main hydraulic connection – and bottleneck – between the Gulf of Mexico and Lake Pontchartrain is seen in Figure 1.This site will be used as the example to illustrate the procedures and results in the remainder of the paper.

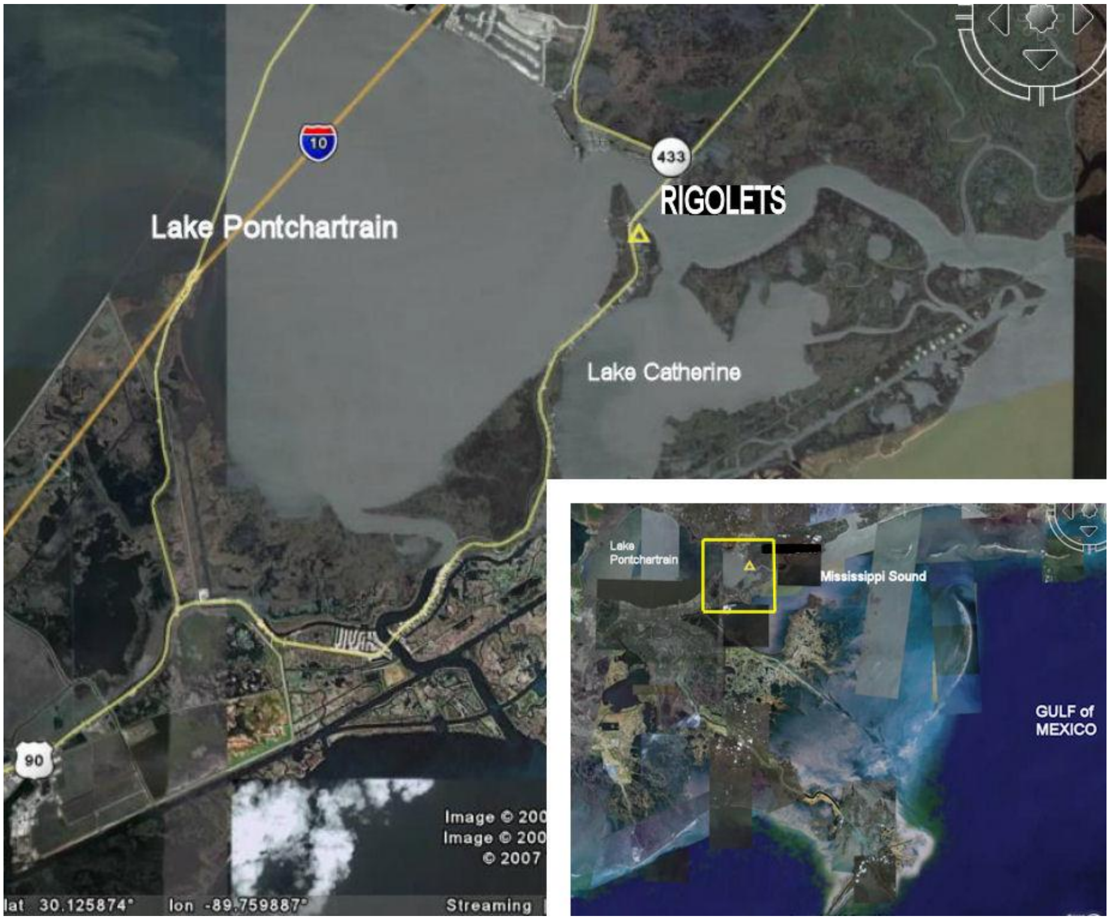

Figure 1. Site and location (inset) maps of example property site (gold triangle)

Hydrodynamic Conditions Module

IPET Data Products: The Draft Final Report of the Interagency Performance Evaluation Task Force (IPET, 2006) was released on June 27, 2006. Despite the stated disclaimer to the contrary, it is still regarded as the de facto “official” report by the US Army Corps of Engineers, and thus the government, on the storm and the performance of the storm protection system. The numerical data values resulting from the IPET suite of models were initially posted online along with the body of the report but after just a few days the data values were removed from the IPET website and distribution of these data to the general public was discontinued (Bruce Ebersole 2006, personal comm.). Afterward, the primary IPET data “products” available were the graphical plots and graphs included within the body of the report. These included: a) relatively low-resolution color contour maps of wind speeds at 3-hour intervals and b) color contour maps of surge elevation overlain with wind velocity vectors, current velocity vectors, or wave vectors at one-hour intervals. Nevertheless, it was deemed necessary to integrate these official results into our product. Each of these plots was digitized by EOE and incorporated into a GIS-based query tool that could be used to extract and interpolate these parameters at any specified location within the model domain. This software tool also accessed and displayed georeferenced data from a variety of government sources: standard topographic maps as well as the most recent, post-storm LIDAR (USGS, 2006), measured high water marks and inundation maps (FEMA, 2006), and pre and post storm aerial imagery (NOAA, 2006).

Figure 2 shows the 3-hour wind contour map at 0700 (CDT) just after Katrina's initial landfall and at 1000, just before its second landfall. The black arrow points to the example property showing that the eye of the hurricane passed about 10 miles to the east. Figure 3 is the hourly IPET color contour map of surge elevations with current velocity vectors for 0900. Magnification of these plots allows better resolution of position, but the accuracy of any measured parameter is still limited to linear interpolation between widely spaced values.

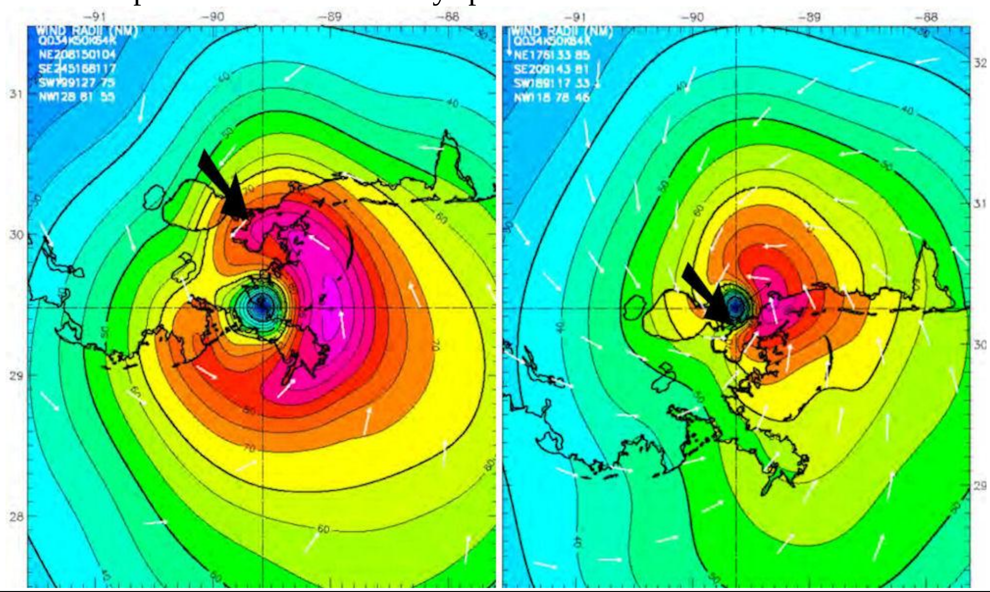

Figure 2. Color contour wind plots at 0700 (l) and 1000 (r) August 29, 2005; arrow is example property site

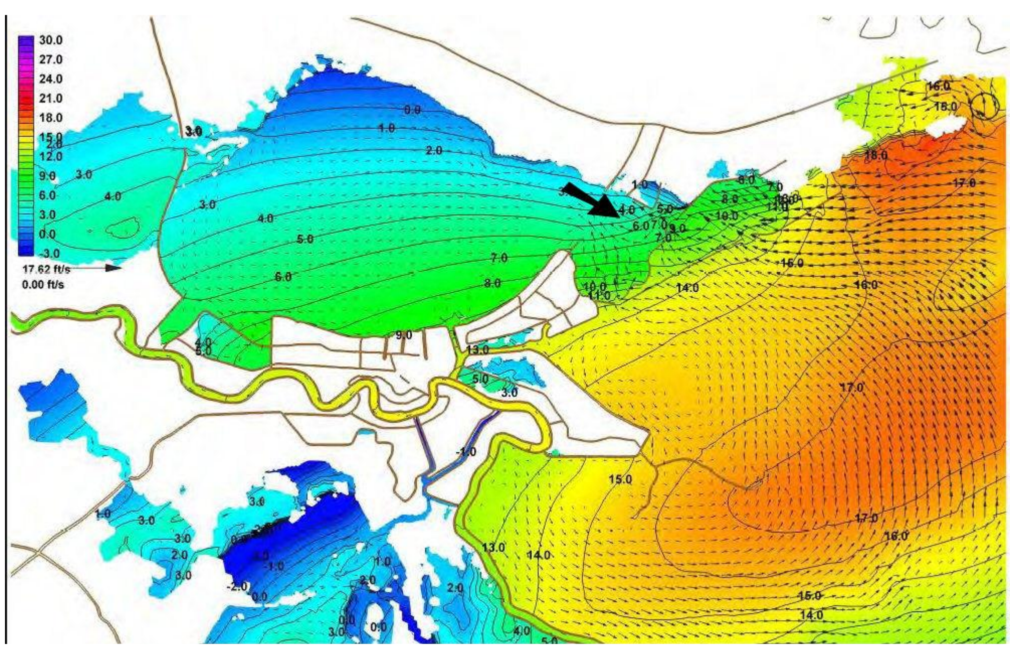

Figure 3. Color contour plot of surge elevation and current vectors at 0900 August 29, 2005

Custom Data Products: An alternative and more robust source of data was developed for EOE that utilizes an approach similar to the IPET effort, but includes an improved, re-calibrated wind field and a different wave transformation model that integrates shallow–water wave effects (set up and set down) into instantaneous surge levels. Access to the actual numerical values of wind, surge, currents, and waves from each of the high-density grid points of the EOE model (order of 100 m) reduced uncertainty associated with digitizing graphics and the 15-minute time step allowed better temporal discrimination of hydrodynamic parameters. Figure 4 shows the improved details of the currents at 1000 as the surge flowed between, but also over, submerged landforms flanking the Rigolets and into Lake Pontchartrain. Note that only one third of the available numeric current vectors are plotted to avoid saturation.

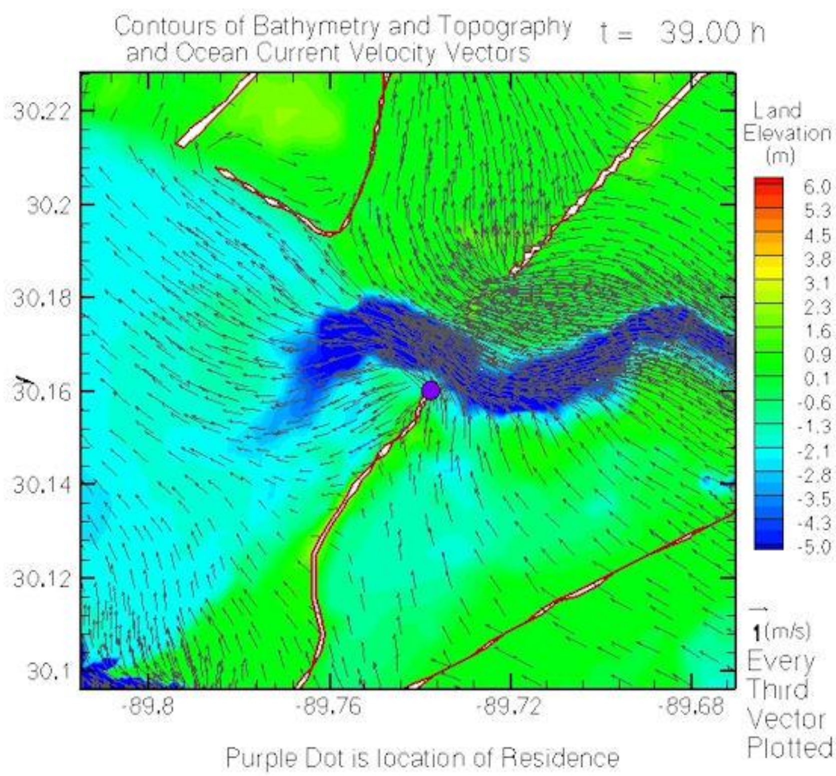

Figure 4. Current vectors from EOE hindcast at 1000 August 29, 2005

EOE Hydrodynamic Product: The final product was the best-estimate of each parameter based on both input sources using recalibration, weighted averaging, and, where necessary, manual editing of unrealistic output not supported by site conditions or physical limits. For example, a depth-limited wave height of 0.6 times the water depth was imposed even if model output predicts a larger wave. In other cases, local, small scale geographical features that would have provided wind, current, or wave sheltering to the structure prompted manual adjustments to the model output. Figure 5 compares the various sources and the final product for the wind velocity time series and Figure 6 shows the final hydrodynamic conditions for the example site. One interesting revelation from Figure 6 is that the currents, unlike the waves, did not reverse direction with the wind. Comparison of water levels on either side of the Rigolets verified that currents continued to fill Lake Pontchartrain – flowing against the wind – for many hours after the storm passed northward.

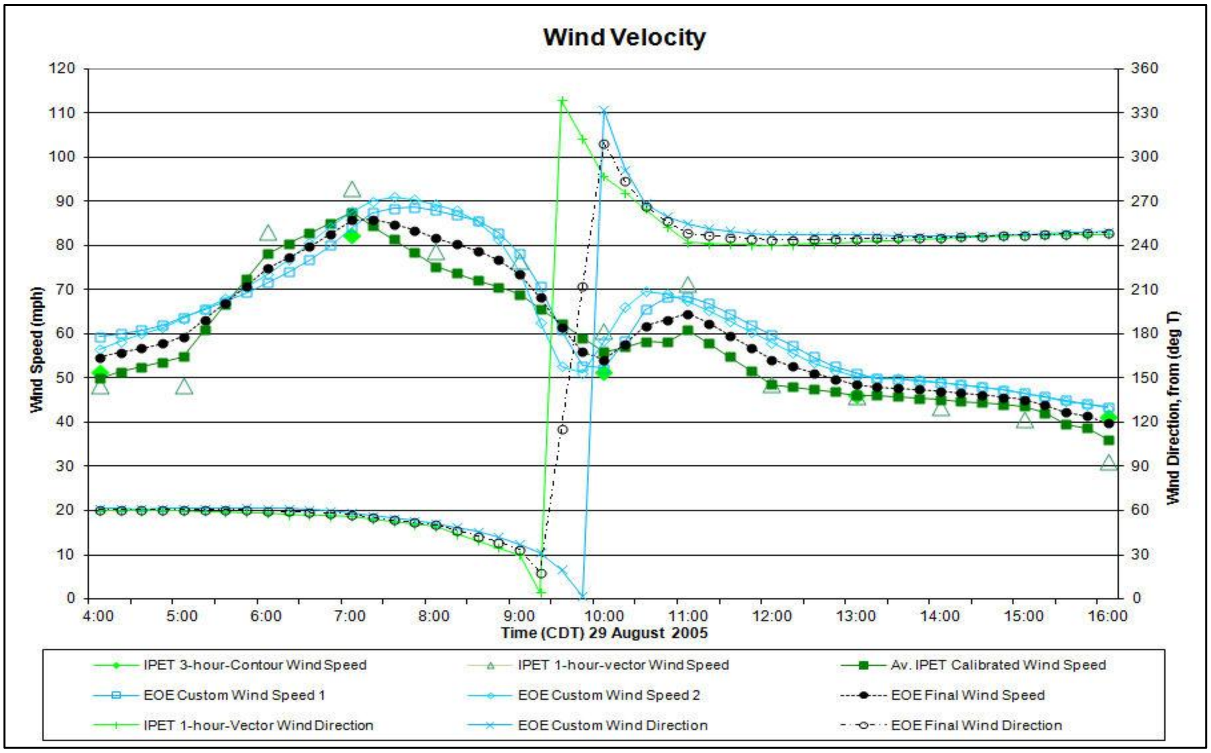

Figure 5. Comparison of IPET and EOE wind parameters at example site, 0400 to 1600 August 29, 2005

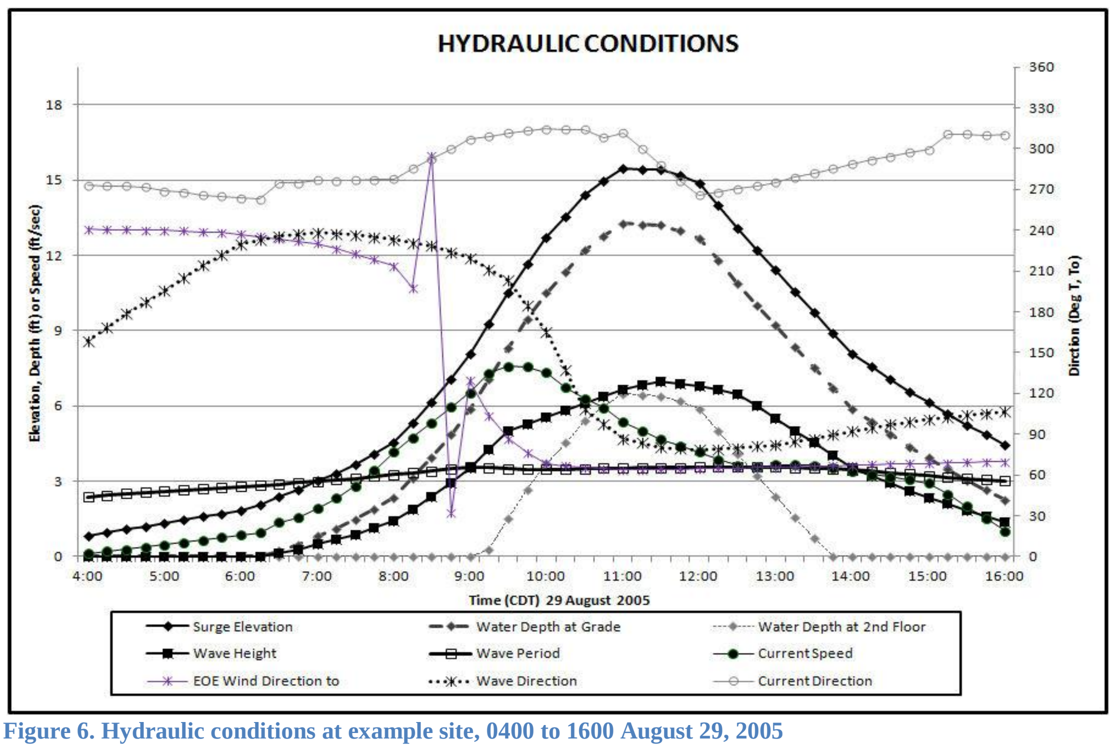

Figure 6. Hydraulic conditions at example site, 0400 to 1600 August 29, 2005

Hydrodynamic Force Module

The total hydrodynamic forces on a structure is the hydrostatic force, the current force caused by the moving water as the surge propagated across the inundated land, the wave forces due to the impact of wind waves on the walls, and, where applicable, the underside of an elevated floor. Since the magnitude and direction of the current and waves are provided by the hydrodynamic module, the time-varying loads on each side of the structure can be calculated from its orientation.

Calculated forces are those the structure would have experienced if it had sufficient structural integrity to endure them without moving. This is a mathematical assumption to allow calculation of the maximum possible hydraulic forces a rigid structure of the given dimensions and orientation would have experienced under the hindcast conditions. It does not mean, of course, that the actual structure remained in place, undamaged, for the entire duration of the hydrodynamic force simulation.

Hydrostatic forces result from a difference in water level between the inside and the outside of the structure as the flood waters leak into the interior, assumed as an instantaneous head difference of 1 ft for most structures. Current forces are calculated by the Bernoulli equation using the current magnitude and depth of submergence at the wall. Wave forces for non-breaking waves are calculated as the crest makes contact with the wall surface based on methods presented in the Coastal Engineering Manual (USACE, 2011). When waves become steep enough to break, the peak wave forces are typically assumed at twice that of a non-breaking wave of the same height and period. On two-story structures subject to wave forces on the second floor, total loads are calculated for two scenarios: 1) *with* the ground level walls in place, in which case the total horizontal wave force is the sum of the ground and second story wave loads, and 2) with ground level walls *destroyed*, in which case the total horizontal wave force includes only the second story wave loads, but vertical uplift forces are calculated (Douglas et al, 2006) for the exposed and elevated second story floor. Determination of if and when ground level walls were destroyed allows selection of the appropriate load curves.

Figure 7 shows the calculated time series of water depth at the level of the 2^{nd} floor (9 ft above normal sea level), the horizontal unit loads (lb/linear ft of wall width) on the ground floor walls (ground level was just 2 ft above normal sea level), along with the horizontal unit loads for the cases with and without the ground floor walls in place, and the vertical uplift pressure loads on the underside of the elevated floor for the case without the ground floor walls in place. The surge level was just reaching the elevation of the 2^{nd} floor by 0900. At that time the ground floor walls were experiencing loads of nearly 1 ton per ft^2. The next module determines the actual time of failure (see Table 1) but it is apparent that those walls had collapsed well before 0900. At that time the horizontal loads on the 2^{nd} floor walls were hundreds of pounds per ft^2, and the elevated floor was experiencing cyclic loads around 1000 pounds per ft^2 with each wave crest. Even had the surge level stopped at + 9 ft it is clear that portions of the elevated structure would be damaged by ‘flood’, despite being “above the high water mark”.

Structural Response Module

The structural response module applies the environmental (wind and hydraulic) loading to the building structure in order to determine the damage and ultimately the governing failure mechanisms. A summary of the forensic process to determine the governing structure failures follows:

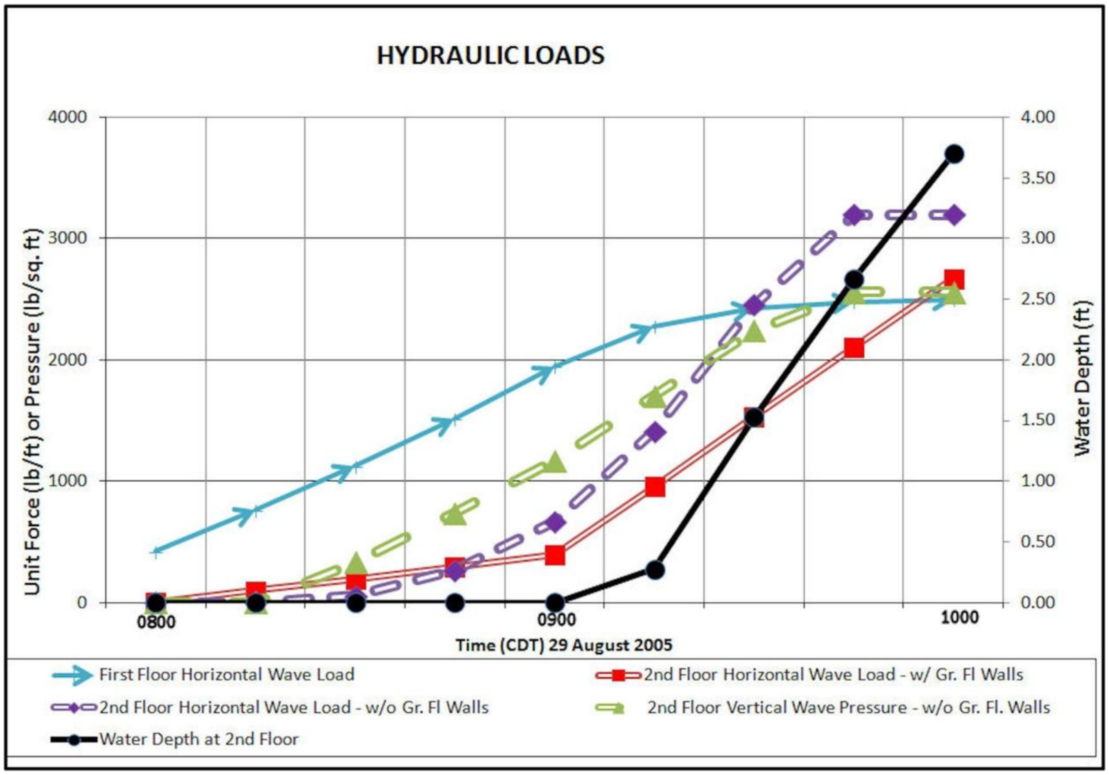

Figure 7. Hydraulic loads on example structure from 0800 to 1000 August 29, 2005

1. Structure Reconstruction - The structure is reconstructed including cardinal orientation based on a physical review of the site and surrounding area, available construction drawings, pre-storm photographs and other available data such as county records.
2. Analytical Modeling - The basic structure exterior is modeled and the wind time history applied to obtain the wind pressures experienced by the critical structure surfaces using ASCE 7 wind provisions (ASCE/SEI 7-05 – 2005). The associated wind forces on critical members (roof sheathing, truss members, eaves, wall stud members, floor members, etc.) and connections (top plate connections, wall sole plate connections or anchorage) are calculated to obtain the time history demand. The pressure boundary integrity of the building envelope is also considered in calculating the applicable wind pressures.
3. The time histories of hydraulic forces are applied to critical exterior walls and underside of the elevated floor system to determine the respective demands on critical structural members and connections. Figure 8 illustrates the wind and hydraulic forces applied to the structure under consideration.
4. Member Capacities - Member capacities associated with failure limit states for the respective building elements (members and connections) are calculated based on industry standard material limit states, fragility data and available empirical test data on materials and connections. Much of this data is drawn from the earthquake engineering field and previous post storm data (ASCE 41-06 - 2007, ANSI/AF&PA NDS - 2001, FEMA 55 - 1986, FEMA 549 – 2006, USDHUD PD&R – 1999 & 2002).

5. Demand to Capacity - A failure limit state demand to capacity ratio is calculated for each critical structural member and connection for the wind and hydraulic time history loading around the peak of the storm. The actual failure progression is determined based on the demand to capacity ratios; the proximate cause of failure is clearly demonstrable.

The failures calculated using the above process established the governing failure mechanisms and clearly demonstrated the proximate cause of failure. Table 1 illustrates the calculated demand/capacity ratios for various structural elements demonstrating the onset of damage, causation and the subsequent failure progression.

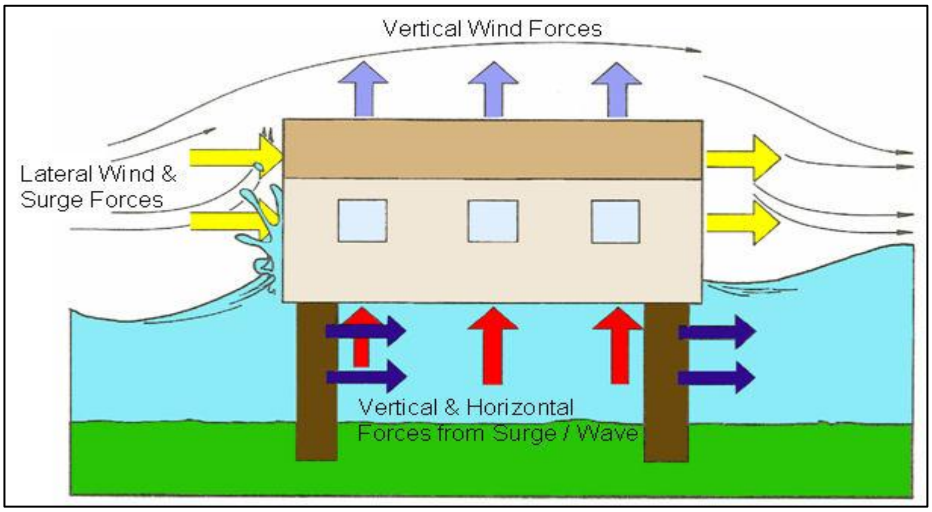

Figure 8. Illustration of typical structure showing horizontal and vertical loading

Table 1. Calculated demand/capacity ratios for various structural elements

Time 8-29-05	Hazard	Failure Mechanism	D/C Ratio	Remarks
0600-0630	Surge	None	----	Storm surge at ground floor slab
0700	Wind	- Uplift @ roof top-plate connection (enclosed) - Elevated floor stud wall in bending (enclosed) - Elevated floor stud wall connection to sill plate	0.53 0.61 0.37	No failures Peak winds 123mph – 3-sec peak gust
0730	Horizontal Surge	- Ground floor stud wall in bending - Ground floor stud wall connection to sill plate	0.59 0.81	No failures
0745	Horizontal Surge	- Ground floor stud wall in bending - Ground floor stud wall connection to sill plate	1.12 1.31	Ground floor walls fail. Ground floor interior inundated
0830	Vertical Surge (wave)	- Elevated floor joist in bending - Joist to girder conn.	0.89 6.13	Winds decreasing – 113 mph – 3-sec Elevated floor failing
0915	Horizontal Surge	- Elevated stud wall in bending - Stud wall to sill plate connection	5.02 5.94	Winds decreasing 88 mph Complete failure of elevated section of home

Site Inspections

We conducted inspections of every property examined. The inspections provided both input data and calibration/verification data for the hindcast, force, and structural response modules. Validation information for the hindcast includes indicators of surge elevation (such as high water marks), the general direction of winds and currents (such as damage and debris distribution), and surrounding property damage observations, – including unusual variations in damage to adjacent structures that would indicate fine-scale variability in the actual wind or flood patterns. Figure 9 shows an aerial view and several ground-level photos of the area surrounding the example property site.

Figure 9. Post storm aerial and ground level photos of example site

Input data for the force module includes surveyed dimensions and elevations of the structures foundation, floors, eaves, and roof; orientation of the floor plan, location and elevation of flow-altering features (seawalls, dykes, embankments). Important data for the structural response module are construction details, including, material, size, dimensions of wall, floor and roof components; fastener details; type and attachment method of claddings, location and dimensions of openings; and details of any observable structural damage. In cases with minimal damage site inspections are straightforward and productive, greatly assisting in validating the overall methodology being applied. In other cases, little of the damaged structure remained because either the storm or the subsequent demolition and cleanup removed the remnants. For pile-supported structures, recovering at least the elevation of the second story (see Figure 9A-C) is still a valuable piece of data.

Limitations of Methodology

The major limitation on the hydrodynamic conditions module is scale. The wind field used in the hindcast did not include local small scale (order of a mile) atmospheric effects such as a tornadoes or microburst, so particular attention was paid during site inspections for empirical evidence of these events. Likewise the circulation/surge model does not include small scale effect on currents, such as sea walls; these are accounted for by manual adjustments on a case-by-case basis. The wave model is a full 2-d spectral model but the hydrodynamic force calculations use the significant wave height, so the wave forces derived are just an average and are not conservative. Modifications can be made to represent the likely highest, and most damaging, waves in each time interval. The major limitation in performing the structural analysis was the amount and quality of the construction data available. Sometimes complete information is available from documentation, but site inspections are still essential. Even after several years most of the sites provided sufficient input data for analysis but repair, demolition, and debris removal all hinder the assessment. Timely post-storm site inspections will always improve the quality of the hindcast.

THE LEGAL LANDSCAPE

Courts have traditionally ruled under the <u>concurrent causation principle</u> that if two causes combine to produce loss or damage, and the insurance policy excludes one cause (e.g. flood) but cover the other (e.g. windstorm), the loss will still be covered. Another principal, the doctrine of <u>efficient proximate causation</u>, is more specific. The entire loss is covered if an included cause is a substantial or predominant factor in the loss and it initially set any other causes in motion in an unbroken sequence leading to the ultimate loss. In response, many wind-only policies contain an anti-concurrent causation clause which excludes coverage for flood damage even if another covered peril or event contributed concurrently or in any sequence to cause the loss.

The <u>Valued Policy law</u> has been applied to insurance contracts in many states for the last 100 years. Its intent is to assure that, in the event of the total loss of an insured property the calculation of indemnity was the same as used to collect the premiums – typically called the face value of the policy. In the famous 2004 Mierzwa case a Florida appeals court interpreted the Valued Policy law to mean that, in case of a total loss, the insurer must pay its *full face value* so long as there is *any* loss caused by an included cause. These various rulings and interpretations can result in any of four possible outcomes when a structure with a "wind only" policy is a total loss due to concurrent wind and flood conditions in a hurricane:

1. The **loss is not covered at all if any portion of the damage was due to flood**, regardless of the sequence of the wind damage with respect to the flood damage.
2. Only that portion of the loss caused by the wind is covered. Flood damage is covered by flood insurance, if any.
3. The loss is covered at face value if the wind damage occurred before the flood damage and was a significant factor in the loss.

4. The **loss is covered at face value if any portion of the damage was due to wind,** regardless of the sequence of damage.

As would be expected under such a wealth of options, the disastrous 2004 and 2005 hurricane seasons resulted in a flood of litigation. Both the courts and legislatures of coastal states responded in an attempt to clarify the issue.

In Landry v. Louisiana Citizens Property Insurance Co, the Supreme Court of Louisiana ruled that the Valued Policy Law does not apply when a different method of loss computation is provided in a policy. Furthermore, if the different method of loss computation is provided that clearly refers to a covered loss, then the computation need only apply to losses from covered causes.

In 2005 the Florida legislature passed an amendment to the Valued Policy law that requires courts to determine whether "the covered perils alone would have caused the total loss." If the property would not have been a total loss but for the loss caused by the covered peril, the Valued Policy law applies. Otherwise, "the insurer's liability . . . . shall be limited to the amount of the loss caused by the covered peril."

In 2009 the California Supreme Court (State of California v. Allstate) ruled that, 1) when a loss results from both included and excluded causes but the policyholder can't allocate the amount of the losses between them, he is entitled to coverage of the whole loss up to the policy limits and 2) that the policyholder can't be required to allocate those amounts.

The recent Mississippi Supreme Court ruling in Corban v. USAA Insurance Agency places the burden on an insurance company to demonstrate that, in order for an exclusion clause to apply, a loss was in fact due to an excluded peril, and furthermore, that it occurred prior to loss or damage from an insured peril.

These measures have reduced the likelihood of option 1, wherein a homeowner receives nothing for his loss in spite of his intention to be insured, and option 4, wherein an insurer is forced to pay for a loss intended for exclusion. However, they probably will not reduce the litigation in cases of loss from concurrent wind and surge damage. If an insurer wishes to avoid paying policy limits, it assumes the burden of determining both the sequence and the pro rata amount of damage resulting separately from wind and flood forces. Thus the "wind versus flood" question has been transformed into "***whence and how much wind versus flood***."

CONCLUSION

The continued development in the coastal zone and the expected increase in intense storms from climate change ensure that the number of structures suffering damage to both wind and flood will increase. Legal responses to disputes over dual causation have shifted the principal burden to the insurer to demonstrate the amount and timing of damage if they wish to enforce exclusion clauses in the policy.

State of the art hydrodynamic modeling and structural analysis can be applied on a property-by property basis to unambiguously determine the cause and timing of damage to each structural member. Evolutions of the models already allow finer spatial and temporal resolution at lower cost and faster speed. It is a straight-forward expansion of this technique to provide this comparable level of analysis for any, or every, property of interest within the affected zone of a hurricane. The hurricane of interest can be any historical storm, a hypothetical future storm, or an imminent storm. If the static boundary conditions (bathymetry, topography, building geometry and structural details, etc.) are input into the model in advance, deterministic damage predictions can be made using *forecast* storm tracks before the hurricane makes landfall. Such prior knowledge of a company's actual liabilities – not merely a probabilistic risk of exposure – would provide significant advantages in resource allocation, budgeting, and, potentially, in precluding litigation altogether.

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