Severe Hurricanes – Facing the Challenge

PART 2

By Joe Kallaby, P.E., S.E.

Hurricane Rita churned a wide path of destruction across the offshore infrastructure as it headed to Texas and Louisiana in September, 2005. Hurricane Rita achieved CAT 5 intensity while over the open waters of the gulf. Fortunately, it diminished to CAT 3 intensity upon entering the Texas Gulf Coast.

Part 1 of this article was presented in the September 2007 issue of this magazine (visit **www.structuremag.org**). It pointed out the need to have a viable concept and a procedure that can be used by practicing engineers to address severe hurricanes. It presented the dual concept of strength and safety to address this need. This was followed by a brief look at the significant elements of hurricanes and a description of how these elements impact structural design.

In Part 2, structural design scenarios impacted by hurricanes are listed, followed by a step-by-step procedure for applying the dual concept. Future needs make up a wish list, followed by conclusions.

A close up on Hurricane Rita's sprawl in Texas and Louisiana, September 24, 2005. Courtesy of NOAA Environmental Visualization Program, GOES-12 imagery.

Design Scenarios

Depending on the elevation of the base floor of the structure with respect to mean sea level (MSL), and the maximum anticipated surge height at its location, several scenarios are possible:

A) The structure may be subject to wind loading only.
B) The structure may be subject to surge loading only.
C) The structure may be subject to wind and surge loading.
D) The structure may be subject to wind and surge loading followed by flooding (radial compression and uplift).
E) The structure may be subject to wind loading followed by flooding.

General Approach

Since design against severe hurricanes (CATs 4 and 5) is in its infancy, the author proposes that structures be:

A) Designed for DSL (Design Strength Level), using a hurricane of intensity two levels below that of the most severe hurricane to which the structure may be subjected, as well as other associated requirements of the *International Building Code* (IBC) or (ASCE-7), such as drift. The design would use standard (elastic) practice, with all stresses and safety factors meeting code and standards requirements.
B) Investigated for the RSL (Reserve Strength Level), under the impact of all pertinent items listed under "What Hurricanes Can Do to Structures", in Part 1. This level can be defined as:
   1) The most severe hurricane to which the structure may be subjected.
   2) Minimum level of reserve strength (expressed as a ratio of DSL) against collapse; referred to as RCR (Reserve Capacity Ratio) such as 2; to be established by the owner or future code requirements.

In either case, the investigation is carried out using the pushover procedure. In this procedure, critical members or joints, may be strengthened, as needed, to satisfy either B1 or B2 above.

These guidelines may be subject to change as experience matures.

Detailed Procedure

A) DSL: Follow standard (elastic) practice and design for all items listed under "What Hurricanes Can Do to Structures" that may apply. We will assume here that all requirements apply, except for waves, which are beyond this scope.
B) RSL: For purposes of this article, assume that RSL calls for CAT 4 survival.

STEP 1. Establish required values for wind and surge for this hurricane category.

STEP 2. Determine latitude and longitude at the location of the structure.

STEP 3 Determine elevation of the base slab of the structure with respect to MSL.

STEP 4. Determine design wind speed associated with CAT 4.

STEP 5. Determine surge elevation and speed in eight compass directions, associated with CAT 4, as in the sample shown in Part 1.

Partial Collapse of the Wendell Hanger, Lakefront Airport, New Orleans, LA ., Courtesy of Ed Huston, Smith & Huston, Inc., All Rights Reserved.

STRUCTURAL PRACTICES

practical knowledge beyond the textbook

STEP 6. Delineate the parts of the structure subject to wind and surge. Note that this changes as the surge height changes with direction of approach.

STEP 7. Determine wind and surge forces on each of the exterior, non-structural cladding walls. If these are part of the structural system, the forces would be applied simultaneously in STEP 9.

STEP 8. Determine capacity of each of the walls to withstand forces calculated in STEP 7, by removing ALL safety factors associated with the design of the wall. If the walls have additional strength or capacity beyond that of removing all safety factors, use this strength. If any of the walls are inadequate, strengthen accordingly. Check that wall connections to the supporting structure are equally adequate. Upgrade if required. Similarly, check that all windows and their connections are also capable of resisting the lateral forces to which they are subjected. If inadequate, strengthen as required. Cladding elements do not contribute to reserve strength, as they are not part of the structural frame; those that are part of the structural frame are discussed in STEP 9.

Wind-borne debris glazing damage to hotel in New Orleans, LA. Courtesy of Ed Huston, Smith & Huston, Inc., All Rights Reserved.

STEP 9. Determine capacity of the structural frame (the skeleton or complete system, including any moment resisting frames, shear walls, roof system and foundations, as made part of the structural model) in all three orthogonal directions, by removing all safety factors. If not adequate, perform a pushover analysis. If it does not have adequate capacity up to collapse, strengthen the weak elements to arrive at the capacity required. P-Delta effects and damping increase can be critical before collapse. It is important to note that deformation of the frame, at the point of providing the required resistance, should be used to re-check cladding, windows, and support connections for adequate resiliency to avoid popping out.

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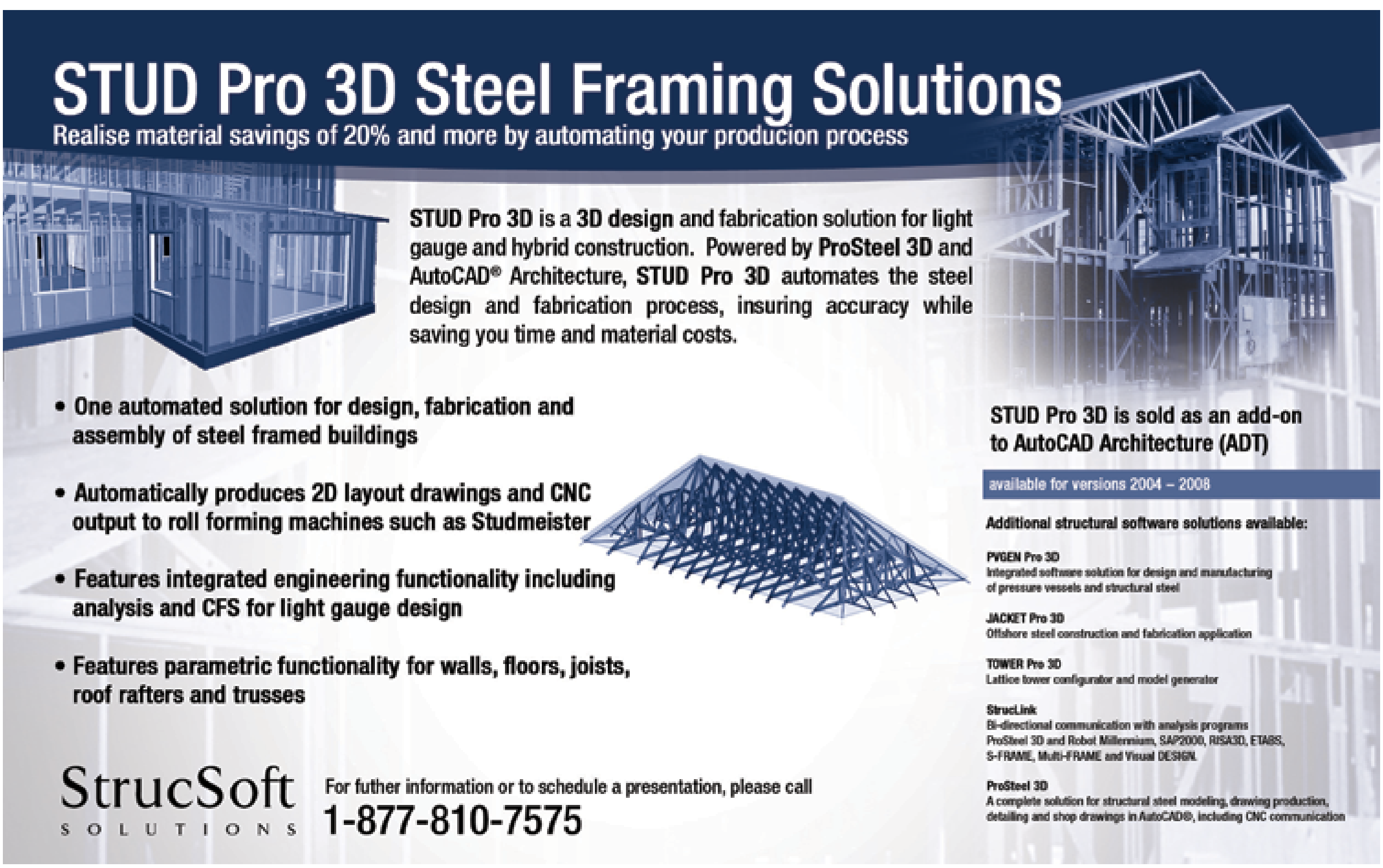

STEP 10. Where the roof or foundations are not part of the structural model, apply loads derived from the analysis in STEP 9 to the roof and foundations. Check against their ultimate capacity, with all safety factors removed. If not adequate, strengthen accordingly.

STEP 11. After the surge has passed, inundation may follow. Check the buoyancy of the structure against its weight, including foundations. The foundation slab may need to be thickened, or other measures applied, to counteract buoyancy. Soil suction may help in resisting buoyancy. Check that foundation soils are stable and would not be subject to erosion.

STEP 12. Evaluate the cladding and the frame for radial compressive forces surrounding the outside of the structure.

Keep In Mind That The Engineer Needs To…

1) Investigate inundation potential for the structure first, under the stipulated severe (RSL) hurricane. If it is to be inundated beyond hope for future use, the most economical design for the statutory wind speed would suffice, unless otherwise required by code or an informed owner.
2) Investigate stability of the foundations next. If severe erosion or subsidence may occur to make it unusable, design the structure as suggested in Item 1 above.
3) Allow for inherently different behavior of materials, such as steel, concrete, masonry, and wood. These differences become much more widely divergent as they approach ultimate strength. This would become apparent as pushover analysis progresses.
4) Strengthen the structural frame only after you complete pushover analysis. Otherwise, you would defeat the purpose of using reserve capacity to withstand severe loads. If pushover indicates it does not provide the required resistance, then strengthening, as needed, would be appropriate.

Partial Collapse of the Million Air Hanger, Lakefront Airport, New Orleans, LA ., Courtesy of Ed Huston, Smith & Huston, Inc., All Rights Reserved.

Future Needs (Wish List)

1) Develop a consensus strategy by the structural engineering community to design for severe hurricanes. The strategy presented in this article, while both logical and viable, is intended as a skeleton to be fleshed out to recognize the many different types of structures, materials, framing concepts, among others, in setting the stage for future action. Such a task is well suited for the Applied Technology Council (ATC) which has pioneered such action for earthquake hazards.
2) Formulate the strategy into a plan for research, investigation of existing structures and testing to determine reserve strength and ultimate behavior (RCR) of typical structures.
3) Involve government agencies (FEMA, NSF, NIST, and others) in formulating and funding the Plan. The same applies to insurance companies that have billions of dollars at stake in reducing hurricane damage losses.
4) Develop new materials and connections, with high strength and resilience, to provide efficient designs for all severe events, including hurricanes, earthquakes, and blast. This allows for high values of RCRs.
5) Develop statutory requirements for hurricane design for shore and near-shore zones, based on assigned regional CAT intensities, as is done with earthquake and wind, recognizing the role of the structure's survival after a severe hurricane (importance factor). For non-public and non-essential structures, owners should be allowed to select the level of risk they deem appropriate.
6) Condense results of the efforts into practical guidelines for design engineers to use in their practice and the academic community to use in the classrooms.

The author recommends that RCR factors be developed for typical structures to account for each severe CAT level. Design guidelines would then be developed for typical structures to provide required RCR factors, avoiding the need to perform complex pushover analyses. This procedure was developed by the author, and adopted by the American Petroleum Institute, for design of offshore platforms for severe earthquake levels.

Conclusions

Hurricanes are here to stay. We have no control over how strong they can get or the path they choose, but we can improve the safety of structures through the use of their reserve capacity.▪

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