

## **Structural Solutions for the Design of a “Cyclonic” or Hurricane Resisting Home Adapted to Simple Construction Methods**

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### **Abstract:**

This current research is based on and directly linked to a prior research entitled: “Wind Loads and Architectural Design - Application to Tropical Cyclonic Dwelling”, carried out at CSTB, Centre Scientifique et Technique du Bâtiment (Center for Building Science and Technology), and presented at the Tenth International Conference on Wind Engineering at Copenhagen, Denmark, by Jacques Gandemer and Sophie Hélyary-Moreau from the Department of Aerodynamics and Climatic Engineering, at the CSTB Research Center of Nantes, France.

In the actual research, the author from the New Jersey School of Architecture is cooperating with the above named french researchers from CSTB, regarding the design of a “cyclonic” or hurricane resisting home. In the prior research, and in order to study the influence of architectural forms on wind loads, home models of different configurations were extensively tested in the sophisticated wind tunnel facility at CSTB. As a result of their extensive testing and research, CSTB researchers provided different architectural interpretations of aerodynamic concepts, and some practical architectural applications of research findings. They ultimately developed a concept of a “cyclonic dwelling”, that would function more efficiently under wind loads in a hurricane environment. The proposed cyclonic home incorporates aerodynamic features and systems designed to reduce loads and pressures due to extreme winds.

The current research, in cooperation with CSTB, is supposed to complete some other aspects of the design of this cyclonic home, by looking mainly into the structural and construction aspects. In a first phase, the author’s work focused on the analysis of damages caused to structures by high winds and hurricanes, by studying the main findings of post-disaster investigations carried out both in the United States and abroad, including the French overseas territories. It is important to remember that damages from hurricanes and windstorm events currently represent a loss of several billions of dollars in the US. A loss estimate of \$30 billion was attributed to Hurricane Andrew alone. A comparative study of research results obtained by CSTB researchers and researchers elsewhere, regarding the influence of architectural forms on wind loads was also completed. The research work is currently focused on developing structural solutions for the design of this cyclonic home. These solutions should adapt to a modular architecture and simple construction methods. Economical issues and construction costs impacts will also be examined. This research will represent a contribution toward improving our understanding of the complex wind effects on buildings and structures. It will also help in applying research findings, and in using our knowledge in this area to improve the quality of design and construction to resist wind hazards.

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## **Structural Solutions for the Design of a “Cyclonic” or Hurricane Resisting Home Adapted to Simple Construction Methods**

### **1- Introduction**

As mentioned above, this paper provides an overview of an ongoing research related to the design of a “cyclonic” home. This work is based on a prior research entitled :”Wind Loads and Architectural Design - Application to a Tropical Cyclonic Dwelling“, carried out at CSTB, Centre Scientifique et Technique du Bâtiment (Center for Building Science and Technology) in France, and presented at the Tenth International Conference on Wind Engineering , Copenhagen, Denmark [3], by Jacques Gandemer and Sophie Hélyary-Moreau, from the Department of Aerodynamics and Climatic Engineering, at the CSTB Research Center of Nantes, France.

In the actual research which is funded by a grant from New Jersey Institute of Technology, the author from the New Jersey School of Architecture is cooperating with the above named french researchers from CSTB, regarding the design of a “cyclonic” or hurricane resisting home. In the prior research, and in order to study the influence of architectural forms on wind loads, home models of different configurations were extensively tested in the wind tunnel facility at CSTB. As a result of their extensive testing and research, CSTB researchers provided different architectural interpretations of aerodynamic concepts, and some practical architectural applications of research findings. They ultimately developed a concept of a “cyclonic dwelling”, that would function more efficiently under wind loads in a hurricane environment. The proposed cyclonic home incorporates some aerodynamic features and systems designed to reduce loads and pressures due to extreme winds.

The current research, in cooperation with CSTB, is supposed to complete some other aspects of the design of this cyclonic home, by looking mainly into the structural and construction aspects. In a first phase, the author’s work focused on the analysis of damages caused to structures by high winds and hurricanes, by studying the main findings of post-disaster investigations carried out both in the United States and abroad. A comparative study of research results obtained by CSTB researchers and researchers elsewhere, regarding the influence of architectural forms on wind loads was also completed. The research work is currently focused on developing structural solutions for the design of this cyclonic home. Economical issues and construction costs impacts will be examined in a later phase.

### **2- Post-Disaster Investigations of Hurricanes and Windstorm Events**

Damages from hurricanes and windstorm events currently represent a loss of several billions of dollars in the United States. A loss estimate of \$30 billion was attributed to Hurricane Andrew alone in Florida. In order to assess damages to buildings and structures, and provide guidance and recommendations to building officials and professionals, some field investigations were carried out, both in the United States and abroad, in the aftermath of hurricanes and major windstorm events, over the past two decades. These investigations constitute important lessons to learn from.

In a first phase of this research, the author completed an analysis of some of the most important post-disaster investigations and their main findings. The analysis was presented in a report [14] which covered investigations both in the US and abroad, including investigations in the French Indies in the aftermath of Hurricane Hugo in 1989.

Extensive investigations led by FEMA, Federal Emergency Management Agency, for instance following Hurricane Andrew in Florida in 1992 [8], and other investigations of the same hurricane event [12], revealed some important facts. Some of their most important observations, in relation to residential construction, were: extensive loss of roofing, specially tile roofs, resulting for instance in water damage to the interior of the house, failure of gable ends and base connections (hip roofs performed well), failures in the attachment of roofing and siding. Greater attention to details and connections in particular was generally recommended. Careful consideration of uplift in the design of foundations and base anchors were suggested. Improved fastening systems were also recommended.

On the other hand, as a result of Hurricane Andrew's devastation to Dade County, Florida, a task force was appointed by the county to study the building code and make recommendations. Some building practices were criticized. Experts pointed out that some of the code provisions were overlooked in construction. The use of some types of building and roofing materials was questioned. Some changes were introduced later, such as banning the use of pressed board and staples for roofing, among other changes which also included improving building inspection practices.

In the French Indies, field investigations by french engineers from CSTB, for instance in Guadeloupe, in the aftermath of Hurricane Hugo in 1989 [1], also revealed a better performance of hip roofs. In wood homes, roof collapse often involved the presence of large overhangs that failed under hurricane-wind loads leading to the roof collapse. Generally, homes built according to codes performed relatively well. In reinforced concrete buildings, inadequate reinforcement, insufficient cover, as well as poor concrete quality in some cases, were believed to have contributed to structural failure under hurricane winds. Field investigations of hurricanes or windstorm events were also carried out in Australia, Canada and other parts of the world [14]. In the US, field investigations of tornadic events were carried out as well, especially by FEMA [14].

### **3- Wind Pressure Distribution on a Building**

Winds generally create a complex pressure distribution on the walls and roof of a building. In a rectangular building, the windward walls are normally under high inward pressure, often called positive pressure. This pressure decreases near the edges of these walls. The leeward wall experiences outward pressures, called negative pressure, which increases near the wall edges and decreases near the center of the wall (Figure 1). Winds flowing around the building also create drag effects on surfaces parallel to the wind direction. Sidewalls generally experience outward pressures, and the corners a relatively large outward pressure due to turbulence in the flow. The wind-load action on a pitched roof is function of different factors, such as the pitch of the roof and the relative dimensions of the building. The effect on a flat roof is generally an outward pressure. Wind pressure distribution on the walls and roof is influenced by the presence of openings. Internal pressures depend on the location of openings.

#### **4- Overview of Architecture Related Wind Engineering Research in Low-Rise Buildings**

In the area of wind effects on buildings and structures, the basic research methodology consists in physical modeling using atmospheric boundary layer wind tunnels. A comparative study of architecture related wind engineering research in low-rise buildings was completed by the author, and presented in a research report [15], which also included a summary of the state of research in the field of wind effects on buildings and structures.

The Boundary Layer Wind Tunnel Laboratory at the University of Western Ontario in Canada, directed by Dr. A.G. Davenport, pioneered the study of wind effects on buildings and structures in the 1960's, and helped establish research methodologies in this field. As a result, its work became the basis for most wind codes in North America. Early research in this field often dealt with low-rise buildings and gable roof models. Examples include a study by Stathopoulos [13], also reported by Stathopoulos, Surry and Davenport [2].

As mentioned earlier, field investigations following hurricanes, revealed that hip roofs generally performed better than gable roofs. Gable roof construction is more common in low-rise buildings, and generally costs less than hip roof construction. After dealing primarily with gable roofs, wind researchers began later on to focus more attention on hip roofs. The effects of wind loads on both roof types were studied and compared by different researchers. Hessig [6] performed a parametric comparison of these two roof types at Clemson University in 1986. In 1988, Meecham [10] studied wind action on hip and gable roofs at the Boundary Layer Wind Tunnel Laboratory, at the University of Western Ontario. Meecham's research showed that the maximum wind action on gable roofs was greater compared to hip roofs. As an example, and for the studied configurations, the worst local peak negative pressures on gable roofs were about 50% greater than those on hip roofs. Distributed pressures on the full-span trusses of the gable roofs were estimated to be roughly twice as important as pressures on the full-span trusses of the hip roofs. Meecham suggested a square hip roof of a steep pitch as the best roof geometry to resist global overturning failure. The effect of fascia rounding of the roof was also studied by Meecham. Test results showed that the rounding alleviates leading edge pressures compared to the bluff-edged normal roof line.

In Australia, Holmes studied the characteristics of wind pressures on the walls and roof of gable-roofed tropical houses [7]. Experiments were carried out in the boundary layer wind tunnel at James Cook University in Australia, to study the effects of different factors such as: elevation of houses on columns above ground, roof pitch and grouping of buildings. Results showed, for instance, that the building elevation resulted in some significant increase in the external wind pressures. Other research examples include: Reardon and Xu [11], on the effect of roof slope on wind pressures of hip roofs, Ginger, Kane and Henderson [4], who also studied wind loads on hip end roofs at the Cyclone Structural Testing Station, James Cook University, Australia.

#### **5- Wind Research at CSTB - Concept of a "Cyclonic" Home**

In order to study the influence of a building's shape and architecture on its behavior under wind loads, wind tunnel tests were extensively carried out at the boundary layer wind tunnel at CSTB, at the research center of Nantes, France. Reduced scale home models were tested using different

configurations. The appropriate wind conditions and wind turbulence were recreated, and wind pressures were measured in different locations. Research and testing over a period of several years resulted in some practical architectural applications. CSTB researchers ultimately developed the concept of a “cyclonic dwelling” that would incorporate some aerodynamic features and systems designed to reduce wind loads in a hurricane environment. This section includes some of their most important findings and a brief description of the “cyclonic dwelling”. More details could be found in other publications [3],[5],[15].

In their wind tunnel testing, CSTB researchers studied the influence on wind loads of various parameters such as: the home shape and orientation with respect to wind, roof geometry and slope, roof overhangs and covered porches, and the control of internal pressure. Results generally showed that hip roofs performed better compared to gable roofs. A roof slope of about 30° was estimated to offer the best results. Roof overhangs were mostly subjected to important uplift forces. These uplift forces could sometimes trigger a roof collapse. Researchers recommended that roof overhangs do not exceed 50 cm (about 20”), specially for roofs with a small slope. They also recommended to structurally disconnect the overhangs from the main structure, if possible. In relation to the building’s shape, a compact building of a square floor plan (or even better: hexagonal or octagonal), with a multiple-panel roof (4 or more), was suggested in order to reduce wind loads. Test results also showed that regardless of the building’s shape, some roof locations (eaves and edges) were always subjected to important uplift forces. In order to reduce the local stresses at the roof’s lower edges, some local devices and systems were suggested:

1- A horizontal grid, similar to sun visor louvers, with a permeability of about 25-30%, and a width of about 50 to 60 cm (20” to 24”). This grid could reduce the vertical component of the wind speed thus decreasing local depression (Figure 2a). The system must be continuous around the perimeter of the building, and attached to the vertical structure (not the roof).

2- A notched frieze in a vertical position, all around the building at the level of the gutters. This frieze would function as a vortex generator, minimizing the roof edge depression (Figure 2b).

The effects of these two systems is not cumulative. Based on tests, their use could reduce localized wind loads by a factor of 1.5 to 2.

In order to control global wind loads acting on a certain surface of the building’s envelope, it is necessary to control both the external wind pressure distribution and the internal wind pressure. CSTB researchers estimated that the presence of a shaft in the center of the home would create a connection between the internal space and the roof ridge, considered as the zone of highest depression, thus allowing a balance of pressure between the exterior and the interior of the home, that could lead to a significant reduction or even a cancellation of roof wind loads. The shaft would also create a strong internal depression minimizing the risks of damage from suction (Figure 3). Tests were carried out using reduced scale home models equipped with a central shaft, and the results were compared to those relating to a regular home model with a closed central shaft. The edge treatment described above was also included. Test results clearly showed the benefits of the central shaft and these edge systems. For a good efficiency, a good airtightness of the home was recommended, and an area of about 1.5 to 2 m<sup>2</sup> (16 to 21.5 ft<sup>2</sup>) was suggested

for the shaft's section. A honeycomb system inserted inside the shaft would provide protection from rain without affecting the mechanism of pressure balancing. It was also suggested to raise the shaft for about 40 cm (15" to 16") above the roof ridge level. Finally, researchers stressed the necessity of maintaining a pneumatic connection between the shaft and the various internal spaces during the hurricane event. Based on research findings, CSTB researchers developed the concept of a "cyclonic home" (Figures 4 and 5). Some systems for the treatment of porch roofs were also suggested and tested by CSTB. Figure 6a shows a porch roof system consisting of vertical slats 15 to 20 cm wide (6" to 8"). It operates in two positions: closed for regular conditions, and open for hurricane conditions. Figure 6b illustrates another system which consists in dividing the porch roof into 3 parts (about 1m wide or 39"). The panels are swiveled to make an angle of 40° with the horizontal. An opaque element installed at the high part of the wall allows the system efficiency for any wind angle incidence.

## **6- Structural Considerations and Solutions for the Design of the "Cyclonic" Home-Building Envelope**

In addition to the regular loads normally considered in the design, a structure exposed to a hurricane can be subjected to high wind loads and flood loads. Flood loads could take different forms. They could be hydrostatic, hydrodynamic (from moving water), they could include breaking waves and debris impact. The effect of flood loads could be magnified by erosion and localized scour, which lower the ground surface around the foundation thus reducing the load-bearing capacity. The wind design is addressed somewhat differently by the various building codes. The ASCE 7-98 standard, "Minimum Design Loads for Buildings and Other Structures", of the American Society of Civil Engineers (ASCE) is considered the state-of-the-art in wind design. Its use is recommended by wind experts and by FEMA. Other helpful design documents include: "The High Wind Edition of the Wood Frame Construction Manual for One-and-Two-Family Dwelling", by the American Forest and Paper association (1996), and the Coastal Construction Manual (2000), published by FEMA.

One of the main objectives of this research is to focus on the structural aspect of the design of the "cyclonic" home, as described in the previous section. The following sections present a brief summary of some possible structural solutions using a wood-frame home, and some guidelines for the design of its framing. Suggestions are also given regarding the design of the building envelope. More details are given in a research report which is currently being prepared by the author. Suggestions are based on building codes and standards, and FEMA's Coastal Construction Manual. Other alternatives to wood products as well as construction costs impacts will be examined in a later phase of this research. Wood is basically the most used construction material for residential buildings in the US. In addition to its warmth and beauty, wood is strong, lightweight and easy to work with. The wood-frame home suggested for the "cyclonic dwelling" at this stage, is an elevated structure on an open foundation, with a hip roof and a somewhat cubical shape. Elevating a structure allows to reduce the risk of damage from flooding and hurricane-driven water. The home is supposed to be equipped with a central shaft and edge treatment systems as described earlier.

**Figures:**

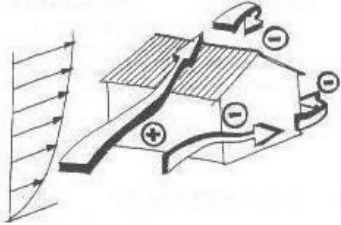
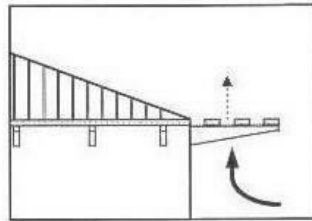
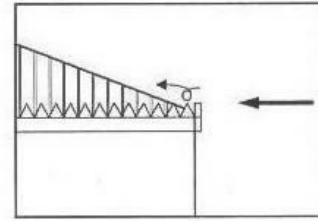


Figure 1 Wind Pressure Distribution on a Building



a) Horizontal Grid



b) Vertical Notched Frieze

Figure 2 Edge Treatment Systems

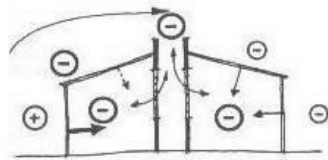


Figure 3 Balancing Pressure Using a Central Shaft

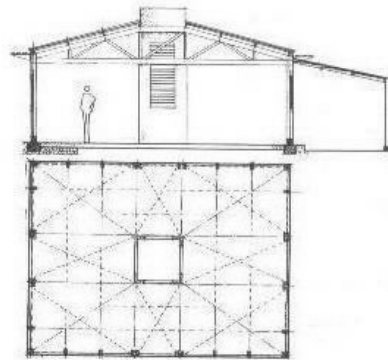


Figure 4 Cyclonic Home Concept as Developed by CSTB

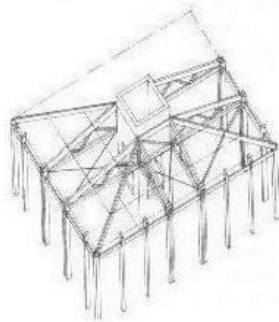
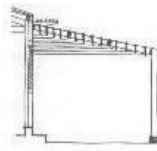
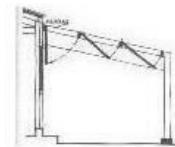


Figure 5 Cyclonic Home Frame as Seen by CSTB



a) Vertical Slats



b) Revolving Panels

Figure 6 Porch Roof Treatment

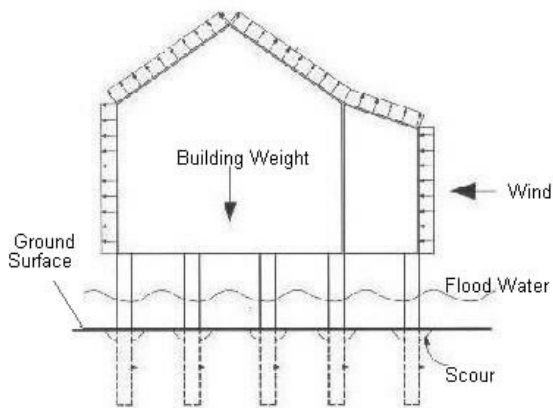


Figure 7 Elevated Structure on Pile Foundation

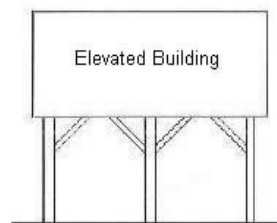


Figure 8 Knee Bracing

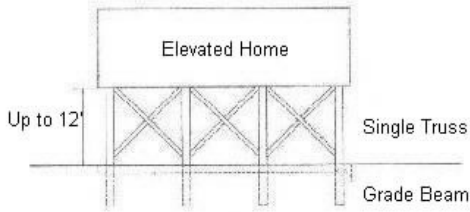


Figure 9 Truss Bracing

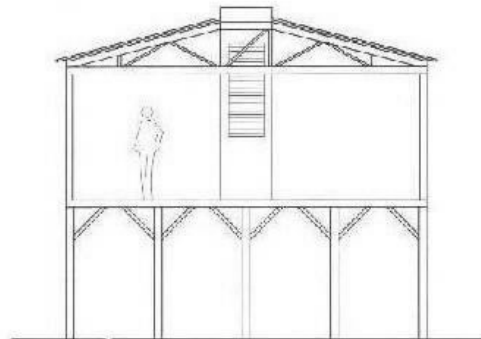


Figure 10 Elevated "Cyclonic" Home

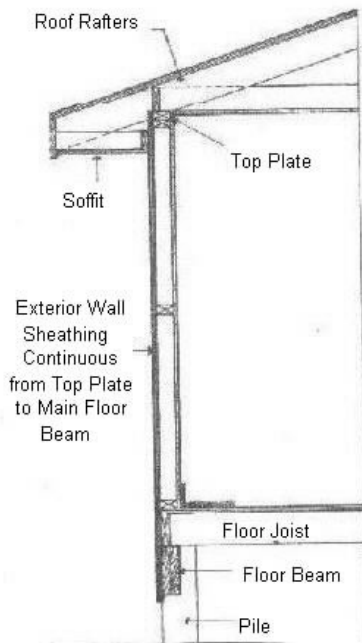


Figure 11 Wall Sheathing  
After FEMA, Coastal Construction Manual

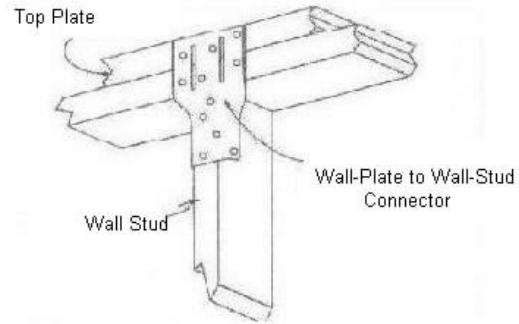


Figure 12 Top Wall-Plate to Wall-Stud Connection  
After FEMA, Coastal Construction Manual (2000)

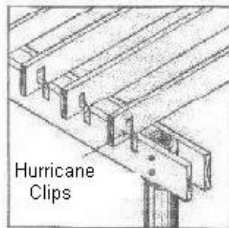


Figure 14 Mechanical Fasteners (Hurricane Clips)  
between Beams and Joists  
After FEMA, Coastal Construction Manual

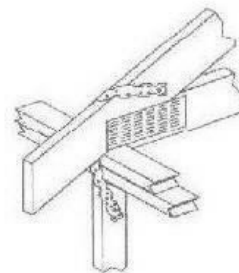


Figure 13 Example of a Roof Framing to Wall Connection  
Using Metal Connectors  
After FEMA, Coastal Construction Manual (2000)

## **6.1- Foundations**

In hurricane prone areas, foundations are at risk from wind forces, and from loads due to hurricane-driven water, flooding, wave action and water-borne debris. Wave action can scour support from beneath a foundation. For the cyclonic home in this study, wood piles are suggested for the foundation system (Figures 7 & 10). Piles could be driven or water-jetted. Driven piles offer a higher pullout resistance. Two types of wood piles are generally used: square timbers or tapered round timber piles. The most common sizes of square timbers are 10-in. and 8-in. (25.4 and 20.3 cm) square rough sawn lumber. The minimum required in coastal high hazard areas is the 8-in (20.3 cm) size. Piles should be embedded well below the scour depth. Horizontal bracing or grade beams could be used for additional pile resistance. The use of grade beams is sometimes criticized by engineers, as it may lead to increased wave action and scour around the foundation. In order to resist lateral loads, piles must be braced. FEMA recommends the use of diagonal bracing or knee braces (Fig. 8) for homes elevated less than 8 to 10 ft (2.4 to 3 m). Truss bracing (Fig. 9) is recommended for higher elevations or a wind speed of 100 mph (161 km/h) or more [9].

## **6.2 - Main Framing System**

### **1- Floor Framing**

For this relatively small cyclonic home, sawn lumber beams are suggested such as 4x10 or 4x12 (10.2cm x 25.5cm, or 10.2cm x 30.5cm - nominal size). Built-up members could also be used such as: two 2x10's (5.1cm x 25.4cm) or two 2x12's (5.1cm x 30.5cm). For longer spans, glulam members could be used. It is recommended to span the primary floor beams in the direction parallel to the flow for better protection from storm water forces and floating debris. Beams must also be treated with chemicals to protect them from decay and the effects of salt air and water. Splices should be located directly over supports. Joists could be sawn lumber members or wooden I-joists. Cross-bridging of all floor joists is generally recommended for floors of elevated homes.

### **2- Subflooring**

Plywood is typically used and is suggested in this case. Guidelines for its use are given in the "Plywood Construction Manual" by the Engineered Wood Association (American Plywood Association). Under these humid conditions, the adhesive between layers must be exterior glue. Subflooring is usually nailed to the joists. In this case, the use of deformed shank nails is recommended for a higher pullout resistance.

### **3- Wall Framing**

Common wood wall studs are suggested such as 2x4 studs (5.1cm x 10.2cm), or in some cases 2x6 studs (5.1cm x 15.2cm) spaced at 16" o.c. (40.6 cm). Special attention must be given to wall bracing, sheathing and nailing. Walls must be placed above solid support such as a beam. Connections to the floor above and below must be firm. Plywood could be used for sheathing of exterior walls, which could also constitute a method of wall bracing, providing a resistance against the effects of lateral loads. In this case, sheathing should span the height from joists to top plate, covering the bottom plate, floor joist and the top wall plate (Figure 11). Another method of wall bracing is the diagonal bracing of studs. The use of exterior glue and deformed shank nails is recommended.

#### **4- Roof Framing**

As mentioned earlier, a hip roof is suggested for the cyclonic home because of its significant structural and aerodynamic advantages compared to the gable roof. Details of the hip roof framing, and its advantages compared to a gable roof are discussed in a report currently being prepared by the author. The roof should be properly constructed and braced. Roof overhangs and porch roofs require careful detailing. Attention must also be given to the roof-wall connections. Trusses could be covered with plywood sheathing. Truss members are often made of 2x4's (5.1cm x 10.2cm) or 2x6's (5.1cm x 15.2cm). A spacing of 16" (40.6cm) or 24" o.c. (61cm) is typically used between trusses. In this case, a spacing of 16" (40.6cm) is suggested for a better framing and connection to the wall studs. The area near the central shaft opening in the roof requires some adjustment in the framing pattern.

#### **5- Connections**

There is an important difference between conventional connections in standard construction and connections in construction in high hazard hurricane prone areas, due to loads from high winds, flooding, wave action and floating debris. Connections using toe-nailing and anchor bolts are insufficient in this case. Toe-nailing is generally not acceptable, and fasteners must perform well under humid conditions. Galvanized bolts and metal straps are suggested. The load path in the structural system must be continuous. The most critical connections are: roof sheathing to roof framing, roof framing to exterior wall, top wall plate to wall studs, wall studs to window header, wall to floor framing, floor joist to floor beam, and floor beam to foundation (pile). FEMA's Coastal Construction Manual [9] includes examples of recommended connections (Figures 12 to 14), and provides guidance to engineers and designers regarding the design and construction of connections.

#### **6.3- Decks, Covered Porches and Stairways**

Decks and attached structures often fail during hurricanes, therefore special attention must be devoted to their design and construction. A deck or covered porch for the cyclonic home should be structurally independent of the main home, and carefully attached to it. It should be also supported in a way similar to the main structure. The deck could be cantilevered from the main structure, if its dimensions are appropriate. It is important to prevent the entry of wind-driven water by lowering the deck surface, or by following special flashing techniques. Porch roof treatment systems could be included as described earlier. Stairs move and get disconnected from the main structure under flood loads, presenting the risk of becoming the source of debris. Open-riser stairs must be used to allow the flow of water, and stringers must be anchored to a pile, and driven to a sufficient depth to prevent scour. The use of the retractable type of stairs is also possible.

#### **6.4- Building Envelope and Breakaway Walls**

##### **1- Breakaway Walls**

In certain high risk areas, both The International Building Code (IBC 2000) and The Residential Building Code (IRC 2000) require elevating buildings on an open foundation. Obstructions below elevated buildings are prohibited, but enclosures are permitted to allow for a limited use of

the space below the elevated structure, provided that they are designed to fail under specific lateral loads (wind and water). Walls designed to fail under certain loads are referred to as breakaway walls. The construction of strong walls is prohibited because they would allow excessive scour and damaging wave runoff during storms.

To enclose the space beneath the elevated cyclonic home, metal or synthetic screening, wood or plastic lattice or solid breakaway walls could be used. To construct the breakaway walls, wood studs are suggested. Studs are typically 2x4's (5.1cm x 10.2cm) and are usually attached to top and bottom nailer plates which are in turn attached to permanent top and bottom plates nailed to the floor beam and grade beam. The wall is designed to fail at the connection to the permanent plate due to nails that are sized and spaced for a required lateral capacity.

## **2- Building Envelope**

The most important risk in the performance of the building envelope is from breaching (loss of roof covering and windows), and subsequent water infiltration. A damaged envelope also becomes a source of windborne missiles. The following guidelines could be applied to the envelope design of the cyclonic home.

If the home is near the ocean, then sheathing of the underside of the bottom floor joists is recommended [9], to protect the insulation from water effects and to reduce the risk of corrosion of connectors and fasteners. For satisfactory performance of the exterior walls in hurricane prone areas, proper attachment of siding and panel systems using a sufficient number of corrosion resistant fasteners is necessary. More blowoff problems were encountered with vinyl siding compared to other types of siding.

Regarding roof coverings, some systems perform better than others during hurricanes. Tile roofs as well as cement fiber systems are generally brittle and vulnerable to breakage from windborne missiles. The wind performance of metal panels and shingles varies. Few data is available on the wind resistance of slate, due to its limited use in the areas affected by hurricanes in the US. Field investigations showed that properly attached wood shingles and shakes can perform well. In this case, preservative treated wood is recommended. Liquid applied membranes are not common on the continental US, but are common in the US Virgin Islands, Puerto Rico and some other areas. Field investigations following hurricanes showed a good wind resistance of some of these systems. Specific guidelines for the use of asphalt shingles with self-seal tabs are provided in FEMA's Coastal Construction Manual. Proper application of fasteners and adequate underlayment design are important for a good performance.

Doors, windows, skylights and their assemblies must be strong enough to resist positive and negative wind pressures. Corrosion and water leakage problems could occur under hurricane conditions. FEMA recommends the use of aluminum or painted galvanized steel doors for locations within 3,000 ft (914 m) from the ocean. FEMA's Coastal Construction Manual also provides recommendations regarding the use of sealants. It is recommended that glazing be designed to resist windborne missiles or be protected by shutters. A variety of designs and materials are available for shutters from the Engineered Wood Association. Shutters could also be made of plywood panels or using 2x4 boards (5.1cm x 10.2cm).

**8- Conclusion**

It is important to improve our understanding of the complex wind effects on buildings and structures, and to apply research findings and our knowledge in this area to improve the quality of design and construction in order to better resist extreme winds and hurricanes. This research is a contribution toward these goals.

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