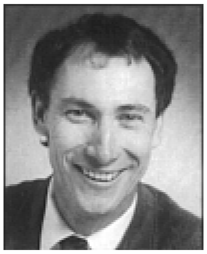
By Charles C. Hoover, Jr. P.E.



Throughout recorded history Man has striven to harness, or at the very least resist, the powerful natural forces that continually alter the earth's landscape. In just the past year North America has witnessed two of Nature's most disruptive events: what has been called a "500-year" flood in the Midwest, and the "100-year" Hurricane Andrew in South Florida.

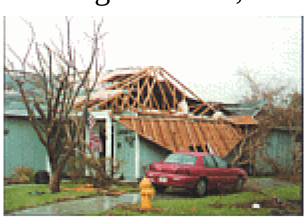
In this article we will:

- A summarize observations made by the author and others who have investigated residential areas impacted by Hurricane Andrew,
- provide an elementary overview of wind effects on residential buildings with particular attention to the roof structure and gable end trusses,
- suggest steps that need to be taken to improve the performance of residential structures under high wind conditions.

First, we'll set the scene.
Sunday, August 23, 1992 found residents scrambling to button up their homes as hurricane warnings sounded across South Florida. Residents along the Atlantic coastline were urged to move inland in anticipation of major flooding. In early afternoon the wind freshened, though the sky remained clear. Soon after midnight strong winds began blasting Miami area beaches and by 3:00 a.m. the mightiest hurricane to hit the United States in modern times surged across the southern end of the peninsula, demolishing 25,000 homes, seriously damaging 50,000 others, and leaving some 175,000 people homeless.

Almost immediately, investigators began pouring over the area to assess the damage. Since then, participating Alpine engineers have contributed hundreds of hours to the investigation and evaluations. The effort continues even today.

Early accounts, such as wind speeds, were often exaggerated or misleading, not unexpected considering the scope of the disaster. Subsequently, interest focused on wind engineering, building materials, and construction quality.



Wind engineering researchers estimate Hurricane Andrew's "fastest mile" wind speeds at 115-120 mph (which would meet design requirements of the South Florida Building Code), while meteorologists place gusts at 140-150 mph. Either way, the design pressure applied to a building is essentially the same. Some uncertainty still exists regarding the possible exacerbating effects of wind phenomena such as convective currents and microburst-like whirlwinds.

Overall, residential structures designed and constructed in accordance with the South Florida Building Code performed favorably. A large portion of damage that residences did sustain occurred because rain and wind gained entry to the interior of the buildings through windows broken by flying objects, doors that failed, and roof openings caused by pressure of hurricane winds trying to escape from the interior.

Lack of Proper Connections

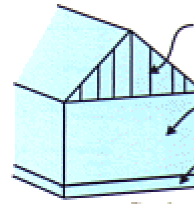
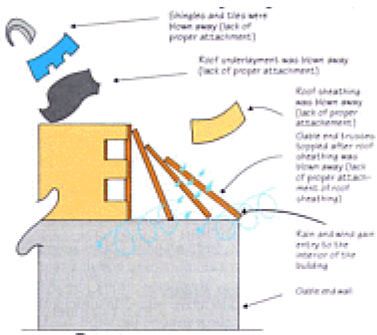


Fig. 1

The cause of gable end collapses in every case I inspected or am aware of, was a lack of proper connections. This was especially true in roof sheathing where one or more of the following conditions were commonly observed (also note Diagram "A"):

- in general, nail spacing did not meet the code minimum of 6" o.c. in the roof panel edges, and 12" o.c. in the interior of the panels,
- staples were not installed at the correct spacing and orientation. Staples must be spaced closer than nails, and installed parallel to the truss rafter chord.
- fastener spacing over the gable probably had been incorrectly considered as interior spacing rather than edge spacing.
- in general, there seemed to be a reliance on the code minimum nail spacing as opposed to the specific connections being designed.
- staples were not installed at the correct spacing and orientation. Staples must be spaced closer than nails, and installed parallel

Diagram "B" illustrates the probable sequence of events when connection of roof sheathing was inadequate. The wind peeled off improperly attached shingles and tiles, which were quickly followed by the underlayment. Then, the improperly attached sheathing was blown away and, since it provides the primary lateral stability to the trusses, they began to topple as rain and wind gained entry to the interior of the building.



B. Typical damage at gable end wall

Not a pretty picture, as far too many damaged buildings testify. Sadly, much of the damage could have been avoided had prudent and proper connection procedures been followed.

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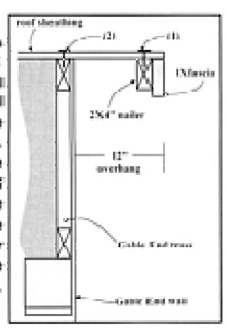
Myths About Gable End Trusses

A. Field observations indicated that nail 1 received closer nail spacing than nail 2. Nail 1 is actually at the edge of the roof sheathing. However, nail 2 is at the intended edge of the roof sheathing over the gable end truss. The fastener spacing over the gable end must be treated as an edge.

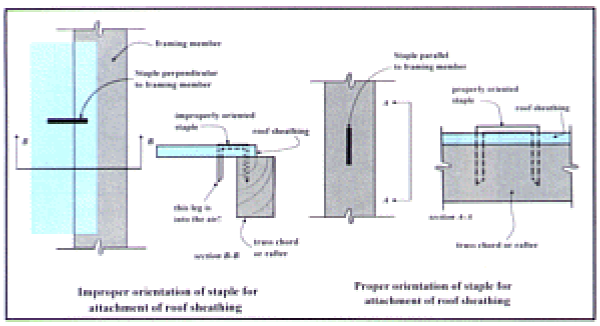


I feel it's important at this point to dispel four commonly held myths about gable end trusses.

Myth 1 - A gable end truss is non-structural. This misperception may occur because the structural portions of the end wall are visible only in the early stages of construction, and then are covered. In fact, the gable end truss is an integral structural component of the gable end wall. Here's how it functions.

The gable end truss receives load from the roof sheathing, transfers "gravity" loads through the top chord to the vertical webs, through the bottom chord, and into the top of the bearing wall. Examples of these loads are the "dead" weight of the roof itself, construction materials, snow, etc. Gable end trusses also support the roof diaphragm and transfer the shear load from the diaphragm to the supporting gable end walls.

Uplift forces due to wind are transferred by the gable end truss from the roof sheathing through fasteners (i.e. nails, staples) into the truss top chord. The forces then pass through the connector plates and verticals into the bottom chord. From the bottom chord, the uplift is transferred to the supporting wall and into the foundation. The gable end bottom chord also resists and transfers a portion of the lateral wind load into the ceiling diaphragm, or bracing members. In turn, the top chord resists and transfers a portion of the lateral wind load into the roof diaphragm.

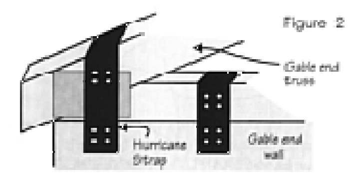


Vertical members of the gable end truss also resist the lateral wind loads. Reactions from these lateral loads are transferred to the connector plates into the top and bottom chords.

When referring to forces transferred between the gable truss and other building components, it is vital that fasteners of adequate size and spacing are in place.

Myth 2 - Gable ends are supported by the bearing walls. This belief occurs because the gable end truss is continuously supported by the end bearing wall.

During normal non-wind loading, this is a reasonable belief. However, during a wind event, it is important that proper connections have been made to keep the gable end truss from either uplifting or laterally coming off the gable end wall.



The load is transferred from the side wall into the strap, and through strap nails into the truss top chord. Nails connecting roof sheathing to the truss top chord transfer the load through the sheathing to the diaphragm and into the gable end wall, where it's transferred to the foundation.

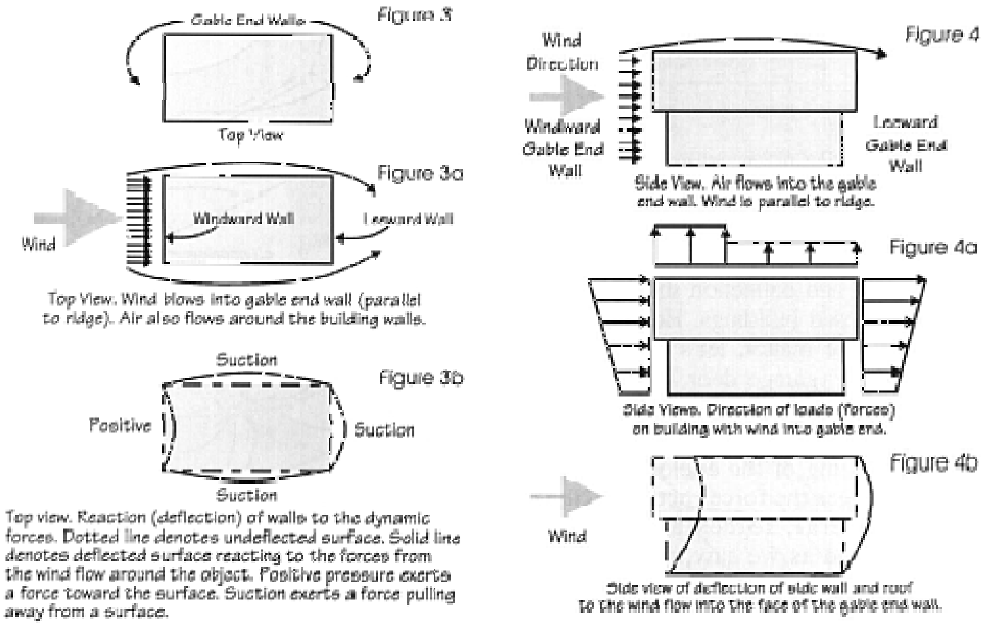
Myth 3 - Walls are self-supporting. The assumption is that walls will stand up on their own, especially masonry walls. However, for vertical loads, the walls are dependent upon the sheathing diaphragm to prevent lateral movement. What's more, when wind loads the side wall, half the wind load on the wall is transferred into the diaphragm.

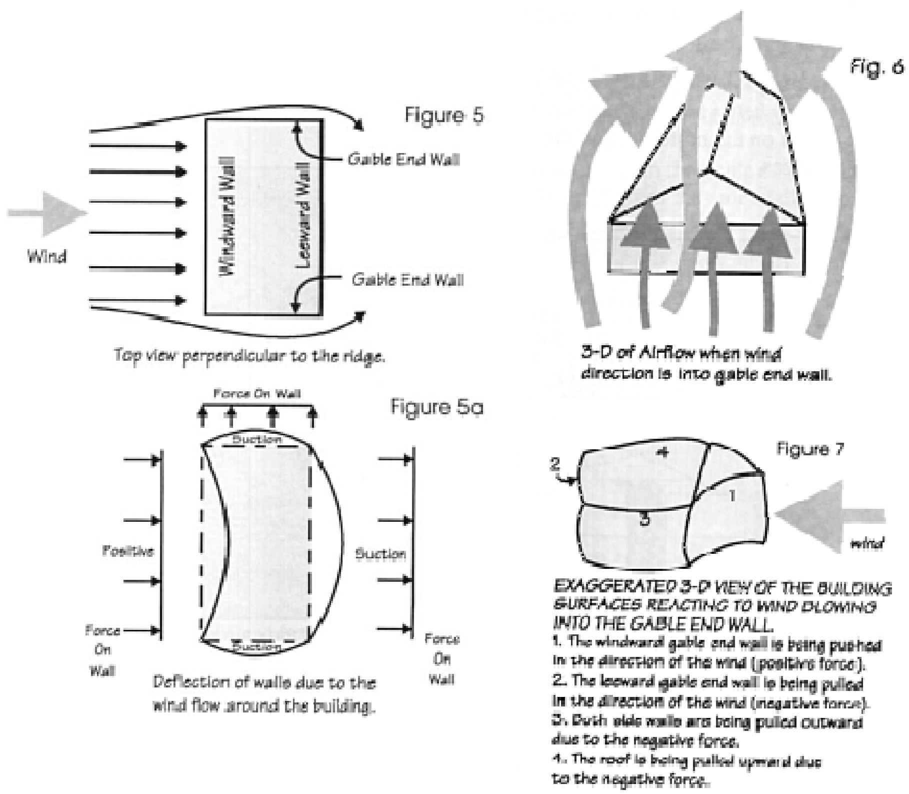
Both wood frame and masonry walls rely on the diaphragm to resist this load. The diaphragm forms a bearing point for the top of the wall, and the footer becomes the bearing for the bottom of the wall.

Myth 4 - Gable end trusses must have x-bracing. There are several ways to brace gable end trusses. The walls and diaphragm provide support, as will 45 degree braces. To really understand how all these loads and building elements interact, it's necessary to understand the basics of wind flow and its effects.

Understanding Elementary Wind Flow

These figures may help you visualize the air flow, and the resulting forces on the building, and the reaction of the building surfaces.





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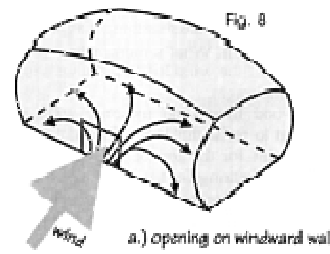
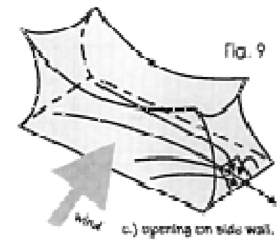
The Influence of an Opening in the Building Envelope

The forces and deflection shown to this point are for enclosed buildings. Hoping now not to complicate the matter, let's introduce a failed large opening (garage door, sliding glass door, etc.). This moves us into what is termed a "partially enclosed building."

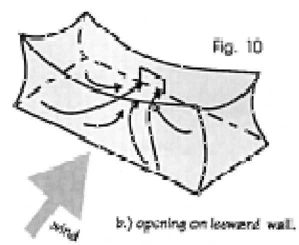


The breaching of the enclosed building envelope changes the forces acting on the building. In general, forces are significantly increased, and as we saw, major damage resulted. Shuttering of glass areas eliminates the catastrophic results that occur with breached openings in a building.



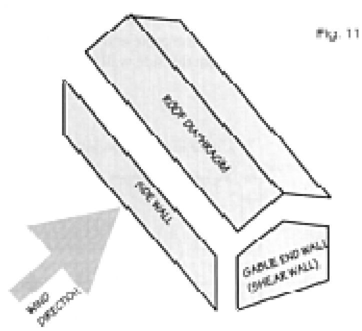
Wind Perpendicular to the Ridge

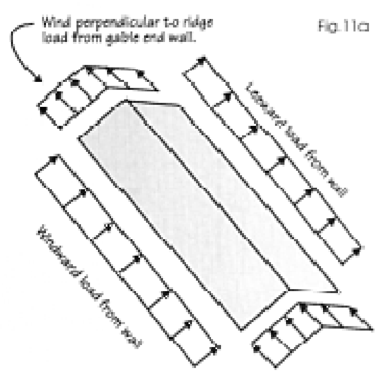
In this case, the wind is blowing perpendicular to the ridge. The wind force on the wall is shared between the lower floor or foundation and the roof diaphragm. The horizontal force of the wind on the roof is transferred into the roof diaphragm. These forces from the wall and roof are accumulated in the diaphragm.



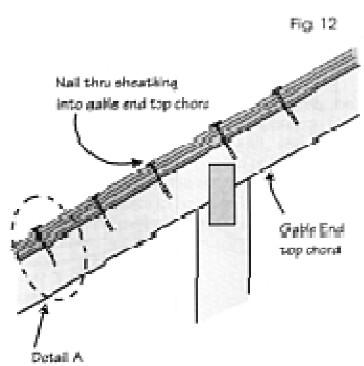
They accumulate toward, and then are transferred through, fasteners (nails, staples, etc.) into the top chord of the gable end truss.

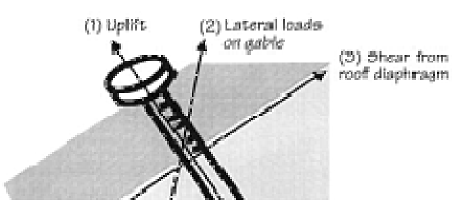
Then, depending on the type of construction methods used, these forces are transferred to the building foundation. The foundation must be sufficient to resist these forces.

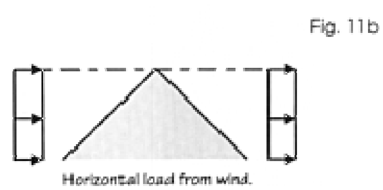




A portion of the wind load on the side and gable end walls is transferred to the roof diaphragm, and then to the gable end shear walls.







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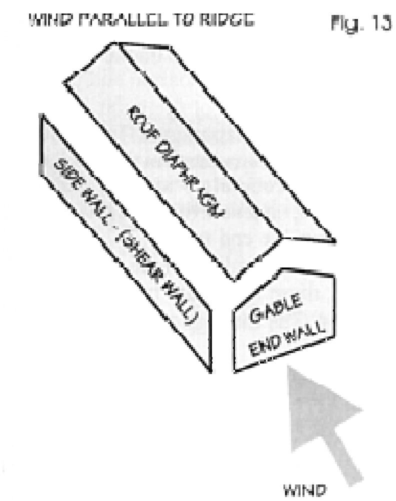
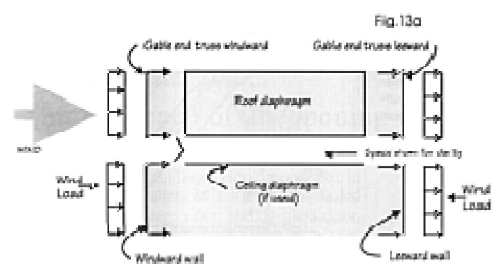
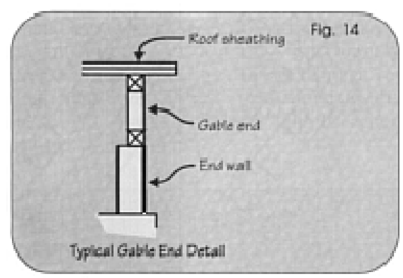
The Influence of an Opening in the Building Envelope

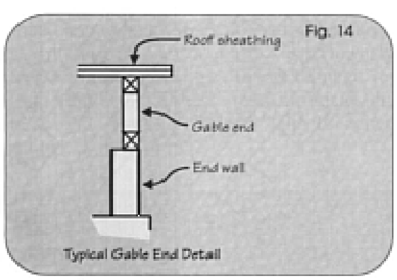
Portions of the force from the gable ends and the force on the walls is transferred into the ceiling diaphragm. The balance of the force is transferred into the foundation and side walls.

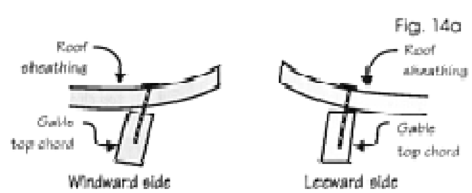
The lateral load from the gable end is transferred into the side walls and from the side walls into the foundation.





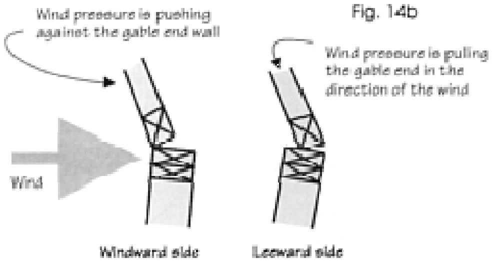






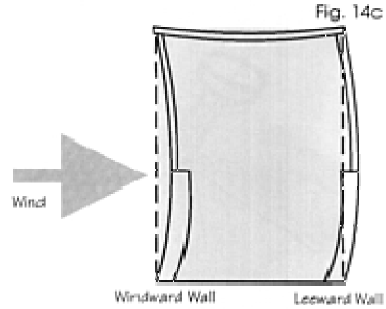
Exaggerated view of deflection of sheathing and gable end top chord when wind blows into the gable end. The fastener (nail) is being loaded in withdrawal and lateral.

Fig. 14b



Exaggerated view of deflection of the gable end bottom chord and the top of the wall. The fasteners are loaded both for uplift and lateral loads.

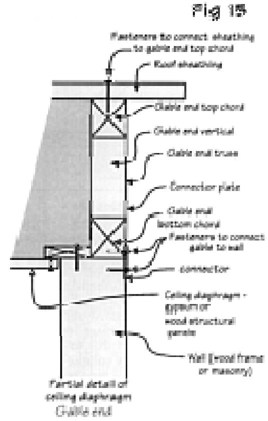
Fig. 14c



Exaggerated view of gable end walls and roof sheathing reacting to wind.

The building designer has several options in the design of wind resisting elements of the gable end wall.

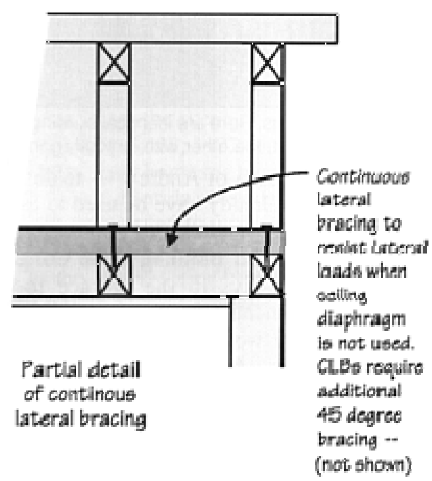
Fig 15



Top chord:

- roof diaphragm of structural wood panels, OSB or plywood,
- roof diaphragm of metal or other special roofing,
- roof diaphragm of structural wood panels, OSB or plywood,
- continuous lateral bracing (purlins).

Fig. 16



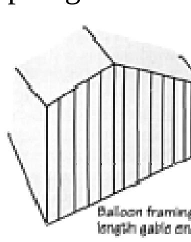
Partial detail of continous lateral bracing

Bottom chord:

- gypsum ceiling diaphragm,
- plywood ceiling diaphragm,
- continous lateral bracing,
- balloon framed end wall,
- raked masonry tie beam.
- roof diaphragm of structural wood panels, OSB or plywood,

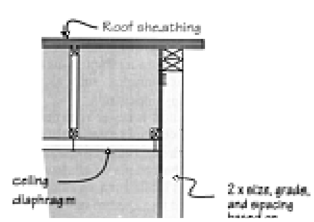
Gable end trusses are structural, and resist both vertical and horizontal loads. Gable end trusses and the building walls depend on the roof and ceiling diaphragms for stability and support.

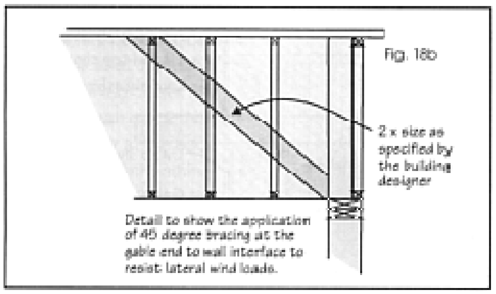
Fig. 18



Balloon framing on full length gable end wall

Fig. 18a





Conclusion

Hurricane Andrew re-emphasized the importance of connections throughout the various elements of a building. In general, where there was a lack of adequate fasteners, masonry, steel, and wood structures collapsed.

Overall the quality of residential construction could have been much better on buildings that collapsed. In fact, many buildings successfully resisted the hurricane winds without structural damage, indicating that quality of workmanship, rather than any specific product, was the root cause of many collapses.

A great deal of education must be done if we are to avoid the tragic consequences of such storms in the future. The building industry needs to be educated (or reeducated) about wind and what is required to design and connect for hurricane winds. We must do a better job of promoting the importance of quality construction. The practice of relying on building inspectors to insure quality can never be completely effective and it is extremely cost-prohibitive.

Homeowners, too, need to understand their responsibilities in protecting their homes, such as the importance of protecting glass openings.

It's been said that education is never as expensive as the cost of ignorance. We certainly saw that at work in the case of Hurricane Andrew. Little new was uncovered regarding wind and the resistance of structures to the wind. Instead, as time healed the wounds of past hurricanes, it also eroded the lessons of experience. And that must be the lesson of Andrew—to demand that the knowledge we already have be used to assure quality housing for all.

Here's what the Southern Building Code Congress International (SBCCI) says in the preface to it's Deemed To Comply standard.

"In 1983, two of the world's prominent wind researchers, G.R. Walker (Australia) and K.J. Eaton (United Kingdom) expressed their frustration concerning the inadequate performance of residential construction on a global scale:

'Basically, society has considered that housing does not warrant engineering analysis and design.'

"While this may overstate the problem in the United States, experience clearly shows that the wealth of information that has been available on wind effects has not been put to good advantage. If property damage is to be mitigated in the high wind regions of this country, increased engineering attention must be given to residential construction."

My goal in writing this article was to help the educational process. I hope the reader gained knowledge and an awareness of how wind affects a building, and that properly connected gable end trusses, shear walls, and diaphragms can reliably resist forces from an Andrew class wind event, and safely protect the homes, occupants and possessions.

Charles C. Hoover, Jr. P.E. is a Florida professional engineer in the structural discipline. He has a bachelor of science degree in Aeronautical Engineering from Embry Riddle Aeronautical University. He has been involved in the wood truss industry since 1973. Charlie has been studying the effects of winds and attending wind related seminars for the last eight years. He was a member of a team that investigated damage from Hurricane Hugo, and a member of the DCA and TPI Hurricane Andrew damage assessment teams. He served as a committee member on the development of the SBCCI Deemed To Comply manual for high wind effects. He is vice president of engineering for Alpine Engineered Products, Inc.