Insurance Institute for Business & Home Safety®

ATTACHED STRUCTURES HIGH WIND RESEARCH

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Introduction

The Insurance Institute for Business & Home Safety (IBHS) conducted unique research, sponsored by American Modern Insurance Group, focused on carport structures that are often attached to factory-built manufactured homes and also are attached to traditional site-built homes. The research evaluated the performance of carports subjected to high winds, such as those experienced during hurricanes, low-level tornadoes, straight-line wind storms, and severe thunderstorms. It identified and demonstrated a variety of failures that are common to these types of structures.

Wind loads on carports and canopies attached to low-rise homes and businesses have been extrapolated from small scale wind tunnel tests. Consequently, this research also provided an opportunity to measure wind loads on these structures. Wind load measurements will be used to evaluate, and if necessary, improve building code wind loads for carports and canopies attached to a variety of low-rise buildings. This report focuses on the high-wind performance of carports, identifies vulnerabilities, describes how to identify these vulnerabilities, and discusses remedial measures that can be taken to strengthen these structures.

Research Applicability

- While this research focused on wind performance of carports attached to factory-built manufactured homes, the test results are equally applicable to lightweight aluminum carports attached to traditional site-built homes.

- The test results also are applicable to other light-weight aluminum attached structures, such as porches, awnings, canopies, etc.

Research Purpose

The amount of insurance claims related to damage or destruction of structures attached to homes (e.g., carports, awnings, and porches) is very high. In fact, both IBHS and the Institute for Building Technology and Safety (IBTS) conducted studies focused on attached structures after Hurricane Charley struck Florida in 2004. IBHS looked at attachments to traditional site-built homes, while IBTS examined attachments to manufactured homes. Both studies found that 80% of attached structures in surveyed areas suffered partial or total destruction. Unfortunately, as they come apart, the attached structures can tear off parts of the home and become wind-borne debris, which is very dangerous both to the homes on which they are attached and to neighboring homes and other structures. Not only is structural damage costly, it also can expose the home to wind-driven rain, which can last for hours during a hurricane, resulting in interior water damage comparable in cost to or higher than the cost of repairing the structural damage.

The purpose of the testing was to examine vulnerabilities of attached structures, and to explore effective mitigation measures to make them more wind-resistant, with the goal of keeping attached structures in place during high wind events.

People are not expected to be in attached structures, such as carports, during severe weather events, so building codes consider them to be lower risk structures for wind design. Consequently, U.S. building codes allow the designer to reduce the wind design loads on these structures by 13% when design wind speeds are less than or equal to 100 mph, and by 23% when design wind speeds are greater than 100 mph. Furthermore, structures such as carports are not considered necessities and prices are market-driven because property owners choose to add them and pay for them. As a result, there is a great deal of pressure to keep these structures as inexpensive as possible. Finally, plan review and inspection of attached structures is generally not a high priority for many building departments.

All these factors have contributed to the creation of a large population of carports that are neither well-designed nor well-built, and it is not surprising that many older attached structures fail in winds that would not otherwise damage the home. Until the American Modern/IBHS tests were conducted, there had been little research on the overall performance of carport structures in realistic wind storms. Consistent engineering and product approvals, such as span limits, based on real-world wind performance are needed. In addition, building departments need to provide better oversight if the design and construction of carports is going to be broadly improved. Without this, it is likely that the design and construction of vulnerable carports will continue in many locations.

Design & Methodology

Research Methodology

A survey of older carports in a number of manufactured home parks was conducted to determine typical sizes and types of roofs and to identify potential vulnerabilities. This survey indicated the most common carport width was 12′ and the typical length was approximately 24′ or more. Consequently, all tests were conducted with nominal 24′ long by 12′ wide carports with one of the long edges connected to a 56′ long by 14′ wide manufactured home. The survey also indicated that most older carports used aluminum pans 12″ wide that snapped together or lapped each other at 1 3/4″ to 3″ tall standing seams. Discussions with carport installers with years of experience in Florida indicated that many older carport roofs were made of aluminum pans that were 19 thousandths of an inch (0.019″) to 24 thousandths of an inch (0.024″) thick, while most newer carport roofs use pans that are 32 thousandths of an inch (0.032″) thick or thicker. Current engineering guidance from a couple of sources also was reviewed.

Wind Uplift Loads on Carport Roofs

Initial tests were conducted using a carport instrumented with 32 pressure transducers installed to measure the net uplift pressure across the roof pans. Net pressures were measured within 1.5′ of each edge at locations 3′ apart and at 3′ centers across the entire plane of the roof. Support posts were instrumented with strain gauges to allow measurement of wind uplift forces transmitted to the posts from the carport roof. Tests were conducted at wind speeds up to 50 mph for a number of wind directions using two configurations. Skirting was installed between the bottom of the manufactured home and the floor of the IBHS test chamber, as shown in Figure 1.

Figure 1. Instrumented carport with skirting and wall blocking wind exit at one end.

Design & Methodology

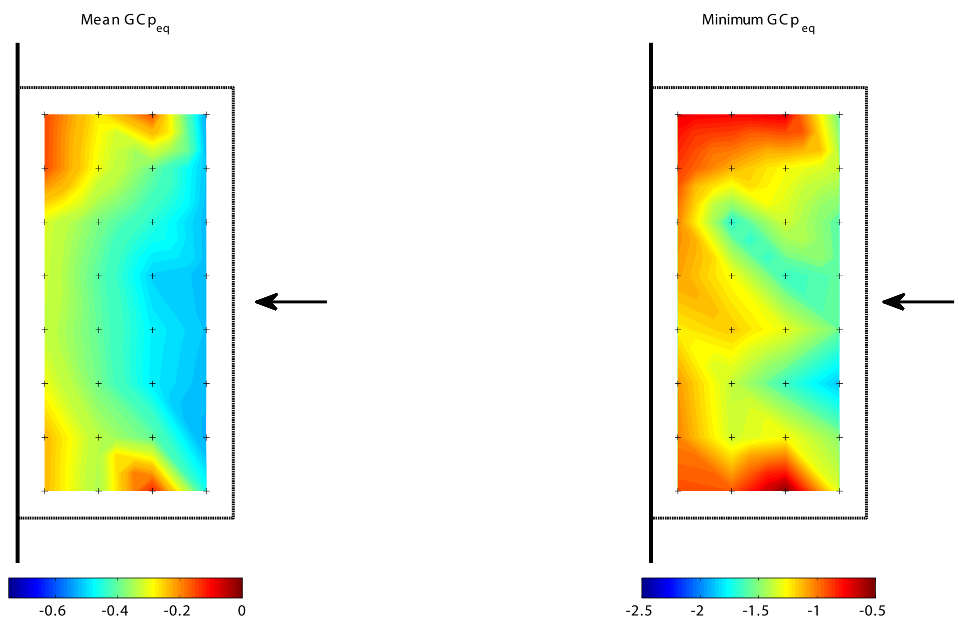

Figure 2. Distribution of mean (left) and minimum (right) wind pressure coefficients on carport roof with ends open and wind blowing perpendicular to the carport eave.

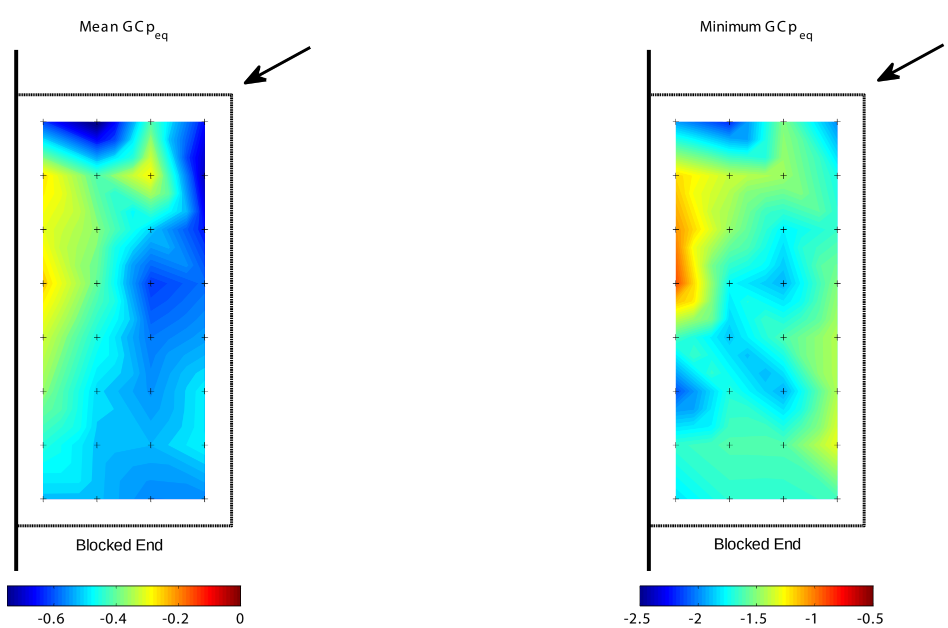

Figure 3. Distribution of mean (left) and minimum (right) wind pressure coefficients on carport roof with one end blocked and winds blowing 30 degrees off perpendicular to the carport eave.

Design & Methodology

CONFIGURATION 1

In one configuration, the 12′ ends of the carport were open, as was the 24′ side facing away from the manufactured home. As expected, the highest average wind uplift pressures occurred when winds were blowing directly toward the open 24′ side of the carport with the home inhibiting the wind's exit (Figure 2, page 5). The global peak uplift coefficient obtained by integrating the peak instantaneous net uplift pressure coefficients over the entire carport roof was -0.82 for this configuration. This is very close to the average uplift pressure coefficient of -0.85 from ASCE 7-10 for an open roof with obstructed flow. Because the carport is 12′ wide from the side of the home to the eave where the beam and posts support the eave, normal engineering design would assume that the tributary area for wind pressures acting on the eave beam and posts would be the 6′ width of the carport roof closest to the eave.

The peak net uplift coefficient for the entire 6′ wide area closest to the eave was determined to be -1.04. Addition of simultaneous peak uplift forces on all three posts, assuming an area 6′ wide by 24′ long, also produced a peak uplift coefficient of -1.04. Since the posts are roughly 12′ apart, corner posts would be assigned tributary areas 6′ x 6′ from each corner, and the middle post would be assigned an area that is 12′ long by 6′ wide. Integrating the net instantaneous pressure coefficients for these areas resulted in uplift pressure coefficients for the corner posts of about -1.00 and -1.23 for the middle post. Strain gauge measurements of axial forces in the posts supporting the carport eave beam produced uplift force coefficients of about -0.83 for the end posts and -1.30 for the middle post in this configuration. These values indicate the uplift load on the middle post is about 6% higher, and the uplift loads on the corner posts are about 17% lower than values calculated based on integrating pressures over the tributary areas assumed in normal engineering design.

CONFIGURATION 2

Another series of tests was conducted with one 12′ end of the carport blocked to represent configurations where a storage shed or some other structure is installed at the end of the carport, which blocks the wind flow through that end (Figure 1, page 4). For this configuration, the highest average uplift wind loads occurred for a wind direction of 30 degrees off perpendicular to the carport eave (Figure 3, page 5). The global peak uplift coefficient obtained by integrating the peak instantaneous net uplift pressure coefficients over the entire carport roof was -1.15 for this configuration. Consequently, the uplift loads are higher for the blocked configuration as compared to the open configuration when it is subjected to the same wind speed.

Strain gauge measurements of axial forces in the posts supporting the carport eave beam produced uplift force coefficients of -1.29 for the upwind corner post, and -1.45 for the middle post in this configuration. Integration of peak net pressures for the assumed tributary areas for these posts resulted in a peak uplift force coefficient of -1.40 for the upwind corner post, and -1.30 for the middle post. These values indicate that the uplift load on the middle post is about 12% higher, and the uplift load on the upwind corner post is about 8% lower than values calculated based on integrating pressures over the tributary areas assumed in normal engineering design.

Once the basic wind load information was collected, IBHS engineers conducted a series of tests over a two-week period to explore the vulnerabilities of carports, identify characteristics that lead to a more wind-resistant carport, and retrofits that can be implemented to strengthen existing installations. During the course of that research, a design that was consistent with the 2010 edition of the Aluminum Association of Florida (AAF) Guide also was constructed and tested. Fasteners with and without combination metal/neoprene washers also were used to attach roof pans in various tests.

Figure 4. Buckling of pans at mid-span.

Figure 5. Separation of carport from home.

Analysis

Identifying Weaknesses/Weakest Links

When faced with near complete destruction of an attached structure following a storm, it is often impossible to determine what failed first and how the failure progressed. With simple attached structures, like carports, failure of the weakest link usually leads to significant damage and collapse of the structure. Consequently, it is important to understand and be able to identify the weaknesses.

The survey of carports at manufactured home parks revealed that damage to, or poor connections of, posts that support the eave edge of the carport were extremely common. Without adequate anchorage of the attached structure's eave, it is extremely vulnerable to wind uplift forces when they exceed the weight of the structure. For lightweight structures like aluminum carports, this failure can occur at a very low wind speed. Since these types of weaknesses are relatively easy to identify and fix, post vulnerabilities were not studied in the IBHS full-scale tests. Nevertheless, common post issues are addressed in the following section.

With post anchorage issues eliminated in the IBHS tests, the following types of failure initiation were observed:

- buckling of pans at mid-span (Figure 4, page 6);
- separation of carport from home (Figure 5, page 6);
- buckling of beams supporting the roof eave (Figure 6);
- failure of connection between roof pans and support beams and channels as screws are stripped from metal, or metal tears around screws from overload or fatigue due to cyclic loading (Figure 7); and
- cracking of roof pans caused by wind-induced vibrations (Figure 8, page 8).

Figure 6. Buckling of beams supporting roof edge.

Figure 7. Failure of connections between roof pans and support beam at roof eave.

Analysis

Identifying and Addressing Weaknesses of Existing Carports

In order to improve the wind resistance of an attached structure such as a lightweight aluminum carport, it is important to evaluate the structure to determine all the potential failure initiation points and try to rank them in terms of the wind speeds likely to cause the particular failure to occur. The following subsections describe the various types of failures observed and provide some general estimates of wind speeds that could result in that failure.

Posts and Post Connections

A carport or attached structure roof acts to some extent like a wing sticking out from a house. Wind uplift forces on this structure can be quite large and the resulting uplift forces on the posts can be hundreds of pounds or even more than one thousand pounds. The survey of carports in manufactured home parks uncovered a large number with posts that were very small, bent or cracked, poorly connected to the concrete slab, poorly connected to the carport roof, corroded, or attached with small or corroded fasteners (Figures 9-12; Figures 13-14, page 9). Having sturdy well-connected posts also is important for holding up the roof and keeping it from collapsing under rain or snow loads. Small size posts can be easily damaged and are more likely to buckle if struck by a car. Posts can be easily replaced and the connections can be substantially strengthened at relatively low cost.

Modern designs tend to use 3″ x 3″ aluminum posts that are anchored top and bottom using 1/8″ or thicker aluminum brackets. Hardware attaching the posts to the brackets and the brackets to eave beams or the concrete foundation should be 3/8″ or larger and hot dipped galvanized or stainless steel. Thinner sheet metal connectors at tops or bottoms of posts and small screws are not capable of withstanding the forces that

Figure 9. Weak bent post; note sagging roof.

Figure 10. Posts with little or no connection to slab.

Figure 11. Damaged decorative support with weak repair attempt of connection/support at base.

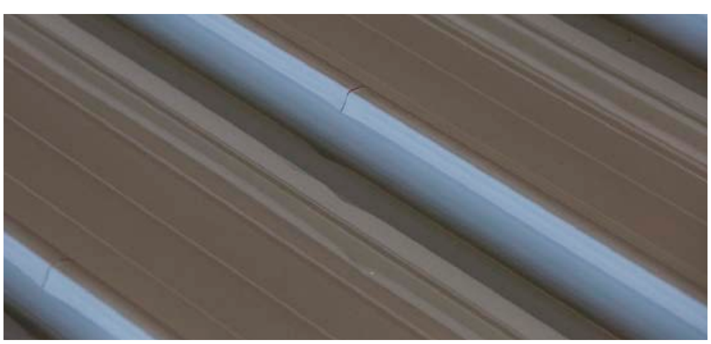

Figure 8. Cracking of roof pans caused by wind-induced vibration.

Figure 12. Thin sheet metal and small sheet metal screws are used to anchor post; anchor bolt is hidden under post and much too close to edge of concrete.

Analysis

may be exerted on them during a severe wind storm. If brackets are cast aluminum or aluminum sheet metal thinner than 1/8", it is worth replacing the brackets with plate type brackets that are at least 1/8" thick. A variety of commercially available brackets for anchoring the bottom of 3" posts to a concrete slab and the top to aluminum beams are shown in Figure 15.

Weak or poorly connected posts can result in lifting of the eave of the carport roof resulting in total destruction of the carport. It only takes a wind gust between 25 mph and 30 mph to create uplift forces on the carport that are greater than its weight. By the time wind gusts reach 60 mph, the total uplift force on the carport can exceed 2,600 pounds (about the weight of a small compact car). At 100 mph, these uplift forces can exceed 7,000 pounds (more than the weight of a large Sports Utility Vehicle). For a 24'-long carport with three posts, the forces trying to rip the middle post loose from the foundation could be more than 1,800 pounds.

In order to resist these kinds of uplift forces, the posts need to be straight and undamaged. Posts should be checked to see if there is bending or cracking, possibly from vehicles hitting them. Have damaged post(s) repaired or replaced. Check to determine whether there is corrosion or rotting of posts at the foundation or whether connection hardware is rusted, missing or limited to small screws. Replace corroded or rotted posts and make sure that hardware anchoring posts are in good condition.

At the base of the post, check how close any anchor bolts are to an edge of the concrete. If they are less than 2.5" from the edge, work with a contractor to find a way to move these connections farther from the edge. Anchors too close to an edge can cause splitting of concrete when high winds try to lift up the carport.

Connections at the tops of the posts are just as important; but experience shows they are likely to be stronger than those at the bottom. Tops of posts are attached to beams that run horizontally parallel to the roof's eave. The top connections should be checked to make sure the hardware is not rusted and the connections are made with bolts, nuts and washers of adequate size.

The survey of carports at manufactured home parks in Florida indicated that owners of about 20% of older carports had attempted to strengthen them. In a number of instances, the retrofits focused on strengthening, doubling up, or replacing posts and beams that support the carport eave. Figure 16 (page 10), Figures 17 and 18 (page 11) show selected retrofits that specifically addressed improving support of the carport at its eave. Unfortunately, probably 50% of the retrofits were ineffective. Knowledgeable advice is essential for ensuring that retrofits are effective.

Figure 13. Cracked, fractured, and bent post.

Figure 14. Other examples of poor post connections at base. Cast aluminum bracket (left) and broken bracket with dislodged screw (right). Note inadequate spacing of fasteners from each other.

Figure 15. Assortment of commercially available brackets and fasteners for attaching posts to beams and foundations.

Analysis

Buckling of Pans at Mid-Span

Most of the roofs observed in the survey of manufactured home parks were fabricated with thin metal pans about 12” wide with vertical ribs along the edges that snap together, overlap or are clamped together. These panels are typically referred to as “pans.” Old pans typically had structural vertical edge ribs that were 1-3/4” tall while new ones typically have 3” tall ribs. Contractors with a long history of carport construction have indicated that 19 thousandths (0.019”) thick and 24 thousandths (0.024”) thick pans were common on older carport roofs while most manufacturers currently only supply thicker pans that are at least 32 thousandths (0.032”) thick. During strong winds, these thin metal pans can buckle as shown in Figure 4 (page 6). For older thin metal pans, buckling may be one of the weakest links. Pans made of 0.024” thick aluminum that spanned from the wall of the home to an eave 12' away (a very common configuration for older carports) buckled when subjected to wind gusts equivalent to building code-defined Exposure B wind gusts of about 70 mph. Thicker 0.032” thick aluminum pans with the same span buckled when subjected to wind gusts equivalent to Building Code-defined Exposure B wind gusts of about 105 mph, a 50% increase in wind speed and a 50% increase in strength.

One design guide (Source A) specifies that for Exposure B design winds of 110 mph, 0.024” thick pans should have a span of less than 7’ and 0.032” pans should have a span of less than 10’. A second guide (Source B) indicates that 0.024” thick pans are suitable for spans up to 12’ when Exposure B design wind speeds are 85 mph, and 0.032” thick pans are suitable for spans up to 12’ when Exposure B design wind speeds are 100 mph. A third reference guide (Source C), provided by a major supplier, indicates that 0.023” thick pans 8” wide can have a span up to 6’-7” when the design wind speed in Exposure B is 100 mph, and that 0.030” thick pans can have a span of 8’ when the design wind speed in Exposure B is 100 mph. These span limits are usually set as the shortest allowable span based on either strength or deflection criteria. Strength calculations are tied to the maximum bending moments that would occur in the pans

Figure 16. Left image shows typical old support system where pipe posts connect to small thin angle. Right image shows carport with replacement beam and 3” x 3” posts; note severely rusted bolts.

TABLE 1: SUMMARY OF ESTIMATED DESIGN, ALLOWABLE AND FAILURE EXPOSURE B WIND SPEEDS FOR VARIOUS ROOF PANS WITH 12’ SPANS

Panel Dimensions Source A Design		Allowable Design and Failure Exposure B Wind Speed (mph) for 12’ Span				
		Source A Design	Source B Design	Source C Design	IBHS Failure Speed	Design with 2.0 Safety Factor on IBHS Result
12” wide	0.024” thick	64	85	--	70	50
12” wide	0.032” thick	92	100	--	105	74
8” wide	0.023” thick	--	--	56	~70*	~50*
8” wide	0.030” thick	--	--	68	~105*	~74*

** The “~” symbol indicates an estimate of the approximate speed.*

Analysis

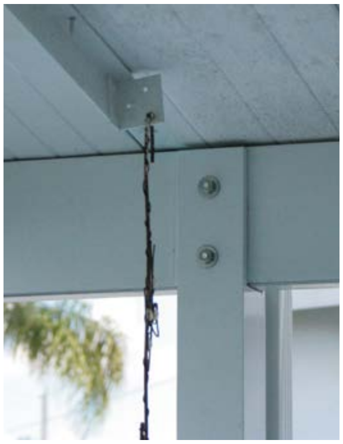

Figure 17. New beam and posts with improved connections supporting old roof.

which depend on the square of the length of the span and the square of the wind velocity. Because both of these variables are squared, if the span is increased by 10%, the allowable design wind speed decreases by 10%. Using this relationship, Source A would limit the design wind speed in Exposure B to 64 mph for the 0.024" thick pans with a 12' span, and to 92 mph for the 0.032" thick pans with a 12' span. Similarly, Source C would limit the design wind speed in Exposure B to 56 mph for the 0.023" thick pans with a 12' span and to 68 mph for the 0.030" pans with a 12' span. These design wind speed limits for 12' spans are summarized in Table 1 (page 10).

Consequently, IBHS test results (IBHS failure speeds listed in Table 1 compared to the listed allowable design wind speeds) suggest that Source C span limits provide a reasonable margin of safety during a design level wind storm. On the other hand, Source A span limits include a smaller safety margin against pans buckling during a design level wind storm event. Source B overestimates the strength of the 0.024" thick pans and only provides a very small safety margin against buckling for the 0.032" pans in a design level wind event. Assuming that a safety factor of 2.0 is desired, this means the load would be reduced by a factor of 2.0. Since the load increases with the square of the wind speed, the allowable design wind speed would correspond to the failure wind speed determined by IBHS multiplied by 0.707 (the wind speed at failure divided by the square root of 2.0). The last column in Table 1 provides estimates of allowable Exposure B design wind speeds based on wind speeds at which buckling occurred in the IBHS tests with a commonly used factor of safety of 2.0.

IBHS tested carports with 0.024" thick aluminum pans, 0.032" thick aluminum pans, and 0.024" thick steel pans supported by frames that limited the span length to 6'. With this kind of support, the pans survived wind speeds in excess of 100 mph. Furthermore, many homeowners are now choosing insulated panels for carport roofs. These panels have metal skins on both the top and bottom surfaces that are glued to rigid foam insulation, making them much stronger in bending. They are suitable for resisting wind uplift loads at much longer spans than the pan-type roof panels, and it is likely the strength estimates

Figure 18. Posts added next to existing decorative post and pipe posts.

Analysis

are more reliable because the calculations are not dependent on the metal panels maintaining their shape in order to provide the expected bending strength.

The survey of carports in manufactured home parks in Florida indicated there is some level of understanding that the thin pan roofs are susceptible to buckling upward in high winds. A number of carports included an angle attached to the top of the roof at mid-span between the wall of the house and the eave. The angle is anchored at the open end of the carport with a post that can be deployed when a storm threatens or when leaving during hurricane season. Two examples are shown in Figures 19 and 20. A more robust truss brace is shown in Figure 21a and was connected to a beam under the edge of the carport roof. Another complicated top-mounted bracing system is shown in Figure 21b (page 13).

IBHS installed and tested two over-the-top bracing systems in an attempt to evaluate these approaches to retrofit/bracing concepts where an attempt is made to prevent buckling upward by holding down the middle of the roof pans. The first bracing system is shown in Figure 22 (page 13), using 0.024″ pans. It consisted of two aluminum 2″ x 7″ beams at each end of the carport roof supporting a 2″ x 4″ beam, installed with the 4″ dimension perpendicular to the roof, that spanned across the middle of the roof pans to restrain their upward deflection and buckling. The system buckled at an Exposure B equivalent gust wind speed of about 85 mph as shown in Figure 23 (page 13). That structure would have been completely destroyed if it had been subjected to higher winds or possibly winds of longer duration.

The second retrofit added two additional 2″ x 7″ beams running perpendicular to the home, as shown in Figure 24 (page 13), so that each section of 2″ x 4″ beam that ran along the middle of the carport roof only had to span 8′. This retrofit was tested with both 0.024″ thick steel and aluminum pans without failure of either when subjected to wind in excess of 100 mph. Based on previous tests, failure would have occurred at lower wind speeds (about 70 mph for the aluminum pans) if these beams had not been added. This type of above-the-roof retrofit is only effective against wind uplift loads and would not help resist water or snow loads. A support structure based on the AAF Guide built under the roof deck, which helps support both wind uplift and snow/water gravity loads, is shown in Figure 25 (page 13). Figure 26 (page 13) shows the AAF-based support frame while the roof pans were being added.

Figure 19. Angle attached to carport roof with temporary anchor post in place.

Figure 20. Close-up of angle and anchor post connection. Usually only the end of the angle is connected to a post.

Figure 21a. Truss installed along middle of carport roof to brace pans.

Analysis

Figure 21b. Complex arch truss and brace system intended to prevent uplift buckling of roof pans.

Figure 24. Modified retrofit with two additional 2″ x 7″ beams so each section of 2″ x 4″ brace only spanned 8′.

Figure 22. Single 2″ x 4″ beam across middle of pans to help resist uplift; 2″ x 4″ beam is supported at ends by 2″ x 7″ beams spanning ends of carport.

Figure 25. Photo of AAF-based design that withstood wind speeds in excess of 100 mph with no damage. Tests were conducted with both 0.024″ and 0.032″ thick pans, which were attached to beam between wall and eave using screws with metal/neoprene washers.

Figure 23. Roof buckled upward when subjected to 80-mph winds.

Figure 26. Frame used to support roof pans in AAF-based design.

Analysis

While some homeowners prefer the clean flat look that is created when additional framing is not used on the bottom of the carport roof (the ceiling), the frame approach to reducing spans of pan-type roofing panels is probably the most efficient and least costly solution. The flat unobstructed surface look can still be created by using insulated pans of sufficient thickness to handle wind uplift loads for the desired span.

Figure 27. (Above) Typical damage to the eave of a home when a carport roof is blown away during a hurricane. About six square feet of area at the top of the wall was opened allowing entry of wind-driven rain.

Separation of Carport from Home

For carports attached to factory-built manufactured or site-built homes, wind uplift forces on the connection to the home can be a big concern. Unfortunately, the attachment of a carport to a home is usually hidden from view and there may be considerable uncertainty about whether the edge of the carport roof was well-attached to the home's structure and whether that structure is capable of carrying the forces imposed by the carport. Nevertheless, this connection is just as important as the

Figure 28. Detaching carport pulled roof sheathing from a manufactured home, introducing blown insulation (white) into the airstream.

Analysis

Figure 29. Carport with 4th wall located next to the home. The 4th wall is highlighted in pink.

Figure 30. Use of a round beam to provide beam support at eave of carport.

Figure 31. Use of a thin sheet metal-like channel to provide beam support at eave of carport.

connections to the posts and beam at the eave of the carport roof because this connection has to carry the other half of the wind loads acting on the carport roof during a severe storm.

When a carport roof detaches from a home it may well take some of the flashing, siding, structure, and possibly part of the roof with it. This damage to the home's exterior can allow tremendous amounts of wind-driven rain to enter the home, destroying finishes and contents. If structural damage occurs, it may lead to progressive damage and possibly collapse of walls or loss of more and more of the roof. Figure 5 (page 6) shows a weak carport connection failing. Figure 27 (page 14) shows typical eave and fascia/sub-fascia damage that occurred when a carport roof blew away during Hurricane Charley, which struck Florida in 2004. This left a hole in the home of about six square feet for rain to enter. Figure 28 (page 14) shows damage to a manufactured home that occurred when the roof of a carport blew off and took some of the roof sheathing with it.

Florida building codes now require that if a carport is to be attached to a manufactured home, either the manufacturer has to provide an engineered attachment point for the carport, or the side of the carport roof next to the home has to be supported by posts and a beam that is similar to that provided at the eave of the home. If the manufacturer provides an engineered attachment point, it usually consists of a wood beam running along the length of the wall of the home that is attached to the wall framing and covered with siding or flashing. When posts and a beam next to the home to support that edge of the carport roof are structurally independent of the home, it is usually referred to as a fourth wall. The addition of a fourth wall to an existing carport installation can make a big difference in reducing the vulnerability of a carport to wind damage.

The final wind tests of carports conducted at IBHS started with two identical carports attached to opposite sides of a manufactured home. One of the carports was retrofitted to improve its wind resistance. The retrofits included the installation of a fourth wall to resist the wind uplift loads on the edge of the carport next to the home as shown in Figure 29. The connection of the carport roof to the side of the home was not altered. Sideways wind forces on the carport roof are much smaller than the wind uplift forces, and these sideways forces can be easily resisted by the connection to the home. The fourth wall was specifically added to keep the roof from lifting up and detaching from the side of the manufactured home.

Analysis

Figure 32. Attachment of roof pans to frame below using small screws with enlarged heads.

Figure 33. Attachment of roof pans to frame below using #10 TEK screws with combination metal/neoprene washers.

Figure 34. Initiation of panel connection failure at connections using small screws without metal/neoprene combination washers.

Figure 35. Corrosion around existing fastener without isolating neoprene layered washer.

Buckling of Beams Supporting the Roof Eave

Beams and other members supporting the eave of the carport roof that are too small or weak for the span between posts also can buckle during a severe wind storm, which can lead to total destruction of the carport and subsequent damage to the home. This type of failure is illustrated in Figure 6 (page 7). The survey of older carports discovered a number of cases where eave beams were basically non-existent or considerably smaller than current engineering would suggest. Figure 16 (page 10) shows two examples. Figures 30 and 31 (page 15) show additional typical examples of weak eave beam supports used in older carports. Figure 30 shows a round beam that was used as the support beam near the edge of the carport roof, while Figure 31 shows use of a small channel. Typically the gutter attached to the edge of the pans provides little additional bending restraint because it is not supported by the posts and is often very thin metal. In addition, the gutter beam that buckled in Figure 6 at an Exposure C equivalent gust wind speed of 95 mph (Exposure B equivalent gust wind speed of 105 mph) had a span of 12'. Replacing the beam at the eave is not a particularly difficult or expensive proposition and should be considered when posts are being replaced. Where beams are replaced, roof pans should be screwed to them. In a couple of instances the survey of carports discovered cases where an additional beam was added at the eave.

Failure of Connections between Roof Pans and Support Beams and Channels

Many roof pans have been connected to the support beams by small sheet metal screws with an enlarged head. This produces a rigid connection and despite the enlarged head a relatively small clamping area for the thin aluminum pans (Figure 32). Initiation of the panel connection failure when such fasteners are used can be seen in Figure 33. Larger self-drilling TEK screws with composite metal/neoprene washers are readily available and provide a much better connection of the pans to the framing below them (Figure 34). The neoprene layer on the bottom of the washer helps spread out the clamping force and also helps keep water from leaking around the fastener. Because older fasteners may have caused some local corrosion (Figure 35) that would weaken the material around it, an easy retrofit is to simply add four larger TEK screw fasteners (typically #10 fasteners) with the combination metal/neoprene washers to anchor the bottoms of the pans to the framing below and just leave the existing fasteners.

Conclusions

Prioritizing Retrofits for Consumers

As you check your carport, you may find a number of situations and connections where retrofitting is recommended. However, budget constraints may limit what you can do and at some point the costs become so large it doesn't make sense to keep pouring money into an old carport. The following are some suggestion for prioritizing what to do.

Given that carports are held up by posts along the eave and on the other side by your home or by a fourth wall, the posts and their connections are the items deserving the most scrutiny. Observations have shown that the weakest link for many carports is the anchorage of the posts to the concrete. That is good news because it is one of the easiest and cheapest things to strengthen. Just replace the post bottom brackets with stronger ones, and in the process make a better connection to the concrete. Weak, damaged, or excessively corroded posts also can be replaced at a reasonable cost. Next, look at the fasteners connecting posts to beams above and to post bottom brackets. If they are screws, replace them with bolts. If they are bolts with lots of rust, replace them. These are inexpensive, easy fixes that will strengthen the connections of your carport.

At the home side of the carport, attachments to the home are usually hidden (difficult to see) and difficult to evaluate. That makes the quality of the connection unknown. However, a general rule is to evaluate what you can see on the carport and assume the condition of what you cannot see is comparable to what you see elsewhere. If many of the parts you can see are weak, then it is likely the attachment of the carport to the house also is weak. You can have a fourth wall added to support the side of the carport next to the house, if one is not there already, and this will relieve the uplift forces on the connection to the house. Expect to spend several hundred dollars on this type of retrofit.

Before you attempt to do more retrofits than those outlined above, check the cost of a new well-designed and well-built carport. You could well end up spending 50% of the cost of a new carport just trying to strengthen an old weak one. It would be worthwhile getting a knowledgeable contractor to make a more sophisticated analysis and recommendation.

IBHS has produced a *Consumer Safety Guide for Attached Structures* with a checklist for homeowners to evaluate existing structures and guidelines for purchasing new structures. Visit DisasterSafety.org for a copy of the guide.

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