

***Bracing For the Future:  
Construction Techniques to Protect Against  
Future Wind Damage in Ladysmith***

***FEMA-DR-1432-WI  
September 2002 Tornadoes***

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## Introduction and Background

The purpose of this document is to provide adequate and inexpensive wind mitigation measures to local officials, residents, and business owners involved with the reconstruction and disaster recovery work in Rusk and Taylor County, Wisconsin, as well as introduce several long term mitigation solutions. Implementation of mitigation measures can minimize and possibly prevent future wind damages to residential, commercial, and public structures in both Ladysmith and Gilman, Wisconsin. It is not the intent of this document to recommend that all structures be retrofitted to become tornado resistant structures (capable of withstanding winds and debris from 250-mph wind events), but rather to provide mitigation measures to the community during reconstruction that will strengthen existing buildings to resist wind forces between the building code minimum requirements and the requirement of tornado resistant construction. The Federal Emergency Management Agency (FEMA) and Wisconsin Emergency Management (under the Department of Military Affairs) hope homeowners can use this information to identify the damage they have sustained and convey to contractors possible mitigation measures to be incorporated during repairs and reconstruction. Similarly, business owners in Ladysmith and Gilman can refer to this document as they develop their Recovery/Mitigation Plan and apply for disaster assistance grants. Towards the goals of assisting both homeowners and businesses, this document contains distinct discussions of damage and mitigation measures relative to residential structures (Residential Buildings: Damage and Mitigation), commercial structures (Commercial and Public Buildings: Damage and Mitigation), and public schools (School Buildings: The Gilman School).

Only specially designed high wind shelters can resist the wind forces and debris produced by extreme wind events such as tornadoes with minimal or no damage. The mitigation strategies presented in this document center on construction enhancements that will allow a building or structure to resist winds above the current building code. These measures are intended to strengthen residential and commercial buildings to resist high winds associated with thunderstorms, downbursts, and the straight-line winds that are on the periphery of tornadoes. These strategies have been successfully applied in other communities around the country that have sustained wind damage similar to that in Ladysmith and Gilman. As such, these measures are appropriate for the damaged structures that were observed after the September 2, 2002, tornado in Rusk County. Mitigation measures can minimize damage to personal property and reduce the risk of loss of life when mitigated buildings experience wind forces generated by smaller tornadoes, downbursts, and strong thunderstorms. The benefits of the proposed measures include reducing the community's future financial debt and property losses, and preserving local businesses.

This document is based on data compiled by Federal, State, and local officials at the Disaster Field Office located in the City of Ladysmith. It contains an outline of wind-damage reduction techniques and relative costs based on estimations from local contractors and suppliers in the Rusk County area. All of the projects and mitigation retrofits will require further engineering analysis and review.

## Residential Buildings: Damage and Mitigation

More than 30 residential buildings in Ladysmith and Gilman were damaged by the wind forces and windborne debris associated with the F3 tornado that occurred on September 2, 2002. Typical residential construction damaged by the event consisted primarily of one- and two-story single family homes with wood framing and attached or detached garages, with a few masonry structures and multi-family dwellings. Most homes in Ladysmith and Gilman have basements (full or walkout), which were some of the safest areas in which to take refuge during this high wind event. The damage caused by the tornado could have been minimized if known construction techniques common to hurricane and tornado prone areas had been in place. This Section discusses observed residential structure damage and appropriate mitigation strategies that can be integrated into reconstruction.

### General Residential Damage Statements and Mitigation Opportunities

Damage to residential structures during high wind events occurs when structural and non-structural building elements cannot resist wind forces or when they are impacted by flying debris. To successfully resist the forces generated by high speed winds, the residential structure must be able to resist the loads by passing them first from the outer surface of the building (the roof coverings, wall coverings, windows, and doors) to the structural members of the building (the rafters, trusses, wood frame walls, masonry walls), and second to the building foundation. To “pass” these loads from the building exterior to the foundation requires a **continuous load path**. An example of a continuous load path in a 2-story wood frame house is shown in Figure R-1.

In Ladysmith, none of the residential structures that experienced tornado damage had a continuous load path. This was the case for the 1- and 2-story wood framed houses, as well as the 2-story masonry houses that were inspected. Height above ground and type of construction **were not key factors** in the damage observed. Rather, lack of a continuous load path (specifically, adequate connections between structural members) was the cause of most building failures.

A **continuous load path** is the series of building members and connections that resist loads that act downward (gravity loads), as well as laterally and upward (wind, flood, or seismic loads). The **connections** between the members are typically the point of failure (and thus most critical) in continuous load path found in residential structures.

The damage observed was typical to an F3 tornado, but other wind storms could cause similar damages, although to a lesser extent. Building damages resulted from wind forces acting laterally or upward from the building surfaces and from impact damage from windborne debris. Damaged building components included roof covering (shingles) and decking, roof framing, porches and decks, exterior wall coverings, windows, doors, and garages (both attached and detached). Two cases of foundation damage were observed, but neither case resulted in the failure of the foundation. Additionally, personal property damage to sheds, mechanical units, and landscaping was observed. Overall, damage was not caused by extreme pressure differentials often associated with tornadoes.

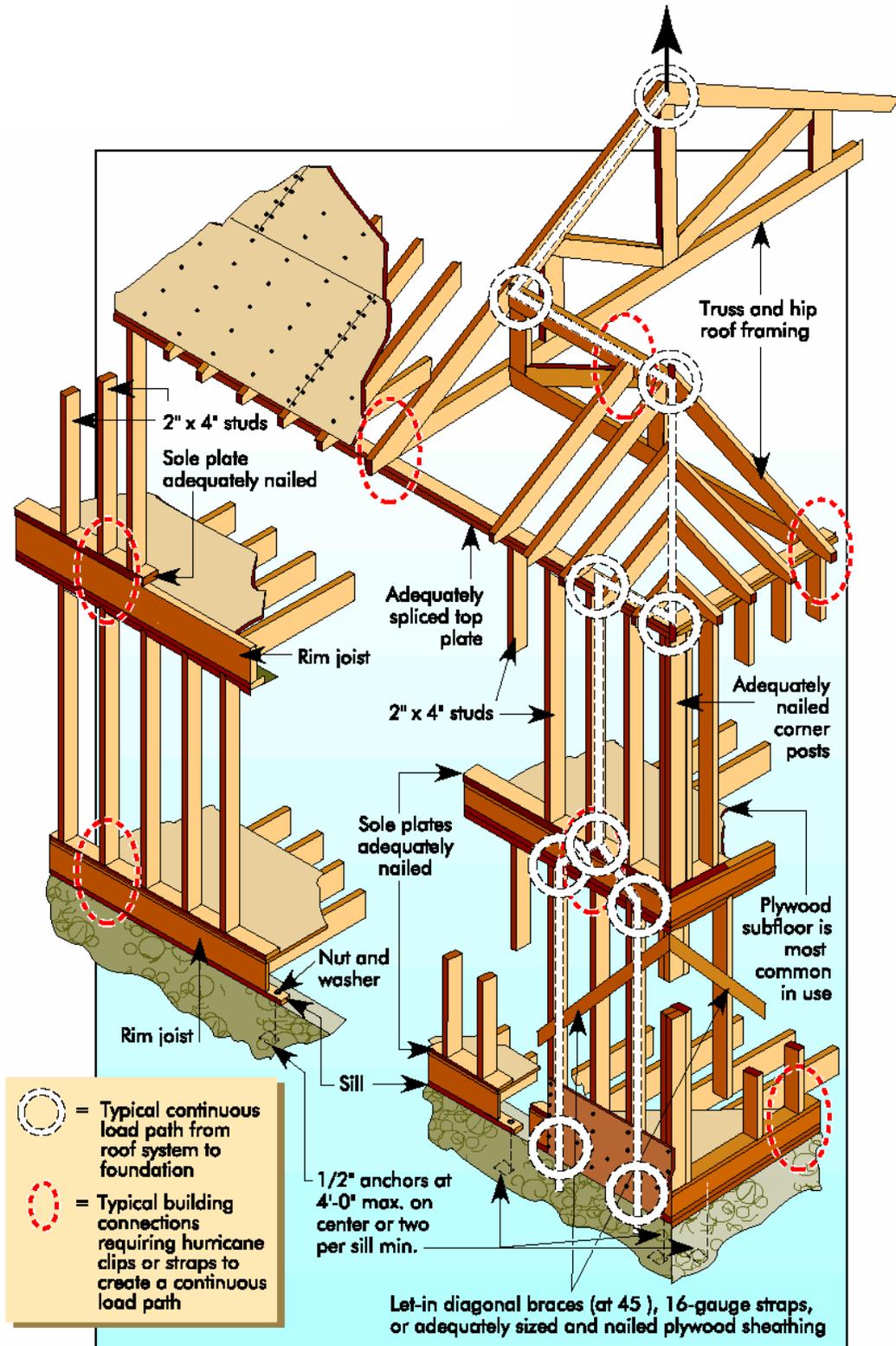


Figure R-1. Continuous load path in a typical 2-story wood frame residential structure. A continuous load path resists uplift and lateral loads that act on a building (From FEMA 342).

An inspection of the damaged residential structures in Ladysmith and Gilman revealed that some types of wind damage were more common than others. Each of these types will be discussed in the paragraphs that follow and illustrated with photographs taken after the September 2, 2002 tornado. The types of wind damage most commonly encountered – beginning at the roof and moving down to the foundation – are as follows:

- Roof Coverings
- Overhangs and Porch Roofs
- Gable End Roofs
- Roof Frame Connections to Walls
- Attached Garages, Detached Garages, and Storage Sheds
- Windows
- Exterior Wall Coverings
- Wall Frame Connections to Foundation
- Trees and Landscaping

**Roof Coverings**

Residential roof coverings consisted of one or more layers of asphalt roof shingles nailed to roof decking that was supported by rafters or trusses. Typically, the roof decking (sheathing) was either plywood, Oriented Strand Board (OSB) sheets, or 1-inch by 6-inch boards nailed to the rafters or trusses. Many homes and garages sustained wind and water damage due to a loss of all or part of their roof covering. Such damage generally began at the corners or edges of the roof – where localized wind forces are highest – and progressed toward the center of the roof. The forces actually “peeled” off one or more rows of the roof shingles (Figure R-2) and sometimes the roof sheathing beneath (Figures R-2 and R-3). However, roof covering damage can occur anywhere along the surface of the roof where one or more shingles are not adequately fastened to the sheets, or where the plywood or OSB sheets are not properly connected to the roof trusses.



**Figure R-2. Loss of roof shingles beginning at roof edge.  
 (507 Lake Avenue, Ladysmith)**



**Figure R-3. Loss of roof shingles and sheathing.  
 (unknown address, Gilman)**

**Overhangs and Porch Roofs**

Most residences in Ladysmith had roofs with small overhangs, and many residences had large overhangs and porches along one or more sides of the house. Small overhangs (those that extend less than 24 inches away from the building) generally resisted the wind forces with little or no damage. However, several of the larger overhangs (greater than 24 inches) and porch roof sections were damaged or destroyed during the tornado. High-speed winds exert extreme forces simultaneously on the top surface and underside of the roof or overhang. Most overhanging roofs are not properly designed and constructed to handle such pressures and can fail due to wind uplift. Such failures often occur when the roof overhang is unsupported, or when the porch columns are not adequately connected (with mechanical fasteners) to the porch roof beams and anchored to the deck (Figures R-4, R-5, and R-6).

Missing porch roof was lightly nailed to building. Missing columns were "toe-nailed" to the porch roof and deck and not connected with mechanical fasteners.



**Figure R-4. Failure of overhanging porch roof.**  
(923? Lake Avenue, Ladysmith)

Columns and roof members with mechanical fasteners remained in place. Damaged roof section (circled) was "toe-nailed" instead of clipped to porch beam.



**Figure R-5. Damage to overhanging porch roof.**  
(421 Lake Avenue, Ladysmith)

Most of this large overhang was removed by the wind. Circles indicate the remaining overhang.



**Figure R-6. Large overhang roof failure.**  
(307 Lake Avenue, Ladysmith)

**Gable End Roofs**

The two most common roof shapes encountered in residences in Ladysmith and Gilman were gable end roofs and hip roofs. Gable end roofs are two-sided roof structures with two sloped roof surfaces and a vertical wall section at each end. These roofs are typically supported by a series of roof trusses oriented in one direction (parallel to each other) or by a series of parallel rafters. Hip roofs are four-sided roof structures with four sloped roof surfaces and no vertical walls. These roofs are supported by roof trusses or rafters that span in two directions. Damage observations of residential roof damage in Ladysmith were consistent with residential roof damage from high-speed wind events in other parts of the country; that is, gable end roofs failed (lost roof coverings, sheathing, and lost roof framing) at a much higher rate than hip roofs. The observed stability of hip roofs is not surprising because they are braced in two directions in a way that is naturally more stable than gable end roofs (Figure R-7). Additionally, gable end roof failures typically occurred at the end walls where the trusses did not have enough lateral support to keep them from blowing inward, toppling the adjacent trusses in a “domino effect,” or being sucked outward from the building (Figure R-8).



**Figure R-7. Hip roof success, gable end roof failure**



**Figure R-8. Gable end wall was pulled off of building.**  
(Lake Avenue, Ladysmith)

### Roof Frame Connections to Walls

Roof frame to wall connections occur where the bottom corners of the roof trusses (and ceiling joists) are connected to the tops of the load-bearing wood or masonry walls. Many homes and garages in Ladysmith were damaged or destroyed due to inadequate connection of the roof framing to the exterior load-bearing walls (Figures R-9 and R-10). For most damaged homes and garages, the roof frame was connected to the walls by “toe nails,” which were driven in at an angle between the corner of the truss and the top of the wall. However, toe nailing alone is not sufficient to withstand uplift forces imposed on the roof during a high-speed wind event; mechanical fasteners are needed to anchor the roof trusses to the walls. These *mechanical fasteners are required by the 2001 Wisconsin Uniform Dwelling Code* when roof members span more than 6 feet.



**Figure R-9. Wood-frame house with missing wood roof due to poor connection at top of wall. (Multi-family house on Lake Avenue, Ladysmith)**



**Figure R-10. Masonry house with missing wood roof due to poor connections. (607 Lake Avenue, Ladysmith)**

### Attached Garages, Detached Garages, and Storage Sheds

Most homes in Ladysmith and Gilman included attached and detached one and two-car garages. Many of the doors to these garages were damaged or destroyed as a result of the tornado. Garage doors were typically damaged when wind pressures bent the door inward so that it popped out of its tracks, or when the tracks supporting the door failed. In many cases, the loss of the garage door led to an increase in wind pressure inside the garage that severely damaged or destroyed the entire garage and structures attached to it (Figures R-11, R-12, and R-13).



**Figure R-11. Garage door failure led to deformation of garage wall. (800 Menasha Avenue, Ladysmith)**



**Figure R-12 and R-13. Loss of garage door allowed wind inside garage. Roof trusses in garage moved from original position. Nails were used to secure clip to wall top plate, but no nails connected the clips to the trusses (607 Lake Avenue, Ladysmith).**

Metal and wood-framed storage sheds were also common structures in Ladysmith and Gilman. Unfortunately, a large percentage of these structures were destroyed as a result of the tornado (Figure R-14). Visual inspection of post-storm damages indicate storage sheds were typically destroyed due to inadequate connections between the bottom of the walls and the grade slab which allowed the shed to be blown off the foundation. In addition, most storage sheds were not designed to withstand the extreme winds or wind pressures inside and outside the structure.



**Figure R-14. Storage sheds and garages destroyed due to poor anchorage to foundations. (Residences along Lake Avenue, Ladysmith)**

### **Windows**

Many home and garage windows were damaged or destroyed throughout Ladysmith and Gilman as a result of the tornado (Figure R-15). Windows were typically damaged by high wind pressures and windborne debris that cracked or shattered glass panes. In some cases, the windows may have been destroyed due to failure of window frames that were weakened by large debris impact or roof failure.

Additionally, some windows failed at the connection between the window frames and the surrounding walls. Although loss of windows and doors results in wind and water intrusion into homes, protecting windows from damage cannot be achieved economically.



**Figure R-15. Windows damaged and covered with plastic (700 River Street, Ladysmith)**

**Exterior Wall Coverings**

Residential exterior wall coverings generally consisted of wood, vinyl or metal siding. Wall coverings are different and separate systems from the wall panels, which complete the structural framing of wood frame houses. Wall panels are located behind the exterior wall covering. The wall panels are often damaged when the exterior wall covering (siding) is damaged and the building interior is exposed to wind and rain of the event. Many homes and garages – regardless of height or building construction type – sustained wind and water damage due to a loss of all or part of their exterior wall coverings (Figures R-16 and R-17). Such damage generally began either where the siding was not adequately connected to the walls, or at a corner or edge of the wall – where wind pressures are highest – allowing wind suction pressures to “peel” off one or more siding panels. However, like windows and doors, protecting wall coverings from damage cannot be achieved economically.



**Figures R-16 and R-17. Loss of exterior wall covering under repair (721 and 923 Lake Avenue, Ladysmith)**

### Wall Frame Connections to Foundation

Wall frames are connected to the foundation at the bottom stud of the wall frame, which is connected to the sill plate and then to the foundation wall or concrete grade slab. A number of wood frame homes in Ladysmith were damaged, and many wood frame garages were destroyed, due to inadequate connection of the wall frame to the foundation (Figure R-18). In most damaged structures, the wall studs were connected to the wall frames by “toe nails,” which were driven through the bottom wall studs into the sill plate; the sill plate was bolted to the foundation wall or grade slab. However, toe nailing alone is not sufficient to withstand uplift and lateral (shear) forces imposed on the wall during a high-speed wind event; a stronger connection is required to anchor the walls to the foundation. In addition, the sill plate was not adequately bolted to the foundation in many of the garages inspected, which could also result in wall damage or failure.



**Figure R-18. Failed wall connection to sill plate at a detached garage. Toe nail marks from wall studs are circled. (415 Lake Avenue detached garage, Ladysmith)**

### Trees and Landscaping

Most residential lots in Ladysmith and Gilman had one or more trees or other landscaping surrounding the houses. Many of these trees were damaged, splintered, or completely uprooted as a result of the tornado (Figure R-19). In some instances, damaged or splintered trees and other landscaping became windborne debris which damaged the exterior of some homes. In other cases, large tree limbs or trunks fell onto homes, garages or storage sheds, causing roof damage or even partial collapse.



**Figure R-19: Uprooted trees in foreground, splintered tree in background (Corner of E10th Street and Miner Avenue, Ladysmith)**

## Specific Component Damage and Mitigation Opportunities

Mitigation measures to reduce or eliminate the types of wind damage most commonly encountered – beginning at the roof level and moving down to the foundation level – are as follows:

- Roof Coverings/Shingles
- Roof/Wall Framing and Connections (Houses and Garages)
- Gable End Wall Bracing
- Connections to Foundations (Houses and Garages)
- Porches and Overhangs
- Garage Doors
- Conclusions and Sheltering

Each mitigation measure listed above is discussed in the paragraphs that follow; details, estimated cost ranges, and sketches or photographs are included. It is important to note that these measures are intended to strengthen residential building to resist high winds associated with thunderstorms, downbursts, and the straight-line winds that are on the periphery of tornadoes. Contractors and building officials may agree to implement these mitigation measures without direct involvement of a structural engineer when published and accepted prescriptive plans or details are used. These mitigation measures, if implemented, will not make a building capable of withstanding a direct hit from tornado.

Further, it is of utmost importance that all mitigation measures be approved by the local building official. The building code currently in effect for residential construction within the state of Wisconsin is the **2001 Wisconsin Uniform Dwelling Code**. Your local building official can provide insight into applicable building codes and ordinances, and explain specific requirements that are in effect in Ladysmith or Gilman.

Notable requirements from the **2001 Wisconsin Uniform Dwelling Code** are:

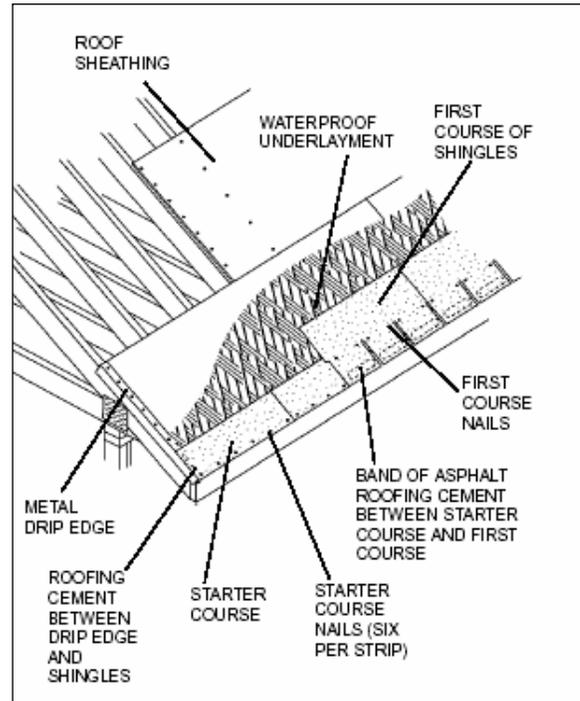
- Roof surfaces must be designed to resist wind uplift of a minimum of 20 pounds per square foot (psf).
- Clips, straps, or mechanical fasteners are required to connect roof framing members with load bearing walls (regardless of construction type) when the roof framing has a span of 6 feet or greater.
- Wall framing must be connected to the foundation or slab at with half-inch diameter anchor bolts spaced at 6 feet on-center (or less) and placed within 18 inches of each building corner.
- Garages have the same structural requirements as dwellings.
- A minimum of 2 exits are required from the first floor of the structure.

**Roof Coverings/Shingles**

Many roof failures begin with the failure of the roof covering, specifically the shingles along the edges and ridges of the roof (Figure R-19). To minimize damage initiated at the roof covering, the shingles along the edges of the roof covering should be secured. As residential roof coverings can be strengthened in a variety of ways during roof repair or replacement, effective solutions other than the proposed retrofit (Figure R-20) may be available from your local roof designer or roofing contractor.



**Figure R-19. Typical roof covering damage along roof edge. (507 Lake Avenue, Ladysmith)**



**Figure R-20. Details for strengthening roof coverings (FEMA How-To Series, [www.fema.gov](http://www.fema.gov))**

- First, if you are replacing an old roof, your contractor should remove the existing shingles and underlayment rather than install new shingles over the existing roof materials. This approach allows the contractor to inspect the sheathing and plan necessary repairs or upgrades.
- A waterproof underlayment should be installed beneath the shingles. When well-attached, the underlayment temporarily protects the building from rain if shingles are torn away by wind.
- Each shingle should be held by at least six nails or screws (rather than staples) which should be installed below the edge of the upper, overlapping row of shingles.
- The first course of shingles should be sealed to the starter strip with dabs or bands of roof cement.
- Your roofing designer/contractor should obtain manufacturer information about bond strength and nail pull-through resistance, and then use products with values in the upper ranges of available strengths.

A roofing contractor may typically charge **\$4.00 to \$6.00 per square foot** of roof area to remove and replace shingles and underlayment.

**Roof Sheathing**

The roof sheathing is the first structural layer of the building that uplift forces act upon and it is the material to which the roof covering is attached. It provides support not only to the roof covering, but provides lateral support to the roof trusses and rafters (Figures R-21 and R-22). To resist wind forces and windborne debris, the following mitigation is recommended:



Screws, nails, and staples are inexpensive construction materials. Contractor costs for installation, however, will vary based on the time and effort necessary to expose the existing connections and perform the necessary work.

**Figure R-21. Typical roof sheathing damage from uplift forces (From FEMA 342).**

- The roof sheathing (typically plywood, OSB panels, or 1-in by 6-in boards) should be at least one-half-inch thick and securely attached to the roof trusses. Your roof designer or roofing contractor should confirm the roof sheathing meets current nail spacing requirements.
- All screws, nails, or staples used to attach the roof sheathing must penetrate the underlying roof trusses for secure attachment.

Nail Size	Allowable Withdrawal per Nail (lb)	Nail Spacing For 2-ft Roof Framing Member spacing	
		Calculated Spacing	Specified Spacing
8d (common) 2-1/2" x 0.131" dia.	44 x 1.6 = 70.4	4.8" o.c.	4" o.c.
10d (common) 3" x 0.148" dia.	62.5 x 1.6 = 100	6.9" o.c.	6" o.c.
8d (box) 2-1/2" x 0.113" dia.	38 x 1.6 = 60.8	4.2" o.c.	4" o.c.
10d (box) 3" x 0.128" dia.	42 x 1.6 = 67.2	4.6" o.c.	4" o.c.
8d (nail gun) 2" x 0.133"	33.6 x 1.6 = 54	3.7" o.c.	3" o.c.

**Notes:**

1. Withdrawal values are derived from Table 12.2A, 1997 NDS, and are for withdrawal from hem-fir roof framing, Specific Gravity = 0.43.
2. Load duration factor is 1.6 per 1997 NDS.

**Figure R-22. Nailing schedules to resist wind uplift forces for a roof sloped of 30° or less (From FEMA 55).**

### Roof/Wall Framing and Connections (Houses and Garages)

Many homes and garages in Ladysmith were damaged or destroyed due to inadequate connection of the roof frame to the walls. Connections between the roof frame and the walls can be upgraded using mechanical fasteners to anchor the roof trusses to the walls (Figure R-23). Figures R-24, R-25, and R-27 represent the retrofit details, or construction guidance can be obtained from the Hazard Mitigation Fact Sheets on *Building to Resist Strong Winds* (FEMA Region V and Wisconsin Emergency Management). Consider the following points when upgrading connections with mechanical fasteners:

- First, verify the type and condition of the existing roof-to-wall connections. Remember that toe nailing alone is **not** sufficient to withstand uplift forces during a high wind event and may **not** meet the current Wisconsin Uniform Dwelling Code (depending upon span of member).
- Mechanical fasteners are required by the current Wisconsin Uniform Dwelling Code when members span more than 6 feet. Consult the code and contact your local building official for details.
- Mechanical fasteners should extend to a point at or below the top of wall stud.
- Mechanical fasteners should be installed by a licensed, qualified contractor.
- The correct type and number of nails or screws must be used to provide effective anchorage of the fasteners to the roof truss, top plate, and top of wall stud.
- If wall sheathing needs to be repaired or replaced, the uplift strength of the roof frame to wall connection can be increased by extending the wall sheathing (typically plywood or OSB sheets) to the top plate and nailing the sheathing to the top plate and wall studs.
- Attached and detached garages should be retrofitted and repaired in the same manner as the residence itself per the Wisconsin Uniform Dwelling Code.



Figure R-23. Properly clipped roof truss at top of wood frame wall (FEMA 55CD, Third Edition *Coastal Construction Manual*).

Mechanical fasteners and nails are inexpensive construction materials. Contractor costs for installation, however, will vary based on the time and effort necessary to expose the existing connections and perform the necessary work. Additionally, nails used in the installation of clips and fasteners are specified by the manufacturers and cannot be installed with power (pneumatic) hammers.

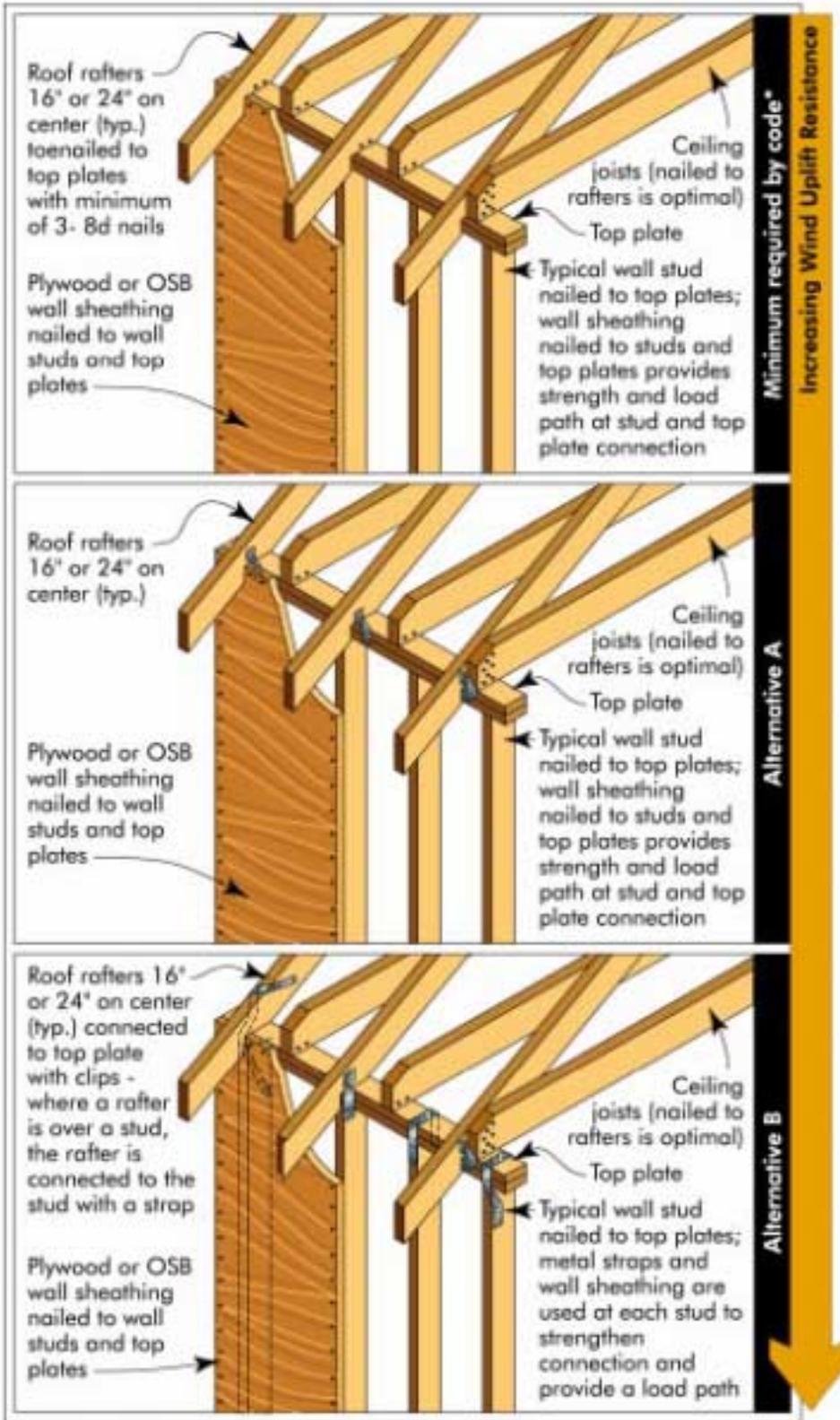
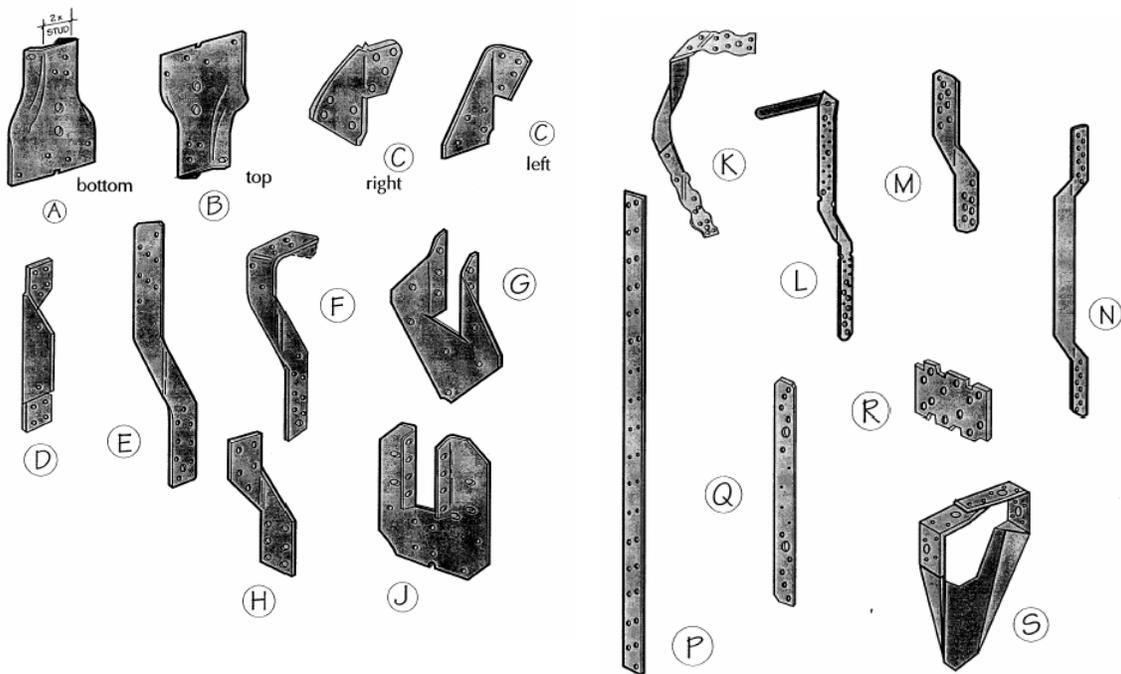
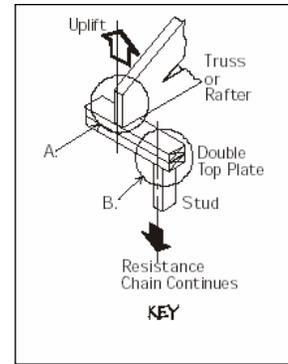
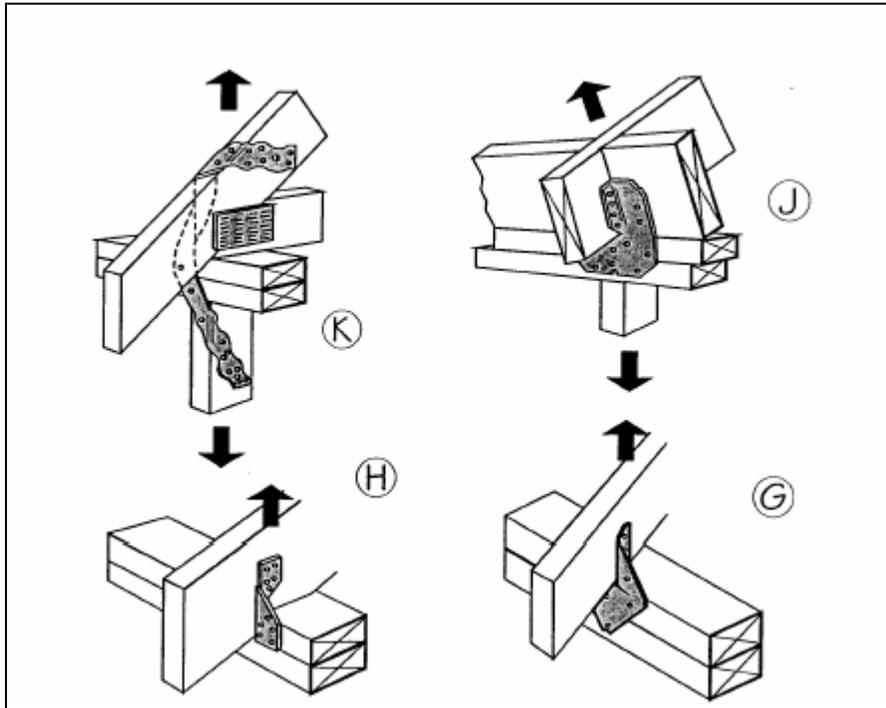


Figure R-24. Details for attached roof rafters to wood frame wall systems. The minimum allowed (top option) may only be used when roof spans are less than 6 feet. When spans are longer, Alternatives A and B are recommended (FEMA 342).



Figures R-25a, 25b, and 25c. Improved roof frame to wall connection details shown as the the clips as attached to framing, the forces the clips are designed to resist, and the clips alone.  
(Illinois EMA, Windstorm Mitigation Manual for Light Frame Construction, August 1997)



### Connections to Foundations (Houses and Garages)

Some homes and many garages in Ladysmith were damaged or destroyed due to inadequate connection of the wall framing to the foundation. However, connections between the wall framing and the foundation can be upgraded using mechanical fasteners to connect to the foundation (Figure R-27). Figure R-27 represents retrofit details to not only connect the sill plates to the foundation, but to ensure that the wall framing is securely attached to the sill plate. Additional detailed guidance is provided in the Hazard Mitigation Fact Sheets on *Building to Resist Strong Winds* (FEMA Region V and the Wisconsin Emergency Management). Consider the following points when upgrading connections with mechanical fasteners:

- First, verify the type and condition of the existing roof-to-wall connections. Remember that toe nailing alone is **not** sufficient to withstand uplift forces during a high wind event and may **not** meet the current Wisconsin Uniform Dwelling Code (depending upon span of member).
- Mechanical fasteners are required by the current Wisconsin Uniform Dwelling Code to secure wall framing to the foundation. These connectors, at a minimum are to be within 18” of each building corner and at a maximum of 6’-0” on center along the run of the wall.
- Mechanical fasteners should be bolts or straps and should be connected to solid, non-splintered wood.
- Mechanical fasteners should be installed by a licensed, qualified contractor.
- The correct type and number of nails or screws must be used to provide effective anchorage of the fasteners to the roof truss, top plate, and top of wall stud.
- If wall sheathing needs to be repaired or replaced, the uplift strength of the wall frame to sill plate connection can be increased by extending the wall sheathing (typically plywood or OSB sheets) to the sill plate and nailing the sheathing to both the wall studs and the sill plate.
- Attached and detached garages should be retrofitted and repaired in the same manner as the residence itself per the Wisconsin Uniform Dwelling Code.

Mechanical fasteners and nails are inexpensive construction materials. Contractor costs for installation, however, will vary based on the time and effort necessary to expose the existing connections and perform the necessary work. Additionally, nails used in the installation of clips and fasteners are specified by the manufacturers and cannot be installed with power (pneumatic) hammers.

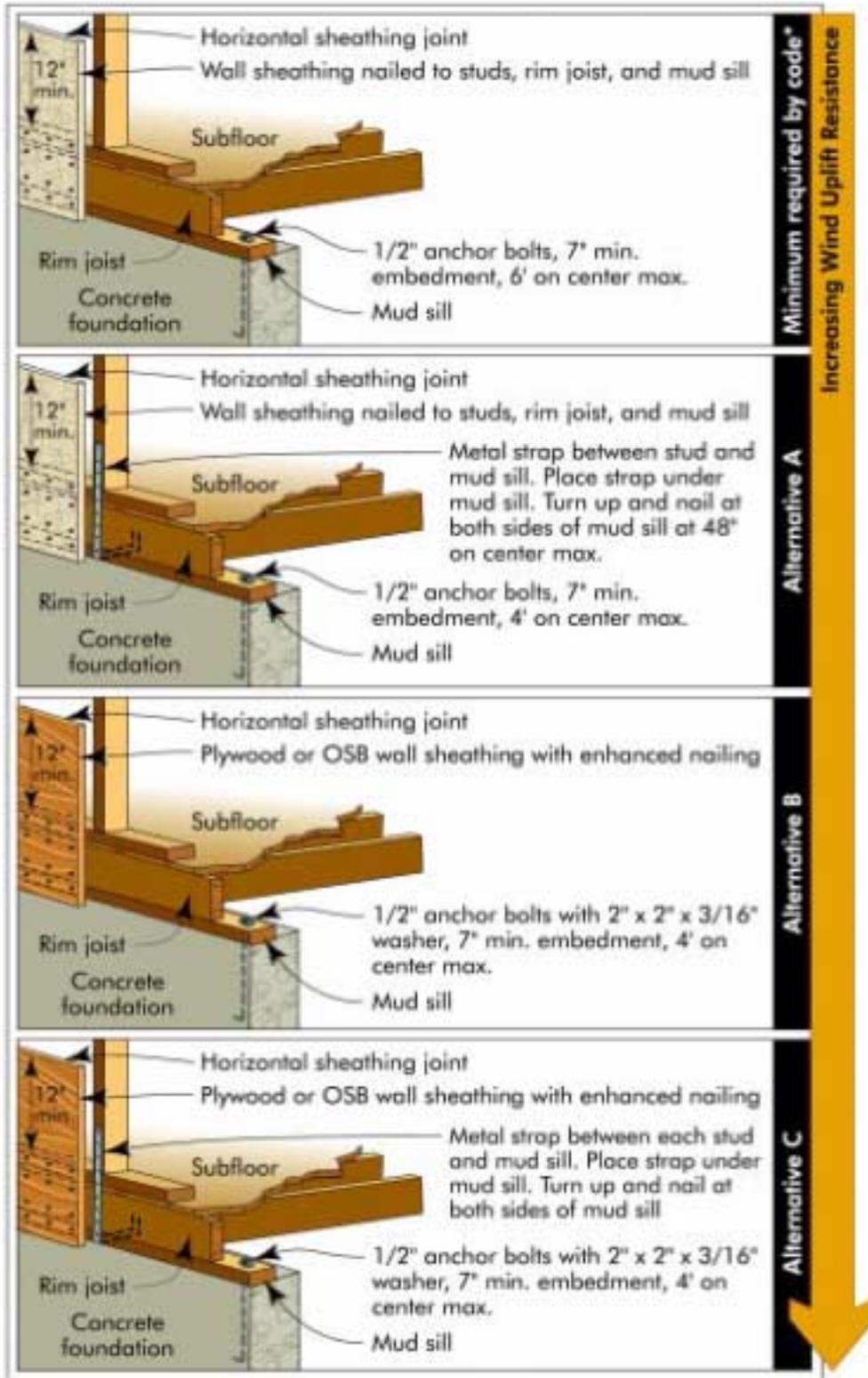
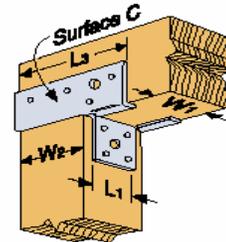


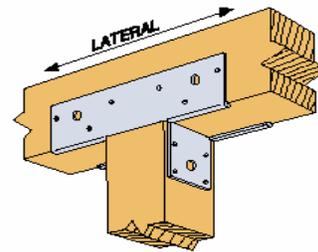
Figure R-27. Details for attached wall framing and sill plates to the house foundation. The minimum connections required by code is the top option, alternatives providing additional strength increase from Alternatives A to C (FEMA 342).

**Porches and Overhangs**

Several residences in Ladysmith had overhanging and porch roof sections that were damaged or destroyed by wind uplift forces during the tornado. This type of damage can be mitigated by anchoring overhanging and porch roofs to the house using mechanical fasteners to connect the roof truss to the columns, and the columns to the floor deck or foundation. Refer to Figure R-29 for connection diagram details.



Typical EPC  
End Post Cap  
Installation



Typical PC  
Post Cap Installation

**Figures R-28 and R-29. Figure R-28 illustrated missing porch post. Porches may be secured using mechanical fasteners at roof-to-beam, beam-to-post, and post-to-foundation connections. Figure R-29 presents two examples of post connectors from the 2002 Simpson Strong Tie Catalog (Use of a mechanical fastener from any manufacturer is acceptable).**

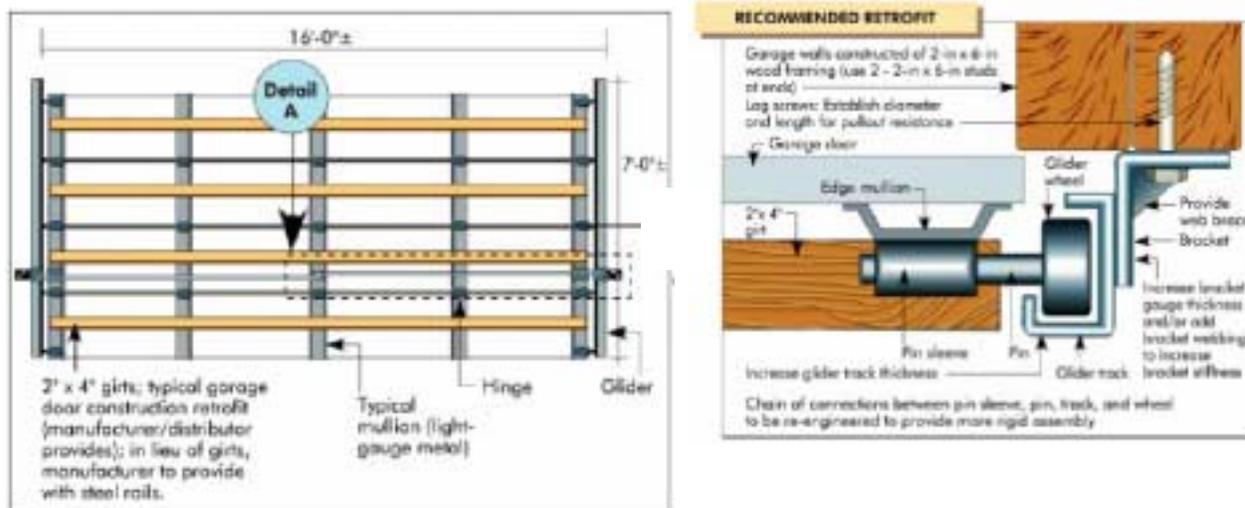
Consider the following points when anchoring overhanging and porch roofs:

- Avoid unsupported roof overhangs greater than 2 feet wide. Such overhangs are subject to high wind pressures and are often a starting point for total roof failure.
- When replacing porch roofs, a design professional should verify that the roof is attached securely to the house such that expected forces are resisted without placing an unexpected additional load on the house.
- Wherever possible, use posts and columns to minimize the unsupported length (span) of the overhang or porch roof. Use mechanical fasteners to connect the roof members to the columns/posts and the columns/posts to foundation elements.
- Fasteners can be added fairly easily, but you should have a licensed contractor perform the work to ensure that the fasteners are properly attached.

Mechanical fasteners and nails are inexpensive construction materials. Contractor costs for installation, however, will vary based on the time and effort necessary to expose the existing connections and perform the necessary work. Additionally, nails used in the installation of clips and fasteners are specified by the manufacturers and cannot be installed with power (pneumatic) hammers.

## Garage Doors

Garage doors and their tracks can be reinforced to mitigate future damage (Figures R-32 and R-33). Such reinforcements not only protect the garage door and garage contents, but can prevent severe structural damage to the garage structure (in the case of a detached garage) or to the house (in the case of an attached garage).



Figures R-32 and R-33 showing placement of wood 2"x4" wood girts to reinforce garage door (left) and recommended retrofit for door track assembly (right) (From FEMA 342).

Consider the following points if your garage door needs to be reinforced or replaced:

- The garage door industry strongly recommends that a decision to reinforce a garage door be based on an inspection by a trained door systems technician or a qualified professional engineer. These professionals will be able to tell you if the proposed reinforcement is the correct type and size and if the garage door itself is worth retrofitting.
- A local garage door professional should be able to assess the wind load requirement of the garage door, which is based on size, local design wind speed, and location on the structure, among other factors. The Door & Access Systems Manufacturers Association International (DASMA) also offers assistance in this area.
- If the existing garage door is old or damaged, replacement with a stronger door system is often recommended.
- Garage door reinforcement should be completed by a trained door systems technician. A technician is familiar with the workings of a garage door, especially automated and mechanically controlled doors. The technician will ensure that items such as stored energy in the door counterbalance system and the potential impact to the counterbalance system's effectiveness when weight is added to an existing door do not adversely affect the system.
- Windows in a garage door can be broken by windborne debris and should be avoided.

If you hire a contractor to reinforce an existing two-car garage door, you can **expect to pay about \$600**. However, this cost can vary depending on the size and type of door.

## Conclusions and Sheltering

In conclusion, there are a variety of wind mitigation measures and methods available to protect residential construction in Ladysmith and Gilman against future wind events. Residential structural damage associated with thunderstorms, microbursts (downslope winds) and the straight-line winds that accompany tornadoes would be reduced by implementing appropriate mitigation measures.

There are few, if any, cost effective mitigation measures to protect entire homes from extraordinary events such as a direct hit by the vortex of a severe tornado of F3 level or greater. In such instances, the best mitigation is to either flee the tornado if warning time allows, or to take refuge in an in-residence shelter that has been constructed within (or adjacent) the house (Figure R-36). An in-residence shelter is a structure designed to withstand winds up to 250 miles per hour and impact forces associated with flying debris (only specific wall types may be used). For additional information, please refer to the FEMA's website at [www.fema.gov](http://www.fema.gov).

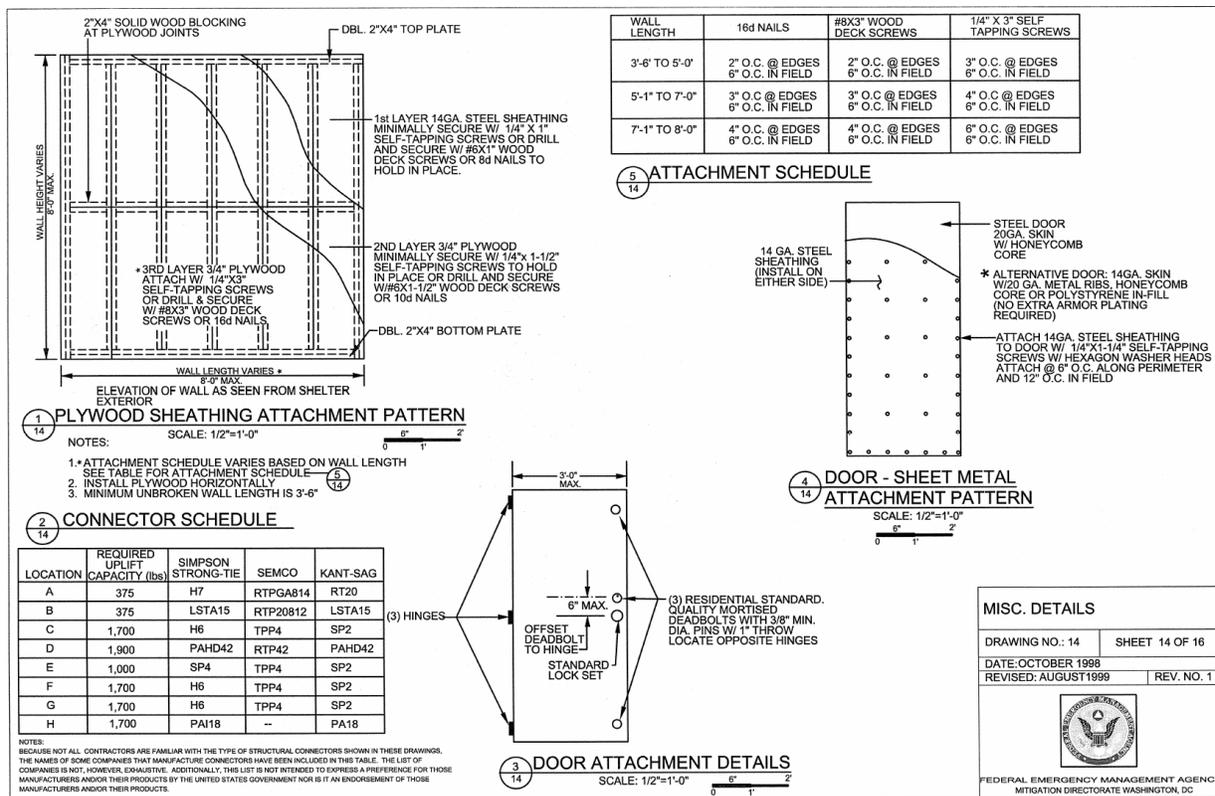
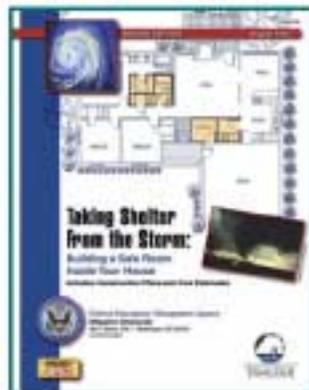


Figure R-36. Sheeting attachment detail sheet from FEMA 320.



In-residence shelters can typically be installed in an existing home for **\$3,000 to \$6,000**, depending on the size and location of the shelter. Detailed design plans for in-residence shelters are available from FEMA Publication 320, *Taking Shelter from the Storm*.

## Commercial and Public Buildings: Damage and Mitigation

Almost the entire business district in Ladysmith was damaged by the wind forces and windborne debris associated with the F3 tornado that occurred on September 2, 2002. Typical commercial construction damaged by the event consisted of one, two, and three-story buildings. Construction types included wood frame, unreinforced brick masonry, unreinforced concrete masonry units (CMU), steel frames, and steel frames with masonry infill. Similar to the residential construction, the damage caused by the tornado could have been minimized if known construction techniques common to hurricane and tornado prone areas had been in place. This Section discusses observed commercial structure damage and appropriate mitigation strategies that can be integrated into reconstruction.

### General Commercial Damage Statements and Mitigation Opportunities

Damage to commercial and public structures during high wind events occurs when structural and non-structural building elements can not resist wind forces or when they are impacted by flying debris. To successfully resist the forces of high speed winds, the structure must be able to resist the loads by first passing them from the outer surface of the building (the roof coverings, wall coverings, windows, and doors) to the structural members of the building (the rafters, trusses, wood frame walls, masonry walls, etc.), and second to the building foundation. To “pass” these loads from the building exterior to the foundation requires a **continuous load path**. An example of a continuous load path in a one-story CMU building is shown in Figure C-1.

In Ladysmith and Gilman, most of the commercial and public structures that experienced damage from this tornado did not have a continuous load path, however, some buildings with a continuous load path experienced notable damage (this will be discussed later in this Section). Damage was evident on all levels of one, two, and three-story buildings, but most damage was located on the second and third floor of multi-story buildings. Lower floors did not sustain as much structural damage because the weight of structure assisted in resisting the wind forces acting on the building. Wood and unreinforced brick and CMU masonry structures were the most heavily damaged construction types. Unlike the residential structures, height above ground and type of construction **were key factors** in the damage observed. In most cases, the lack of a continuous load path at a specific location was the cause of most building failures.

A **continuous load path** is the series of building members and connections that resist loads that act downward (gravity loads), as well as laterally and upward (wind, flood, or seismic loads). The **connections** between the members are typically the point of failure (and thus most critical) in continuous load path found in commercial structures.

The damage observed was typical of an F3 tornado, but other wind storms could cause similar damages, although to a lesser extent. Building damages resulted from wind forces acting laterally or upward from the building surfaces and from impact damage from windborne debris. Damage was not caused by extreme pressure differentials often associated with tornadoes. Buildings with steel frame construction, such as the County Courthouse, experienced isolated roof failures and exterior window and wall damage; wide-spread structural failures did not occur. These observations demonstrate the stability of this type of construction; however, it should not be assumed that repairs to steel frame structures would be minimal. The complex nature of large buildings, the buildings codes in effect, and the physical constraints encountered during a restoration project (minimizing the effect to on-going building operations and services) can lead to expensive repair projects, regardless of the type of construction.

Damage to commercial and public building components included roof covering (primarily gravel ballasted roof systems), metal and wood roof decking (sheathing), roof framing, parapets, exterior walls,

awnings, exterior wall coverings, windows, and doors. In addition, damage to roof-mounted mechanical units was observed.

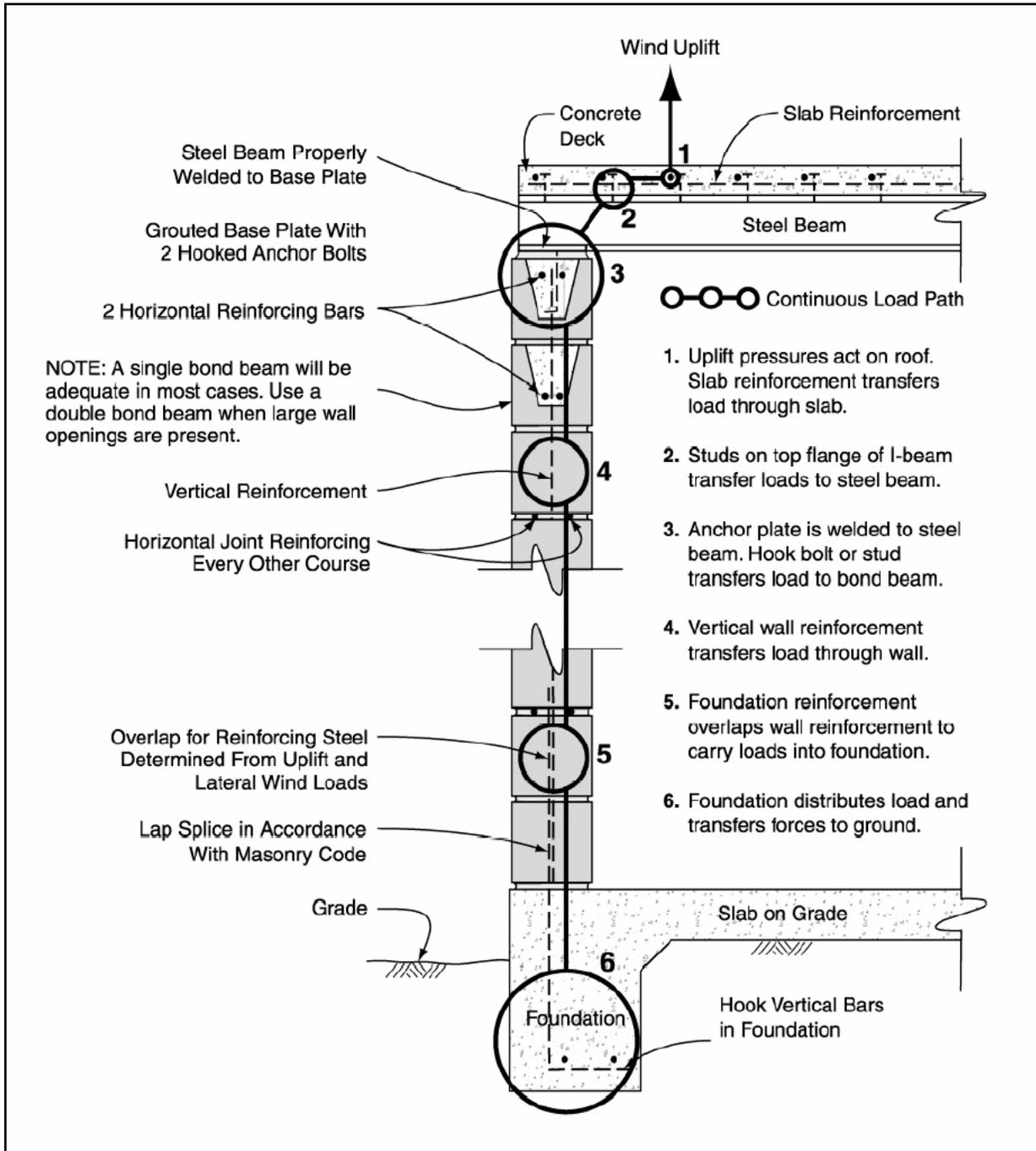


Figure C-1. Example of a continuous load path in a masonry wall accomplished with reinforcing steel and proper connections. The solid line depicts the continuous load path and the circles identify critical connections.

An inspection of the damaged commercial and public structures in Ladysmith and Gilman revealed that some types of wind damage were more common than others. Each type of wind damage will be discussed in the paragraphs that follow and illustrated with photographs taken after the September 2, 2002 tornado. The types of wind damage most commonly encountered – first by building type and then beginning at the roof and moving down to the foundation (for all building types) – are as follows:

- Wood Structures
- Concrete Masonry Unit (CMU) Structures
- Brick Masonry Structures
- Roof Coverings and Roof Decking
- Parapets
- Windows and Doors
- Exterior Wall Coverings
- Awnings and Overhangs
- Roof Mounted Mechanical Units

### Wood Structures

Some wood frame buildings were utilized for light commercial activities. Most damage was isolated to roof covering, roof framing, and upper story wall section damage. For most damaged structures, the roof frame was connected to the walls by “toe nails,” which were driven in at an angle between the corner of the truss and the top of the wall. Additionally, only “toe nails” secured wall framing on upper stories to the floor framing below, and no connection across the floor framing from the upper story to the lower story existed. Toe nailing alone is not sufficient to withstand uplift forces imposed on the roof



during a high wind event, and mechanical fasteners are needed to anchor the roof trusses to the walls. Most wood frame structures were constructed prior to the adoption of the 2000 International Building Code (IBC) which requires wind loads to be considered. As a result, most commercial buildings of this construction type were damaged because of a lack of a continuous load path. Even though some structures were intact after the 2002 event, those buildings remain vulnerable to wind event damage if mitigation measures are not implemented.

**Figure C-2. Damage to 2<sup>nd</sup> story of wood frame commercial building (Minor and 5<sup>th</sup> Avenue).**

### Concrete Masonry Unit (CMU) Structures

Many commercial structures in Ladysmith were constructed of CMU block. The structures may be constructed without reinforcing steel, or with reinforcing steel within the walls. Most buildings constructed with CMU exterior walls prior to the 1980s are not likely to have reinforcing in the walls. Similarly, many buildings constructed after the 1980s may have only horizontal joint reinforcing, with

no vertical reinforcing placed within the cells of the CMU. As a result, a continuous load path does not exist in these buildings and they are vulnerable to damage from strong winds capable of exerting lateral and uplift forces on the buildings. Typical failures (Figure C-3, C-4, and C-5) are due to wind forces that push the wall into the building, pull the CMU wall out of the building, or pull the wall apart along the mortar joints.



**Figure C-3. Second story masonry wall failure. Wall failed from lateral wind pressure probably after roof was separated from structure.**

If the weight of the building and roof system is not adequate to resist the wind forces, the CMU block walls fail along their joints and fall apart. This leads to the progressive collapse of roofs, adjacent walls, and other building elements. Additionally, the connections between the roof system and the supporting walls are often incapable of resisting uplift forces.



**Figure C-4. Second story masonry wall damage. Uplift on roof caused step cracking in wall.**



**Figure C-5. First floor masonry wall failure. Wall failed from lateral wind pressure probably garage door failed.**

### **Brick Masonry Structures**

Brick masonry structures are typically constructed without reinforcing steel in the walls and have unreinforced brick masonry walls along the perimeter of the building. Roof and floor systems either span from exterior wall to exterior wall, or are supported by interior load bearing wood frame walls.

Much like the CMU block structures that failed, a number of brick masonry structures sustained upper floor damage, while some experienced complete wall failures. Again, these failures indicate a lack of a continuous load path from the roof to the foundation to resist lateral and uplift forces. Typical failures (Figures C-6 and C-7) are due to wind forces that push the wall into the building, pull the CMU wall out of the building, or pull the wall apart along the mortar joints. Since there is no means to resist the uplift

loads on a roof of a brick masonry structure, roof failures are common. If a roof failure occurs, the wall is more likely to fail or collapse because it is not supported at the top and has a reduced ability to resist lateral wind forces.

If the weight of the building and roof system is not adequate to resist the wind forces, the brick masonry walls fail along their joints and fall apart. This leads to the progressive collapse of roofs, adjacent walls, and other building elements.



**Figure C-6. Completed failure of 1<sup>st</sup> and 2<sup>nd</sup> story unreinforced brick masonry walls.**



**Figure C-7. Failure of 2<sup>nd</sup> story brick masonry walls from lateral wind forces.**

### **Roof Coverings and Roof Decking**

Roof coverings damage varied depending on the type of roof system. Flat roofs were observed to be covered with ballasted (gravel) roof systems using either rubber roofing or built-up coverings, with fully-adhered roof systems, or membranes secured with mechanical fasteners. Gravel ballasted roof systems are problematic in high wind areas as the damaged roof systems and adjacent windows throughout Ladysmith and Gilman demonstrate. Observed damages indicate that winds displaced the roof ballast and exposed the roof coverings to wind and windborne debris (Figure C-8). Further, the ballast itself became windborne debris and damaged other building components such as roof top equipment, windows, doors, and exterior walls systems.



**Figure C-8. Roof ballast is missing along roof edges.**

Flashing and trim damage was observed after the event. This damage often appears trivial and repairs to these elements are not always prioritized. It is important to note, however, that the failure of edge trim and flashing is often the first event in a chain reaction that leads to the failure of an entire roof system during high wind events.



**Figure C-9. Uneven roof decking and roof insulation and displaced roof vents above classrooms.**

Roof decking and sheathing were both damaged by the high-speed wind event, however, wood roof sheathing sustained the most damage due primarily to the failure in the structural systems to which they were attached. Additional roof failures may have resulted from loss of wood sheathing that provided lateral stability to structural roof members (Figure C-10). Metal roof decks performed better than the wood decks with few exceptions. At the County Courthouse in Ladysmith, the roof decking was damaged after high winds temporarily lifted the roof structure (beams and decking) slightly off their supporting walls. Similarly, the gymnasium roof deck (constructed of acoustical tectum roof decking) at the Gilman School was almost completely removed from the supporting steel trusses when the tornado passed directly over the school (Figure C-11).



**Figure C-10. Gable end wood roof with decking failure. Loss of decking may have lead to instability and failure of end trusses.**



**Figure C-11. Tectum roof deck loss at the Gilman School (Courtesy of the Gilman School).**

**Parapets**

Parapet damage was observed in the CMU and brick masonry buildings. Unreinforced masonry parapets cannot resist the lateral wind forces from high winds. As a result, many parapets failed and topple either onto to roof adjoining roof or away from the building. These failures led to additional damage of roof coverings, roof decks, and to exterior masonry walls (Figures C-12 and C-13).



**Figures C-12 and C13. Masonry parapet failure over and entranceway (left) and masonry parapet failure that led to partial collapse of exterior wall (1<sup>st</sup> street and 111 Minor Ave, Ladysmith).**

**Windows and Doors**

Many windows in commercial buildings were damaged or destroyed as a result of the tornado. Store-front style windows are vulnerable to damage from wind pressures due to their large surface areas; however, both large and small windows are susceptible to damage from windborne debris. Windows were typically damaged by high wind forces and windborne debris that cracked or shattered glass panes. In some cases, the windows were destroyed due to failure of window frames that were weakened by large debris impact or roof failure. Additionally, some windows failed at the connection between the window frames and the surrounding walls. Although loss of windows and doors results in wind and water intrusion into buildings, protecting windows from damage cannot be achieved economically.

It should be noted that there was increased window damage adjacent to buildings with ballasted roof systems. Damage to the exterior window panel or storm window, but not to a second panel located behind the first, indicates that much of this window damage was caused by small debris – most likely from the roof ballast.



**Figures C-14. Typical window damage to commercial buildings.**



**Figure C-15. Exterior window pane is broken, but interior window paint is intact.**

### Exterior Wall Coverings

Exterior wall coverings on commercial buildings were damaged from the tornado, most likely from windborne debris impacts. Stone and brick masonry exteriors (when used as a wall covering and not as a load bearing wall) survived the event with minimal wall damage. Siding systems (vinyl, plastic, or wood) were damaged by both wind and windborne debris. Synthetic stucco systems (also referred to as EIFS – Exterior Insulated Finishing Systems) experienced impact damage from the windborne debris (Figures C-16 and C-17).

It should be noted that exterior wall coverings are architectural finishes to a building. These systems may be designed to resist removal from high wind, however, they are not typically resistant to debris impact. Interior building strength, as it pertains to resisting debris impact, is afforded by the structural wall behind the wall covering. Thus, the ability of structures to resist damage is more a function of the structural wall component than of the wall covering. Although the loss of exterior wall coverings may result in wind and water intrusion into buildings, protecting wall coverings from damage cannot be achieved economically.



**Figure C-16. Siding damage from wind suction forces.**



**Figure C-17. Windborne debris impacted into EIFS wall system.**

### Awnings and Overhangs

Cantilevered metal and wood roof awnings and overhangs were damaged throughout the business district. Cantilevered awnings and overhangs are supported only at their connection to the building and are not supported on posts or columns. Wind forces caused the failure of these awnings and overhangs, most of which are older and were likely not designed to resist wind loading. The large surface areas of these building components received significant wind loads and as a result, connections between the elements and the building were overloaded and failed as a result (see Figure C-18). Awnings and overhangs constructed of wood framing or metal tube framing performed the best; however, there were isolated locations where large, wood framed overhangs failed and detached from the buildings.



**Figure C-18. Damaged store awning. The cantilevered awning failed from wind uplift forces.**

### **Roof Mounted Mechanical Units**

Roof top equipment units were either damaged in place by windborne debris or were dislodged from their anchorages (if any) by wind forces. Although it is not considered practical to protect these units from damage associated with windborne debris, it is practical to design and anchor the units to resist wind forces.

Damaged roof top mechanical units are a hazard during high wind events for several reasons. First, when mechanical units are displaced, an opening on the roof is created, which exposes the building interior to wind forces, windborne debris, and rain. Second, displaced units can damage the roof covering and/or the roof deck. Finally, if units are completely removed from their roof location, they may fall and injure individuals adjacent the building (see Figure C-19). For these reasons, roof units should be designed to resist displacement from the code specified design wind (at a minimum). Mechanical units in Ladysmith were observed to have been displaced from their original position in the downtown area.



**Figure C-19. Roof top unit removed from roof by wind forces. Electrical conduit is all that has kept this unit from falling completely off the roof.**

## Specific Damage and Mitigation Opportunities

Mitigation measures to reduce or eliminate the types of wind damage most commonly encountered – beginning at the roof level and moving down to the foundation level – are as follows:

- Wood Frame Structures
- Concrete Masonry Unit (CMU) Structures
- Brick Masonry Structures
- Roof Coverings and Roof Decking
- Parapets
- Awnings and Overhangs
- Roof Mounted Equipment
- Conclusions and Sheltering

Each mitigation measure listed above is discussed in the paragraphs that follow. It is important to note that these measures are intended to strengthen commercial and public buildings to resist high winds associated with thunderstorms, downbursts, and the straight-line winds that are on the periphery of tornadoes. The measures are presented as guidelines for mitigation or as examples of successful mitigation. Commercial design and construction requires the involvement of a design professional, such as an architect and/or a structural engineer, and thus these mitigation strategies are intended to guide the design professional and they are not intended to dictate or imply that there is only one acceptable solution. These mitigation measures, if implemented, **will** help a building resist high winds, but additional mitigation is required if the building is meant to function as a high wind shelter capable of preventing loss of life. References for guidance on the design and construction of high wind shelters are provided in Appendix B.

Furthermore, it is of utmost importance that all mitigation measures be approved by the local building official. The building code currently in effect for commercial construction within the state of Wisconsin is the **2000 International Building Code (IBC) with State of Wisconsin Amendments** – adopted in the Summer of 2002. However, insurance policy requirements and state building code requirements indicated that the damaged building components only need to be replaced to the pre-damage condition as specified by the building code in effect at the time of original construction. Should there be an opportunity to improve the structure, the **2000 IBC with State of Wisconsin Amendments** is to be used to regulate the redesign and reconstruction if it is structurally different or an improvement to the existing structure. Your local building official can provide insight into applicable building codes and ordinances.

Notable requirements from the **2000 (IBC) with State of Wisconsin Amendments** are:

- The building structure must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The windows and doors must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The parapets, awnings, and exterior wall coverings must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The roof top equipment must be designed to resist wind loads from a 90-mph wind (3-second gust).
- Wind loads are factored during design by a factor of safety as high as 1.6 x (calculated wind load).

### Wood Frame Structures

As stated previously, most of the damage to wood frame commercial buildings in Ladysmith was due to inadequate connection of the roof frame to the walls and from upper to lower story walls across the floor system (Figure C-21). These connections can be upgraded using mechanical fasteners to anchor the roof trusses or rafters to the walls from wall to wall across a floor system. The retrofits discussed for residential wood structures are applicable for commercial wood structures, but the engineer of record should review the retrofit relative to the commercial building and for the desired wind speed. Examples of proper wood frame connections are illustrated in Figures C-20, C-22, and C-23. Keep the following points in mind when upgrading connections with mechanical fasteners:

- Verify the type and condition of the existing roof-to-wall and wall-to-wall connections. Remember that toe nailing alone is **not** sufficient to withstand uplift forces during a high wind event and **may not** meet the current wind load requirements set forth in the 2000 International Building Code (IBC).
- Mechanical fasteners should extend to a point at or below the top of wall stud.
- Mechanical fasteners should be used to ensure continuous load path across all floor systems.
- Mechanical fasteners should be installed by a licensed, qualified contractor.
- The correct type and number of nails or screws must be used to provide effective anchorage of the fasteners to the roof truss, top plate and top of wall stud.
- If wall sheathing needs to be repaired or replaced, the uplift strength of the roof frame to wall connection can be increased by extending the wall sheathing (typically plywood or OSB sheets) to the top plate and nailing the sheathing to the top plate and wall studs.

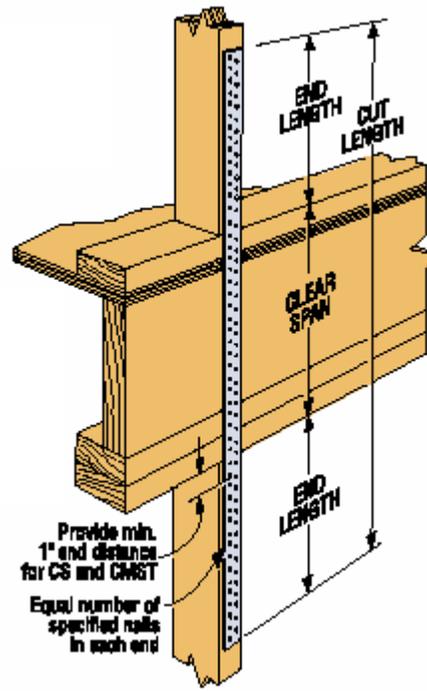
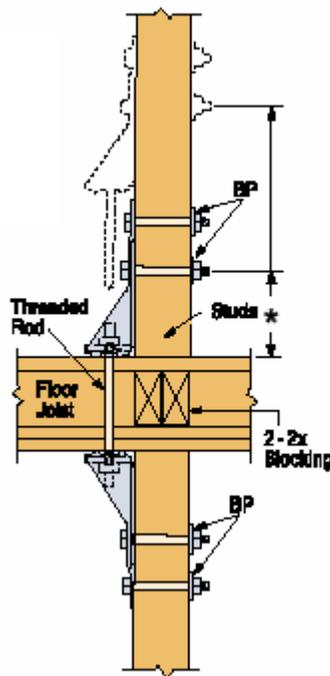


**Figure C-20. Properly clipped roof truss at top of wood frame wall. (FEMA 55CD, Third Edition *Coastal Construction Manual*)**

Mechanical fasteners and nails are inexpensive construction materials. Contractor costs for installation, however, will vary based on the time and effort necessary to expose the existing connections and perform the necessary work. Additionally, nails used in the installation of clips and fasteners are specified by the manufacturers and cannot be installed with power (pneumatic) hammers.



Figure C-21. Second floor wood framing failure.  
 (Minor Ave. Ladysmith)



Figures C-22 and C-23. Examples of mechanical fasteners providing continuous load path across floor systems. From the 2002 Simpson Strong-Tie Catalog. Mechanical fasteners may be used from any manufacturer as long as an engineer verifies that they provide adequate strength for the predicted loads.

### CMU Structures

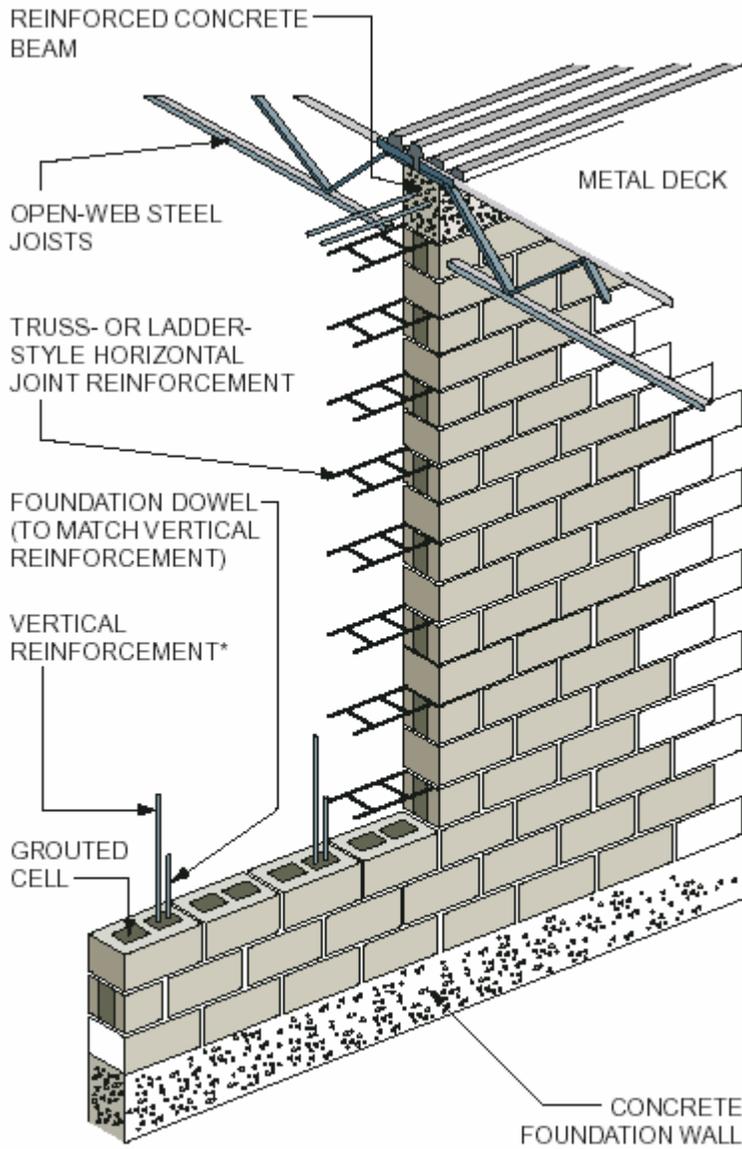
Concrete masonry unit load bearing walls (CMU) are a common construction type in commercial buildings that are only a few stories in height. Typically, these wall systems are constructed of CMU block grouted together with the open cores either left empty or filled with insulation – the walls are “un-reinforced”. Assuming these walls are constructed in this manner, the CMU walls rely on the weight of the roof to resist uplift forces. Additionally, these wall systems do not have a flexural capacity to resist the wind forces acting against them. These wall systems may resist lateral and wind uplift forces only if the wall is strengthened or reinforced. The most common way to provide a continuous load path in CMU walls is to reinforce the wall vertically with grout and reinforcing steel (see Figure C-25). The walls can also be reinforced by using Kevlar strap systems or with steel channel sections bolted to the walls.

When reinforcing CMU walls, keep the following in mind:

- Verify the type and condition of the existing roof-to-wall and wall-to-wall connections. Remember gravity (self-weight) connections are **not** sufficient to withstand uplift forces during a high wind event and **may not** meet the current wind load requirements set forth in the 2000 International Building Code (IBC).
- The reinforcing should extend from the bond beam at the top of the wall, down through the entire wall, and connect into the foundation of the building (see Figure C-24).
- Use at least #4 or #5 reinforcing bars.
- Cells that have vertical reinforcement must be fully grouted.
- To improve resistance to wind force damage, reinforcing may not be required in every cell. A design professional will determine the number of cells (and reinforcement in each) that is required for a given wind speed.
- Horizontal (ladder) joint reinforcement is not considered structural wall reinforcement.



**Figure C-24. Bond beam detached from top of CMU wall (with brick veneer). There was no connection between the bond beam and the top of the wall. (From FEMA 342).**



\* SPACING OF VERTICAL REINFORCING BARS IN MASONRY WALLS VARIES AND IS CONTROLLED BY FACTORS SUCH AS WALL HEIGHT, WALL WIDTH, AND DESIGN WIND SPEED.

Reinforcing CMU walls during initial construction is the most cost effective means of reinforcing the walls. Cost increases for adding reinforcing in the walls with reinforcing steel will vary with frequency of reinforcement, but is often less than a 5% increase in total cost for the CMU wall. Adding reinforcing steel to an existing CMU wall typically costs **\$100 per linear foot of reinforcing.**

Figure C-25. Schematic drawing of a reinforced (interior or exterior) CMU wall.

### Brick Masonry Structures

Unreinforced masonry structures may also be constructed of brick masonry. These solid units are not easily reinforced after initial construction and alternatives are limited. Brick masonry walls (Figure C-26) can be tensioned so it may act as a large unit to resist uplift forces. An example of a retrofitted brick masonry wall is shown in Figure C-27.



**Figure C-26. Typical second story brick masonry failure. (between xx Avenues, Ladysmith)**



**Figure C-27. Brick masonry wall reinforcing on upper story of building (Minor Avenue, Ladysmith)**

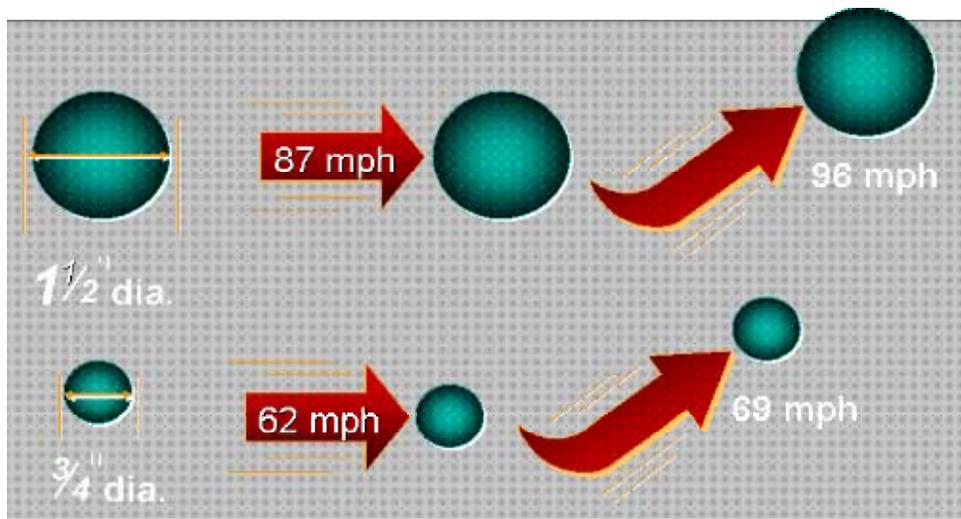
Retrofitting brick masonry walls will require the assistance of a design professional and a skilled contractor. Keep the following in mind when retrofitting brick masonry walls:

- First, determine the construction of the wall (i.e., is the wall constructed of 1-, 2-, or 3-wythes of brick). Second, determine if a wall cavity is present. A wall cavity may provide a means to add reinforcing and grout.
- Have the wall evaluated by a design professional to determine if any retrofit is possible. Remember gravity (self-weight) connection are **not** sufficient to withstand uplift forces during a high wind event and **may not** meet the current wind load requirements set forth in the 2000 International Building Code (IBC).
- The selected reinforcing method should extend from the bond beam at the top of the wall, down through the entire wall, and connect into the foundation of the building.

Retrofitting brick masonry to resist lateral and uplift forces is dependent upon the type of masonry construction, number of floors, and retrofitting method selected. Consult your local masonry contractor and design professional for a cost estimate prior to reconstruction. Strengthening existing brick masonry structures to resist lateral and uplift loads may be cost prohibitive.

### Roof Coverings and Roof Decking

Roof coverings should be selected based on their ability to resist high winds. Metal, rubber, and other roofing coverings have been developed that have tested for resistance to wind of up to 100-mph and may be specified for use on commercial buildings. The roof covering most vulnerable to damage (and most likely to contribute to building damage) is an aggregate (stone) ballast roof system. The aggregate ballast used to protect the roof covering from UV rays is susceptible to displacement from wind (Figure C-28). A wind of just over 60 mph can displace aggregate ballast across and off a roof. Roof coverings are not required to resist wind loads in current codes, but consideration should be given to selecting the most wind resistant roof covering available.



**Figure C-28. Wind speed required to displace and lift aggregate roof ballast into the air.**

Roof decking, beneath the roof covering, may be strengthened to resist wind loads. The current building code for Wisconsin, the 2000 IBC, directs the design professional to standards for determining wind loads on roofs. The roof decking and the connectors used to connect the roof deck to the supporting structural members should be designed to meet or exceed the loads required.

When strengthening roof covering and roof decking, keep the following in mind:

- Aggregate ballast roof coverings are most vulnerable to damage from high wind events. Avoid these roof systems when possible.
- To mitigate the vulnerability of displaced ballast, the roof can be covered with a membrane that secures all the ballast to the roof. As an option, 2-foot by 2-foot concrete pavers may be used along roof edges instead of roof ballast. Concrete pavers are less susceptible to displacement from wind.
- If mechanical connectors are used to secure a roof covering to the roof deck, these connectors may be designed to resist the anticipated wind forces. Remember, when designing roof systems using the 2000 IBC, the roof-covering-to-roof-deck-connectors are required to be designed to wind forces that are higher than those that act on the roof surface as a whole (Components and Cladding loads). The design professional should be careful to use the correct wind loads.
- Roof trim and flashing can also be designed to resist wind loads. Trim and flashing are located along roof edges where wind forces are the highest. Failure of these components can lead to progressive failure of the entire roof system.

- Roof decking relies on its weight and connectors to secure it to the roof structural members. It is not typically economical to design a heavyweight roof system to resist all roof uplift forces, so the key components are the connections of the roof deck to the structural members. Screws, clips, shear studs, and welds may all be used to connect roof decking to supporting members, but the designer must ensure an adequate number of connectors have been specified (Figure C-29). When designing roof systems using the 2000 IBC, the roof-deck-to-structural-members-connectors are required to be designed to wind forces that are higher than those that act on the roof surface as a whole (Components and Cladding loads). The design professional should be careful to use the correct wind loads.
- Loads should be transferred from the roof decking, to the roof structural system, and to the walls which support them to create a continuous load path. The roof structural members may require strengthening around the perimeter of the roof to resist the wind loads.
- Flat roofs will experience the highest uplift forces of all roof shapes (for the same wind event). The design professional may be able to recommend a roof slope and shape that might be less susceptible to damage than a flat roof system. For information on using parapets to reduce wind loads, see the **Parapets** section of this document.
- Roof overhangs that extend out from the building more than 2 feet are susceptible to damage from wind forces and should be avoided.

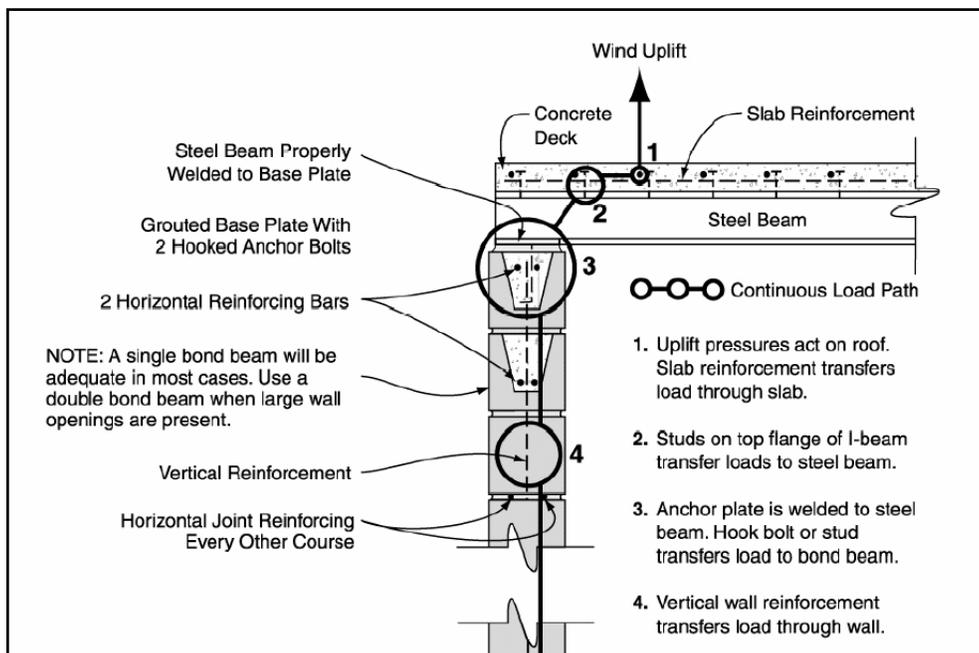


Figure C-29. Example of a continuous load path from a roof deck to the top of a reinforced masonry wall.

The design professional can assist in selecting roof coverings that are resistant to wind forces. If an existing building has an aggregate ballast roof, **cost to replace the roof covering** with a rubber roof covering is approximately **\$6 to \$9/ per square foot of roof**. Additionally, most structural retrofits to secure roof decking to structural members supporting them cannot be performed without removal of the roof covering (on an existing building). Cost to strengthen these connections may vary widely depending upon the type of construction and the cost to replace the roof after structural repairs should be included in the retrofit costs.

### Parapets

Roof parapets, regardless of construction, may be retrofitted to resist lateral wind forces, and to prevent building materials from falling off of the building. Wood parapets should be connected to wall framing using the retrofit techniques previously described to strengthen wood framing. Masonry parapets should be reinforced and connected to the vertical reinforcement in the masonry or reinforced concrete walls system supporting them.

When strengthening parapets to resist lateral wind loads, keep in mind:

- Parapets can be designed to resist the wind loading requirements specified in the 2000 IBC.
- The continuous load path in the parapet should be connected to the continuous load path with the supporting wall or structural frame.
- Parapets at and near the corners of buildings experience higher wind loads than parapets along the center of the building walls. Parapets will need to be stronger to resist the wind loads without failure.
- Parapets may be used as a mitigation measure to reduce wind loads on roof structures, but advantages are minimal. If a the roof has a continuous parapet around its perimeter, if the parapet is at least 3 feet in height, and if the parapet is designed to resist the lateral wind load without failures (including the higher loads at building corners) then the high wind loads are deflected away from the roof deck at the building corners by the parapets. Thus the wind loads around the roof corners are reduced, but no other reductions may be taken at other roof locations.

Costs associated with retrofitting roof parapets to resist lateral wind forces will be similar to the costs associated with strengthening wall systems of the same construction type.

### Awnings and Overhangs

Most of the awnings and overhangs damaged in Ladysmith were on older buildings (Figures C-30 and C-31). These buildings were constructed during times when lateral and uplift wind forces were not considered in the design of buildings, building components, or appurtenant structures. To mitigate the damage to awnings and overhangs observed in Ladysmith, these building components should be designed to resist wind forces that are now outlined in the 2000 IBC. Thus, these building elements will be designed to resist the same wind forces as the building itself.



**Figures C-30. Awning damage in foreground and intact awning framing in background.**



**Figure C-31.. This gas station canopy can be replaced with a new canopy designed to resist high winds.**

When designing awnings, canopies, and overhangs to resist high winds, keep in mind the following:

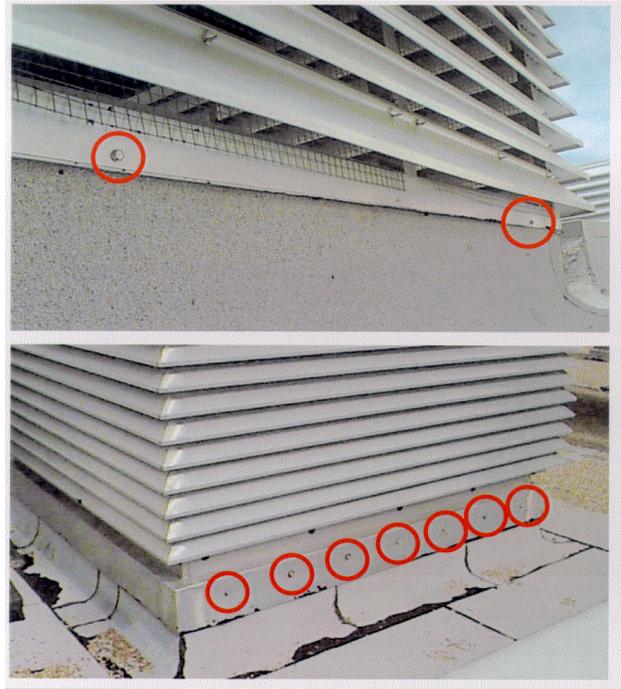
- Awnings, canopies, and overhangs that extend from a building more than 2 feet have large surface areas and are susceptible to damage from high wind events.
- Design of awnings, canopies, and overhangs using the 2000 IBC requires that these elements be designed to wind forces that are higher than those that act on the roof surface as a whole (Components and Cladding loads). The design professional should be careful to use the correct wind loads.
- When large overhangs are cantilevered away from the building, additional strength may be achieved when the structural elements are connected into the continuous load path of the building to which the overhang is attached.
- The designer should **not** design these elements to “break-away” at weak connections as a method to reduce damage to the building/structure itself. This approach does not comply with the 2000 IBC. Additionally, this approach would result in the awnings, canopies, and overhangs contributing to the debris field of the wind storm which will contribute to building damage and potentially lead to injury of individuals unable to take safe refuge.

**Roof Mounted Mechanical Units and Vent Cowlings**

Roof mounted mechanical units and vent cowlings may be secured to the roof structure to resist displacement from high winds (Figures C-32 and C-33). Smaller and lighter roof units, such as vent cowlings (and hoods) may be secured with additional fasteners to the existing roof curb supporting the unit (a curb is the raised area around the opening in the roof). Larger units that transfer higher loads to the roof curb may require additional fasteners and strengthened roof curbs.



**Figure C-32. Example of well-secured roof top unit to resist lateral and uplift wind forces (Source FEMA Archives).**



**Figure C-33. Comparison of minimally secured (top) to well secured vent hood (bottom) (Source FEMA Archives).**

When securing rooftop units, keep in mind:

- For all units, a minimum of one connector should be used on each side of the unit where it attached to the roof curb.
- For large units, connectors should be placed no more than 12 inches apart.
- When designing roof curbs supporting roof equipment and vent cowlings using the 2000 IBC, these elements are to be designed to wind forces that are higher than those that act on the roof surface as a whole (Components and Cladding loads). The design professional should be careful to use the correct wind loads.

For budgetary estimate purposes, installing additional metal screws (#14 with gasket washers) to **improve the connection** of existing equipment to a roof curb will cost **approximately \$100 per unit**. The cost to reconstruct the roof curb to provide additional supports will vary based on the type of roof construction and the equipment being secured.

## Conclusions and Sheltering

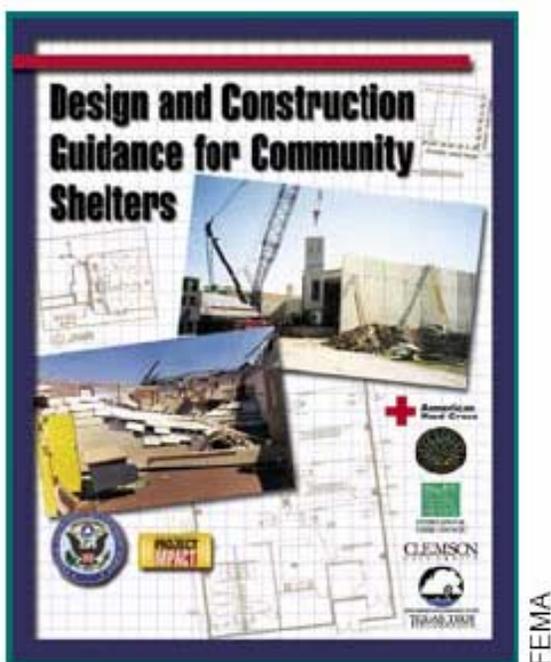
In conclusion, there are a variety of wind mitigation measures and methods available to protect commercial structures in Ladysmith and Gilman against future wind events. Commercial structural damage associated with thunderstorms, microbursts (downslope winds), and the straight-line winds that accompany tornadoes would be reduced by implementing appropriate mitigation measures.

There are few, if any, cost effective mitigation measures that protect entire businesses from extraordinary events such as a direct hit by the vortex of a severe tornado of F3 level or greater. In such instances, the best mitigation is to either flee the tornado if warning time allows, or to take refuge in a shelter that has been constructed within (or adjacent) the building.

Shelters constructed for use in commercial or public buildings are often large than the in-residence shelters discussed in FEMA 320. Community shelters and other large shelters, must comply with **all** requirements of the local building code. Design requirements for such structures are not covered in any building code. *FEMA 361 Design and Construction Guidance for Community Shelters*, July 2000, provides the FEMA guidelines that should be considered in designing a community shelter. The design guidelines include, but are not limited to:

- The structure should withstand winds up to 250 miles per hour and impact forces associated with flying debris (only specific wall types may be used).
- Square footage requirements for shelter occupancy (a minimum of 5 square feet per person).
- Doors and door hardware that comply with ADA and code specified egress requirements while still resisting wind forces and debris associated with 250 mph winds.
- Shelter operations manuals to govern maintenance, access control, signage, and coordination with local emergency management for the shelter.

For additional information, please refer to the FEMA's website at [www.fema.gov](http://www.fema.gov).



The **increase in cost** to modify a construction type to have improved wind load resistance during initial construction is **approximately 15%-25%**. However, the cost to retrofit existing buildings for resistance to lateral and uplift loads will vary with the type of construction, use of the building, and degree of protection desired.

**Note:** When providing areas with improved wind resistance or shelters in commercial buildings, the increased cost of construction will only apply to the areas being strengthened and not the entire building. As a result, the increased cost to provide a shelter area within a new facility may only be approximately 5%, depending on project details.

## School Buildings: The Gilman School

On September 2, 2002, the Gilman School was struck by an F2-F3 tornado. The tornado damage at the school was extensive at the gymnasium area, the corridors around the gymnasium, and the classroom roof and exterior wall to the east; these areas are the focus of this section. An aerial view of the school and damage is shown in Figure S-1. Minor damage occurred at other locations throughout the school such as broken windows and doors, debris impact damage to exterior walls, and roof covering (including flashings) damage. At the time of this report, repairs to the school have begun and mitigation measures indicated as being implemented refer to those being performed during this initial reconstruction. Implementation of additional high wind mitigation measures and the possible inclusion of a high wind shelter within the school are still being considered.

The school was constructed in over a period of years from 1960 to 1998. The gymnasium area was constructed in the 1960s and the classroom area to the east was constructed in 1998. The building code currently in effect that will govern the reconstruction is the *2000 International Building Code (IBC)*.



**Figure S-1. Damage to the Gilman School. Damaged gymnasium and classrooms are circled (Photo by the Eau Claire Leader-Telegram).**

Mitigation measures are discussed in the paragraphs that follow. It is important to note that these measures are intended to strengthen schools and public buildings to resist high winds associated with thunderstorms, downbursts, and the straight-line winds that are on the periphery of tornadoes. The mitigation measures are presented as guidelines for mitigation or as examples of successful mitigation. Since school design and construction requires the involvement of a design professional and government agencies, the mitigation strategies presented here are intended to guide the design professional to a correct solution and they are not intended to dictate or imply that there is only one acceptable solution that may be used. These mitigation measures, if implemented, **will not** render the Gilman School capable of withstanding a direct hit from tornado, or allow it to function as a high wind shelter capable of preventing loss of life. References for guidance on the design and construction high wind shelters are provided in Appendix B.

Furthermore, it is of utmost importance that all mitigation measures be approved by the local building official. The Wisconsin Department of Commerce oversees the construction of schools in Wisconsin. The building code currently in effect for school construction within the state is the *2000 International Building Code (IBC) with State of Wisconsin Amendments*. It should be noted that, insurance policy requirements and state building code requirements indicated that the damaged building components only need to be replaced to the pre-damage condition as specified by the building code in effect at the time of original construction. However, should there be an opportunity to improve the structure, the *2000 IBC with State of Wisconsin Amendments* is to be used to regulate the redesign and reconstruction if it is structurally different or an improvement to the existing structure. Your local building official can provide insight into applicable building codes and ordinances, and explain specific requirements that are in effect in Ladysmith or Gilman.

Notable requirements from the *2000 IBC with State of Wisconsin Amendments* are:

- The building structure must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The windows and doors must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The parapets, awnings, and exterior wall coverings must be designed to resist wind loads from a 90-mph wind (3-second gust).
- The roof top equipment must be designed to resist wind loads from a 90-mph wind (3-second gust).
- Wind loads are factored during design by a factor of safety as high as 1.6 x (calculated wind load).

## Roof Damage and Mitigation Opportunities

This section discusses the roof damages observed and mitigation opportunities at the Gilman School. The roof damage at the Gilman School occurred due to loss of roof covering (roof ballast damage), wind uplift damage, and falling debris damage.

### Roof Damage

Damage to the roof system and windows around the school was directly affected by the loss and displacement of the aggregate ballast on the roof of the school. Although relatively large rock is used for ballast at the school, winds from 62 to 87 mph can displace the ballast stones and wind from 69 to 96 mph can lift the stone into the windstream. When the ballast left the roof, the roof covering was vulnerable to damage from uplift (dead load on the deck was reduced) and impact and tearing from other debris. In addition, the windborne stone ballast impacted windows and doors causing damage. Figure S-2 shows the classroom area east of the gymnasium. The most heavily damaged roof sections are missing their roof ballast immediately after the wind event.



**Figures S-2. Damaged roof at Gilman School. Ballast is missing along edge sections of the roof where wind forces are the highest.**

Roof damage was also caused by wind uplift on the roof surface that was generated by the fast moving winds as they passed over the building. The wind uplift forces pull the roof decking off the structural

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members that support them. At Gilman, the wind was strong enough to remove almost all the tectum roof decking from the trusses in the gymnasium with little comparative damage to the walls supporting the roof trusses (Figure S-3). Only the roof trusses over the mechanical room were damaged severely enough that they had to be replaced. Over the gymnasium, the roof trusses experienced only light damage and these trusses will be repaired in place. The walls at the ends of gymnasium were heavily damaged and this will be discussed in the wall damage section. The failure point in critical load path was the clips used to attach the roof decking to the trusses. However, if this connection had been sufficient to transfer wind loads to the roof trusses, the trusses and the walls supporting them would have been subject to significant uplift and lateral forces and different structural damage may have been observed (assuming the tectum decking itself did not fail). Different damage was observed over the classrooms east of the gymnasium (Figure S-4). In this area, the metal roof decking remained attached to the roof system. Damage in this area included warped and bent roof decking, failure of roof trim and flashing, and separation of roof structural members (bar joists) from the top of the masonry wall. Figure S-4 shows the damaged roof over the classrooms after the ballast has been removed for repairs.



**Figures S-3. Missing roof decking in the gymnasium. It should be noted that these walls did not collapse.**

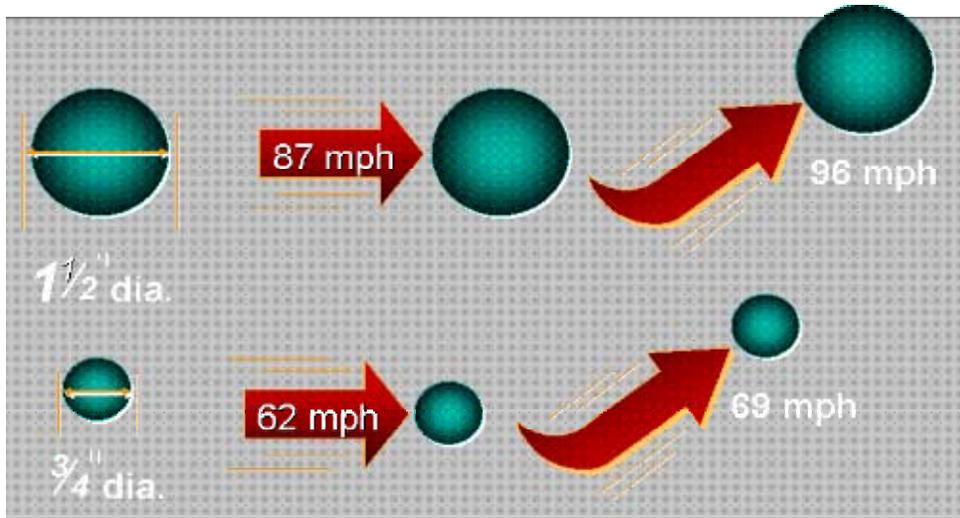


**Figure S-4. Roof decking is uneven, insulation boards are uneven under roof membrane, and vents/fan cowlings are damaged. (Note: Gravel ballast was removed so repairs could be preformed.)**

Additionally, there were isolated locations of roof impact damage. Large stone masonry blocks located atop the gymnasium wall between the roof trusses were displaced when the roof decking was removed by the wind. When these blocks were displaced, they fell off the top of the wall and damaged the hallway roof areas (both the decks and the bar joists) adjacent the gymnasium; these blocks did not penetrate the roof.

**Roof Mitigation**

Roof coverings should be selected for their ability to resist high winds. Metal, rubber, and other roofing coverings have been developed that have tested for resistance to wind of up to 100-mph and may be specified for use on commercial buildings. The roof covering most vulnerable to damage (and most likely to contribute to building damage) is an aggregate (stone) ballast roof system. This system was used on the classroom roof area, but the gymnasium roof used a fully-adhered rubber roof system. A wind of just over 60 mph is capable of displace aggregate ballast across and off a roof (Figure S-5). Roof coverings are not required to resist wind loads in current codes, but consideration should be given to selecting the most wind resistance roof covering available.



**Figure S-5. Wind speed required to displace and lift aggregate roof ballast into the air.**

Roof decking, beneath the roof covering, may be strengthened to resist wind loads. The current building code for Wisconsin, the 2000 IBC, directs the design professional to standards for determining wind loads on roofs. The roof decking and the connectors used to connect the roof deck to the supporting structural members should be designed to meet or exceed the loads required.

When strengthening roof covering and roof decking, keep the following in mind:

- Aggregate ballast roof coverings are most vulnerable to damage from high wind events. When possible, these roof systems should be avoided. If possible, the rubber roof covering proposed for the gymnasium roof should also be used as the roof covering over the classroom area.
- To mitigate the vulnerability of displaced ballast, the roof may be covered with a membrane that secures all the ballast to the roof or installation of 2-foot by 2-foot concrete pavers may be used along roof edges instead of roof ballast. Concrete pavers are less susceptible to displacement from wind.
- The tectum roof deck over the gymnasium is being replaced with a metal deck system. Although this system is lighter than the tectum deck that was damaged, heavy gauge decking may be used. Additionally, the proposed welded connections to the supporting roof trusses can be designed to resist wind forces specified by the 2000 IBC and avoid the connection failures observed at the school (Figure S-6).

- Roof trim and flashing can also be designed to resist wind loads. Trim and flashing are located along roof edges where wind forces are the highest. Failure of these components can lead to progressive failure of the entire roof system.
- Roof decking relies on its weight and connectors to secure it to the roof structural members. Typically, it is uneconomical to design a heavyweight roof system to resist all roof uplift forces, so the key components are the connections of the roof deck to the structural members. Screws, clips, and welds may all be used to connect roof decking to supporting members and should be considered when repairing the metal roof deck areas at the school. The designer must ensure an adequate number of connectors have been specified. Remember, when designing roof systems using the 2000 IBC, the roof-deck-to-structural-members-connectors are required to be designed to wind forces that are higher than those that act on the roof surface as a whole (Components and Cladding loads). The design professional should be careful to use the correct wind loads.
- Loads should be transferred from the roof decking to the roof structural system, and then to the walls which support them to create a continuous load path. The roof structural members may require strengthening around the perimeter of the roof to resist the wind loads.



**Figure S-6. Clips from the tectum roof deck system at the gymnasium. The loss of the roof deck was a result of the inability of these clips to restrain the deck or the failure of the deck itself at the clips.**

## Wall Damage and Mitigation Opportunities

This section discusses the wall damage observed and mitigation opportunities at the Gilman School. The wall damage at the Gilman school can be summarized into two categories: tall walls/exterior walls and interior walls.

### Wall Damage

At the gymnasium, the tall non-load bearing walls sustained the most structural damage with a complete wall failure occurring at the end of the gymnasium at the mechanical room (Figure S-7) and significant damage to the other endwall. These walls were constructed of unreinforced concrete masonry units (CMUs) that do not have the ability to resist lateral and uplift loads. The load bearing walls that supported the roof trusses performed better than the endwalls, but experienced cracking. The load bearing walls have a reinforced bond beam along the entire length of the walls. When the roof decking failed, the roof trusses remained and provided lateral support to the top of the walls and their weight assisted in resisting uplift loads. Large coping stones atop the bond beam (and between the trusses) were displaced and many fell outside the gymnasium damaging the lower roof decking adjacent the gymnasium.



**Figure S-7. The non-load bearing endwall in the mechanical room (missing from right side of photo) at the gymnasium failed from lateral wind pressures and instability at the top of the wall caused by the failed roof decking.**

Exterior walls on the east side classroom section of the school experienced damage similar to the gymnasium endwalls. These walls were cracked and some wall sections were out of plumb. This was likely the result of lateral and uplift wind forces acting on the CMU walls. This area also experienced roof uplift damage and the exterior walls were likely unsupported at their tops as wind forces were acting on the walls. Interior walls in the classroom sections were damaged when the roof system lifted up during the event. Load bearing interior walls were damaged where the structural roof trusses/joists were pulled from the top of the walls.

### **Wall Mitigation: CMU Wall Reconstruction (Tall Walls/Exterior Walls)**

Concrete masonry unit load bearing walls (CMU) are a common construction type in school buildings that are only a few stories in height. Typically, the wall systems at Gilman are constructed of CMU block grouted together with the open cores either left empty or filled with insulation – the walls are “un-reinforced”. These wall systems may resist lateral and wind uplift forces only if the wall is strengthened or reinforced. The most common way to provide a continuous load path in CMU walls is to reinforce the wall vertically with grout and reinforcing steel (Figures S-8 and S-9). This mitigation is being performed at the endwalls of the gymnasium. The load bearing walls supporting the roof trusses cannot be mitigated as easily and are not being improved at this time. Additional means of reinforcing the wall can be accomplished with Kevlar strap systems or with steel channel sections bolted to the walls.



**Figures S-8 and S-9. Vertical reinforcing steel being installed in the gymnasium endwalls. The reinforcing steel spans the length of the wall (vertically) and is placed in grout filled cell every 3'-0".**

When reinforcing CMU walls at Gilman or at other schools, keep the following in mind:

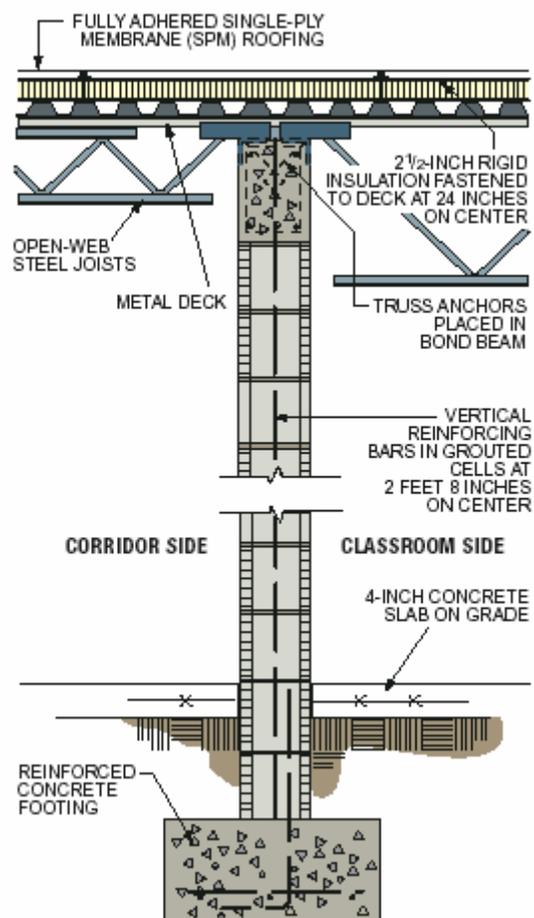
- First, verify the type and condition of the existing roof-to-wall and wall-to-wall connections. Remember gravity (self-weight) connections are **not** sufficient to withstand uplift forces during a high wind event and **may not** meet the current wind load requirements set forth in the 2000 International Building Code (IBC).
- The reinforcing should extend from the bond beam at the top of the wall, down through the entire wall, and connect into the foundation of the building (This is being implemented at Gilman: see Figure S-8).
- Use at least #4 bars or #5 bars for vertical reinforcement and the cells that have vertical reinforcement must be fully grouted (This is being implemented at Gilman: see Figure S-9).
- To improve resistance to damage from wind forces, reinforcing may not be required in every cell. A design professional will determine the number of cells (and reinforcement in each) that is required for a given wind speed.
- Structural connections to adjacent roof structures may act as a strut to reduce the unbraced length of the tall gymnasium walls providing additional stability.
- Horizontal (ladder) joint reinforcement is not considered structural wall reinforcement.

**Wall Mitigation: CMU Wall Reconstruction (Interior Walls)**

Interior walls can be mitigated to resist damage from uplift forces (Figure S-10). In addition, strengthening of these walls will provide support to and a continuous load path to the roof structural members. The result is a reinforced masonry interior wall that not only provides gravity support for the roof, but stability for the roof system.

When reinforcing interior, load bearing CMU walls at Gilman or at other schools, keep the following in mind:

- First, verify the type and condition of the existing roof-to-wall and wall-to-wall connections. Remember gravity (self-weight) connections are **not** sufficient to withstand uplift forces during a high wind event and **may not** meet the current wind load requirements set forth in the 2000 International Building Code (IBC).
- The reinforcing should extend from the bond beam at the top of the wall, down through the entire wall, and connect into the foundation of the building.
- Use at least #4 bars or #5 bars for vertical reinforcement and the cells that have vertical reinforcement must be fully grouted.
- To improve resistance to damage from wind forces, reinforcing may not be required in every cell. A design professional will determine the number of cells (and reinforcement in each) that is required for a given wind speed.
- Horizontal (ladder) joint reinforcement is not considered structural wall reinforcement.



**Figure S-10. Example of a typical wall section providing improved resistance to wind uplift loads. (Tornado Protection: Selecting Safe Areas in Schools, Florida DCA, March 2002)**

## Conclusions and Sheltering

In conclusion, there are a variety of wind mitigation measures and methods available to improve the wind resistance of the Gilman School gymnasium and classrooms to resist future wind events. Damage to the School associated with thunderstorms, microbursts (downslope winds), and the straight-line winds that accompany tornadoes would be reduced by implementing appropriate mitigation measures.

There are few, if any, cost effective mitigation measures to protect entire school building from extraordinary events such as a direct hit by the vortex of a severe tornado of F3 level or greater. In such instances, the best mitigation is to either flee the tornado if warning time allows, or to take refuge in a shelter that has been constructed within (or adjacent) the building.

Shelters constructed for use in schools are often larger than the in-residence shelters discussed in FEMA 320. Community shelters and other large shelters must comply with **all** requirements of the local building code. Design requirements for such structures are not covered in any building code however, and as such, designers should consult *FEMA 361 Design and Construction Guidance for Community Shelters (FEMA, 2000)* for FEMA guidelines pertaining to community shelter design. Design guidelines include, but are not limited to:

- Structure should withstand winds up to 250 miles per hour and impact forces associated with flying debris (only specific wall types may be used).
- Square footage requirements for shelter occupancy (a minimum of 5 square feet per person).
- Doors and door hardware that comply with Americans with Disabilities Act (ADA) and code specified egress requirements while still resisting wind forces and debris associated with 250 mph winds.
- Shelter operations manuals to govern maintenance, access control, signage, and coordination with local emergency management for the shelter.

Locating shelter areas in schools is a design challenge. The balance is to identify the most cost effective area or areas to retrofit or construct that will meet all the operational requirements of the users. For example, smaller shelter areas such as hallways and classrooms are typically easier to structurally retrofit to resist wind loads and impact from windborne debris. However, multiple small shelters are required for the large populations requiring sheltering (a school looking to provide shelter for 1,000 individuals without special needs would require a minimum of shelter space of 5,000 square feet). In addition, securing the multiple egress points common to hallway shelter areas to resist wind loads and windborne debris is a complex design and logistic issue.

Large shelter spaces simplify shelter operation plans by locating the population to be sheltered in one area and minimizing the number of doors and egress points that need to be protected. Large shelter spaces, however, present structural design challenges because they often use long span roofs and tall walls. Although designers can design large structures to resist the wind forces, aesthetics and day-to-day usefulness of the space must be considered. A study should be performed to identify the current tornado refuge areas being used with the school and if these are the safest areas available. The study should also evaluate all possible areas in the school that could be retrofitted for shelter use and recommend the most cost effective location of shelters within the Gilman school.

The reconstruction of the Gilman school from the tornado damage experience on September 2, 2002, will improve the original design of the gymnasium to resist wind loads. Exterior walls (previously



## Appendix A Glossary of Terms

**Anchor** – To secure a structure to its footings or foundation wall in such a way that a continuous load transfer path is created and so that it will not be displaced by flood, wind, or seismic forces.

**Building code** – Regulations adopted by local governments that establish standards for construction, modification, and repair of buildings and other structures. Most states, including Wisconsin, have separate building codes to govern residential and commercial construction. In Wisconsin, the residential building code is the **2001 Wisconsin Uniform Dwelling Code** and the commercial building code is the **2000 International Building Code with State of Wisconsin Amendments**.

**Built-up roof covering** – Two or more layers of felt cemented together and surfaced with a cap sheet, mineral aggregate, smooth coating, or similar surfacing material. Common to commercial construction. Often protected from UV rays with aggregate (gravel) ballast.

**Clip/connector** – Mechanical device for securing two or more pieces, parts, or members together, including anchors, wall ties, and fasteners.

**Continuous load path** – A continuous load path may be defined as a series of structural members, and connections between those structural members, that transmits loads (gravity, lateral, uplift, or other) from the roof or walls of a building to the foundation.

**Debris impact loads** – Loads imposed on a structure by the impact of windborne debris. These loads are often sudden and large. Though difficult to predict, debris impact loads can be designed for and must be considered when designing high wind shelter structures are designed and constructed.

**Federal Emergency Management Agency (FEMA)** – Independent agency created in 1979 to provide a single point of accountability for all Federal activities related to disaster mitigation and emergency preparedness, response and recovery.

**Gable End Roof** – Two-sided roof structures with two sloped roof surfaces and a vertical wall section at each end. These roofs are typically supported by a series of roof trusses oriented in one direction (parallel to each other) or by a series of parallel rafters.

**High Wind Shelter** – A building or area within a building that has been designed and constructed to resist forces from high winds and windborne debris. Typically, these buildings or building areas have been constructed to resist 250-mph winds (3-second gust) and impacts from debris that is typical of a 15-lb, 2"x4" wood member traveling horizontally at 100-mph. Details regarding the construction of such structures in residential buildings may be found in *FEMA 320: Taking Shelter From the Storm* (August 1999) and in commercial buildings in *FEMA 361: Design and Construction Guidance for Community Shelters* (July 2000).

**Hip Roof** – Four-sided roof structures with four sloped roof surfaces and no vertical walls. These roofs are supported by roof trusses or rafters that span in two directions. Hip roofs typically perform better during high wind events due to the lateral stability provided by the construction of the roof itself.

**Hurricane clip or strap** – Structural connector, usually metal, used to tie roof, wall, floor, and foundation members together so that they can resist wind forces.

**Improved wind resistance** – A building or structure is said to have improved wind resistance (but is not necessarily a high wind shelter) when a continuous load path to resist lateral and uplift loads has been established within the structure. This typically entails installing proper clips, connectors, and anchors between the structural members of the building system at a frequency that exceeds the minimum requirements of the building code.

**Load-bearing wall** – Wall that supports any vertical or lateral load in addition to its own weight.

**Local building/code official** – Officer or other designated authority charged with the administration and enforcement of the building code (residential or commercial), or a duly authorized representative, such as a building, zoning, planning, or floodplain management official.

**Mitigation** – Any action taken to reduce or permanently eliminate the long-term risk to life and property from natural hazards.

**Non-load-bearing wall** – Wall that does not support vertical loads other than its own weight.

**Oriented strand board (OSB)** – Mat-formed wood structural panel product composed of thin rectangular wood strands or wafers arranged in oriented layers and bonded with waterproof adhesive.

**Plywood** – Wood structural panel composed of plies of wood veneer arranged in cross-aligned layers. The plies are bonded with an adhesive that cures on application of heat and pressure.

**Roof deck(sheathing)** – Flat or sloped roof surface not including its supporting members or vertical supports. Common residential materials are plywood or OSB. Common commercial materials are wood, metal, or concrete.

**Single-ply membrane** – Roofing membrane that is field-applied with one layer of membrane material (either homogeneous or composite) rather than multiple layers. This is typically used in commercial roofing applications.

**Substantial Damage:** Damage of any origin sustained by a structure whereby the cost of restoring the structure to its pre-damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred.

**Substantial Improvement:** Any reconstruction, rehabilitation, addition, or other improvement of a structure, the cost of which equals or exceeds 50 percent of the market value of the structure before the “start of construction” of the improvement. For the purposes of this definition, “substantial improvement” is considered to occur when the first alteration of any wall, ceiling, floor, or other structural part of the building commences, whether or not that alteration affects the external dimensions of the structure. This term includes structures which have incurred “substantial damage”, regardless of the value of or actual cost of repair work performed.

The above term does not, however, include either (1) any project for improvement of a structure to correct existing violations of state or local health, sanitary, or safety code specifications which have been identified by the local code enforcement official and which are the minimum necessary to assure safe living conditions or (2) any alteration of a structure listed on the National Register of Historic Places or a State Inventory of Historic Places, provided that the alteration will not preclude the structure’s continued designation as a “historic structure”.

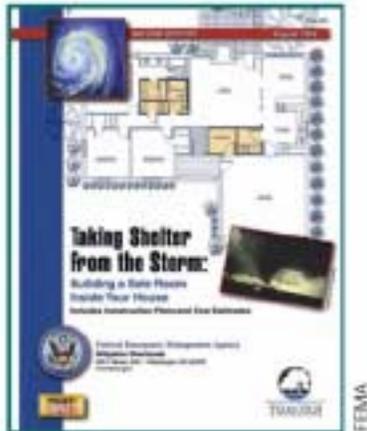
**Underlayment** – One or more layers of felt, sheathing paper, nonbituminous saturated felt, or other approved material over which a steep-sloped roof covering is applied.

**Uplift** – Wind forces/pressure caused by wind moving across a roof surface. It can be strong enough lift and remove roof coverings, sheathing, decking, structural members, and in extreme cases lift building off their foundations, especially when the building is not properly anchored to its foundation.

**Windborne debris** – Solid objects or masses carried by wind.

## Appendix B Additional Wind Mitigation Resources

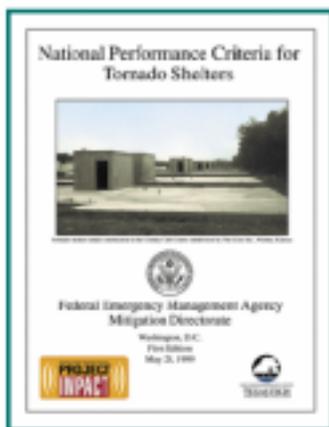
### FEMA Publications



#### **Taking Shelter From the Storm: Building a Safe Room in Your House**

**FEMA Publication 320, August 1999**

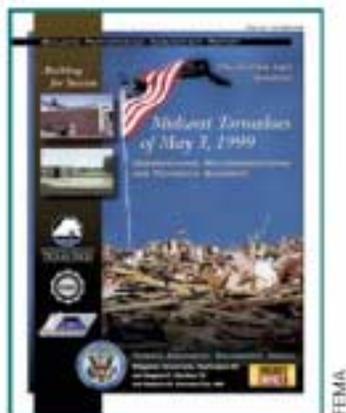
This illustrated, full-color booklet is intended for homeowners and construction contractors. It explains the hazards posed by severe winds associated with tornadoes and hurricanes, includes maps and charts for assessing tornado risk, presents shelter design criteria, and includes estimated costs and detailed construction drawings for several types of in-residence shelters.



#### **FEMA NPC National Performance Criteria for Tornado Shelters**

**August 1999**

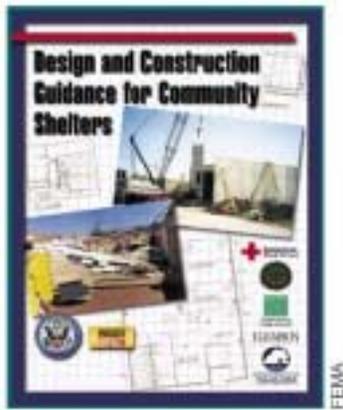
The performance criteria presented in this booklet are intended for design professionals, shelter manufacturers, building officials, and emergency management officials. The issues addressed include resistance of shelter walls, ceilings, and doors to wind loads and missile impacts; shelter size, ventilation, lighting, and accessibility; and multihazard (e.g., flooding and earthquake) effects. The criteria form the basis for the construction of wind shelters that will provide a consistently high level of protection.



#### **Building Performance Assessment Team Report, Midwest Tornadoes of May 3, 1999**

**FEMA Publication 342, October 1999**

This illustrated, full-color report presents the observations and conclusions of the Building Performance Assessment Team (BPAT) deployed by FEMA after the May 3, 1999, tornadoes in Oklahoma and Kansas. The report describes the tornado damage; assesses the performance of residential and non residential structures, including wind shelters; and presents recommendations for property protection, building code enforcement, and residential and group sheltering.



### **Design and Construction Guidance for Community Shelters**

#### **FEMA Publication 361, July 2000**

This illustrated manual is intended for engineers, architects, building officials, and prospective shelter owners. It explains tornado and hurricane hazards, presents shelter design criteria based on performance requirements and human factors, and outlines emergency management considerations for community shelters. Also provided are site assessment checklists that can be used in the selection of shelter areas in existing buildings; case studies that include wind load analyses, costs, and construction drawings; and the results of laboratory tests of shelter construction materials. For more information about FEMA publications, wind hazards, and wind shelters go to [www.fema.gov/mit](http://www.fema.gov/mit).

### **Other Wind Mitigation Guidance**

**Illinois EMA, Windstorm Mitigation Manual for Light Frame Construction**, August 1997

**Illinois EMA, Companion to the Windstorm Mitigation Manual for Light Frame Construction**,  
December 1999

**Wisconsin Emergency Management and FEMA Region V Wind Mitigation Fact Sheets: *Building to Resist Strong Winds***