7 Conclusions

The conclusions presented in this report are based on the BPAT's observations, an evaluation of relevant codes and regulations, and meetings with state and local officials, and other interested parties such as organizations representing builders and contractors. The conclusions of this report are intended to assist states, communities, businesses, and individuals, and to provide technical guidance for personal and property protection.

7.1 Residential Property Protection

The BPAT observed considerable damage to single-family housing, multi-family housing, and manufactured housing. Failures observed resulted from windborne debris and high winds that often produced forces on buildings not designed to withstand such forces. Failures, in some cases, also were observed that were due to improper construction techniques, poor selection of construction materials, and ineffective detailing of connections. Damage, in some situations, could have been reduced or avoided if newer building codes and engineering standards that provided better guidance for high wind events had been adopted, followed, and enforced.

The majority of residential construction in Oklahoma and Kansas is currently required to be designed and constructed in accordance with the 1995 CABO One- and Two-Family Dwelling Code. Although local municipalities have adopted some amendments to this code, it does not incorporate wind speed design parameters used by the newer 1997 UBC, 1997 SBC, and 1996 NBC codes. Furthermore, engineering standards such as ASCE 7-98 and its predecessor 7-95, provide better structural and non-structural design guidance for determining design wind loads than the most recent versions of the UBC, NBC, or SBC. Although designing for tornadic wind events is not specifically addressed in any of these newer codes or standards, constructing homes to the most recent versions of these codes and standards would improve the strength of these structures. Building to these codes and standards would have reduced damage in areas that were affected by the inflow winds of all tornadoes and reduced the damage to residences impacted by the vortices of weak and possibly strong tornadoes.

7.1.1 Single- and Multi-Family Homes

The BPAT observed many single-family residential buildings that were in the inflow areas of violent and strong tornadoes and in the direct path of weak tornado vortices that received avoidable structural damage. This damage was typically a result of the lack of capacity in the structural system to resist wind-induced uplift loads, wind-induced lateral loads, or increased loads on the building due to internal pressurization after the building envelope was breached. It is crucial to establish a continuous load path to provide improved resistance to wind forces.

It is neither economical nor practical to construct an entire home that is resistant to tornadoes of all strengths. However, improved design and construction and implementation of details and techniques that are used in other high wind regions of the country may have significantly reduced the property damage caused by weak tornado vortices and inflow winds of strong and violent tornadoes.

7.1.1.1 Load Path and Structural Systems

Foundations in conventionally constructed single- and multi-family homes performed adequately during the tornadoes in both Oklahoma and Kansas. The deficiency or failure mode of the load path at this point was the connection of the structural systems to the foundation. Wood framing relied on the connection of the sole plate or floor framing to the foundation wall or slab to maintain the load path. Straps, anchor bolts, epoxy set anchors, and nails were the most common fasteners. When properly used, the straps, anchor bolts, and epoxy set bolts maintained the connection of sole plate and floor framing to the foundations for most wind conditions. However, numerous instances of anchor bolts without nuts or misaligned anchor bolts at the sole plate and floor framing resulted in the house lifting off the foundation. Nailing of the sole plate to the foundation was adequate only in the areas that incurred minimal damage from inflow winds along the periphery of the tornado paths.

Wall framing in single-and multi-family houses commonly failed at the sole plate to stud connection. This was the most common failure observed by the BPAT in wall framing. Revisions in the normal way of constructing wall framing are necessary if these weak links are to be addressed. A positive method of connecting the studs to the sole plate that can resist design uplift forces is a necessity for providing a continuous load path. Recommenatations regarding the construction of this connection are illustrated in Chapter 8.

Wood framed walls also saw failures at the double top plate connection with the wall and the roof systems. Attention must be given to ensure a positive connection is provided for the uplift load transfer from the double top plate to the wall below. Straps or other connectors that would ensure a continuous load path to resist uplift loads were not observed at this location. Nails were the primary fasteners at this connection. Failures were observed between the studs and the top plate and between the two top plates. Typically, when this connection failed, no continuous structural sheathing was observed to help with this load transfer. Full length wood structural panels (e.g., plywood), from the top plates to the sill plate or floor framing, could act as the uplift load transferring mechanism. The sheathing or other means of transferring the force must be connected to the double top plate by sufficient fasteners such as those noted in the model building codes.

The primary shear wall failure observed was that of garage return end walls that frame the garage door. The narrow walls where failure was observed have an aspect ratio (height to width ratio) that generally was less than that allowed by model building codes. The current building codes, which contain industry recommendations that are intended to provide a narrower shear wall, but yet be capable of resisting the design wind loads, should be followed.

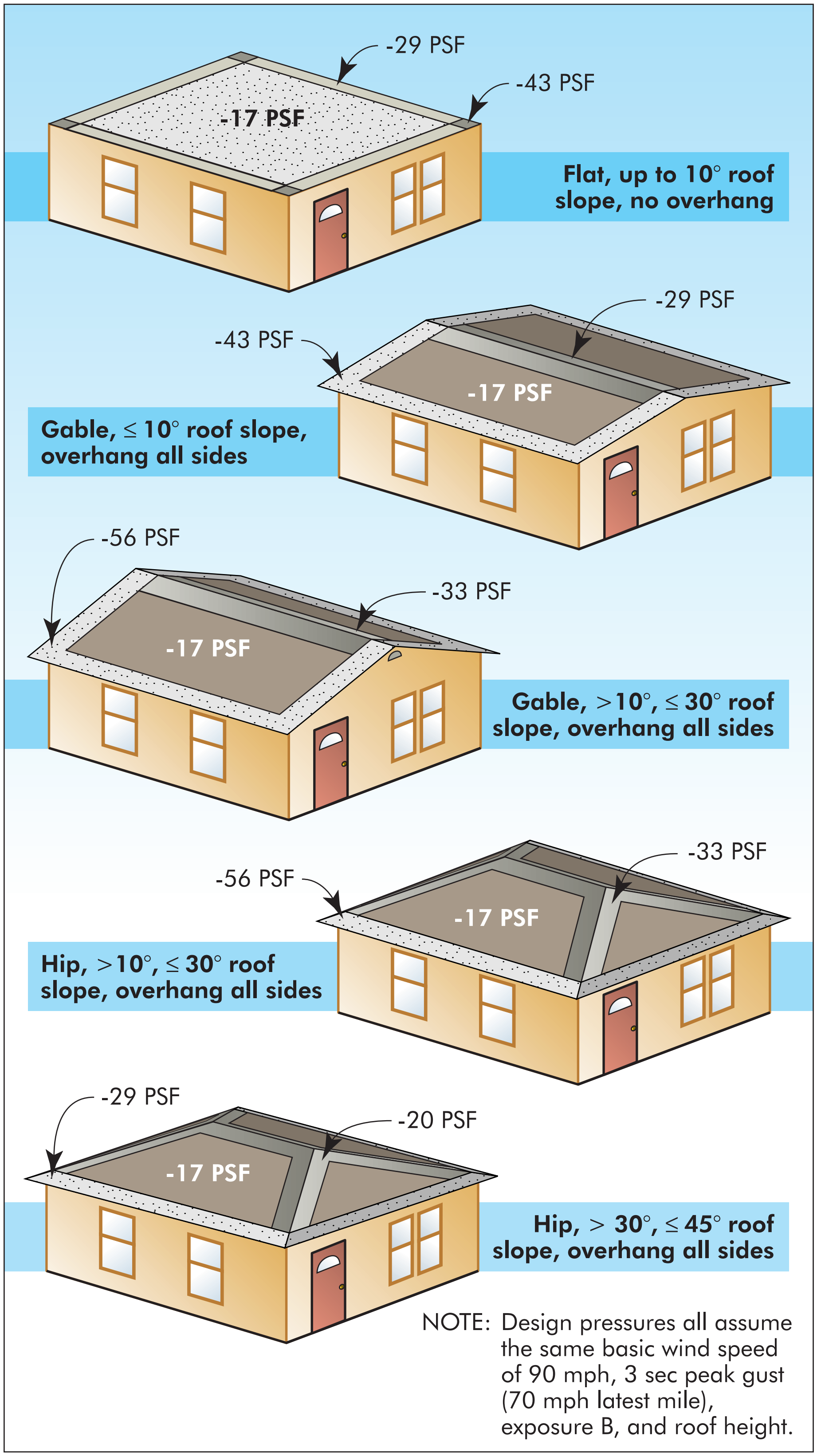
Although most of the roof framing configurations observed did not include a sufficient connection of the rafter to the ceiling joist, at least one of the model building codes does require such connection. In those cases where the ceiling joists existed and were parallel and adjacent to the roof rafters, additional resistance would have been provided if roof framing was connected to the ceiling joists. For the cases where the roof framing and ceiling joists were not parallel or adjacent, an insufficient number of observations were made to be able to draw any conclusions. Recommendations to improve the strength of these connections are illustrated in Chapter 8.

Roof geometry was observed to affect building performance in two significant ways. First, the roof geometry affected both the local and overall wind loads acting on the roof. Second, the roof geometry affected the overall strength of the roof system based on its framing configuration (e.g., hip versus gable framing).

In general, for flat, gable, and hip roof geometry, the largest uplift loads occurred near the corners, the gable ends, and the edges of the roof ridge. However, the largest localized loads for gable roofs are noticeably higher than those for hip roofs. Although a localized load may fail a single piece of roof sheathing, it will not always cause the entire roof to fail. Such localized roof failures often allow rainfall to enter the structure, causing significant collateral damage to the building interior and furnishings. When the roof fails as a single entity, it is the overall combination of all wind loads that will cause this failure. The maginitude of the loads that will couse roof failures are influenced by the roof geometry, slope, pressure of roof overhangs, and location on the roof. Roof geometry and their effect on resultant wind loads are illustrated in Figure 7-1.

The effect of roof shape on the performance of residential buildings in high winds varies with the size of the roof element being considered (e.g., roof covering, roof sheathing, single truss, entire roof, etc.), the wind directions producing the high winds, and the quality of the design and construction.

FIGURE 7-1: Relative uplift pressures as a function of roof geometry, roof slope and location on roof. Negative values indicate that wind pressures act upward and perpendicular to the roof surface.



However, hip roof systems are generally stronger than gable roofs because of the bracing that is imported by their construction.

7.1.1.2 Increased Load Caused by Breach of Envelope

BPAT inspections of wind-induced damage to residences indicate that internal pressurization is a major contributor to poor building performance under weak to strong wind loading conditions. Field observations provided strong evidence of partial and total roof and exterior wall failures that may have been initiated by breaches in the building envelope. These breaches lead to internal pressurization, significant load increases, and failures. The structural elements, roof and wall coverings, garage doors, entry doors, and windows that are exposed to strong or violent tornado vortex winds are not expected to survive. However, on the periphery of strong and violent tornado tracks and in the path of weak tornado vortices where the wind speeds were near or below design wind speed conditions prescribed in model building codes, the performance of these elements was less than expected. If the structural and non-structural envelope elements are suitably designed and tested to meet the wind loads derived from ASCE 7-98, and are appropriately installed, much of the damage on the periphery of strong and violent tornado tracks and in the track of the vortex of weak tornadoes would be significantly reduced. An exception is windborne missile-induced damage.

For residences, a significant contributor to catastrophic failures due to internal pressurization appeared to be the failure of single skin, non-insulated, and non-reinforced double width garage doors. Breaches of windows and entry doors also caused significant damage to the residential building through internal pressurization. However, where wind speed and direction did not produce high local loads on the building, the breach of a window or door might not be as dramatic as that associated with a larger breach such as a garage door. Preliminary investigations determined that most garage doors were not rated or tested for wind pressures calculated from the design wind speeds indicated in the current 1995 CABO One- and Two-Family Dwelling Code. Although this code does not specifically address designing garage doors and other architectural finishes for the wind speeds prescribed in the code, if these doors had been designed for the design wind speed indicated, damage in the inflow areas of the weak and strong tornadoes might have been significantly reduced.

7.1.1.3 Roof and Wall Coverings

The observed wind performance of T-lock asphalt shingles was not significantly better than that of three-tab or laminated strip asphalt shingles. Wind-induced damage to T-lock shingles was observed on roofs that were likely exposed to wind speeds that were in the range of design conditions (i.e., 70-80 mph fastest mile sustained or 90-mph 3-second peak gust).

Vinyl siding offered very limited resistance to low-energy windborne missiles. The vinyl siding investigated also offered limited wind load resistance. Although the nailing patterns were erratic and the distance between nails was relatively large, it is difficult to envision that the investigated products had sufficient strength to meet the wind loads derived from the 1997 UBC, 1996 NBC, 1997 SBC, or ASCE 7-98.

7.1.1.4 Masonry Veneer

The BPAT observed extensive brick veneer loss in homes of all ages, indicating inadequate composite action caused by a failure of the brick ties. Masonry veneer and framed walls should provide some level of composite action to resist wind forces, even though this is not considered explicitly in design. However, to act as a composite section, the connection between the veneer and backup wall (normally galvanized steel brick ties) needs to be maintained. Extensive brick veneer loss in homes of all ages indicates a failure of the brick ties, a failure of the nailing of the ties to the wood framing, or failure of the mortar bond to the ties. Even though some walls appeared undamaged, they could be deflected with hand pressure.

Many of the failures observed stemmed from brick-tie to mortar bond failure. In a majority of cases of masonry veneer loss, either corrugated or scalloped-edge galvanized steel brick ties remained attached to wall studs with one 6d common nail (withdrawal load = +/- 30 lb times a safety factor of 4 or 5), when a rigid insulation board was used as wall sheathing. The bond between mortar and brick tie was often not sufficient to even exceed the withdrawal capacity of the tie nail. Therefore, there was inadequate bond between mortar and brick tie to resist the wind forces experienced. The 1995 CABO One- and Two-Family Dwelling Code specifies that the maximum horizontal spacing of brick ties is 24 in on center, and each tie shall support not more than 3.25 sq. ft of wall area. At the code-required spacing to support 3.25 sq. ft, the maximum wind suction pressure on the veneer prior to failure could not have exceeded 37 psf, unless the rigid brick facing failed prior to the deflection required to allow the brick tie to develop its full capacity.

There were a few instances of nail pull-out at brick ties fastened to wall studs. Therefore, in these cases, the wind suction pressure exceeded the withdrawal strength of the one nail holding the brick tie. Causes of failure could be insufficient nail length or diameter, low withdrawal resistance, or ties having too high a tributary area. There were many instances of brick ties spaced at greater distances than stated in the building codes. Proper connection of brick masonry to a wood frame wall system is shown in Figure 7-2.

The 1995 CABO One- and Two-Family Dwelling Code also requires that if sheet metal ties are used, they shall not be less than No. 22 U.S. gauge by 7/8 in corrugated. The most common form of tie was a 7/8-in wide galvanized steel strip with a ¼-in deep scalloped edge on each side (steel strip was 3/8 in wide, with very minor corrugation less than 0.5 mm). There was

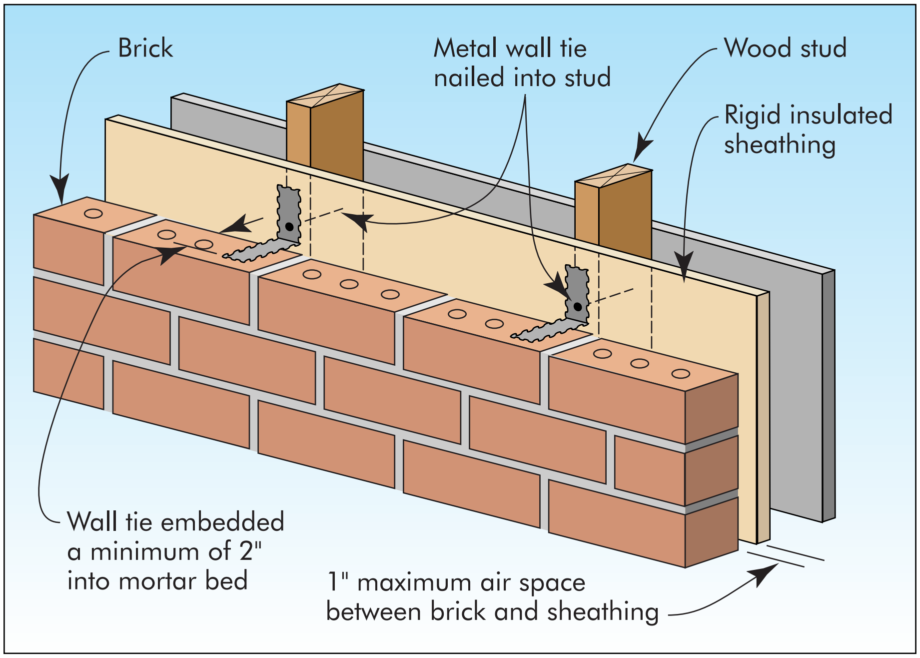


FIGURE 7-2: Illustration of a proper connection of brick masonry to a wood frame wall system.

notable absence of compliance with these specifications in what could be considered a random sample of homes impacted by the tornadoes.

Because failures of brick masonry veneer were found at homes from less than 1 year old to over 20 years old, mortar bonding strength did not seem to vary with age. There were several instances of loose brick on the ground with no mortar attached or only attached to one side. Mortar bond strength was inadequate to bond bricks together and to bond mortar to brick ties to resist negative (suction) wind pressures experienced. Some possible causes could be from a weak mortar mix, a too dry mortar, or use of low porosity brick.

There were several instances where an air space between brick veneer and plastic foam insulation sheathing was 1.5 in or more, which reduced embedment length of brick ties in mortar joints to 1 in or less. Some model building codes specify 1-in maximum air space or grouted space, and 1.5 in minimum embedment of brick tie into mortar.

The BPAT observed masonry chimneys that had fallen on roofs causing considerable damage to houses that otherwise had very minor wind damages. This damage placed the occupants of the house at a significant risk of death or injury from falling masonry debris. Calculations performed by the BPAT indicated the wind speeds necessary to cause the chimney failures were as low as 75-85 mph (fastest mile).

7.1.2 Manufactured Housing

The design and construction of manufactured housing has been governed since 1976 by Federal preemptive standards that are enforced by the U.S Department of Housing and Urban Development (HUD) under Federal Regulation and through a Monitoring and Enforcement Contractor, the National Conference of States on Building Codes and Standards (NCSBCS). Recently, the HUD Standard has been placed under a consensus process administered by National Fire Protection Association (NFPA).

Wind resistance standards for manufactured housing differ from and are less than model building code provisions and standards for conventional site-built and modular or panelized construction. Minimum wind pressures for design of all homes located outside of hurricane coastline areas are 15 psf for horizontal wind loads and 9 psf for net uplift load (equivalent to about a 65-mph fastest-mile wind speed, less than the 70-mph fastest-mile wind speed specified in the CABO One- and Two-Family Dwelling Code, and less than the 70-to 80-mph fastest-mile wind speed specified in the 1997 UBC for this area of the country). Explicit engineering or test-based performance provisions require a minimum safety factor of 1.5 relative to these design loads. However, simplified design wind loads and the required safety factors do not consider the rare but significant overload that may occur due to inflow winds of violent and strong tornadoes or direct strike by the vortex of weak tornadoes. Design loads are primarily associated with the level or risk that is associated with extreme thunderstorm winds.

Installation and setup of manufactured housing, including foundations, ground anchors, and strapping or cables, are enforced by state and local officials. The Federal standards only address the design of the overall anchoring and tie-down systems and require that they be designed by a qualified professional.

In general, manufactured housing did not resist wind forces as well as conventional site-built detached single-family dwellings for inflow winds of violent and strong tornadoes and vortex winds from all tornadoes. This was primarily because of inadequate fastening of roof systems to wall systems and inadequate resistance to uplift and overturning provided by anchorage and tie-downs. An exception to this was the observed improved performance of newer manufactured home especially double-wide models that had been installed on permanent foundations.

7.1.2.1 Foundations

Permanent foundations performed better in resisting lateral wind loads than did ungrouted and unreinforced CMU piers having wood leveling shims under the chassis beams. However, the BPAT observed that connections of chassis and perimeter joists to permanent foundations were inadequate to resist the moderate wind uplift and overturning forces generated at the periphery of most tornado tracks investigated. It is difficult to make positive connections between the units and the non-permanent foundations. Furthermore, these connections are difficult to inspect once the units are installed. In addition, local building officials who were interviewed by the BPAT did not seem to be aware of manufacturers' installation or setup instructions with specific connection requirements for permanent foundations.

7.1.2.2 Anchors

Depths and locations of helical ground anchors and soil conditions varied considerably from site to site. Ground anchors pulled out of the soil because of inadequate depth, or steel anchor shafts bent over from lateral wind forces, thus leading to failure of the superstructure. Some ground anchors were installed at an angle with the base under the home, leading to bending of the shaft from lateral wind forces. Thus, deformation of the anchor and strapping arrangement could allow significant movement (vertically and horizontally) prior to developing substantial resistance to wind loads. Most observed ground anchors did not appear to comply with requirements of the Federal Manufactured Home Construction and Safety Standards (MHCSS), which state the following:

> "Sec. 3280.306(f) Anchoring equipment shall be capable of resisting an allowable working load equal to or exceeding 3,150 pounds and shall be capable of withstanding a 50 percent overload (4,725 pounds total) with out failure of either the anchoring equipment or the attachment point on the manufactured home."

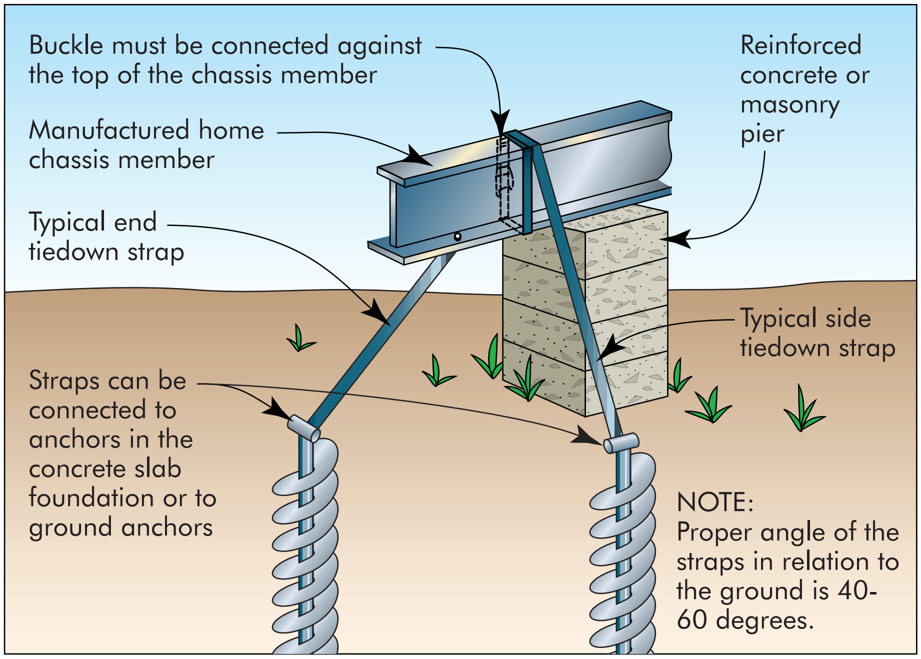
In 1994, the standard was revised to add Sec. 3280.306(b)(2) For anchoring systems, the instructions (provided by the manufacturer) shall indicate:

> "(ii) That anchors should be certified by a professional engineer, architect, . . . as to their resistance, based on the maximum angle of diagonal tie and/or vertical tie loading . . . and angle of anchor installation, and type of soil in which the anchor is to be installed; (iv) That ground anchors should be installed to their full depth, and stabilizer plates should be installed to provide added resistance to overturning or sliding forces."

7.1.2.3 Strapping

Galvanized steel strapping in several instances failed in tension from wind uplift and overturning forces, or became loose when the home moved laterally from wind forces. An example of a properly restrained chassis member is shown in Figure 7-3. In addition, connections of strapping to chassis beams often came loose and were on the ground, and there was no positive bolted or welded connection. The apparently premature failure of these ties was related to the number of ties, location of first ties from end of

FIGURE 7-3: Illustration of a proper connection of a manufactured home to a dry-stacked CMU foundation using straps only; L-clips are not illustrated here.



chassis, and tensile strength or ductility of steel. Several of the following provisions of the Federal MHCSS appeared to not be consistently complied with, possibly leading to failure:

> "Sec. 3280.306(c)(1) The minimum number of ties required per side shall be as required to resist the design loads . . ."
>
> (2) Ties shall be evenly spaced as practicable along the length of the manufactured home with not more than 8 feet open-end spacing on each end." (This provision was revised in 1994 to require not more than 2 feet open-end spacing on each end.)
>
> The current material specification for manufactured home strapping "Strapping, Steel, and Seals, with Notice #1 and Amendment #2, only Type 1, Finish B, Grade 1 of the plating/coating sections," was Federal Spec. FS QQ-S-781H-1974 with 1977 amendments. (This was revised in 1994 to "Standard Specification for Strapping, Flat Steel and Seals – ASTM D 3953-91").

7.1.2.4 Superstructure

Generally, newer manufactured housing units, particularly multi-wide units on permanent foundations, resisted straight-line inflow wind forces better than older single-wide units. Newer units are generally constructed of more conventional wall and roof framing, and connections between roof systems and walls, and walls to floors, provide load paths to transmit wind uplift, lateral, and overturning forces to the foundations. Internal shear walls, and bolted or steel strapped floors and roofs of multiple units at marriage walls provide a stiffer three-dimensional structure. Additional attention, however, needs to be paid to the design of uplift straps from roofs to walls and walls to floors, and to bolting of units to permanent foundations, similar to conventional site-built home construction in tornado-prone areas.

7.2 Non-Residential Property Protection

Visual observations indicated that non-residential structures were, with few exceptions, as vulnerable to damage as conventionally built residential construction. Many non-residential buildings received structural damage as a result of a lack of capacity in the load path to resist wind-induced uplift loads. Observed damage, however, was typically not as complete or devastating for non-residential buildings that were exposed to similar vortex winds of violent and strong tornadoes as that observed in residential construction. This was primarily due to the engineering that is required by model building codes for non-residential buildings and that is not typically required for one and two family residential buildings.

Non-residential construction in Oklahoma is currently required to be designed per 1996 NBC and non-residential construction in Kansas is designed per the 1994 and 1997 UBC, depending upon local jurisdiction. Although local municipalities have adopted some amendments, these amendments were not significant relative to the structural issues discussed in this report. For current construction, these model building codes provide guidance for loads other than gravity loads. However, engineering standards such as ASCE 7-98 provide better structural and non-structural guidance for determining design wind loads than these newer model building codes. Although designing for tornadic wind events is not specifically addressed in any of these newer model building codes or standards, constructing non-residential buildings to these codes and standards would improve the strength of the buildings. Building to ASCE 7-98 would have reduced or minimized damage in areas that were affected by the inflow winds of all tornadoes and reduced the damage observed where vortices of weak and possibly strong tornadoes impacted non-residential construction.

7.2.1 Load Path

Although non-residential construction is currently designed to specifically consider some wind load resistance, in many cases, a lack of attention to uplift and lateral loads resulted in failure to provide a continuous load path and greatly increased damage to the buildings. In many cases, structural damage would have been reduced if adequate uplift resistance had been provided to steel roof joists and metal roof deck systems. Additional resistance to uplift could have significantly reduced damage to engineered construction on the periphery of strong and violent tornadoes or in the vortex of a weak and possibly strong tornado track.

Continued construction with materials such as URM that is capable of carrying gravity loads, but unable to carry uplift loads, will continue to lead to wall and roof failures during moderately high wind events. Better attention to the design of and selection of materials for connections throughout the structural system will also minimize and reduce the number of failures that are currently observed in non-residential construction after moderately high wind events such as along the periphery of strong and violent tornadoes or in the vortices of weak and possibly strong tornadoes.

After roof decking and other parts of the structure were blown loose by the wind, these pieces became windborne missiles that created additional damage to nearby structures. Greater attention to attachment of perimeter wood nailers, copings and metal edge flashings, and perimeter attachment of metal roofing panels will enhance performance of roof coverings and reduce the debris on the periphery of strong and violent tornadoes and in the vortices of weak tornadoes.

7.2.2 Increased Load Caused by Breach of Envelope

The BPAT observed that the failure of commercial rollup (overhead) doors, depending on their location, may initiate or contribute to major failures of primary structural systems. Observations suggest that overhead doors failing near building corners may significantly contribute to catastrophic failures of exterior walls and roof systems. This is particularly true for pre-engineered metal (light-steel frame) buildings that typically have little redundancy in their load transfer paths. For buildings that have several interior rooms or partitions, the propagation of internal pressures may be hindered and collateral damage to exterior walls minimized.

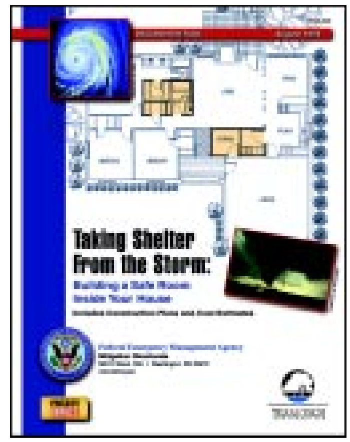
Breach of the building envelope was observed to result in extensive collateral damage to non-residential buildings. Garage doors and large windows were particularly vulnerable. All garage and rollup doors should have adequate strength to resist wind loads derived from ASCE 7-98, which provides design guidance for determining wind loads on non-structural elements such as garage doors and windows. Also, owners of buildings that use EIFS for exterior walls should be advised by the building designer that, although the wall has the appearance of concrete, it offers minimal resistance to high wind pressures and windborne missiles unless the EIFS is installed over concrete or reinforced CMU.

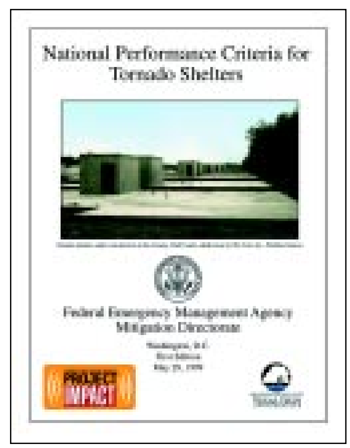
To reduce the number of windborne missiles generated from roofs on essential facilities (e.g., hospitals) and buildings such as schools, aggregate and paver surfacing should not be used. Aggregate and paver surfacing can be picked up by winds and cause injury or death and significant damage to architectural finishes, windows, and doors.

Protection of windows from wind pressures and windborne debris was not extensively investigated by the BPAT. However, it is important to consider protecting glass in essential facilities. Laminated glass and shutter protection systems can offer substantial protection from modest-energy windborne missiles. Laminated glass has the potential to offer significant occupant protection along the periphery of strong tornado tracks and in the vortex of weak tornadoes and is a permanent protection device that does not need warning time to be installed, which can be a problem with many storm shutter systems.

7.3 Personal Protection and Sheltering

The best way to reduce loss of life and minimize personal injury during any tornadic event is to take refuge in a specifically designed tornado shelter. Although improved overall construction may reduce damage to buildings and contribute to safer buildings, an engineered shelter is the only means of providing individuals with near absolute protection from strong and violent tornadoes.





7.3.1 Residential Shelters

The residential shelters observed by the BPAT included aboveground in-residence shelters and storm cellars. Although the aboveground in-residence shelters provided safety for the occupants, no direct windborne missile strikes were recorded on the shelter doors that the BPAT was able to locate and visit. The doors observed were light gauge hollow metal with a single deadbolt locking device, which is less than the 14 gauge hollow metal door held by three hinges and three deadbolts, as required in *FEMA 320: Taking Shelter From the Storm: Building a Safe Room Inside Your House* (see a summary in Appendix C) and *FEMA's National Performance Criteria for Tornado Shelters* (see Appendix D).

Assuming proper construction and location outside flood-prone areas, storm cellars offered safety during severe wind events. Observed problems with storm cellars included lightweight doors and hardware, poor maintenance, and unprotected ventilators. Storm cellars are typically not fully waterproofed and, therefore, can be damp, musty environments with poor ventilation. Ventilators were not constructed of heavy gauge steel or protected by heavy gauge shrouds or saddles that would have prevented their removal by windborne debris or extreme winds during a tornado, allowing the subsequent entrance of free-falling missiles and debris through the remaining openings in the shelter roof.

7.3.2 Group Shelters

The BPAT observed group shelters at a manufactured housing rental development and at a plastics manufacturing plant in Haysville, Kansas. A rental development of manufactured homes provided shelters at a rate of one shelter per four homes. Shelters were located in close proximity to the homes and were accessible by the occupants, but none of these shelters were easily accessible to persons with disabilities. All group shelters were below or partially below ground and required access by stairs.

The group shelter at the plastics manufacturing plant functions daily as a conference room and lunchroom. On May 3, 1999, it performed its third function as a tornado shelter. Although the building housing the shelter was not significantly damaged (one area suffered roof damage), other buildings that are part of the plant complex suffered substantial damage. The workers at the plant when the tornadoes struck and who were able to utilize the shelter were uninjured.

7.3.3 Community Shelters

The BPAT observed two community shelters that were utilized during the May 3 storm. One shelter was located in a manufactured housing park in Wichita, Kansas. The second shelter was located in Midwest City at the Midwest City High School gymnasium. Both were partially belowground shelters and suffered from problems of moisture infiltration, mustiness, poor ventilation, and poor exterior doors and hardware. Other concerns common to community shelters include travel time required to access the shelter, accessing the shelter when the shelter is locked, accessibility for persons with disabilities (ADA compliance), and rules for gaining admittance.

7.3.4 Other Places of Refuge

Not all buildings, residential or non-residential, have designated tornado shelters or staffs with tornado plans for implementation during an event. Subsequently, in buildings without designated shelters or places of refuge, occupants are left on their own to identify places of refuge appropriate in a tornado event. The observations of the Oklahoma and Kansas tornadoes, as well as other tornado events, indicate that small interior rooms within buildings often survive when the other portions of the building are destroyed. Rooms such as closets beneath staircases, small bathrooms, or other small interior rooms are the preferred place of refuge when no hardened shelter is provided in the building.

Basements can also offer another alternative place of refuge. However, basements demonstrated vulnerability from windborne missiles through windows, window wells, and through the wood floor/ceiling structure. Although not observed in this storm event, previous observations have shown unreinforced basement walls collapsed as the result of the floor/ceiling diaphragm displacement by the winds of the tornadoes.

The BPAT visited public use facilities during the field investigations to determine how these facilities addressed tornado threats that affect the users of the facilities. The team interviewed staff at schools, day-care centers, nursing homes, and churches, and found that not all public use facilities had a formalized tornado emergency refuge plan. Additionally, not all public facilities had a NOAA weather radio in continuous operation to monitor storm events that may lead to a tornado. When tornado plans were implemented by a facility, these plans were often not conspicuously posted and the plans were not always exercised as drills so building occupants could become familiar with the plan. It is unclear whether all plans allow sufficient time for the building occupant type (e.g., children, elderly, etc.) and if the shelter had adequate capacity for the quantity of building occupants and others who may attempt to seek shelter in the planned place of refuge.

The BPAT also observed a significant number of destroyed cars and trucks in the debris of the tornadoes in Oklahoma and Kansas. Cars and trucks do not provide a safe refuge from the winds of any tornado and should not be used as a shelter.