Reconstructing Non-Residential Buildings After a Tornado

FEMA

TORNADO RECOVERY ADVISORY *RA8, August 2011*

Purpose and Intended Audience

The purpose of this advisory is to identify which standard of construction should be considered for repairing buildings damaged in high-wind events (see Figure 1). The intended audience for this Tornado Recovery Advisory is architects, engineers, builders, and building owners. This advisory explains how to determine which building code is appropriate, incorporating best practices into construction, common building failures and how to avoid them, and resources for installing shelters and safe rooms.

This Recovery Advisory Addresses:

- Determining the appropriate building code
- Incorporating best practices
- Common building failures and recommendations to mitigate them
- Protecting building occupants by installing shelters and safe rooms

Figure 1: A business damaged by roof damage and water intrusion from a weak tornado

Determining the Appropriate Building Code

Building codes are used in many jurisdictions as a minimum standard of construction practice to provide occupants with an improved level of safety for natural hazards, fire, and air quality. Building codes are instituted when either the State or a local jurisdiction adopts them. Most building codes are based on a model building code.

The current prevailing model building code is the family of International Building Codes produced by the International Code Council (ICC). Codes are typically updated on a predetermined cycle of reviews. Codes from the ICC are updated on a 3-year cycle, and most governmental bodies are using a code based on the 2003, 2006, or 2009 ICC building codes. At the time of this publication, the 2012 ICC building codes have been published, but few local jurisdictions have adopted this version of the code yet. Building codes typically use a performance approach, which means that construction practices are based on a specific building's design and location. In addition to construction methods, building codes also usually dictate administrative practices such as permitting, reviews, and inspections.

Design loads are calculated using design standards or other design guidance referenced by the codes. With only a few exceptions, the International Building Code (IBC) requires the use of American Society

Standard of Care

Critical facilities have facility and operational requirements that should be met in addition to building code requirements. Building codes do not stipulate expected building performance for tornadoes. The designer should discuss expectations regarding acceptable building damage, operational requirements, and occupant safety with the facility owner to ensure the full range of requirements is considered.

of Civil Engineers (ASCE) 7, *Minimum Design Loads for Buildings and Other Structure*, to calculate wind and other loads on buildings.

Even if there is no building code enforced in the jurisdiction where you are building, it is still important to construct to a building code to provide a minimum standard of care. While building permits in these areas may be required, building inspections may not be conducted, and it may be necessary to hire a qualified professional to conduct inspections to verify that the work is being done properly. The latest version of the International Codes (2012) is recommended as a minimum code.

Incorporating Best Practices

Best practices are design or construction practices that go beyond minimum code requirements to improve building performance. Four options should be considered for increasing the design loads on buildings: increasing the occupancy category, increasing the design wind speed, designing as a partially enclosed building, or designing as if in a hurricane-prone region. Each of these methods will effectively result in a building that can withstand higher wind pressures and/or improve debris impact resistance. Increasing the building occupancy category typically only results in minimal increases in wind resistance; the other methods will improve building performance more substantially.

Increasing Design Wind Speed: ASCE 7 promulgates the minimum loading requirements for building design. To improve wind resistance, higher wind loads can be calculated using the calculations in ASCE 7. For an Occupancy Category II building in a non-hurricane-prone area, the standard design wind speed is 90 mph, but increasing the design wind speed to 115 mph will result in a 63 percent increase in velocity pressures and be consistent with similar buildings using the ASCE 7-10 wind speeds. In addition to using a higher design standard for loads, improved construction methods and materials can also improve building performance. Even small practices—such as slightly increasing reinforcing steel sizes and increasing development and lap splice lengths—can greatly improve building performance.

Designing as a Partially Enclosed Building: In most cases, buildings are designed to function as an enclosed structure, meaning that it is designed to only allow minimal air into the building even during a high wind event. Once windows or doors are broken by windborne debris, wind pressures can greatly increase and cause significant structural damage to the building. Designing exterior and load-bearing walls, roof systems, and the foundation to resist the increased wind pressures will result in significant improvements to the building structure performance. The recent edition of the International Building Code has tables and charts for these wind speeds and wind pressures that can aid in building detailing.

Designing as if in a Hurricane-Prone Region: The design strategies and building materials used in hurricane-prone areas result in buildings that are more resistant to most tornadoes (i.e., Enhanced Fujita [EF] 0–EF3). With appropriate strengthening and selection of building materials and systems, both the potential for disruption of operations and the cost of repairs after a tornado event can be reduced. If the costs associated with loss of function or business interruption are significant, then a higher standard of construction may be appropriate. Building performance can also be improved with engineering techniques introduced through some of the observations noted for critical facilities (see Recovery Advisory No. 6, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers* [FEMA 2011] for additional information).

Common Building Failures and Recommendations to Mitigate Them

Table 1 describes the typical failures observed after the 2011 tornadoes. The table also provides recommended practices to reduce these failures in buildings subjected to weak tornadoes and minimize them for buildings on the periphery of stronger tornadoes.

Table 1. Building Failures and Recommendations

Building Component	Typical Failure	Recommended Practice
Superstructure		
Pre-Engineered Buildings	Failure of endwall trusses and endwall truss bracing. 	Size the endwall trusses to resist wall loads and verify that anchor bolts are sized to resist lateral loading. (Source: FEMA 489)
Masonry Buildings	Collapse of unreinforced masonry walls. 	Fully grout walls and increase reinforcement to resist lateral loads and uplift loads on the roof system. (Source: FEMA P-424)
Roof Coverings and Roof Systems		
Ballasted Roofs	Ballasted roof systems can become wind-borne debris and damage surrounding objects. 	Select an alternative ballasting system or fully adhere ballast to the roof system. (Source: FEMA P-424)

Building Component	Typical Failure	Recommended Practice
Roof Truss Connections	Loss of roof trusses from uplift loads. Trusses typically fail at the connection with the wall system, either through poor grouting of anchor bolts or insufficient embedment. 	Improve connection of roof trusses to prevent failure from uplift loads. Verify that the load path is continued through the wall system into the foundation. (Source: FEMA P-424)
Double Tee Connections	Double tees shift due to uplift loads and failures at angle iron welds or insufficient anchor bolts, allowing the double tee to slip off the corbel. 	Ensure that anchor bolts provide sufficient strength to prevent uplift. (Source: FEMA P-424)
Gable End Walls	Insufficient attachment of gable end walls results in building pressurization, loss of the roof system, and possibly large sections of the building. 	Improve the gable end wall bracing details with additional connections and strengthen the load path. (Source: FEMA P-804)

Building Component	Typical Failure	Recommended Practice
Building Envelope		
Metal Sheeting	Loss of wall coverings due to insufficient girts. 	Increase framing between trusses to reduce loads on metal sheeting. Increase metal sheeting thickness to resist the potential for pulling off connectors. (Source: FEMA 489)
Brick Veneer	Wall failures resulting from insufficient brick ties. 	Increase number of brick ties, properly attach ties to the wall system, and sufficiently embed ties into the brick veneer. (FEMA P-499, Fact Sheet 5.1)
Exterior Insulation and Finishing System (EIFS)	Loss of large sections of EIFS due to impact of wind-borne debris. 	Reduce vulnerability of EIFS by using it in locations that are high enough to prevent damage from wind-borne debris. (Source: FEMA 424)
Rooftop Equipment	Damage to rooftop equipment, typically by wind-borne debris or as a result of insufficient anchorage. 	Protect exterior equipment from wind-borne debris. Evaluate connections to rooftop or slab. (Source: FEMA 424)

Building Component	Typical Failure	Recommended Practice
Roll-up Door Systems	Buckling of roll-up door systems, typically due to either positive or negative pressures. Door tracks and rollers can fail in high winds. 	Specify a door system for a higher wind speed than the minimum required by code. (Source: FEMA 489)

Two common building types that failed in the recent tornadoes were masonry buildings and pre-engineered buildings. Both of these building types are common and have aspects that put them at risk of significant damage in high-wind events.

Masonry Buildings: Masonry buildings can be constructed as either reinforced or unreinforced masonry. The most common failure noted is with unreinforced masonry walls. The lack of reinforcement makes them particularly susceptible to collapse. Unreinforced walls are commonly observed in older construction, but numerous examples of more recently constructed buildings that contained little or no reinforcement were observed after the 2011 tornadoes. Due to the lack of rigidity, unreinforced masonry walls tend to bow and collapse in high-wind events. The lack of reinforcement also makes the roof system particularly susceptible to uplift.

Failure of reinforced masonry walls is also not uncommon. The failures noted after the 2011 tornadoes were because the wall systems either contained too little reinforcement or insufficient splices or development lengths in the bars. The walls failed in large sections and pulled away from the foundation or slab due to insufficient splice designs. Poor connections between roof systems and wall systems were also noted to cause failure of reinforced masonry walls.

Pre-Engineered Buildings: Pre-engineered buildings can sustain significant loss of exterior sheeting, and in some cases, failure of the frame. Exterior sheeting should be sufficiently supported to resist deflection from high winds; additional girts and purlins may be required. Increasing the thickness of the exterior sheeting can reduce the potential for sheeting pulling off connectors. Endwall trusses of pre-engineered buildings should be designed to resist wall loads, and anchor bolts should be sized to resist uplift from high wind loads.

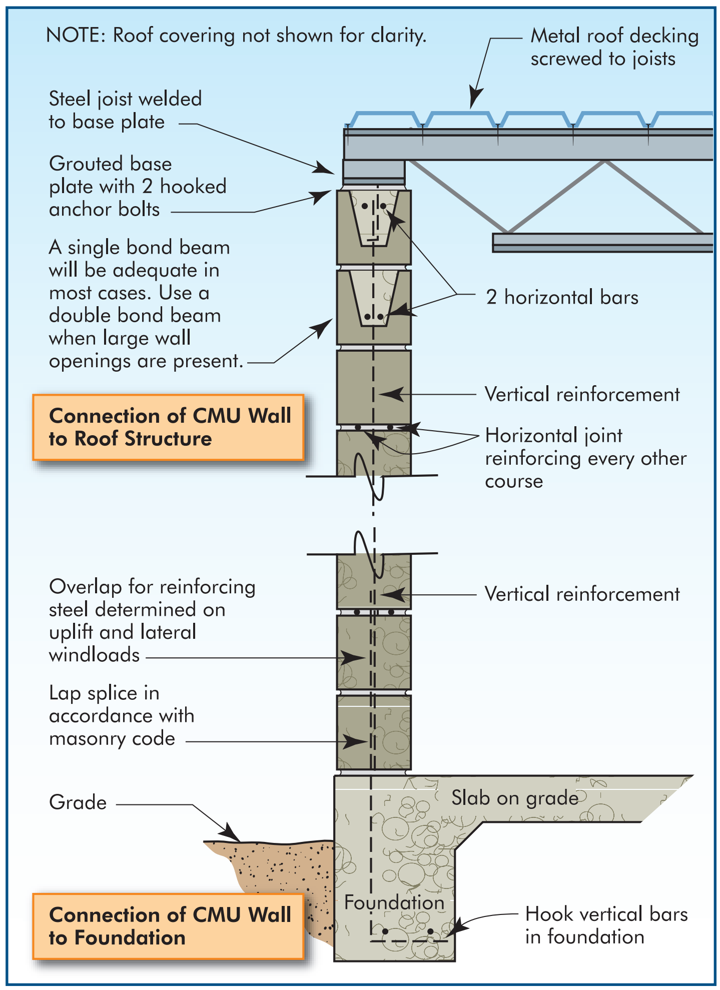

Figure 2: Example of a masonry wall detail, incorporating many construction best practices. Source: FEMA P-424, Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA 2010)

Protecting Building Occupants by Installing Shelters and Safe Rooms

When reconstructing after a tornado event, building owners may want to consider installing a safe room or shelter to protect occupants in the event of a future tornado. The distinction between a safe room and a shelter is described in the following text box.

More information on the construction of safe rooms can be found in the FEMA 2011 Recovery Advisory No. 2, *Safe Rooms: Selecting Design Criteria*.

A ***shelter*** (including safe rooms) is typically an interior room, space within a building, or an entirely separate building, designed and constructed to protect occupants from tornadoes or hurricanes. Shelters are intended to provide protection against both wind forces and the impact of wind-borne debris.

Useful Links and Resources:

Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers (ASCE), 2005. ASCE Standard ASCE/SEI 7-05.

Minimum Design Loads for Buildings and Other Structures, American Society of Civil Engineers (ASCE), 2010. ASCE Standard ASCE/SEI 7-10.

Recovery Advisories from the Tornado Mitigation Assessment Teams (MATs) for Alabama, Mississippi, Tennessee, and Georgia. FEMA. 2011. Available from: http://www.fema.gov/library/viewRecord.do?id=4723.

- Recovery Advisory No. 1, *Tornado Risks and Hazards in the Southeastern United States*
- Recovery Advisory No. 2, *Safe Rooms: Selecting Design Criteria*
- Recovery Advisory No. 6, *Critical Facilities Located in Tornado-Prone Regions: Recommendations for Architects and Engineers*

Taking Shelter from the Storm: Building a Safe Room For Your Home or Small Business *(FEMA 320), August 2008, 3rd Edition.* http://www.fema.gov/library/viewRecord.do?id=1536

Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds (FEMA P-424), 2010. http://www.fema.gov/library/viewRecord.do?id=1986

Building Performance Assessment Report. Oklahoma and Kansas, Midwest Tornadoes of May 3, 1999 – Observations, Recommendations and Technical Guidance (FEMA 342), October 1999. http://www.fema.gov/library/viewRecord.do?id=1423

Design and Construction Guidance for Community Safe Rooms (FEMA 361), August 2008, 2nd Edition. http://www.fema.gov/library/viewRecord.do?id=1657

Home Builder's Guide for Coastal Construction (FEMA P-499), December 2010, Second Edition. http://www.fema.gov/rebuild/mat/mat_fema499.shtm

Wind Retrofit Guide for Residential Buildings (FEMA P-804), December 2010. http://www.fema.gov/library/viewRecord.do?id=4569

ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500), June 2008. http://www.iccsafe.org/Store/Pages/Product.aspx?id=8850P08_PD-X-SS-P-2008-000001

International Building Code (IBC), ICC. 2009. Country Club Hills, IL.