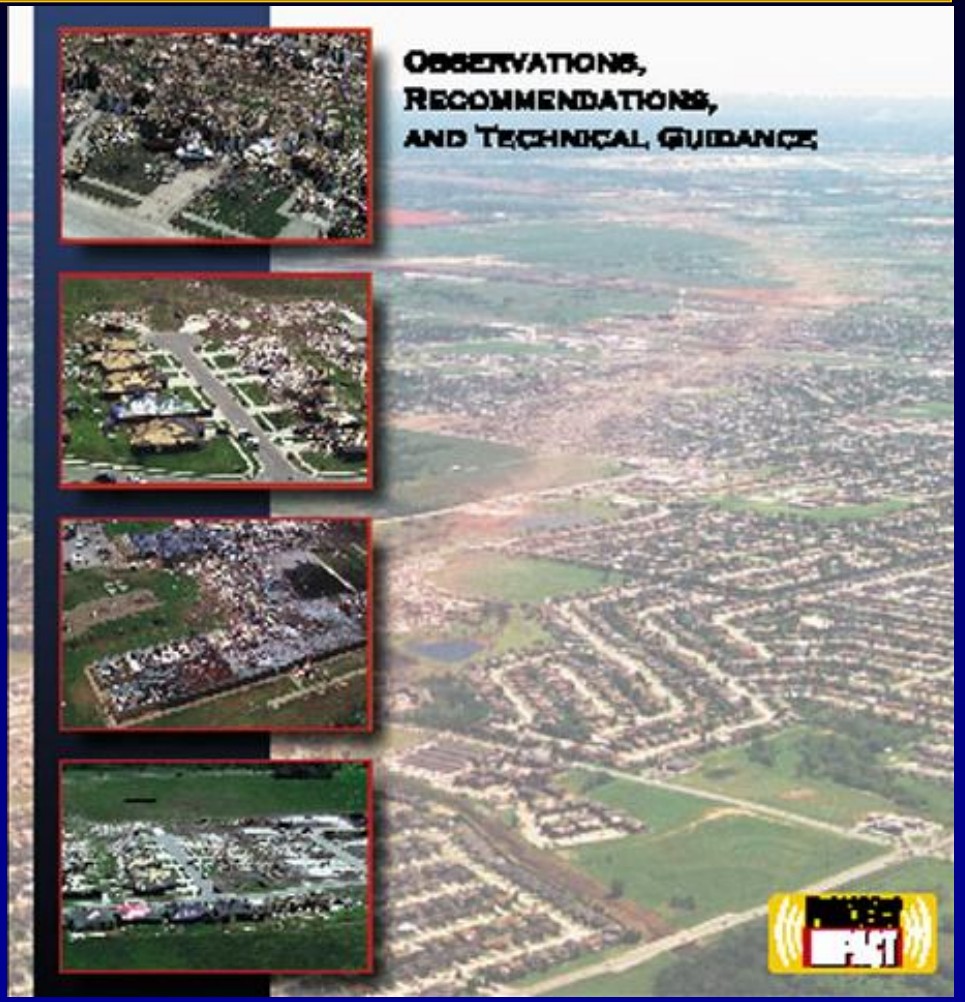
BUILDING PERFORMANCE ASSESSMENT TEAM

OKLAHOMA AND KANSAS

Midwest Tornadoes of May 3, 1999

OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE



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MITIGATION DIRECTORATE

FEMA Building Performance Assessment Teams

- **Team Members**
  - **Representatives of public and private sectors and expertise in:**
    - **structural and wind engineering**
    - **building design and construction**
    - **code development and enforcement**
    - **meteorology**

FEMA Building Performance Assessment Teams

- **Team Objectives**
  - Inspect damage to buildings
  - Assessment performance of buildings
  - Evaluate design and construction practices
  - Evaluate code requirements and enforcement
  - Make recommendations as necessary

Fujita Scale	BPAT Characterization	Windborne Debris	Property Protection	Personal Protection	Sheltering
F5 F4		Large, medium, and small airborne and rolling debris	Protecting entire buildings other than critical facilities is uneconomical and impractical.	Must have an area specifically engineered for extreme wind protection such as that described under "Sheltering".	To attain near absolute protection, a shelter should be constructed that is built in accordance with FEMA 320: *Taking Shelter From the Storm*, or the *National Performance Criteria for Tornado Shelters*, within or adjacent to a home, office, or business.
F3 F2		Medium and small airborne and rolling debris	Voluntary retrofitting and strengthening of homes and buildings with existing technology.	Additional strengthening of building structure and envelope may reduce risk; a specifically engineered area is suggested such as that described under "Sheltering".	
F1 F0		Small airborne and rolling debris	Constructing to newer building codes and standards strengthens buildings.	Constructing building envelope to newer building codes and standards, such as those described under "Sheltering", minimizes risk and injury.	


INFLOW
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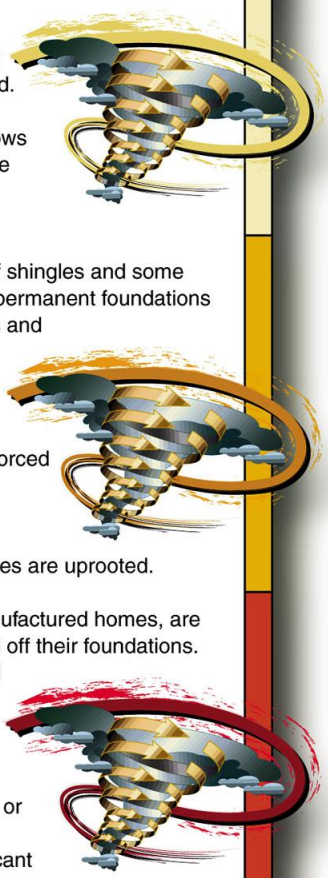
INFLOW
TORNADO PATH

Managing Risk	Damage Color Code	Description of Damage
The Threat to Property and Personal Safety Can Be Minimized Through Compliance With Up-To-Date Model Building Codes and Engineering Standards		Some damage can be seen to poorly maintained roofs. Unsecured light-weight objects, such as trash cans, are displaced.
		Minor damage to roofs and broken windows occur. Larger and heavier objects become displaced. Minor damage to trees and landscaping can be observed.
Property and Personal Protection Can Be Improved Through Wind Hazard Mitigation Techniques Not Normally Required by Current Building Codes		Roofs are damaged, including the loss of shingles and some sheathing. Manufactured homes, on nonpermanent foundations can be shifted off their foundations. Trees and landscaping either snap or are blown over. Medium-sized debris becomes airborne, damaging other structures.
		Roofs and some walls, especially unreinforced masonry, are torn from structures. Small ancillary buildings are often destroyed. Manufactured homes on nonpermanent foundations can be overturned. Some trees are uprooted.
Personal Protection Can Only Be Achieved Through Use of a Specially Designed Extreme Wind Refuge Area, Shelter, or Safe Room		Well constructed homes, as well as manufactured homes, are destroyed, and some structures are lifted off their foundations. Automobile-sized debris is displaced and often tumbles. Trees are often uprooted and blown over.
		Strong frame houses and engineered buildings are lifted from their foundations or are significantly damaged or destroyed. Automobile-sized debris is moved significant distances. Trees are uprooted and splintered.



Background

- Oklahoma / Kansas affected
  - May 3, 1999
  - Tornado warnings issued by NWS
  - 70 tornadoes affected both states
  - 4 violent (F4 or F5) tornadoes

Observations

- Residential Building Types Inspected
  - single and multi-family, one- to two-story
  - manufactured and modular homes
  - accessory structures
- Non- Residential Building Types Inspected
  - tilt-up pre-cast concrete with steel joists
  - load-bearing masonry walls with steel joist and pre-cast concrete hollow-core floor
  - pre-engineered buildings

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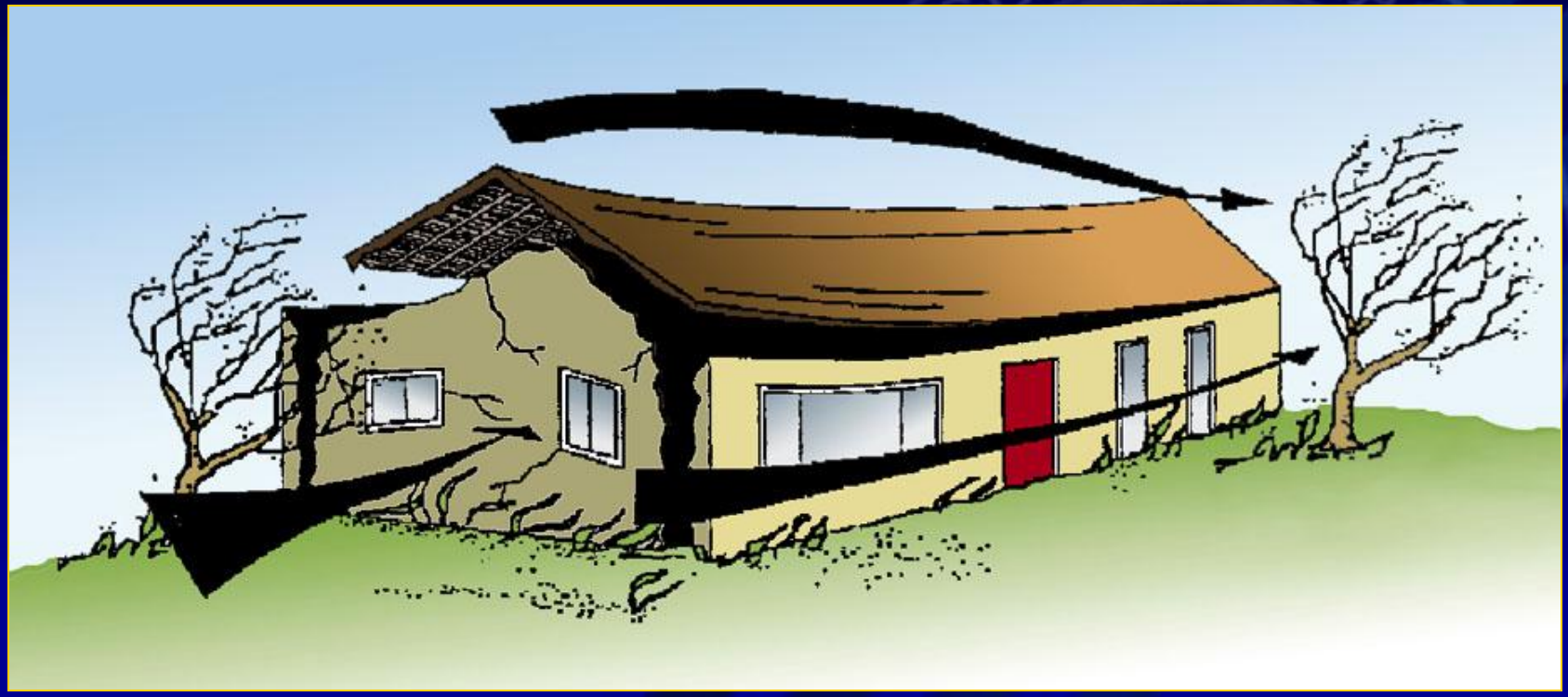

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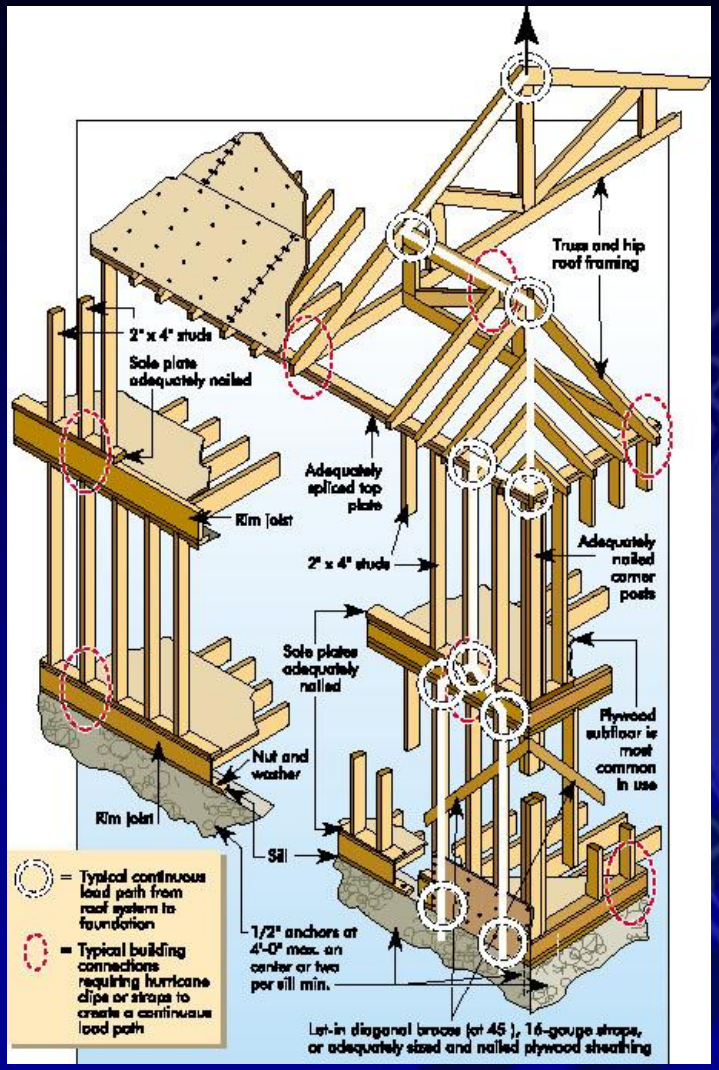
Observations

- **Windborne Debris**
  - debris can breach the building envelope that results in overpressurization of the building
  - debris can cause human injury to individuals who are not in a safe shelter
  - missiles often completely covered the ground
  - in many houses, the floors were covered with small tree branches and fragments of broken framing members

Missile Size	Typical Debris	Associated Damage Observed
Small	Aggregate roof surfacing, pieces of trees, pieces of wood framing members, bricks	Broken windows, doors, and other glazing, some light roof covering damage
Medium	Appliances, HVAC units, long wood framing members, steel deck, trash containers, furniture	Considerable damage to walls, roof coverings, and roof structures
Large	Structural columns, beams, joists, roof trusses, large tanks, automobiles, trees	Damage to wall and roof framing members and structural systems

Observations - Residential

- Roof and Wall Sheathing
- Structural Connections
- Exterior Wall Coverings
- Garage Doors
- Windows and Doors
- Masonry Veneer / Chimneys
- Manufactured Housing


Truss and hip roof framing
2" x 4" studs
Sole plate adequately nailed
Adequately spliced top plate
Rim joist
2" x 4" studs
Adequately nailed corner posts
Sole plates adequately nailed
Plywood subfloor is most common in use
Nut and washer
Rim joist
Sill
= Typical continuous load path from roof system to foundation
= Typical building connections requiring hurricane clips or straps to create a continuous load path
1/2" anchors at 4'-0" max. on center or two per sill min.
Let-in diagonal braces (at 45), 16-gauge straps, or adequately sized and nailed plywood sheathing

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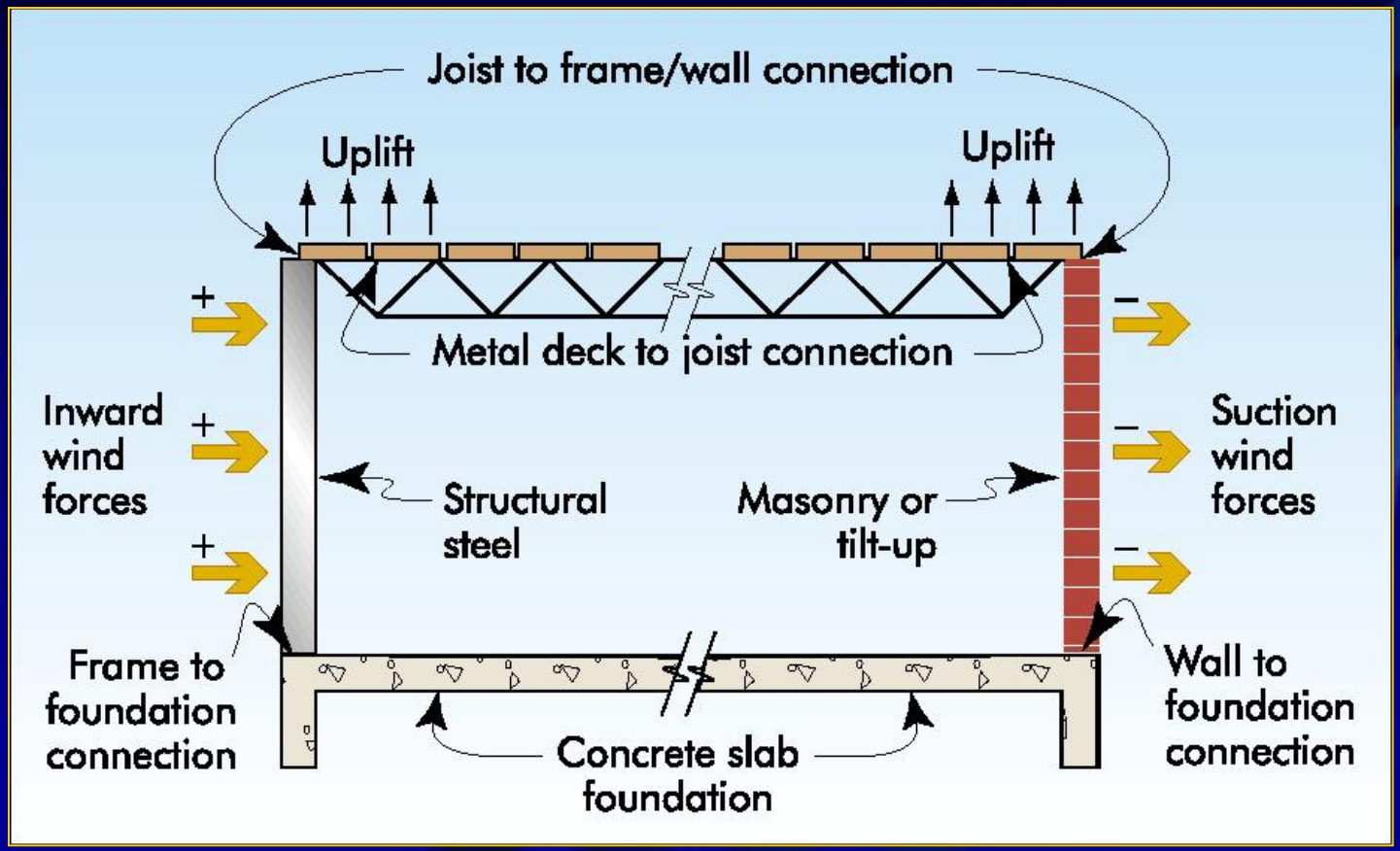
Observations - Non-Residential

- Continuous Load Path
- Increased Load
- Building Envelope


Joist to frame/wall connection
Uplift
Uplift
Metal deck to joist connection
Inward wind forces
Suction wind forces
Structural steel
Masonry or tilt-up
Frame to foundation connection
Wall to foundation connection
Concrete slab foundation

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Observations - Personal Protection and Sheltering

- Type of Shelters
- Use of Shelters
- Maintenance and Design Issues
- Shelter Accessibility
- Shelter Location
- General Observations

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MS. LENABURG

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Conclusions

- Residential Property Protection
- Non-Residential Property Protection

Conclusions

- **Building Codes**
  - **local codes do not incorporate wind speed design parameters used by 1997 UBC, 1997 SBC, 1996 NBC and ASCE-7-98**
  - **constructing homes to these standards would improve the strength of these structures**

Conclusions - Single and Multi-Family Homes

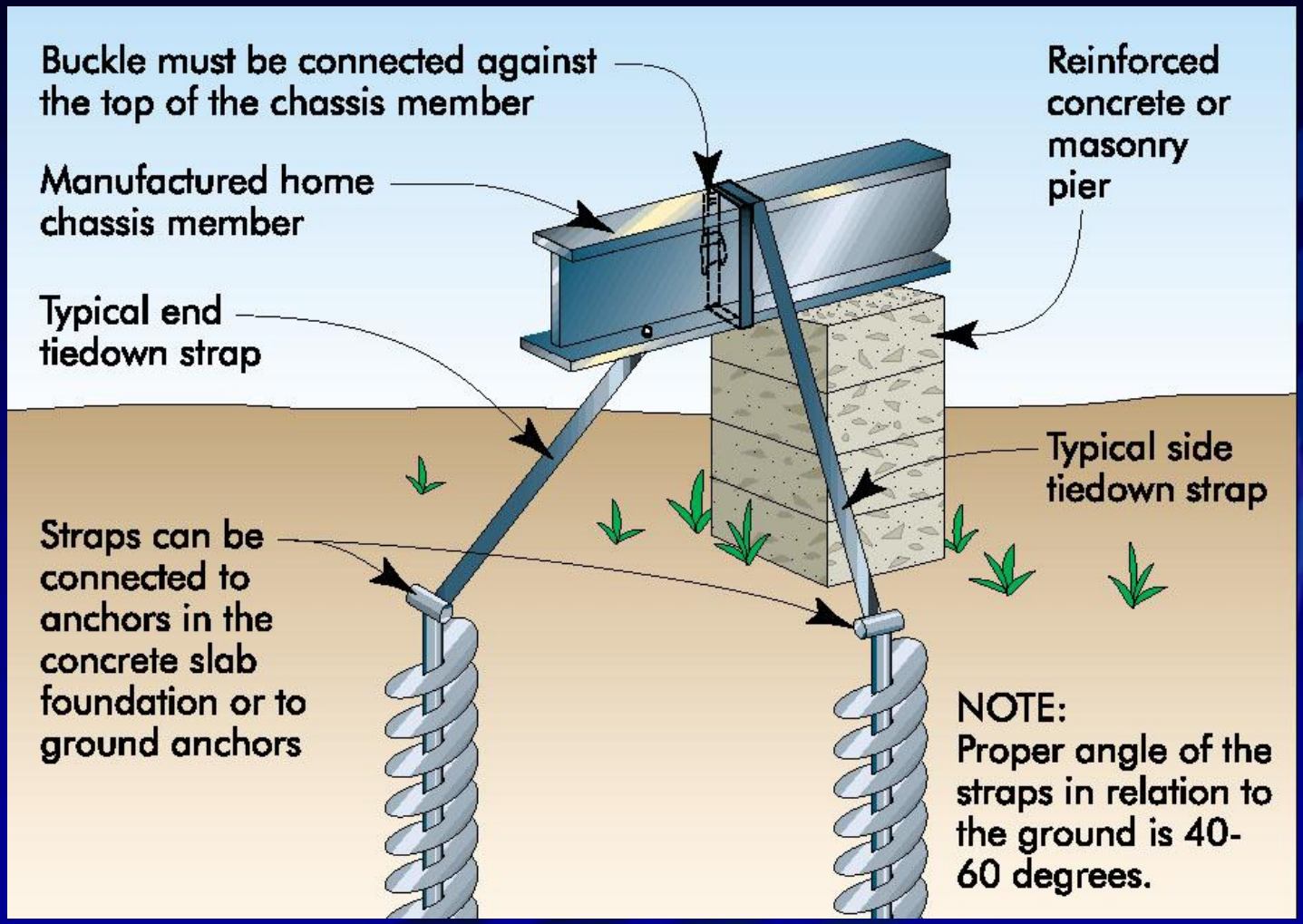
- **Load Path and Structural Systems**
  - **Foundations performed adequately**
  - **Where failures were observed, the deficiency was the connection of the structural systems to the foundation**

Conclusions - Single and Multi-Family Homes

- **Increased Load - Breach of Envelope**
  - internal pressurization is a major contributor to poor building performance
  - many building failures were caused by a breach in the building envelope
  - garage door failure a primary cause of building envelope breach

Conclusions - Manufactured Housing

- Manufactured housing did not resist wind forces as well as single-family homes
  - inadequate fastening of roof to wall systems
  - inadequate resistance to uplift and overturning provided by tie-downs


Buckle must be connected against the top of the chassis member
Manufactured home chassis member
Typical end tiedown strap
Straps can be connected to anchors in the concrete slab foundation or to ground anchors
Reinforced concrete or masonry pier
Typical side tiedown strap
NOTE:
Proper angle of the straps in relation to the ground is 40-60 degrees.

Conclusions - Non-Residential Structures

- Non-residential structures were as vulnerable to damage, but received less damage than residential structures
  - Primarily due to engineering required by model building codes

Conclusions - Non-Residential Structures

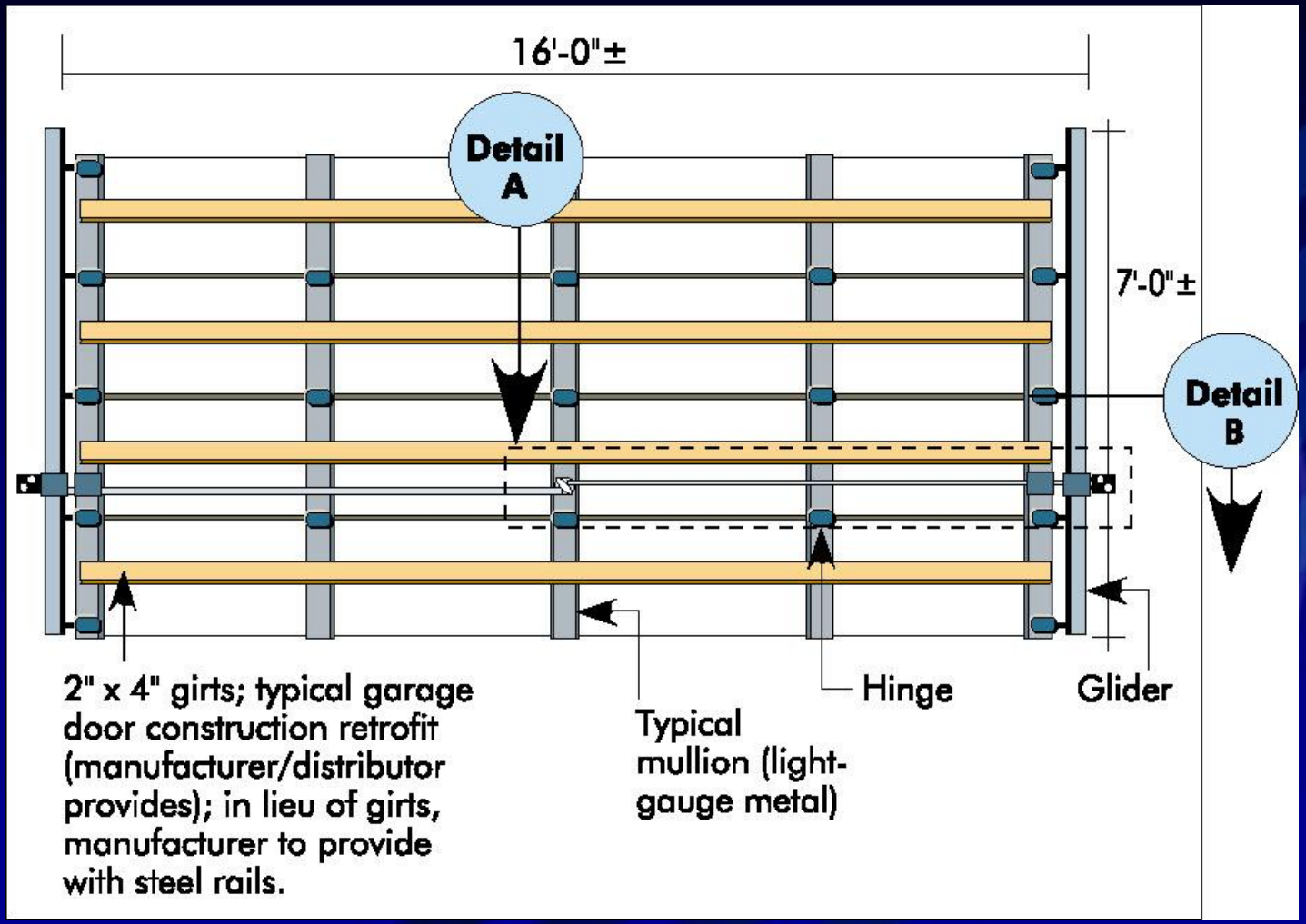
- Failure modes similar to residential structures
  - lack of attention to uplift and lateral loads
  - no continuous load path
  - breach of building envelope
  - failure of commercial rollup doors

Conclusions - Residential Shelters

- **Observed Problems:**
  - lightweight doors and hardware
  - poor maintenance
  - unprotected ventilators

Recommendations

- General recommendations for the rebuilding effort
  - design buildings to the most current codes and engineering standards
  - provide safe refuge by constructing engineered shelters


16'-0"±
Detail A
7'-0"±
Detail B
2" x 4" girts; typical garage door construction retrofit (manufacturer/distributor provides); in lieu of girts, manufacturer to provide with steel rails.
Typical mullion (light-gauge metal)
Hinge
Glider

Recommendations

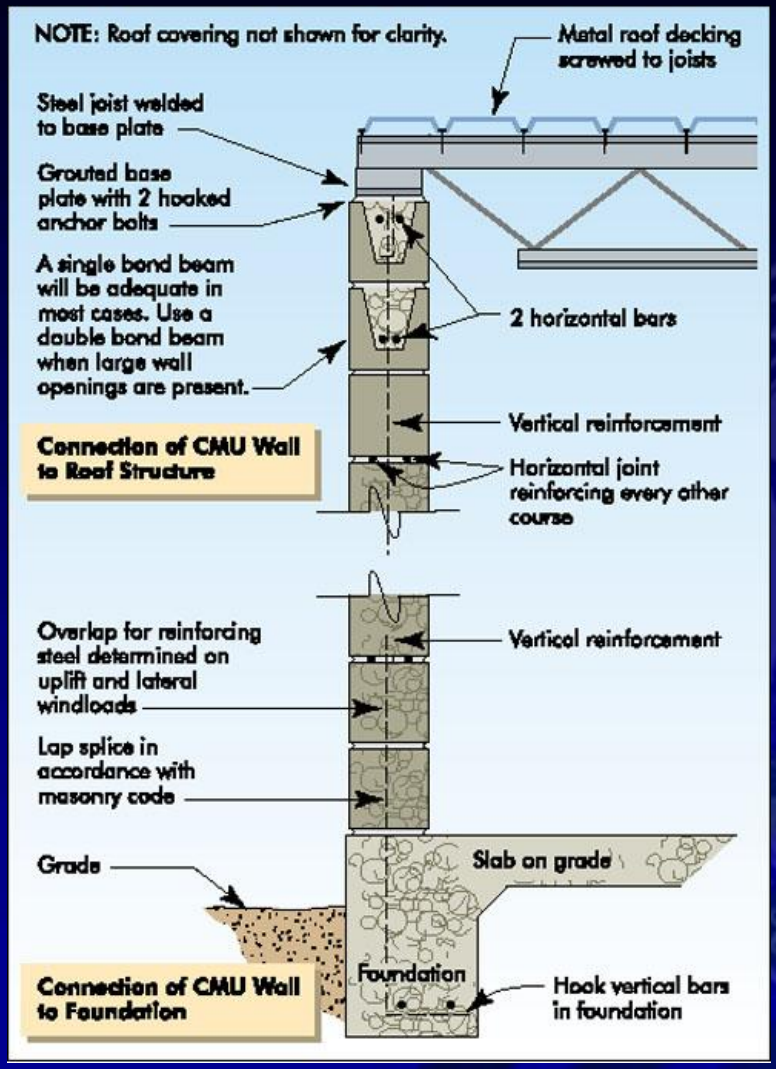
- **Manufactured Housing**
  - **HUD should review its standards and enforcement program**
  - **Consider permanently connecting the manufactured home to its foundation**

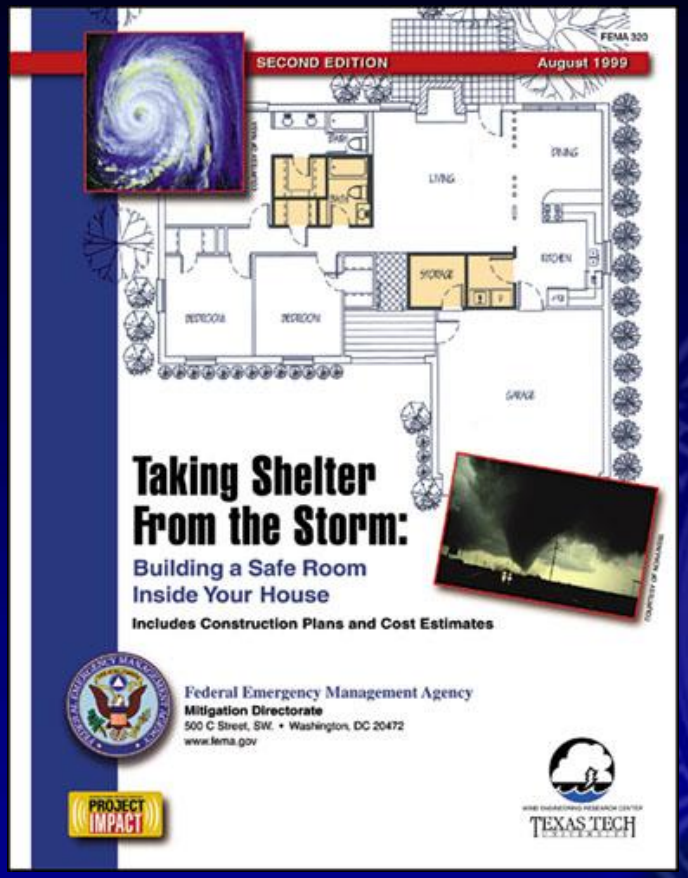
Recommendations

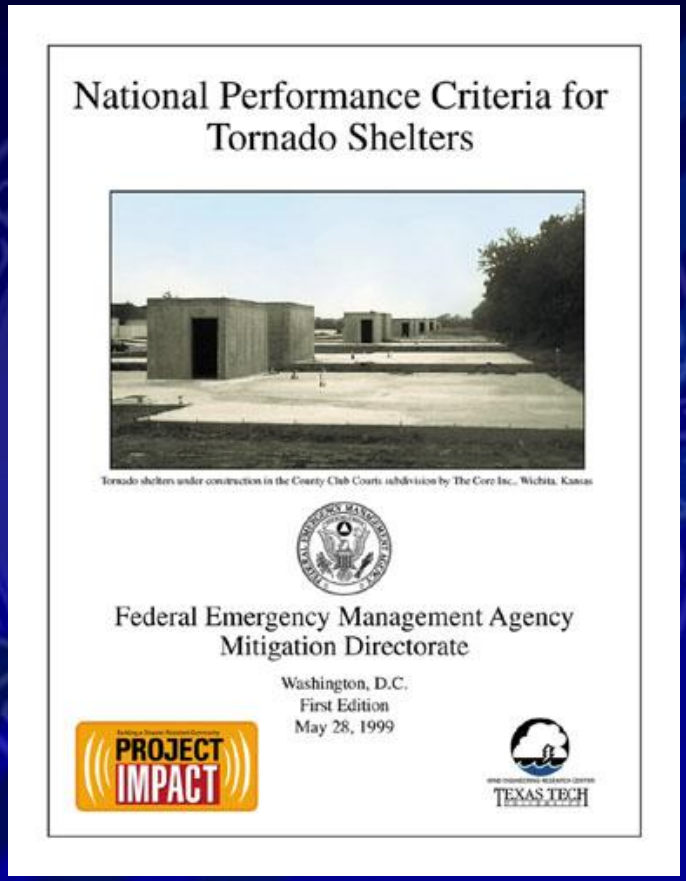
- **Non-Residential Buildings**
  - **Threaded fasteners to attach metal decking**
  - **Essential facilities should not use aggregate and paver roof surfacing**
  - **Enhanced wind design for roof coverings**

Recommendations

- **Non-Residential Buildings**
  - **Brick veneer walls system should be designed as “stand alone”**
  - **Masonry chimney design should change**
  - **Design guidelines for installation of laminated glass in essential facilities**


NOTE: Roof covering not shown for clarity.
Metal roof decking screwed to joists
Steel joist welded to base plate
Grouted base plate with 2 hooked anchor bolts
A single bond beam will be adequate in most cases. Use a double bond beam when large wall openings are present.
2 horizontal bars
Vertical reinforcement
Horizontal joint reinforcing every other course
Connection of CMU Wall to Roof Structure
Overlap for reinforcing steel determined on uplift and lateral windloads
Vertical reinforcement
Lap splice in accordance with masonry code
Grade
Slab on grade
Foundation
Hook vertical bars in foundation
Connection of CMU Wall to Foundation


FEMA 320
SECOND EDITION
August 1999
Taking Shelter From the Storm:
Building a Safe Room Inside Your House
Includes Construction Plans and Cost Estimates
Federal Emergency Management Agency
Mitigation Directorate
500 C Street, SW. • Washington, DC 20472
www.fema.gov
PROJECT IMPACT
TEXAS TECH


National Performance Criteria for Tornado Shelters
Tornado shelters under construction in the County Club Courts subdivision by The Core Inc., Wichita, Kansas
Federal Emergency Management Agency
Mitigation Directorate
Washington, D.C.
First Edition
May 28, 1999
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