Hurricane Evacuation Shelter Project
Final Report

Conducted by

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for

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HAZARD REDUCTION RECOVERY CENTER
A United Nations (OCHA) Collaborative Centre
1.0 Project Overview

The purposes of this project were to: 1) identify facilities outside the storm surge risk area of the Texas Gulf Coastal that could be used as hurricane evacuation shelters (HESs), 2) train Texas A&M University (TAMU) and local inspection teams, 3) gather basic data about the safety and functionality of these facilities, and 4) store this information in a database that can be used by state and local emergency management personnel to judge the suitability of these facilities for sheltering evacuees during a hurricane.

During the spring and summer of 1999, the staff of the Hazard Reduction & Recovery Center (HRRC) and the Construction Science (COSC) Department surveyed 342 HESs in 14 Texas counties (see Table 1). These counties were selected because they are outside hurricane storm surge risk areas, but additional data were collected to ensure that the HESs would have high levels of shelter safety and functionality. Safety is defined by the facility’s vulnerability to hurricane winds, to inland flooding, and to hazardous materials releases from nearby facilities. Functionality is defined by the facility’s capacity to house and feed evacuees (e.g., floor space, kitchen facilities, showers, etc.).

Data regarding wind vulnerability were collected through examination of archival documents such as structural drawings and onsite inspections. Vulnerability to inland flooding was assessed by determining if each facility lies within a 100-year flood plain, while vulnerability to hazardous materials releases was evaluated by determining if each facility lies within the vulnerability zone for facilities handling Extremely Hazardous Substances (EHSs).

The onsite inspections were conducted by teams comprised of Texas A&M faculty and students. Team leaders were engineers and architects from the Departments of Construction Science and Architecture. Team members were students from the Departments of Construction Science, Architecture, Landscape Architecture and Urban Planning, and Civil Engineering.

As a major part of their site visits, the Texas A&M teams also trained local teams to conduct inspections. Training of the local teams will make it possible for additional HESs to be inspected throughout the state of Texas after that termination of the project. Consequently, a centralized database of HESs can be maintained and updated by the Governor’s Division of Emergency Management (DEM) as the need arises.
2.0 Project Implementation

The project was implemented in the eight steps listed below. First, the checklist used by the state of Florida was reviewed and modified (Department of Community Affairs/Division of Emergency Management, 1997). At the same time, HRRC staff developed training materials for use in training members of the TAMU and local inspection teams. Paper copy of the training slides is included as an Appendix to this report. HRRC staff used these materials to train the members of the TAMU Site Inspection Team, who later trained members of Local Inspection Teams. In cooperation with DEM staff, HRRC scheduled inspections for the TAMU Site Inspection Teams at HESs throughout the state. Simultaneously, HRRC staff collected data on HES vulnerability to hazardous materials releases and inland flooding. Finally, HRRC staff entered the data on each HES into a computer database.

2.1 Checklist development

The draft checklist for hurricane shelter assessment developed by the state of Florida was reviewed by the project team to assess its adequacy for determining the functionality and safety of these facilities in Texas. Numerous modifications were required because of the differences between Texas and Florida in local building types and construction practices. After discussion with DEM personnel and building design and construction professionals, the revised checklist was pretested in the Nacodoches/Lufkin area before being used on the remaining HESs. Further revisions were identified during surveys in the Longview/Tyler area.

2.2 Training material development

Concurrent with the development of the checklist, HRRC staff developed training materials to be used first for the TAMU Site Inspection Team and later for the Local Inspection Teams. The training materials consisted of a 90 minute oral presentation on hurricane resistant construction and a step by step description of the criteria for evaluating HES functionality and safety.

2.4 TAMU Site Inspection Team staffing and training

Seven team leaders and nine team member served on the inspection teams. As noted above, team leaders had advanced degrees and/or professional certification in the architecture and engineering. Team members received classroom training in the use of the checklist and worked in the field under the close supervision of the team leaders. In general, team leaders conducted the wind design and load path verifications and assessed the building condition, exterior wall construction, fenestration, roof construction, roof open span, roof drainage, interior safe space,
and life safety criteria. By contrast, team members were assigned to assess laydown hazard exposure, wind and debris exposure, site infrastructure, and mass care facilities.

2.5 Initial local contacts
HRRC staff worked with DEM staff to contact county emergency managers and designated facility administrators to establish master schedules for the inspections. This master schedule ensured that teams were efficiently assigned to facilities, travel time was minimized, and needed documents (e.g., “as built” drawings and specifications) and facility staff were available when needed. In addition, prior scheduling ensured that Local Inspection Teams were afforded an opportunity to receive training from the TAMU Site Inspection Team.

2.6 Site visits
Teams conducted inspections of the primary HESs in each county in order of priority determined by DEM staff and local representatives. In general, the first morning of the visit to each county consisted of a training session for Local Inspection Team members. The TAMU Site Inspection Team Leader present a 90 minute oral presentation on hurricane resistant construction, followed by a description of the specific criteria for evaluating HES functionality and safety. The TAMU Site Inspection Team Leader concluded the morning sessions by scheduling members of the Local Inspection Team to accompany the TAMU Site Inspection Team on HES inspections.

2.7 Inland flood zone data collection and analysis
Assessing the vulnerability of hurricane evacuation shelters to inland flooding was accomplished in three stages. First, HRRC staff identified the geographical location of each of the HESs. Second, they compared the location of each HES location to FEMA Flood Insurance Rate Maps (FIRMs) to determine if it is within a 100-year flood plain. Third, all HESs lying within a 100-year flood plain were recorded in the data base.

2.8 Hazardous materials Vulnerable Zone data collection and analysis
Assessing the vulnerability of HESs to hazardous materials was accomplished in four stages. First, HRRC staff contacted LEPCs within the participating counties to determine whether they have computed the Vulnerability Zones (VZs) for those facilities. Where VZs already had been calculated, they were entered into the database. Where VZs had not been calculated, the project staff collected Tier II reports on all hazardous materials facilities within the county and performed the calculations using the procedure outlined in the U.S. Environmental Protection Agency's (1987) guidance document, *Technical Guidance for Hazards Analysis* or by using
CAMEO/ALOHA. VZs were drawn around each of these facilities so that the areas within each county that lie inside the VZs of all facilities could be identified. Third, the VZs were compared to the locations of HESs to determine if any of them are within any of the VZs. Fourth, all HESs lying within VZs were recorded in the data base.

3.0 Deliverables
HRRC has prepared the following products, all based on data gathered in the survey process, as deliverables to DEM:

- A master and one backup copy on a disk of a computer database containing all data collected during the survey process in a comma-delimited ASCII file. Surveyed facilities have been sorted alphabetically by county, then by city within each county.

- A copy of the entire database on disk in the Lotus Notes format provided on the template disk provided by the DEM at the outset of the project. Facilities within this database have been sorted alphabetically by county, then by city within county.

- A copy of the entire database on disk in the Microsoft Access format. Facilities within this database have been sorted alphabetically by county, then by city within county.

- A subset of the overall database containing shelter data for each individual jurisdiction. This has been provided for distribution to those jurisdictions in a comma-delimited ASCII file.

The team also has produced a Least Risk Decision Making Table including information about all facilities so emergency managers can make rapid decisions when emergency conditions are imminent. This decision making table has been produced during the development of the database, but will be refined following completion of the database. Buildings are described in terms of their storm resistance, accessibility, capacity, and other characteristics included in the survey data.

4.0 Reference

<table>
<thead>
<tr>
<th>County</th>
<th>Number of HESs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angelina</td>
<td>17</td>
</tr>
<tr>
<td>Bexar</td>
<td>37</td>
</tr>
<tr>
<td>Brazos</td>
<td>38</td>
</tr>
<tr>
<td>Gregg</td>
<td>24</td>
</tr>
<tr>
<td>Harris</td>
<td>2</td>
</tr>
<tr>
<td>Hidalgo</td>
<td>53</td>
</tr>
<tr>
<td>Montgomery</td>
<td>16</td>
</tr>
<tr>
<td>Nacodoches</td>
<td>3</td>
</tr>
<tr>
<td>Panola</td>
<td>5</td>
</tr>
<tr>
<td>Shelby</td>
<td>5</td>
</tr>
<tr>
<td>Smith</td>
<td>58</td>
</tr>
<tr>
<td>Travis</td>
<td>64</td>
</tr>
<tr>
<td>Trinity</td>
<td>2</td>
</tr>
<tr>
<td>Washington</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>342</strong></td>
</tr>
</tbody>
</table>

Table 1: Number of Hurricane Evacuation Shelter (HES) surveys conducted, by county.
Hurricane Evacuation Shelter Survey Training
Texas A&M University
Hazard Reduction & Recovery Center
and
Department of Construction Science

Project Goal
- Support local officials' evaluations of Texas Hurricane Evacuation Shelter (HES) capacity and safety.
  - TAMU Survey Teams will conduct initial HES Surveys.
  - Hazard Reduction & Recovery Center's Hazard Analysis Laboratory (HRRC-HAL) will conduct inland flooding and hazardous materials analyses.

Project Goal (cont.)
- TAMU HES Survey Teams will train local teams in the appropriate procedures for additional surveys.
  - By providing training materials (lectures and student manuals), and
  - By providing guidance during walk-through demonstrations and proficiency evaluations.
- TAMU Survey Teams will provide local officials with a systematic process and sufficient data for assessing HES safety.

Hurricane Vulnerability
- Hurricanes can initiate primary and secondary hazards to HESS.
  - Storm surge can flood or batter structures.
  - High winds can
    - Generate significant windborne debris, and
    - Produce severe lateral and upward forces upon structures.

Hurricane Vulnerability (cont.)
- Torrential rains can damage the contents of compromised structures.
- Rains also can cause severe inland flooding many miles from the coast, but generally only in floodplains.
- Hazardous materials can be released from containment systems failed by high winds or flooding.

The HES Survey Process
HES Survey Process

- Assessing safety from storm surge
- Assessing safety from inland flooding
- Assessing safety from hazardous materials releases
- Assessing safety from wind, debris, and direct rain damage
- Understanding the Least Risk Decision Matrix

Safety from Storm Surge

- Storm Surge is a problem only in areas very near the coast, not for inland facilities

Safety from Inland Flooding

- HRRC-HAL staff will identify HES locations by latitude/longitude and transfer this data to a Geographical Information System.
- HES locations will be superimposed onto Federal Emergency Management Agency Flood Insurance Rate Maps (FIRMs).
- HESs within a 100 year flood plain will be identified and recorded.

Safety from Hazardous Materials Releases

- HRRC-HAL staff will contact Local Emergency Planning Committees (LEPCs) to collect data on Vulnerable Zones (VZs) around chemical facilities.
- If VZs are unavailable from the LEPC, HRRC-HAL will use data on the quantity, volatility, and toxicity of hazardous materials to compute VZs.
- These VZs will be superimposed upon maps to determine if any HESs fall within them.

Safety from Wind, Debris, and Direct Rain Damage

- Wind, debris, and direct rain damage decrease with distance from the coast, but can extend far inland.
- Methods of analyzing structural vulnerability to these hazards will be the focus of this training session.

Least Risk Decision Matrix

- The Least Risk Decision Matrix contains data from all phases of the assessment:
  - Analysis of inland flood vulnerability,
  - Analysis of hazardous materials vulnerability, and
  - Onsite survey of vulnerability to wind, debris, and direct rain damage.
Least Risk Decision Matrix (cont.)
- Local officials can reduce HES vulnerability to wind, debris, and direct rain damage by authorizing structural mitigation, especially when the roof needs to be replaced for normal wear.
- Local officials can open HESs in sequence (least risky facility first, most risky last) as risk area evacuees arrive.

Classroom Training Overview
- HES vulnerability to wind, debris, and rain
- Basic hurricane resistant design principles
- Procedures for HES surveys

HES Vulnerability to Wind, Debris, and Rain
- Hurricane wind speed and direction
- Wind effects on walls
- Wind effects on roofs
- Debris effects on structures
- Wind/debris effects on windows and doors

HES Vulnerability to Wind, Debris, and Rain (cont.)
- Consequences of failed windows and doors
- Wood frame structure failures
- Large masonry structure failures

Hurricane Wind Speed and Direction
- Depend upon location of the structure in relation to the hurricane eye.
- Can vary substantially during the course of the storm.

Hurricane Wind Speed and Direction (cont.)
- Are affected by exposure:
  - Rough terrain can cut the wind to one-third of its speed over open water.
Hurricane Wind Speed and Direction (cont.)

- Wind gusts can be 25-50% higher than sustained winds.
- A Category 5 hurricane could have gusts > 200 mph and exert wind pressures > 135 psf.

Wind Effects on Walls

- Building height
  - Wind speed increases with height above the ground.
- Building design
  - Asymmetric shapes are subject to torsional (twisting) forces.

Intact building envelopes experience:
- Positive pressure on the windward wall.
- Negative pressure on the leeward wall and side walls.

Wind Effects on Roofs

- Roof slope/pitch: increasing slopes are less vulnerable because pressure increases (lift decreases) on the windward surface.
  - Flat (0 - 1° or ≤ 1/47/12)
  - Shallow (2 - 10° or ≤ 2/12)
  - Moderate (11 - 29° or ≤ 7/12)
  - Steep (≥ 30° or ≥ 7/12)
Wind Effects on Roofs (cont.)

- **Roof style**
  - Gable: moderately vulnerable, especially at gable ends
  - Hipped: least vulnerable

- **Roof span**
  - Long span (> 40 ft.) is vulnerable because of light weight and poor anchoring.
  - Short span (< 40 ft.) is less vulnerable.

Wind Effects on Roofs (cont.)

- **Roof overhang**
  - Uplift on large overhangs can tear away decking and sheathing even if the overhangs are anchored by posts.

- **Overhang failure**
  - Can initiate progressive loss of sheathing.
  - Loss of sheathing can initiate progressive failure of rafters/trusses.

Wind Effects on Roofs (cont.)

- **Overhang depth**
  - > 3 ft. increases vulnerability.

- **Soffit vents**
  - Decrease vulnerability.

- **Roof vulnerability**
  - Low if overhangs are independent of:
    - Roof sheathing,
    - Rafters or purlins.
Wind Effects on Roofs (cont.)

- Mechanical equipment mounted on the roof can be exposed to strong winds under hurricane conditions.
  - Air conditioner units and large vents are very vulnerable to damage from hurricane force winds and windborne debris impact.
  - If these units are torn off, the resulting breaches of the roof envelope can cause interior damage and roof failures.

- Additional considerations
  - Roof corners can experience up to 2.5 times the force on other parts of the roof.
  - The dynamic nature of the uplift creates cyclic pressures that add significant stress to framing members and connectors.

Debris Effects on Structures

<table>
<thead>
<tr>
<th>Type</th>
<th>Materials</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Small tree branches, gravel, and pieces of asphalt shingles.</td>
<td>&lt; 5 lbs.</td>
</tr>
<tr>
<td></td>
<td>Building materials (wall framing, studs, plywood sheets, roof tiles, etc.), postcard plants, tree branches, patio furniture, and garbage containers.</td>
<td>6 - 20 lbs.</td>
</tr>
<tr>
<td>Large</td>
<td>Large portions of roof, ceiling beams, porches and walkways, walls and roof materials from large buildings including HVAC units and ventilators.</td>
<td>&gt; 20 lbs.</td>
</tr>
<tr>
<td>Heavy</td>
<td>Trailers, portable structures, vehicles, unanchored HVAC units, and empty fuel tanks.</td>
<td>&gt;&gt; 20 lbs.</td>
</tr>
</tbody>
</table>

Debris Effects on Structures (cont.)

- Debris speeds range from 30% of windspeed for heavy objects to 100% of windspeed for light objects.
- Windborne debris is primarily a threat to building soft spots.
  - Unshuttered windows
  - Unreinforced garage doors
  - Unreinforced double doors

Wind/Debris Effects on Windows and Doors

- Window vulnerability decreases with
  - Increasing glass thickness,
  - Decreasing glazed area,
  - Application of protective film,
  - Installation and use of protective shutters.

Wind/Debris Effects on Windows and Doors (cont.)

- Double doors tend to experience:
  - Pullout of center pin, or
  - Shattering of door leaf at center pin.
Wind/Debris Effects on Windows and Doors (cont.)

- Garage doors fail due to:
  - Unreinforced glide tracks/supports and
  - Lack of bracing especially on double-width doors.

Effects of Failed Windows and Doors

- Window and door failures create:
  - Positive pressure if the breach is on the windward wall.
  - Negative pressure if the breach is on the leeward or side walls.

Effects of Failed Windows and Doors (cont.)

- Internal pressure adds to the effect of lift on the roof.
- Internal pressure can blow out other windows and doors.

Rainfall Effects on Structures and Contents

- Rain saturated ground allows high winds to uproot trees, causing
  - Breached building envelopes,
  - Severed pipelines,
  - Broken telephone and power lines, and
  - Obstructed streets.

Rainfall Effects on Structures and Contents (cont.)

- Buildings with flat roofs and parapet walls may have insufficient drainage.
  - The increasing weight of water initially helps by holding down lightweight, poorly connected roof systems.
  - However, it ultimately can cause structural failure.
- Rain can damage contents in buildings whose envelopes have been breached.
Wood Frame Structure Failures

Inadequate connection of shingles to roof deck causes separation.
- Failure of self-seal adhesive
- Inadequate type (staples) or number (fewer than 6 nails) of fasteners
- Improper location or orientation of fasteners
- Poor shingle attachment at eaves
- Poor quality shingles allow nail pull-through

Wood Frame Structure Failures (cont.)

- Inadequate connection of sheathing to truss top chord causes separation.
  - Most commonly due to inadequate (< 8d nails at 4 in. o.c. at roof corners, ridges, and eaves; 6 in. o.c. elsewhere) or improper (misplaced rafter) nail or staple spacing.
  - Especially problematic when roof sheathing is the only stiffener for the roof diaphragm.

Wood Frame Structure Failures (cont.)

- Inadequate connection between roof and exterior walls causes separation.
- Inadequate roof venting fails to relieve internal pressure.
- Inadequate bracing of trusses and gable ends allows progressive failure as sheathing is peeled away by the wind.

Wood Frame Structure Failures (cont.)

- Rafters are attached by insufficient toenails (e.g., ≤ 3-16 d box nails) to the top plate.

Wood Frame Structure Failures (cont.)

- Rafters are attached by hurricane clip to the top plate only, not the studs.
Large Masonry Structure Failures

- Large Masonry Structures (LMSs) often are surrounded by very large parking areas, exposing them to high winds.

Large Masonry Structure Failures (cont.)

- LMS roofs often are overloaded by rainwater due to inadequate drainage through parapets.

Large Masonry Structure Failures (cont.)

- LMS roof membrane often is penetrated by displaced rooftop equipment (e.g., HVAC units).

Large Masonry Structure Failures (cont.)

- Loss of metal edge flashing or coping allows water infiltration, resulting in separation of roof membrane.

Large Masonry Structure Failures (cont.)

- LMSs often have inadequate uplift resistance.
  - Loose or broken welds and inadequate panel fastening in steel decks cause deck sections to lift progressively.
  - Noncontinuous load path (e.g., poor connection of roof to bond beam) fails to prevent the roof from lifting.
Large Masonry Structure Failures (cont.)

- LMSs often have inadequate vertical supports:
  - Lack of reinforcing columns at wall intersections and corners,
  - Vertical ties missing, located in unfilled cells, or missing hooks to bond beams and foundation, or
  - Poor mortar joints between wall and floor slab.

Basic Hurricane Resistant Design Principles

- Provide a sheltered exposure: downwind from:
  - hills,
  - woodlands, or
  - urbanized areas.

Basic Hurricane Resistant Design Principles (cont.)

- Provide a secure foundation: reinforced concrete (anchored below scour lines if in marine or riverine flood zones).

- Verify that those will not:
  - generate missiles, or
  - funnel winds.
Basic Hurricane Resistant Design Principles (cont.)

- Provide a simple symmetric shape:
  - Square plan
  - Hipped roof
- Provide tough, ductile materials: wood, steel, and reinforced concrete.
- Reinforce soft spots:
  - Windows should be covered, and
  - Double doors should be braced.

Basic Hurricane Resistant Design Principles (cont.)

- Provide strong connections for the building envelope:
  - Staples should be avoided.
  - Wall sheathing should use closely spaced nails (no more than 6" o.c. at panel edges and 12" o.c. in panel interior), and
  - Roof sheathing should use closely spaced screws.

Basic Hurricane Resistant Design Principles (cont.)

- Ensure load paths continuity so structures resist:
  - Downward vertical (compressive) and
  - Horizontal (shear), and
  - Upward vertical (tensile) forces.

Basic Hurricane Resistant Design Principles (cont.)

- Roof systems:
  - Must be well constructed and well connected to the walls.
- Wall systems:
  - Must be well constructed, have strong (or well protected) windows and doors, and well connected to the foundation.

Procedures for Surveying an HES

- Evaluate the HES Site
- Document the Wind Design

Evaluating the HES Site

- Assess laydown hazard exposure.
  - Document distances to large trees, tall structures, and rollover hazards.
- Assess wind/debris exposure.
  - Document the extent of shelter afforded by terrain in all directions around the HES.
  - Document the extent of exposure to debris sources such as gravel, construction materials, and unanchored light buildings.
Documenting the Wind Design

- Examine the construction drawings.
- Verify a continuous load path.
- Document the condition of the building.
- Evaluate exterior walls.

Documenting the Wind Design (cont.)

- Evaluate the roof system.
  - Overhangs
  - Mechanical equipment
    - Roof span
    - Interior partition walls
- Evaluate interior safe areas.
- Evaluate life safety/emergency power.

Examining the Construction Drawings

- Document the building height.
- Document the type of drawings examined.
- Determine if there is documentation of adequate hurricane wind resistance.
  - Structural engineer's certification, or
  - Construction to recent (e.g., post 1986 SBC) building codes

Identifying a Continuous Load Path

- Identify the roof support system.
- Identify the load-bearing structure.
- Describe the connection between the roof support system and the load-bearing structure.
- Describe the connection between the load-bearing structure and the foundation.

Identifying a Continuous Load Path (cont.)

- Connections must not rely on
  - gravity,
  - girt,
  - friction, or
  - withdrawal.
- The weakest link in the loadpath is likely to be the building's limiting factor.

Documenting the Condition of a Building

- Good Condition: There are no apparent signs of structural deterioration.
- Minor Deterioration: Some deterioration exists but does not significantly reduce wind resistance.
- Major Deterioration: At least two instances of one or more of the following types of deterioration that may affect wind resistance.
Major Cracks in Concrete or Masonry

- There are cracks in walls, columns, beams, or slabs (not slabs-on-grade) > 1/16 in. wide and > 3 ft. long, or
- There are diagonal cracks at beam ends or through the story height of a wall.

Major Deterioration

- Mortar is soft or eroded, and is removed with a key.
- Hairline cracks run diagonally up masonry walls.
- Cracking of CMUs may also be present, indicating significant yielding of joint reinforcement.

Major Spalling

- Pieces of concrete larger than a golf ball have broken away.
- Reinforsing bars are exposed significantly, or the member's cross section has been compromised significantly.

Major Corrosion

- Structural steel members have rusted to the point where the cross section is reduced significantly.
- Rust stains on the concrete indicate rusting reinforcing bars may be present to a substantial degree in numerous places.

Major Foundation Settlement

- Foundation settlement is greater than 1 in. or
- Walls or columns are out of plumb more than 1 in. for each story of height.

Major Rot

- There is significant rotting or degradation of wooden members to the extent that a key or similar metal object can penetrate the wood easily.
Documenting Exterior Wall Construction

- Document the type of exterior wall construction.
  * Reinforced or precast concrete,
  * Masonry: reinforced, partially reinforced, or unreinforced,
  * Light wood/metal stud,
  * Metal or other.
- Document any softspots.

Evaluating Masonry Construction

- Bond beams of reinforced concrete should be installed at each floor or roof level (≤ 16 ft.).

Evaluating Masonry Construction (cont.)

- Concrete tie-columns should be installed at all corners and at intervals ≤ 20 ft.

Evaluating Masonry Construction (cont.)

- Maximum area of wall panels for 8 in. CMU should be ≤ 256 sq. ft.

Evaluating Masonry Construction (cont.)

- Review the construction drawings for the foundation plan, first-floor plan, and typical upper-floor plan (if applicable).
  * If the CMU cells are shaded, the wall is reinforced.
  * If no cells are shaded and the building was constructed before 1997, assume the walls are unreinforced.
  * If the wall was constructed after 1987 or the reinforced cells are spaced 8 ft. o.c. or closer, the masonry wall is at least partially reinforced.

Fully Reinforced Masonry

- Has #5 rebar or larger:
  * At 4 ft. o.c. or closer vertically, and
  * At wall corners, and
  * Around window and door openings.
Partially Reinforced Masonry (cont.)

Vertical reinforcing:
- Spaced at 8 ft o.c. or closer,
- With vertical bars at wall corners, and
- At wall intersections,
- And around window and door openings.

Partially Reinforced Masonry (cont.)

Horizontal reinforcing is located
- At roof and floor levels, and
- Above and below window or door openings.

Partially Reinforced Masonry (cont.)

A wall is partially reinforced if pilasters contain at least 4 rebar ≥ #5, arranged in a rectangular or square pattern, and
- The bond-beam vertical spacing is less than 13'-3" o.c., and
- The nominal thickness of the masonry is greater than 6 in., and
- The pilaster spacing is no greater than 13'-3" o.c.

Unreinforced Masonry

Unreinforced masonry can have adequate wind resistance if correctly designed.
- However, design verification requires engineering analysis.

Evaluating Building Softspots

- Document glazed area, type, and protection.
  - Hurricane shutters are not expected in this area.
- Document any oversized doors.
  - Double doors
  - Overhead doors

Evaluating Roof Systems

- Document the roof construction type.
- Classify the roof weight:
  - Light: ≤ 25 psf
  - Medium: 26–49 psf, or
  - Heavy: > 50 psf
- Document the roof geometry: Flat, hipped, gable-end, other.
- Document the roof pitch.
Evaluating Roof Systems (cont.)

- Document the overhang width.
- Document the age of the roof covering.
- Document any vulnerable roof structures:
  - Mechanical equipment,
  - Penthouses, or
  - Antennas.

Evaluating Roof Systems (cont.)

- Assessing roof weight
  - Only the dead-weight of the roof's structural plate-like layer should be used in this computation.
  - Roof covering materials generally are not included in dead weight estimates because they typically are removed by wind erosion.

- Exceptions:
  - Include the weight of roof tiles if they have been fastened to a roof deck with nails and full mortar bed.
  - Include poured gypsum or insulating concrete in the weight if applied directly to a structural deck (i.e., not on rigid insulation boards).
  - Include the weight of the roof deck covering and support members if they are expected to remain intact.

To determine if a roof system is lightweight

- Review the construction drawings and note typical roof cross-sections.
- Estimate the dead weight of the roof system using the procedure provided on pp. 4-36 and 4-37 of the Student Manual.

Evaluating Building Overhangs

- Examine the roof framing plan in the construction drawings.
- For loadbearing walls (shaded gray), the overhangs will extend beyond the walls' outer faces.
- For loadbearing frames, the overhang will extend beyond the support beam or truss.

Evaluating Building Overhangs (cont.)

- If construction drawings are not available, the roof's overhang's width can be measured at the site.
  - If the overhang > 1 ft., it will significantly increase uplift forces on the roof.
  - Buildings constructed before 1987 with overhangs > 1 ft. should be avoided.
  - Buildings constructed after 1987 with overhangs ≤ 3 ft. are acceptable.
Evaluating Building Overhangs (cont.)

- Determine if the overhang is:
  - an extension of the roof system, or
  - an independent architectural feature.

- If the overhang is structurally independent of the roof, damage to it will have a negligible impact upon the roof system.

Evaluating Rooftop Mechanical Equipment

- Document whether the equipment is designed to be attached directly to the supporting frame or roof structure.

- Verify whether the equipment is actually attached to a frame.
  - Equipment might not be completely reattached after it is removed from repair (i.e., placed back on the frame without replacing some or all bolts).

Evaluating Roof Span

- For loadbearing frames:
  - Buildings with a structural frame, columns, and beams typically are laid out in bays.
  - If the maximum distance between columns for any of the bays > 40 ft., classify as long-span.

Evaluating Roof Span (cont.)

- For loadbearing walls:
  - Any shear walls should be considered boundaries.
  - If the maximum distance between any of the shear walls > 40 ft., classify as long-span.

Evaluating Roof Span (cont.)

- Some buildings may be a combination of structural frame and wallbearing systems.
  - The same procedures apply as described previously.
  - If construction drawings are not available, and a site survey is the only available option, care must be taken to identify all loadbearing components.

Evaluating Interior Partition Walls

- Some interior walls extend above the ceiling line, but the lateral support for the partitions is only a nominal attachment to roof framing members or deck.

- Some interior walls have roof support members (e.g., beams) that extend through them but are not supported by the them.
## Evaluating Interior Partition Walls (cont.)

- Measure between bearing plates and/or framed connections to bearing walls, beams, or columns at both ends of the roof support.
- If the maximum distance > 40 ft., classify as long-span.

## Evaluating Buildings with Mixed Spans

- For buildings that have both long- and short-span areas, determine if failure of the long-span area will impact short-span areas.

## Evaluating Buildings with Mixed Spans (cont.)

- The short-spar area may provide a safe HES area in hurricane winds if:
  - The long-spar area is compartmentalized (separated structurally from the short-spar area) by bearing walls, and
  - The roof supports of the long- and short-span areas are independent, so damage to the long-span area cannot initiate progressive failure into the HES area.

## Evaluating Hipped Roofs

- Hipped roofs with moderate to steep slopes may permit spans up to 50 ft.
- Also, lightweight and medium weight roofs with moderate to steep slopes may permit longer spans up to 50 ft.

## Evaluating Roof Drainage/Ponding

- List the height of the parapet above the roof. Increases height:
  - Decreases the wind/debris vulnerability of roof mounted equipment, but
  - Significantly increases ponding.
- Generally, a parapet wall less than 4 in. high will not trap enough water on the roof to cause a roof system failure.

## Evaluating Roof Drainage/Ponding (cont.)

- Parapet walls greater than 4 in. have reduced vulnerability to roof ponding if they have scuppers to supplement roof drains.
- Look for indications of roof problems.
  - If such problems exist under normal conditions, then they probably will be worse in a hurricane.
Evaluating Interior Safe Areas

- Document the area of any interior corridor/rooms.
- Determine the construction type of the corridor walls from the structural drawings.
  - Reject any rooms attached to, or immediately adjacent to, unreinforced masonry walls.

Evaluating Interior Safe Areas (cont.)

- Document the type of doors that open onto these areas.
  - From inside the building, and
  - From outside the building
- Note any details affecting wind vulnerability:
  - Softspots that might be breached by windborne debris.
  - Drawbells that can increase wind resistance.

Evaluating Interior Safe Areas (cont.)

- Document any slabs or decking over the interior safe area.
  - Concrete slabs or metal decking can seal off a "core" area inside a building.
  - Use technical drawings and on-site verification to determine if slabs/decking are properly attached to corridor walls.

Evaluating Life Safety/Emergency Power

- Check with local building officials and determine if there are any known life safety/fire code violations in the candidate HES.
- Address the potential for emergency power at the site.

Categories of Debris Exposure

<table>
<thead>
<tr>
<th>Debris Exposure</th>
<th>Minimal</th>
<th>Low</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of structure within 300 ft or site having potential to be affected by unforeseen extreme events</td>
<td>&lt;10%</td>
<td>10% ≤ Area ≤ 30%</td>
<td>&gt;30%</td>
</tr>
</tbody>
</table>
Evaluating Roof Systems

- Roof failures
  - Lightweight roof decks typically fail at their connections with supporting roof trusses or joists.
  - Roof weight is needed to resist uplift.
  - Roof weight is determined by the weight of the roof deck and integral support elements.
  - A weight of 25 pounds per square foot (psf) or less is classified as lightweight.

Evaluating Roof Systems (cont.)

- Lightweight roof materials include:
  - Wood boards,
  - Plywood,
  - Precast cement-fiber planks,
  - Fiberboard,
  - Gypsum board,
  - Metal decking,
  - Wire-fabric or other similar material, with or without poured gypsum or insulating (lightweight) concrete.

Large Masonry Structure Failures (cont.)

- LMSs often have large glass windows and overhead doors that fail, causing internal pressurization.
Identifying a Continuous Load Path

- Identify the Main Wind Force Resisting System (MWFRS) vertical structural components.

MWFRS vertical structural components include:
- Columns of structural frames,
- Reinforced pilasters in bearing walls,
- Vertical reinforcement in grouted masonry wall cells,
- Metal rods, and
- Cables or straps.

Identifying a Continuous Load Path (cont.)

- Assess the exterior envelope: all components connected to the MWFRS.
  - Satisfactory connections
    - Primary elements: beams, columns, and loadbearing walls
    - Secondary elements: light wood or metal framing
  - Unsatisfactory connections
    - Lightweight claddings and soft-spoil materials: EIFS, light-gauge metal, and glazed panels

- Identify the MWFRS lateral stability components
  - Shear wall/diaphragm systems
  - Semi-rigid or rigid framing and bracing systems