Welcome to the
2018 Annual Conference
Educational Sessions

Session: Lessons Learned from the 2017 Hurricanes: A Technical Evaluation of Building Performance & the Impact of Code Adoption and Enforcement
Lessons Learned from the 2017 Hurricanes: A Technical Evaluation of Building Performance & the Impact of Code Adoption and Enforcement

FEMA Building Science Branch and 2017 Hurricane Mitigation Assessment Team Members

DATE TBD (Agenda Not Out)
Session Description

- The FEMA Mitigation Assessment Team (MAT) Program is managed by the Building Science Branch at Headquarters. Following a natural disaster, the team conducts field assessments and makes technical observations on the performance of buildings subjected to the effects of the natural hazard event.

- The MAT’s observations are used to recommend changes to building codes and standards groups, prepare recovery advisories, gather information to improve guidance and influence construction practices during repair, support the integration of hazard mitigation measures into the repair process, provide technical assistance related to codes and standards, and contribute to research efforts.

- In this session, a representative of the Building Science Branch will summarize lessons learned with respect to building performance and also illustrate the impact that code adoption and enforcement has had on reducing damage.
MAT Program Background

Mitigation Assessment Team (MAT)

▪ Observes building performance under severe hazard events.
▪ Determines causes of building damage, failure and success.
▪ Evaluates performance of mitigation projects.
▪ Provides design and construction strategic recommendations for reducing damage and protecting lives in hazard areas.
▪ Draws on combined resources of federal, state, local, academia, and private sectors.
▪ Supports building science/building code elements of NDRF.
2017 Hurricanes

- FEMA Mitigation Assessment Teams
  - Harvey – TX
  - Irma – FL, PR, USVI
  - Maria – PR & USVI
Hurricane Harvey - Texas

- Landfall as a Category 4 hurricane.
- Friday Aug 25 at 10 PM CDT with winds of 130 mph near the Rockport and Fulton, TX.
- System remained over Texas for several days, resulting in constant rain from Houston to western Louisiana.
- On Monday August 28th, the eye of the system moved off-shore and turned north towards Port Arthur and Beaumont.
Source: Google Earth
Houston, TX (Meyerland Area)
Wortham Theater
Failed flood door between the Bayou Place Parking Garage and the Little Tranquility Park Parking Garage (left); remains of the failed door (right).
Glass block wall that failed when exposed to floodwaters (left); flood gate between garage and the network of tunnels that connects buildings in Downtown Houston (right).
Lessons Learned from the 2017 Hurricanes
Lessons Learned from the 2017 Hurricanes
Two Westlake (left); loading dock and ramp (right).
Texas Medical Center

Lessons Learned from the 2017 Hurricanes
Hurricane Irma – Florida

- Eye in Keys (≈MM 19.5) Sunday Sep 10 at 9AM EDT (130 mph-Cat 4, 928mb, NNW at 8 mph)
- Eye just east of Marco Island Sunday Sep 10 at 3:30PM EDT (115 mph-Cat 3, 940mb, N at 12mph)
- Reduced to Tropical Depression Monday Sep 11 at 11 PM EDT over Columbus, GA
Residential Building Envelope Performance

- Roof Covering
- Soffits
- Wall Covering
- Opening Protective Systems
Building Envelope Performance: Roof Covering

Roof Covering: Asphalt shingles failure fairly widespread – both new and old construction. Shingle loss on approx. 6-year home in Marathon.
Building Envelope Performance: Roof Covering

Roof Covering: Clay and concrete tile failure was limited and generally minor. Clay tile roof damage on Cudjoe Key home. Close-up shows hip tiles circled on left image.
Building Envelope Performance: Soffits

Soffits: Vinyl soffit failure widespread. Vinyl soffit damage on Sugarloaf Key.
Building Envelope Performance: Soffits

Soffits: Aluminum soffit failure was also observed. Aluminum soffit damage on Ramrod Key.
Building Envelope Performance: Wall Covering

Wall Covering: Vinyl siding failure was widespread. Vinyl siding damage on Ramrod Key.
Building Envelope Performance: Wall Covering

Building Envelope Performance: Opening Protection

Opening Protection: Glazing damaged but not failed. Outer pane penetrated but inner pane left intact on Little Torch Key.
Building Envelope Performance: Opening Protection

Garage Door: Failure generally isolated. Garage door failure on Duck Key.
Typical Structural Wind Damage

Structure Failure: Mainly older residential buildings. Roof and wall loss on Cudjoe Key.
MH & Mobile Homes: Wind Damage

Mobile Home Damage: Connected Appurtenances. Connected front porch and carport damaged Collier County unit.
Flood Damage – Big Pine Key (Ave D)

- Older NPS building, lower story and columns damaged
- USGS HWM shows 8.8 ft NAVD elevation
- Building to be demolished.

Effective Zone, BFE: VE 11 ft NAVD
Est. Depth of Water during Irma: 4.4 ft above grade
Flood Damage – Big Pine Key (Ave D)

- Two story, multi-family, under renovation at time of Irma
- USGS high water mark at site (6.9 ft NAVD = 8.3 ft NGVD)
- Inundation above finished floor = 4.4 ft.

Effective Zone, BFE: AE 9 ft NGVD
Water Elev during Irma: 8.3 ft NGVD
Flood Damage – Big Pine Key (Ave D)
Flood Damage – Marathon
(61st St Ocean)

- A few elevated homes, mostly MH and RVs
- Elevated homes performed well (flood), MH/RVs inundated

Effective Zone, BFE: VE 10 ft NGVD to AE 7 ft NGVD
Est. Depth of Water during Irma: 3-4 ft above grade

Lessons Learned from the 2017 Hurricanes
Scour – Lower Matecumbe Key

- Deep scour across some lots, and around some foundations.
- Water depth 30 in above top of slab.
- Scour enhanced by privacy walls/driveways and utilities?

Effective Zone, BFE: AE 10 ft
NGVD to AE 11 ft NGVD
Est. Depth of Water during Irma:
30 in above slab
Scour – Lower Matecumbe Key

- Collapse of elevated two-story building over parking

Effective Zone, BFE: AE 10 ft NGVD to AE 11 ft NGVD
Est. Depth of Water during Irma: 2-3 ft above grade
Scour – Marathon

- Adjacent to Sombrero Park
- USGS HWM nearby (7.2 ft NAVD, 8.6 ft NGVD), estimate water at 1+ ft above slab of scour house

Effective Zone, BFE: VE 11 ft NGVD to AE 10 ft NGVD
Est. Depth of Water during Irma: 1+ ft above slab
Scour – Big Pine Key

- Visited on pre-MAT
- Estimated water depth 2-3 ft above grade
- USGS HWM 1,200 ft west = 7.7. ft NAVD = 9.1 ft NGVD

Effective Zone, BFE: AE 9 ft NGVD
Est. Depth of Water during Irma: 2-3 ft above grade

House demolished prior to MAT
Breakaway Wall Performance – Cudjoe Key

- Visited on pre-MAT
- Siding (wind) damage (preceeded flood)
- Water depth 9 in (front) to 24 in (rear) above top of slab

Effective Zone, BFE: AE 11 ft NGVD
Est. Depth of Water during Irma:
~ 1 ft above grade
Breakaway Wall Performance – Big Pine Key

- Walls caused damage to columns when they broke away?

Effective Zone, BFE: AE, 8 ft NGVD
Est. Depth of Water during Irma: 3 ft above grade
Floodproofing – 1300 Brickell Avenue, Miami

- Non-Residential Building, flood panels installed
- First floor ~20 inches above adjacent grade
- Area briefly inundated – actual depth unknown
- Interview: evidence of minor flooding inside upon return

Effective Zone, BFE: AE 12 ft NGVD
Est. Depth of Water during Irma: ~2-3 ft above street
Floodproofing – 54-story residential buildings under construction, Miami

- Floodproofing to protect elevators
- Complicated (large posts and heavy flood panels) – protect to 9 ft depth above grade (installed for Irma)
- 20+ openings; crew needs equipment

Effective Zone, BFE: AE 11 ft NGVD
Est. Depth of Water during Irma: 1-2 ft above grade
US Virgin Islands

- Hurricanes Irma and Maria
- Focus on Performance of Single and Multi-Family Homes
- Schools, Hospitals, Fire Stations
- Photovoltaic Panels
- Building Codes
Residential Performance - Overall

- Performance relative to flooding: Little to no flood damage observed across all islands. HWM could not be identified.
- Water intrusion from building envelope extensive even when roof system performed well.
- Roof systems designed according to Home Protection Roof Program (HPRP) performed extremely well.
- Many HPRP were not fully compliant.
- Windows: Jalousie windows were predominant. Neither metal or glass had good impact resistant and water intrusion prevalent.
- Doors: Water intrusion at doors prevalent.
Residential Performance – Home Protection Roof Program

- Consistent success with compliant roof systems.
- Where failures were observed, mainly due to non-compliance (subject to further analysis).
Residential Performance

Glass jalousie windows failed often due to impact and increased winds.

Doors were often the source of water intrusion even roof performance was good.
Manufactured Home Performance

- Manufactured Homes performed poorly
- Failures observed included:
  - Exterior cladding loss, siding and wallboard
  - Roof covering and deck loss
  - Tie downs mostly effective
  - Openings unprotected and damaged
  - HUD label missing, covered or removed
  - Unpermitted mods
School Performance - Overall

- Performance relative to flooding: Little to no observed flooding in schools.
- Roof Systems:
  - Liquid applied membrane performed well if substrate stayed in tact.
  - Issues observed with vents, flashing, gutters.
  - Rooftop equipment caused significant failures.
  - Long span roof systems (mainly in gyms) did not perform well.
  - Water intrusion significant (often related to cistern conveyance failures).
- Temporary portable classrooms did not perform well.
- Older pre-engineered metal building systems did not perform well.
- Windows: jalousie windows often first point of failure in schools.
- Enclosed spaces (mechanical, drop ceilings, etc.) led to mold growth, vermin, and environmental issues.
School Performance

- Existing guidance includes:
  - FEMA P-1000, Safer, Stronger, Smarter: A Guide to Improving School Natural Hazard Safety
Hospitals – Overall Performance

- Roof system impacted by debris and roof covering failed at parapet attachment
- Glazing protected but water intrusion pervasive
- Storm and sanitary sewer capacity issues
- Loss of vertical conveyance (elevator)
- Power maintained throughout event in buried lines
- Debris from rooftop equipment punctured roof
- Roof mitigation recommendations not implemented

Existing FEMA Guidance includes:
  - Guidance on rooftop equipment (FEMA P-424)
  - Guidance on Hospitals (FEMA P-577)
Fire Stations - Overall

- Fire Stations performance varied (primarily function of age).
- Many failures a function of the fenestrations.
- Many fire stations were provided with mitigation (hardening of doors, shutters, etc.), however, a holistic approach to building mitigation was not included.
- Existing FEMA Guidance Includes:
  - FEMA P-543, Design Guide for Improving Critical Facilities
Photovoltaic (PV) Systems - Overall

- Ground Mounted
  - Ground Mounted PV supports up to 20% of island’s power.
  - Performance of ground mounted PV systems varied due to fastening hardware quality and overall structure/cross members.
    - St. Thomas had significant failures in all observed systems.
  - Closed tube shaped structural members performed well.
  - C shaped, thin gauge structure members did not perform well.
  - Failure of clips from the frame supports to the beams were the initiation point of the failures.
PV – Ground Mounted

“C” Shaped Structures performed poorly.

Closed tubed members performed better.
PV – Roof Mounted

- Roof mounted PV prevalent across USVI
- Wind load criteria is included in ASCE 7-16 (residential and commercial)
- Roof mounted allowed power for some homeowners after grid power loss
- Performance varied greatly
  - Failure mainly due to clips that attach to rails
  - Panels became windborne debris
  - Panels also disabled due to debris
Puerto Rico

- Hurricanes Irma and Maria
- Wind and Flood Impacts to Residential Buildings and Critical Facilities
  - Topographic Effects, Erosion, Landslides, Storm Surge, Riverine
- Implementation of Georges MAT Recommendations
  - Adoption of I-Codes, Corrosive Protection, Flood Risk Education
- Performance of post-Georges Construction and Mitigation Projects
  - New Secure Housing Program, Storm Shutters, Generators
- Alternative Energy Systems including Solar Rooftop solar systems and solar farms
Codes, Standards and Regulations

- Meetings held with planning, permitting and floodplain management (included regular and autonomous municipalities) Entities included:
  - Planning Board (Junta de Planificación)
  - Permits Management Office (“Oficina de Gerencia de Permisos, known as OGPe”)
  - Municipalities:
    - Toa Baja, Bayamon, Carolina, Vega Alta
- Location visits to both formal and informal construction methods. Locations included:
  - New Secure Housing Program, Governmental facilities, Residential locations including coastal and mountainous
Wind, Shelters, and Critical Facility

- **Structural systems**
  - Concrete and well-detailed wood construction performed well
  - Light framed wood and informal construction performed poorly
- **Roof coverings**
  - Covering failures lead to water intrusion and loss of building functions
  - Hospitals (critical facilities) did not perform better than commercial buildings
- **Window and Door Systems**
  - Unprotected and damaged
  - Significant water intrusion
- **Rooftop equipment**
  - Light/informal detailed systems performed poorly
  - Solar panel performance varied widely
Coastal erosion failures observed along east, north and west coast of the island in all coastal flood zones mapped on current FIRMs. Riverine flood damages to residential buildings, critical facilities and emergency power systems were observed in various locations. Landslide risks and damages to structures observed in higher elevations due to poor siting decisions and rainfall-induced slope instability.
Residential Performance – Wood Framed

- Permitted Home – Canovanas
  - Wood frame construction at hilltop location
  - Clips and straps provided continuous load path
- Unpermitted Home - Yubacoa
  - Lightly built wood frame structure
  - Significant structural damage
  - Loss of roof system
  - Roof covering was light metal panel with no structural deck
Elevated home – Punta Santiago
- Elevated home did not flood when neighborhood flooded
- Several feet of freeboard provided by “full story” elevation

Well-built hilltop homes in Punta Lima

Well-built homes – Canovanas
- No structural or window damage
- Opening protected with pre-cut wood panels (track mounted)
Multi-Family Housing

- Elevated building – Punta Santiago
  - Elevated on fill, stem walls supporting fill
  - Zone AE
  - Top of lowest floor approx. 3 ft above high water mark
- Coastal condominiums - Loriza
  - 4 story units, in 2009
  - Reinforced concrete
  - Some units protected openings, others did not (failures observed)
  - Stucco loss on portions of walls
Schools and Shelters

- Georgia Baquero High School – Canovanas
  - Shelter for Irma and Maria
  - Reinforced concrete, impacts - water intrusion and loss of power/water
  - No rated opening protection devices
  - No generator on site
- Escuela Superior de Loiza - Loiza
  - Alternate shelter site
  - Reinforced concrete, impacts - water intrusion and loss of power
  - No rated opening protection devices
  - On-site generator locked by City
Critical Facilities

- Police Station – Fajardo
  - Reinforced concrete facility
  - Converted from fire station (fire station received HMGP funds for shutters)
  - Backup power generator allowed for continued operations
- Fire Station - Toa Baja
  - Shutters performed well
  - Lowest floor elevated, minimized flooding damage
Hospital Performance

- Hospitals in Arecibo, Bayamon, San Juan, and Vieques
- Hospital Susana Centeno in Vieques, PR
  - Significant windborne debris damage to the roof, waterproofing membrane puncture, roof top equipment damage
  - Tesla – installed solar panels and battery system
PV – Ground Mounted

- Connection to framing failed
- Framing distorted
- Siting and topographic effects
Coastal Flood Damages and Successes

- Coastal flood damage causes:
  - Storm surge
  - Breaking waves
  - Coastal erosion
Riverine Flood Damages and Successes

- Riverine flood damage causes:
  - Inundation
  - Velocity and flood-borne debris
  - Stream bank erosion

Lessons Learned from the 2017 Hurricanes
Landslide Damages and Successes

- Landslide risk triggered by:
  - Development along unstable slopes
  - Deterioration of rock faces in from water/rainfall infiltration
Topography and Wind Speed Up
Topography and Wind Speed Up
Material Performance: Corrosion

- Materials Corrosion (Inland)
  - Maintenance and protection
  - Galvanized vs. Stainless Protection
Window Performance

- Glazing (window) failures due to wind pressures and debris impact
- Water intrusion through systems
- Protection systems in poor condition
- Protection systems at end of useful life
Rooftop Solar System Observations

- Panels vulnerable to debris impact, but can resist wind loads
- Connections from roof decks to frames systems affect performance
- Connections from frames to panels variable – clamps and brackets performed best
2017 Hurricane MAT Themes

- Building codes work! AND hazard mitigation too!
- Codes and standards are the minimum requirement – performance reflects that
- A thorough vulnerability assessment is critical
- Redundancy, freeboard, additional level of protection is key
- Code officials expressed a need to reduce workload post-disaster
- Ensure seismic resistance is incorporated into all “new construction”
- Education of microzoning/topography and landslides into building code and guidance
- Performance of ‘homemade’ versus ‘tested’ (ASTM, ANSI, etc.) products
- Overestimating resources/implementation capacity
- Continued need to spread awareness of best practices

https://www.fema.gov/media-library/assets/documents/158123
Thank You

For more information visit:

https://www.fema.gov/mitigation-assessment-team-program
Thank You For Attending