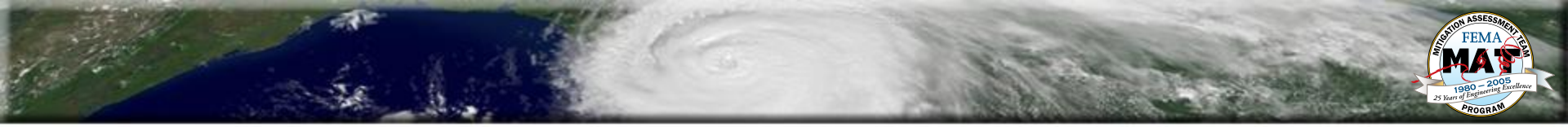
Mitigation Assessment Team Report on

Hurricane Katrina in the Gulf Coast

Observations, Recommendations, and Technical Assistance

Objectives of the MAT Program

- Conducts *forensic engineering analyses* to determine causes of structural failure and success
- Provides *recommendations* that communities, states and organizations/agencies can take to reduce future damages and protect lives and property in hazard areas
- Increase damage resistance through *improvements in construction codes and standards, designs, methods, and materials* used for both new construction and post-disaster repair and recovery

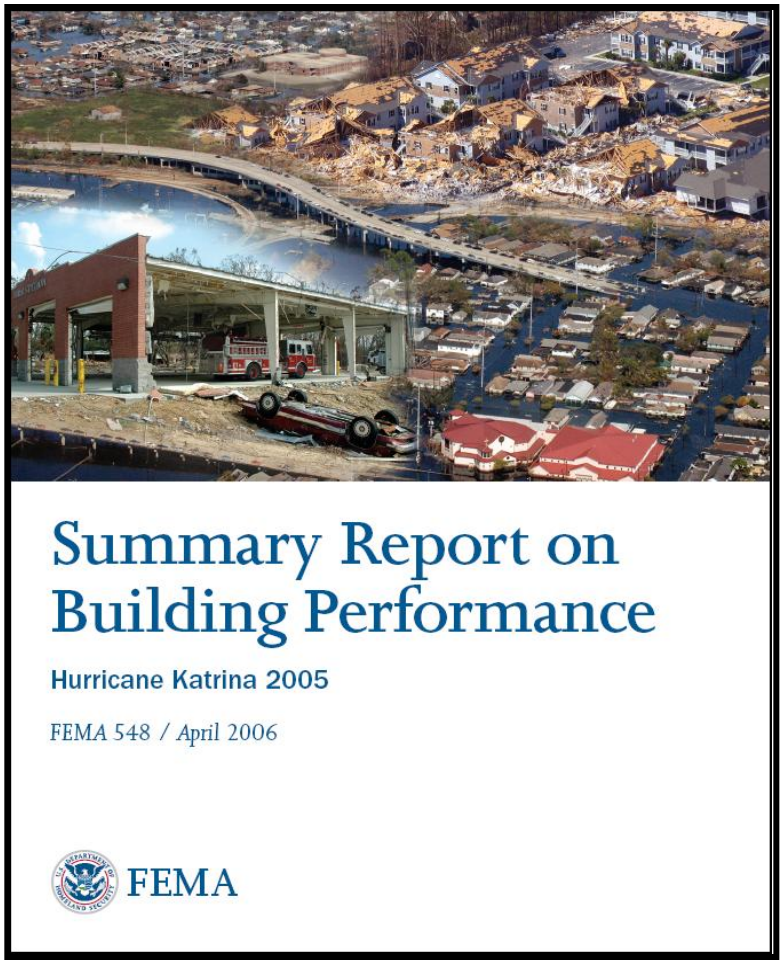


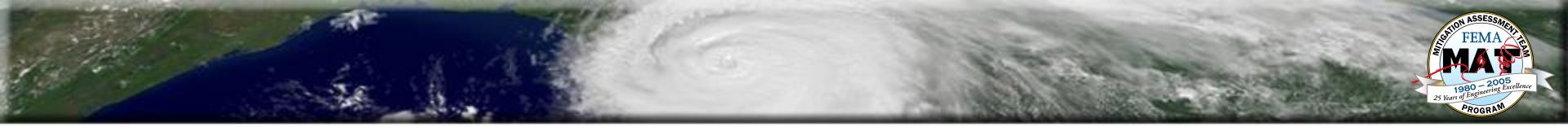
MAT Composition and Duties

- Deployed September-October 2005
- Representatives of FEMA Headquarters and FEMA Regional Offices
- State and local officials
- Public- and private-sector experts:
  - Team comprised of national experts in wind engineering, building codes, and coastal construction
  - Experienced in mitigation solutions for coastal flood and wind events
- Assigned Task: study and document building performance; develop recommendations and reconstruction guidance

MAT Reports and Presentations

- Exit Presentations, AL, MS, LA (fall 2005)
- Other presentations, fall 2006 to present
- Summary Report (April 2006)
- Full Report (May 2006)
- Recovery Advisories





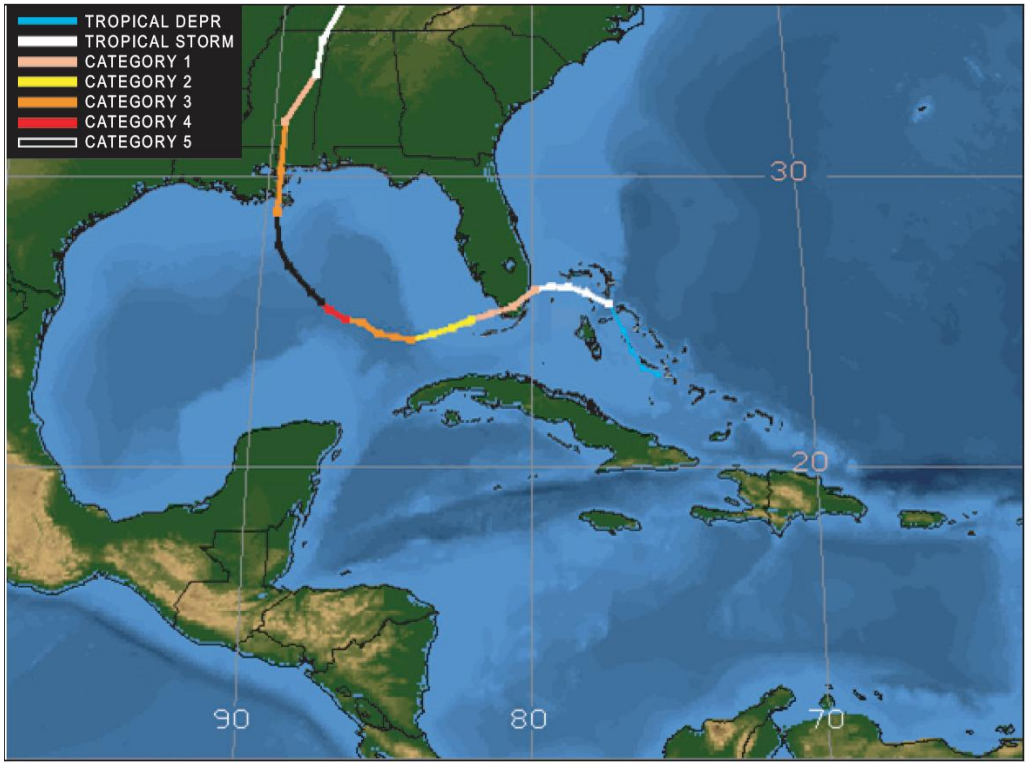
OBSERVATIONS

Hurricane Katrina August 29, 2005

Made landfall near Buras, LA as a strong Category 3 storm

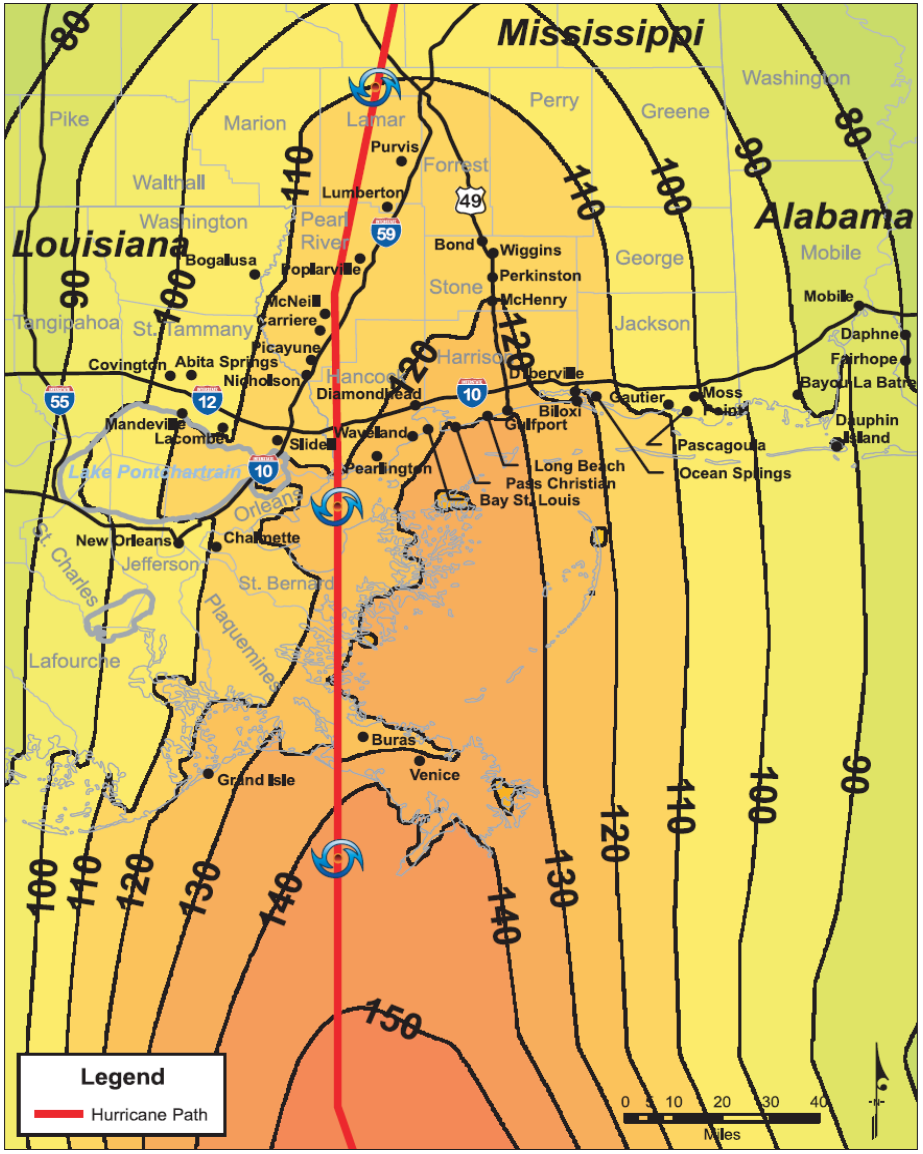
(Category 5 storm 18 hours prior to landfall)

Landfall near LA/MS border as Category 3 storm



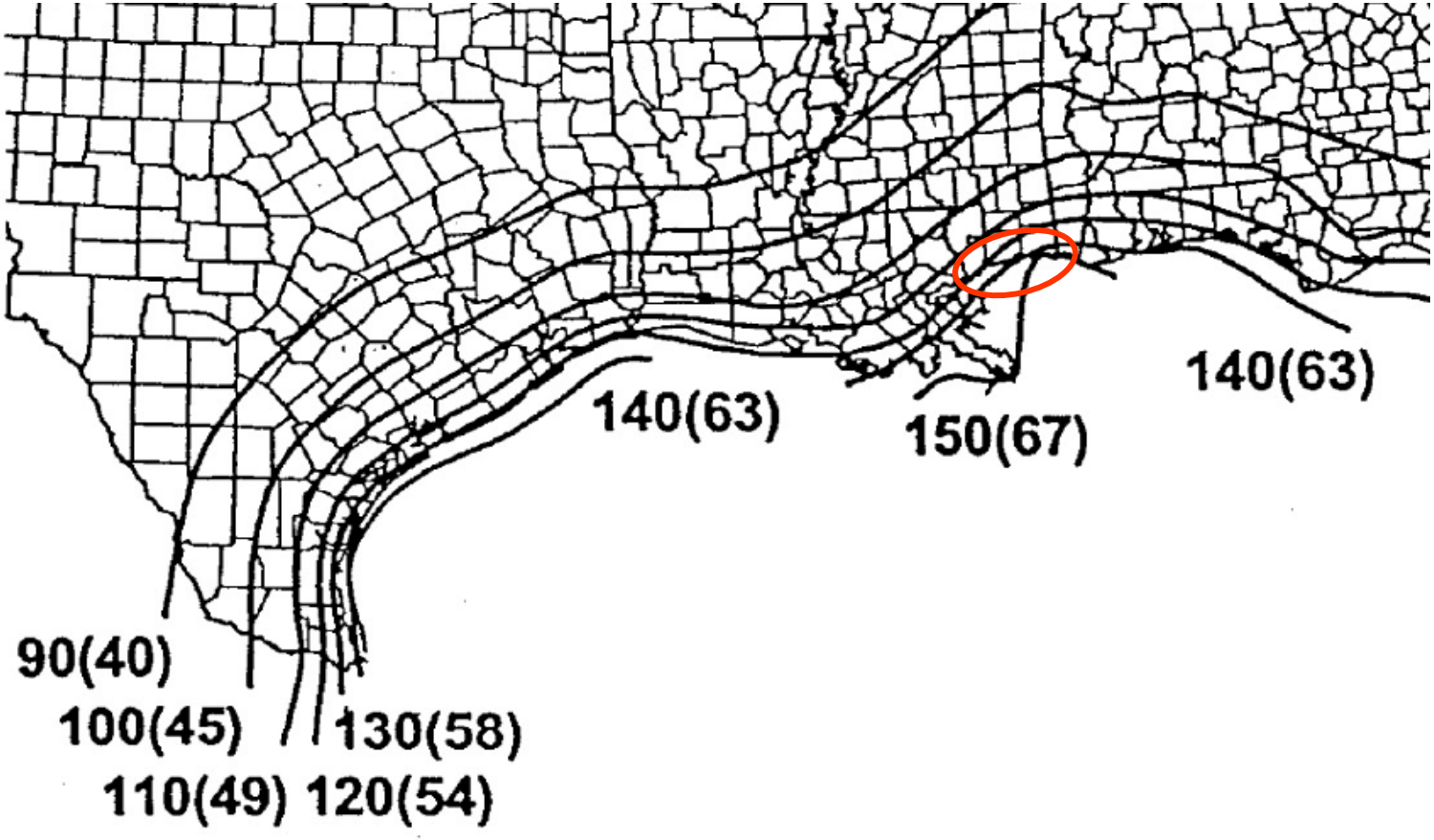
Wind Speeds

With the exception of a small portion of the MS coast, wind speeds were generally less than a current design speeds (per ASCE 7)

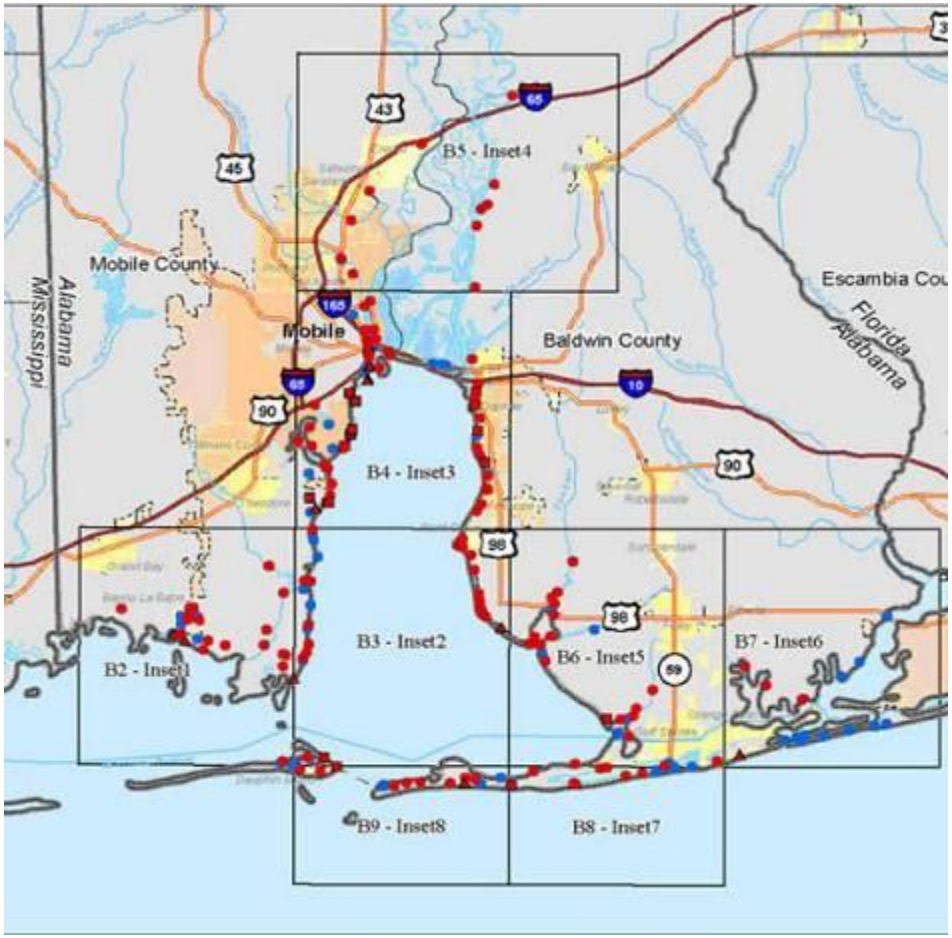


Wind Swath contour plot (3-second gust at 10 meter elevation) based on HAZUS-MH wind field methodology (ARA)

Wind Speed Map, IBC 2003 (ASCE-7)

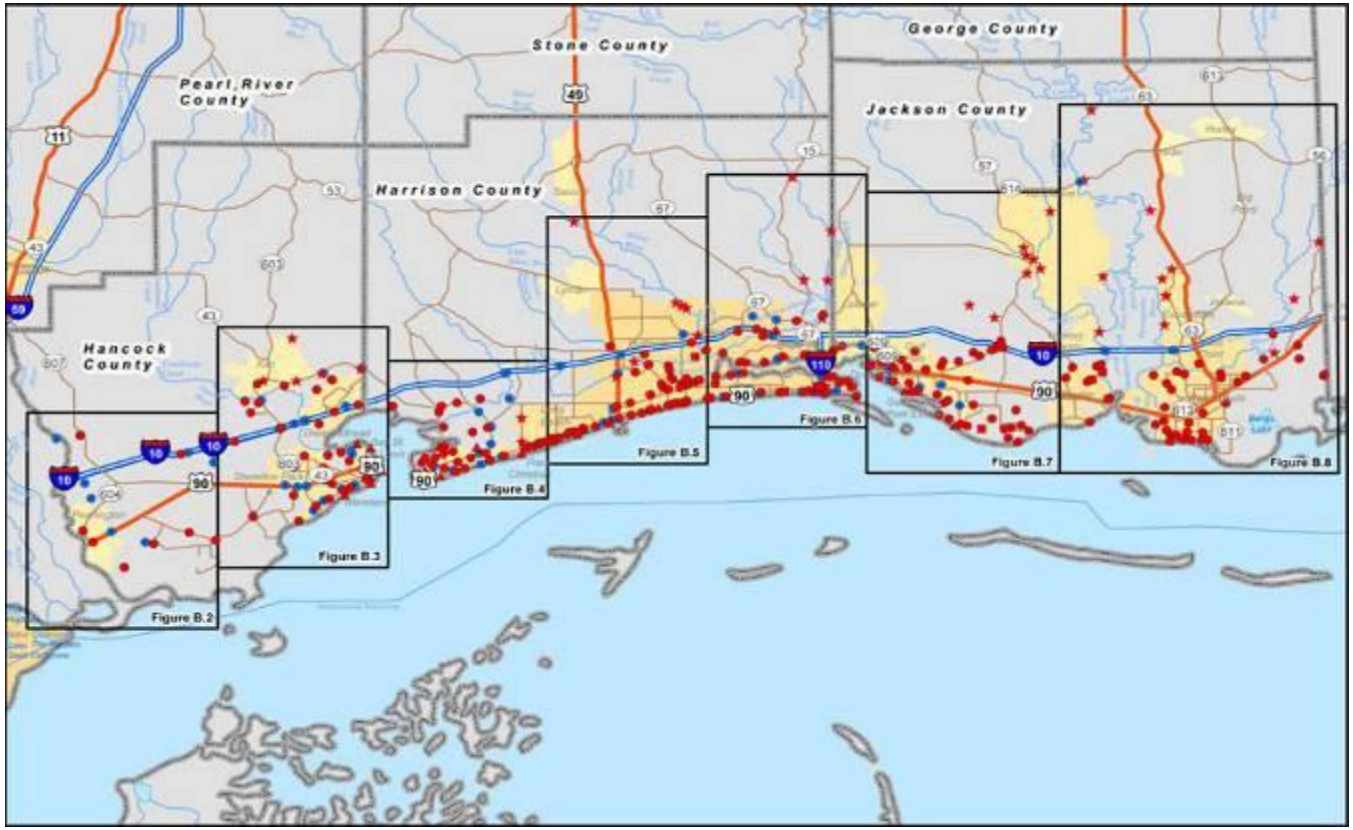


High Water Mark Surveys



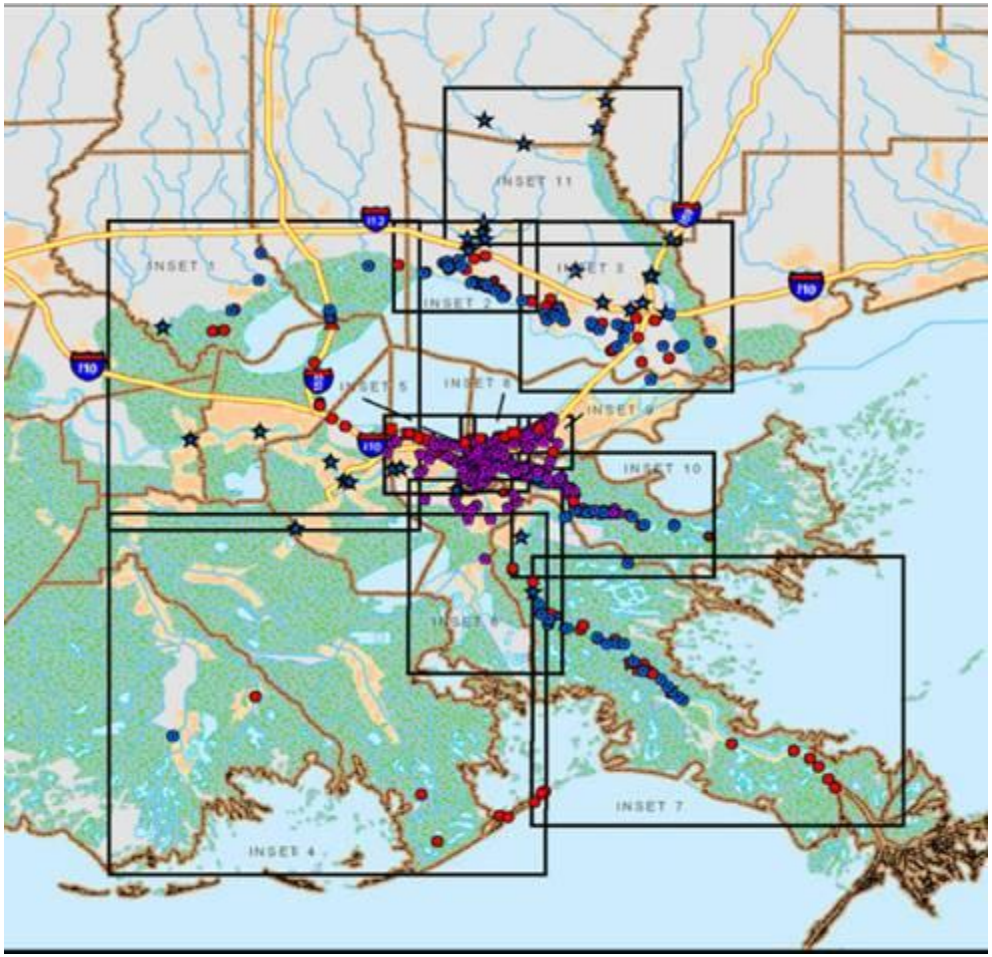
AL: 222 HWMs

High Water Mark Surveys



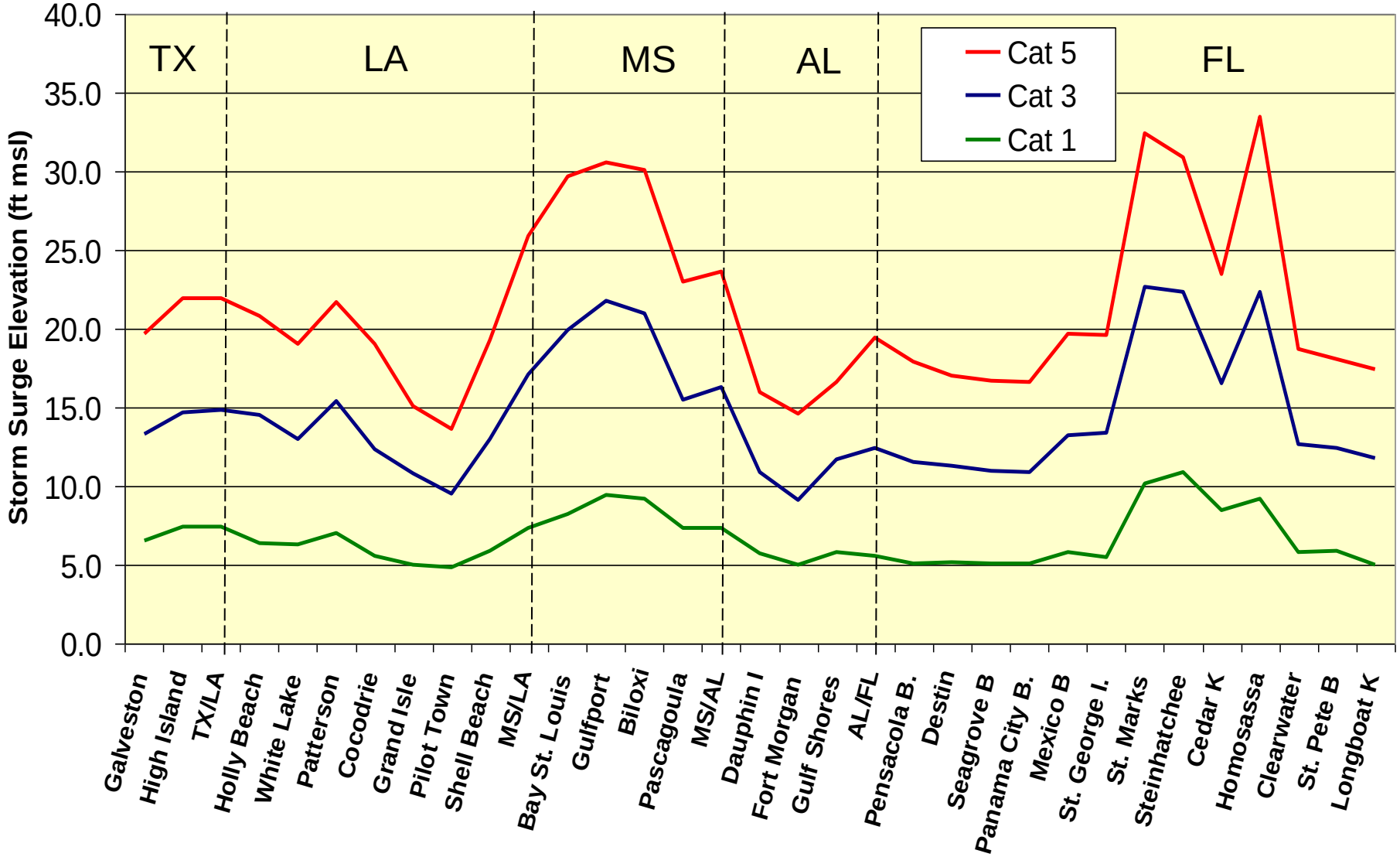
MS: 402 HWMs

High Water Mark Surveys



LA: 482 HWMs

Variation in SLOSH Model Storm Surge Elevations at Developed Shoreline



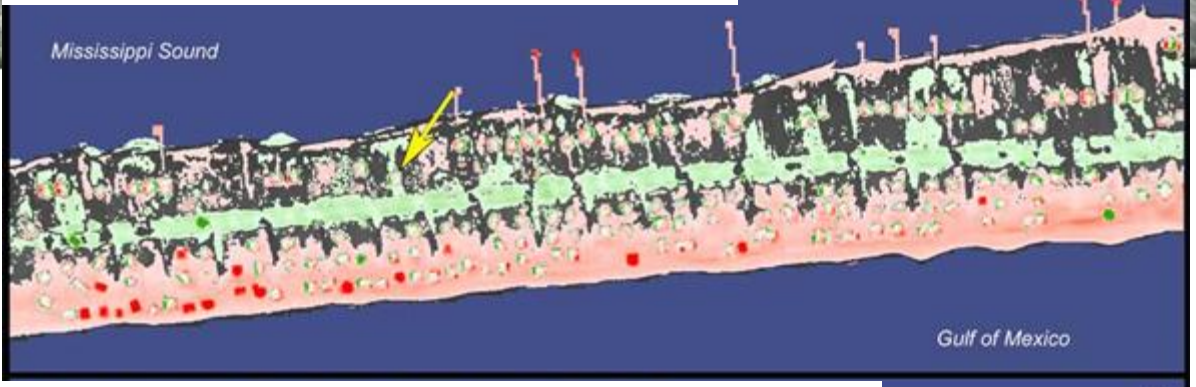
PRELIMINARY
source: FEMA MAT, 2-26-06

MAT Coverage

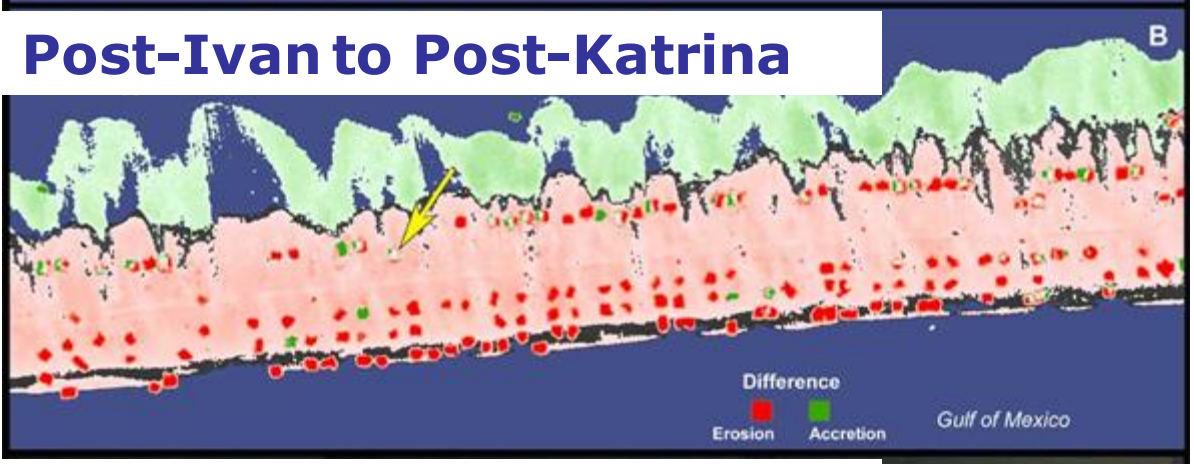
Dauphin Island

Failures and near-failures due to erosion of shallow pile foundations

Pre-Ivan to Post-Ivan



Post-Ivan to Post-Katrina



Post-Katrina (Sept. 2005)

USGS study shows 2'-5' erosion across the developed west end of the island (100 of 148 homes destroyed)

Stillwater elevation of 10.5' NGVD, compared to FIS stillwater elevation of 7.8'

Preliminary wave height estimates indicate that Gulf-front wave crest elevations were as high as +14' NGVD

Pre-Katrina BFEs in V Zone 10'-12' NGVD, and 8'-9' in A Zone, north of road

Dauphin Island

Surviving houses typically had higher floor elevation with larger diameter and deeper piles

Many of the least damaged buildings had been constructed after Hurricane Ivan to superior designs compared to older buildings

Dauphin Island

Loss of asphalt shingles and roof underlayment

Wind borne debris damage to windows and EIFS exterior

Dauphin Island

Jackson County

Over 2.7 miles of shoreline, we counted 105 homes:

- 98 destroyed

- 7 survivors

Jackson County, ¼ mile from shore

Wave damage in Zone C

Ocean Springs

EIFS Failure, Biloxi

Water entered through holes in exterior

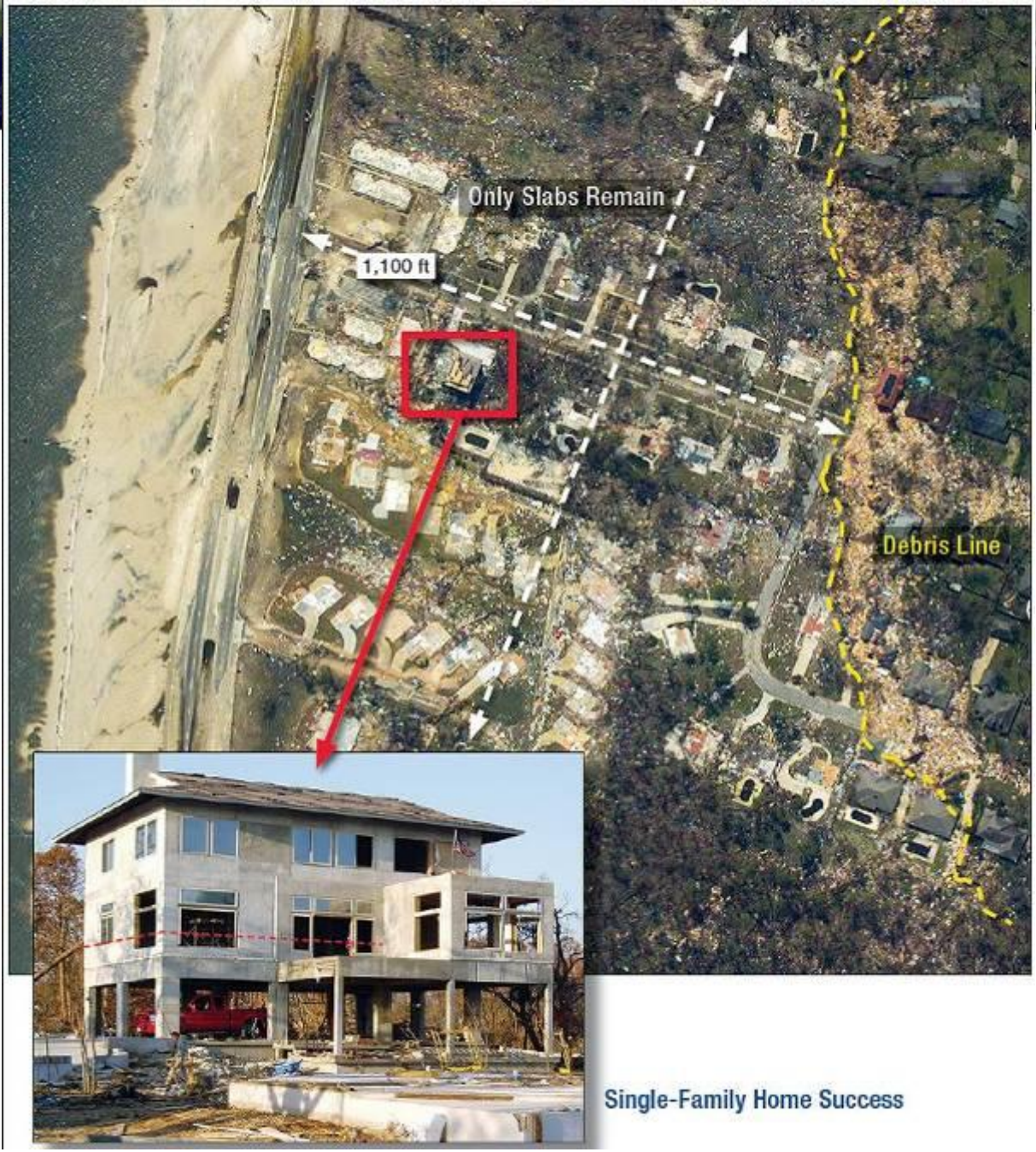
Debris near Port of Gulfport

Gulfport, new construction, only minor damages

Waves and Surge above Lowest Floor

Soffit, Gable End, Roof Deck Failures

Wave, Debris and Wind Damage



Single-Family Home Success

Pass Christian

In this neighborhood, 0.9 mi from the Gulf, 19 of 32 homes floated off their foundations

Pass Christian, “Survivor”

Hancock Bank

Bay St. Louis, New Home Success

Good shear wall connections

Jourdan River

Waveland

Neighbor boasted that his house would withstand 200 mph winds

New Home Failures - Wind

House racked due to inadequate shear wall nailing

Garage Collapse

Historic Structures

“Success: Mandeville c.1905”

St. Bernard Parish, LA

Plaquemines Parish – Areas Protected by the Levees

Typical flooding – Building floating off foundations

Hospital in New Orleans evacuated due to flooding and loss of utilities

Aggregate broke windows

Roof covering blown off

Damaged rooftop equipment

Characterization of New Orleans Flooding

17th Street Canal – site of levee breach

Levee breaches resulted in flooding well above BFE

Actual flood level

BFE

Long-Duration Flood Impacts in New Orleans Area

- **New Orleans Area:** City of New Orleans, Orleans Parish, Chalmette (St. Bernard Parish), Metairie (Jefferson Parish)

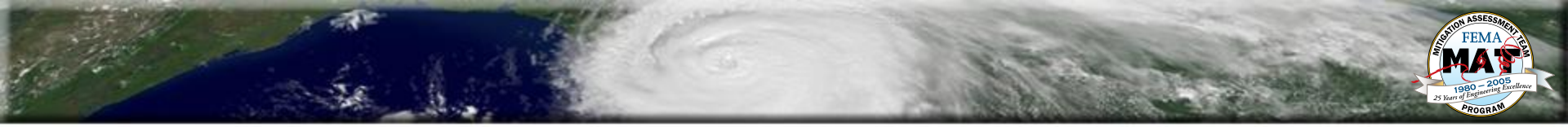
- **MAT Observations:** 23 residential buildings and critical facilities, with 9 buildings sampled for contaminants

Long-Duration Flood Impacts in New Orleans Area

- Levee failure resulted in significant damage to pre-FIRM and post-FIRM buildings
- Most of the damage to areas protected by the levees was *non-structural* damage from long-duration flooding
  - Severe damage to interior of buildings
  - Mold and contaminants
- Most buildings appear to be *restorable*; if properly dried, cleaned and sanitized

Long-Duration Flood Impacts in New Orleans Area – Non-Structural Damage

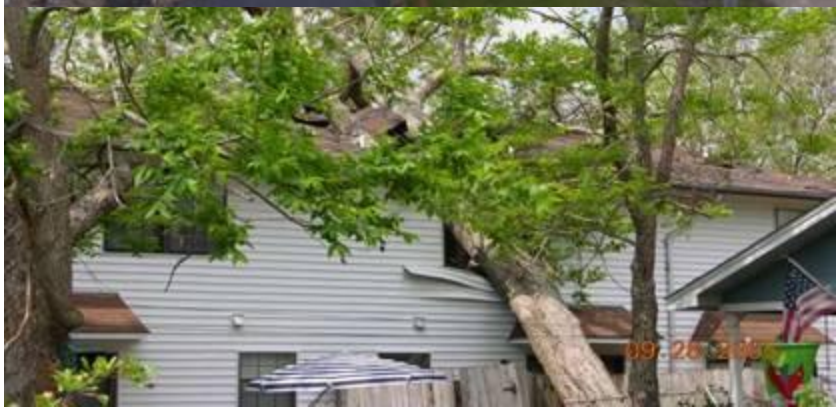
- **Biological contamination:**
  1) High to extreme bacteria contamination levels
  2) Extensive fungal growth (mold) above the flood line
- **Chemical contamination:**
  1) Some high heavy metals
  2) High petroleum hydrocarbon contamination levels (DROs)
  3) Frequent pesticide/chlordane contamination in older buildings
  4) No PCBs detected



CONCLUSIONS AND RECOMMENDATIONS: WIND

Wind Conclusions -- Structural

- Limited Structural Damage
- Typically Older Buildings
- Tree fall



Wind Conclusions -- Structural

- Many problems with new residential construction

-- Inadequate shear wall and diaphragm nailing, lack of metal framing connectors

-- New residential construction in Florida much better

Wind Conclusions – Envelope & Equip

- Poor performance of envelope and rooftop equipment – including new buildings

-- Roof coverings

-- Vinyl siding

-- Soffits

-- EIFS

Wind Conclusions – Envelope & Equip

-- Glazing – use of shutters not as prevalent as in Florida

-- Rooftop equipment

Wind Conclusions – Older Buildings

- Many pre-1990s buildings are vulnerable

-- Will be damaged

-- Will be phased out

-- Mitigate to avoid damage

Wind Recommendations -- Code

- **Adopt current code**
- Don't reduce provisions (speed, debris, aggregate)
- Specific recommendations given for improvements

-- Research needed before implementation of some items

Wind Recommendations – Design and Construction

- Specific recommendations for designers and contractors

Wind Recommendations – Test Methods and Design Guidelines

- Specific recommendations for new and improved test methods and design guides

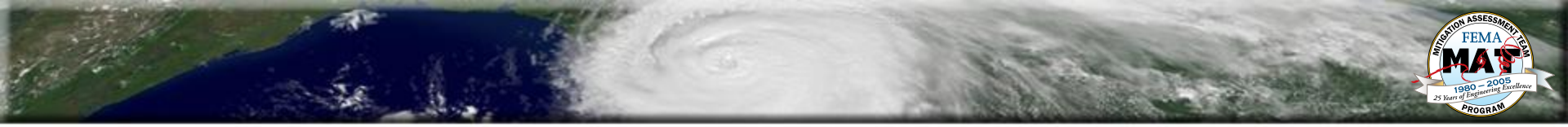
Wind Recommendations -- Education

- Building owners
- A/E (incl. students)
- Contractors & manufacturers (trade schools)
- Building officials
- Current knowledge not being followed

Wind Recommendations -- Inspection

- Increased inspection for residential & non-residential

-- By designers or third-party



CONCLUSIONS AND RECOMMENDATIONS: CRITICAL AND ESSENTIAL FACILITIES

Wind Conclusions – Critical Facilities

- Performance similar to commercial buildings
- Poor building performance affected operations

Wind and Flood Recommendations -- Critical Facilities

- New facilities

-- Locate above 500 yr flood & not isolated

-- Enhanced envelope and equipment attachment

-- Peer review

-- Special inspections

Wind and Flood Recommendations -- Critical Facilities

- Existing facilities

-- Plan to evacuate outside SFHA

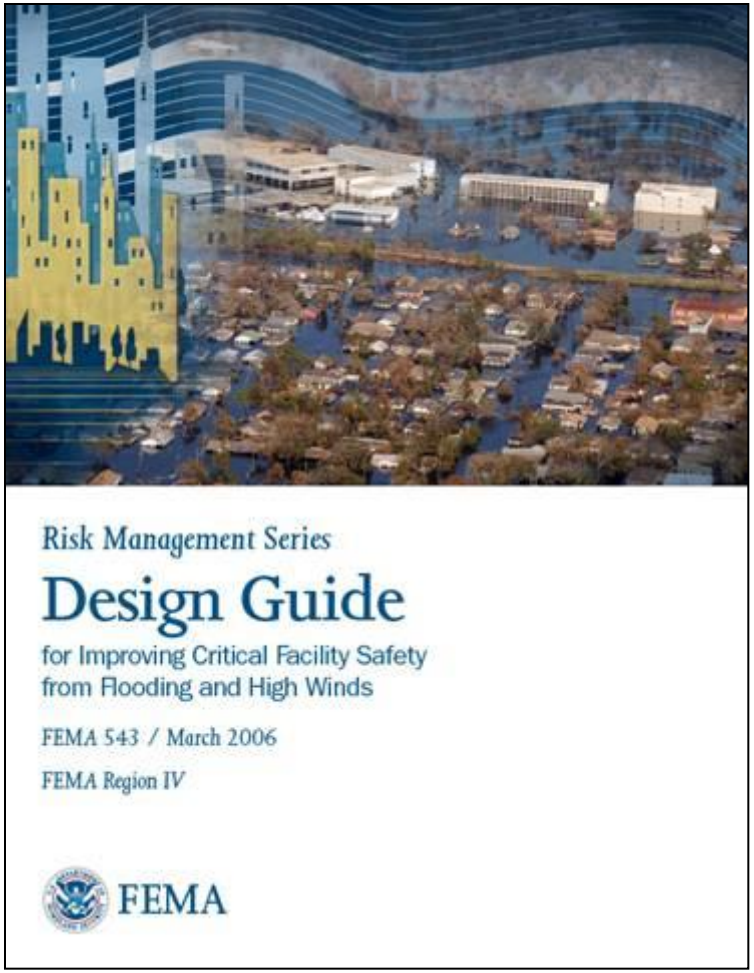
-- Also evacuate equipment

-- Perform Vulnerability assessment

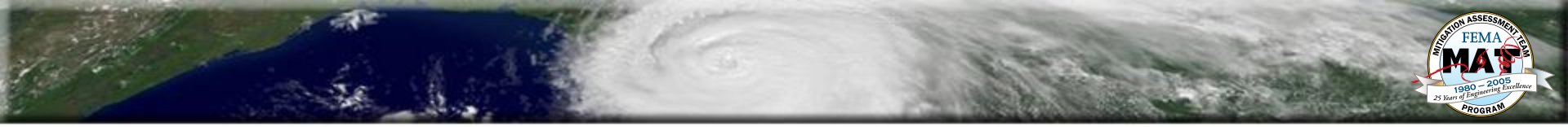
-- If vulnerable, strengthen or build new facility

-- Don't occupy if vulnerable

Design Guide for Critical Facilities



- **Design Guide for Critical Facilities (FEMA 543)**
- **3-day Training Course**



CONCLUSIONS AND RECOMMENDATIONS: FLOOD

Hazard ID Recommendations

- Update *Storm Surge Modeling* which serves as the basis for FIRMs
- Map flood hazards based on *Future Conditions* (sea level rise, subsidence, wetland loss, erosion), even if on optional DFIRM layers
- Develop *"What-If" Maps*

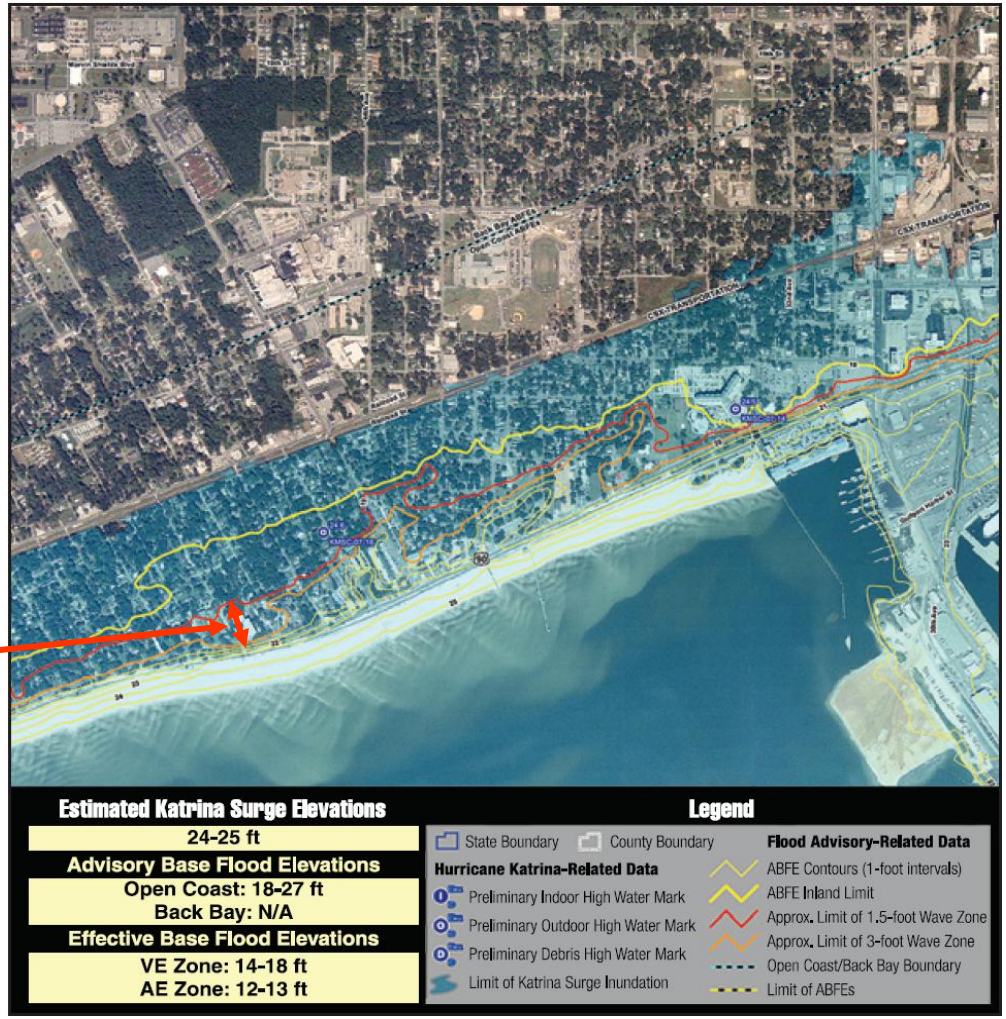
Levees

Implement FEMA Procedure Memorandum No. 34 – Interim Guidance for Studies Including Levees.

If levee is not recertified then the area behind the levee will reflect the actual BFE.

Design Recommendations

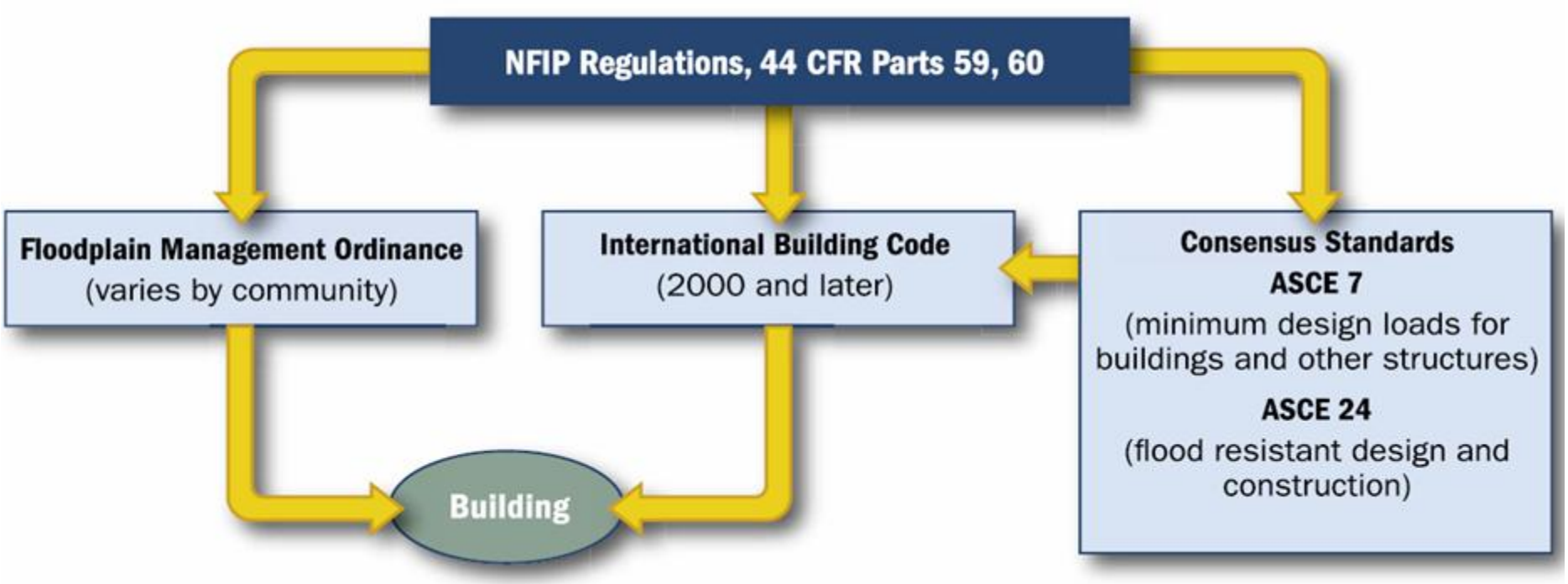
- As an interim, use the Katrina Recovery Maps and construct to the ABFEs
- Adopt V Zone Practices in Coastal A zones



Design Recommendations

- *Adopt the latest model building codes*
  - IBC, IRC, etc., NFPA 5000
- Use *ASCE 7-05* and *ASCE 24-05*
- Use *Recommended Residential Construction for Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, proposed May 2006)
- Use *Home Builder's Guide to Coastal Construction* (FEMA 499) and *Coastal Construction Manual* (FEMA-55)
- Use NIBS' *Building Envelope Design Guide*
- Use NFPA 225 *Manufactured Home Installation Standard*
- Add *freeboard*, and *anticipate flood levels above the BFE*

Flood-Resistant Construction: Building Codes and Standards



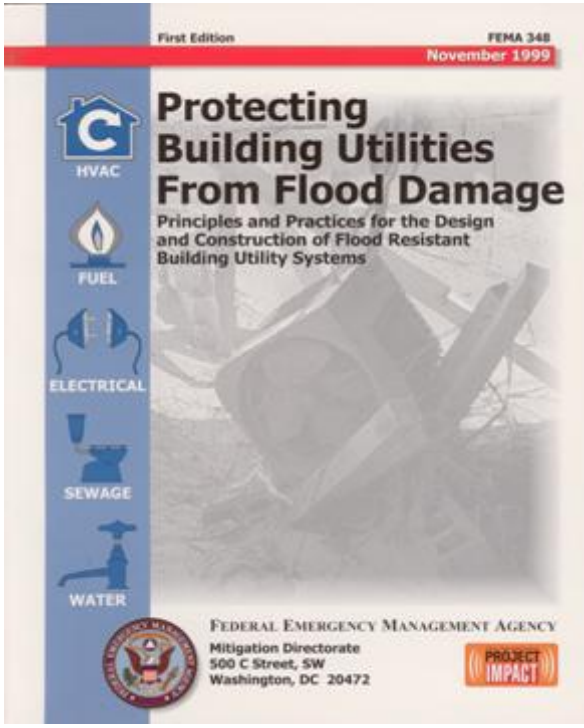
ASCE 7, Minimum Design Loads for Buildings and Other Structures Construction

- **7-02 referenced by 2003 I-Codes**
- **7-05 referenced by NFPA 5000 (2006)**
- **7-05 will be referenced by 2006 I-Codes**

ASCE 24, Flood-Resistant Design and Construction

- **24-05 referenced by 2006 NFPA 5000, will be referenced by 2006 I-Codes**
- **Changes from 24-98:**
  - **Added freeboard**
  - **Coastal A Zone**

Other Guidance

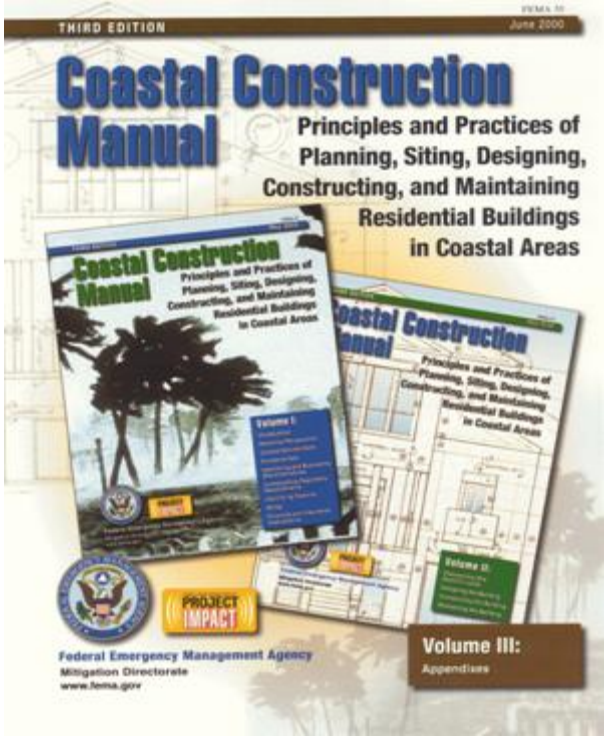


Home Builder's Guide to Coastal Construction

Technical Fact Sheet Series

FEMA 499 / August 2005

FEMA



NIBS Building Envelope Design Guide

- Part of Whole Building Design Guide
- Federal office buildings
- Applicable to other building types

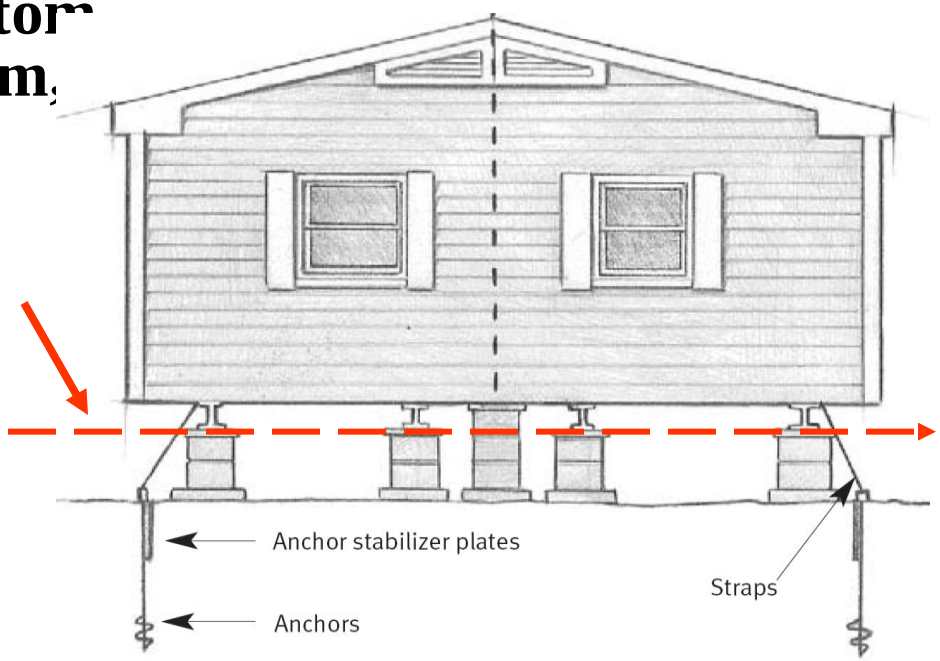
WBDG
Whole Building Design Guide

- ***Below-grade***
- ***Walls***
- ***Fenestration***
- ***Roofing***
- ***Atria***
- ***Wind, flood, blast, seismic***
- ***Indoor air quality and mold***
- ***Sustainability***
- ***HVAC Integration***

http://www.wbdg.org/design/envelope.php

NFPA 225, Manufactured Housing Installation Standard

- **Flood-, wind- and seismic-resistant foundations**
- **Reference elevation is bottom of main chassis frame beam, not top of floor**
- **3-ft pier exception in existing MH park**

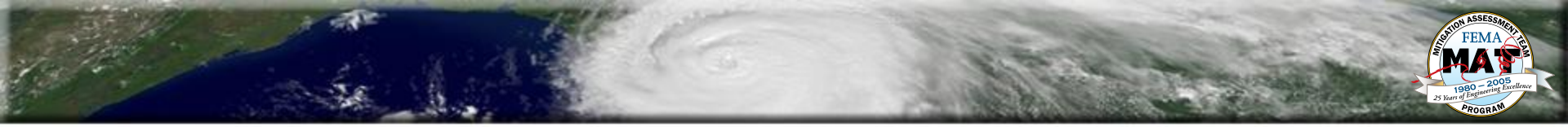


Foundation Recommendations

- Select and design *foundations based on Flood Recovery Maps and ABFEs*, not FIRMs
- Use *Recommended Residential Construction for Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, proposed May 2006)
- Elevate the *bottom of the lowest horizontal structural member above the BFE* in all coastal flood zones

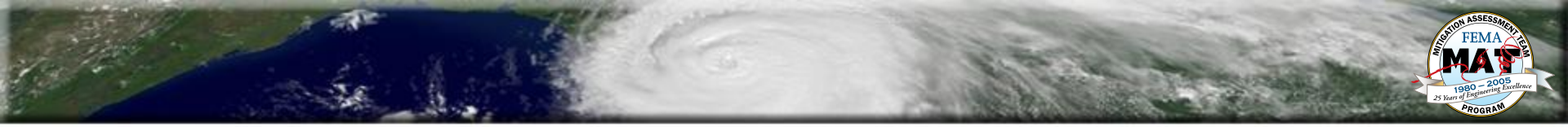
FEMA 550 - Recommended Residential Construction for the Gulf Coast

- Many of the foundations historically used are not adequate for the higher flood elevations
- "New Approaches" to elevate homes are needed



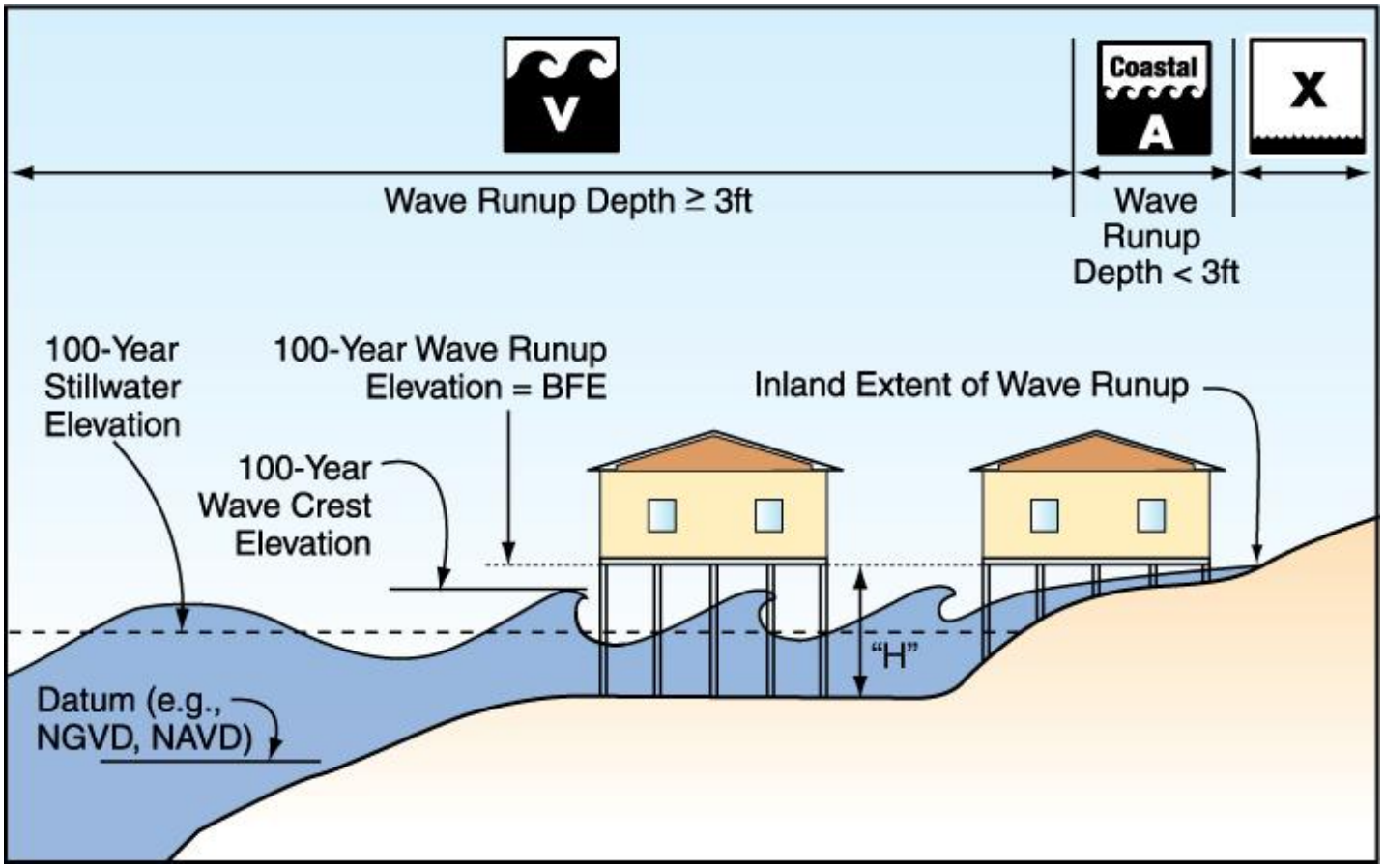
Project Goals

- Develop multi-hazard residential foundation concepts
- Provide designs for specific homes that can used off the shelf
- Provide designs that, when needed, can be modified by local engineers with a minimal amount of effort
- Satisfy needs of 80% of homes being rebuilt in the Gulf Coast
- Use conventional materials and methods where possible
- Develop foundations that will support many of the Mississippi Renewal Forum Pattern Book home designs

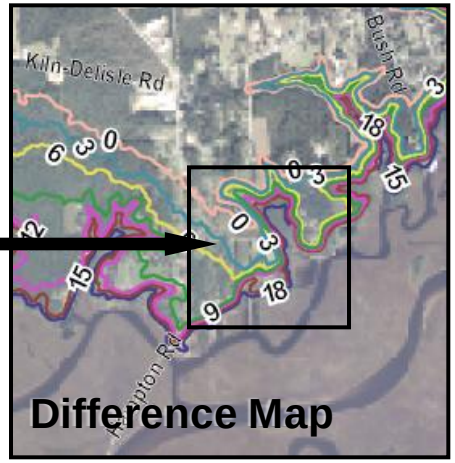


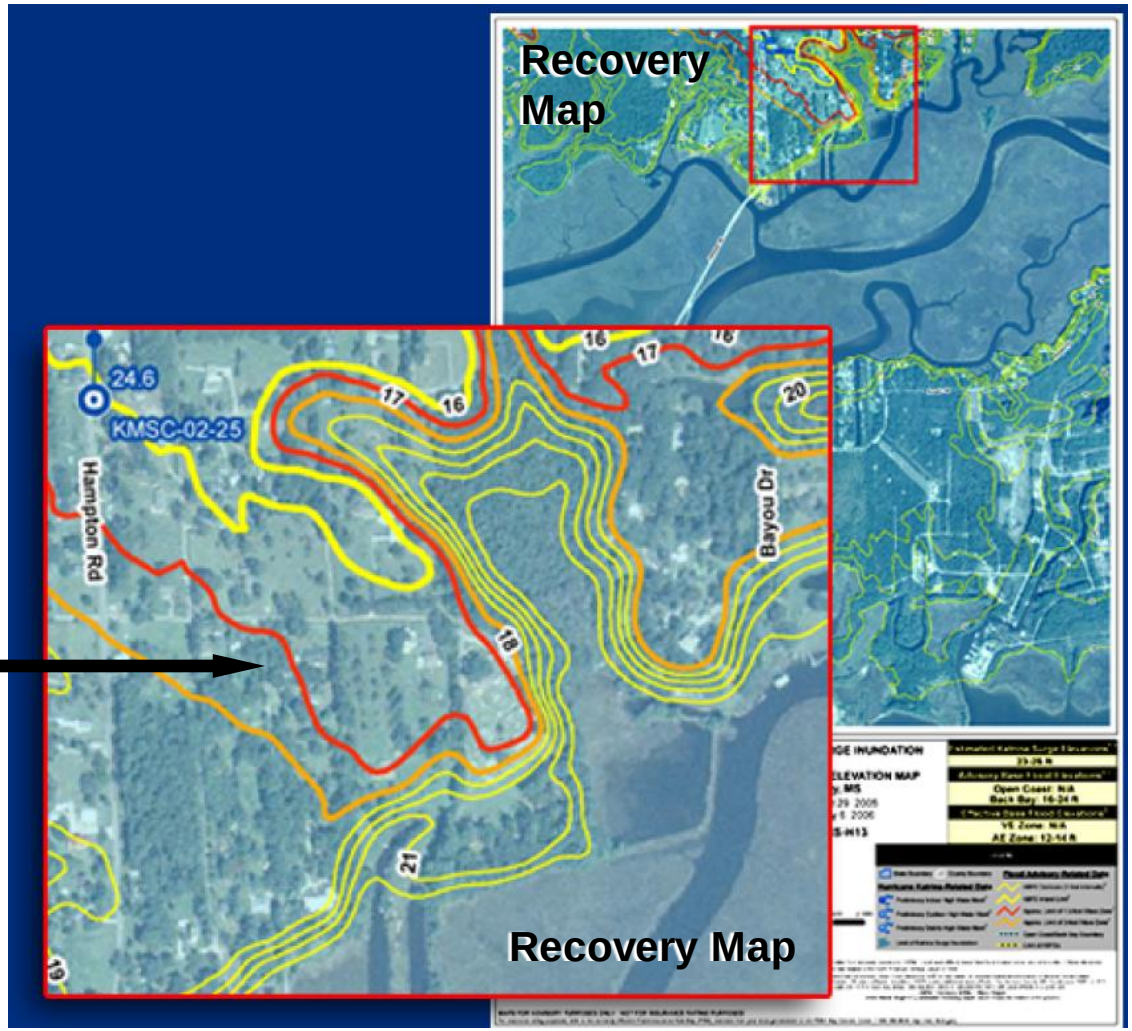
Flood Zones

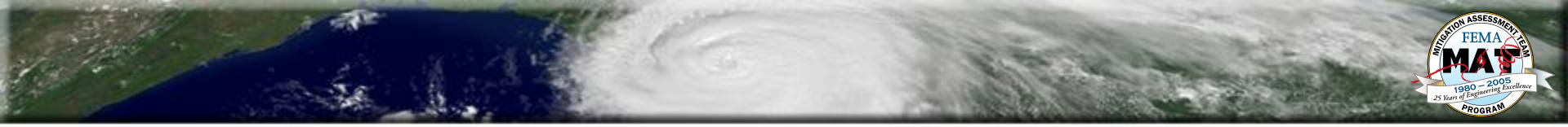
- V Zone
  - Breaking wave height H_b = three feet or greater
  - Open foundations required
- Coastal A Zone
  - Breaking wave height H_b = 1.5 feet to 3 feet
  - Open foundations recommended
- Non Coastal A Zone
  - Breaking wave height H_b < 1.5 feet
  - Either open or enclosed foundations allowed


V
Coastal
A
X
Wave Runup Depth ≥ 3ft
Wave
Runup
Depth < 3ft
100-Year
Stillwater
Elevation
100-Year Wave Runup
Elevation = BFE
Inland Extent of Wave Runup
100-Year
Wave Crest
Elevation
"H"
Datum (e.g.,
NGVD, NAVD)

Example: Home located on site with an estimated flood elevation of 18 ft. Site elevation is 14 ft NAVD. Home would need to be elevated 4 ft (18' – 14') above grade.

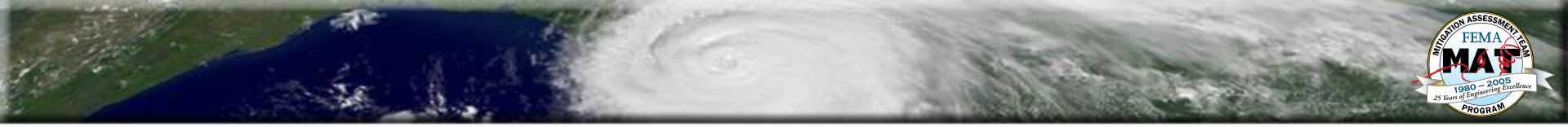






Elevation

- Designs provided for a range of foundation heights
  - Enclosed foundations up to 8 feet
  - Open foundations up to 15 feet
- Designs provided for one and two-story homes
- Designs for V-Zone, Coastal A-Zone and Non-Coastal A Zone



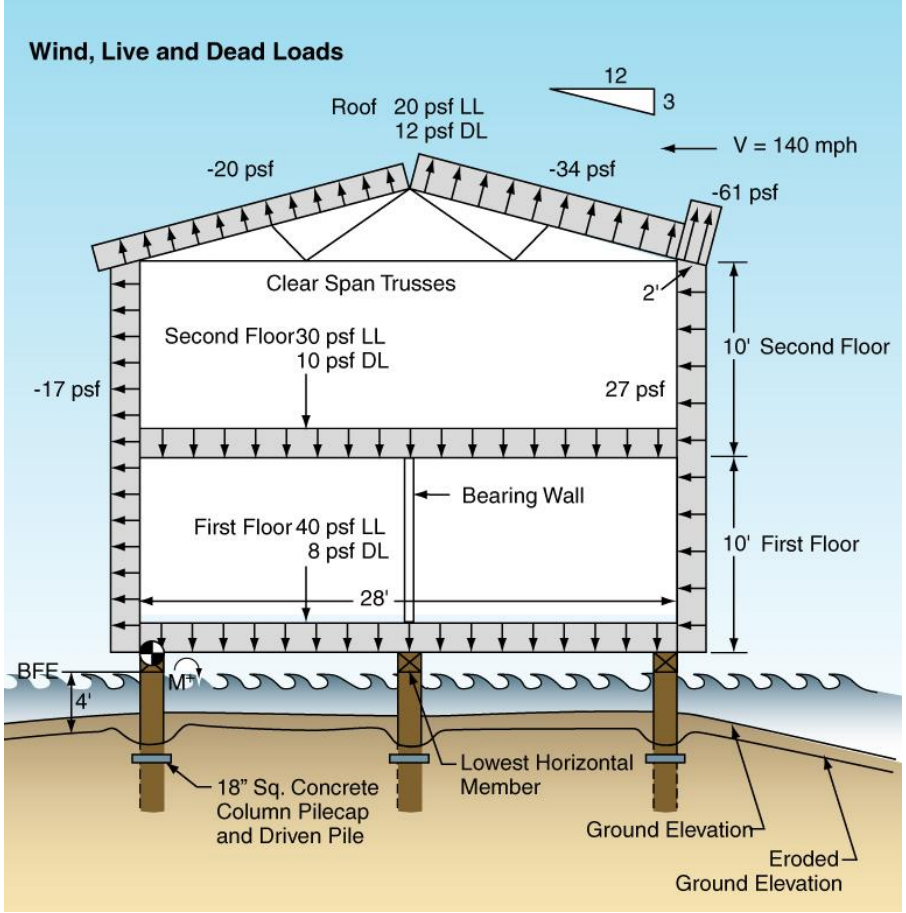
Wind Speed[1]

Gulf Coast Communities

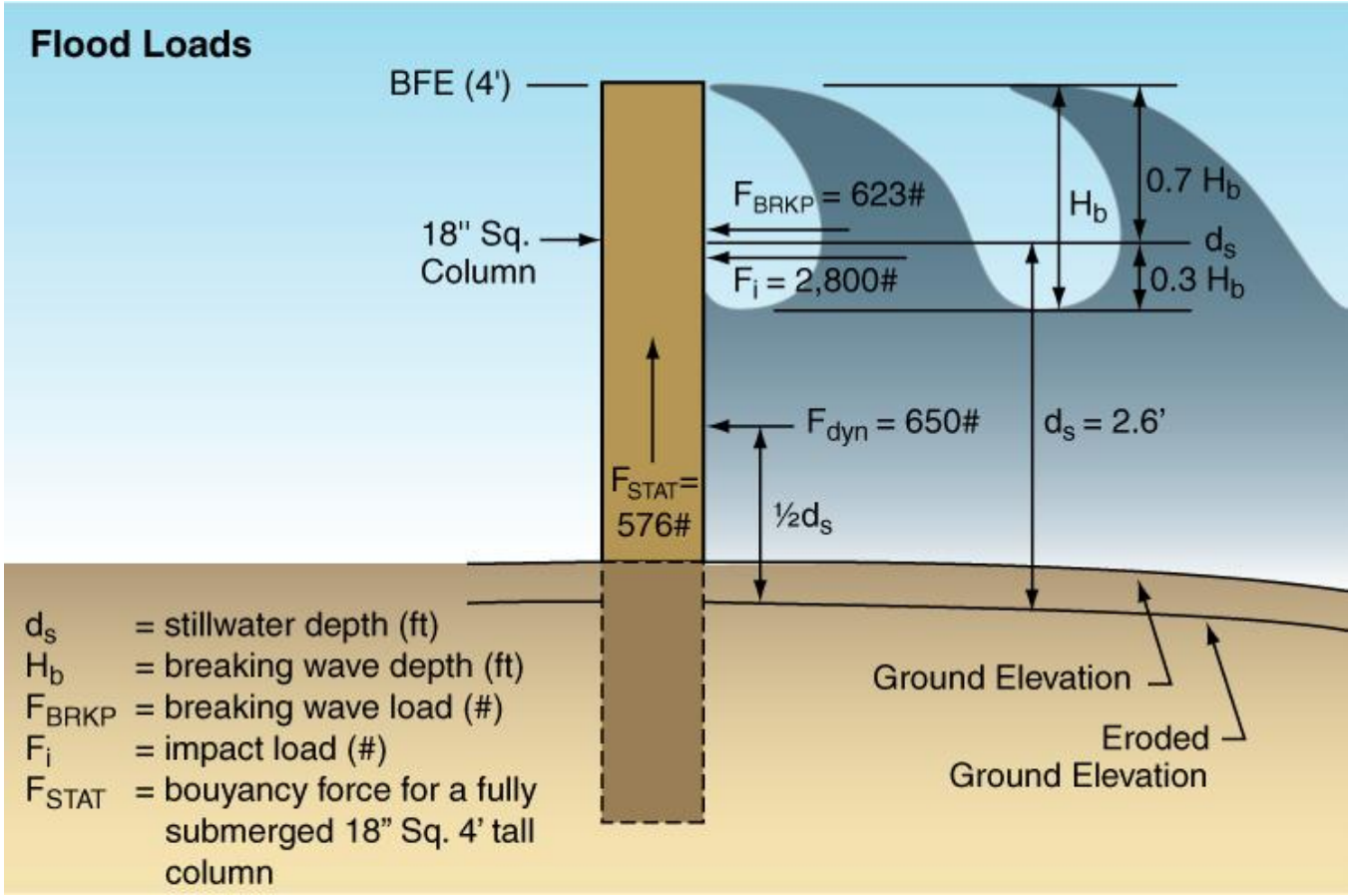
- 120 to 150 miles per hour (3-second gust)
- A small area SE of Pascagoula, MS and the SW tip of Plaquemines Parish, LA have design wind speeds in excess of 150 mph

[1]ASCE 7-02/International Building Code

Loads on Home

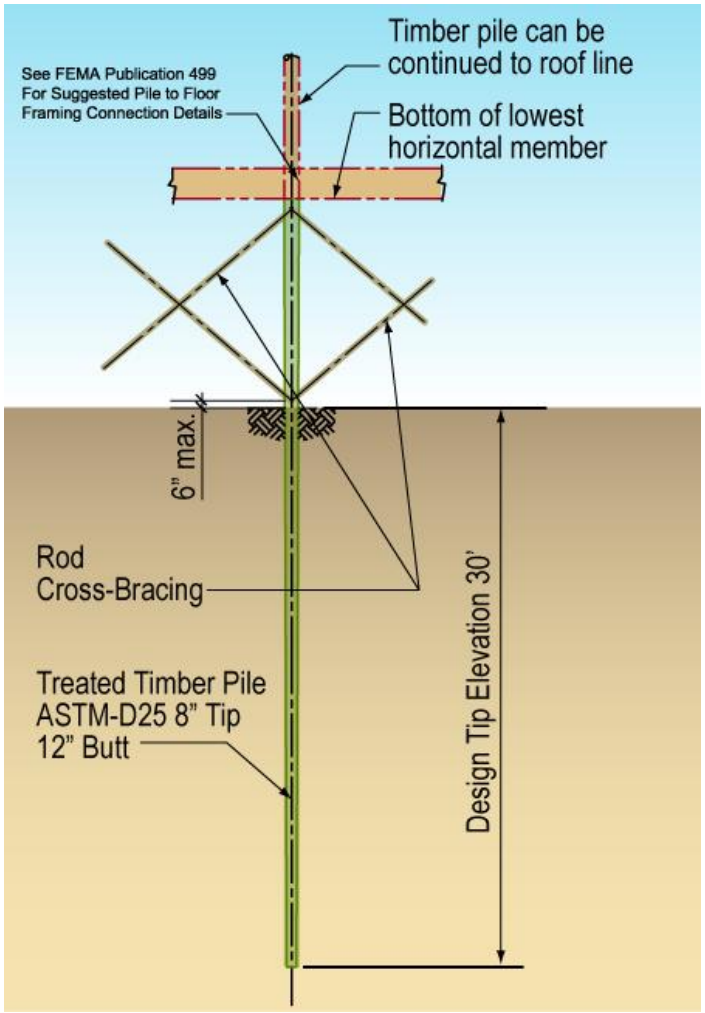


Loads on Foundation



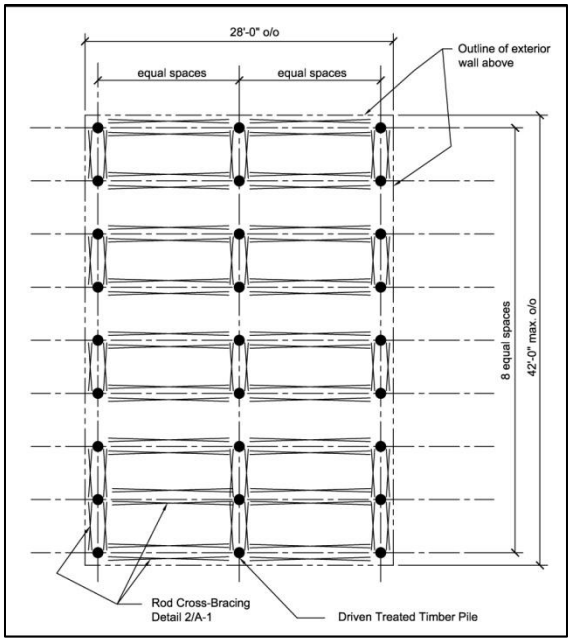
Designs

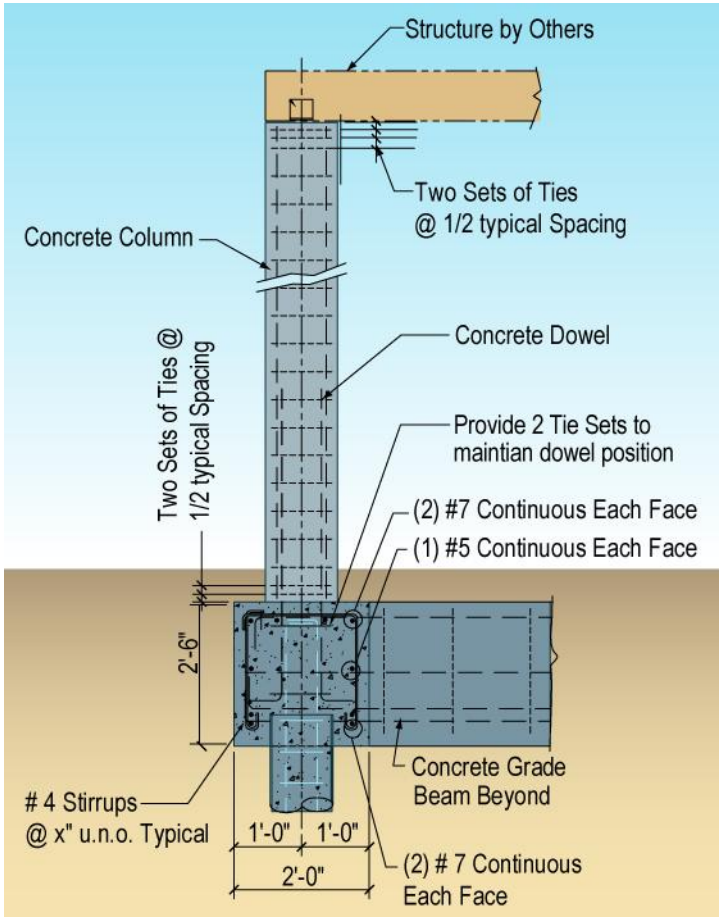
- Case A - Driven Braced Timber Pile
- Case B - Steel Pipe Pile with Grade Beam
- Case C - Driven Timber Pile with Grade Beam
- Case D - Grade Beam/Waffle Foundation
- Case E - Masonry Crawl Space Foundation
- Case F - Masonry Stem Wall Foundation
- Case G - Grade Beam/Mat Foundation



Case A - Driven Braced Timber Pile

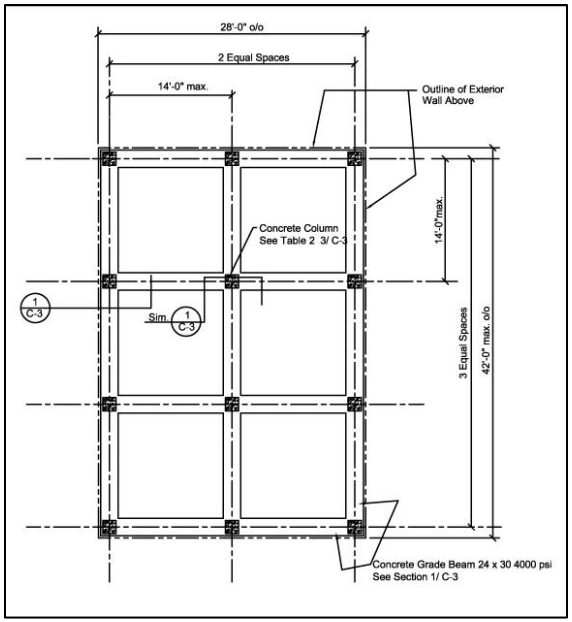
- Good for V, Coastal A, or A Zones
- Maximum height above ground level is 10 feet
- Deep foundation

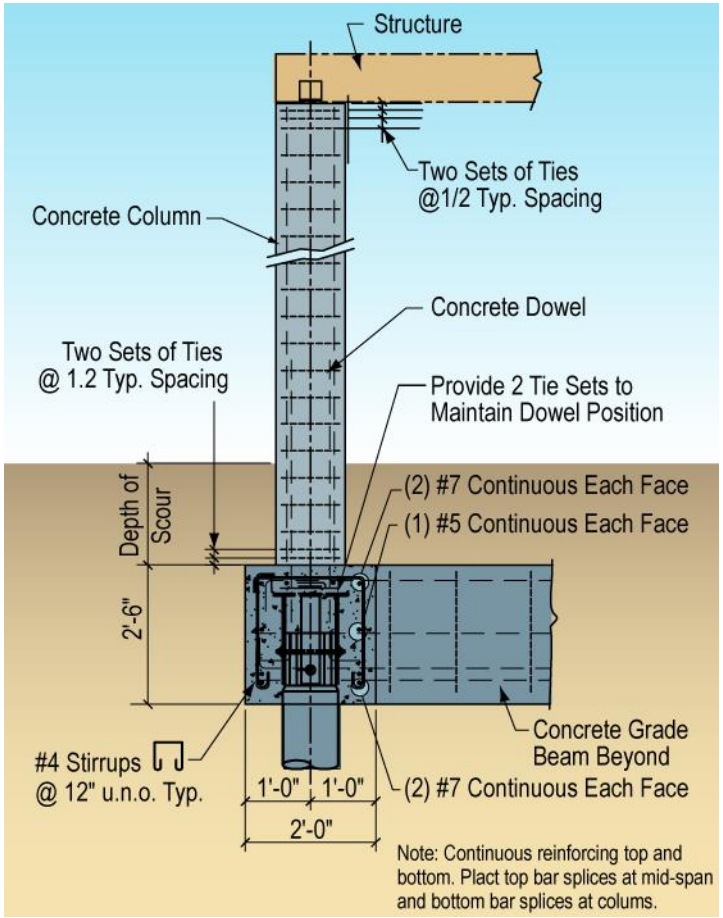




Case B - Steel Pile with Grade Beam

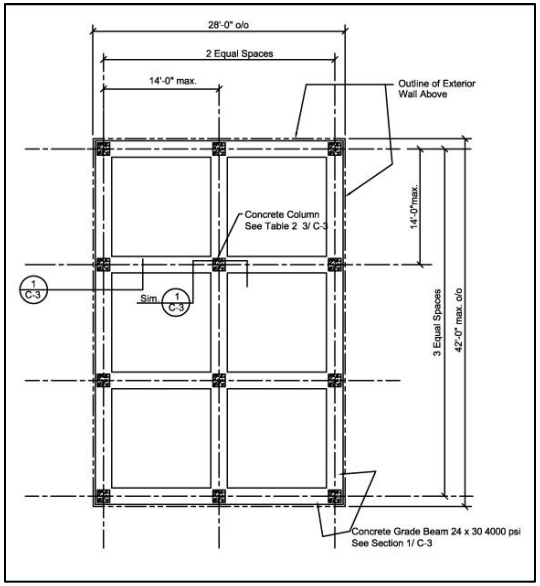
- Concrete column above ground level
- Good for V, Coastal A, and A Zones
- Suitable for elevations up to 15 feet above grade
- Deep foundation

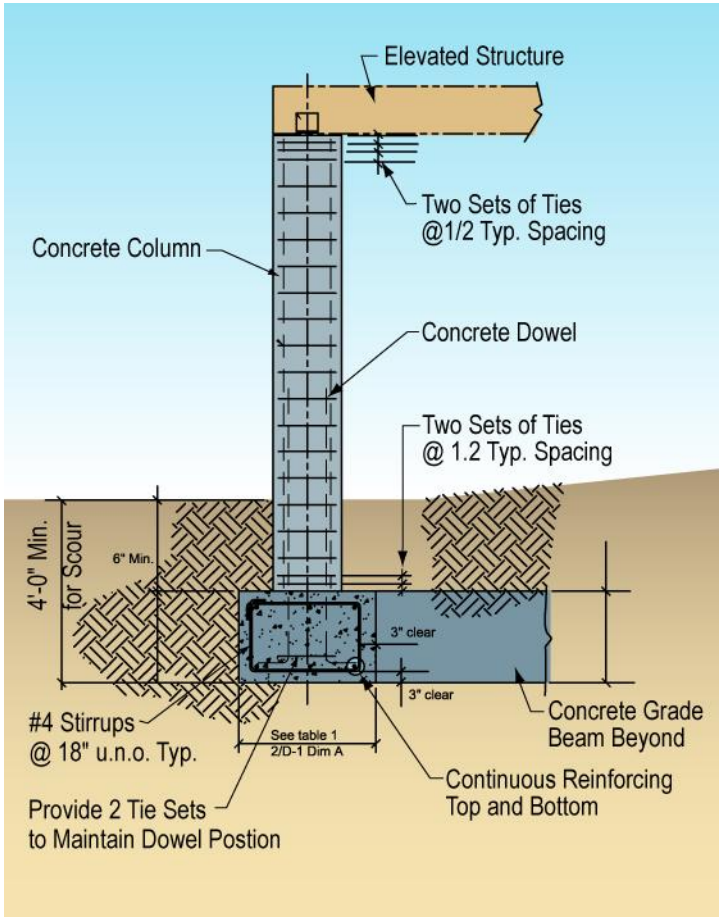




Case C - Driven Braced Timber Pile with Pile Cap

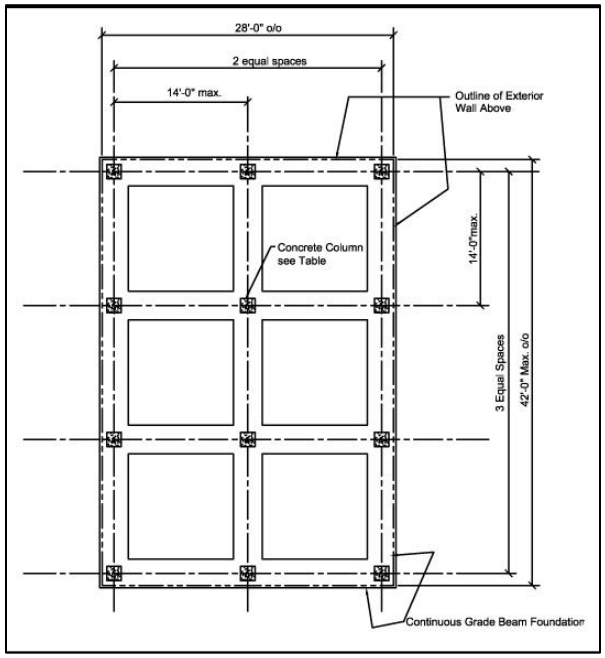
- Concrete column above ground level
- Good for V, Coastal A, and A Zones
- Suitable for elevations up to 15 feet above grade
- Deep foundation

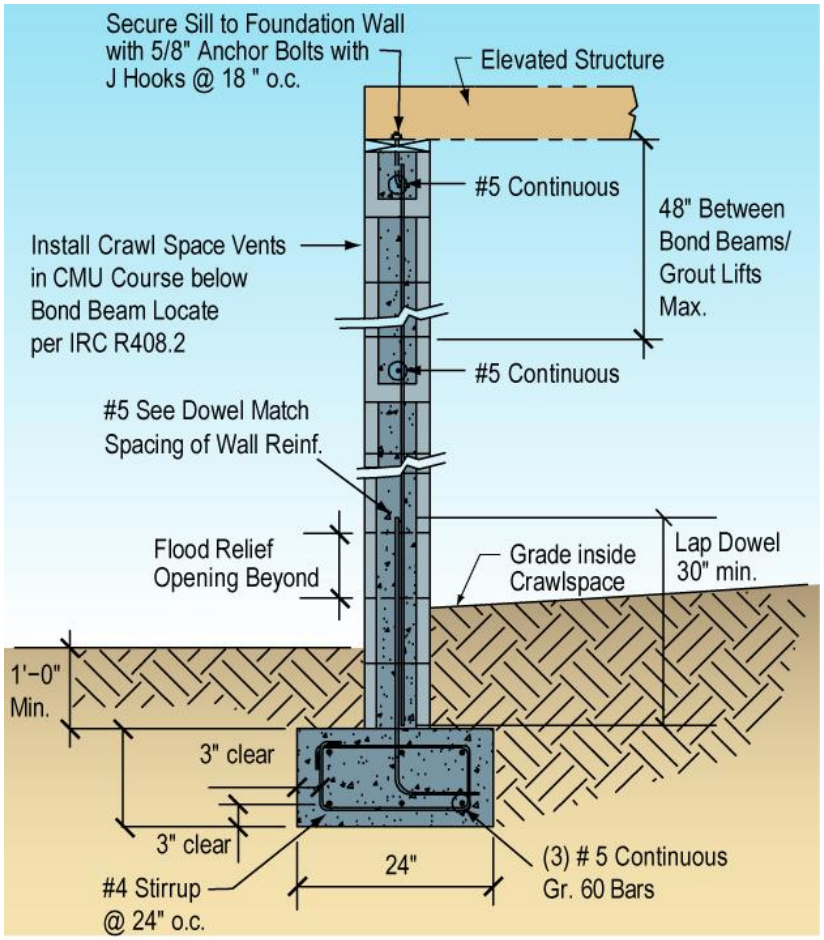




Case D - Grade Beam/Waffle Foundation

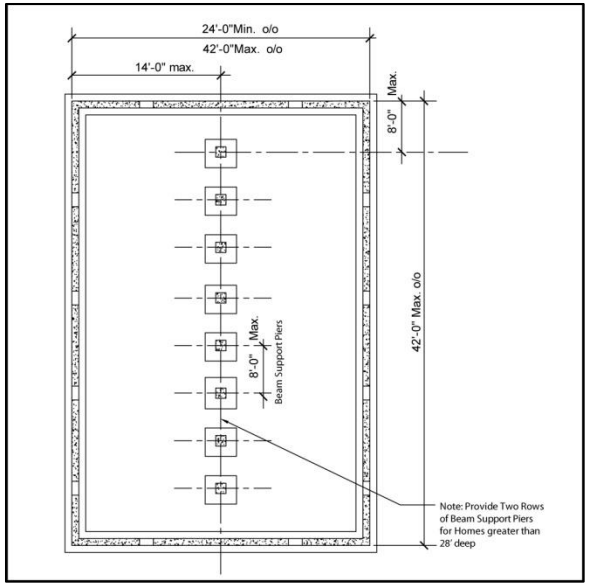
- Good for A Zones (and Coastal A where scour and erosion is limited)
- Maximum height above ground level is 8 feet
- Shallow foundation

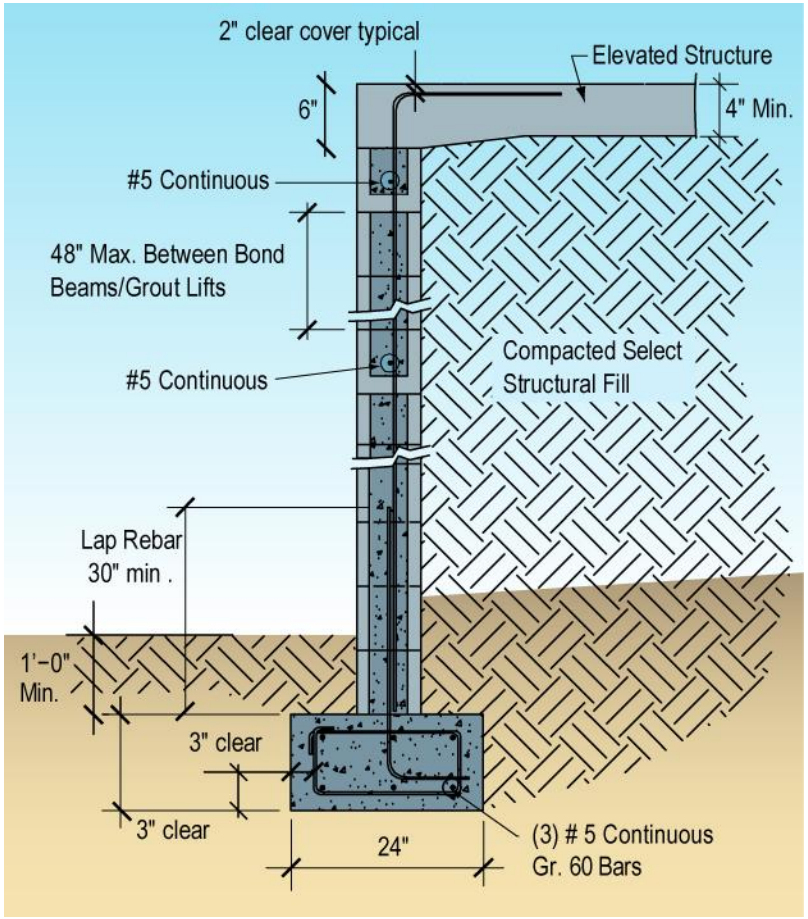




Case E - Masonry Crawl Space Foundation

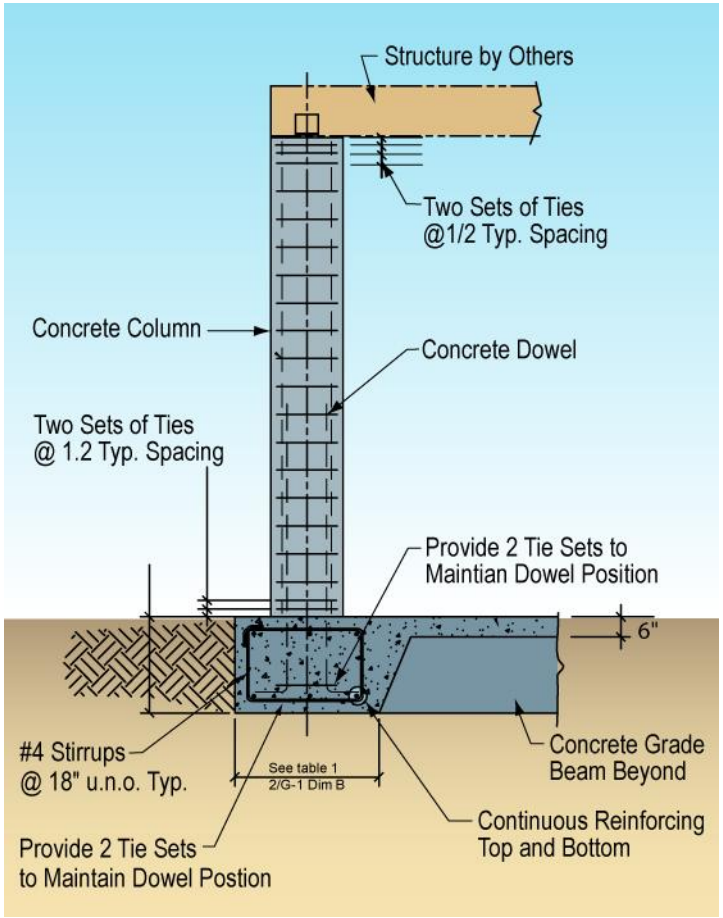
- Good for A Zone only
- Maximum height above ground level is 8 feet
- Shallow foundation





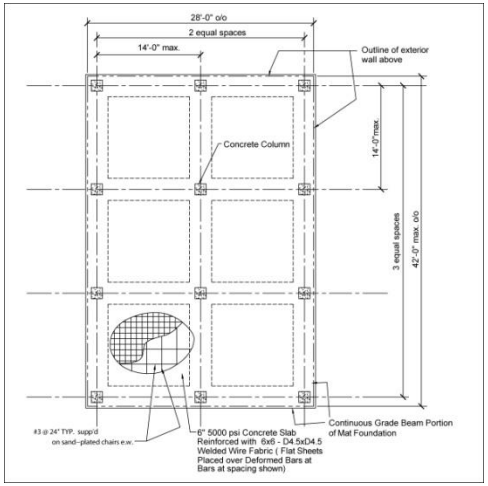
Case F - Masonry Stem Wall Foundation

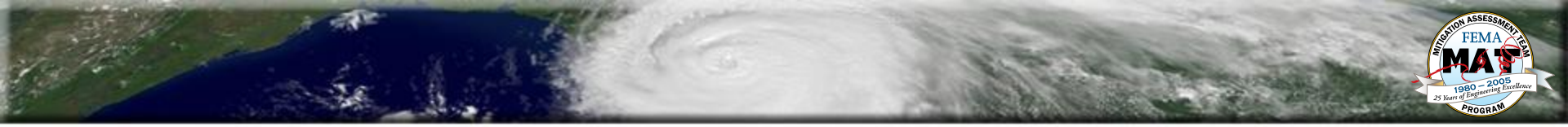
- Good for A Zone only
- Maximum height above ground level is 4 feet
- Shallow foundation



Case G - Grade Beam/Mat Foundation

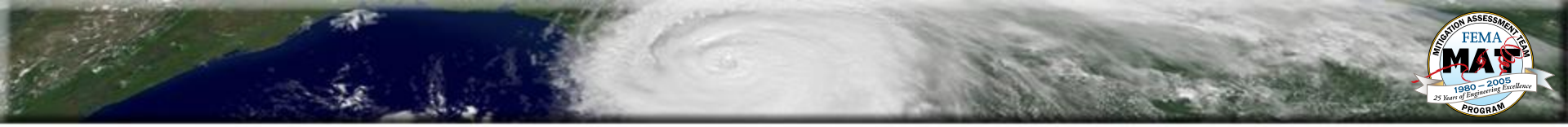
- Concrete column on concrete grade beam
- Reinforced slab provides additional uplift resistance
- Good for A zone (and Coastal A where scour and erosion is limited)
- Maximum height above ground level is 8 feet
- Shallow foundation





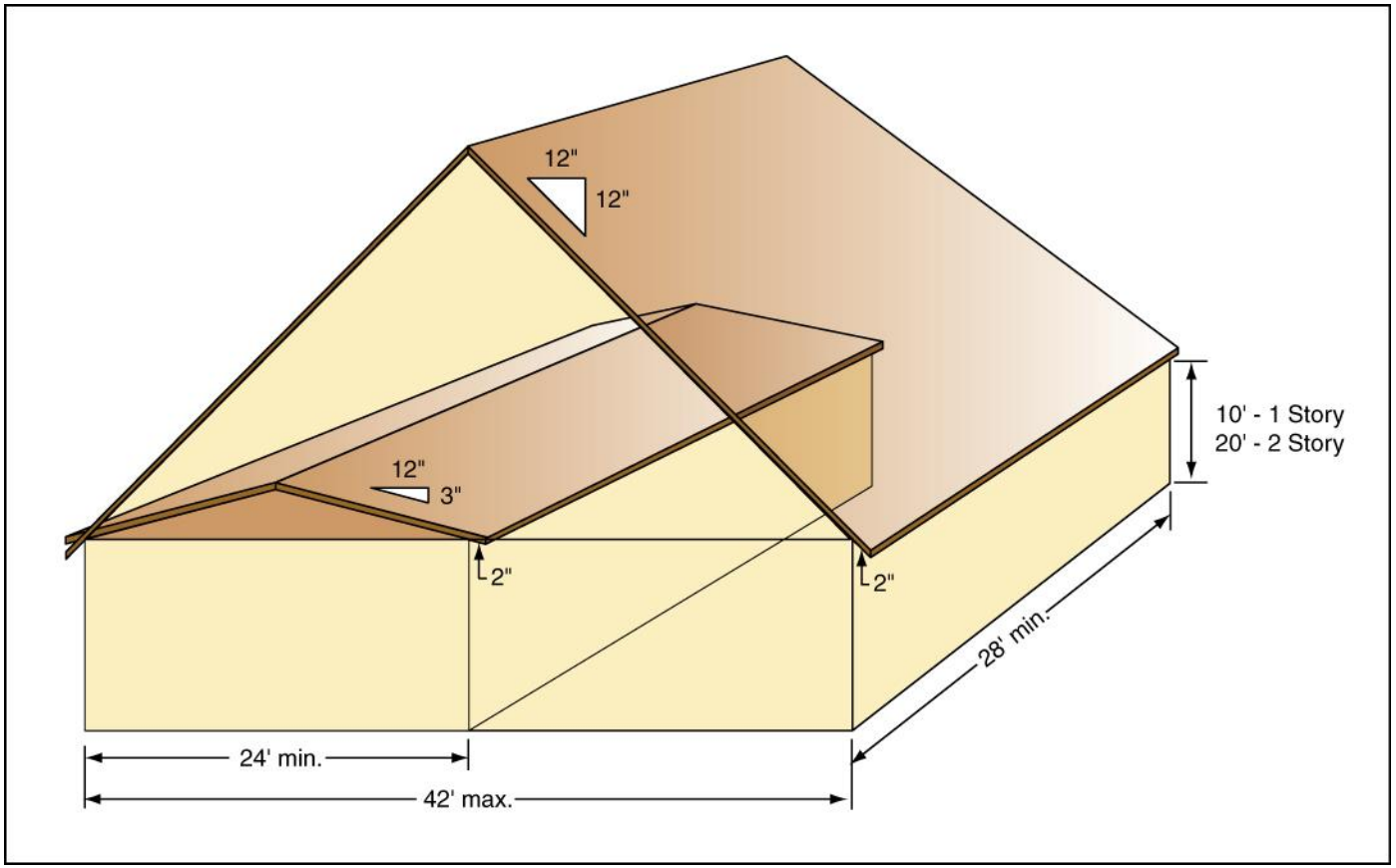
Foundation	Case	V Zones	A Zones in Coastal Areas	
			Coastal A Zone	A Zone
Braced Driven-treated timber pile	A	✓	✓	✓
Open-ended steel pile with grade beam	B	✓	✓	✓
Wood pile with grade beam	C	✓	✓	✓
Open foundation concrete column with continuous spread footing	D	NR (scour)	✓	✓
Closed foundation—crawlspace reinforced concrete masonry unit (CMU)	E	✗	✗	✓
Closed foundation backfill	F	✗	✗	✓
Open waffle slab	G	NR (scour)	✓ (limited scour)	✓

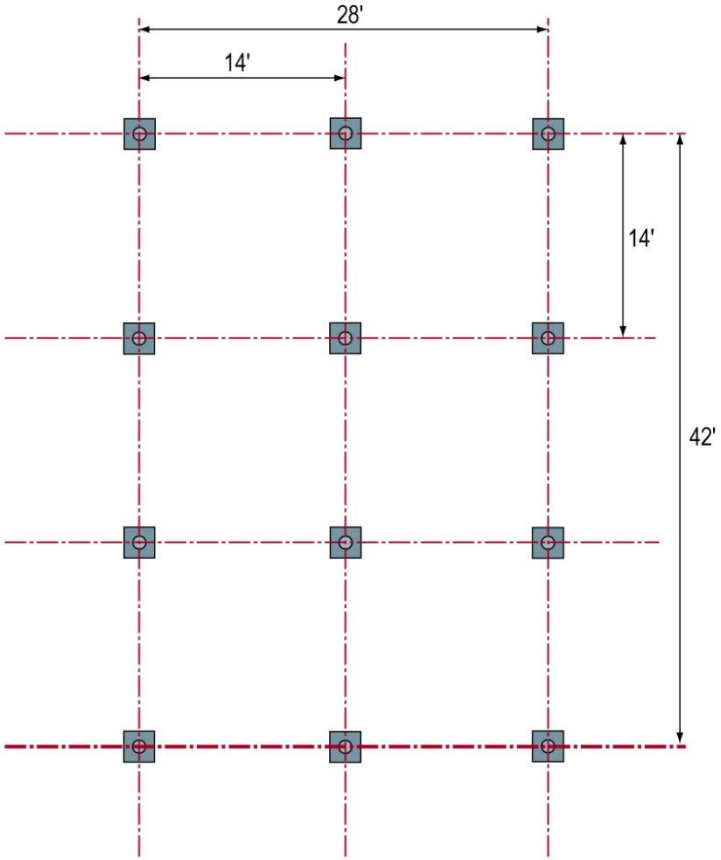
✓ = Acceptable
NR = Not Recommended
✗ = Not Permitted



Design Approach for use

- Design foundation in “modules”
- Combine modules to create an actual building footprint
- Modules are for one and two story homes


12"
12"
12"
3"
2"
2"
10' - 1 Story
20' - 2 Story
28' min.
24' min.
42' max.



Typical foundation footprint

- 28’ by 14’ bays
- Maximum 42’ depth (with additional row of piers)

Foundations for "Other Homes"

- Example
- Elevations greater than 15 feet
- Slender homes (less than 28 feet deep)
- Homes with flat roofs or roofs greater than 12:12 pitch
- Very heavy (gravity) or very light homes (uplift)

If home doesn't match criteria used in the designs

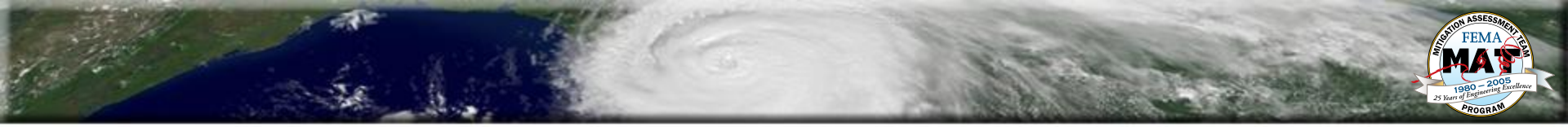
- Consult with a licensed professional engineer to design the foundation
- Analyze loads per IBC/IRC or ASCE 7
- Use the *Coastal Construction Manual*, FEMA 55, for guidance on issues not covered in the Model Codes (IBC or NFPA 5000) and Standards (eg. ASCE-7, ASCE-24)
- Recommend following guidance found in other FEMA publications to make homes more hazard resistant than criteria contained in Model Codes

Walls Below V Zone Buildings

- NFIP regs prohibit solid walls below V zone buildings
- Mid- and high-rise buildings often employ shear walls below the BFE
- Investigate technical, policy and financial implications of allowing shore-perpendicular walls below highly elevated 1- and 2-family buildings in V zones

Use of Fill in Coastal Flood Zones

- NFIP prohibits fill for structural support in V zones, allows in A zones
- ABFEs can result in lowest floor > 1 story above grade:
  - Consider use of non-structural fill to facilitate access and improve aesthetics of highly elevated buildings
  - Community approach may be best
  - Technical, economic, environmental evaluations required



RECOVERY ADVISORIES

Reconstruction Guidance for the Mississippi Coast

Using Advisory Flood Elevations and Coastal Flood Recovery Maps

HURRICANE KATRINA RECOVERY ADVISORY Mississippi

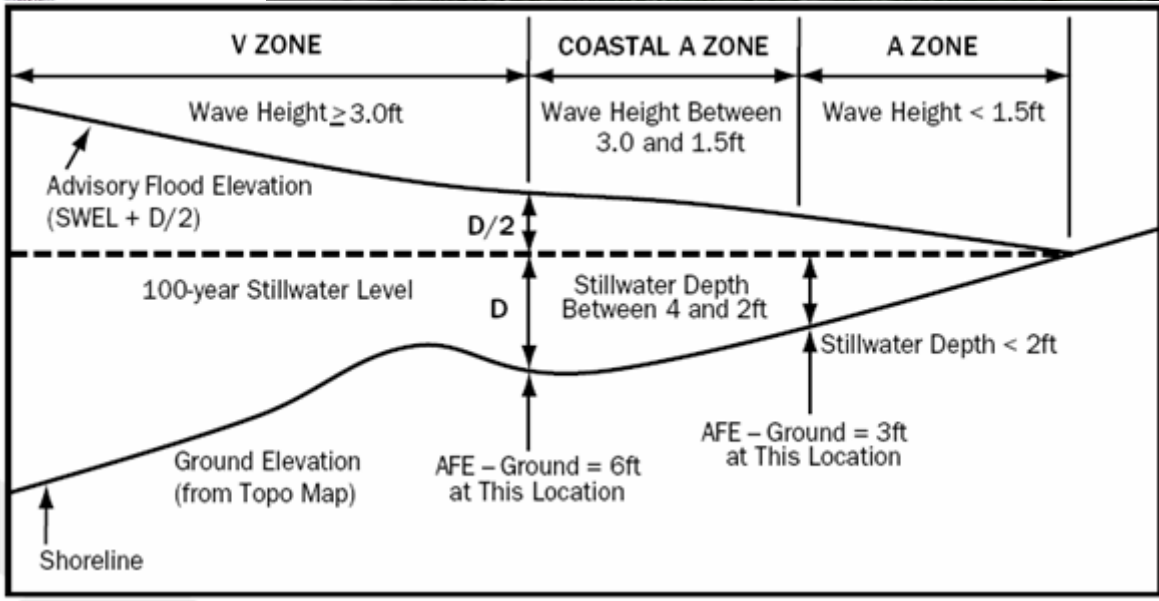
Purpose: To discuss available flood hazard information and to recommend reconst
Advisory Flood Elevations (AFEs) and Coastal Flood Recovery Maps (CFRMs).

Key Issues

- The effective FIRMs for communities in Hancock, Harrison and Jackson Counties early 1980s and 2002. However, all were based on storm surge studies and flooc are over 25 years old.
- Following hurricane Katrina, FEMA updated its flood frequency analyses to include elevation data (including Katrina). The results of this effort are known as Advisory AFEs are updated estimates of the 1% (100-yr) flood elevations, and are several f shown on the effective FIRMs.
- FEMA will also produce a series of maps showing the extent of flood inundation a hurricane Katrina (expected release, November 2005). These maps will be known Recovery Maps (CFRMs). Flood elevations on the CRFMs will be several feet high Katrina was more severe than a 100-yr flood on the updated flood frequency anal
- Although the information contained in the AFEs and CRFMs is advisory, communit AFEs or CRFMs to regulate reconstruction and new construction.
- Revised FIRMs will be produced (anticipated completion, 2007) for the coastal co will be mapped using the updated 100-yr stillwater elevations, but with detailed a result, BFEs on the revised FIRMs may differ somewhat from the calculated AFEs In the interim, the AFEs should be treated as the best available 100-yr flood elevation information

Advisory Flood Elevations

Advisory Flood Elevations were published by FEMA for Hancock, Harrison and Jackson Counties on October 3

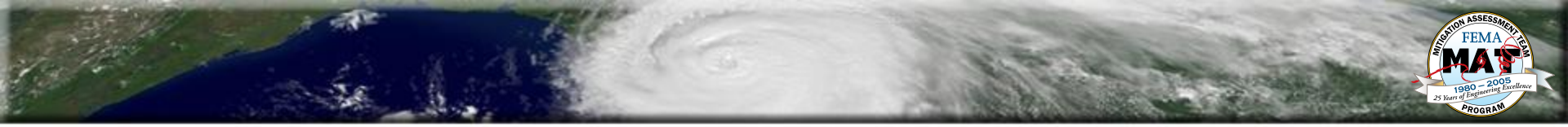


County, Flood Source	100-Year Stillwater Elevation (ft NGVD)	Ground Elevation Corresponding to Inland Limit of V Zone (ft NGVD)	Ground Elevation Corresponding to Inland Limit of Coastal A Zone (ft NGVD)
Jackson, Gulf of Mexico	14	10	12
Jackson, Back Bay	12	8	10
Harrison, Gulf of Mexico	18	14	16
Harrison, Back Bay	16	12	14
Hancock, Gulf of Mexico	20	16	18
Hancock, Back Bay	18	14	16

Brick Veneer Failures → Recovery Advisory

Brick Veneer stripped from wall

Improper veneer tie placement and embedment



Recovery Advisories

- Design and Construction in Coastal A Zone
- High-Wind Shingle Attachment
- Initial Restoration for Flooded Buildings
- The ABCs of Returning to Flood Buildings
- Design for Flood Levels Above the BFE (May 2006)
- Reconstruction Guidance Using ABFEs in Louisiana (May 2006)
- Attachment of Brick Veneer (May 2006)
- Attachment of Lightning Protection Systems (Proposed 2006)
- Use of Fill in Coastal Flood Hazard Areas (May 2006)