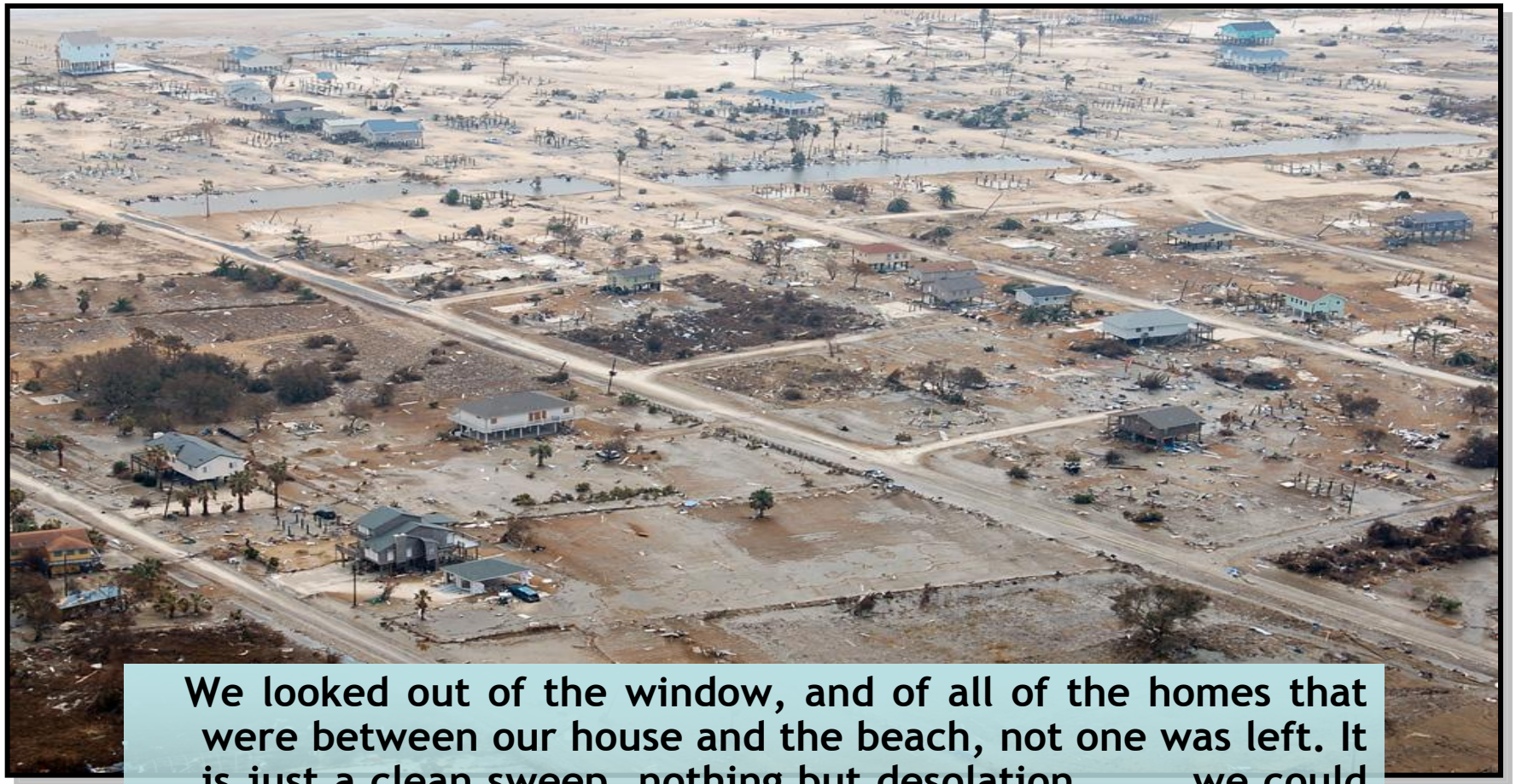
Mitigation Assessment Team Report on

Hurricane Ike

National Hurricane Conference

Hurricane Ike damage—Seen again and again



We looked out of the window, and of all of the homes that were between our house and the beach, not one was left. It is just a clean sweep, nothing but desolation. . . . we could not see the water from our house before this storm.

. . . Sarah Littlejohn, following the 1900 Hurricane

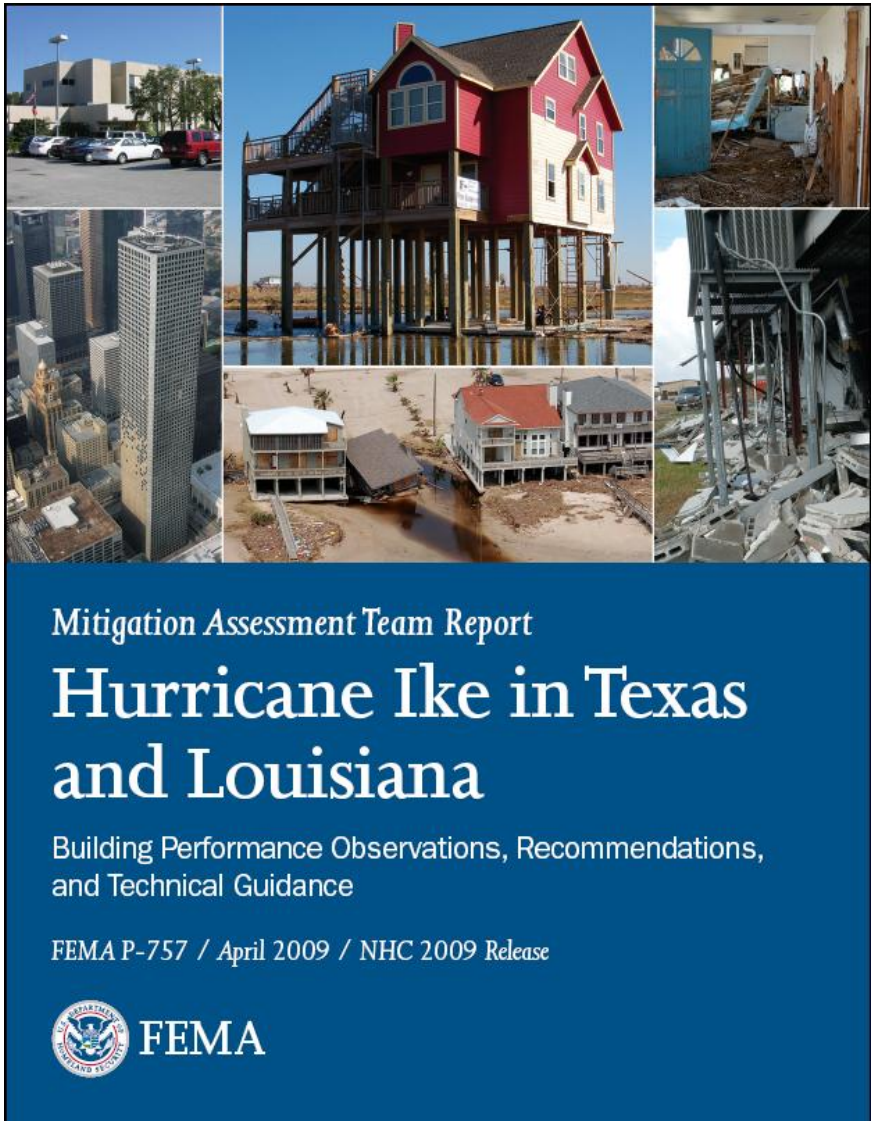
(Bixel and Turner. *Galveston and the 1900 Storm*. Univ. of Texas Press, 2000)

MAT Mission

- Conduct *forensic engineering analyses*
- *Recommendations* to communities, states and organizations/agencies
- *Improve construction codes and standards, designs, methods, and materials*

Products

- Ike MAT Report (400+ pages)
- 46 Specific Recommendations
- 8 Recovery Advisories (3-9 pages w/specific target)



MAT Recommendations

- 46 Specific Recommendations
  - 21 Residential
  - 11 Critical Facilities
  - 14 Further Studies and Standards/Codes Revision
- Some recommendations that will be highlighted:
  - 3 feet of freeboard until new DFIRMs in place
  - Foundation scour and erosion guidance needed
  - Vulnerability assessment of critical facilities
- Please ask questions

Recovery Advisories

- *Attachment of Brick Veneer in High-Wind Regions*
- ***Design and Construction in Coastal A Zones***
- ***Designing for Flood Levels Above the BFE***
- ***Enclosures and Breakaway Walls***
- ***Erosion, Scour, and Foundation Design***
- *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions*
- *Metal Roof Systems in High-Wind Regions*
- *Siding Installation in High-Wind Regions*

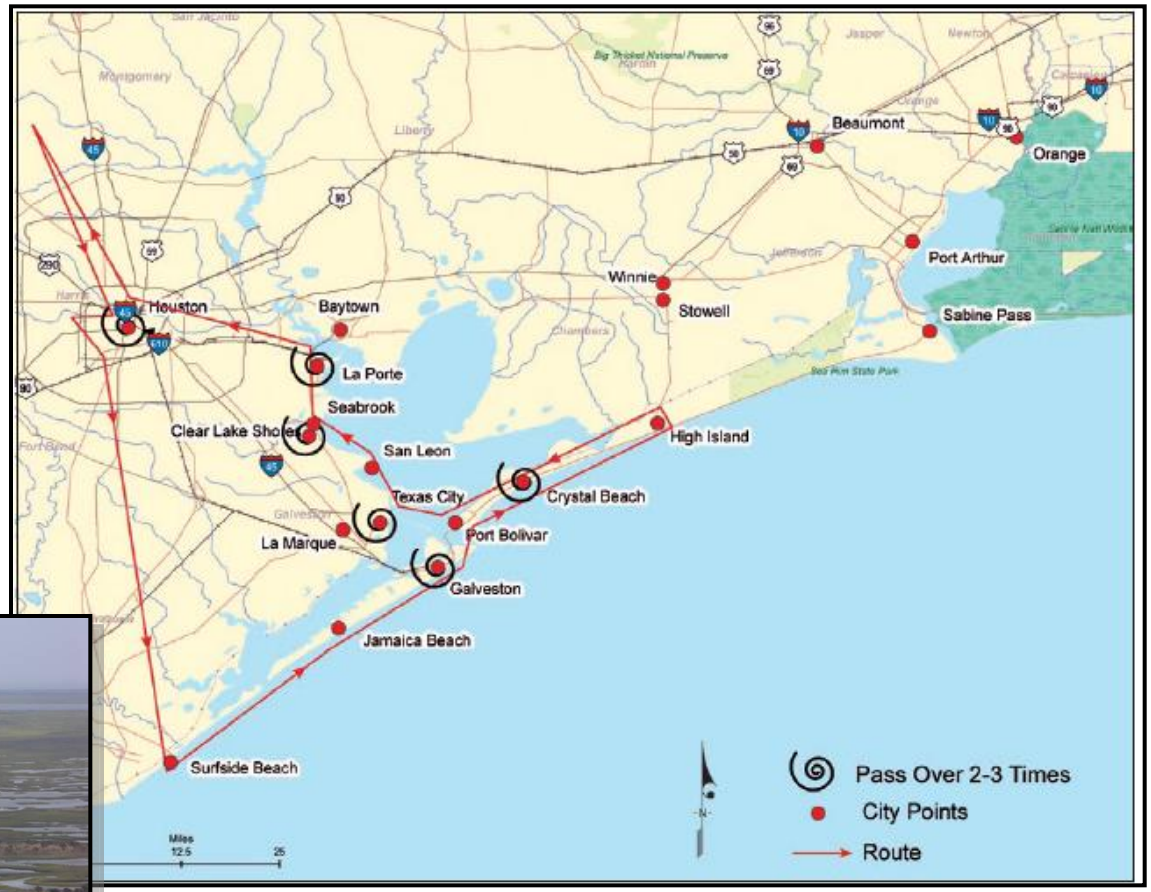
MAT Deployment

- Small team goes out first (pre-MAT)
- Gather information
- *Go or no go decision*
- Ike MAT activated, 3 main teams deployed 1 month post-Ike
  - Louisiana Flood
  - Texas Flood
  - Texas Wind
- Some teams split up for special assignments
  - Houston CBD
  - Revisit homes from 1990 TTU/SBCCI study
  - Investigate performance of mitigation projects (HMGP, ICC)

Pre-MAT

6 people deployed to field within 5 days

Ground and aerial inspections



Customs and Border Patrol Support

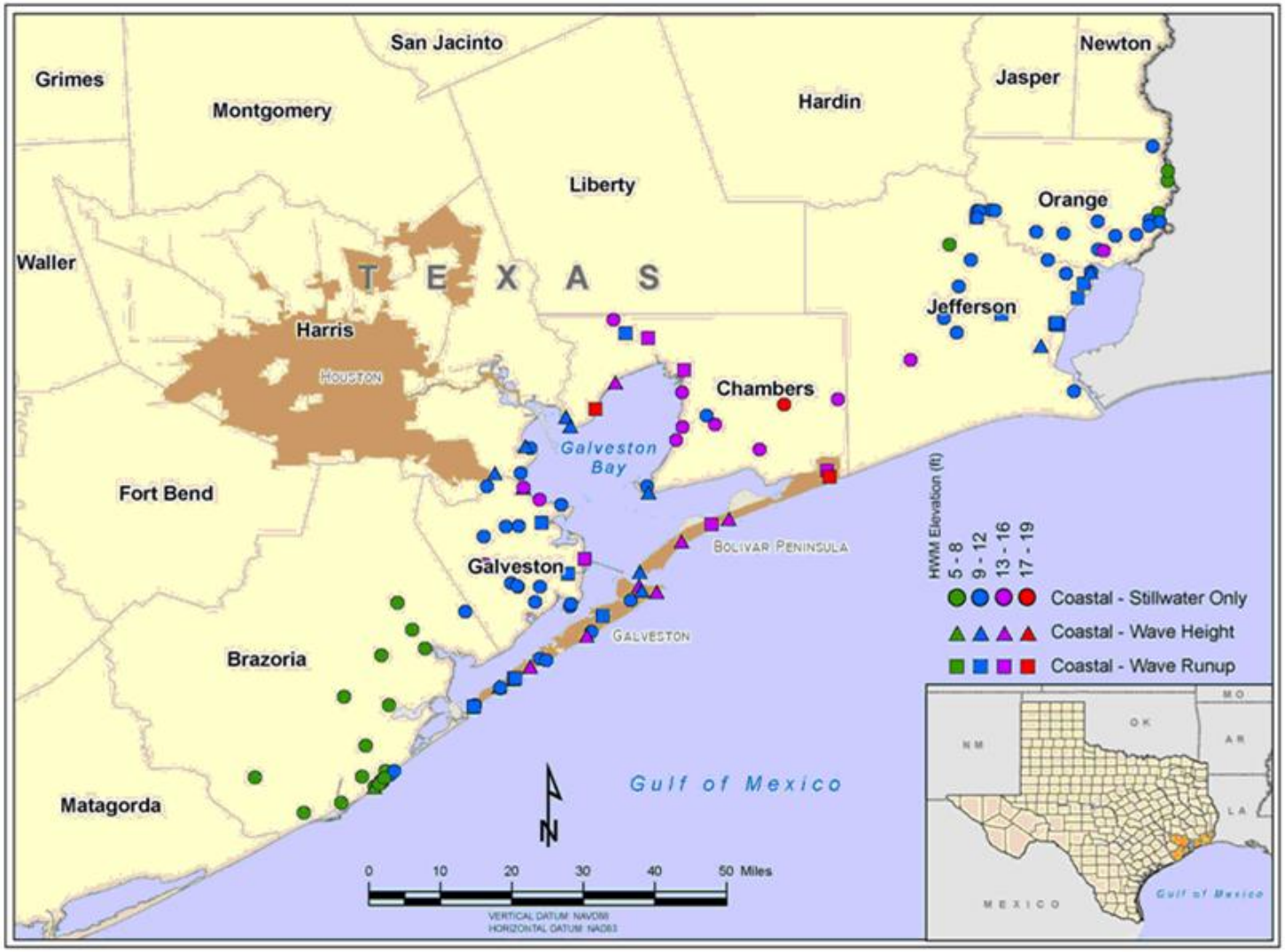
MAT

October 2008: 20+ people deployed for > 1 week

Assisted by local builders, engineers, facility managers

MAT "Borrows" from Others

- High Water Mark Surveys (HCFCD, USGS, FEMA)
- Wind Speed Measurements and Models (NWS, others)
- Aerial Imagery (NOAA, others)
- Other Field Investigations, e.g., ASCE-COPRI


San Jacinto
Newton
Grimes
Jasper
Montgomery
Hardin
Liberty
Orange
Waller
T E X A S
Jefferson
Harris
HOUSTON
Chambers
Galveston Bay
Fort Bend
BOLIVAR PENINSULA
Galveston
GALVESTON
Brazoria
Gulf of Mexico
Matagorda
0 10 20 30 40 50 Miles
VERTICAL DATUM: NAVD88
HORIZONTAL DATUM: NAD83
HWM Elevation (ft)
5 - 8
9 - 12
13 - 16
17 - 19
Coastal - Stillwater Only
Coastal - Wave Height
Coastal - Wave Runup
MO
OK
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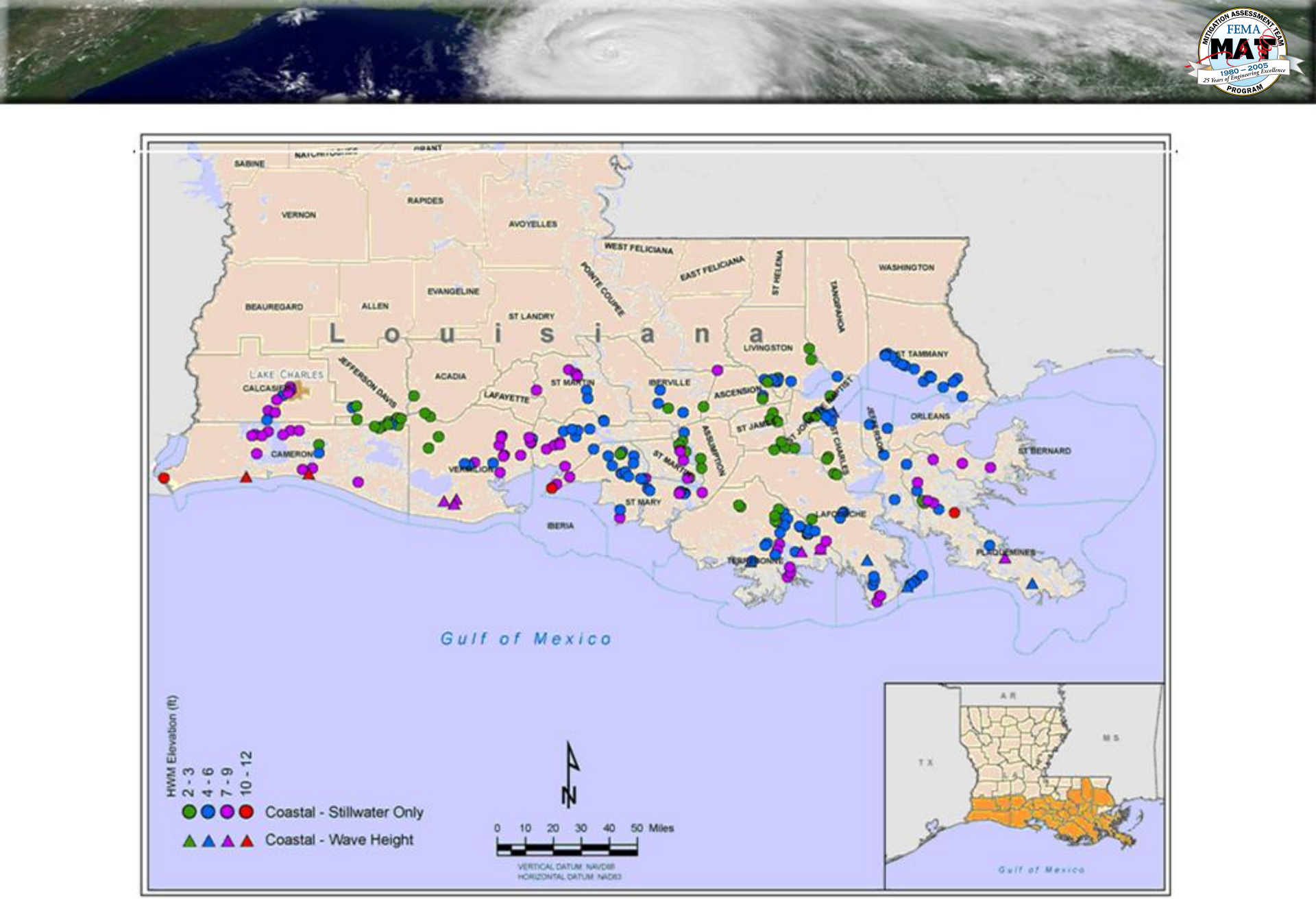
Gulf of Mexico


SABINE
VERNON
RAPIDES
AVOYELLES
WEST FELICIANA
EAST FELICIANA
POINTE COUPEE
ST HELENA
TANGIPAHOA
WASHINGTON
BEAUREGARD
ALLEN
EVANGELINE
ST LANDRY
Louisiana
LIVINGSTON
ST TAMMANY
LAKE CHARLES
CALCASIEU
JEFFERSON DAVIS
ACADIA
LAFAYETTE
ST MARTIN
IBERVILLE
ASCENSION
ORLEANS
CAMERON
VERMILION
ST MARY
IBERIA
ASSUMPTION
ST JAMES
ST JOHN THE BAPTIST
ST CHARLES
JEFFERSON
ST BERNARD
PLAQUEMINES
Gulf of Mexico
HWM Elevation (ft)
2 - 3
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Coastal - Stillwater Only
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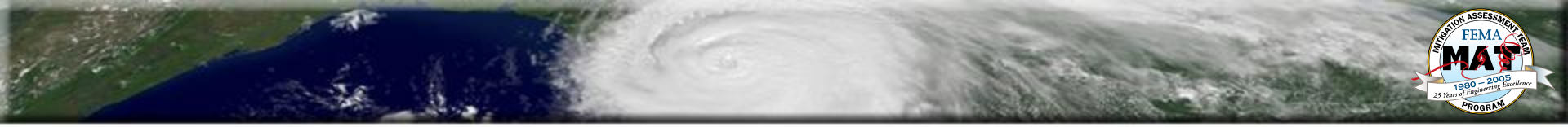
Gulf of Mexico



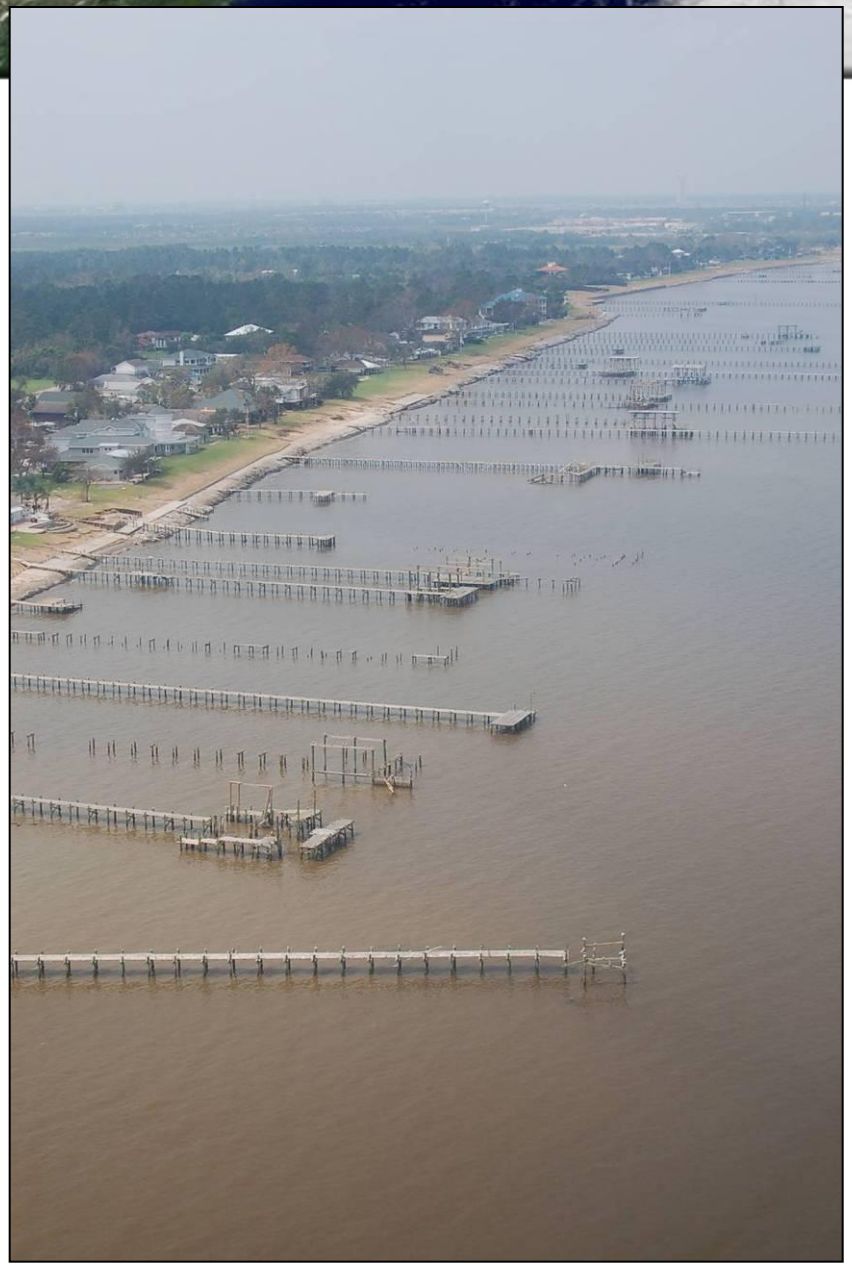
IKE FLOOD LEVELS

Although data reviewed by the MAT indicated that the area flooded by Ike exceeded the Effective Special Flood Hazard Area (SFHA), and Ike wave crest levels exceeded the Effective Base Flood Elevations (BFEs) by up to approximately 5 feet in east Texas and southwest Louisiana, Ike flooding should not be considered a rare event. A new flood study begun before Ike will likely show Ike flood levels to be below the new BFEs for much of the affected area.


422

The MAT had excellent cell phone coverage on Bolivar Peninsula, 6 days after Ike


COASTAL COMPONENTS
14 ft



Ike Lesson 1: Elevate Residential Structures

- **Observation: Ike Flood Levels reached 2-5 ft above the BFE across much of the study area**
- **Pre-FIRM and low didn't have a chance**

Ike Lesson 1: Elevate Residential Structures

- **Observation: Ike Flood Levels reached 2-5 ft above the BFE across much of the study area**
- **Many Zone X homes were flooded**

Zone X, nearest BFE = 4 ft below flood level


Hannas Reef Dr
Elm Grove
Sea Breeze
Smiths Point
© 2009 Tele Atlas
277 ft
Image Houston-Galveston Area Council
29°28'42.42" N 94°34'28.56" W
Eye alt 958 ft

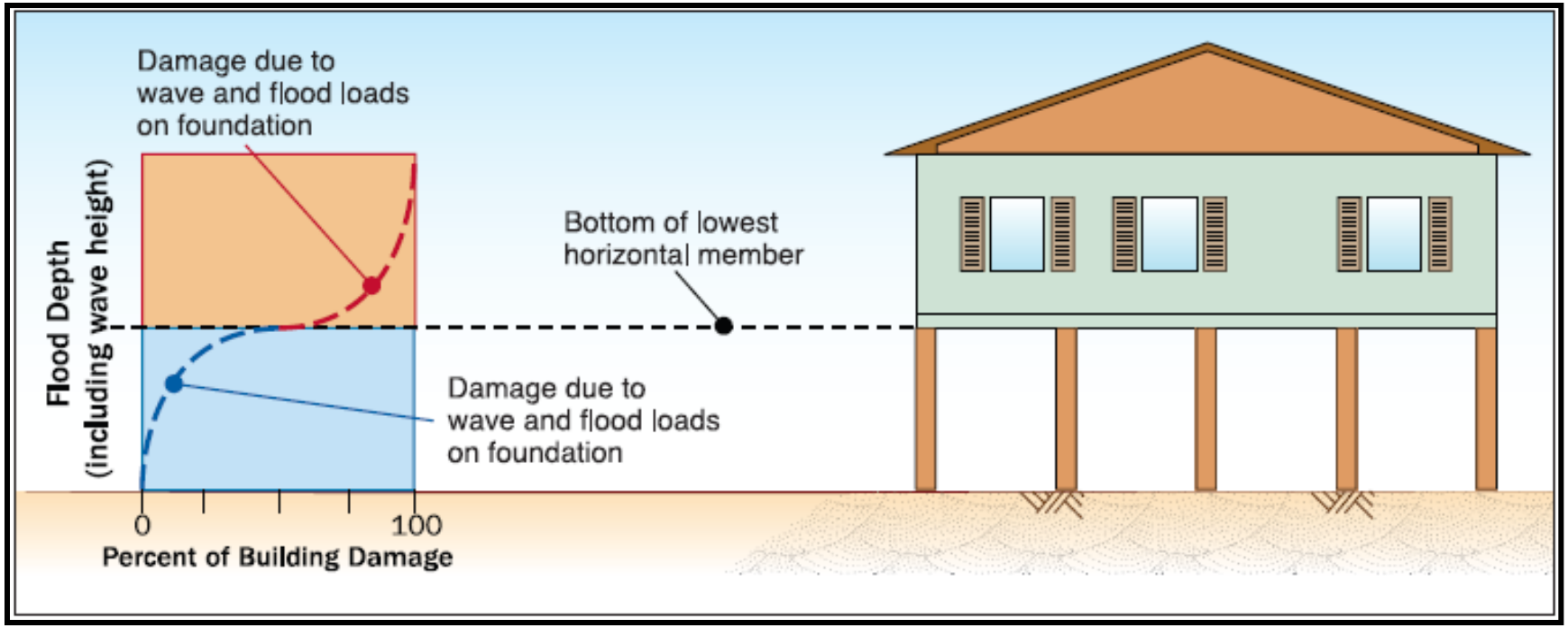
Ike Lesson 1: Elevate Residential Structures

- **Observation: Ike Flood Levels reached 2-5 ft above the BFE across much of the study area**
- **Homes elevated several ft above BFE survived**

BFE = 16 ft NGVD, Floor at 21.5 ft

Floor at +/- BFE

Ike Confirmed Wave Damage Patterns from Prior Storms



Incipient Wave Damage

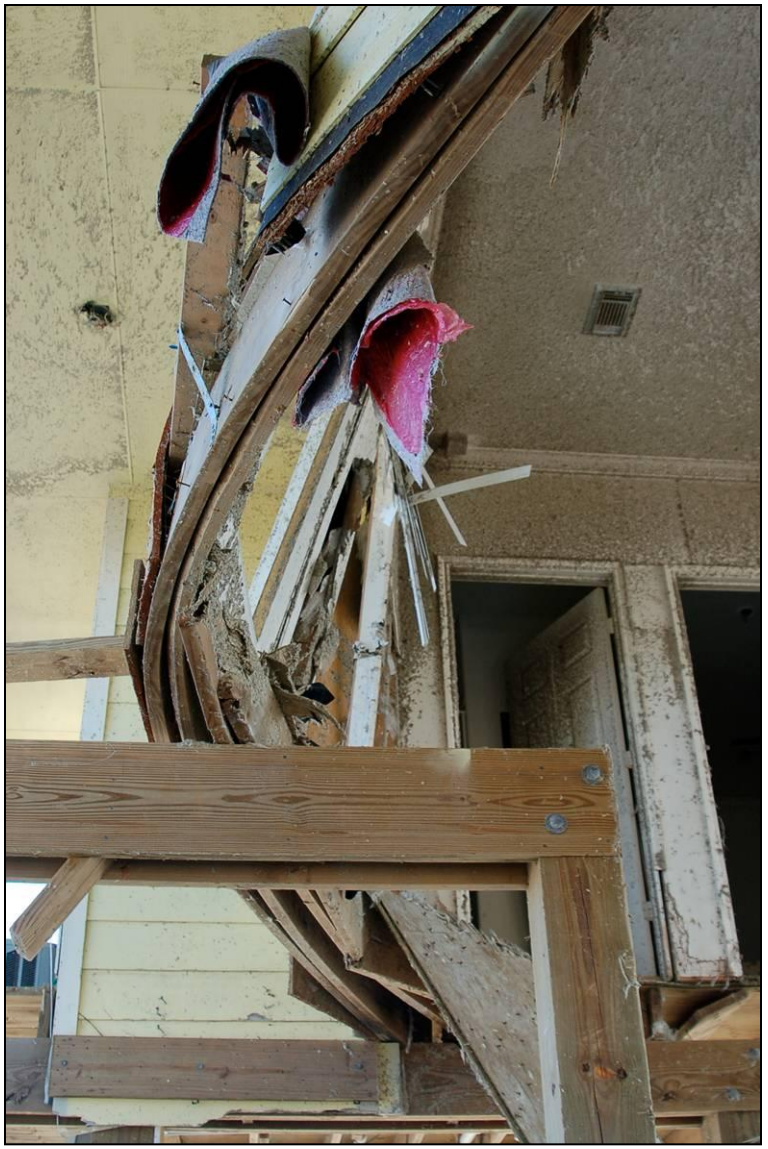
Sheathing on underside removed

Joists pushed landward

Wave Crest Above Floor

Wave Crest Above Floor

Wave Crest Above Floor



Wave Crest Above Floor

Recovery Advisory on Designing for Flood Levels Above BFE

Designing for Flood Levels Above the BFE

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend design and construction practices that reduce the likelihood of flood damage in the event that flood levels exceed the Base Flood Elevation (BFE).

Key Issues

- BFEs are established at a flood level, including wave effects, that has a 1-percent chance of being equaled or exceeded in any given year, also known as the 100-year flood or base flood. Floods more severe and less frequent than the 1-percent flood can occur in any year.
- Flood levels during some recent storms have exceeded BFEs depicted on the Flood Insurance Rate Maps (FIRMs), sometimes by several feet. In many communities, flooding extended inland, well beyond the 100-year floodplain (Special Flood Hazard Area (SFHA)) shown on the FIRM (see Figure 1).
- Flood damage increases rapidly once the elevation of the flood extends above the lowest floor of a building, especially in areas subject to coastal waves. In a V zone, a coastal flood with a wave crest 3 to 4' above the bottom of the floor beam (approximately 1 to 2 feet above the walking surface of the floor) will be sufficient to substantially damage or destroy most light-framed residential and commercial construction (see Figure 2).
- There are design and construction practices that can eliminate or minimize damage to buildings when flood levels exceed the BFE. The most common approach is to add freeboard to the design (i.e., to elevate the building higher than required by the FIRM).
- There are other benefits of designing for flood levels above the BFE: reduced building damage and maintenance: longer building life; reduced flood insurance premiums; reduced displacement and dislocation of building occupants after floods (and need for temporary shelter and assistance); reduced job loss; and increased retention of tax base.
- The cost of adding freeboard at the time of home construction is modest, and reduced flood insurance premiums will recover the freeboard cost in a few years time.

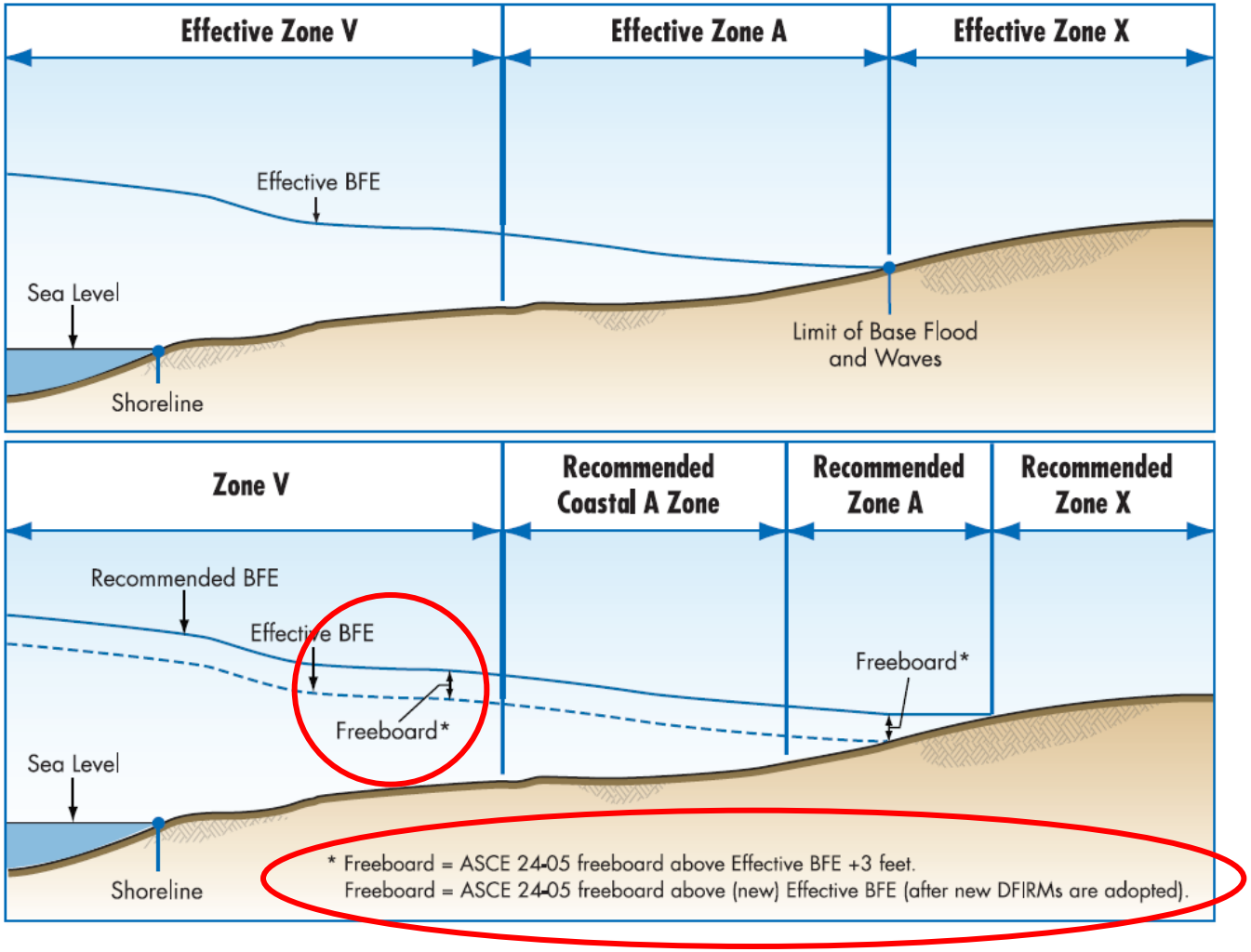
Figure 1. Bridge City, TX, homes were flooded during Ike, even though they were constructed outside the SFHA and in Zone B. The flood level was approximately 4' above the closest BFE.

Figure 2. Bolivar Peninsula, TX, V-zone house constructed with the lowest floor (bottom of floor beam) at the BFE (dashed line). The estimated wave crest level during Ike (solid line) was 3 to 4' above the BFE at this location.

How High Above the BFE Should a Building be Elevated?

Ultimately, the building elevation will depend on several factors, all of which must be considered before a final determination is made:

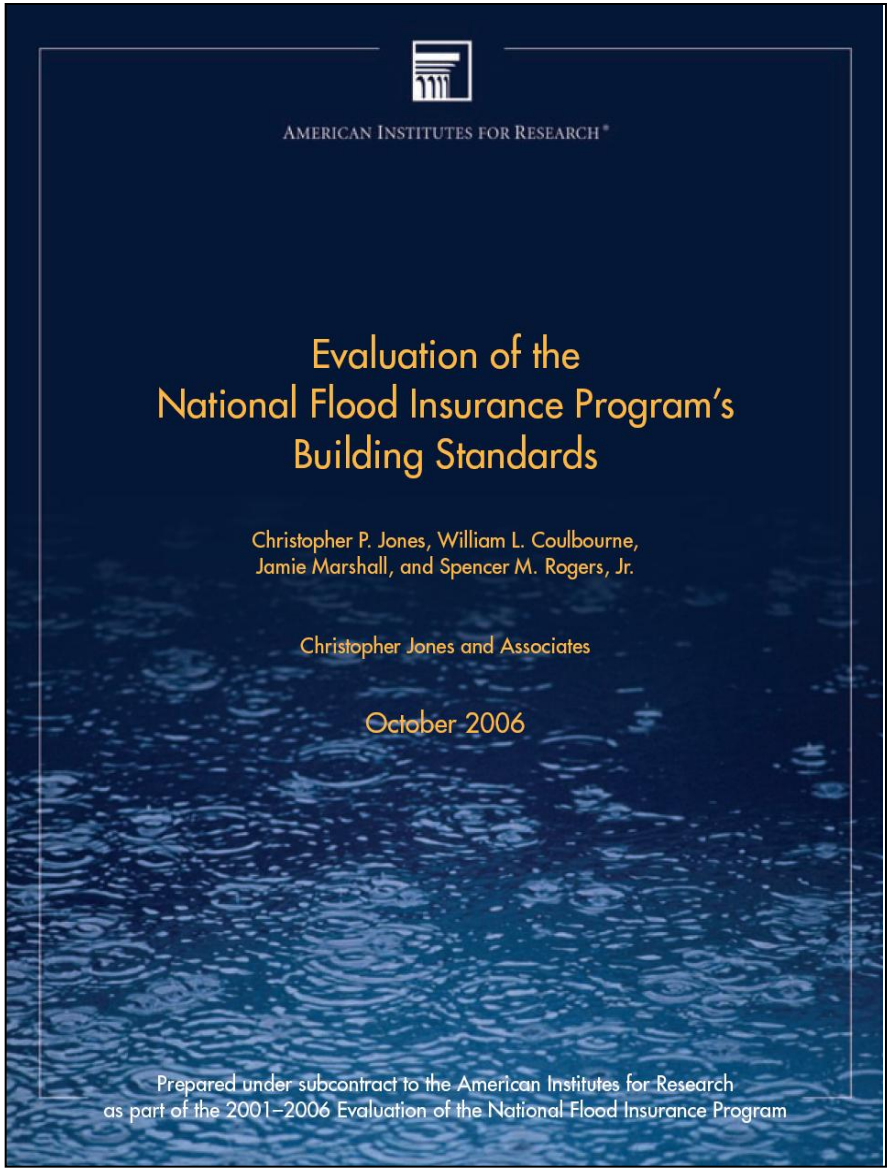
MAT Recommendation: Freeboard



But Adding Freeboard is Too Expensive. . . No-One Does It

2006 Study Demonstrated Freeboard is Cost-Effective

(search FEMA web site for "NFIP Evaluation")



2006 Study, Flood Damages Avoided Benefit:

V Zones: It is almost always worth spending an additional 2.0 - 2.5% of the at-BFE construction cost, per foot of freeboard

Construction cost ~ 0.25 - 0.5% per foot

B/C >> 1.0

2006 Study, Flood Damages Avoided Benefit:

A Zones: It is almost always worth spending an additional 0.5 - 1.0% of the at-BFE construction cost, per foot of freeboard

Construction cost ~ 0.8 - 1.5% per foot

1.0 < B/C < 1.0 (depends on scenario)

But Adding Freeboard is Too Expensive. . .

~~No One Does It~~

A 2007 Survey showed > 60% of the 20,000 NFIP communities have a freeboard requirement (0.5 ft to 3 ft). TFMA (May 2008) survey results are available on-line.

The 2009 IRC will mandate 1 ft of freeboard in V Zones and Coastal A Zones

But Owners Don’t Think About Avoiding Flood Damage -- It Won’t Happen to Them

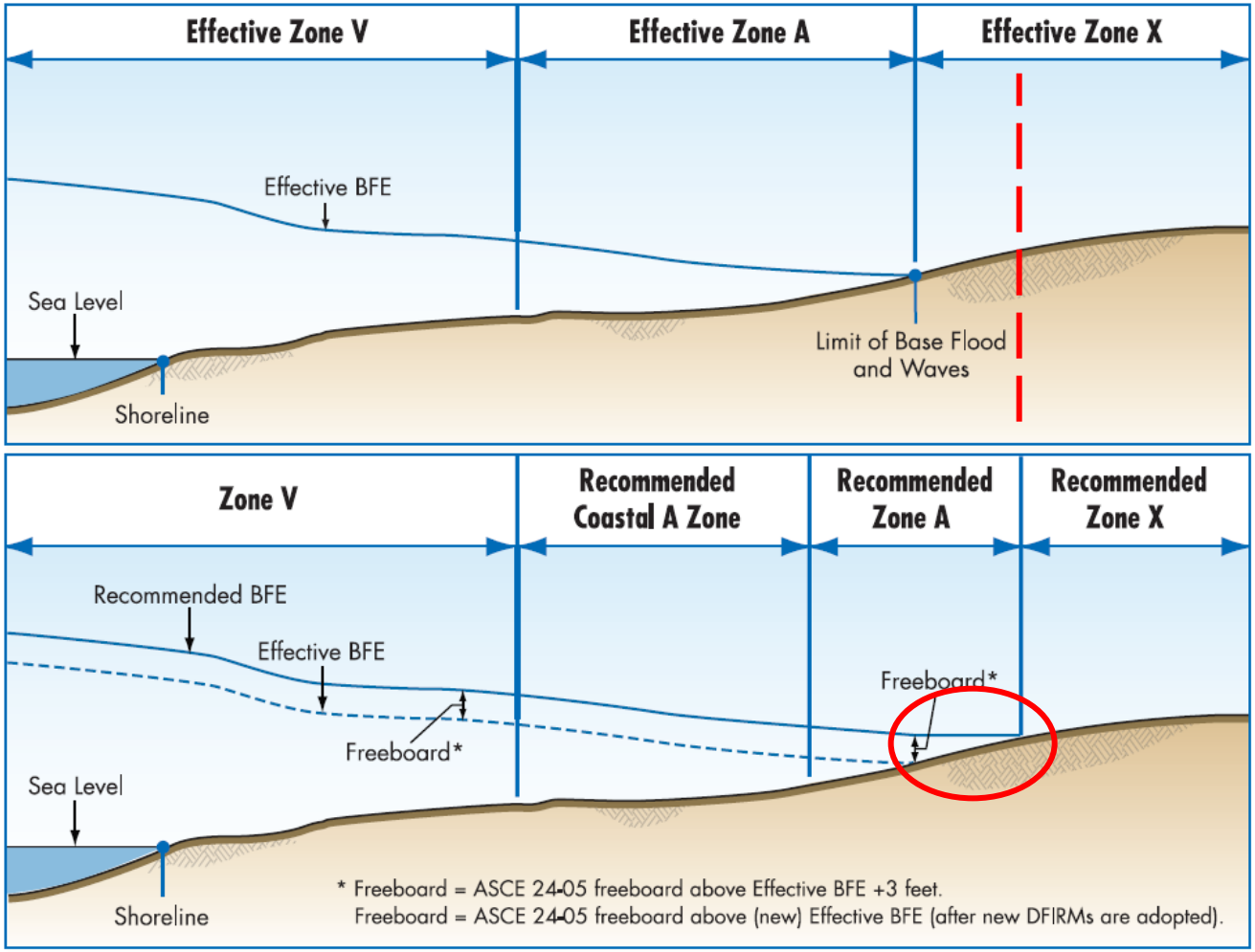
But Owners Don't Think About Avoiding Flood Damage -- ~~It Won't Happen to Them~~

2006 Study, Flood Premium Savings:

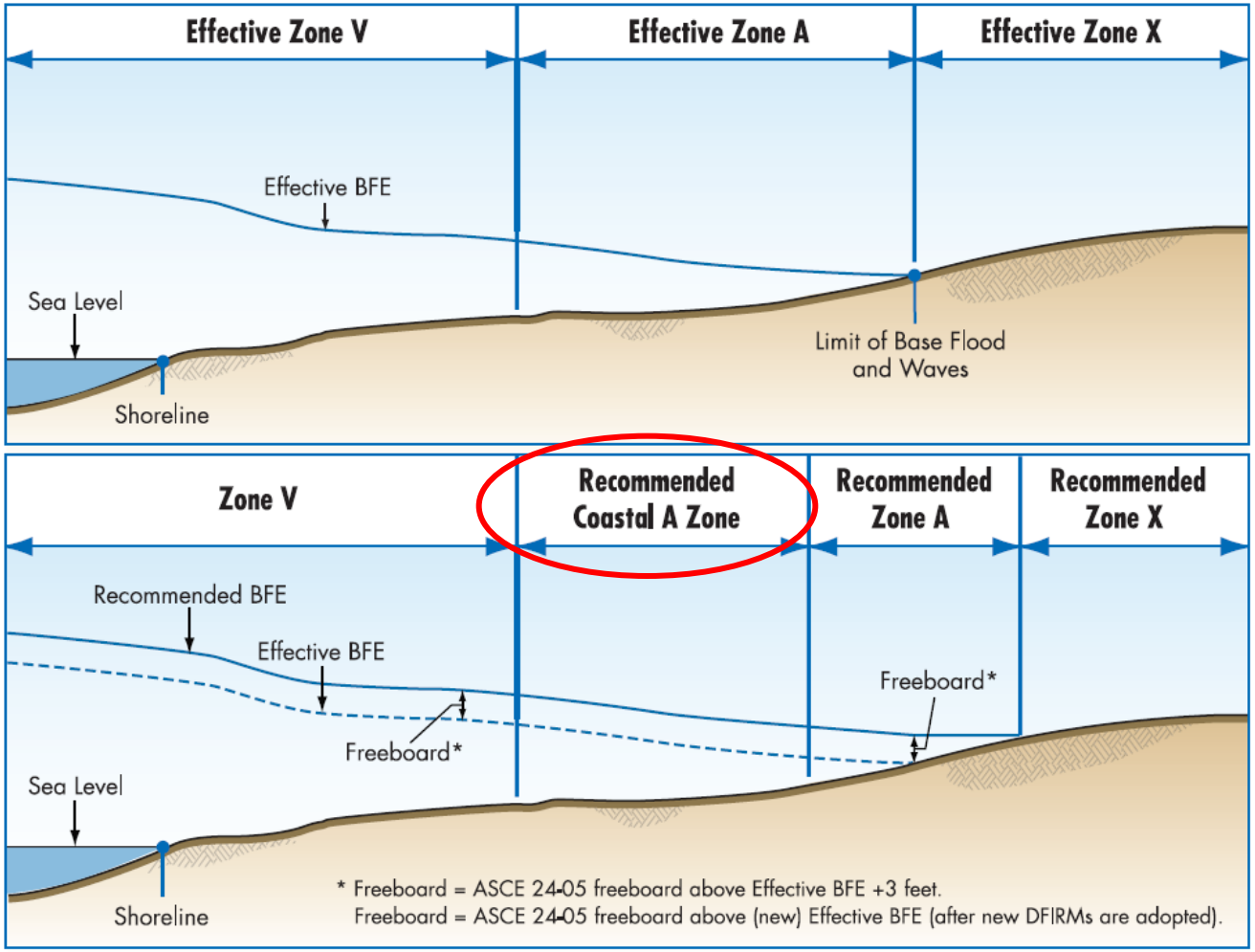
V Zones: an owner can recover freeboard costs in 1-3 years through reduced flood insurance premiums

A Zones: an owner can recover freeboard costs in <5 to >10 years

MAT Recommendation: Outside SFHA



MAT Recommendation: Coastal A Zone



Recovery Advisory on Coastal A Zone

Design and Construction in Coastal A Zones

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend design and construction practices in coastal areas where wave and flood conditions during the base flood will be less severe than in V zones, but still cause significant damage to typical light-frame construction.

Key Issues

- Recent post-storm investigations have shown that typical A-zone construction techniques (e.g., wood-frame, light gauge steel, or masonry walls on shallow footings or slabs, etc.) are subject to damage or destruction when exposed to less than 3' waves, which is the current threshold for V-zone conditions.
- Coastal A-zone buildings that employ typical residential and light commercial walls to elevate and support habitable space above the flood level will be susceptible to flood damage (Figure 1). Laboratory tests and recent field investigations confirm that breaking wave heights as small as 1.5' will cause failure of these types of walls (Figure 2).
- Other flood hazards associated with coastal waves (e.g., floating debris, high velocity flow, erosion and scour) also damage A-zone type construction in coastal areas (Figure 3).
- National Flood Insurance Program (NFIP) flood hazard mapping is generally divided into two categories, V and A zones. In coastal areas, the A-zone category could be subdivided into "Coastal A zone" and "A

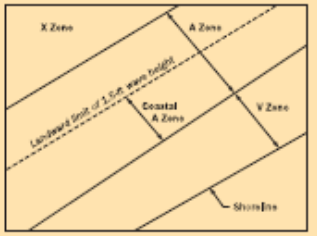
Figure 1. Failure of wood-frame walls used to support a coastal building, which was subjected to shallow flooding, small waves, and floating debris (Fort Walton Beach, FL, Hurricane Opal).

The Hurricane Ike Mitigation Assessment Team (MAT) observed small wave damage consistent with Coastal A-zone conditions throughout the area affected by Ike, including portions of west Galveston Island (Figure 4), communities situated along portions of Galveston Bay (Figure 5), Orange County (Figure 6), and portions of coastal Louisiana (Figure 7).

Coastal A Zone, Defined

Coastal A Zone: area landward of a V zone, or landward of an open coast without mapped V zones. In a Coastal A zone, the principal source of flooding will be astronomical tides, storm surges, seiches or tsunamis, not riverine flooding. During base flood conditions, the potential for wave heights between 1.5 and 3.0' will exist. At least 2 to 4' of stillwater depth is necessary to support these wave heights.

Coastal A-zone design and construction practices described herein are not mandated by the NFIP, but are recommended for communities that wish to adopt higher floodplain management standards. Community Rating System (CRS) credits are available for doing so. Note that some Coastal A-zone practices may be required by the International Building Code®, through its reference to ASCE 24, *Standard for Flood Resistant Design and Construction*.



Plan view showing a Coastal A zone landward of a V zone (source: ASCE 24-05).

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: Many foundations failed when lateral loads exceeded column/pile capacity**

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: columns of surviving homes showed numerous horizontal cracks -- a result of lateral flood loads on the foundation and wind loads on the elevated building**

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: non-breakaway decks caused damage to columns when decks failed**

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: Many foundations failed due to lack of embedment and/or scour/erosion**

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: scour and erosion far exceeded design guidance**

Design guidance estimates scour around pile = 2 x pile diameter

Scour hole was reported to be 10 ft deep

Ike Lesson 2: Use Strong & Deep Foundations

- **Observation: linear scour features follow roads, canals**

Recovery Advisory on Erosion, Scour and Foundation Design

Erosion, Scour, and Foundation Design

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To discuss how any lowering of the ground surface can affect the ability of a building foundation to resist design loads, and to provide additional guidance for coastal foundation design.

Key Issues

- Coastal buildings are often subject to flood loads and conditions that do not affect inland buildings. These include waves, high velocity storm surge flow, floodborne debris, and **erosion** and **scour**. This Recovery Advisory will focus on erosion and scour. See FEMA 499, *Home Builder's Guide to Coastal Construction* (2005), Fact Sheets 11 through 15 at: http://www.fema.gov/library/viewRecord.do?id=1570, and FEMA 55, *Coastal Construction Manual* (2000) at: http://www.fema.gov/library/viewRecord.do?id=1671 for discussion of other foundation issues.

Erosion refers to a general lowering of the ground surface over a wide area.

Scour refers to a localized loss of soil, often around a foundation element.

- Foundations must transfer all loads imposed on the building into the ground. If the foundation is not strong enough or deep enough to do this, the building will be destroyed. If the foundation embedment into the ground is not sufficient to account for erosion and scour that may occur over the life of the building, the building is vulnerable to collapse under design flood and wind conditions.
- Predicting the incidence, location, and magnitude of coastal erosion and scour is difficult, and present-day building codes and standards do not prescribe clear-cut solutions for designers. Therefore, designers should be conservative with their foundation designs. This means foundations may need to be stronger, deeper, and higher than what has historically been used. Lessons learned from Hurricane Ike and other recent coastal storm events should be incorporated into foundation designs.

Erosion and Scour Basics

Erosion is defined by the International Building Code® (ICC, 2006) as the "wearing away of the ground surface as a result of the movement of wind, water or ice." Section 7.5 of FEMA's *Coastal Construction Manual* describes erosion as "the wearing or washing away of coastal lands." Since the exact configuration of the soil loss is important for foundation design purposes, a more specific definition is used in this Recovery Advisory (see text box and Figure 1).

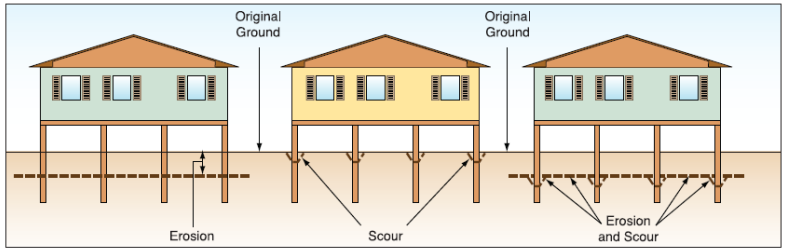


Figure 1. Distinguishing between coastal erosion and scour. A building may be subject to either or both, depending on the building location, soil characteristics, and flood conditions.

Erosion, Scour Foundation Design

	Affect Flood Loads?	Affect Embedment?
Erosion 	**Yes**	**Yes**
Scour 	**No**	**Yes**


Hannas Reef Dr
Smiths Point
© 2009 Tele Atlas
Image Houston-Galveston Area Council
Google
277 ft
29°28'42.42" N 94°34'28.56" W
Eye alt 958 ft


Hannas Reef Dr
Smiths Point
© 2009 Tele Atlas
Image Houston-Galveston Area Council
Google
277 ft
29°28'42.42" N 94°34'28.56" W
Eye alt 958 ft

Ike Lesson 2: Use Strong & Deep Foundations

- **Does method of foundation design/construction, or soil disturbance contribute to scour?**

Maybe, but there are other (unknown) factors at work . . .

It is unlikely all 5 buildings circled above had the same foundation design or level of soil disturbance . . .

MAT Recommendation: Scour

- **FEMA should assist engineers and codes/standards organizations to develop new scour guidance based on Ike knowledge**
- **FEMA should study foundation scour in detail following future events**
- **Potential linear scour should be incorporated into design and land development guidance/practices**

Ike Lesson 3: Breakaway Wall Performance Can be Improved

Ike Lesson 3: Breakaway Wall Performance Can be Improved

Louvers Performed Better Than Solid Walls

MAT Recommendation: Breakaway Walls

- Promote use of lattice/louvers
- Promote use of flood vents

A change to the May 2009 FIM will rate V zone enclosures as "free of obstructions" if they are constructed with louvers/lattice on all walls except one (for garage door or solid breakaway wall).

Current rating practice calls this "with obstruction".

V zone Flood insurance premiums will drop significantly with this change (new construction and re-rating of existing homes).

Recovery Advisory on Enclosures and Breakaway Walls

Enclosures and Breakaway Walls

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To discuss requirements and recommendations for enclosures and breakaway walls below the Base Flood Elevation (BFE).

Key Issues

- Spaces below elevated buildings can be used only for building access, parking, and storage.
- Areas enclosed by solid walls below the BFE ("enclosures") are subject to strict regulation under the National Flood Insurance Program (NFIP). Note that some local jurisdictions enforce stricter regulations for enclosures.
- Enclosures in V-zone buildings must be breakaway (non-breakaway enclosures are prohibited). Breakaway enclosures in V zones must be built with flood-resistant materials, meet specific design requirements, and be certified by a registered design professional.
- Enclosures (breakaway and non-breakaway) in A-zone buildings must be built with flood-resistant materials and equipped with flood openings that allow water levels inside and outside to equalize.
- Breakaway enclosure walls should be considered expendable, and the building owner could incur significant costs when the walls are replaced. Breakaway wall replacement is not covered by the flood insurance policy.
- For V zones, breakaway wall enclosures below an elevated building will result in higher flood insurance premiums; however, surrounding below-BFE space with insect screening, open lattice, slats, or shutters (louvers) can result in much lower flood insurance premiums (Figure 1). Use of these materials will allow floodwaters to pass into and out of the enclosed space and minimize damage to the enclosure "walls." Although not required by the NFIP, installation of flood openings in breakaway walls may also reduce damage to the walls.

Space Below the BFE – What Can It Be Used For?

NFIP regulations state that the area below an elevated building can be used only for parking, building access,

WARNING

Designers and owners should realize that: (1) enclosures and items within them are likely to be destroyed even during minor flood events; (2) enclosures, and most items within them, are not covered by flood insurance and can result in significant costs to the building owner; and (3) even the presence of properly constructed breakaway wall enclosures will increase flood insurance premiums for the entire building (the premium rate will increase as the enclosed area increases). Including enclosures in a building design can have significant cost implications.

The Hurricane Ike Mitigation Assessment Team (MAT) observed some breakaway walls in excess of 11' high. While FEMA promotes elevating homes above the BFE (i.e., adding freeboard), one of the unintended consequences appears to be the increasing size of floodborne debris elements due to taller breakaway walls.

Figure 1. Wood louvers installed beneath an elevated house in a V zone are a good alternative to solid breakaway walls.

Ike Lesson 4: We Need to do a Better Job Mitigating Residential Structures

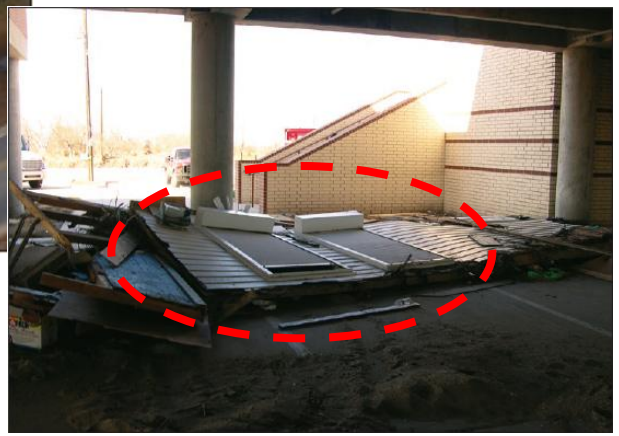
- **MAT viewed 31 homes that had been elevated using HMGP or ICC funds**
- **Good News: none sustained flood damage during Ike**
- **Bad News: many of the homes lacked continuous load paths from elevated home to foundation to ground; other problems**

Ike Lesson 5: Elevate Critical Facilities

- **Observation: Critical Facilities elevated above Ike surge and waves on strong foundations survived**

Crenshaw Elementary and Middle School, Bolivar Peninsula

Elevated 10 ft above grade, Ike surge reached 5 ft above grade



Ike Lesson 5: Elevate Critical Facilities

Many existing critical facilities are vulnerable

Approximately 2/3 of the UTMB buildings had first floors below Ike's 12.5 ft NGVD flood level; virtually all had equipment and utilities below ground.

Ike Lesson 5: Elevate Critical Facilities

- Criminal Justice Complex Ike flood at 6 ft (18-24” depth)
- Similar flooding during Rita (2005)
- All utilities for security and communications systems run under the slab, and were damaged
- Prisoners had to be transferred.

- 1985 FIRM classified as Zone C
- Post-Rita map shows ABFE = 6 ft

MAT Recommendations: Critical Facilities

- New/replacement critical facilities should be located outside the 500-yr floodplain, where possible.
- Where not possible, elevate at least to 500-yr flood level or to ASCE 24-05 freeboard, whichever is higher
- Executive Order 11988; other guidance
- For existing facilities, evaluate vulnerability; raise or floodproof critical components; relocate or replace facility if necessary
- Audit facilities for flood, wind and other hazards

Ike Lesson 6: We Need to do a Better Job with *Some* New Critical Facilities - Case in Point

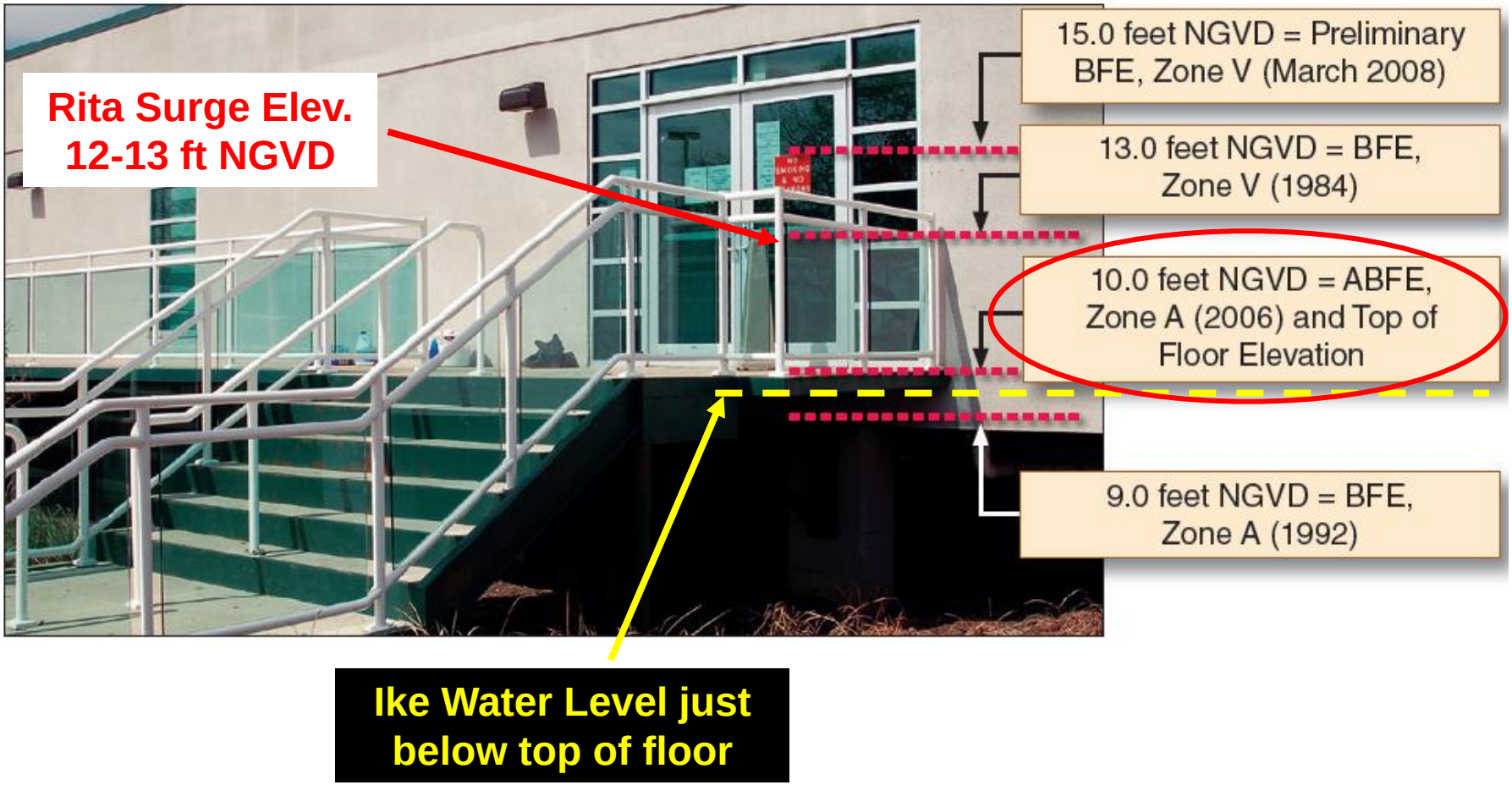
Pre-Rita

Post-Ike

South Cameron Parish Hospital

- Constructed in 1963, 6 years after Audrey, with floor elevation ~ 8 ft NGVD (several feet below Audrey surge level)
- Destroyed by Rita in 2005 (storm surge at site ~ 12-13 ft NGVD)
- Rebuilt in 2008, with top of floor elevation at 10 ft NGVD
- Ike water level was just below floor, utilities were damaged

South Cameron Hospital



Ike Damaged Below-Floor Utilities

Piping and Conduits Replaced Post-Ike

Marsh Grass Trapped at Top of Columns During Ike

Rooftop Condition, Post-Ike

Ike Lesson 6: We Need to do a Better Job with Some New Critical Facilities

Case in Point: South Cameron Parish Hospital

- It is not clear what, if any, influence the flood history at the site had in choosing a site or the floor elevation for the new facility
- The 2008 construction represents a missed opportunity to truly mitigate at this site