Flood and Groundwater Control for Buildings and Facilities: Managing the Water and the Risks

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Provider Number: J380
Course Number: FLOOD90

10.14.2015 | Waltham, MA

About the Speakers

Aaron Lewis

- Multi-disciplined (Geotechnical, Civil, and Structural)
- Heavy Civil Infrastructure

Greg Doelp

- Waterproofing Systems
- Below-Grade Waterproofing

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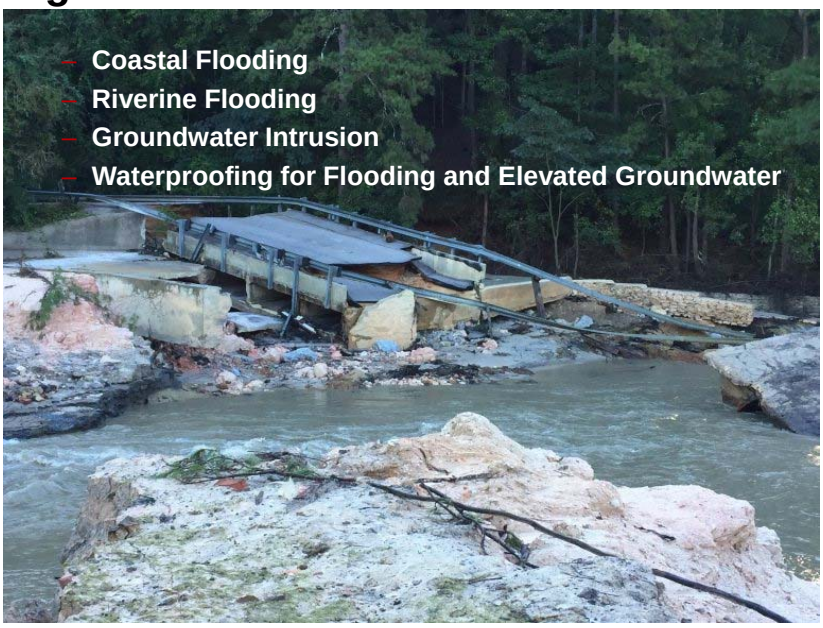
Course Description

Natural disasters can significantly damage the built environment and disrupt communities. This presentation will focus on evaluating the risk of surface water and flooding to individual sites and buildings. Understanding flood risk is important for facility owners because the cost of hardening existing infrastructure can be substantial. We will discuss methods we use to help building owners understand flood risk vulnerability, both from a riverine and coastal environment, and methods for hardening infrastructure. We will examine procedures for evaluating critical buildings, their typical vulnerabilities, and potential measures to reduce risk of flood damage. We will also look at flood proofing measures, such as temporary flood walls, permanent flood barriers, and waterproofing. We will also discuss methods to reduce leakage and flooding of below-grade spaces from rising ground water levels. Solutions such as below-grade waterproofing, injection grouting, foundation drains, and sub-slab depressurization systems will be discussed.

Learning Objectives

1. Understand flood risks and recognize vulnerabilities.
2. Understand methods to evaluate and identify risk mitigation methods and harden buildings and sites related to flooding.
3. Recognize risk of groundwater flooding and leakage.
4. Understand methods for mitigating groundwater flooding and leakage.

Agenda



- Coastal Flooding
- Riverine Flooding
- Groundwater Intrusion
- Waterproofing for Flooding and Elevated Groundwater

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Understanding Flood Risk

Sources of Flooding:

- Coastal Flooding (Hurricanes, Tropical Storms, Nor'easters) – Generally more warning >>24 hrs
- Riverine Flooding – Warning is Less but Varies about 6-48 hrs
- Local Surface and Groundwater Flooding – Generally no warning

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Coastal Flooding

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Damage Due to Flooding

- **Flooding is nation's leading cause of disaster ($50 billion in 1990s)**
- **Recent events reinforce issues**
- **Future forecasts (associated with sea level rise) are not better**

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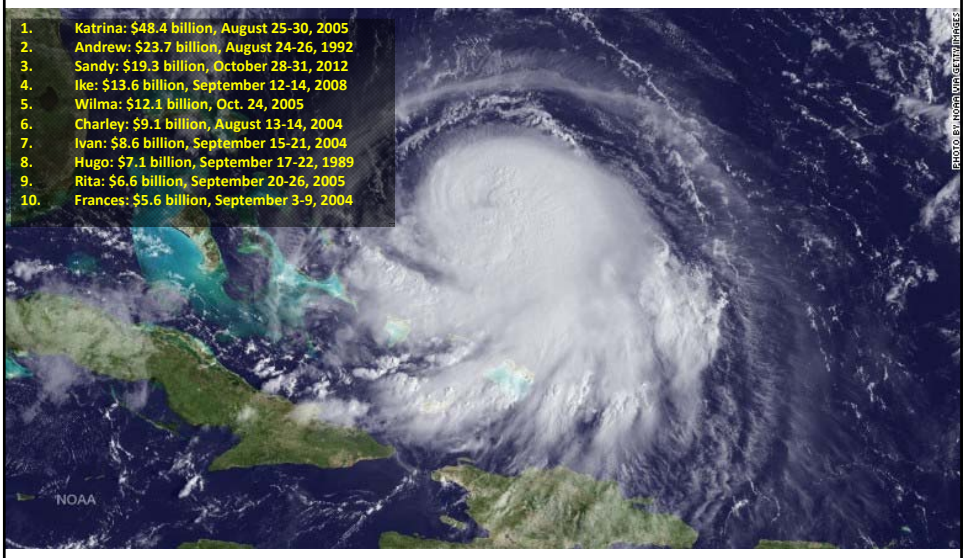
Hurricane and Tropical Storm Damage



1. Katrina: $48.4 billion, August 25-30, 2005
2. Andrew: $23.7 billion, August 24-26, 1992
3. Sandy: $19.3 billion, October 28-31, 2012
4. Ike: $13.6 billion, September 12-14, 2008
5. Wilma: $12.1 billion, Oct. 24, 2005
6. Charley: $9.1 billion, August 13-14, 2004
7. Ivan: $8.6 billion, September 15-21, 2004
8. Hugo: $7.1 billion, September 17-22, 1989
9. Rita: $6.6 billion, September 20-26, 2005
10. Frances: $5.6 billion, September 3-9, 2004

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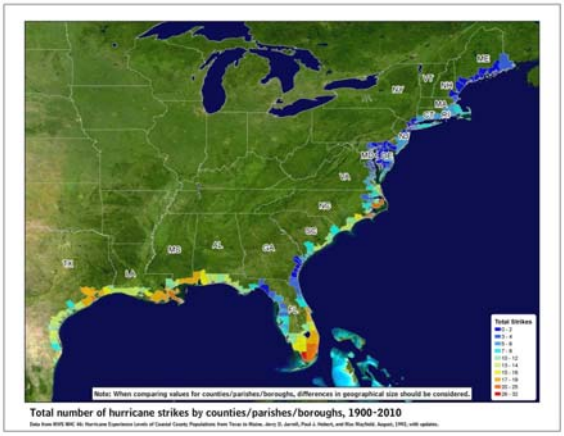
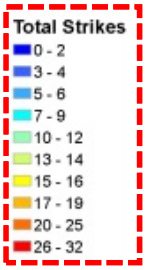
Hurricane Frequency (1900-2010)





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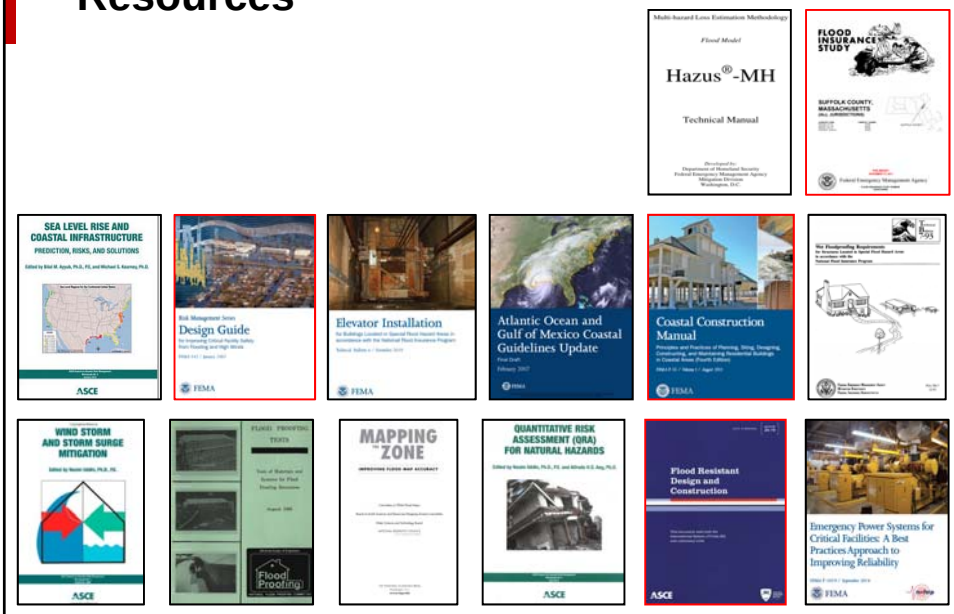
Resources



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Saffir/Simpson Hurricane Scale

Hurricane Category	Sustained Wind Speed (1) mph	(m/s)	Central Barometric Pressure inches of mercury	millibars	Storm Surge ft	(m)	Damage Potentia
1	74–95	33.1–42.5	>28.91	>979	4 to 5	0.8 to 1.2	Minimal
2	96–110	42.6–49.2	28.50–28.91	965–979	6 to 8	1.3 to 1.8	Moderate
3	111–130	49.3–58.1	27.91–28.47	945–964	9 to 12	1.9 to 2.7	Extensive
4	131–155	58.2–69.3	27.17–27.88	920–944	13 to 18	2.8 to 3.7	Extreme
5	>155	>69.3	<27.17	<920	>18	> 3.7	Catastrophic

1000 millibars = 100 kPa
(1) 1-minute average wind speed at 33 ft (10 m) above open water

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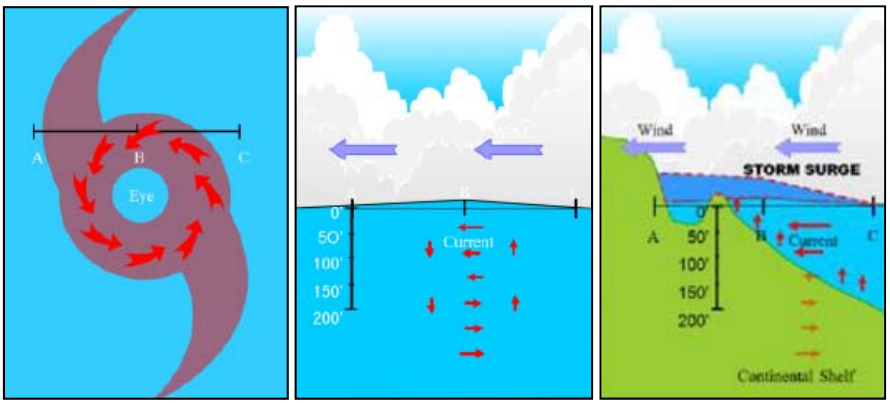
Storm Surge



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Coastal Flooding Terminology

The storm surge stillwater elevation (SWEL) and added effects of wave setup and wave runup.

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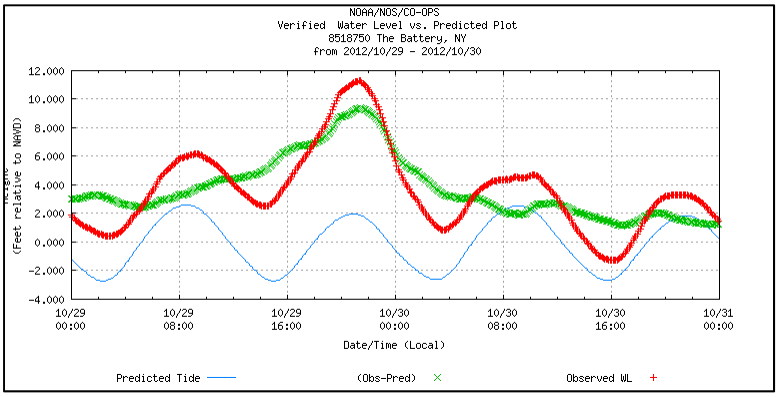
Surge and Tide



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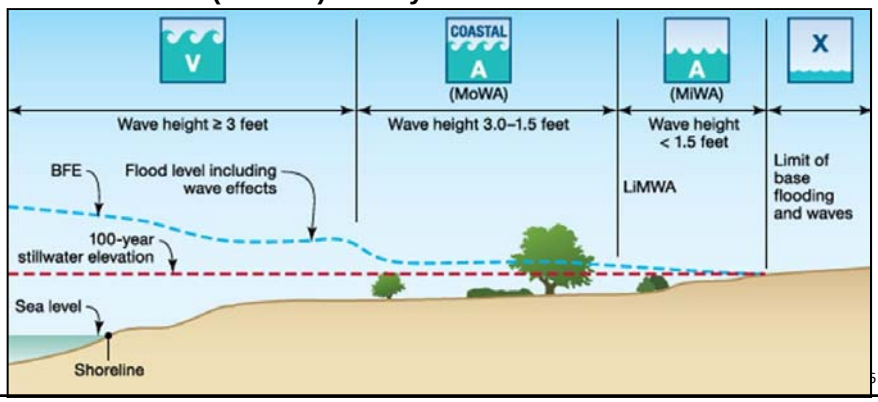
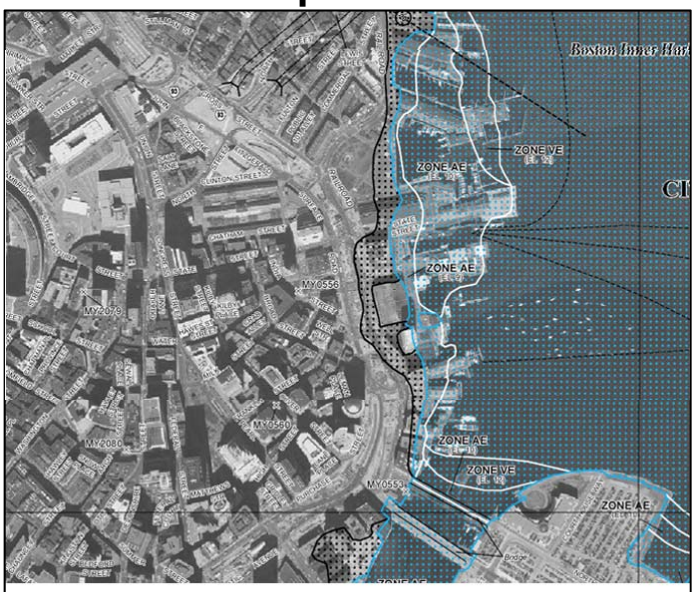
FEMA Flood Maps

- **Base Flood Elevation (BFE) – FEMA flood elevation from 100-year event**
- **Design Flood Elevation (DFE) – BFE plus some freeboard**
- **Special Flood Hazard Area (SFHA): Area subject to flooding during a 100-year event**
- **Zone X (Shaded) – 500-year flood event**



FEMA Current Map - Boston



Current

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FEMA Preliminary Map - Boston

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Modeling Coastal Flooding–The Variables

- **Storm Characteristics:**
  - Differential Pressure
  - Forward Progression Speed
  - Maximum Wind Speed
  - Radius of Maximum Wind Speed
  - Track
- **Wave Height**
- **Tide**
- **Topography, Bathymetry, and Ground Cover**
- **Sea Level Rise**

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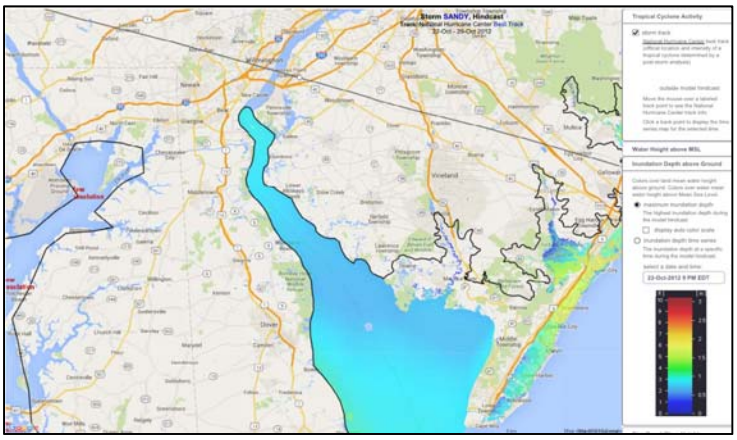
Modeling Coastal Flooding – Coastal Hydraulics (Surge)

Storm Surge:

- **Advanced Circulation Model for Oceanic, Coastal and Estuarine Waters (ADCIRC)**
- **Regression Analysis of Tide Gauges**



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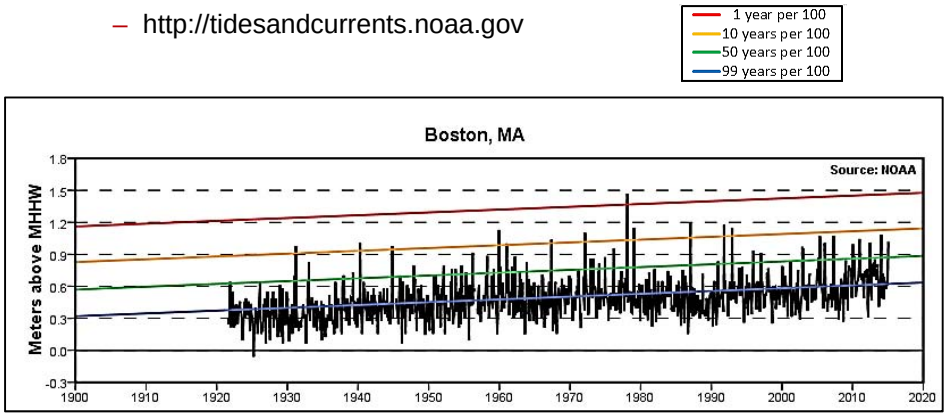
Sea Level Rise

– http://tidesandcurrents.noaa.gov



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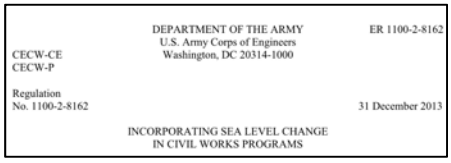
Sea Level Rise

- **Scenarios**
  - Low, Intermediate, High
  - NOAA, NRC, and USACOE
  - http://corpsclimate.us/ccaceslcurvesECB.html



DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

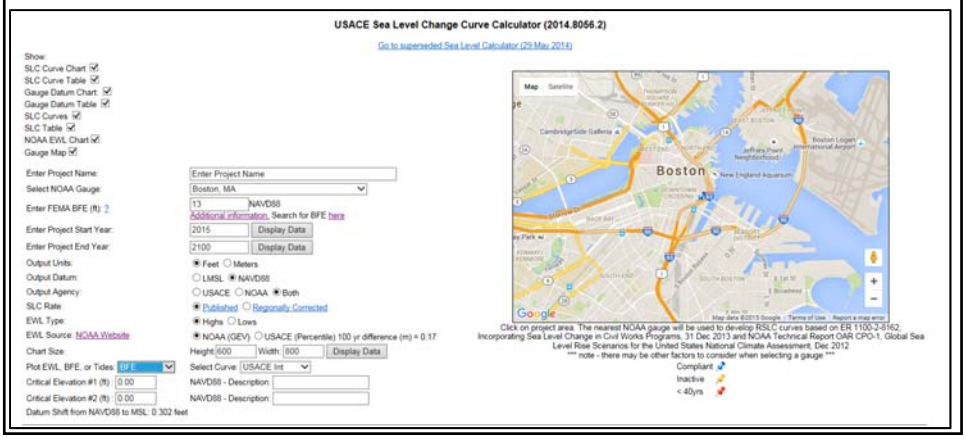
ER 1100-2-8162

CECW-CE
CECW-P

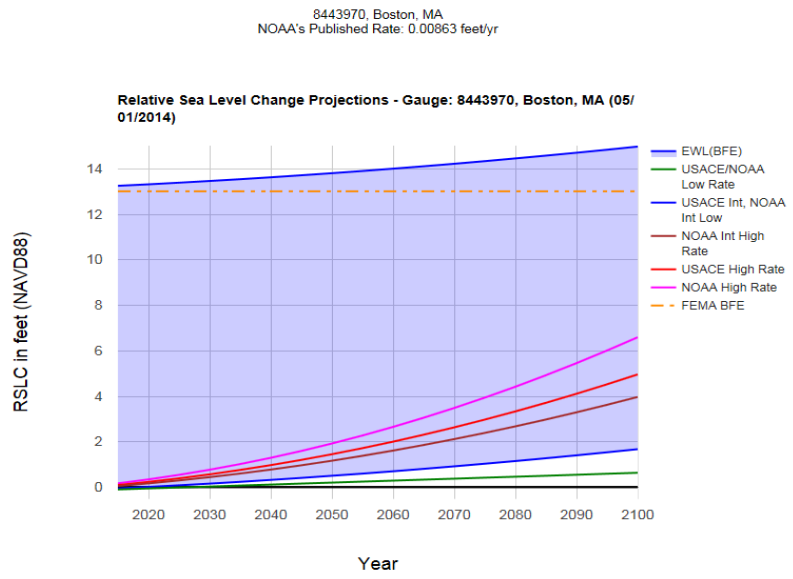
Regulation
No. 1100-2-8162

31 December 2013

INCORPORATING SEA LEVEL CHANGE
IN CIVIL WORKS PROGRAMS



Sea Level Rise Calculator



Design Flood Elevation – ASCE 24

TABLE 6-1. Minimum Elevation of Floodproofing, Relative to Base Flood Elevation (BFE) or Design Flood Elevation (DFE)—Outside of High Risk Flood Hazard Areas

Structure Category[a]	Minimum Elevation of Floodproofing[b]
I	BFE + 1 ft or DFE, whichever is higher
II[c]	BFE + 1 ft or DFE, whichever is higher
III	BFE + 1 ft or DFE, whichever is higher
IV	BFE + 2 ft or DFE, whichever is higher

[a]See Table 1-1 for structure category descriptions.
[b]Wet or dry floodproofing shall extend to the same level.
[c]Dry floodproofing of residential buildings and residential portions of mixed-use buildings shall not be permitted.

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Risk Mitigation

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Overview of Methods

ELEVATION – Raising your home so that the lowest floor is above the flood level. You can accomplish this in several ways.

WET FLOODPROOFING – Making uninhabited portions of your home resistant to flood damage and allowing water to enter during flooding.

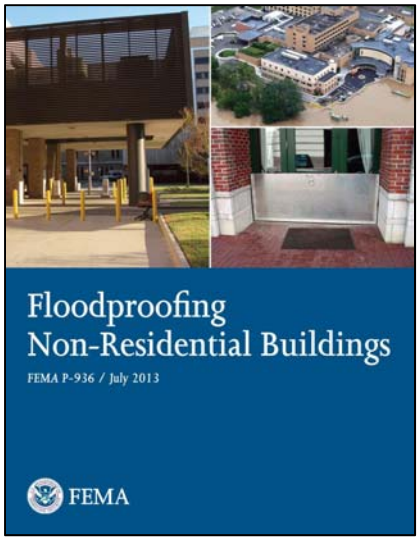
RELOCATION – Moving your home out of the floodplain to higher ground where it will not be exposed to flooding.

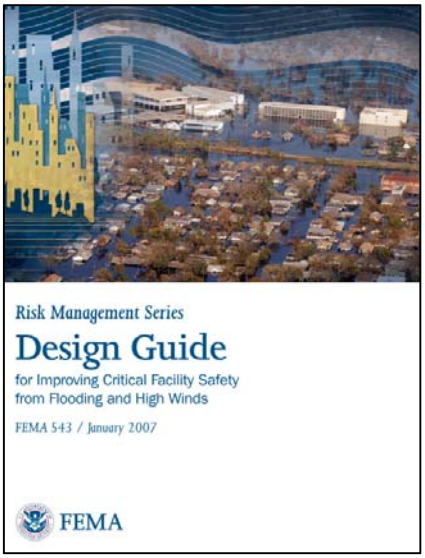
DRY FLOODPROOFING – Sealing your home to prevent floodwaters from entering.

LEVEES AND FLOODWALLS – Building a floodwall or levee around your home to hold back floodwaters.

DEMOLITION – Tearing down your damaged home and either rebuilding on the same property or buying or building a home elsewhere.

FEMA Guides for Mitigation





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Hazard Mitigation

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Relocation of Critical Equipment

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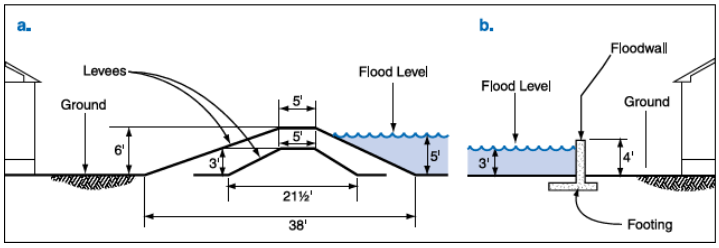
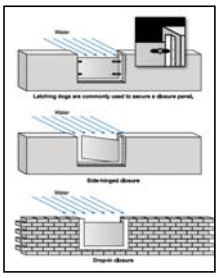
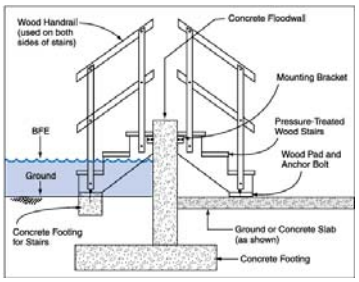
Levees and Floodwalls







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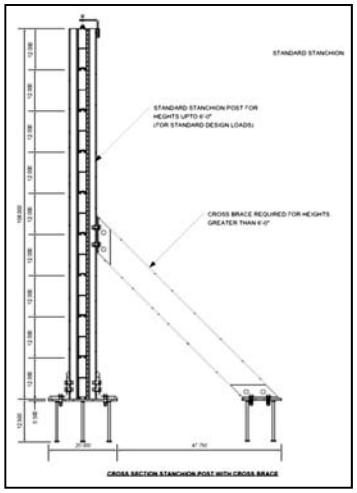
Temporary Floodwalls: Product Examples – Stop Log



Example of anchors into concrete footing for the Stop Log barrier.

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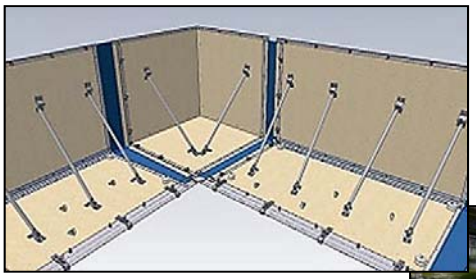
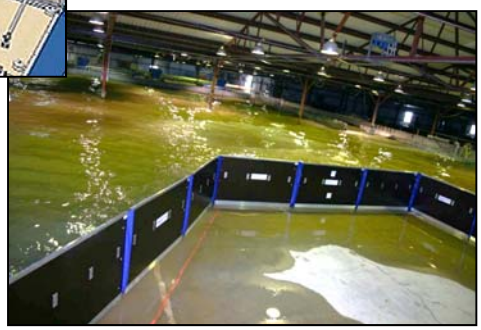
Temporary Floodwalls: Product Examples - AcquaFence





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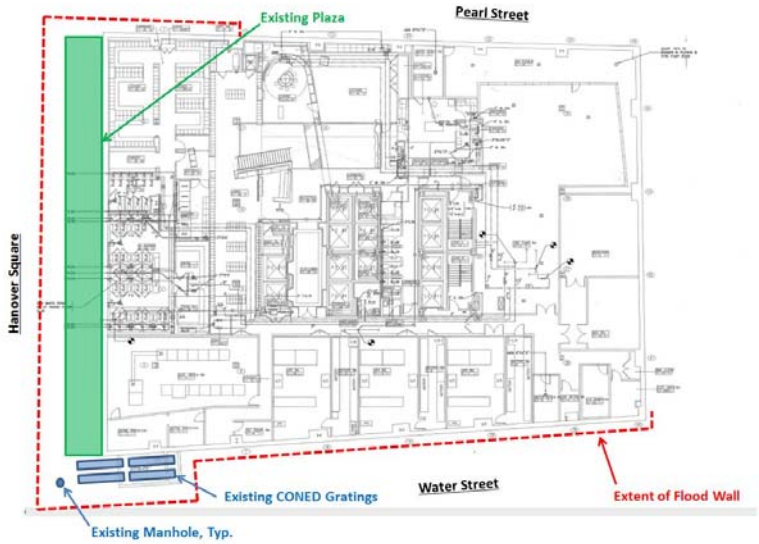
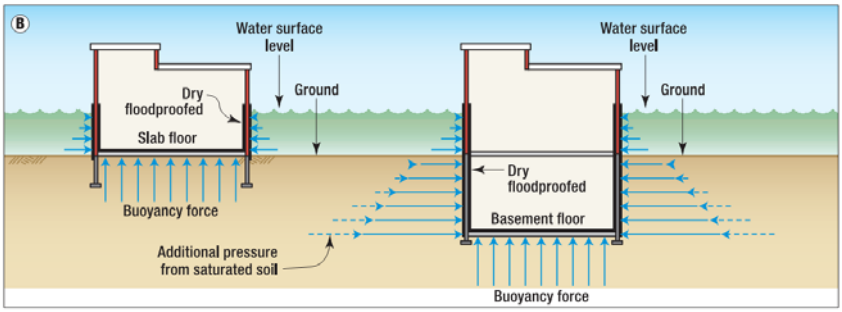
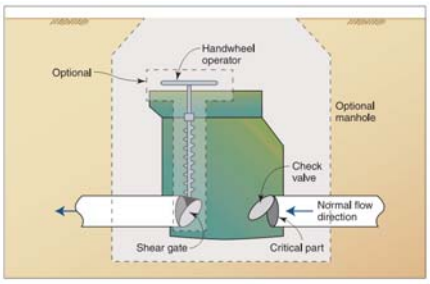
Temporary Floodwalls



Dry Floodproofing





Flood Proofing Tests

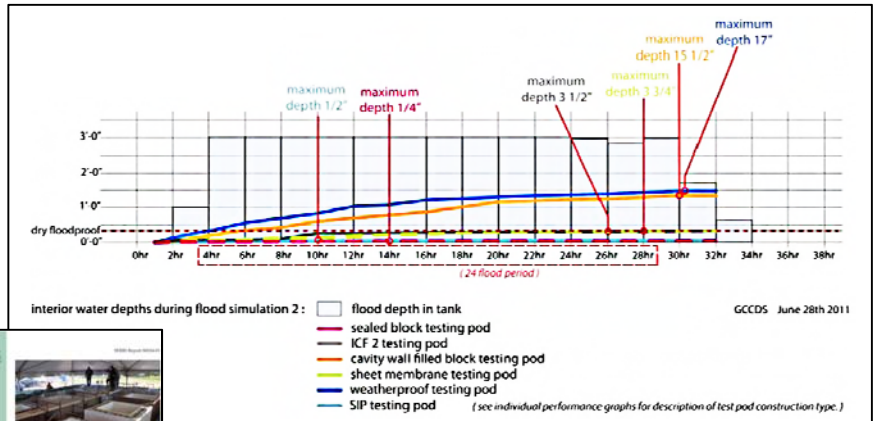
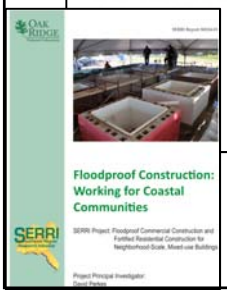


Fig. 4.32. GRAPH: Interior water depths, flood simulation 2.



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In Addition to Floodwalls: Flood Doors…

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Mobile Bay Critical Equipment

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Gulf Coast

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Mobile, AL Building

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FEMA Flood Insurance Rate Map

Site 1% annual chance flood Elevation = 12 ft NAVD
FF El. = 15 ft NAVD

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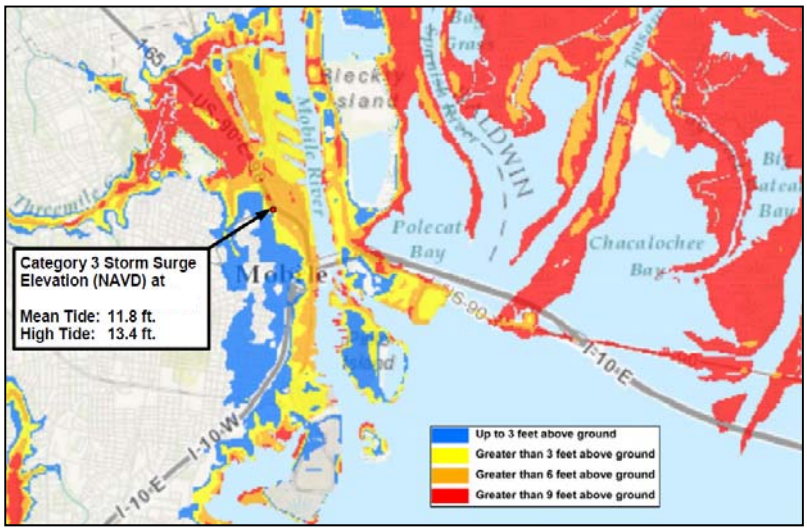
NOAA SLOSH Maximum of Maximums for Category 3



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Building Vulnerabilities

- Ungrouted CMU walls
- Garage and person doors
- Dock levelers
- Full-height glazing
- Utility penetrations
- Building expansion joints
- Sewer/floor drain backflow
- Slab uplift capacity

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Protecting Critical Equipment with Modular Flood Barriers and Interior Pump Stations

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School Building

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School Building

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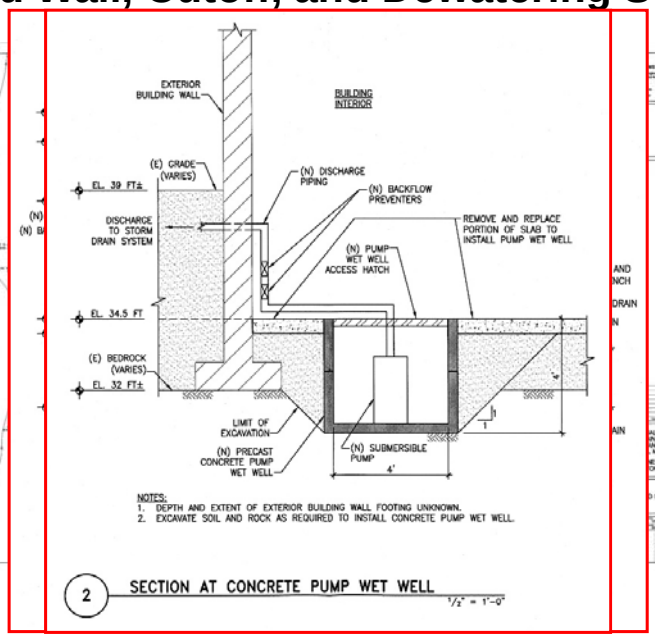
AL1

Flood Wall, Cutoff, and Dewatering Sump



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Slide 46

AL1 Graphics to insert cleaner version from backup files. Also highlight building face and flood wall.
Aaron Lewis, 9/23/2015

Riverine Flooding

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Riverine Flooding

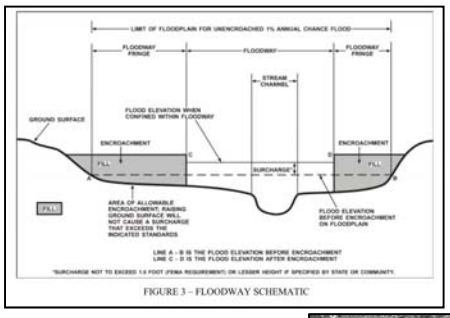

FIGURE 3 – FLOODWAY SCHEMATIC

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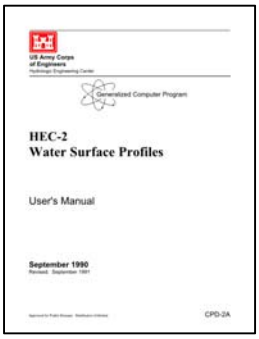
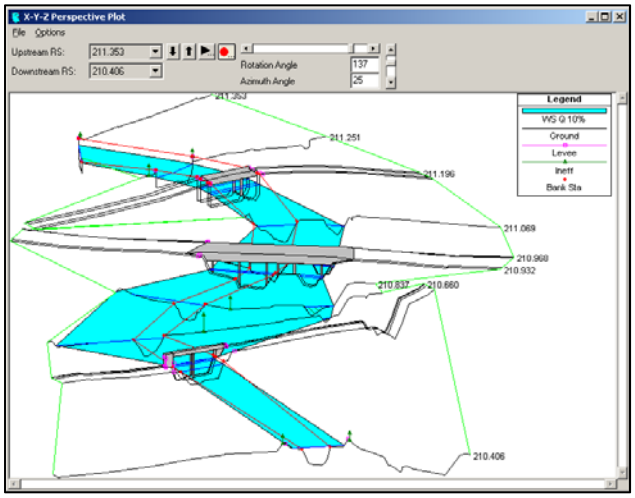
Riverine Flood

- Analyze Hydrology and Hydraulics to Determine Flood Elevations
- HEC-2
- HEC-RAS





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Groundwater

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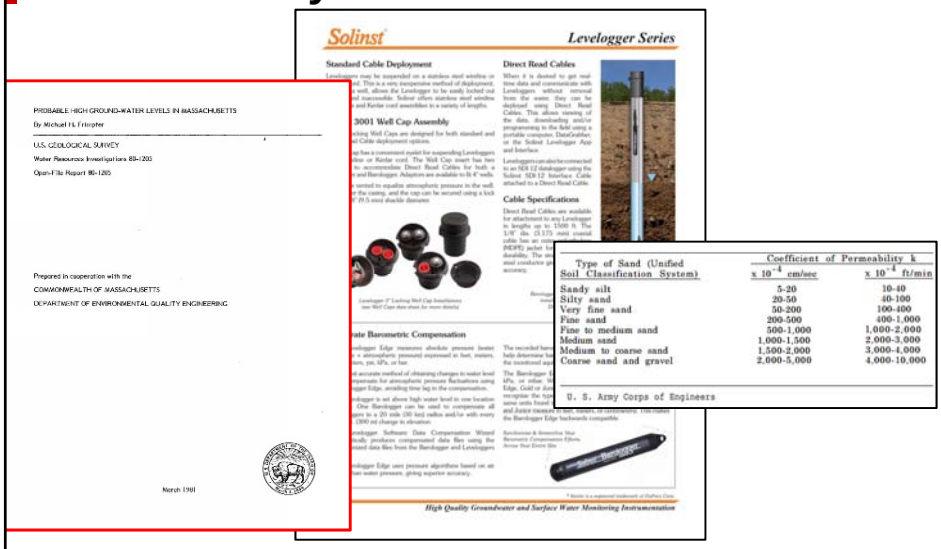
Estimate High Groundwater and Permeability of Soils



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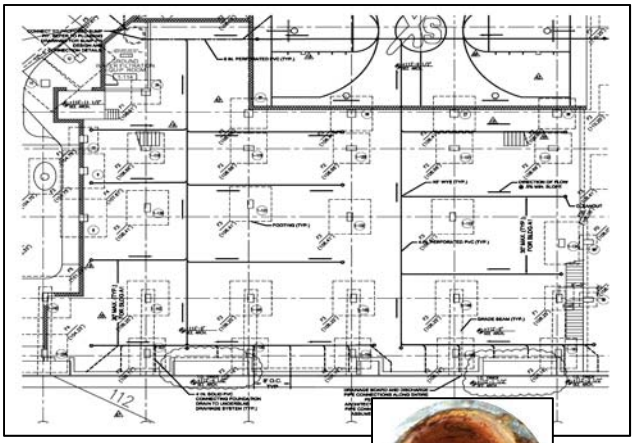
AL13

Underslab Drainage

- Design groundwater Level
- Flow (Q)
- Pipe spacing
- Pipe size and slope
- Pipe invert
- Dewatering pump details
- Iron ochre?



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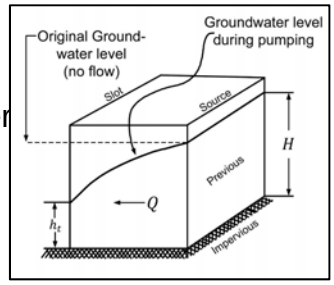
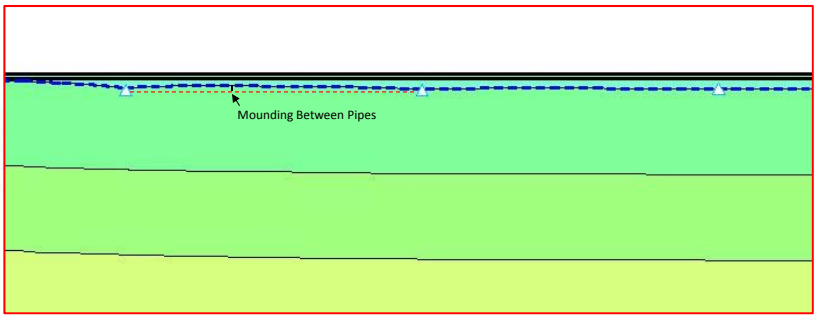
Slide 52

AL13 insert picture of trench detail
Aaron Lewis, 10/7/2015

Underslab Drainage Calculations

- **Q (Flow per unit length)**
  - Groundwater elevation
  - Depth to impermeable layer
  - Soil permeability





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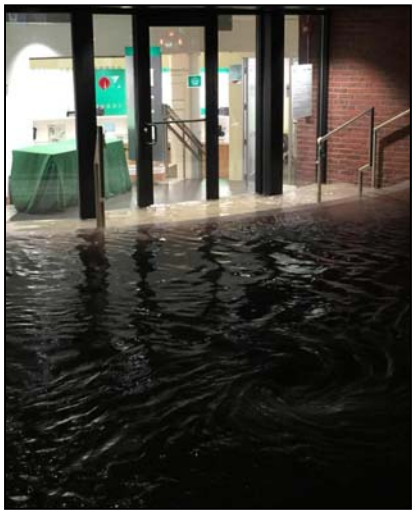
Waterproofing for Flooding and Elevated Groundwater

How Can Below-Grade Waterproofing Resist Flooding?

How Can it Resist More Common Leakage Risks?



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Waterproofing for Flooding and Below-Grade Leakage

- How Water Gets in
- Concepts for Below-Grade Waterproofing
- Types of Waterproofing
- Case Study: Flooding Protection

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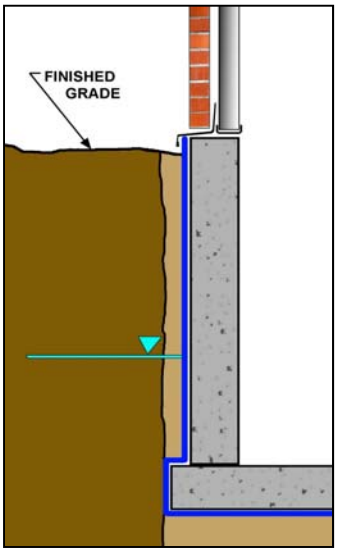
Common leakage paths:

- Surface run-off
- Water against the foundation wall
- Groundwater hydrostatic pressure



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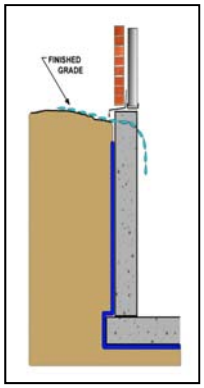
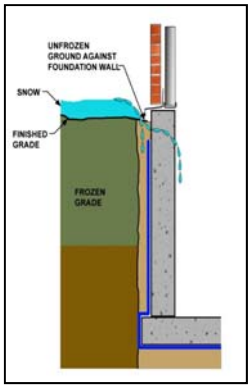
Common Types of Below-Grade Leakage

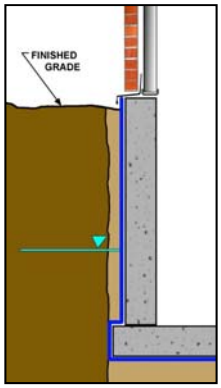
Grade slopes towards foundation wall



Water against foundation wall (frozen ground)



Solution: extend waterproofing above grade



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• Mat slab-to-wall construction joint
• Most common type of below-grade leakage
• Failed waterstop and waterproofing tie-in
• Water migration
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Why do below-grade waterproofing systems require special attention?

1) Only "one chance" to get it right – inaccessible after construction. (Repairs are impractical after construction because of expense and disruption).

2) Waterproofing installation must be coordinated with the construction of the foundation.

3) Leakage water can travel laterally in cracks and between waterproofing and structure.

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Considerations When Selecting a Below-Grade Waterproofing System

- Is the structure into the water table? Hydrostatic pressure will force water through smallest defects.
- Use of space? How reliably dry does it need to be?
- Complexity of below-grade structure? A lot of transitions, details, and individual concrete elements (placements) make it difficult to install continuous membrane.

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Low Tolerance for Leakage

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Below-Grade Waterproofing

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Address complex substrates:

- Create smooth, even substrates
- Minimize complex transitions details
- Plan for transitions between sections

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Little Preparation of Excavation

- Many corners
- Nothing smooth
- Expect leakage

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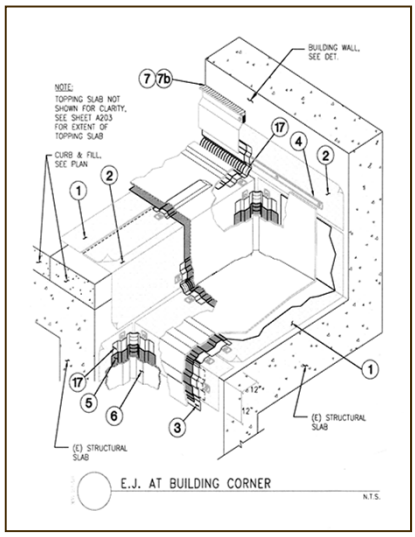
Below-Grade Waterproofing Success Requires a High-Level of Coordination at Construction:

- Provide sequence drawings where needed and appropriate
- Require shop drawings showing sequencing and coordination
- Meetings with all trades
- Field monitoring
- Waterproofer "on standby" for repair



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Damage to Waterproofing from Construction

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Concepts for Below-Grade Waterproofing

Option 1: Waterproofing without Sub-Slab Drainage

Option 2: Waterproofing with Sub-Slab Drainage
(may not be practical in some groundwater conditions)

Option 3: "Box-in-a-Box" (expensive but most reliable)

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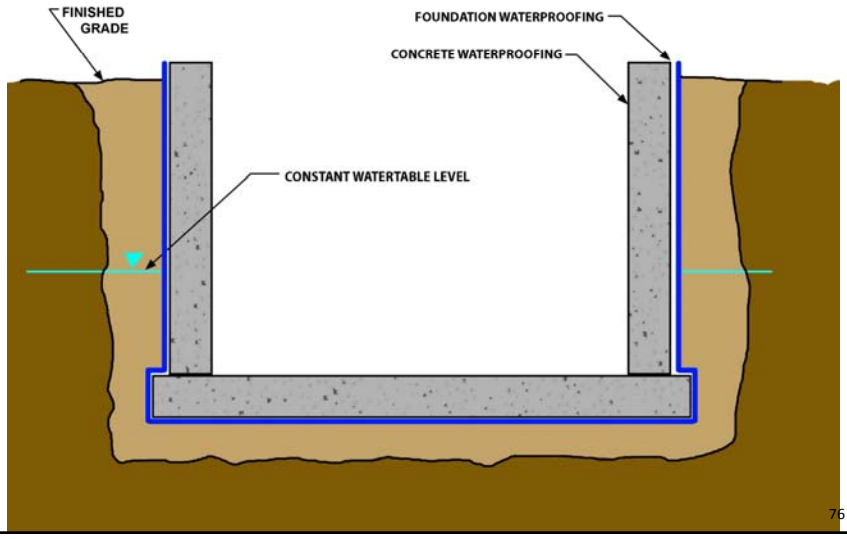
DIRECT-APPLIED, POSITIVE-SIDE WATERPROOFING IN THE WATER TABLE



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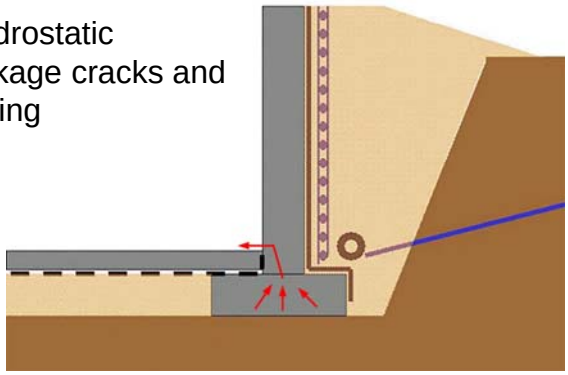
Hydrostatic Pressure Relief Systems: Foundation and Sub-Slab Drainage

Leakage from hydrostatic pressure at shrinkage cracks and pour joints in footing



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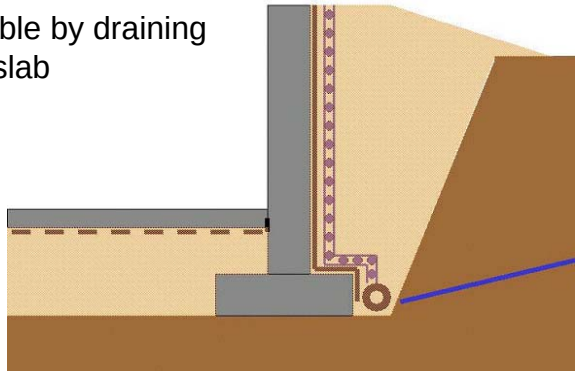
Hydrostatic Pressure Relief Systems: Foundation and Sub-Slab Drainage

- Lower water table by draining at level below slab



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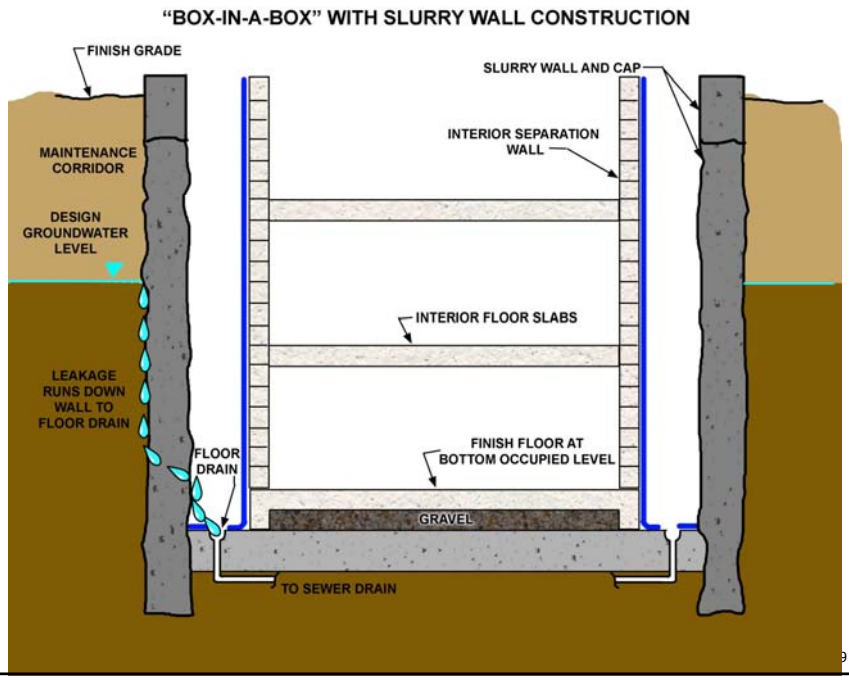

Types of Below-Grade Waterproofing

- Positive Side
- Blind Side
- Negative Side
- Hydrostatic Pressure Relief Systems

Remedial:

- Chemical Grout Waterproofing

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Types of Positive-Side Waterproofing Membranes

- Self-adhering modified bituminous sheet
- Hot-applied rubberized asphalt
- Spray and liquid-applied elastomeric coatings
- Bentonite (also used in blind-side waterproofing)
- Thermoplastic/bentonite composite sheet

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Types of Positive-Side Below-Grade Waterproofing

Hot-Applied Rubberized Asphalt

Spray-Applied

Bentonite

Thermo-Plastic Bentonite Composite

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Blind-Side Waterproofing

- Installed against excavation shoring *before* concrete
- Used where outside of foundation wall is inaccessible
- Must allow for connections at transitions and perimeters
- Vulnerable to damage during steel reinforcement install

Types:

- HDPE (High-density polyethylene) with pressure-sensitive coating
- Bentonite (also used in positive site applications)
- Others

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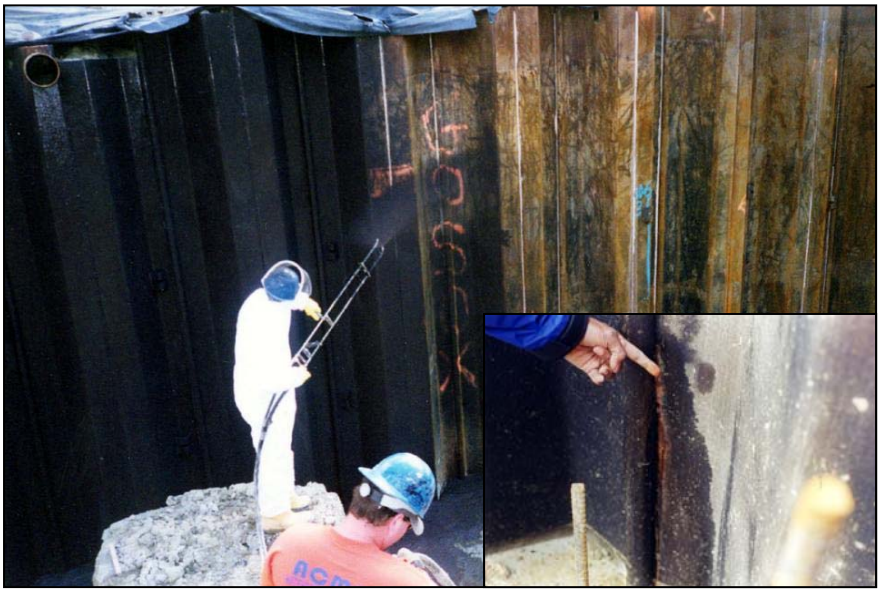
Asphalt Rubber Emulsion



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Types of Negative-Side Waterproofing

- Chemical grout injection (polyurethane, others)
- Metallic - older than other products (ironite)
- Crystalline – applied to cured or uncured concrete

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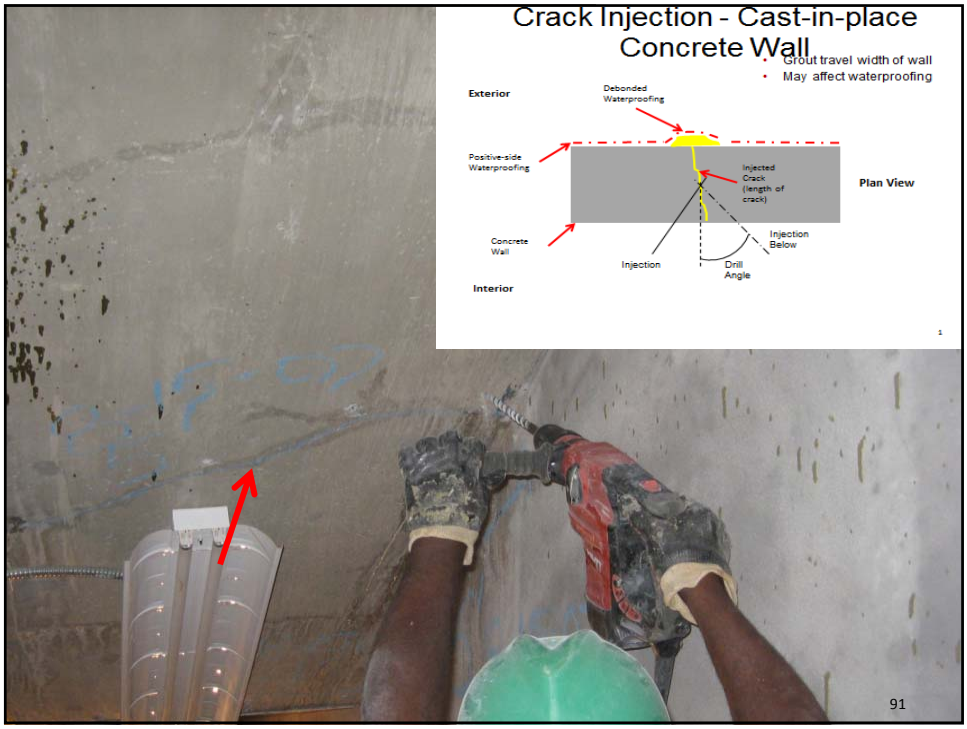

Case Study
Retail Space Below Grade
Massachusetts

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Basement Level Building at Low Point at Intersection

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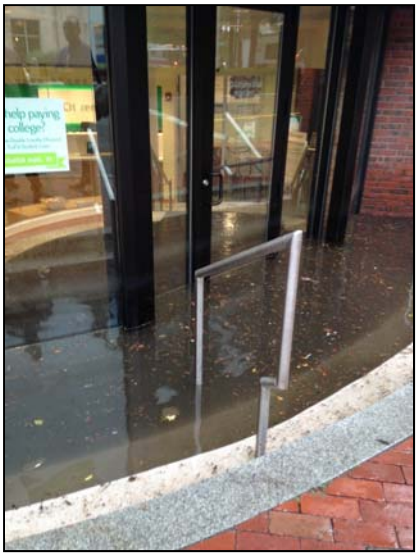
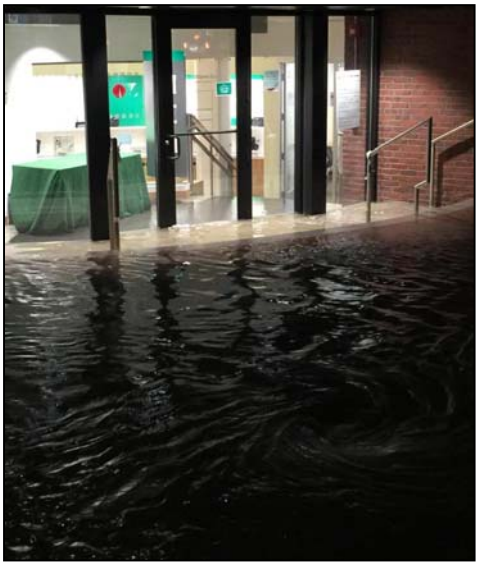
Flooding





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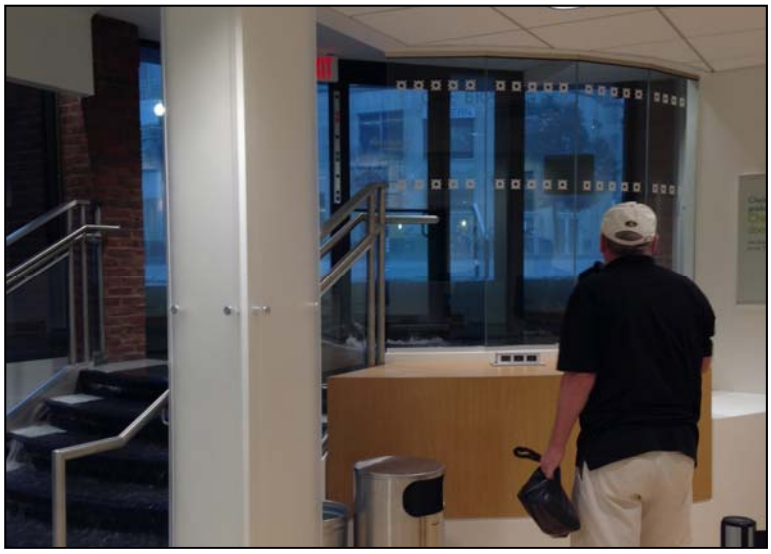
Flooding Due to High-Intensity Storm



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Flooding Due to High-Intensity Storm

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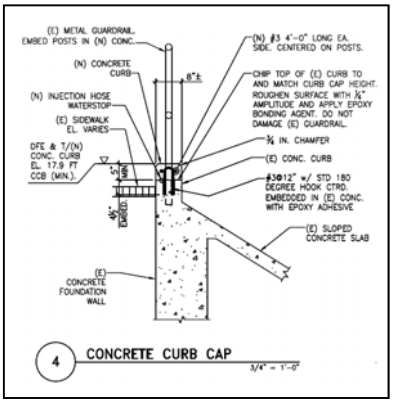
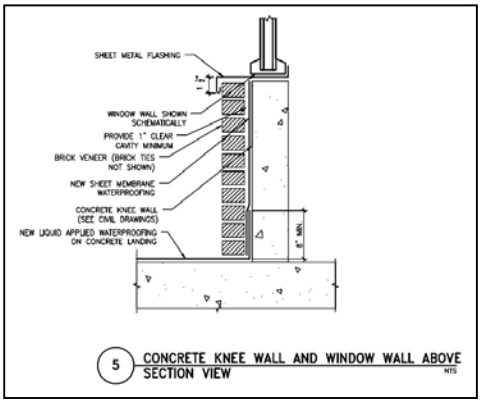
Flood Protection Measures

- Flood barrier at entrances
- Raise curbs
- Waterproofing





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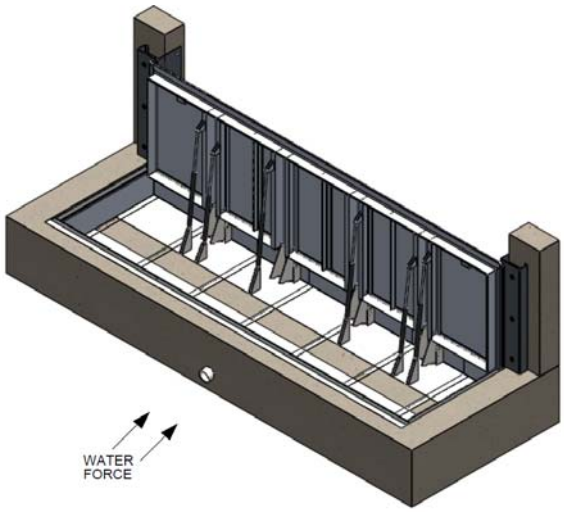
Flood Barrier Protection



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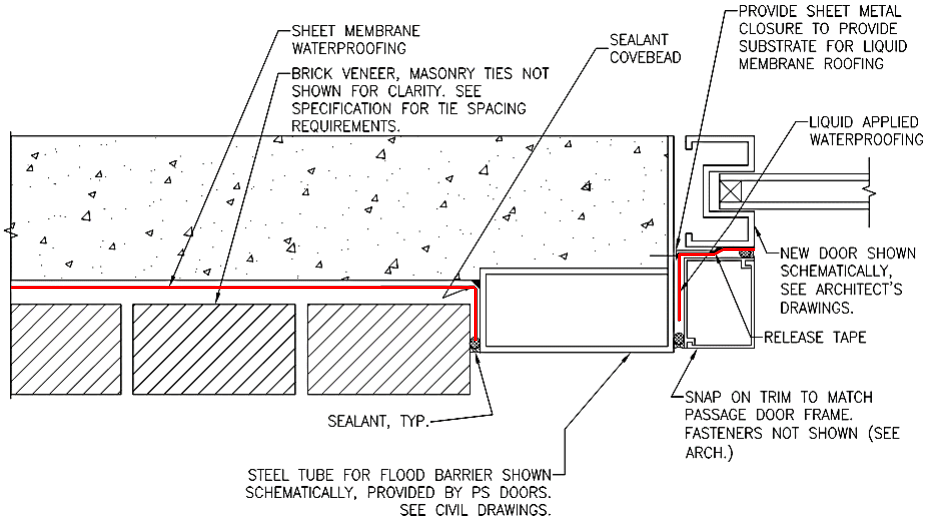

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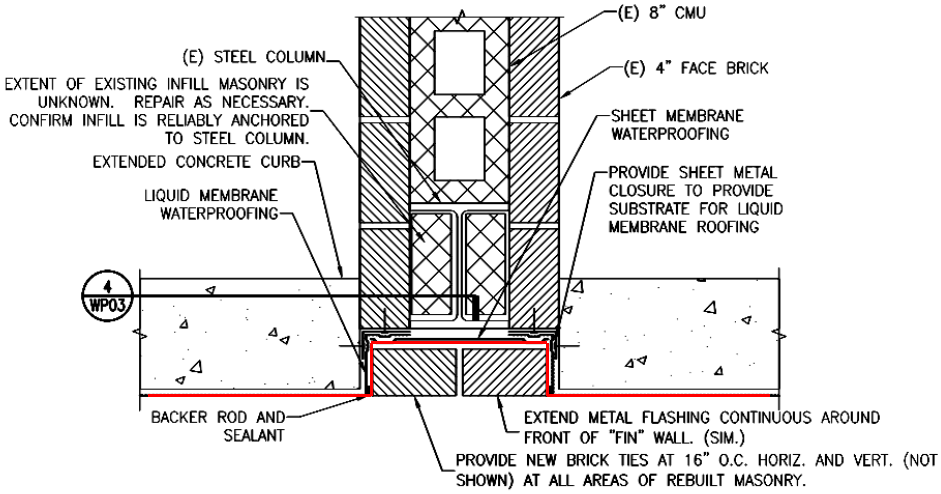

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Waterproofing to Protect Against Flooding and Below-Grade Leakage

- Extend below-grade waterproofing above grade or finished paving and integrate with above-grade wall waterproofing.
- Provide adequate drainage.
- Select waterproofing system with successful track record and design to address weaknesses.
- Use a “belt and suspenders” approach for below-grade waterproofing because of high-risk.

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