Best Practices in Dam and Levee Safety Risk Analysis

25. Levee Floodwalls

6 September 2012

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BUREAU OF RECLAMATION
RECLAMATION
Managing Water in the West

US Army Corps of Engineers
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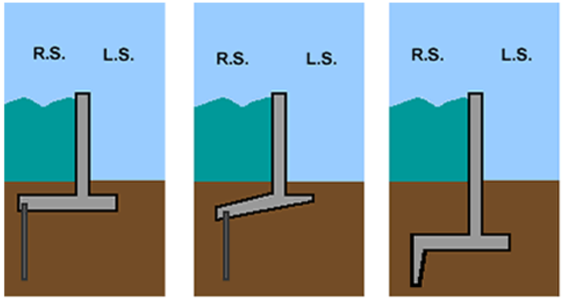
Background Information

- Local flood protection projects (LFPP) utilize both embankment levees and floodwalls for flood prevention
- Floodwalls generally used when space is limited and embankment section is too large to reach desired height of protection
- Much more prevalent in urban/industrial areas because of space restrictions
- There are a variety of floodwall types in existence and each has unique performance characteristics

TYPES OF FLOODWALLS

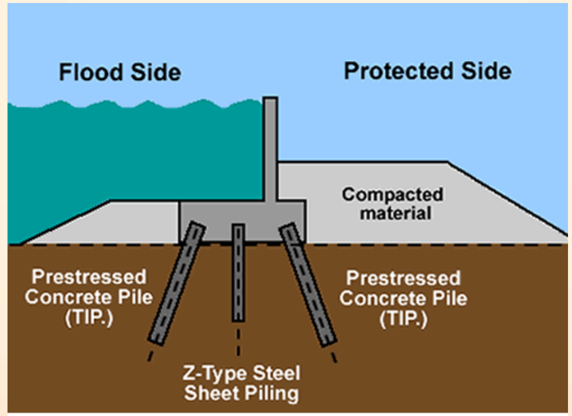
(http://www.iwr.usace.army.mil)



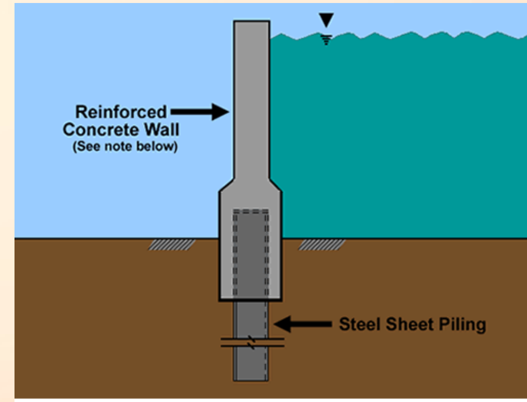
Horizontal Base | Sloped Base | Horizontal Base Keyed Into Stronger Soil

Note: R.S. = River Side (or seaward, unprotected side)
L.S. = Land Side (or protected side)

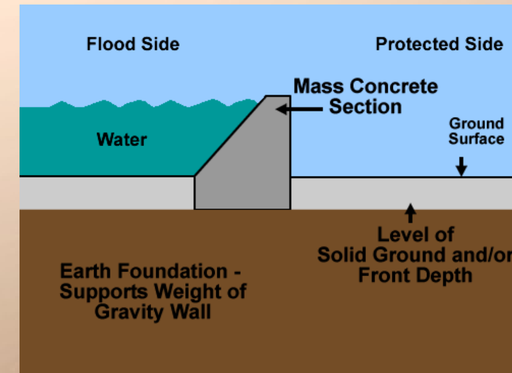
Inverted T-Type Cantilever Walls



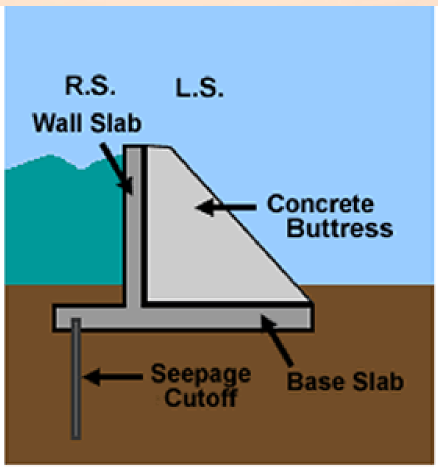
T-Wall supported on a pile foundation



Basic I-Wall Configuration



Gravity Wall



Buttress Wall

Note: R.S. = River Side (or seaward, unprotected side)
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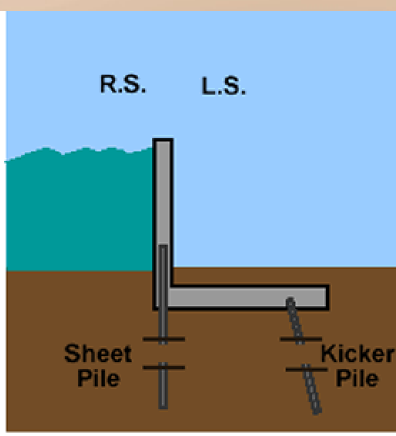

L-Wall With Kicker Pile

Note: R.S. = River Side (or seaward, unprotected side)
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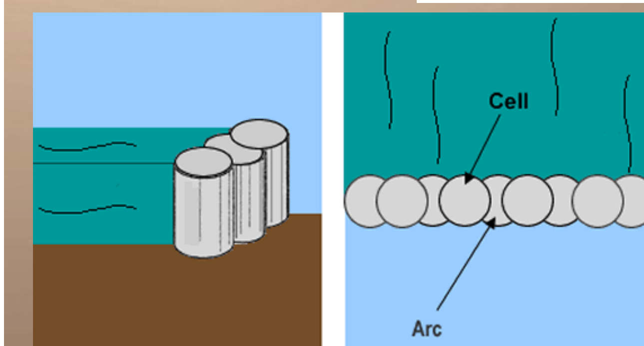


Horizontal View | Vertical View

Sheet Pile Cells

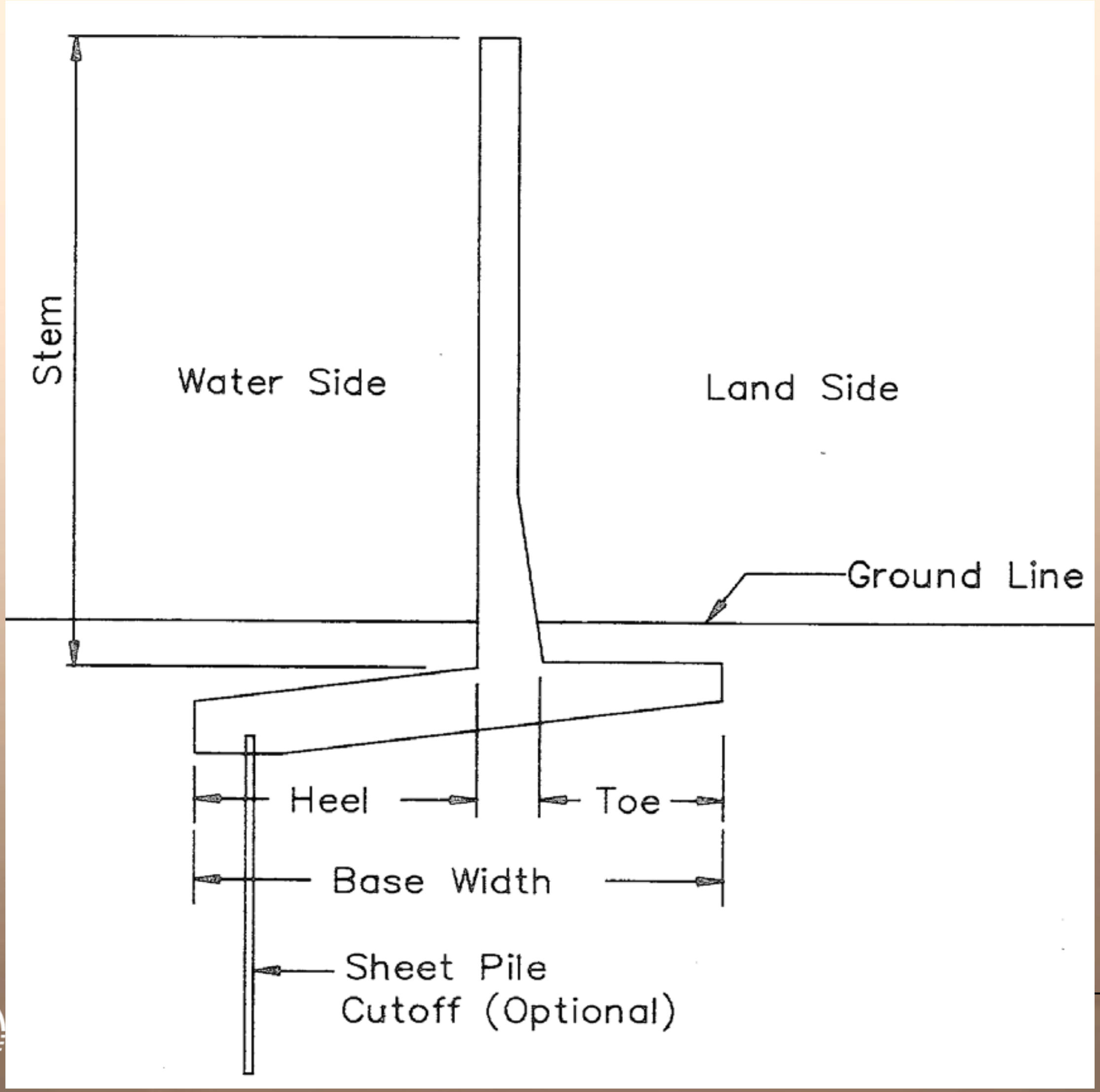
More Info on Floodwall Types

- Overwhelming majority of floodwalls in service within the US are composed of T-walls and I-walls. These are the focus of the Best Practices Manual and this presentation
- Gravity walls (multiple sources including EM 1110-2-2100) for analysis techniques and other important considerations
- L-walls have similar considerations as T-walls with respect to most performance considerations
- Sheet pile cells (multiple sources including EM 1110-2-2503)
- EM 1110-2-2502 also has general information related to other wall types when these are encountered

T-WALLS

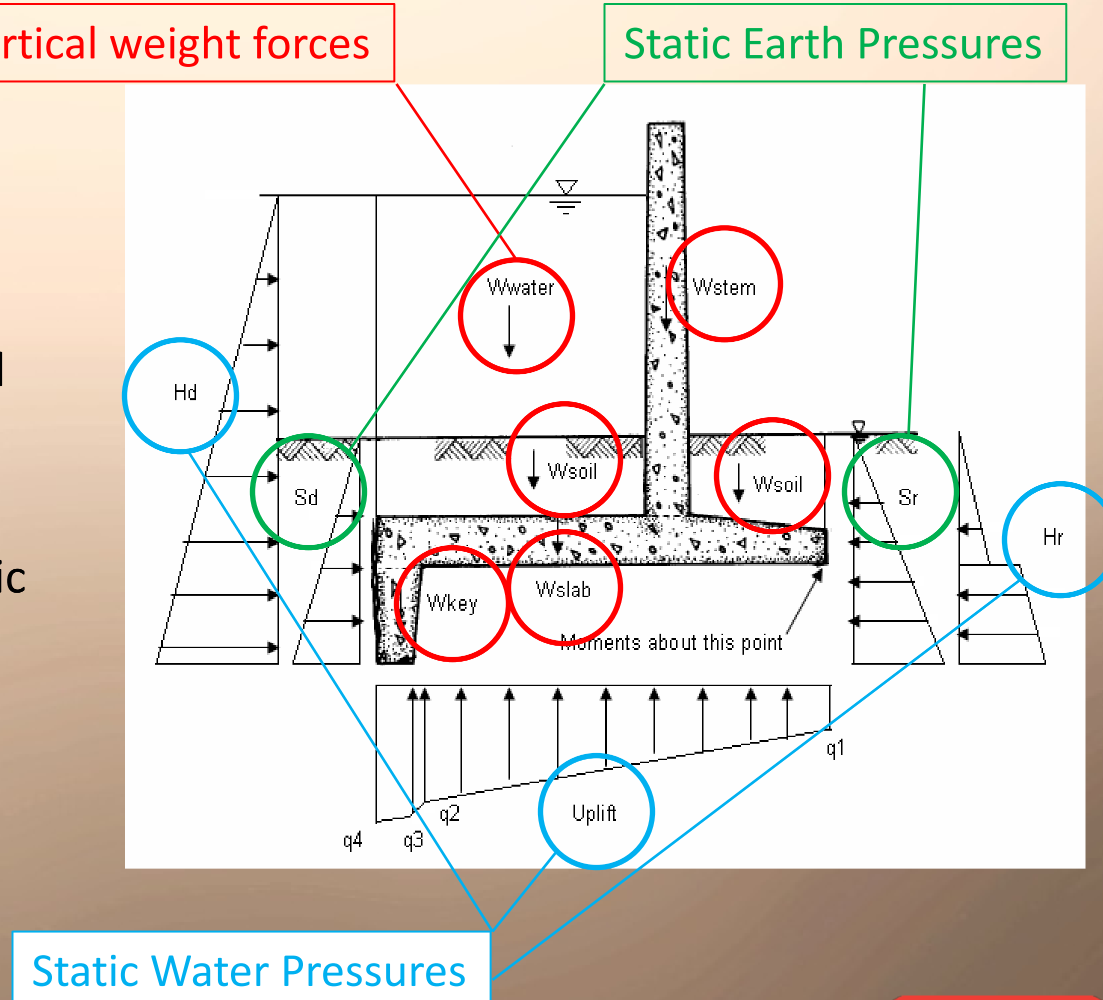
- T-walls take their name by the cross-section (inverted "T")
- Generally used when exposed height of wall becomes too excessive for an I-wall, which is a cheaper construction alternative
- Usually only a review of the as-built plans will let you know if you have a T-wall or I-wall section as they look the same above ground
- Multiple configurations possible based upon site conditions
  - *Horizontal base, sloped base*
  - *Sheetpile cutoff for underseepage control, no sheetpile*
  - *Shear key, no shear key*
  - *Pile founded, no piles*
- Generally have performed well assuming proper design assumptions. Performed well during Hurricane Katrina.

T-WALLS - Terminology



Forces Acting on a T-Wall

- Seismic forces are usually not risk drivers for levees due to requirement of simultaneous infrequent events
- Levee systems that are loaded frequently and are in high-to-moderate seismic areas would warrant an evaluation of concurrent flood/EQ events
- Walls that form canals or river passages with navigation traffic may require impact loads as part of a risk assessment
- Consider potential for scour along the riverside face of the wall
  - *Velocities, foundation soils, orientation of wall, etc*



Force Computations

- **WEIGHT Computations**
  - *Use 150 lbs/ft^3 for unit weight of concrete unless there are other specifications provided*
  - *Use 62.4 lbs/ft^3 for unit weight of water*
  - *Use submerged unit weights for saturated soils below water line*
- **EARTH PRESSURE Computations**
  - *Already covered in Chapter 23 of Best Practices Manual*
  - *May want to initially consider conservative K_o (at rest) earth pressure coefficients for an initial analysis and adjust if necessary*
  - *Lateral displacement may be too large to fully develop passive resistance depending upon wall configuration and type of soil*
  - *Consider drained and undrained conditions depending upon situation*
- **WATER PRESSURE Computations**
  - *Consider underseepage (uplift) acting on base of T-wall*
  - *Evaluated effectiveness of underseepage control systems taking into account likelihood of deterioration or reduced efficiency*
  - *Wind & wave considerations (more on next slide)*

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Other Water Forces to Consider

- Wind & Wave Considerations
  - *Surge*
  - *Wave action*
  - *Fetch*
  - *Original design considerations*
- Significant concern for coastal areas
- Less concern for inland river floodwalls, but can be an issue depending upon situation
- Good info source – USACE Shore Protection Manual

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Underseepage Considerations

- General seepage considerations covered elsewhere in Best Practices
- Types of underseepage control measures for T-walls
  - *Sheetpile cutoff below shear keys are fairly common*
  - *Landside toe drains are many time used as an extra safety measure*
  - *Relief wells can be used when pervious layers are well below base slab*
  - *Riverside impervious blanket*
  - *Landside seepage berm*
- Sheetpile walls will not totally cutoff underseepage but will help performance tremendously if driven through pervious stratum or deep enough to significantly lengthen the seepage path.
- Important considerations:
  - *What is the condition of the underseepage control system? Is it well maintained and operating at its intended functionality?*
  - *What were the original design assumptions regarding underseepage?*
  - *Advised to work closely with your geotechnical engineer on the team*

Water Levels for Evaluation

- Not always 'straight forward' for levee floodwalls
  - *Consideration of incipient overtopping location*
    - Water surface profile, top of levee embankment/floodwall profile
  - *Where is the 'critical' wall section?*
  - *Will overtopping be considered in the evaluation?*
- Usually will need to evaluate the wall for multiple water levels
  - *General rule of thumb → ¼, ½, ¾, 90% of exposed height, and to the top of the wall relative to the overtopping location along the LFPP*
- When developing the system response curve (probability of failure vs. water level), you should evaluate performance for the mid-point of the range
  - *¼ to ½ exposed height range would be evaluated at the 3/8 exposed height and considered representative for that range*
- The water levels evaluated need to also consider what is being considered as part of the consequences for the risk analysis

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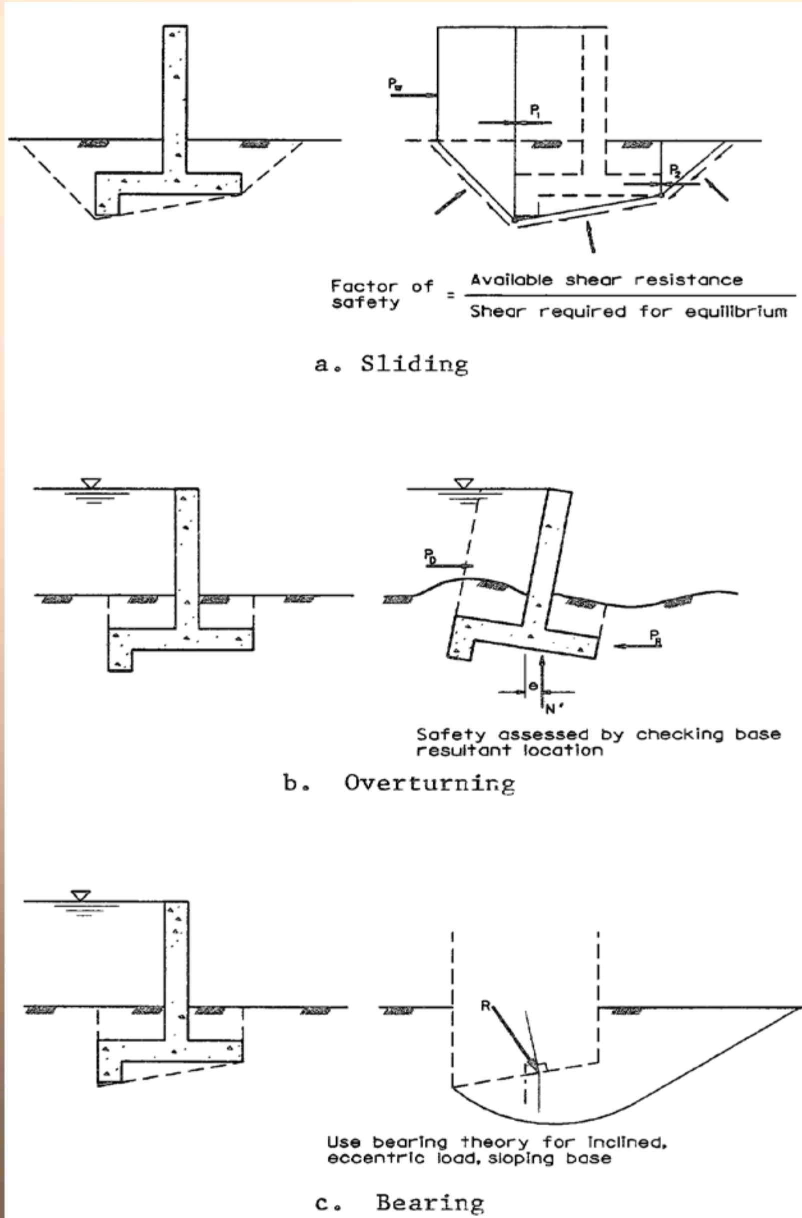
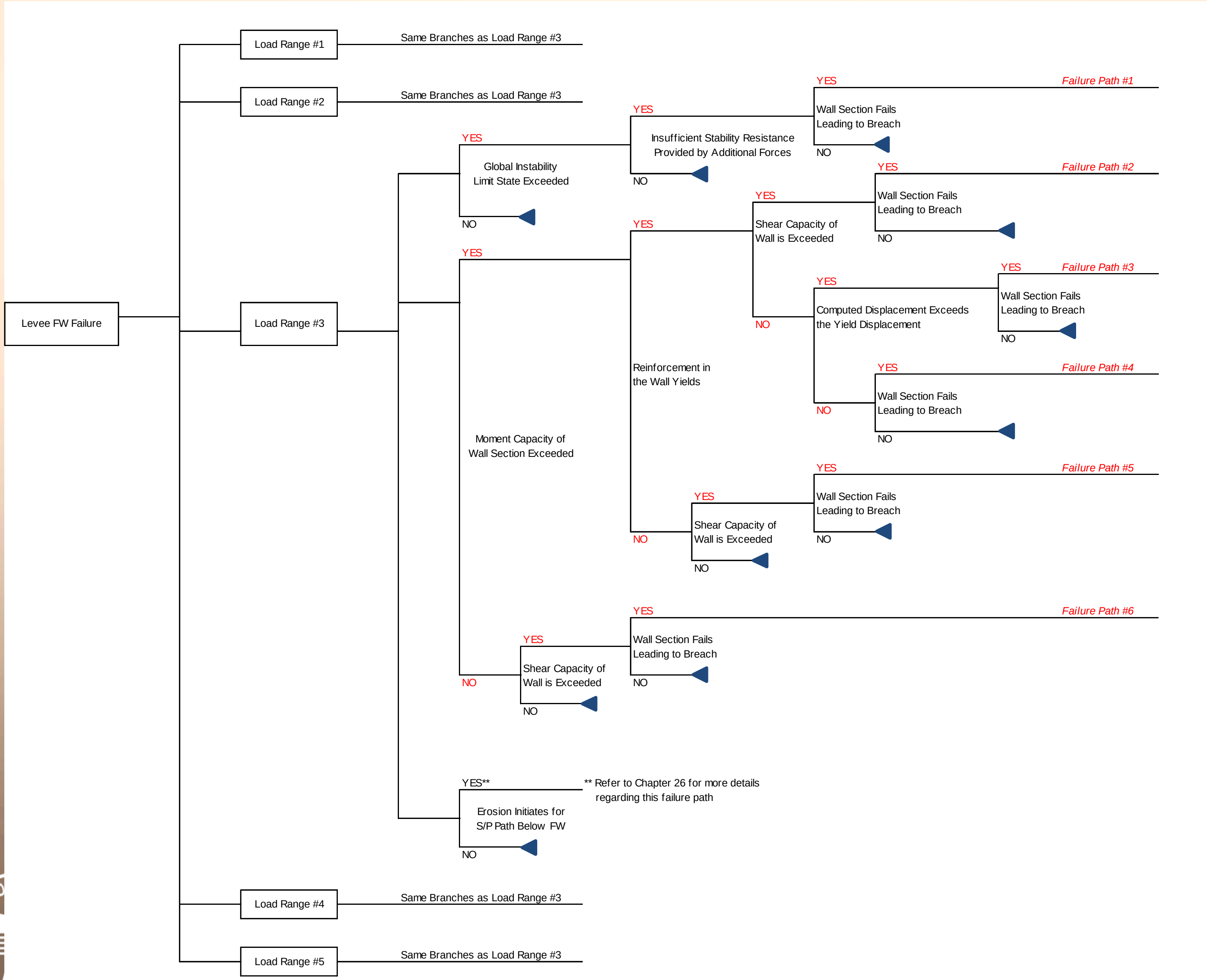
T-Wall Failure Modes



- Global Instability
  - ✓ *Sliding*
  - ✓ *Overturning*
  - ✓ *Bearing*
- Structural Performance
  - ✓ *Excessive moment*
  - ✓ *Excessive shear*
- Underseepage and piping
  - *Consider condition of underseepage control system*
- Instability caused by overtopping scouring passive resistance
- Need to fully describe failure path from initiation through breach

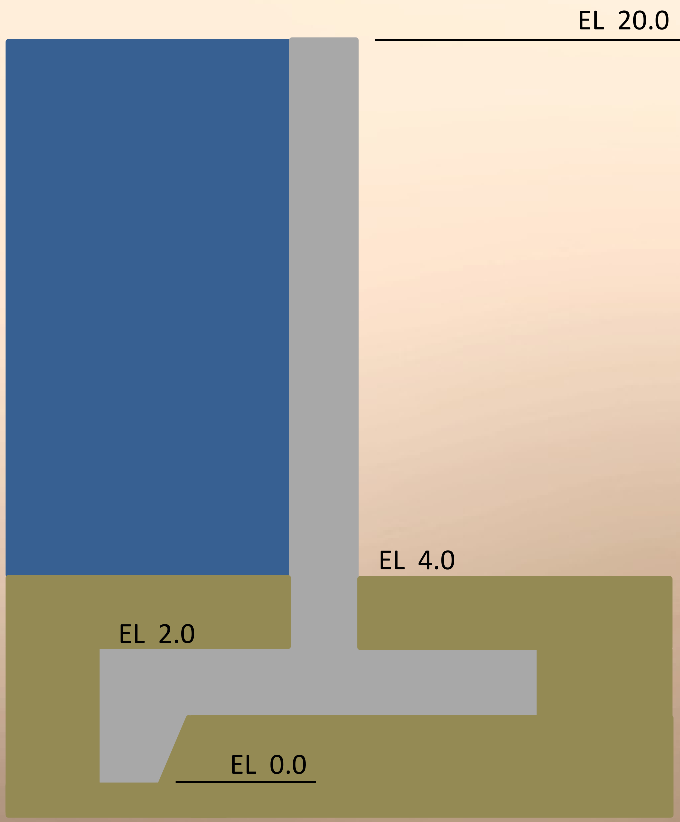
Example Event Tree for Floodwalls

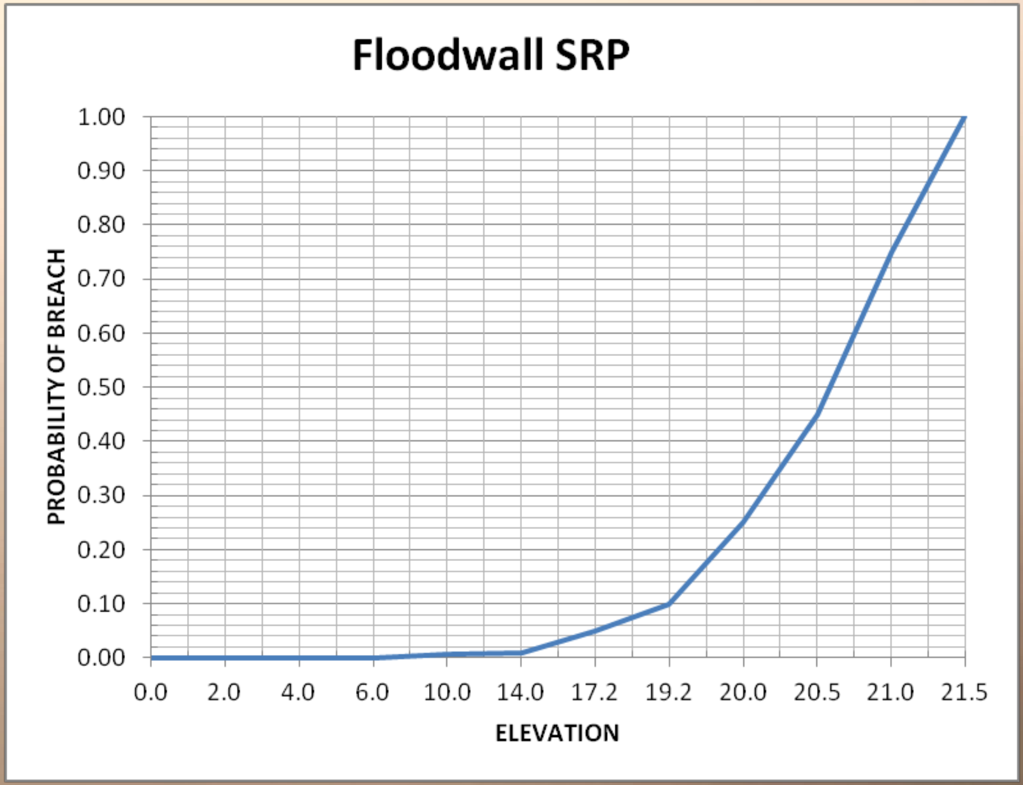


System Response Curve for T-Walls

- Floodwalls lend themselves well to analytical methods to support development of performance-based probabilities
  - *Simulation based spreadsheet analysis with @Risk™ software is an example*
- Information developed from analytical methods can be used to support a follow-on elicitation approach of an expert panel
- When assessing performance using analytical methods, you need to pay special attention to other issues that can adversely affect performance (vegetation, deteriorated seepage control system, encroachments, etc…) of the floodwall
- Uncertainty can be added to the evaluation as part of the elicitation by having the panel provide responses for high and low likelihood values for each event tree branch

Simple Example of SRP for Floodwall



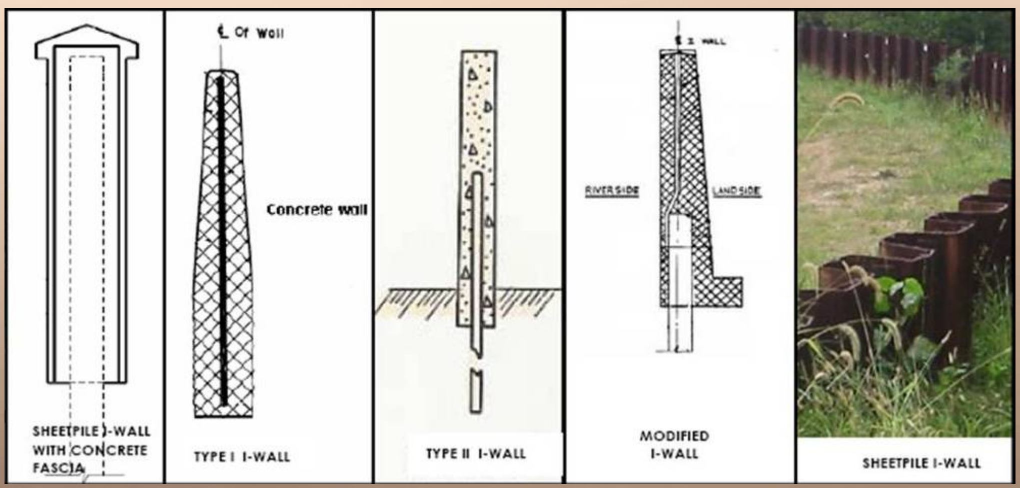


I-Walls

- I-walls require special consideration in light of performance during Hurricane Katrina and follow-on development of updated criteria for assessment

I-Walls – Background Information

- I-walls were generally used when the exposed height of wall was fairly low (usually < 10 feet, but there are many exceptions)
- I-walls are used because they are much cheaper than T-walls because no base slab is required
- I-walls are used in both flat, natural/engineered ground or within an embankment as a means to raise an existing level of protection
- There are a variety of I-wall types in use, but the Type II I-wall and sheetpile I-walls are the most prominent



I-Walls Failures in New Orleans

- There were multiple I-wall failures during Hurricane Katrina
- A thorough detailed field investigation and follow-on analysis was carried out on the various I-wall failures. Advanced FEM and laboratory centrifuge testing were used to help verify the cause of the failures.
- Failures of New Orleans I-walls were mainly caused by two issues:
  - *Overtopping of wall causing scour and loss of wall support on the passive side (Lower 9th Ward); thus, the wall protected up to its full height but breached after it was overtopped*
  - *Formation of a flood side gap against the wall causing fully hydrostatic head along the face of the wall down to the depth of the crack (London Avenue wall failure)*
  - *The foundation conditions at New Orleans were the primary issue causing the formation of the flood side gap*

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Updated I-Wall Guidance

- Multi-discipline, multiple phase analysis used to develop new guidance for assessing I-walls within the USACE inventory
- New guidance – Engineering Technical Letter (ETL) 1105-2-575
  - *Failure modes should include rotational instability, translational/deep-seated instability, and underseepage*
  - *Rotational instability is dominant failure mode for most situations*
  - *Translational instability is controlling failure mode for I-walls founded in soft clays or a stiff clay overtop of a soft clay*
  - *Both drained and undrained soil conditions should be considered*
  - *Flood side gap analysis is applicable for undrained soil conditions*
  - *USACE program CWALSHT is a freely accessible program that can be used to assess stability for drained soil conditions*
  - *CWALSHT can overestimate resistance provided by soft clays and a new methodology within ETL 575 is provided to account for this condition*
  - *Wall friction can be important and should be included in analysis*
  - *Much more guidance provided in ETL 575*

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System Response Curve Development

- Methodology to develop a system response curve for I-walls would follow a similar approach as outlined for T-walls accounting for different failure modes applicable to I-walls
- Analytical methods (CWALSHT) or other tools can provide key information to an expert panel and then an elicitation approach can be used to develop the fragility curve
- Only the dominant failure mode needs to be evaluated. If unsure, you may need to develop system response curves for multiple performance modes to determine the 'composite' fragility for the floodwall section being evaluated
- Similar approach to water levels should be used as outlined in the T-wall discussion

In Summary…

- Multiple types of floodwalls exist, majority are T-walls and I-walls
- Many of the forces acting on walls are the same whether they are T-walls or I-walls, but failure modes vary between the 2 types
- Both types of walls lend themselves well to a risk-based analysis approach that can help serve as the 'backbone' of the development of the system response curve
- Relatively recent performance of I-walls and subsequent analysis have identified specific failure modes when certain types of foundations are present
- There are multiple detailed references freely available to help support any level of analysis to be carried out, but the level of effort needs to be commensurate with the overall purpose of the evaluation