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Critical State for Probabilistic Analysis of Levee Underseepage

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1. Failure Prediction
2. Reliability
3. Levee Underseepage
4. Surcharge Factor
5. Evidence (Case Histories)
6. Recommendations

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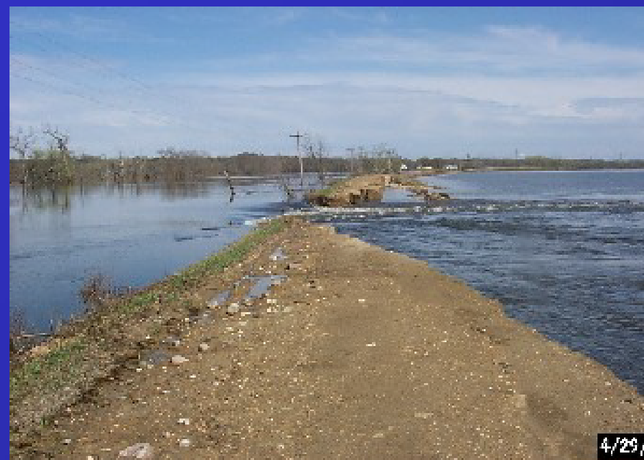
Levee Consequences & Damages



- Impending Failure Mechanism
- Prediction of Limit (Collapse) State
- Not Design Criteria

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Reliability Criteria

- PGL No. 26 (1991)
  - Requires reliability approach for levees
  - Mentions PFP/PNP
- ETL 1110-2-328 (1993)
  - Template Method
- ER 1105-2-101 (1996)
  - Requires risk analysis for flood damage reduction studies
- EM 1110-2-1619 (1996)
  - Economics
- ETL 1110-2-556 (1999)
  - Geotechnical risk analysis for planning studies
  - Appendix B, "Evaluating the Reliability of Existing Levees"

Reliability

Methods

- Taylor’s Series (first order – second moment)
- Point Estimate
- Advanced Method (Hasofer & Lind)
- Monte Carlo

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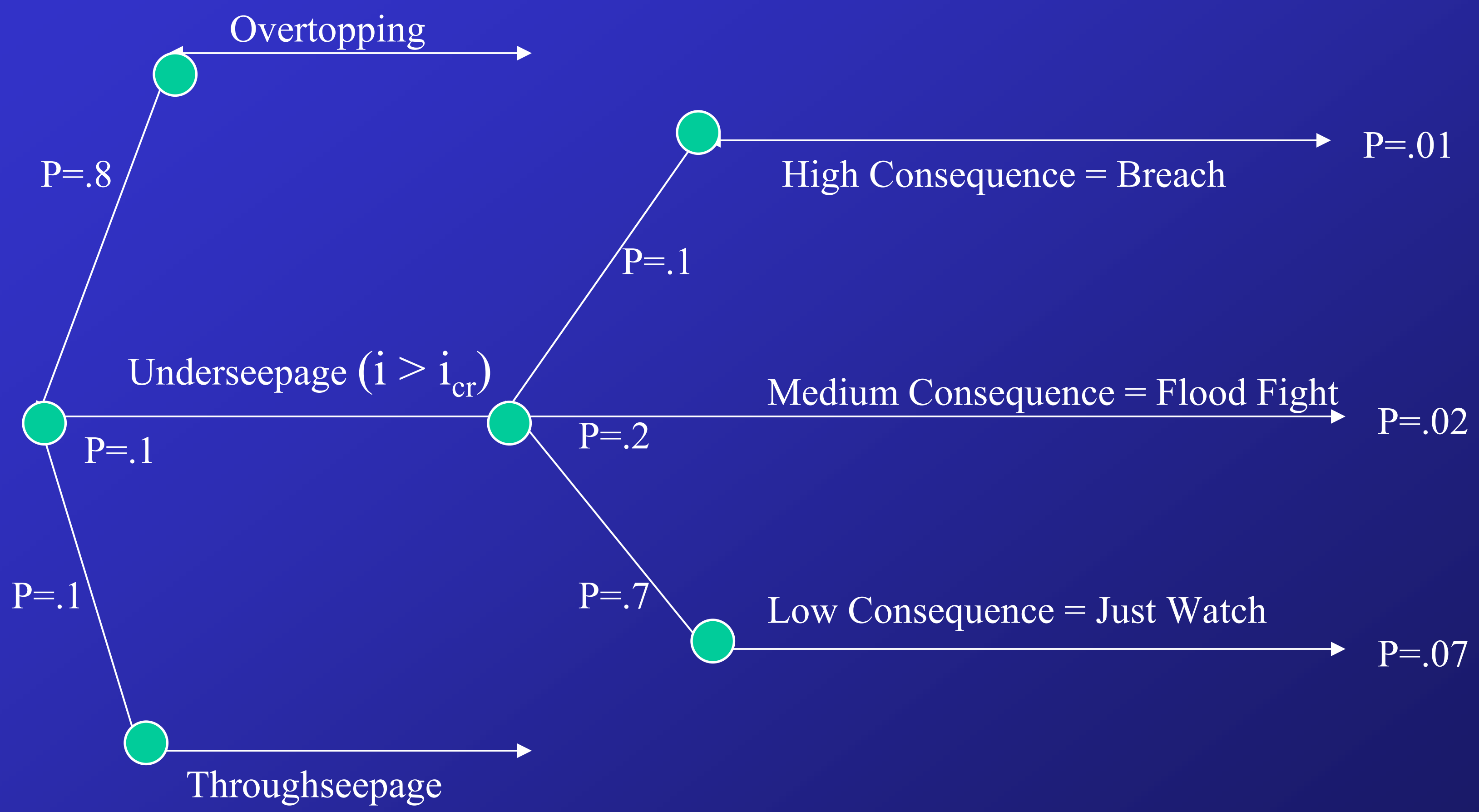
Reliability



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LEVEE FAILURE MODES

- Overtopping

- Other (Scour, Trees, etc.)

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LEVEE FAILURE MODES

Slides

- End of Construction
- Steady State Seepage
- Rapid Drawdown

- Seepage

Under-seepage

Through-seepage

Pipes/Structures

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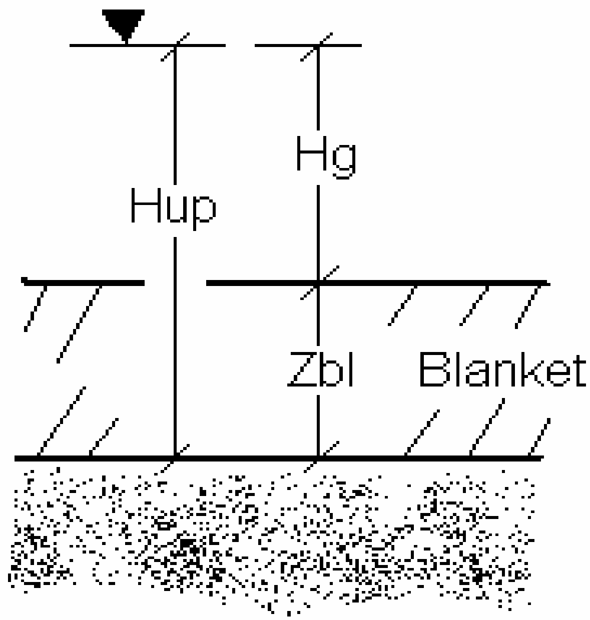
Levee Underseepage: Piping and Heave

$$FS_g = \frac{\gamma_{sat} \cdot Z_{bl} - \gamma_w \cdot Z_{bl}}{\gamma_w \cdot H_g}$$

$$FS_{up} = \frac{\gamma_{sat} \cdot Z_{bl}}{\gamma_w \cdot H_g + \gamma_w \cdot Z_{bl}}$$

At critical state:

$$FS_{up} = FS_g = 1$$



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Performance Function

$$FS_g = i_{cr}/i$$

Critical state at "quick conditions"is when effective stress throughout layer is reduced to zero.

$$i_{cr} = \gamma_b/\gamma_{h20} = (G_s - 1)/(1+e)$$

Unsatisfactory Performance at the Critical Gradient

$$FS_g = i_{cr}/i$$

Capacity (C) = i_{cr} = critical gradient

Demand (D) = i = calculated gradient

Normally distributed, uncorrelated:

$$\beta = \frac{E(C) - E(D)}{\sqrt{\sigma_C^{\ 2} + \sigma_D^{\ 2}}}$$

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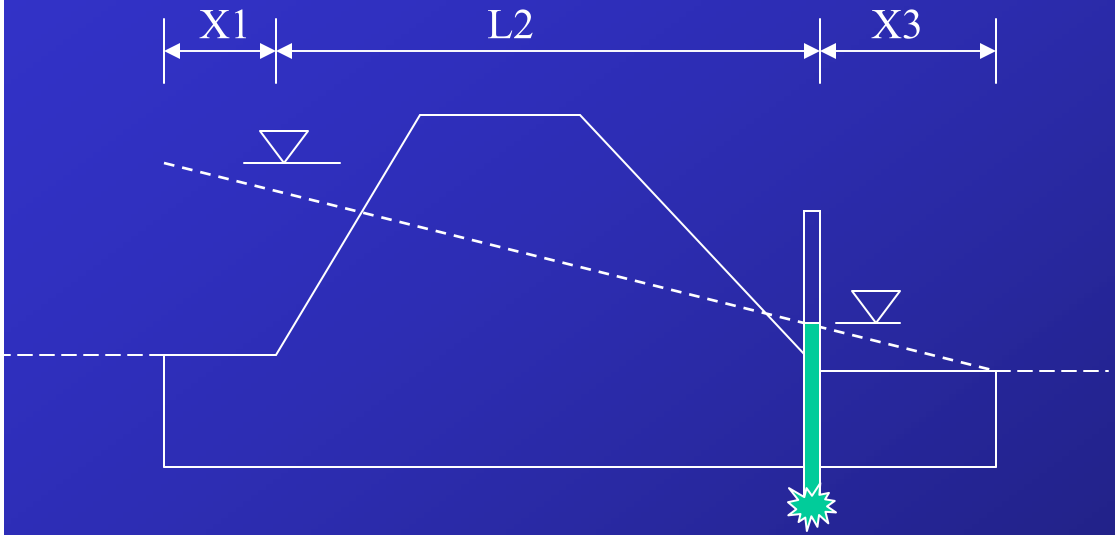
Levee Underseepage



$$m_{toe} = \frac{X3}{X1 + L2 + X3}$$

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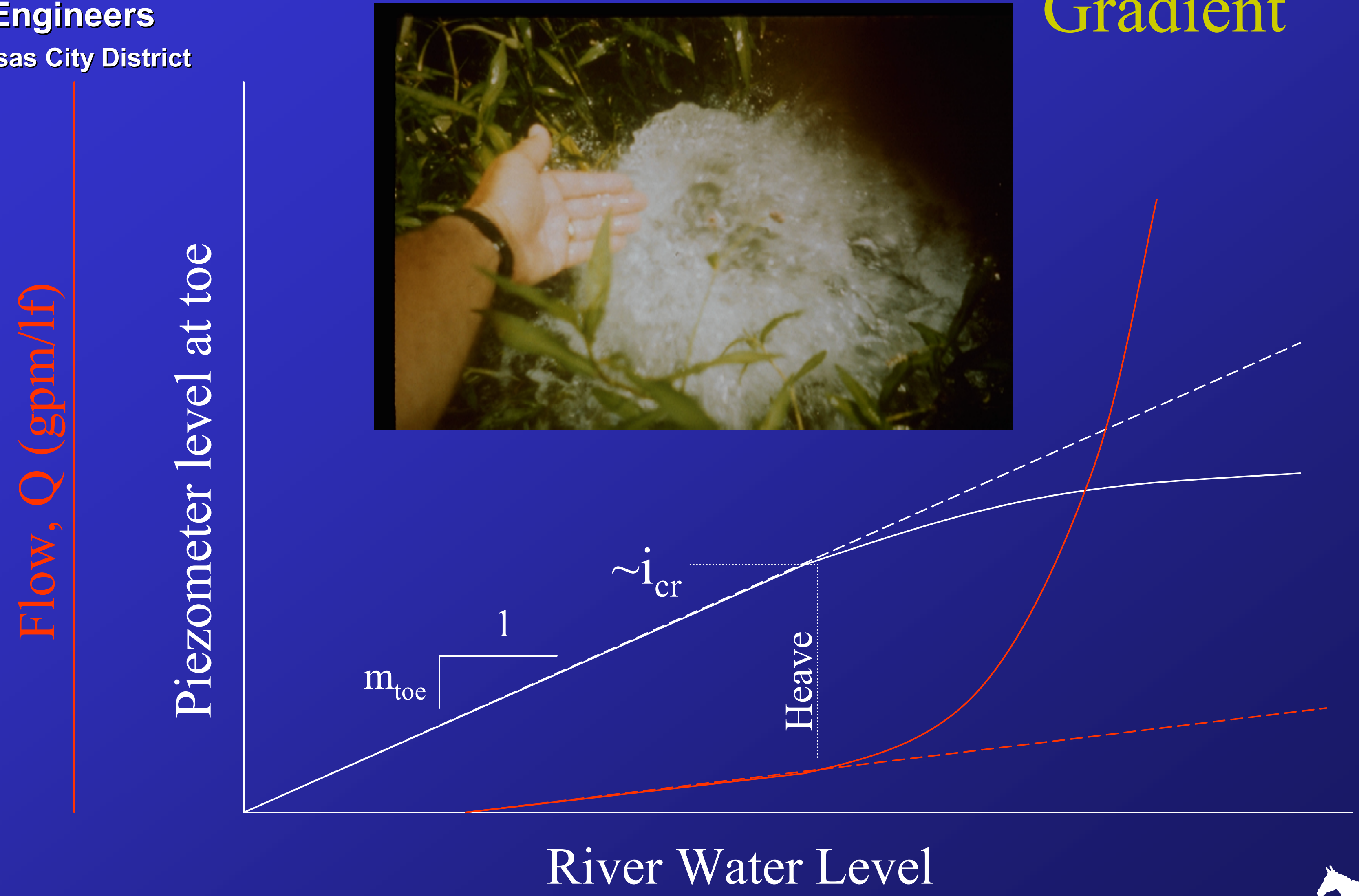
Levee Underseepage: Extrapolated Gradient



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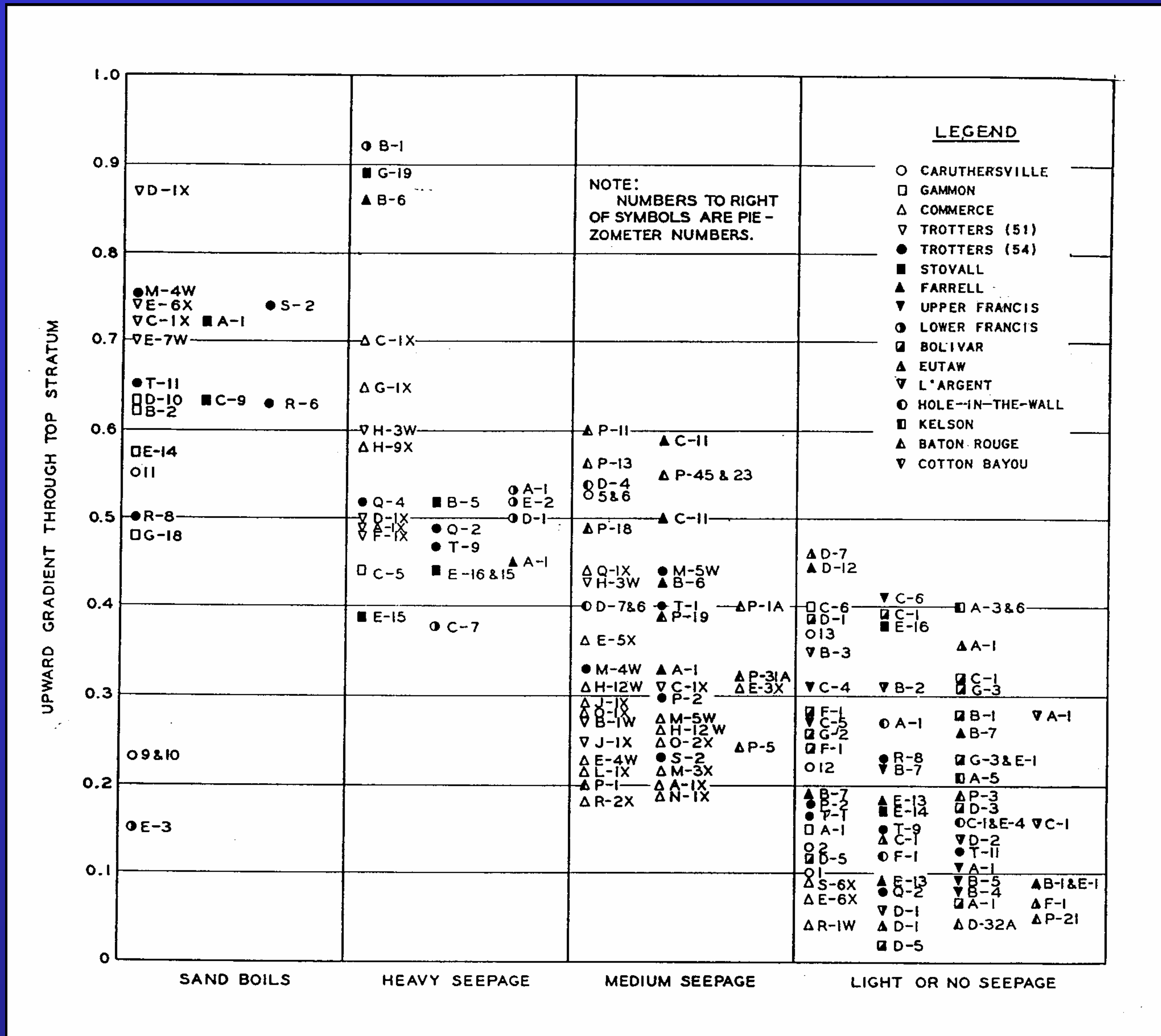
WES Technical Memorandum 3-424 Figure 47 (1956)



CASE 1: Kansas City District, Historic Design Criteria for Agricultural Levees

- No past boil activity, $FS_g = 1$
- Minor boil or heavy seepage, $FS_g = 1.25$
- Major boil activity, $FS_g = 1.5$

The ratio 1:1.5 approximates
(Critical State : Failure State).
$\rightarrow (i_{cr}/i_f) = 1/1.5 = 0.67 \cong 0.7$

References:
Design memorandum no. 1 – underseepage control – levee unit 400-L, 20 Nov. 1953
Design memorandum no. 1 – underseepage control – levee unit 406-L, revised 24 mar 1953

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CASE 2: Rock Island District, Historic Design Criteria for Agricultural Levees

- "The Rock Island District has a philosophy….. to organize the necessary men and equipment to put up a flood fight. …they feel justified in allowing major boils to develop…"
- Design criteria at toe: $FS_g > 0.7$

  Assuming a necessary flood fight to prevent a breach is tantamount to failure, $i = i_f$

  $\rightarrow (i_{cr}/i_f) = FS_g = 0.7$

Reference:
Rock Island District Levee Practices, MRKED-F Memorandum for Branch File, 25 October 1962.

CASE 3: Kansas City District, Back Calculation from 1952 Flood

Computed FS_g at flood crest	**Seepage Conditions during flood crest**
< 0.55	Objectionable seepage, major flood fight, boils requiring sandbagging
> 0.8	Tolerable Seepage, distributed seepage, pin boils

$$\rightarrow (i_{cr}/i_f) = (.55/.8) = 0.6875 \cong 0.7$$

Reference:

Meeting at MRD on Underseepage Control on Agricultural Levees, 27 November 1962.

CASE 4: St. Louis District, Back Calculation from 1993 Flood

Bois Brule & Kaskaskia Island levee failures

- Both failures were due to underseepage and resulted in an actual breach of the levee.
- Back calculated gradient = 1.35
- Assume $i_{cr} \cong 0.85$

$$\rightarrow (i_{cr}/i_f) = (.85/1.35) = 0.63$$

Reference:
Communication with Mr. Edward Demsky, CEMVS, 19 July 2004

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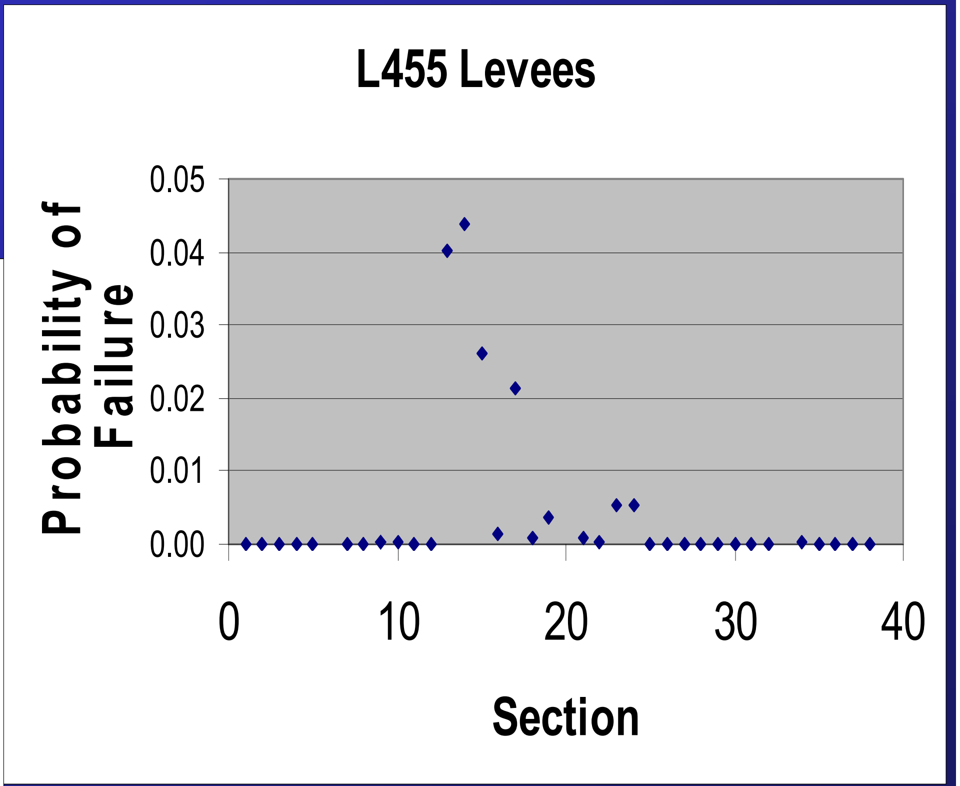
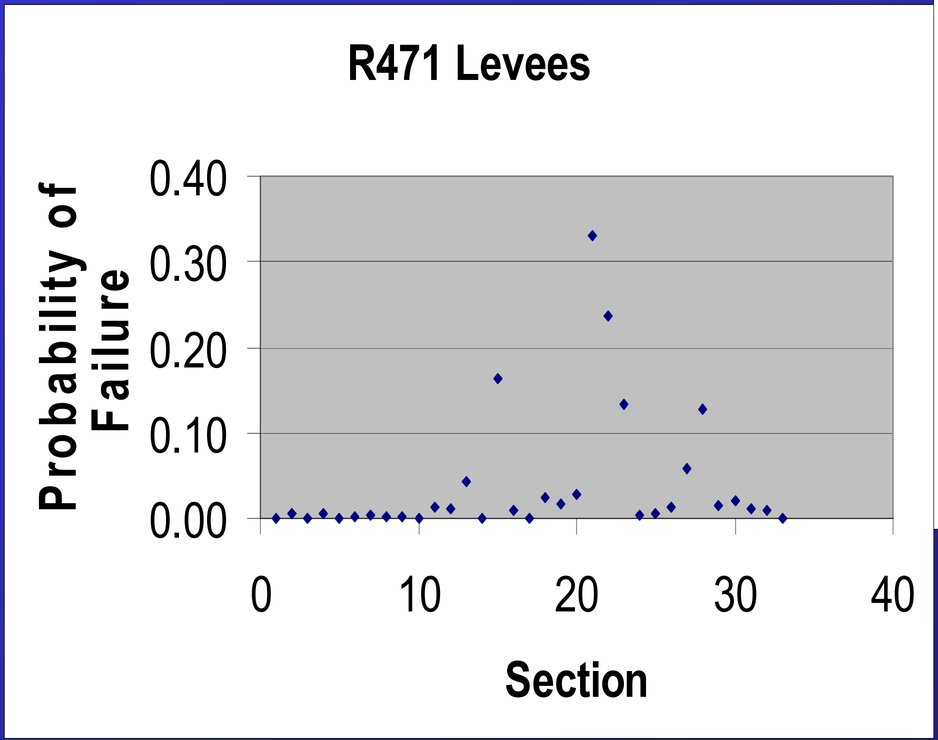
CASE 5: 1993 Flood Calibrations for Existing Projects





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Unsatisfactory Performance at the Critical Gradient

$$FS_g = i_{cr}/i$$

Capacity (C) = i_{cr} = critical gradient

Demand (D) = i = calculated gradient

Normally distributed, uncorrelated:

$$\beta = \frac{E(C) - E(D)}{\sqrt{\sigma_C^{\,2} + \sigma_D^{\,2}}}$$

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Unsatisfactory Performance at Impending Failure

$$FS = i_f / i$$

Surcharge Factor = $(i_{cr}/i_f) \cong 0.7$

Capacity (C) = $i_f = i_{cr}/(i_{cr}/i_f)$ = "failure" gradient

Demand (D) = i = calculated gradient (extrapolated)

Normally distributed, uncorrelated:

$$\beta = \frac{E(C) - E(D)}{\sqrt{\sigma_C^{\ 2} + \sigma_D^{\ 2}}}$$

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Recommendations

- Rational methods are necessary for deriving the Limit State from design criteria
- A consistent methodology should be adopted
- Impending Levee Breaches Occur near a Surcharge Factor of $(i_{cr}/i_f) = 0.7$

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Design Criteria Concerns

- Deterioration of Levee from Past Seepage Distress
- Flood Fight Capability
- Managing Risk & Consequences (Urban/Rural/Agricultural)
- Affect on B/C ratio

From executive summary, "*Risk Analysis and Uncertainty in Flood Damage Reduction Studies*", National Academy Press, (2000).

"The committee recommends that the Corps undertake statistical ex post studies to compare predictions of geotechnical levee failure probabilities made by the reliability model against frequencies of actual levee failures during floods."

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~~Questions~~

Comments

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