# A UNIFIED METHOD FOR ESTIMATING PROBABILITIES OF FAILURE OF EMBANKMENT DAMS BY INTERNAL EROSION AND PIPING

BY

JOHN CYGANIEWICZ

Reference:
Loren R. Anderson. 2554. เอกสารประกอบการอบรม "การวิเคราะห์เพื่อออกแบบและประเมินความปลอดภัยเขื่อน", ระหว่างวันที่ 5,7 และ 8 เมษายน 2554, จัดโดย ศูนย์วิจัยและพัฒนาวิศวกรรมปฐพีและฐานราก มหาวิทยาลัยเกษตรศาสตร์ ร่วมกับ Thai Geotechnical Society (TGS), ณ โรงแรมมิราเคิล แกรนด์ คอนเวนชั่น, กรุงเทพฯ.

# Risk Analysis for Dam Safety

## A Unified Method for Estimating Probabilities of Failure of Embankment Dams by Internal Erosion and Piping

## Guidance Document

**Version: Delta, Issue 2**

**August 2008**

| | |
|---|---|
| **Reclamation Document:** | **Risk Analysis Methodology – Appendix E** |
| **Corps of Engineers Document:** | **UFC** |
| **URS Document:** | **22238839** |
| **UNSW Document:** | **UNICIV R 446** |

U.S. DEPARTMENT OF THE INTERIOR
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# Risk Analysis for Dam Safety

## A Unified Method for Estimating Probabilities of Failure of Embankment Dams by Internal Erosion and Piping Supporting Information Report

**Version: Beta**
**July 2007**

| | |
|---|---|
| **Reclamation Document:** | **Risk Analysis Methodology – Appendix E** |
| **Corps of Engineers Document:** | **UFC XXX XXX** |
| **URS Document:** | **22238839** |
| **UNSW Document:** | **UNICIV R 446,** |

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# HISTORY

1998 to Present

# Key Members

Robin Fell

Mark Foster

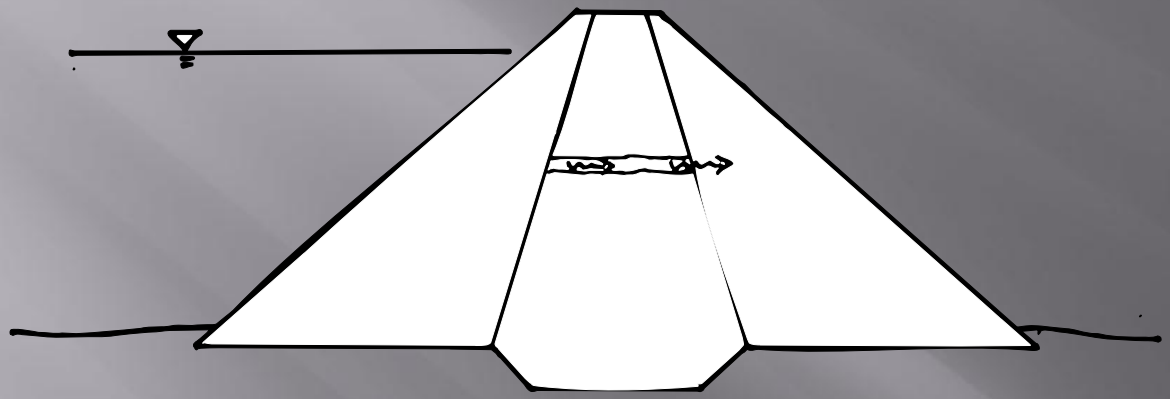
Dick Davidson

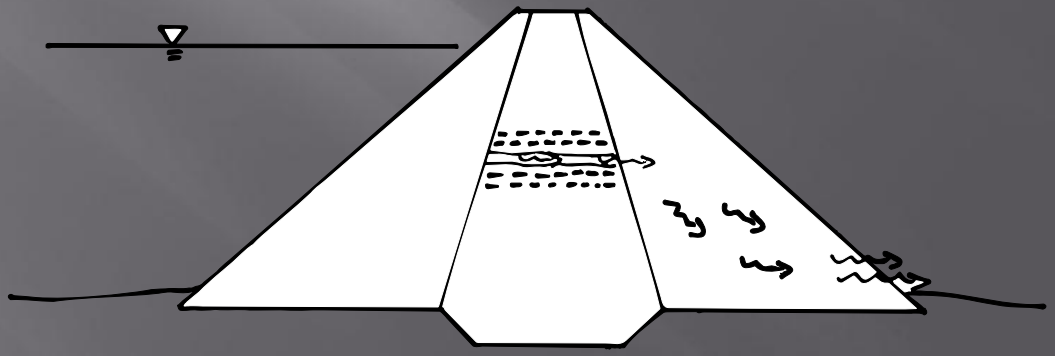
John Cyganiewicz

George Sills

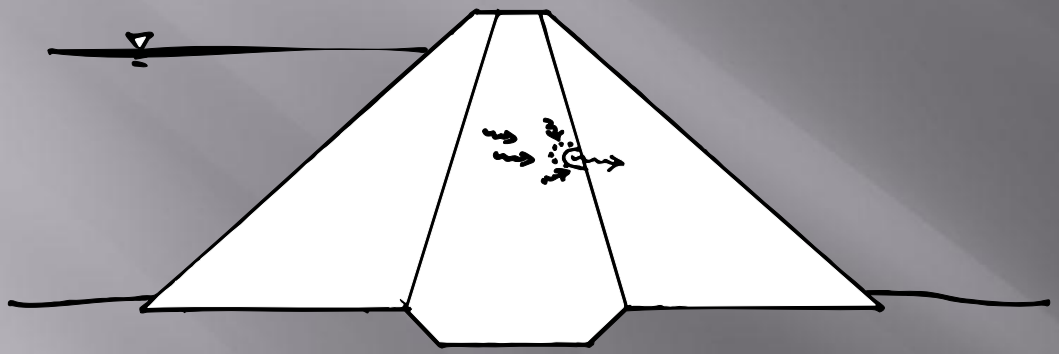
Noah Vroman

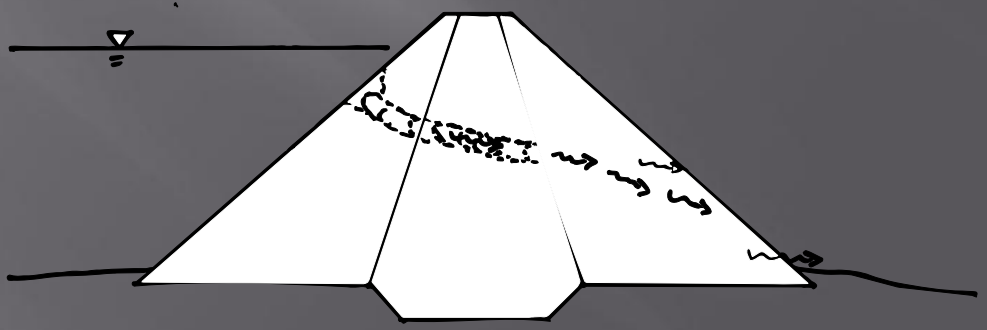
# Concentrated Leak Piping



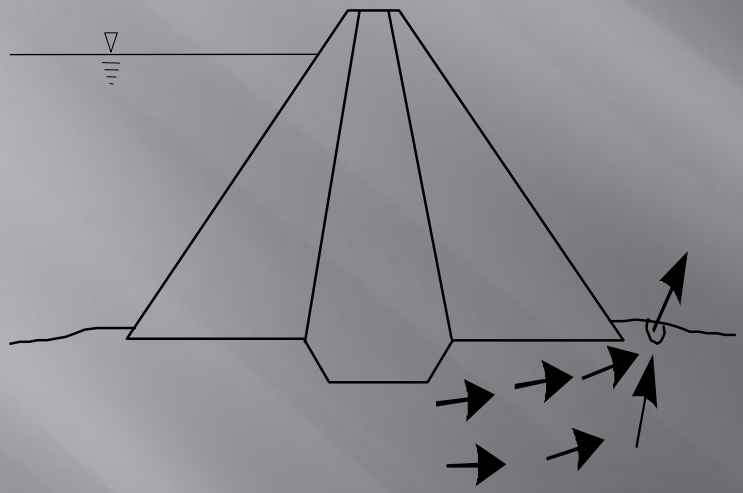


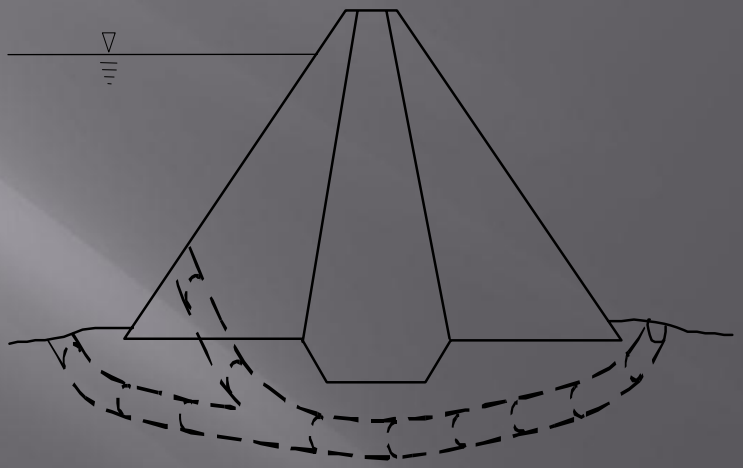
# Backward Erosion Piping



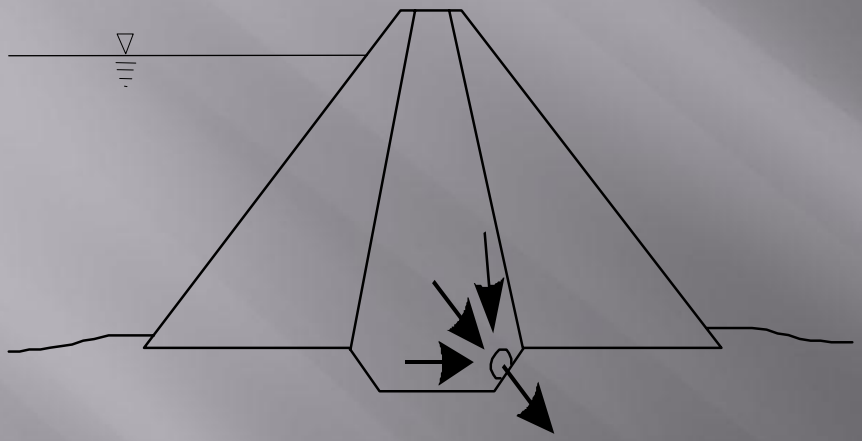


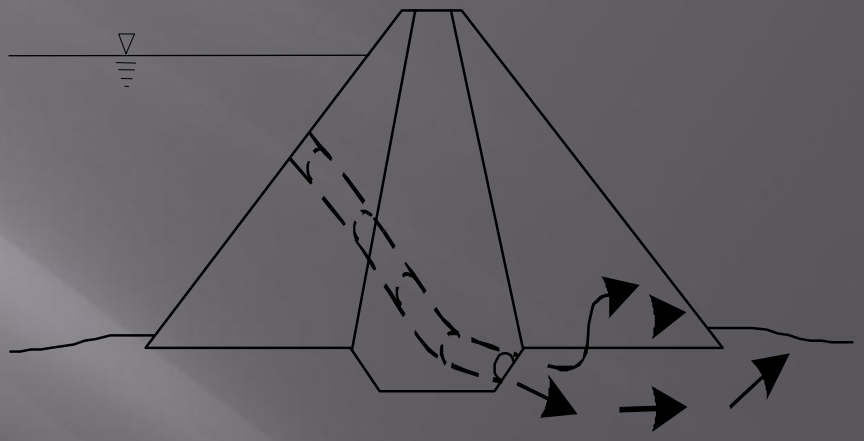
# Foundation





# Embankment to Foundation



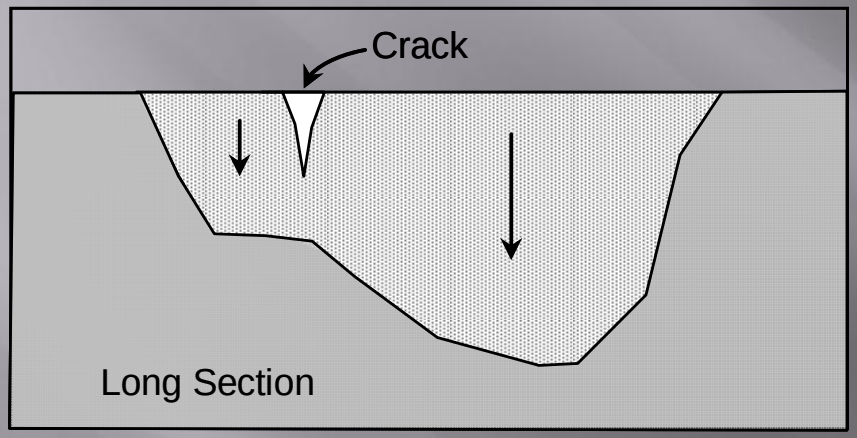


- Reservoir Rises
  - Initiation – Flaw exists[1]
    - Initiation – Erosion starts
      - Continuation– Unfiltered exit exists (consider: no erosion/some erosion/excessive erosion/continuing erosion)
        - Progression – Roof forms to support a pipe
          - Progression – Upstream zone fails to fill crack
            - Progression – Upstream zone fails to limit flows
              - Intervention fails
                - Dam breaches (consider all likely breach mechanisms)
                  - Consequences occur

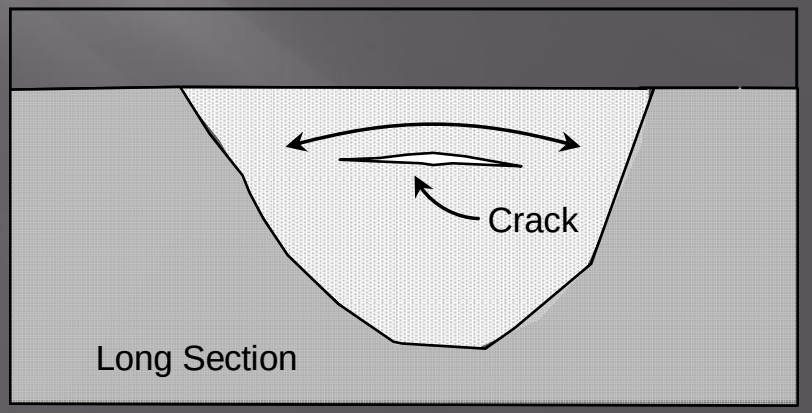
(1) For Backward Erosion Piping failure modes, no flaw is required. In the case of BEP, initiation assesses the soil type, gradient and heave potential.

# Initiation

Cross Valley Differential Settlement

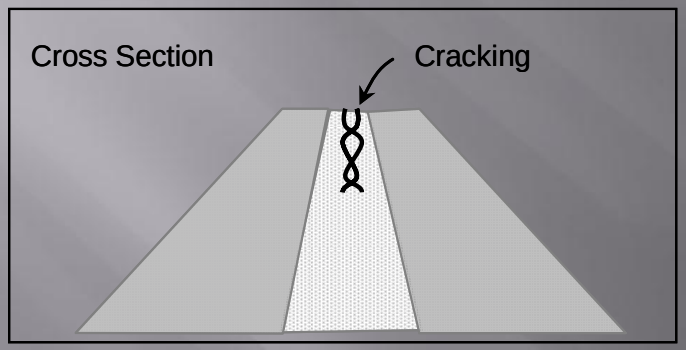



**Cross Valley Arching**

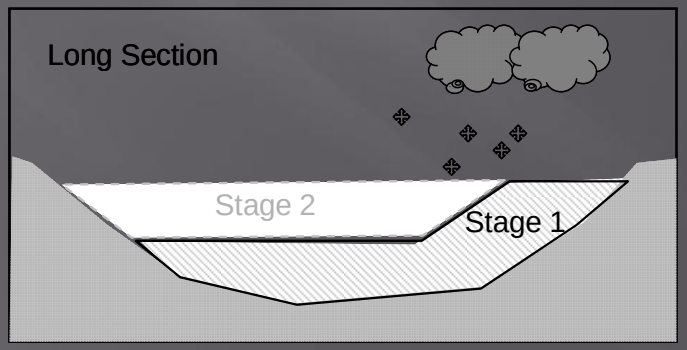


# Initiation

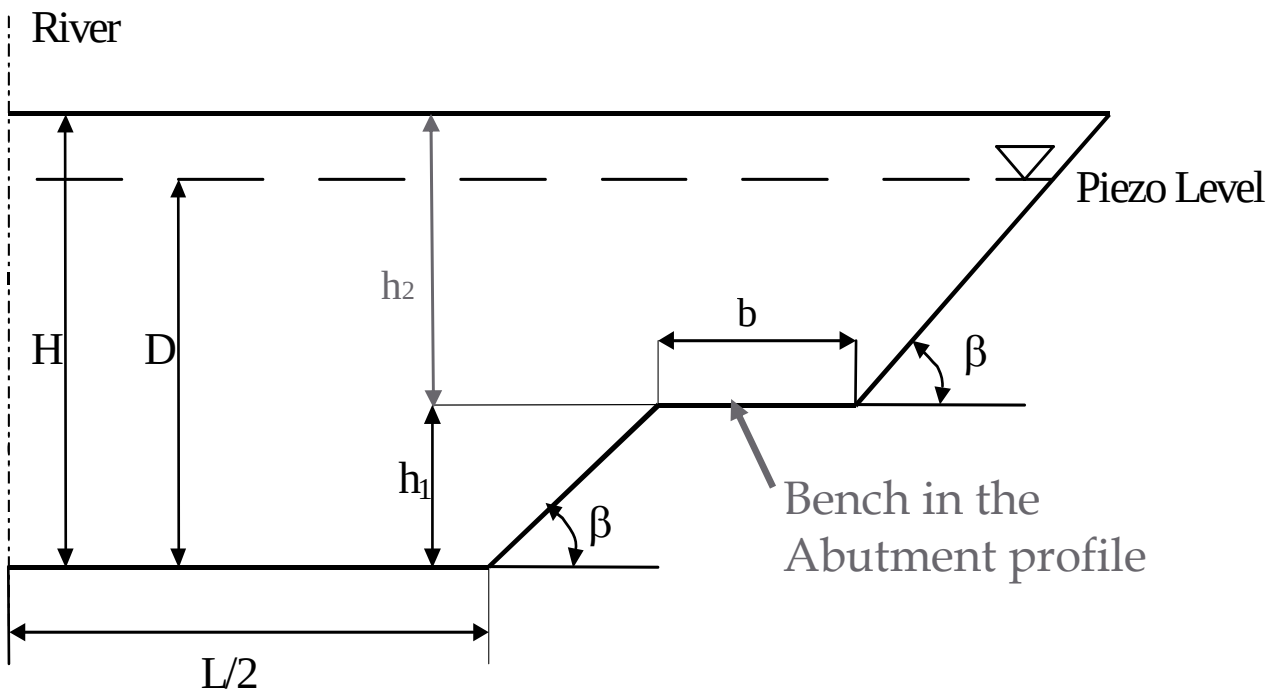
**Cracking in the crest due to desiccation by drying.**




**Seasonal shutdown layers during construction and staged construction surfaces due to freezing.**



# Cracking and hydraulic fracture due to cross valley differential settlement




## Factors influencing the likelihood of cracking

- Slope of the abutment
- b/h2
- h2/h1
- Height of the embankment

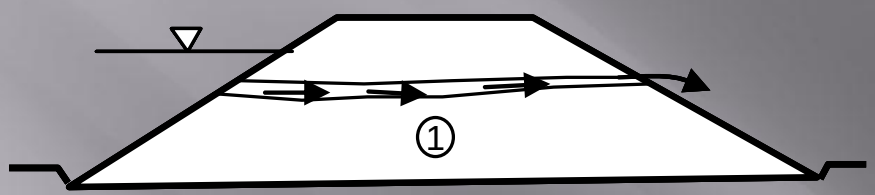
# Continuation – Unfiltered Exit

Foster and Fell

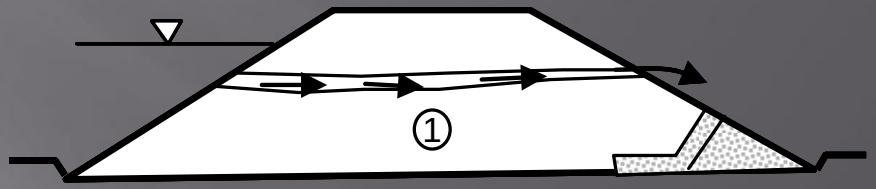
- No Erosion
- Some Erosion
- Excessive Erosion
- Continuing Erosion

# Continuation

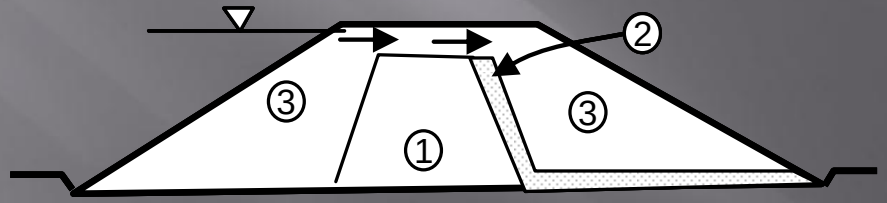
**Scenario 1: Homogeneous zoning with no fully intercepting filter**




HOMOGENEOUS EARTHFILL




EARTHFILL WITH TOE DRAIN,
INTERNAL EROSION ABOVE TOE DRAIN

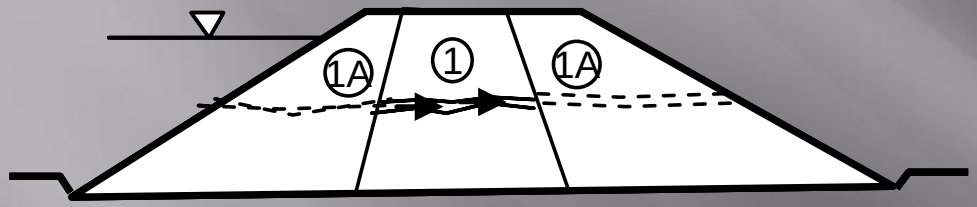



INTERNAL EROSION ABOVE CORE AND FILTERS

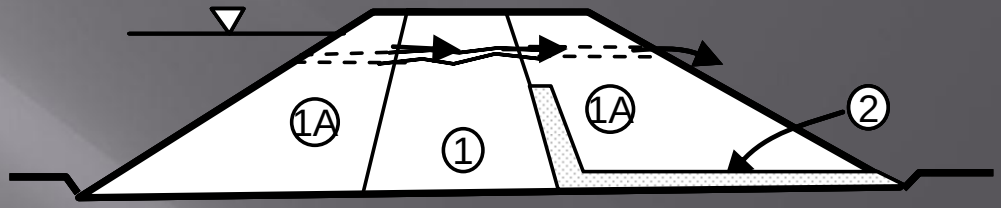
**Probability of Continuing Erosion = 1.0**

# Continuation

**Scenario 2: Downstream shell of cohesive material which is capable of holding a crack/pipe**



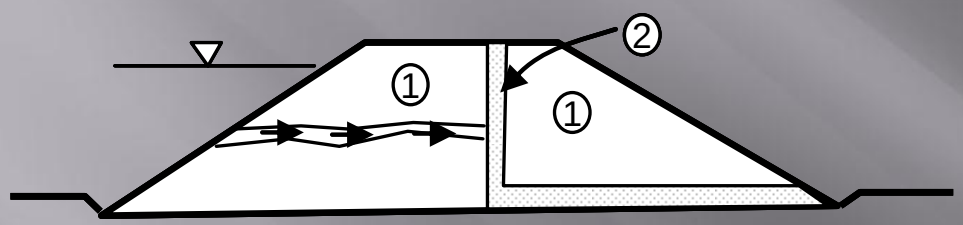

ZONED EARTHFILL WITH COHESIVE SHELLS



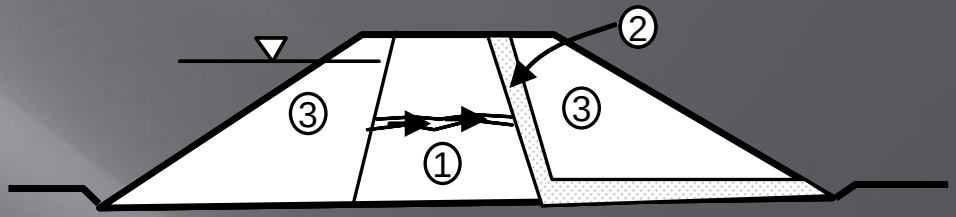

INTERNAL EROSION ABOVE FILTER ZONE, COHESIVE DOWNSTREAM SHELL

# Continuation

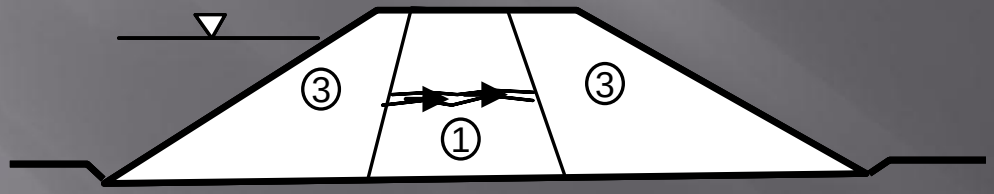
**Scenario 3: Filter/transition zone is present which is not capable of holding a crack/pipe**




EARTHFILL WITH CHIMNEY FILTER

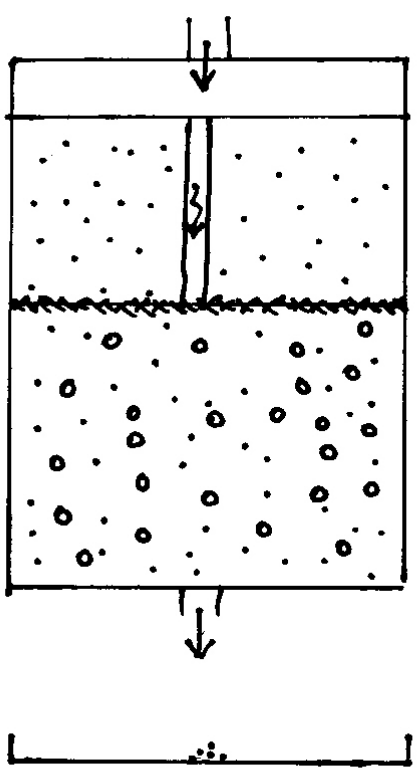



ZONED EARTHFILL WITH CHIMNEY FILTER

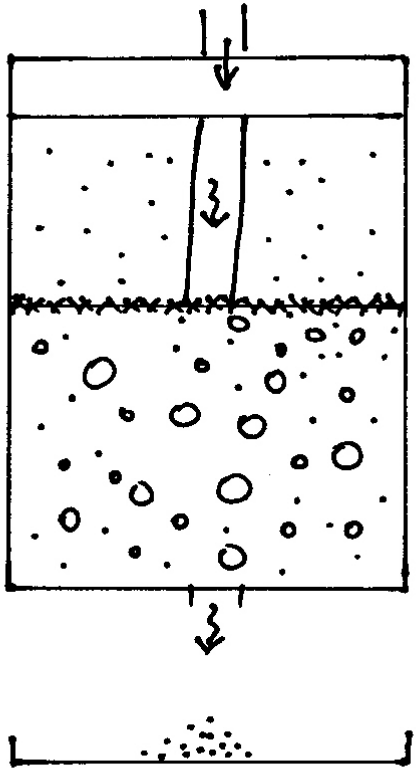



ZONED EARTHFILL WITH GRANULAR SHELLS

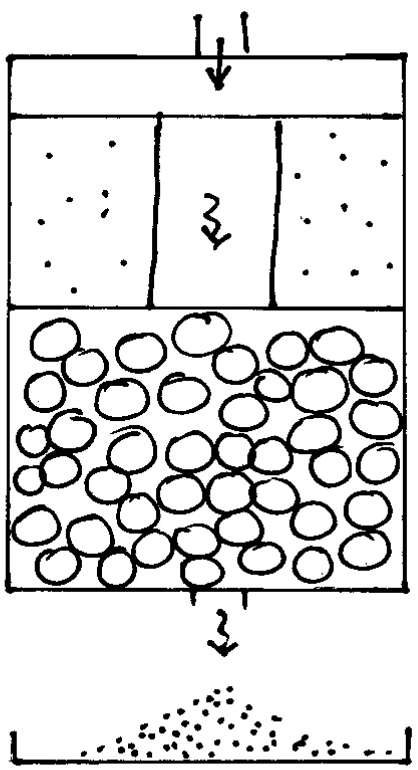
# Continuation – Filter Concepts



NO EROSION

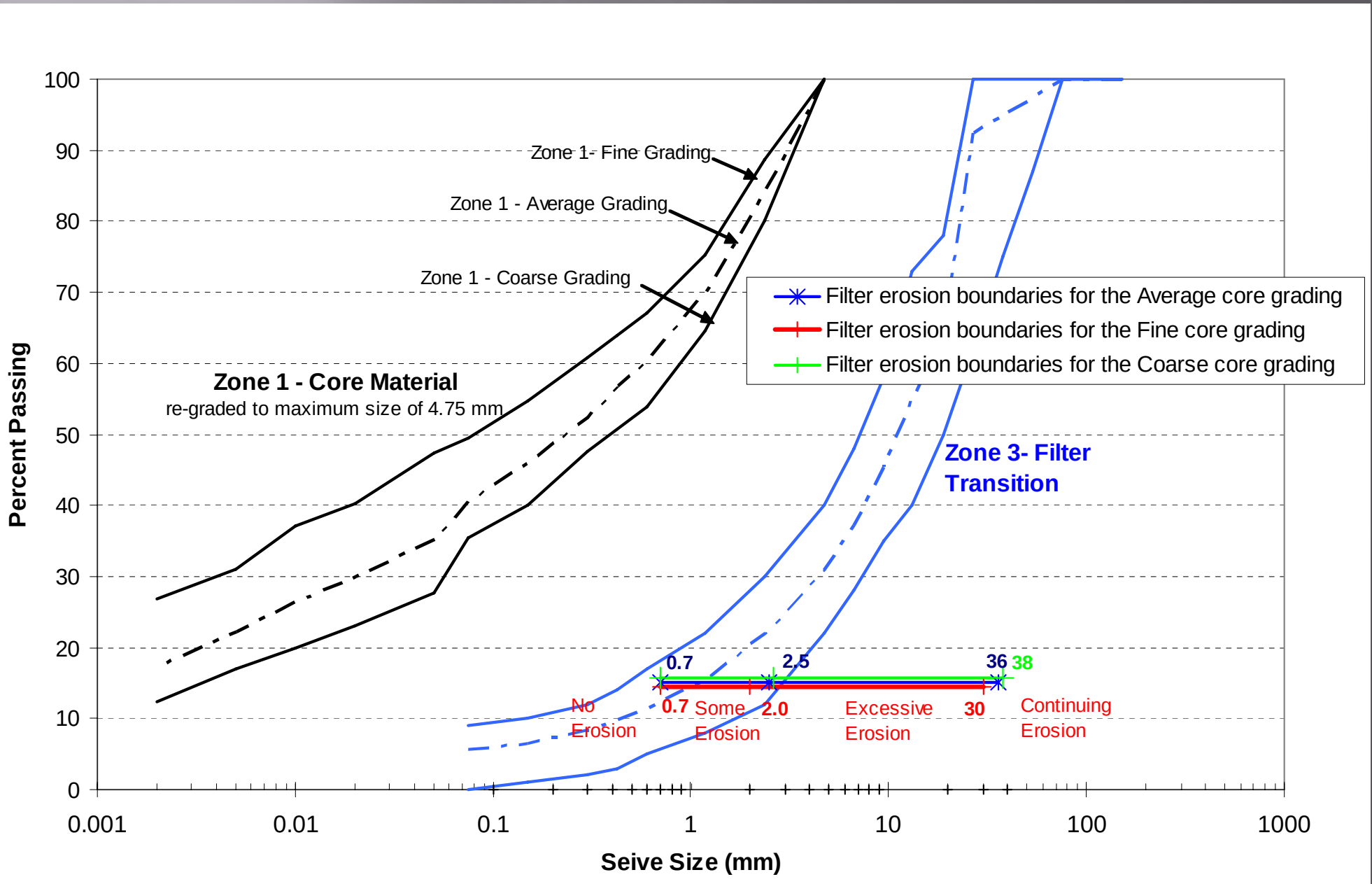


SOME OR EXCESSIVE EROSION



CONTINUIN G EROSION

# Continuation – Estimating Probabilities



# Intervention Fails

- Reservoir Rises
  - Initiation – Flaw exists[(1)]
    - Initiation – Erosion starts
      - Continuation– Unfiltered exit exists (consider: no erosion/some erosion/excessive erosion/continuing erosion)
        - Progression – Roof forms to support a pipe
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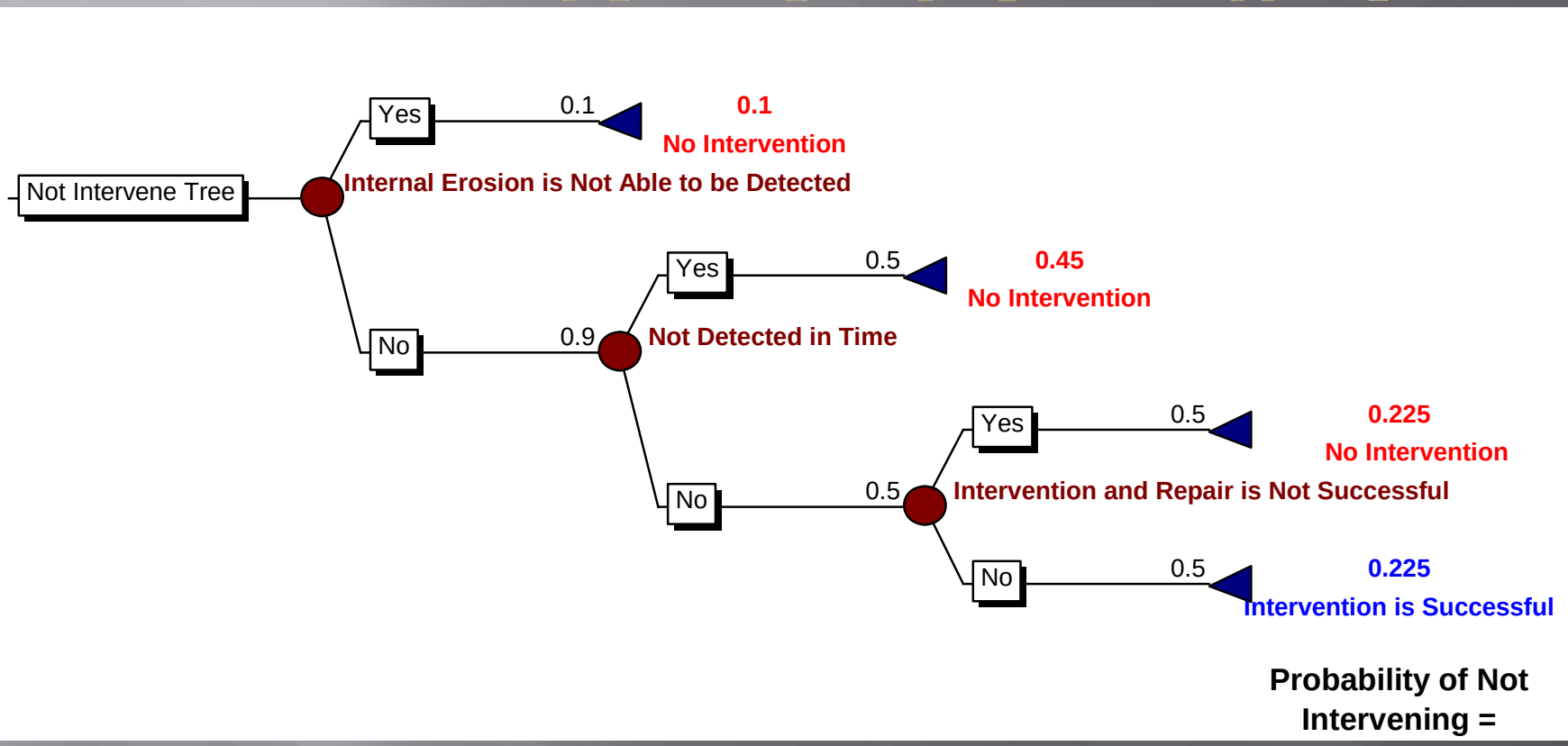
                - Dam breaches (consider all likely breach mechanisms)
                  - Consequences occur

# Intervention Fails




| Probability of Not Intervening |
|---|
| 0.1 |
| 0.45 |
| 0.225 |
| 0.775 |

**Probability of Not Intervening =**

- Sub Event Tree

# Breach

- Reservoir Rises
  - Initiation – Flaw exists[(1)]
    - Initiation – Erosion starts
      - Continuation– Unfiltered exit exists (consider: no erosion/some erosion/excessive erosion/continuing erosion)
        - Progression – Roof forms to support a pipe
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            - Progression – Upstream zone fails to limit flows
              - Intervention fails
                - Dam breaches (consider all likely breach mechanisms)
                  - Consequences occur

# THE END