Dispersive Clays – Experience and History of the NRCS (Formerly SCS)

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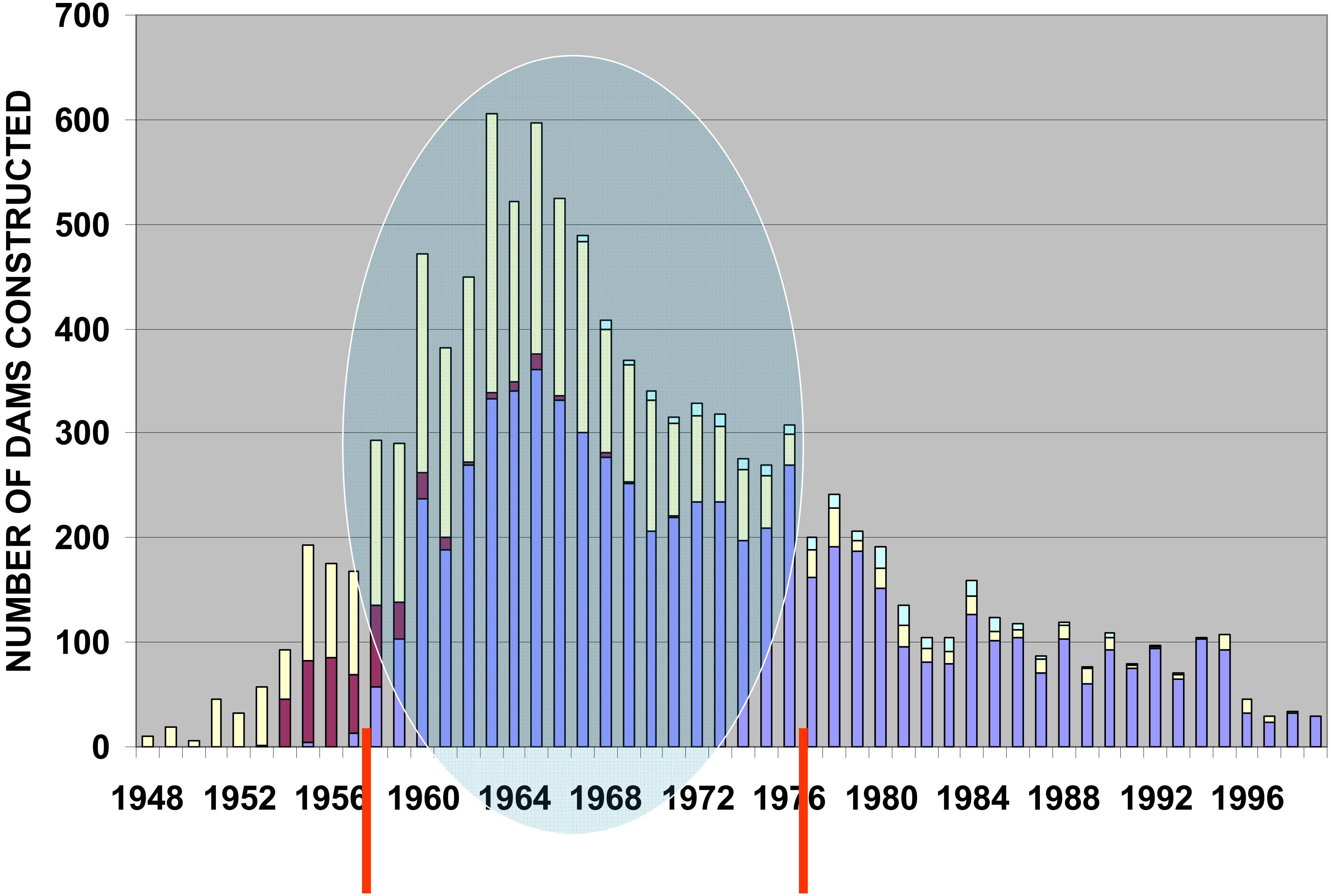
Outline

- NRCS Embankment Construction History
- Problems with Dispersive Clays
- Tests Developed
- Defensive Design/Remedial Treatment

Embankment Construction History of NRCS

- 11,000 + dams constructed between 1949 and present
- Average dam height 25-60 feet
- Majority are single-purpose flood control
- Significant number of high hazard, multi-purpose dams included

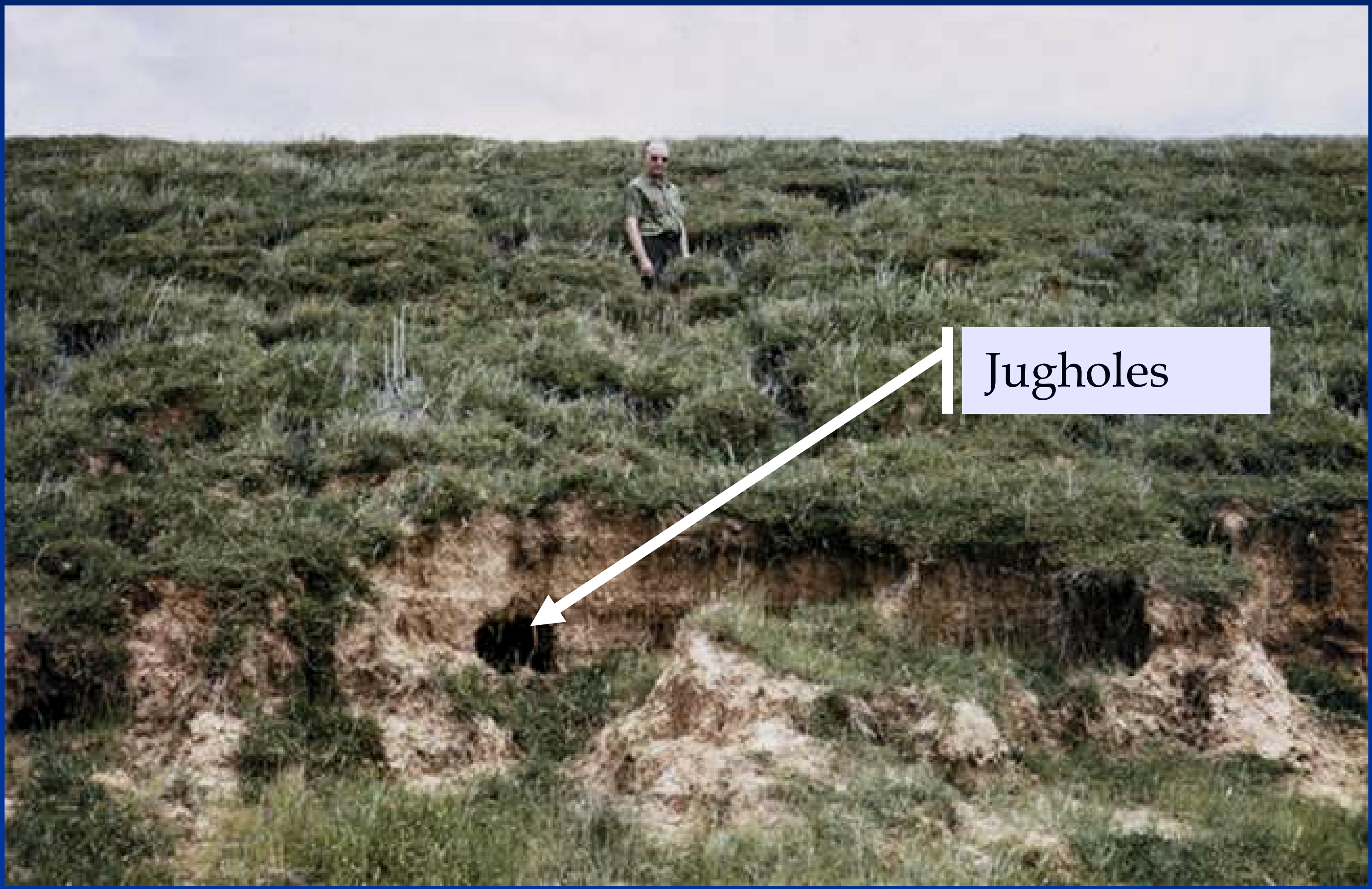

NUMBER OF DAMS CONSTRUCTED
700
600
500
400
300
200
100
0
1948
1952
1956
1960
1964
1968
1972
1976
1980
1984
1988
1992
1996

Typical Dam

Engineering Problems with Dispersive Clays

- Erosion of external slopes - embankments and channel slopes
  - Jugging
  - Rilling

Surface Erosion and Jugging



Surface Erosion and Jugging

Engineering Problems with Dispersive Clays

- Internal erosion of fills through cracks
  - Catastrophic failures
  - Usually occur during first filling
  - Hydraulic fracturing contribution

Owl Creek 13, OK

- No eyewitness
- Failure tunnel along right side of conduit
- Failure tunnel about 18 feet in diameter with bottom near bottom of conduit

Example Failures – Owl Creek, Site 13

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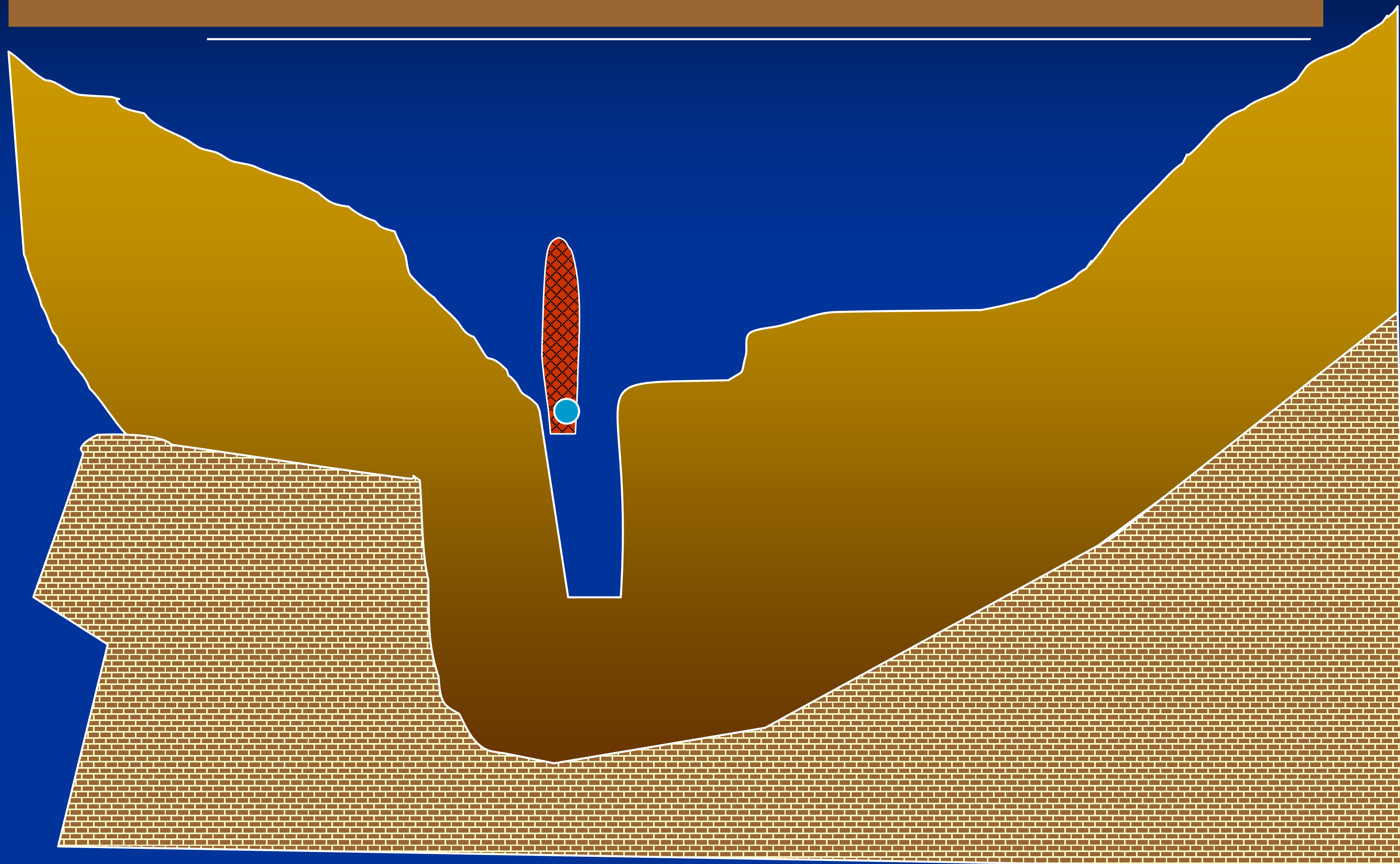
Natural Resources Conservation Service

Example Failures – Owl Creek, Site 13



Owl Creek 13 Causes of Failure

- Embankment compacted dry of optimum
- Highly dispersive clays
- Conduit installed on highly compacted trench backfill
- Near sharp bedrock profile under dam

Upper Red Rock Site 20, Oklahoma

- Failure on Second First Filling
- Site Built in 1973
- Impounded pool of water until 1986 with no problems
- Unprecedented pool level reached that was 4 feet below dam crest
- Failure tunnel 40 feet to side of conduit


Note water flowing from other smaller flow concentration

Upper Red Rock, Site 20, OK – Causes of Failure

- Lack of bonding of lifts in embankment – discing not required
- Embankment highly compacted – imprints of sheepsfoot obvious in exposed lifts
- Highly dispersive clays

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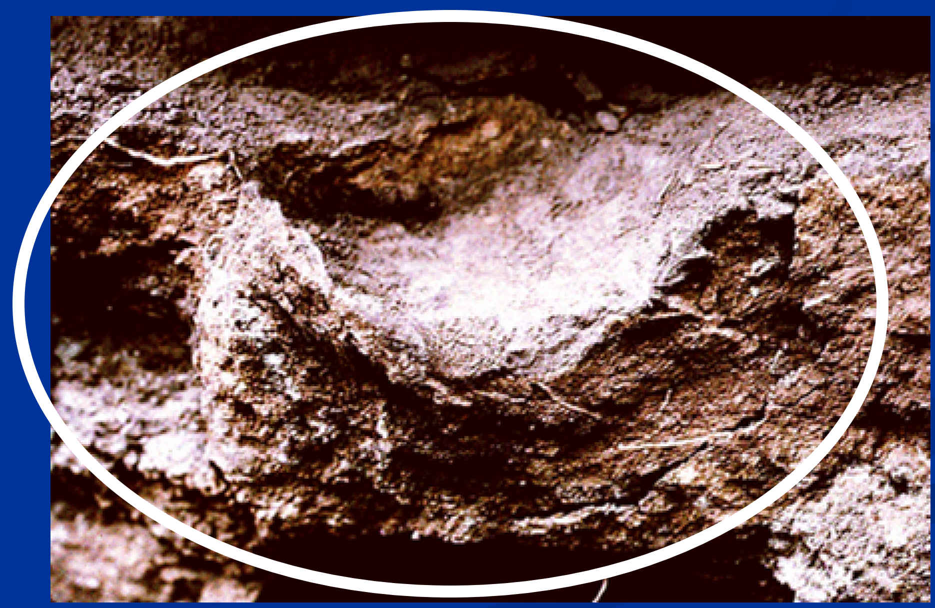
- Embankment highly compacted – imprints of sheepsfoot obvious in exposed lifts



Common Factors in Failures

- Ten of 11 OK dams failed on first filling, usually shortly after construction during a large rainfall event that filled reservoir rapidly
- Failures begin with an initial leak that gradually eroded a tunnel. If the tunnel became large enough, the roof collapsed forming a breach

Conditions Common in Problems/Failures

- Excavations made to install conduits (transverse to the embankment) with too steep side slopes
- Variable foundation materials and thicknesses of materials along alignment of embankment

Conditions Common in Problems/Failures

- Difficulty in compacting under haunches of circular conduits.
- Interruptions in fill placement and lack of bonding of lifts
- Dispersive clays –almost universal factor

Conditions Common in Problems/Failures

- Embankments constructed at overly high density and low water contents (brittle fill)
- Absence of chimney filter or filter diaphragm in design – no failures since inception of filter diaphragms in mid 1980's
- Differential settlement associated with conduit

Other observations

- Hundreds of dams built of similar soils and the same quality of construction did not fail
- Speed of filling and conditions conducive to hydraulic fracturing are thought to have been less severe at the non-failed dams.
- Differential settlement is thought to be a prime contributor to hydraulic fracturing

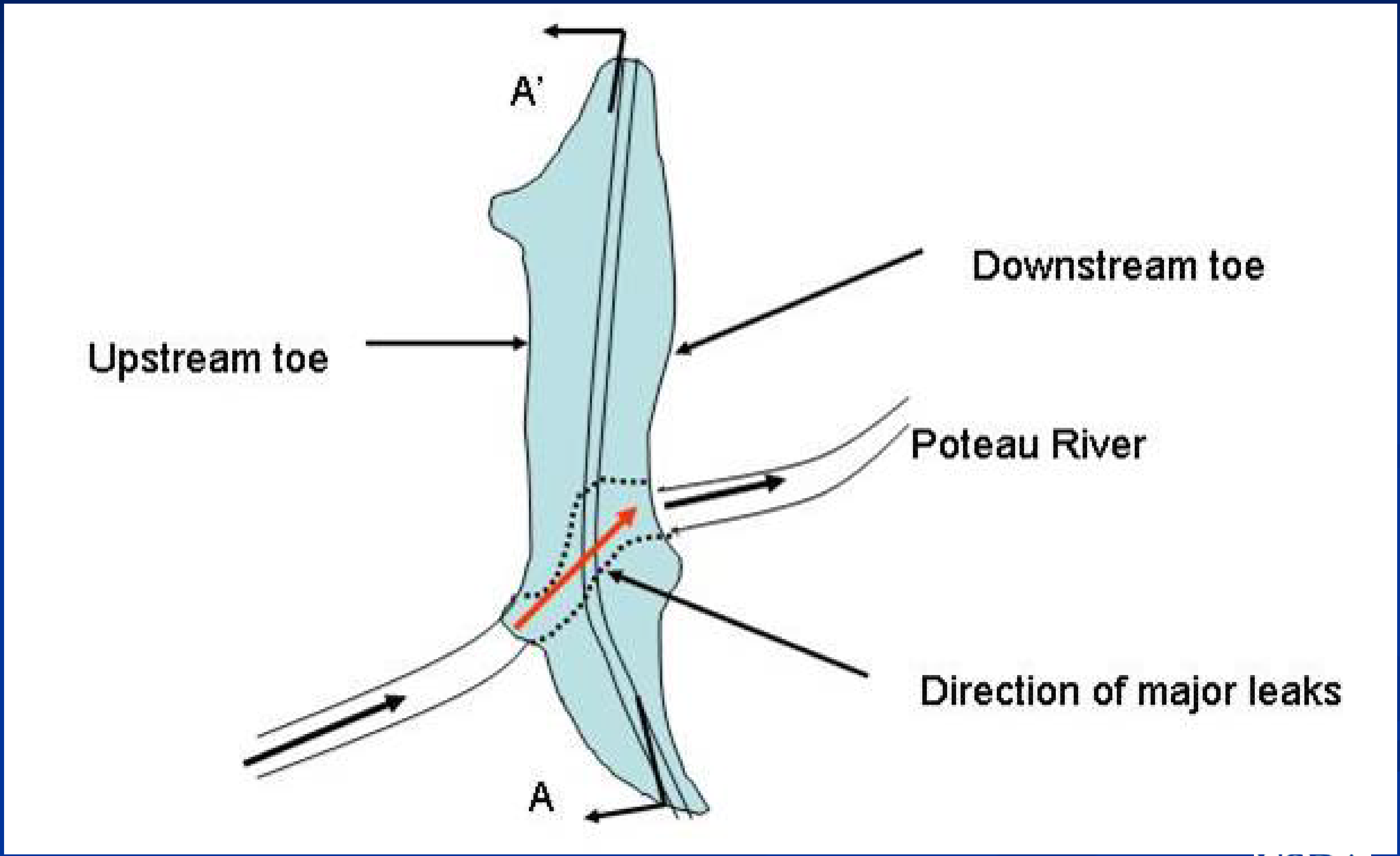
USACE Wister Dam

- Constructed in 1949
- Concentrated muddy leaks and sinkholes occurred on first filling
- Failure narrowly averted by drawing down reservoir
- Reported by Casagrande in 1950 Boston Society of Civil Engineers article

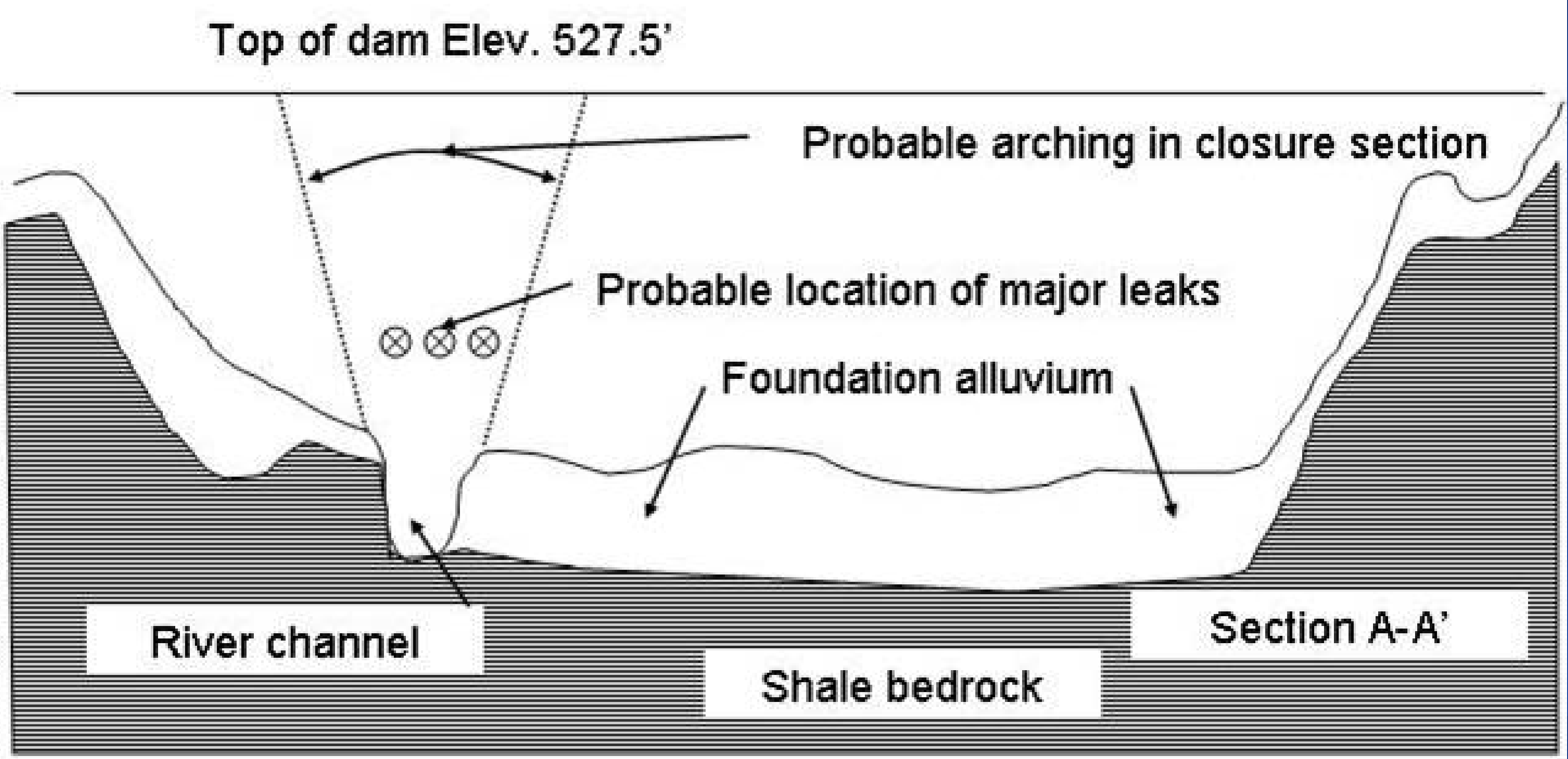
Wister Dam

- Extensive remediation in early 1990’s

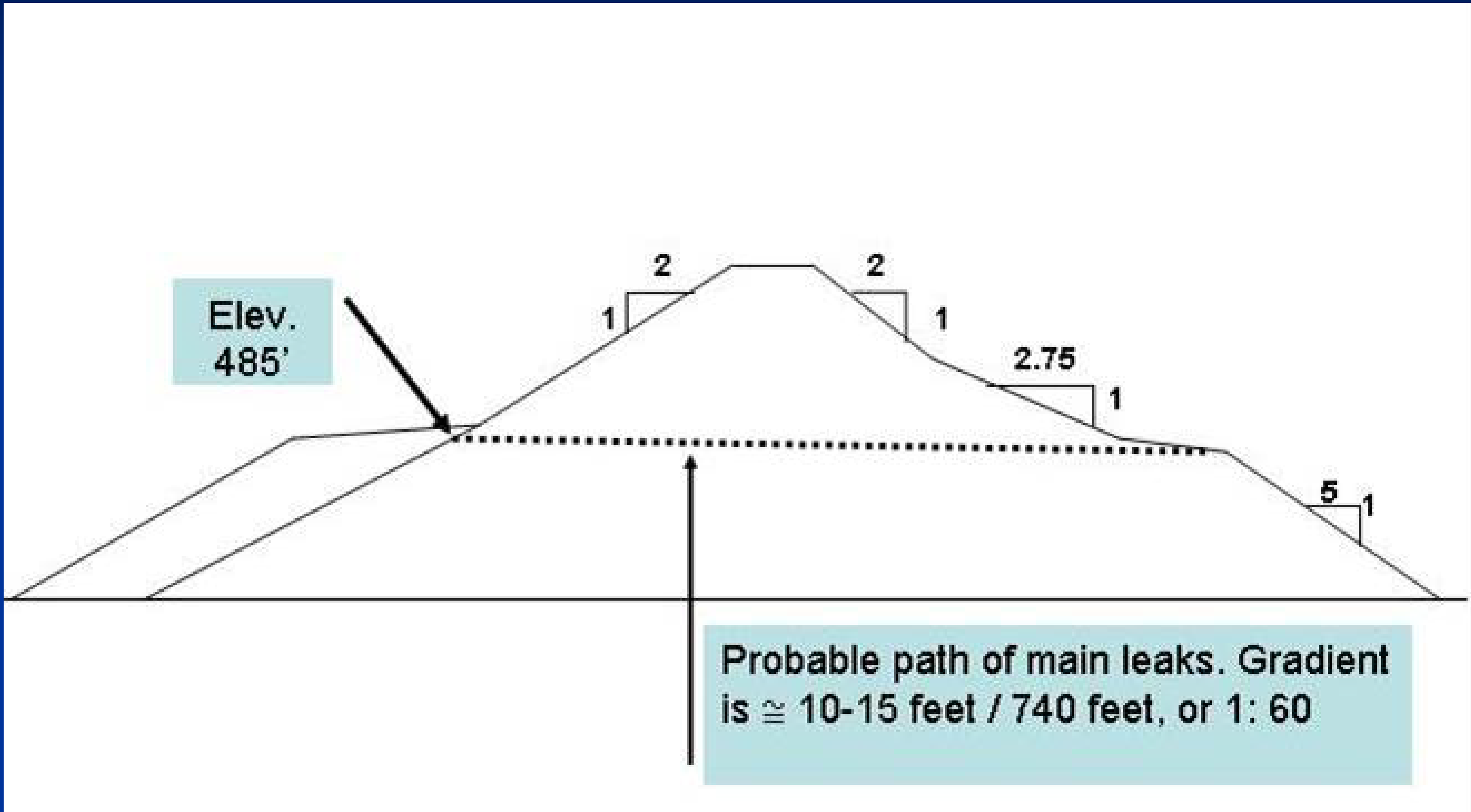
Closure Section at Wister Dam, Oklahoma



Closure Section at Wister Dam, Oklahoma



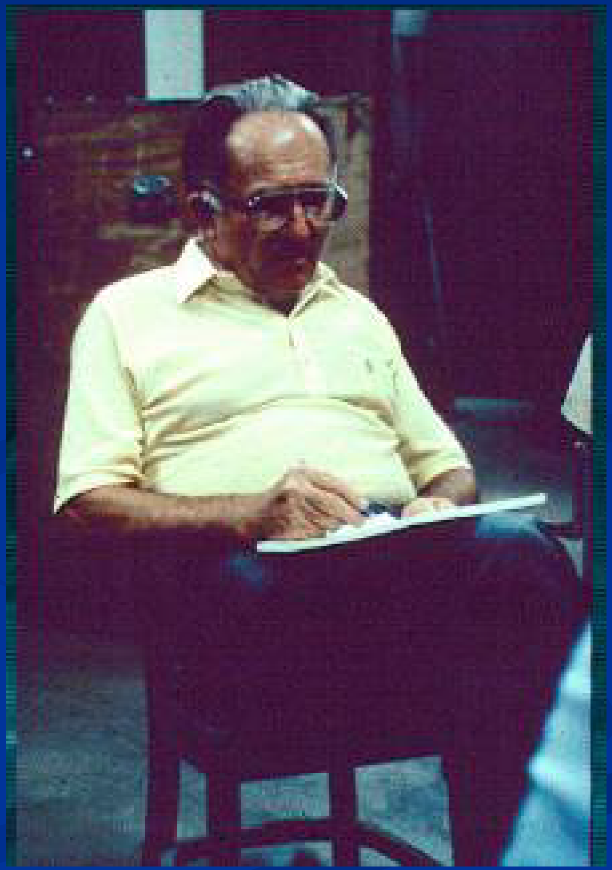
Closure Section at Wister Dam, Oklahoma



SCS and Dr. James Sherard

Dr. Sherard cooperated with then SCS in extensive research into the basic nature of dispersive clays and in filter research.

His studies expanded to include sites such as the USACE Wister dam in Eastern Oklahoma and many others.



References

- June, 1972, – ASCE Specialty Conference, Performance of Earth and Earth-Supported Structures, Purdue, IN "Piping in Earth Dams of Dispersive Clay", Sherard, Decker and Ryker

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- June, 1972, – ASCE Specialty Conference, Performance of Earth and Earth-Supported Structures, Purdue, IN "Hydraulic Fracturing in Low Dams of Dispersive Clay", Sherard, Decker and Ryker

References

- April, 1976 – ASCE Geotechnical Journal, "Identification and Nature of Dispersive Soils" – Sherard, Dunnigan and Decker

References

- September, 1979 – ASCE Geotechnical Journal, "Dispersive Soil Problem at Los Esteros Dam" – Decker (retired SCS) and McDaniel

References

- ASTM Special Technical Publication 623 "Dispersive Clays, Related Piping and Erosion in Geotechnical Projects"
- May, 1977

References

- Waterways Experiment Station
  Technical Report GL-79-14
  "Dispersive Clay at Granada Dam …."
  – Ed Perry (retired WES)

Dispersive Clays

- Definition
  - Fine-grained CL, CH, MH, ML
  - Dispersive fines in Sands/Gravels
  - Sodium predominates pore-water chemistry

Dispersive Clays

- Origin of Dispersive Clays
  - Marine Shale Formations
  - Loess
  - Soils derived from metamorphic rocks, igneous rocks, and limestones are rarely dispersive

Dispersive Clays

- Sampling for Dispersion
  - Random, Discrete Samples Advisable
  - Moist Samples !
  - Numerous samples required for statistical inferences
  - Don’t composite!!

Tests for Dispersive Clays

- Normal tests do not identify dispersive clays – they have the same Atterberg limit and other characteristics as normal clays.
- Dispersive character results from chemical imbalance

Dispersive Clays

- Recognition
  - Outcrops - Extreme rilling/jugging
  - Sometimes mottled but color not helpful

Outcrops of Dispersive Clay

Outcrops of Dispersive Clay

Outcrops of Dispersive Clay

Dispersive Clays

- Field Tests
  - Crumb Test
  - Portable Pinhole
  - Field Turbidity Ratio

Dispersive Clays

- Laboratory Tests
  - Crumb
  - Double Hydrometer
  - Pinhole
  - Chemical Test on Pore Water Extract

Dispersive Clays

- Crumb Test – ASTM Method 6572
  - 1 - No reaction
  - 2 - Cloud immediately around clod
  - 3 - Cloud is appreciable distance from clod but does not cover bottom or meet on opposite side
  - 4 - Cloud spreads around bottom and may cover bottom

Dispersive Clays

- Crumb Test
  - 3 and 4 reactions very positive indicator of dispersive soil
  - Unfortunately, 1 and 2 reactions not always positive for lack of dispersive nature

Crumb Test 1

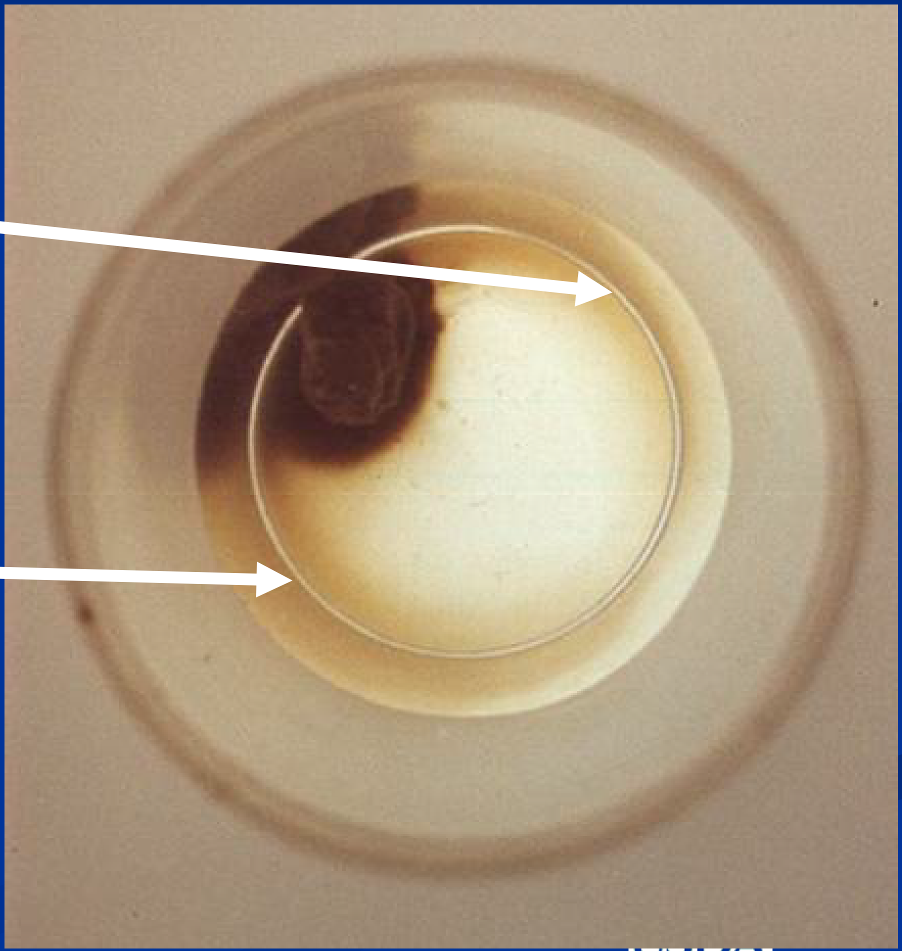
Water in glass remains clear - Ignore any slaking of clod - examine only for turbidity

Crumb Test 2

A hint of a cloud occurs very near the clod - it does not spread significantly away from the clod however

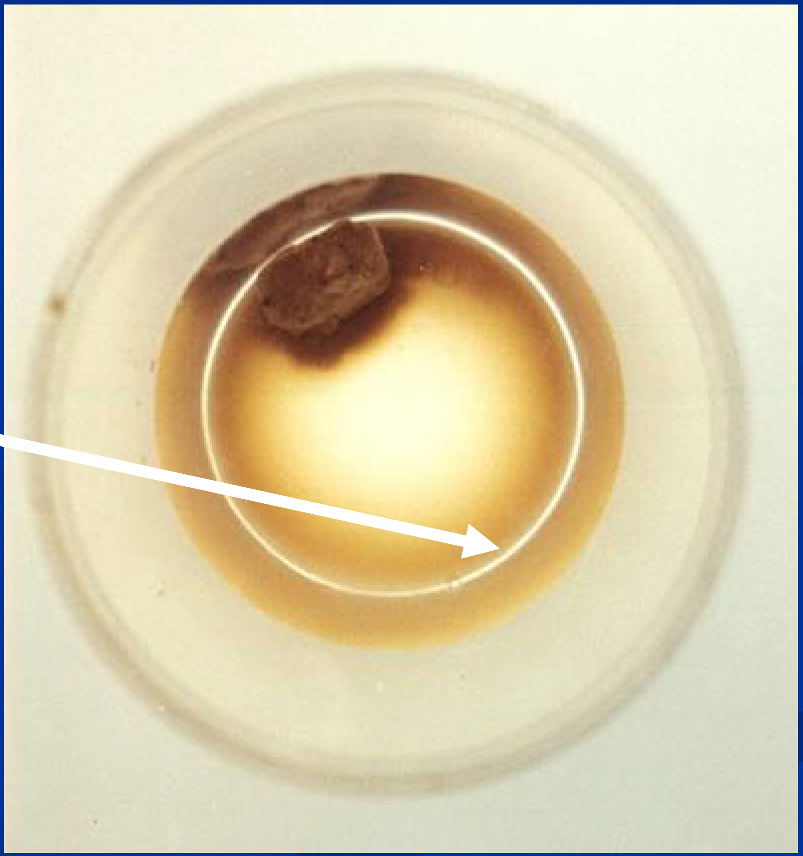
Crumb Test 3

A colloidal cloud spreads a considerable distance from the clod - it does not spread completely to meet at the opposite side of the glass



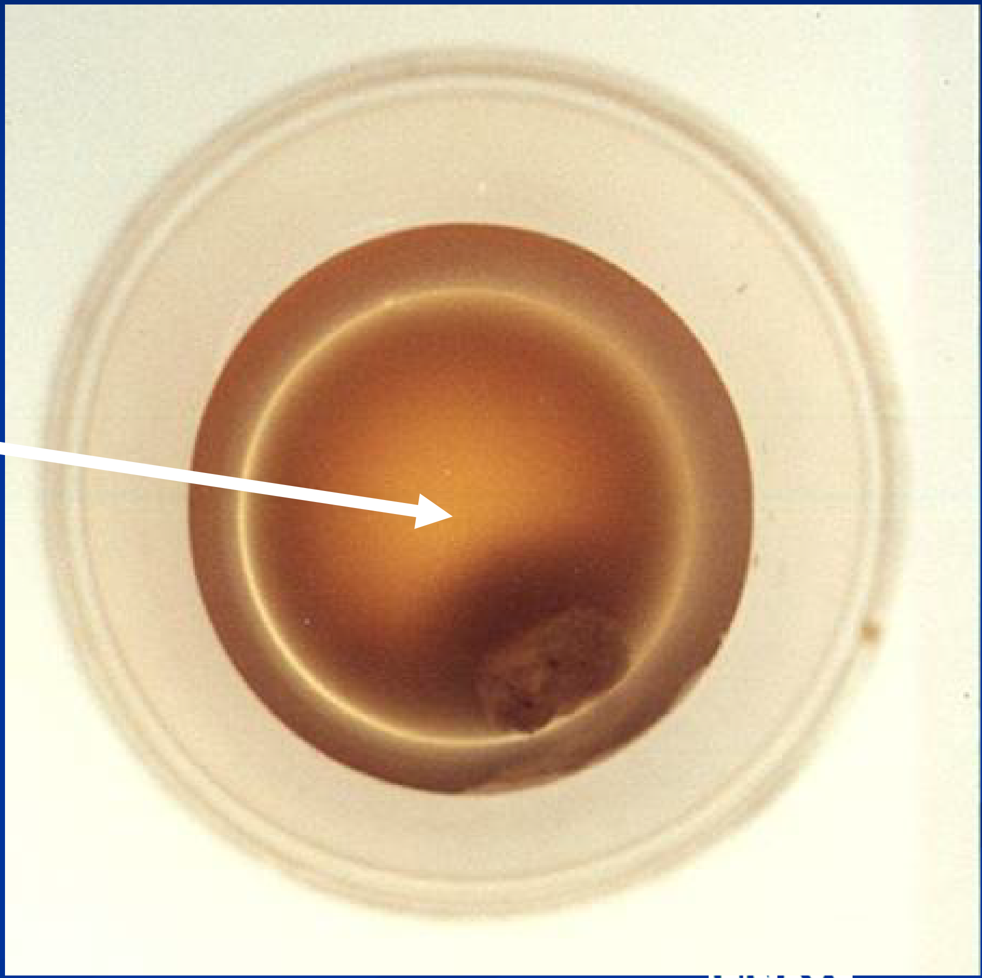
Crumb Test 4

A colloidal cloud spreads so that the cloud meets at the opposite side of the glass



Crumb Test 4 alternative

A colloidal cloud may be so extensive that the whole bottom of the glass is covered- obviously also a 4 reaction



Double Hydrometer Test

- ASTM Standard D4221
  - Compares 0.005 mm size of natural soil to that of chemically dispersed sample

Double Hydrometer

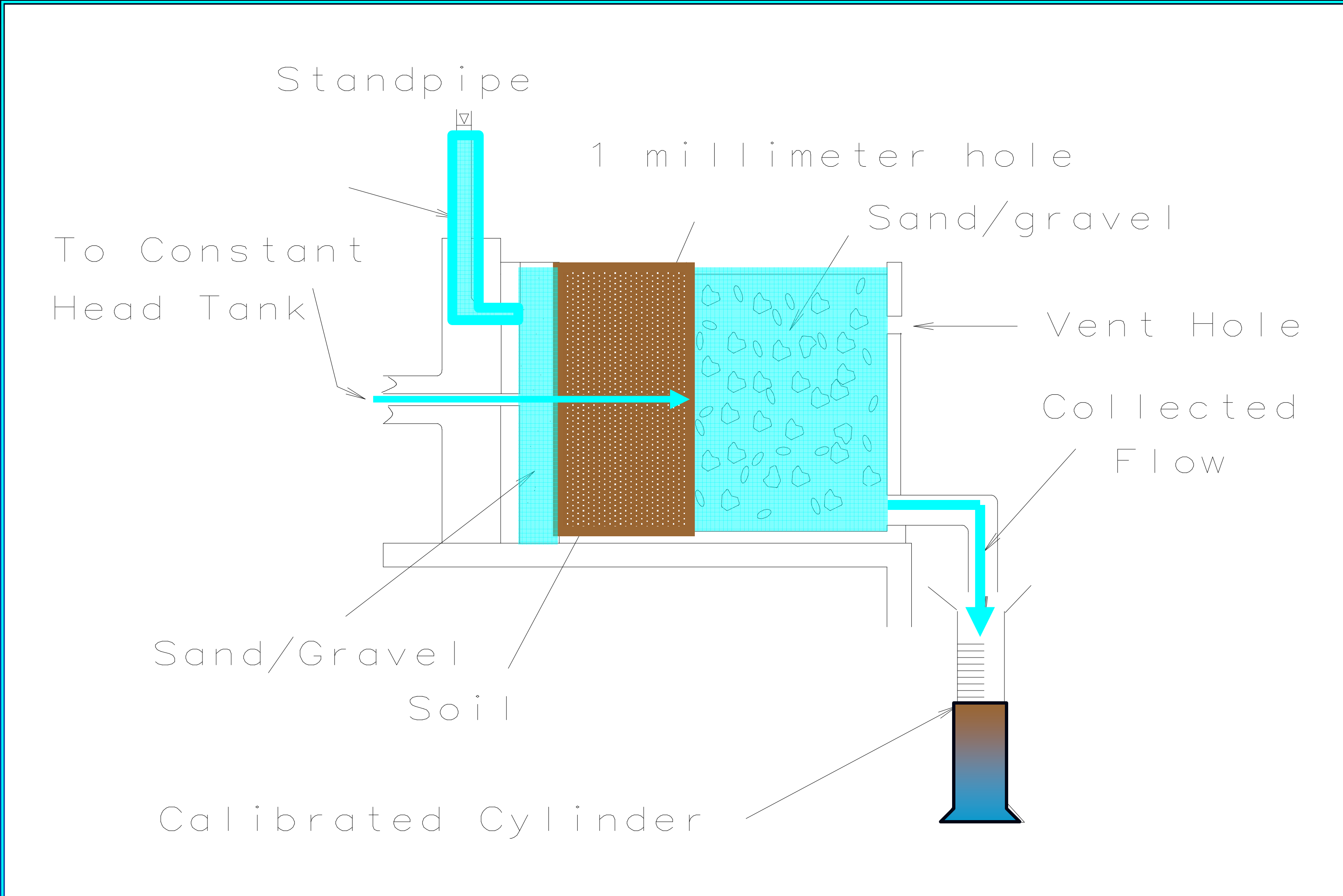
- % Dispersion is ratio of 5 micron size natural to 5 micron size chemically dispersive, expressed as percentage

$$\%Dispersion = \frac{\%5\mu\_naturally\_prepared}{\%5\mu\_chemically\_dispersed} x100$$

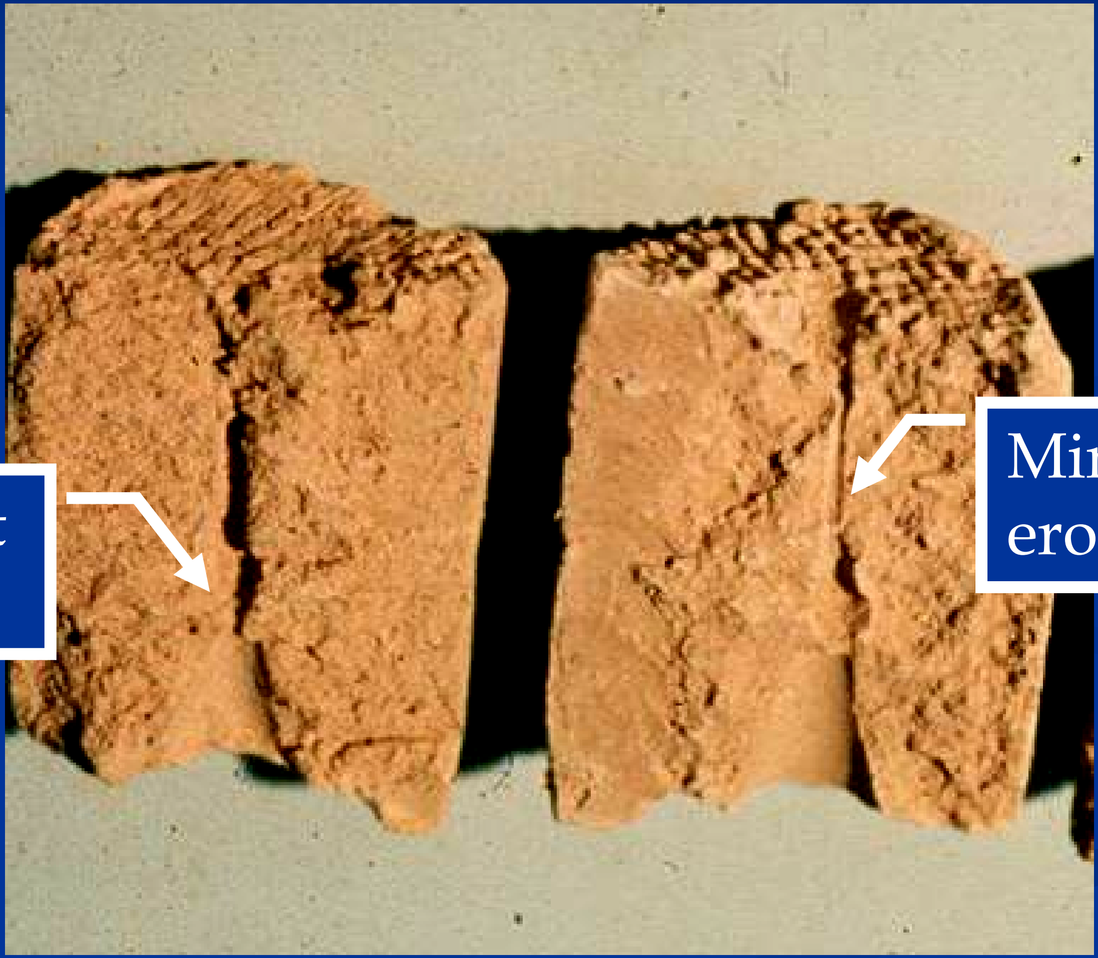
- **< 30 % Not Dispersive**
- **30-60 % Transition**
- **> 60 % Dispersive**

Pinhole Test - ASTM D4647

- Direct measure of erosivity
- Dispersive soils fail rapidly under flow at 2 inches of head
- Non-dispersive soils show little erosion under flow at 40 inches of head
- Ratings are D-1, D-2, ND-4, ND-3, ND-2, and ND-1 most dispersive to non-dispersive)


Standpipe
1 millimeter hole
Sand/gravel
To Constant
Head Tank
Vent Hole
Collected
Flow
Sand/Gravel
Soil
Calibrated Cylinder

Pinhole Samples



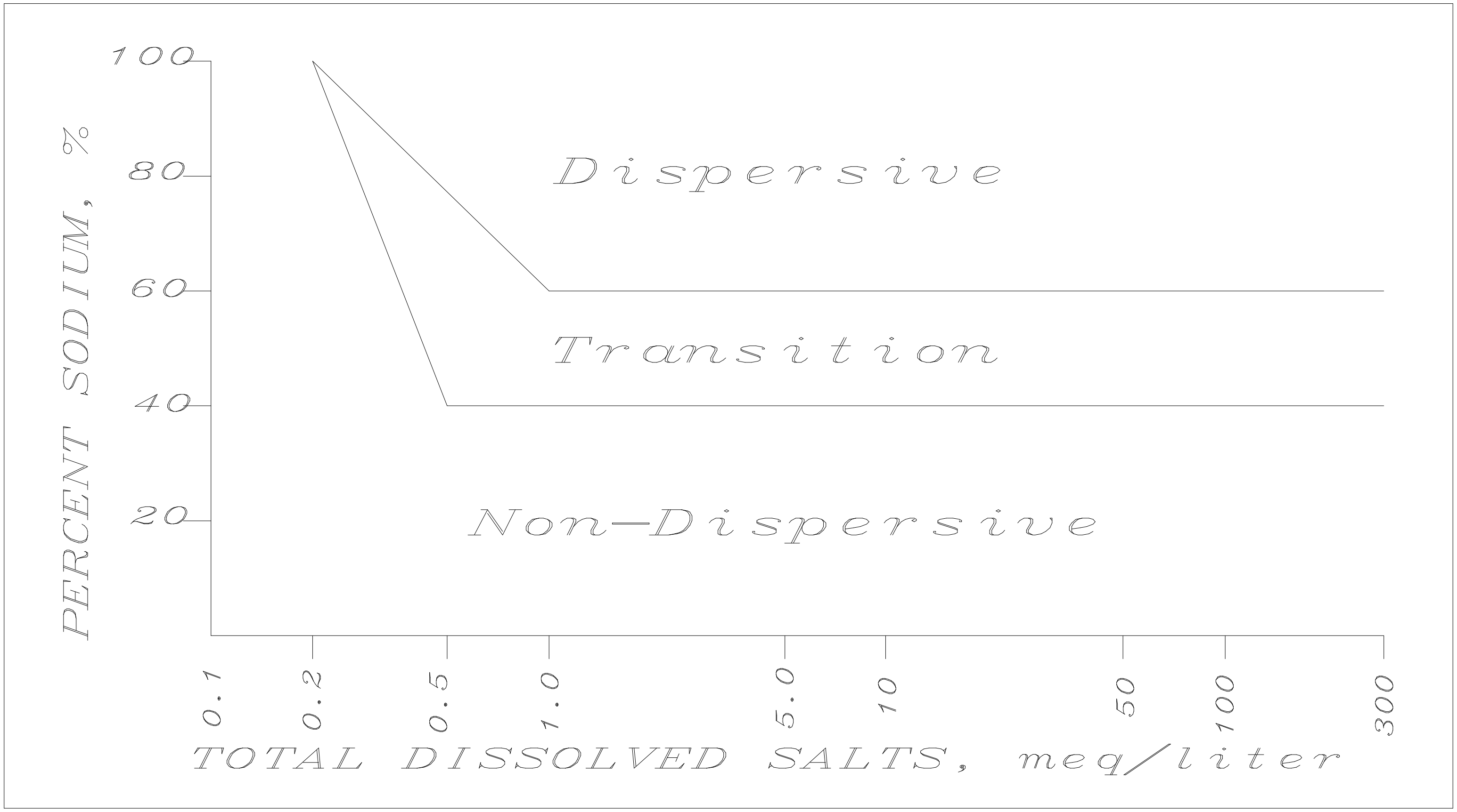
Significant erosion

Minor erosion

Dispersive Clays

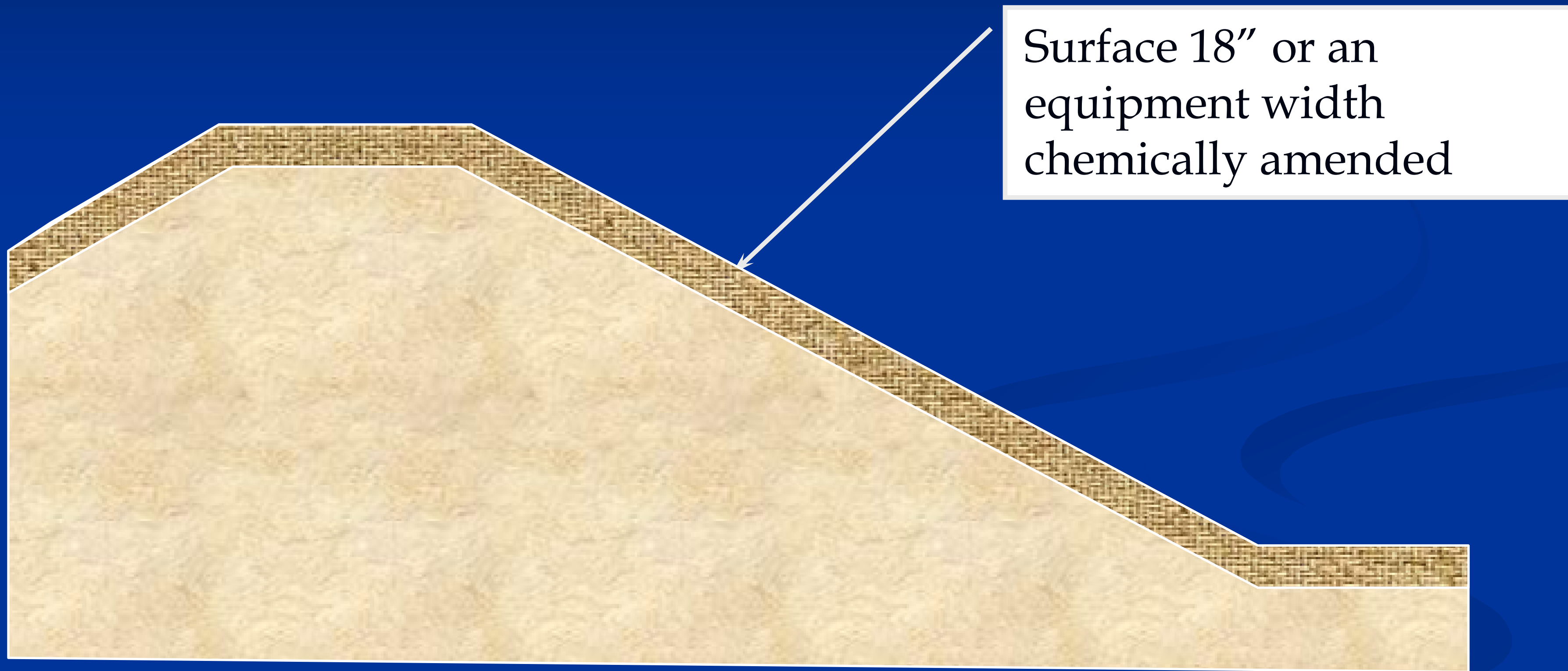
- Chemical Test on Pore Water Extract
  - Dispersive soils have > 60 % of total salts being sodium
  - Non-dispersive soils have < 40 % of total salts being sodium

Chemical Test For Dispersion



- Design Measures to Combat Dispersive Clays
  - Selective Placement/Avoidance
  - Chemical Amendments
    - hydrated lime
    - fly ash
    - alum
    - gypsum

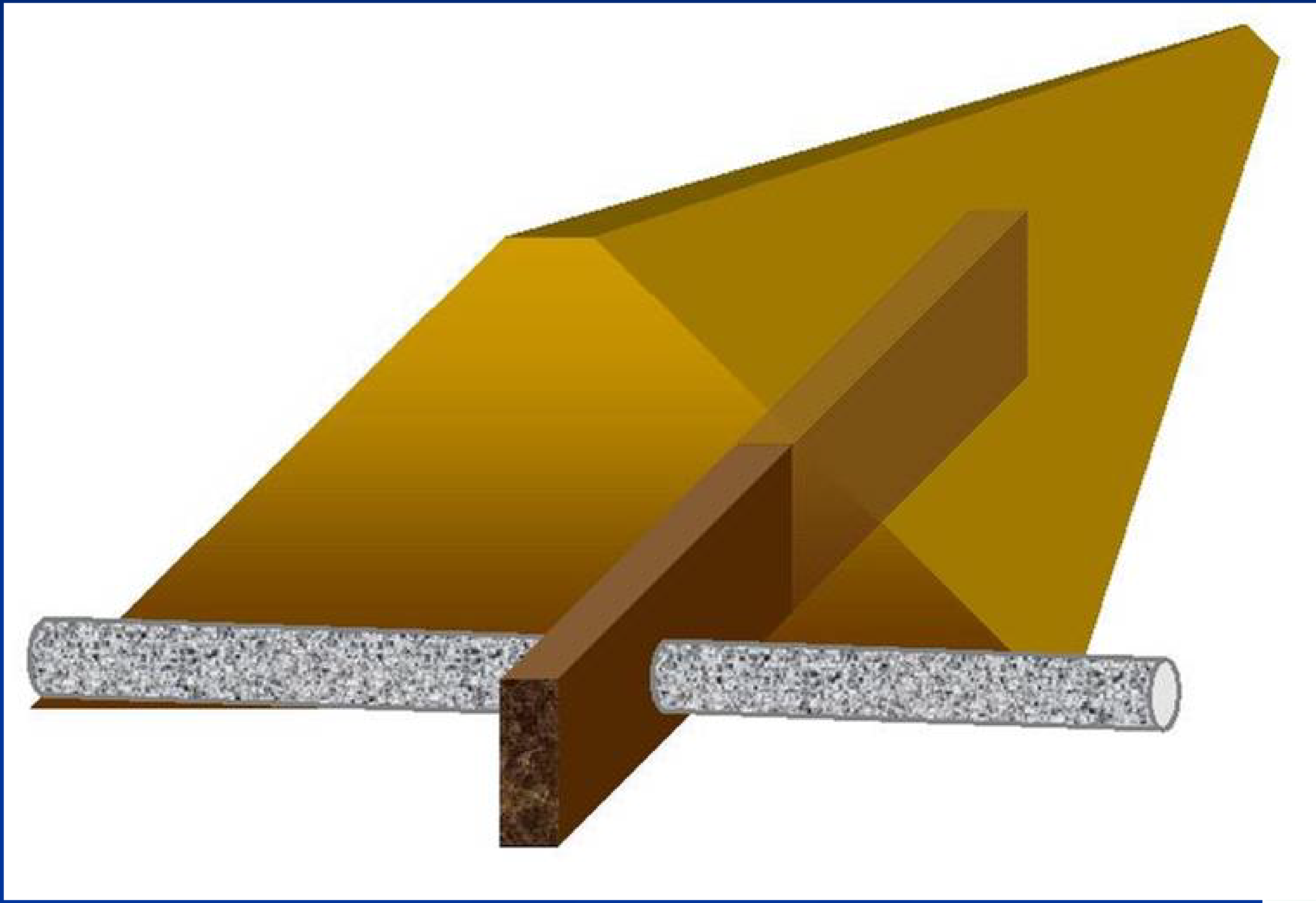
Surface Treatment

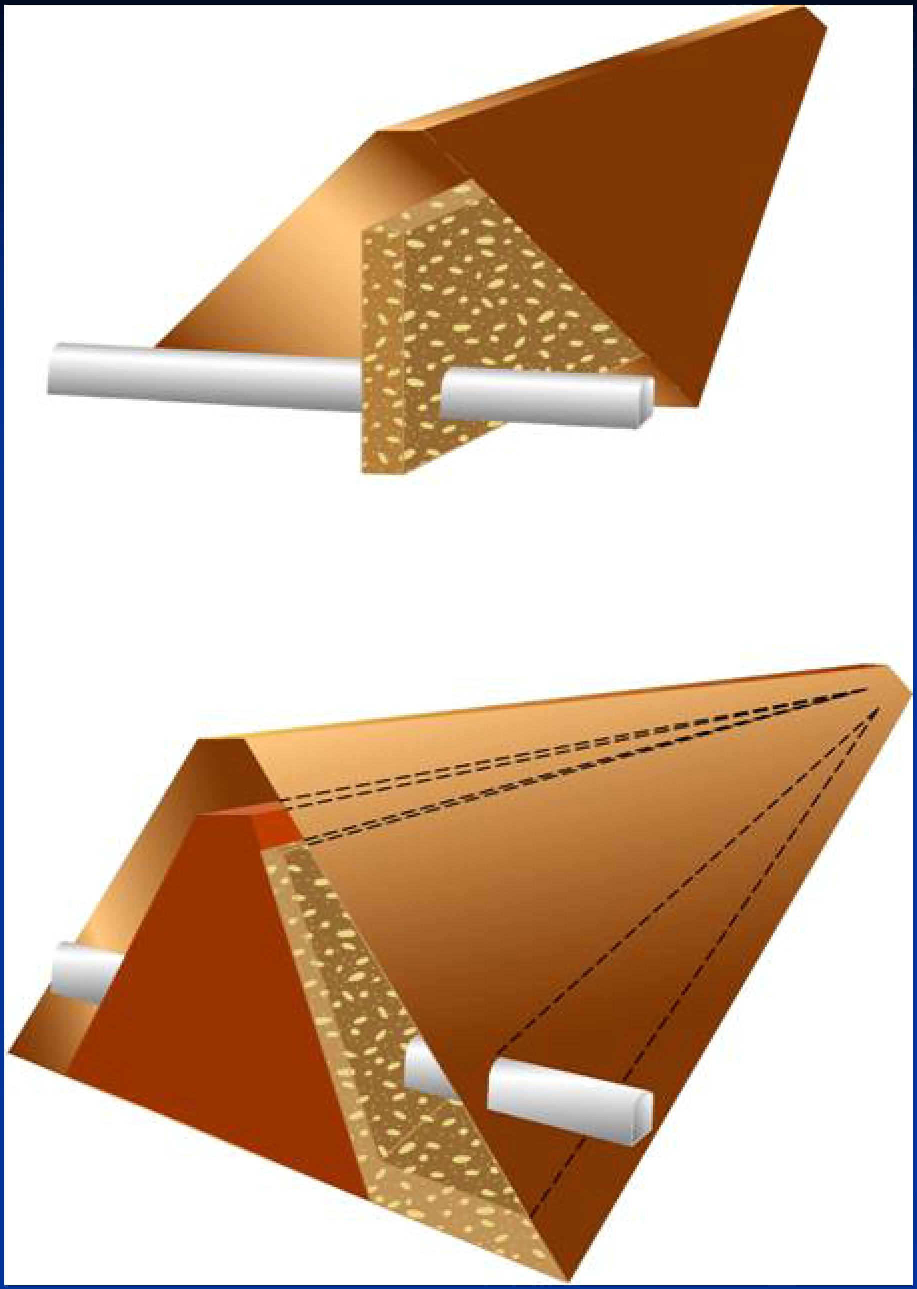


Design Measures to Combat Dispersive Clays

- Chimney Filters or Filter Diaphragms around Pipes and areas of hydraulic fracturing
- Avoid Differential Settlement
- Provide for Flexible Fill - compact wet of optimum

Chimney Filters or Filter Diaphragms around Pipes





Chimney Filters and Filter Diaphragms around Pipes

Chemical Admixtures

- Lime, Fly Ash, Alum Treatment
- Spread 2% hydrated or quick lime
- Incorporate with rotomixer
- Cure and place on dam