Seepage Rehabilitation for Embankment Dams

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Maryland Dam Safety Training
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Presentation Content

- Seepage control objectives and categories of options
- Seepage collection and control
- Seepage reduction (barriers)

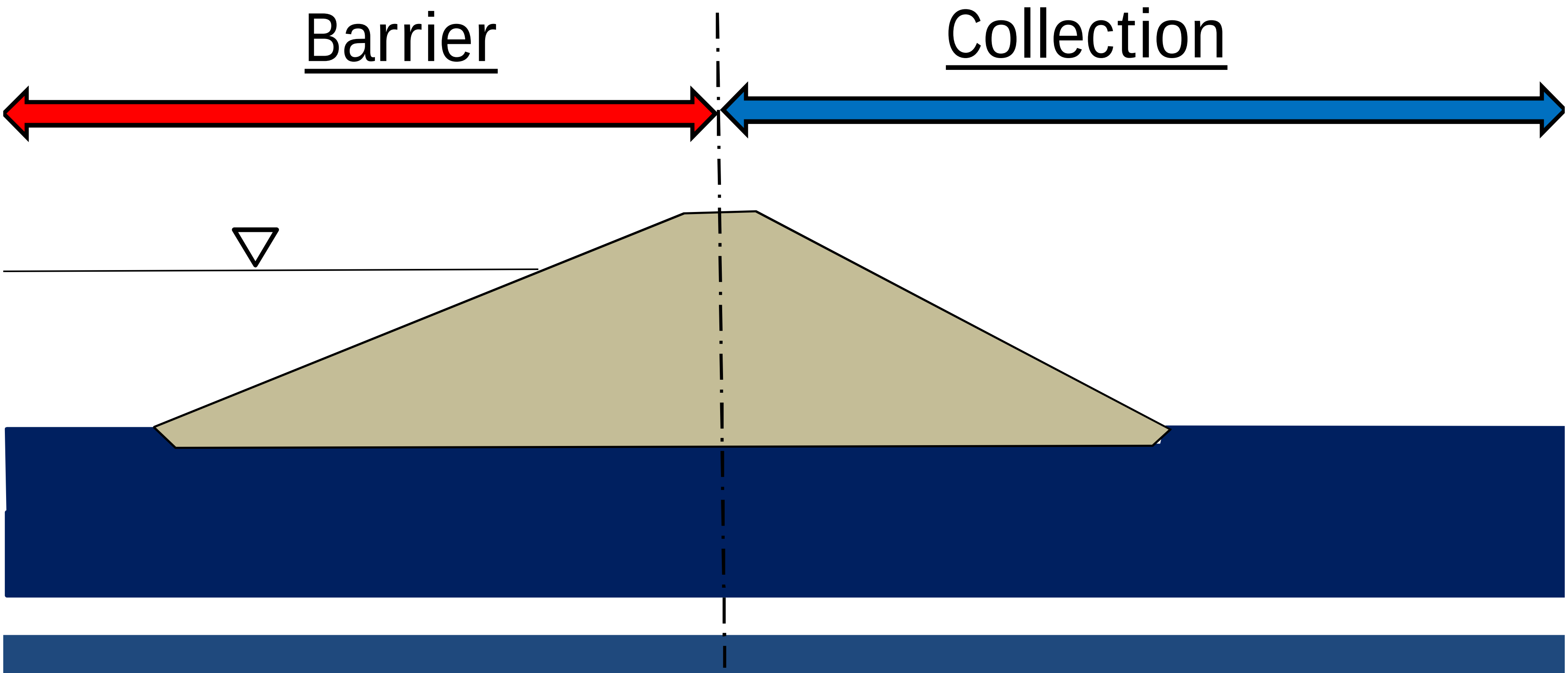
Seepage Control Objectives

- Prevent Piping and Internal Erosion
- Limit Pore Pressures, Uplift, and Seepage Forces
- Prevent Slope Instability and Surface Sloughing
- Prevent “Wet Spots” and Surface Erosion
- Limit loss of stored water (operational concern, not dam safety)

Seepage Rehabilitation Methods

- Two Broad Categories
  - Collection and Control
  - Seepage Reduction (Barriers)
- "Best" Solution
  - Depends on particular dam and foundation
  - Consider full range of alternatives – avoid tunnel vision or bias
  - Sometimes a combination of both are used

Barriers and Collection



Some Collection and Control Considerations

- Can construct remediation where seepage has been observed
- Often can directly observe placement of all elements of construction
- May require reservoir lowering
- May require dewatering

Some Collection and Control Considerations

Seepage does not threaten dam safety, ...

when it is directed to through a filtered exit.

R.B. Peck, lecture, 1985[1]

Regarding the idea of designing dams for controlled under seepage, without filters –

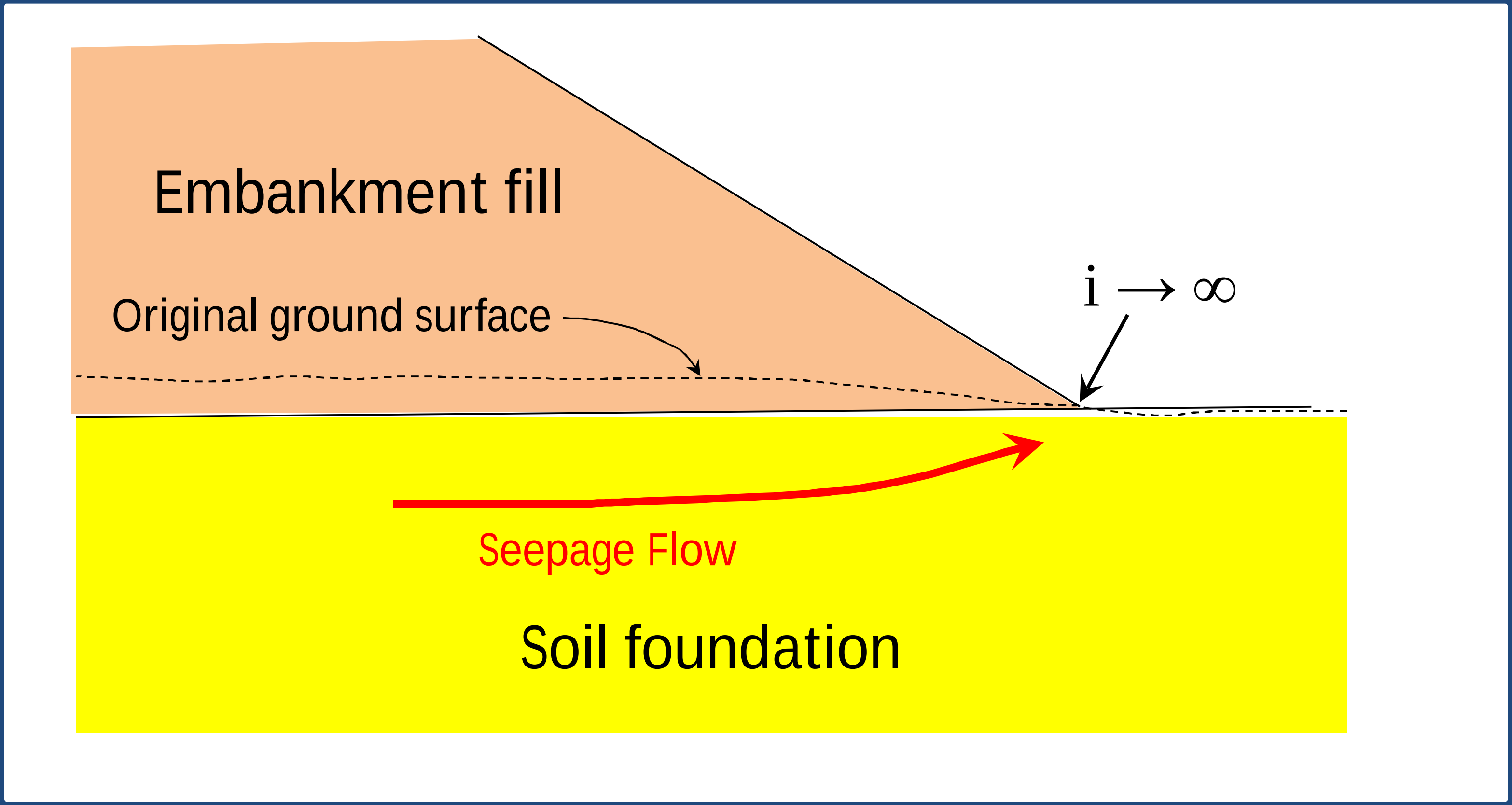
I consider we have gotten scared out of doing this.

Effective filters are critical to success of seepage collection and control alternatives.

[1] "Closing Keypoints", Presentation to Bureau of Reclamation, Seminal Paper Series, Unpublished, 1985.

Filtered Exit

Seepage can be addressed by providing a 'filtered exit' (toe drain)



Nomenclature

Old

"Filter" and "Drain"

Historically used interchangeably as nouns and verbs.

New

Filter = first stage, primary function is to provide filter

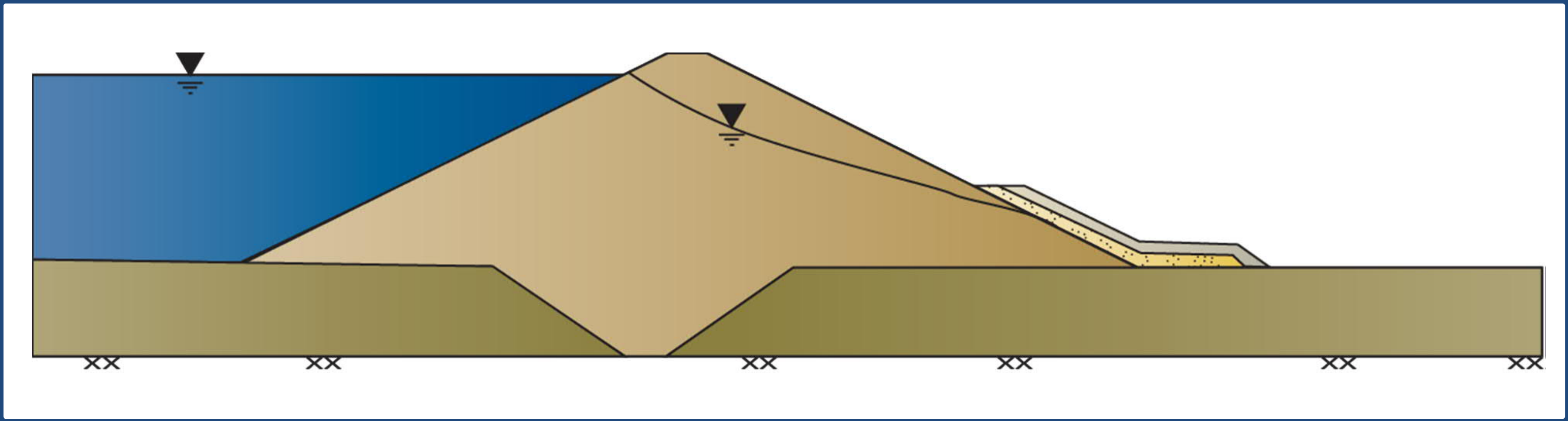
Drain = second stage, primary function is to provide flow capacity

Tools to Provide Collection and Control

- Filters to limit piping potential
- Drains to collect and convey seepage
- Berms to resist uplift and provide stability
- Relief wells to reduce uplift

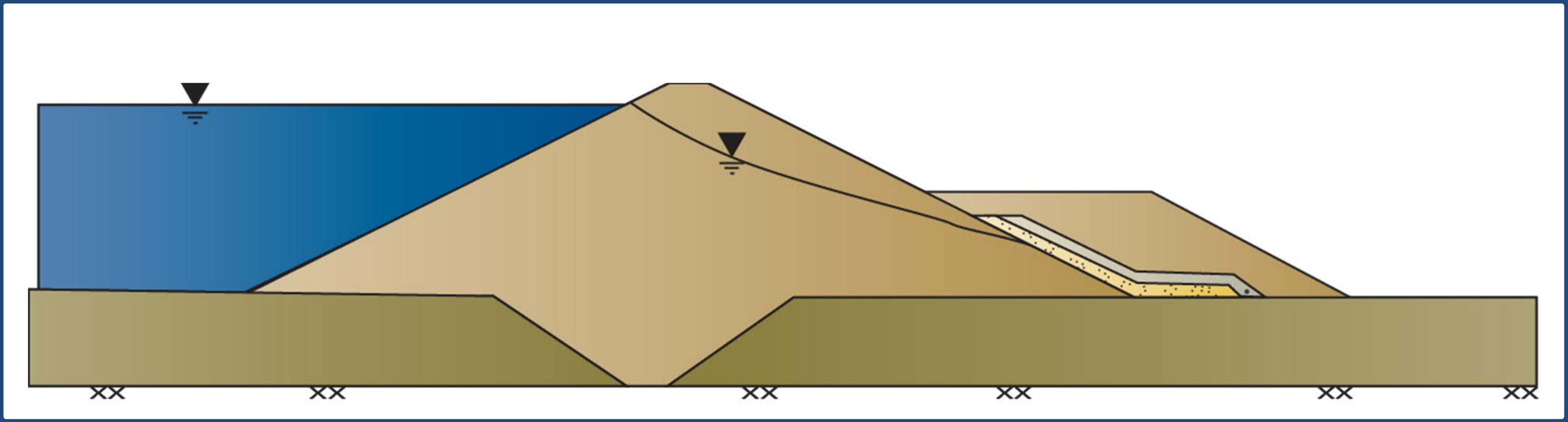
These tools can be used in different combinations as illustrated in the next several slides.

Filter/Drain Blankets



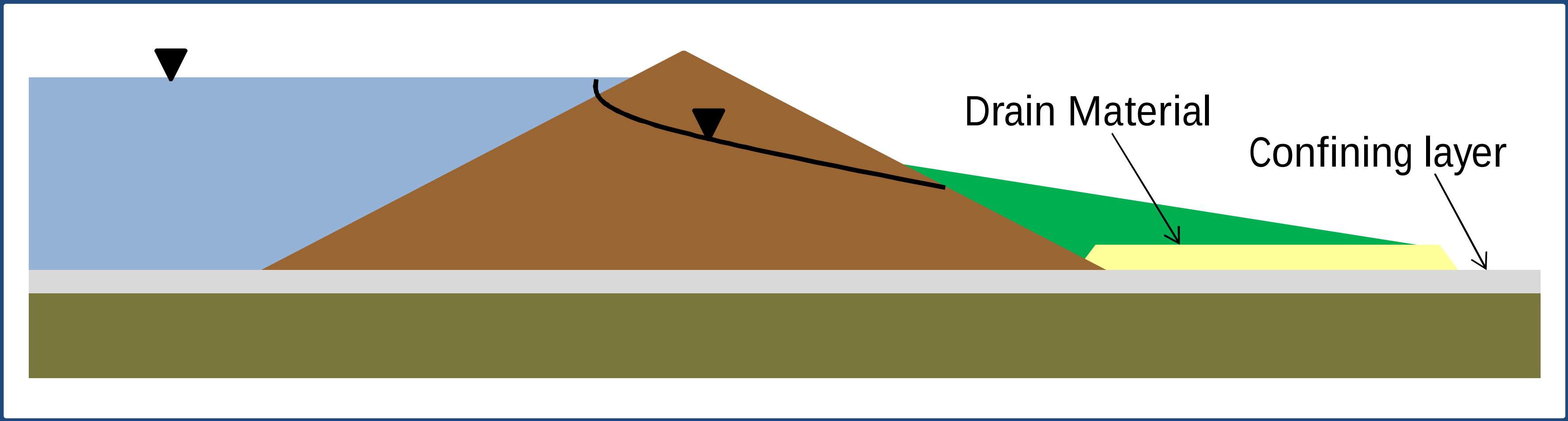
- Generally for limited seepage
- Can also be applicable to abutment seepage

Filter/Drain Blankets and Berm



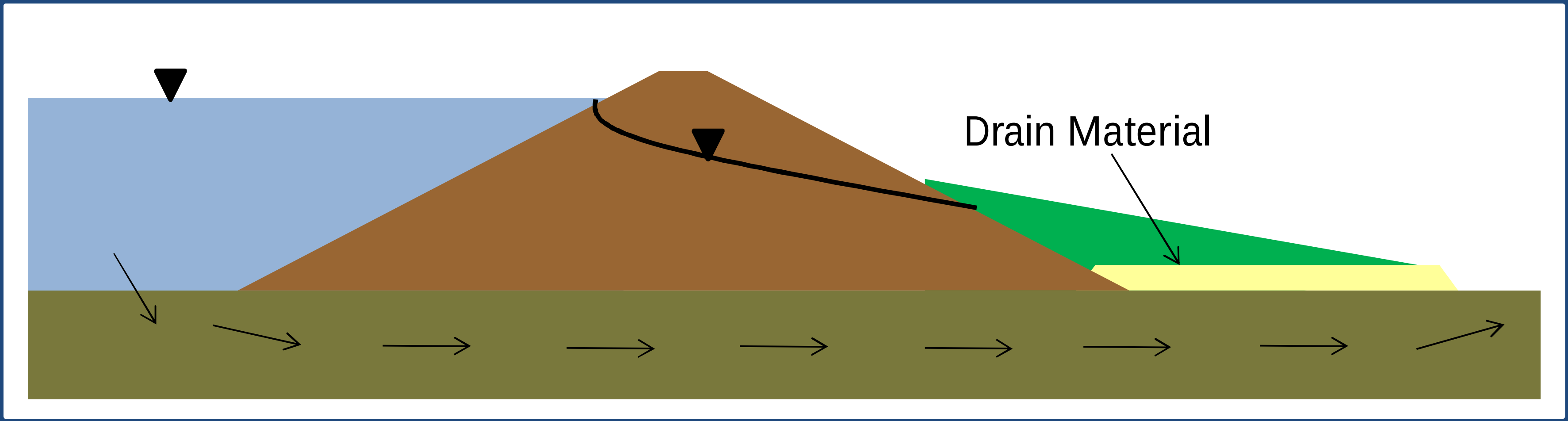
- Berm provides resistance for pressure and improved stability

Seepage Berm Over Confining Layer



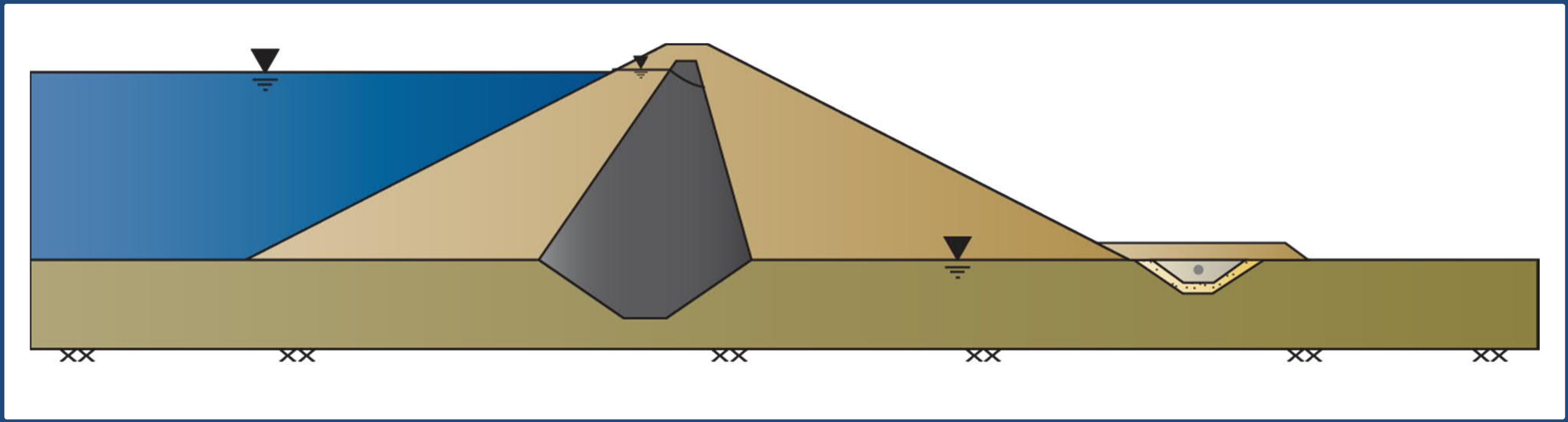
- Not highly effective - seepage will not enter drainage layer because it is blocked by the confining layer

Seepage Berm - No Confining Layer



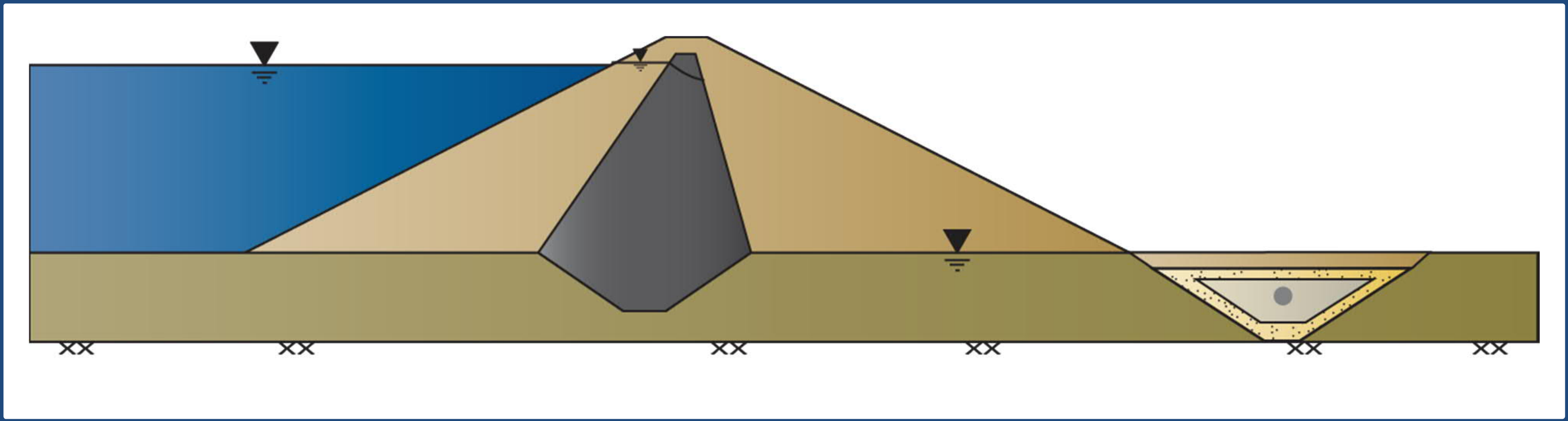
- If foundation horizontal permeability is very high, the seepage berm may only ‘push’ the seepage downstream
- A vertical drainage element (toe drain or vertical trench) may be needed to intercept horizontal flow

Shallow Toe Drain



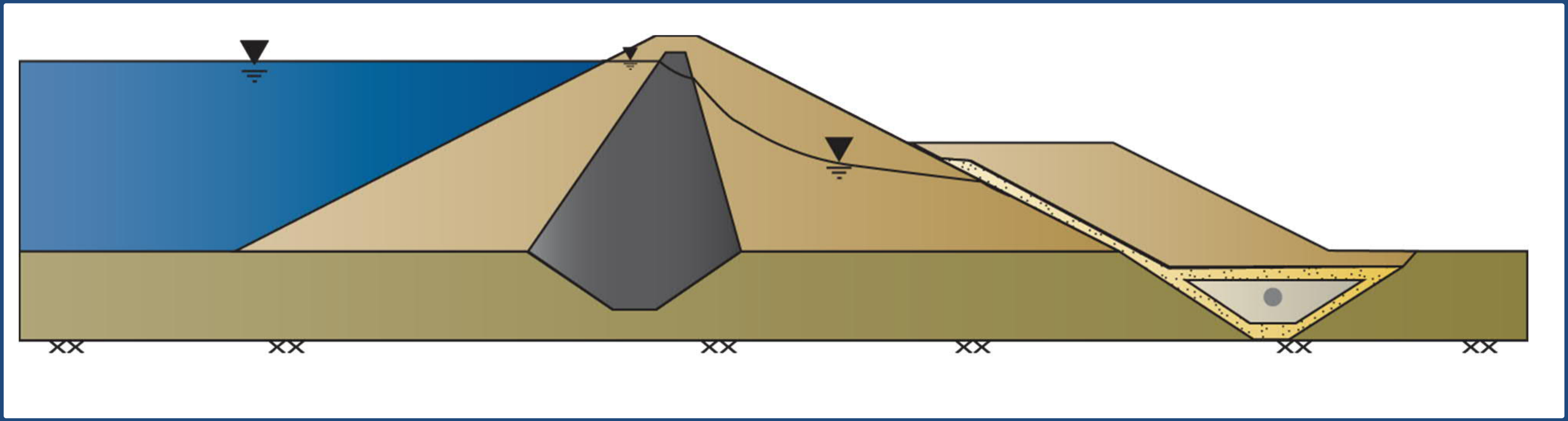
- For limited, shallow foundation seepage
- Likely requires dewatering
- May require reservoir lowering

Deep Toe Drain



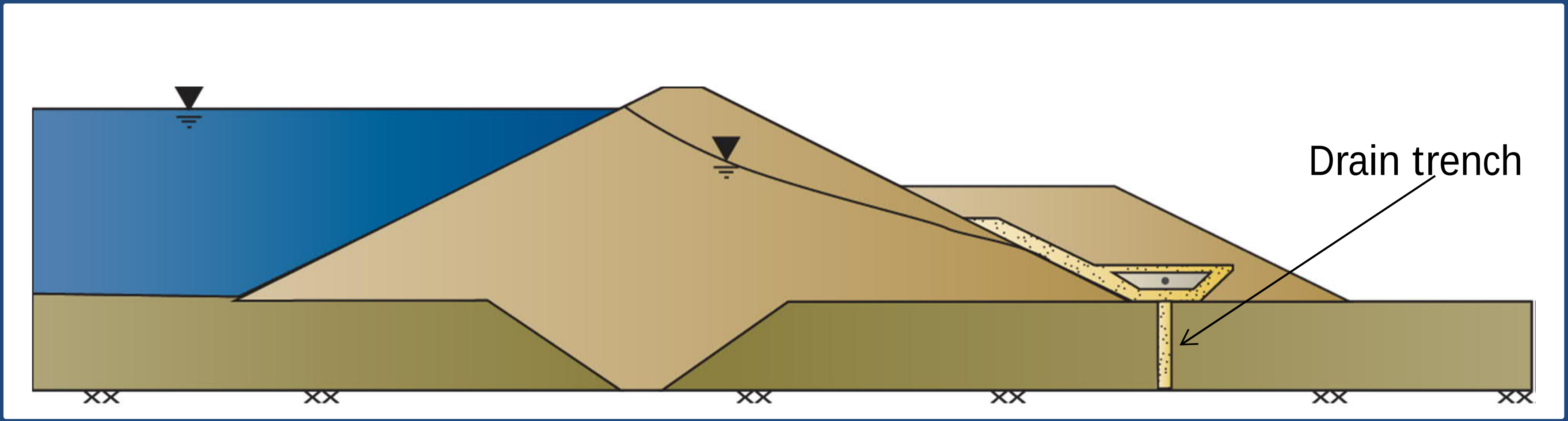
- For more extensive, deep foundation seepage
- Almost certainly requires dewatering
- Likely requires reservoir lowering

Toe Drain and Berm



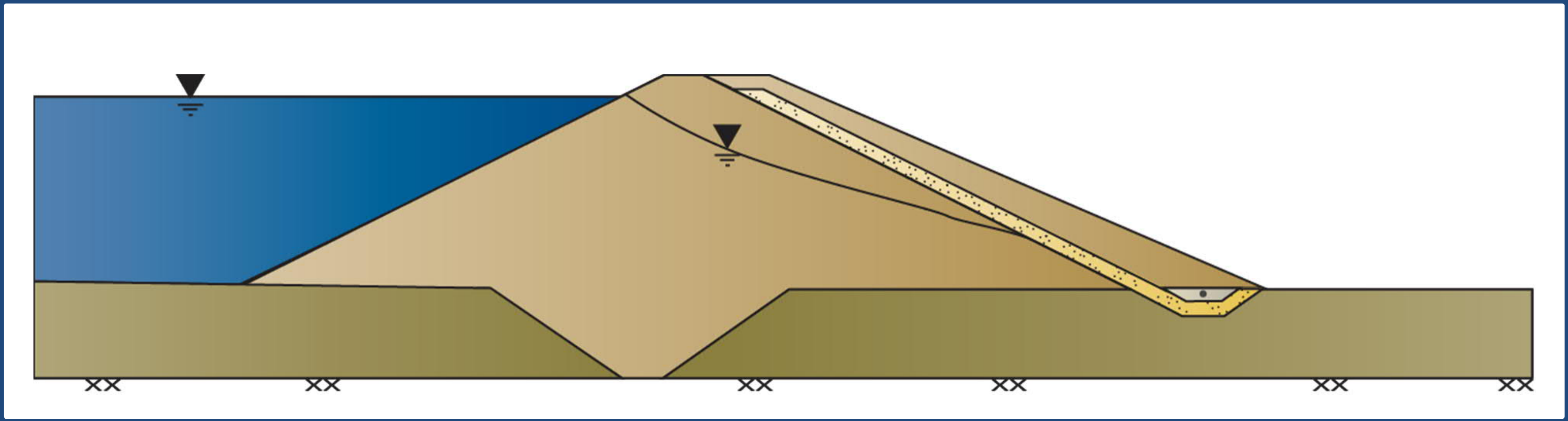
- Addresses foundation and embankment seepage
- Berm provides resistance for pressure and improved stability

Trench Toe Drain Trench and Berm



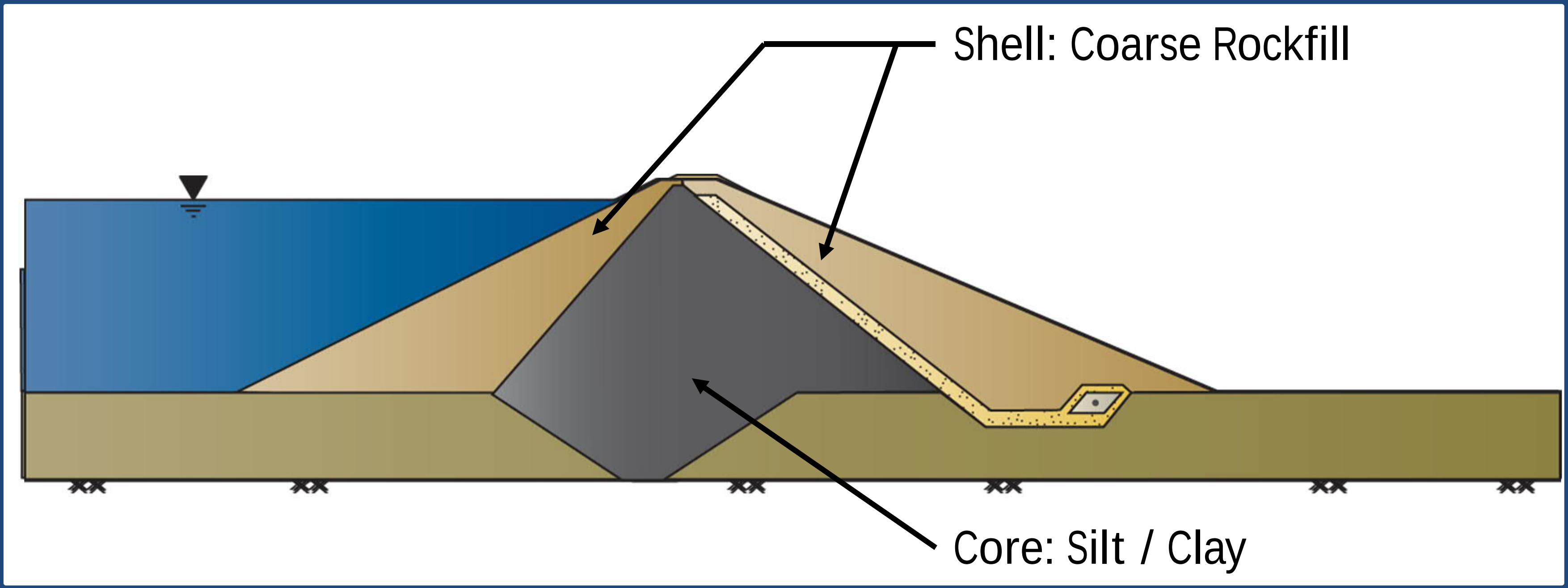
- With slurry (biodegradable) methods, trench drain can be constructed without dewatering
- Potential constructability issues
  - ❖ Slurry does not revert
  - ❖ Trench instability
  - ❖ Backfill contamination

Chimney Filter Overlay



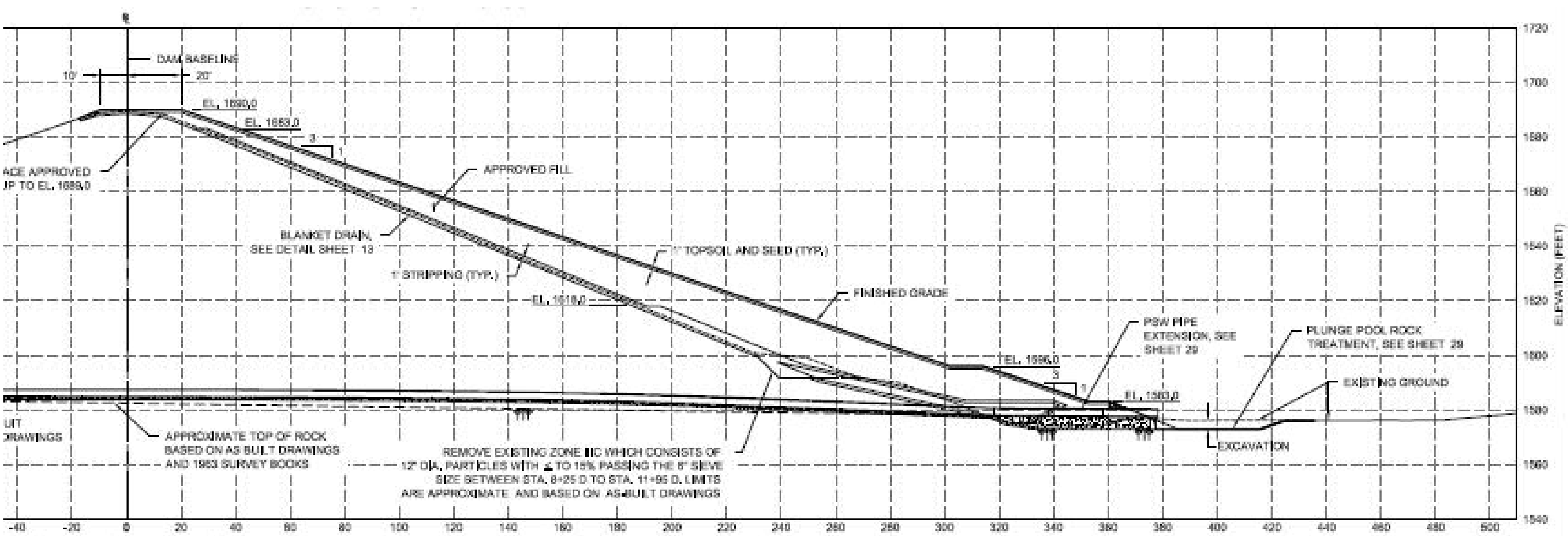
- Relatively simple solution for embankment seepage
- May not require reservoir lowering
- Embankment zoning can cause complications (e.g. coarse downstream shells)

Internal Chimney Filter



- Comprehensive embankment solution
- Construction risks need to be addressed
- Reservoir lowering almost certainly required

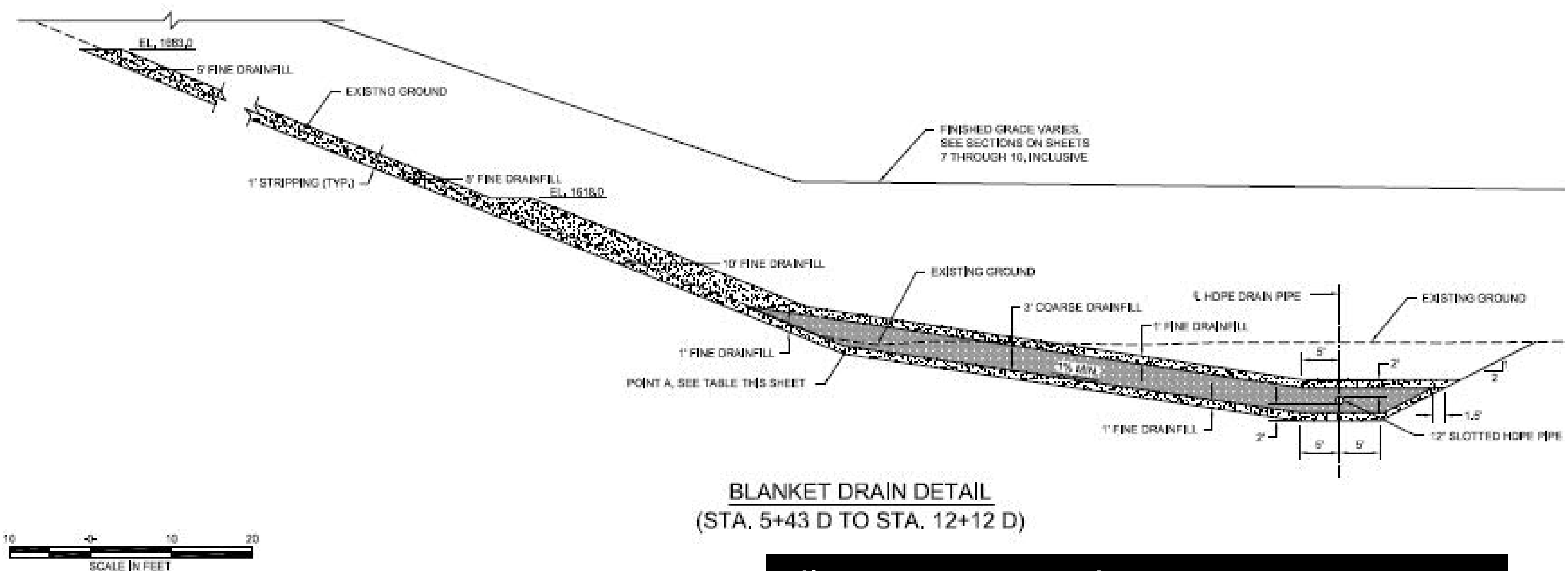
New Creek 14 - Typical Section



SECTION STA. 11+20 D

Courtesy of T. Brown, NRCS

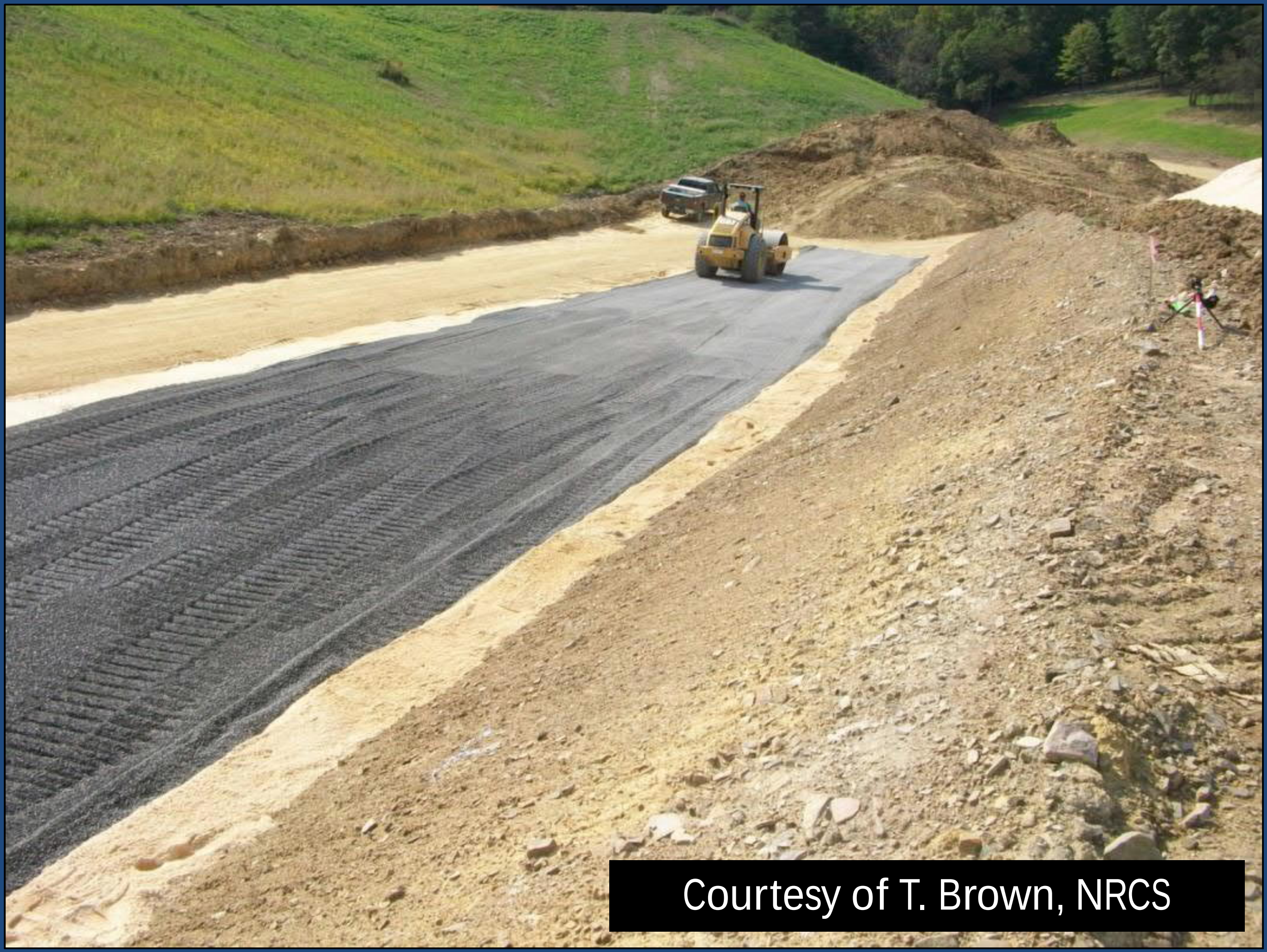
Blanket Drain Detail



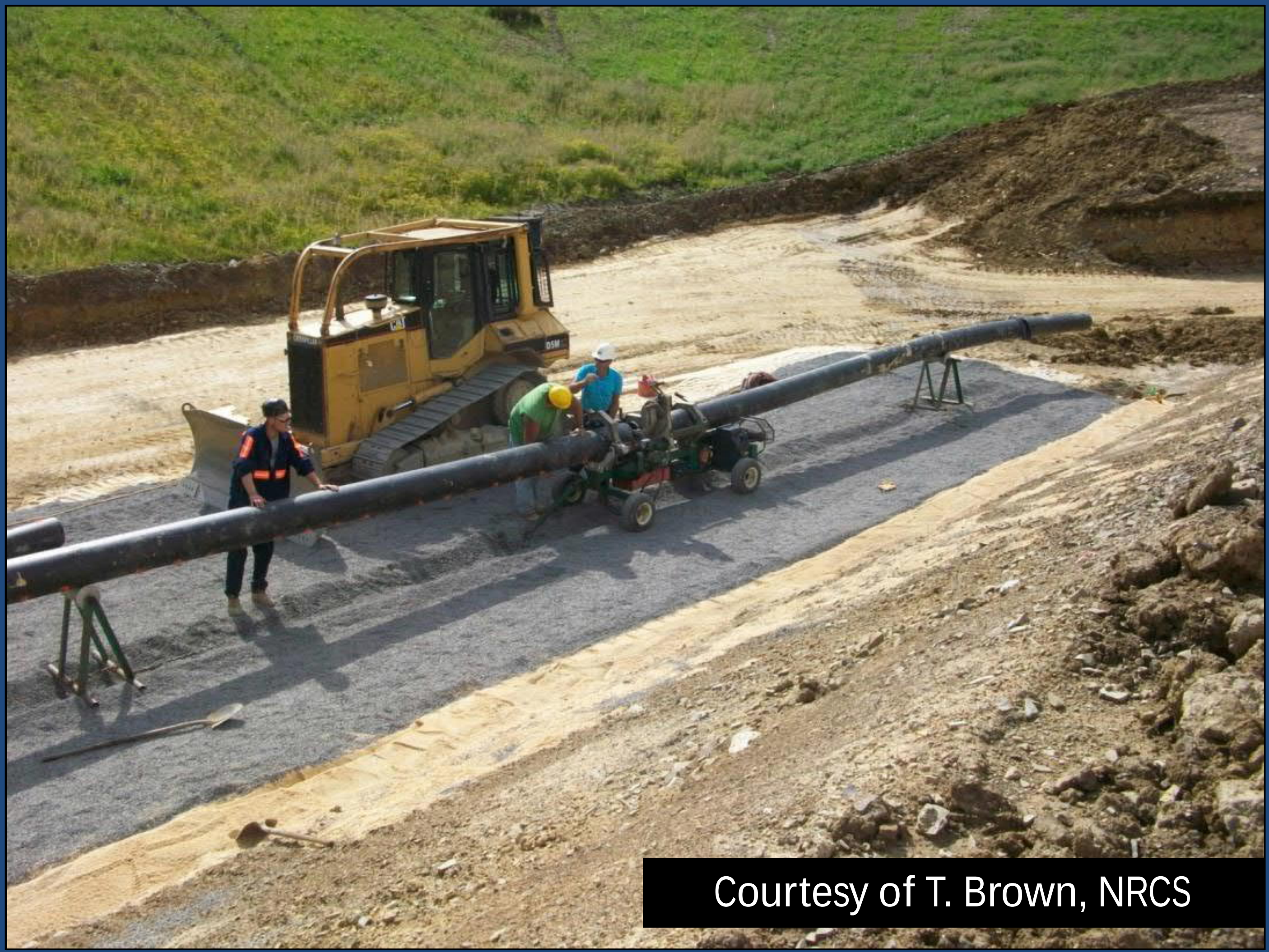
Courtesy of T. Brown, NRCS

Filter – ASTM C33 Fine Aggregate
Drain – ASTM # 8

Drain and Filter Placement



Welding HDPE Toe Drain



Placing Fill on Top of Blanket

Courtesy of T. Brown, NRCS

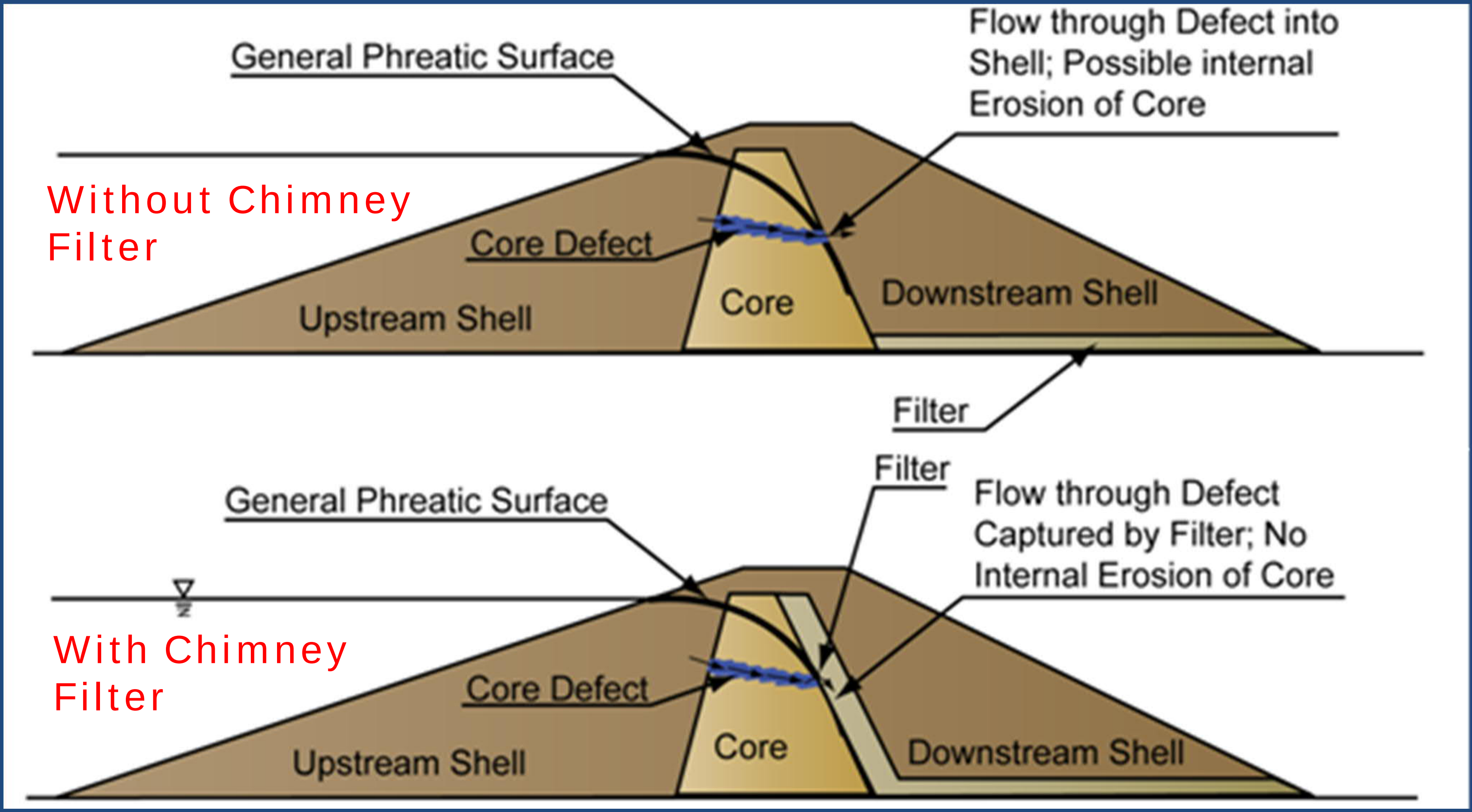
Placement of Chimney Filter and Berm


Courtesy of T. Brown, NRCS

Benefits of Chimney Filters

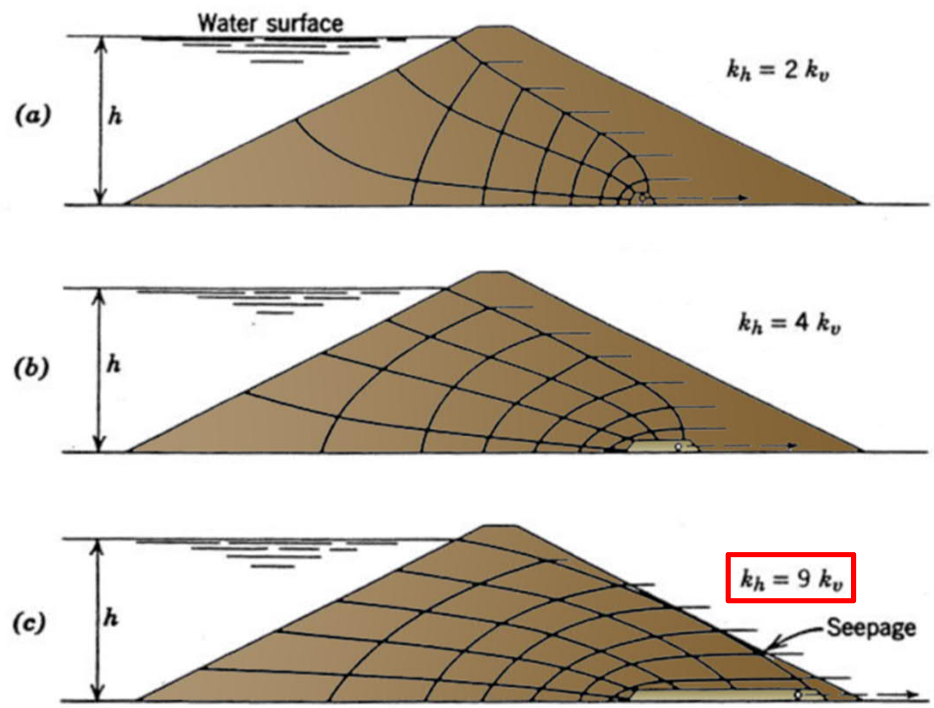
- Provide protection against internal erosion through defects
- Lower phreatic surface
  - Preventing breakout of seepage on downstream face
  - Increasing stability of downstream slope

Prevention of Internal Erosion Through Defects

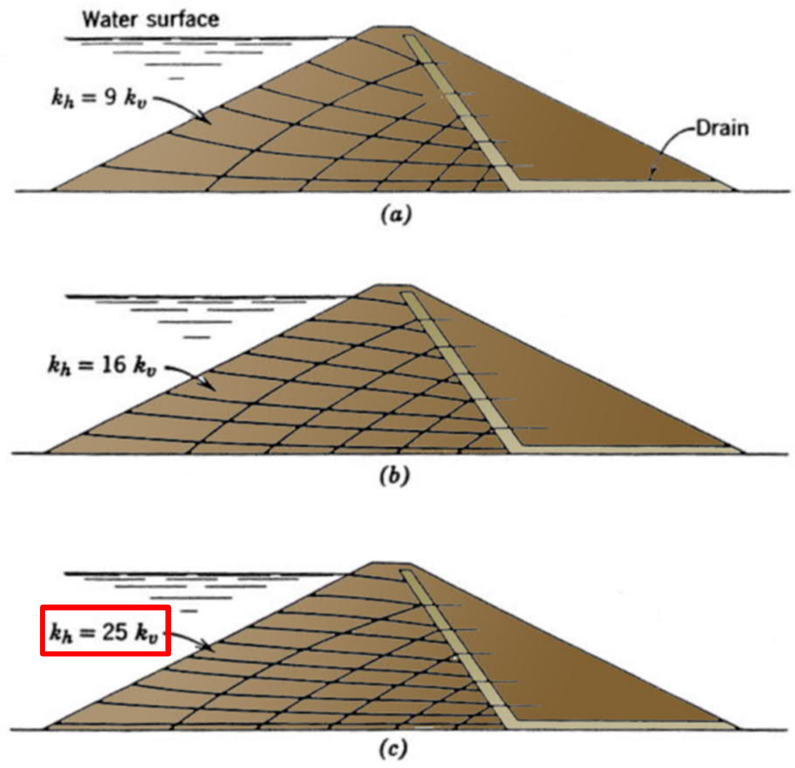


Lowering of Phreatic Surface

Without Chimney Filter



With Chimney Filter



Top Elevation for Chimney Filter

- Historic practice – top of estimated phreatic surface
- Current practice
  - Top of maximum normal pool as a minimum
  - Often top of maximum flood pool or dam crest

J.L. Sherard, lecture, 1984[1]

- P. 5. I believe there is already sufficient evidence from dam behavior, supported by theory, to require the designer to assume that small concentrated leaks can develop through the impervious section of most embankment dams, even those without exceptional differential settlement.

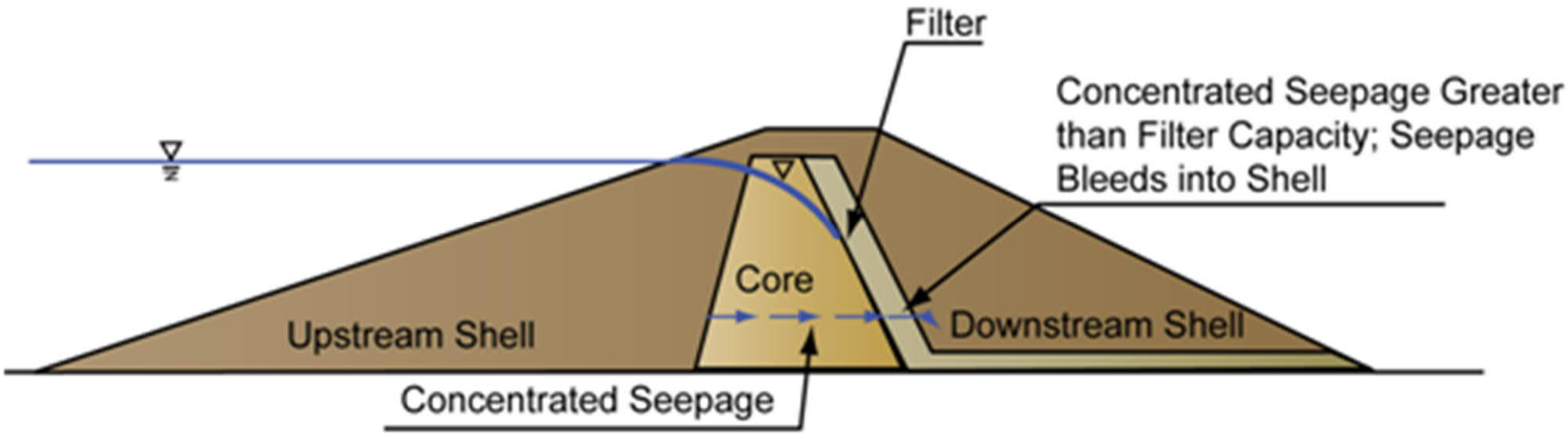
[1] "Debatable Trends in Embankment Engineering," Presentation to the A.S.C.E. National Capital Section Geotechnical Committee, Seminar on Lessons Learned from Geotechnical Failures, February 3, 1984.

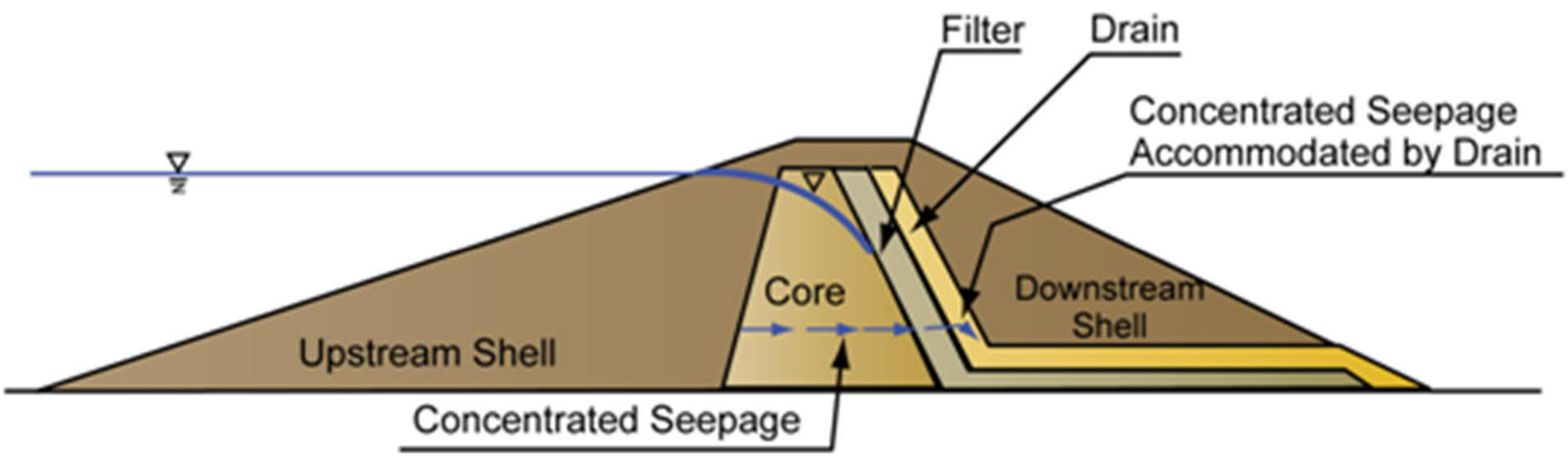
One-Stage vs. Two-Stage Chimneys

Two-stage:

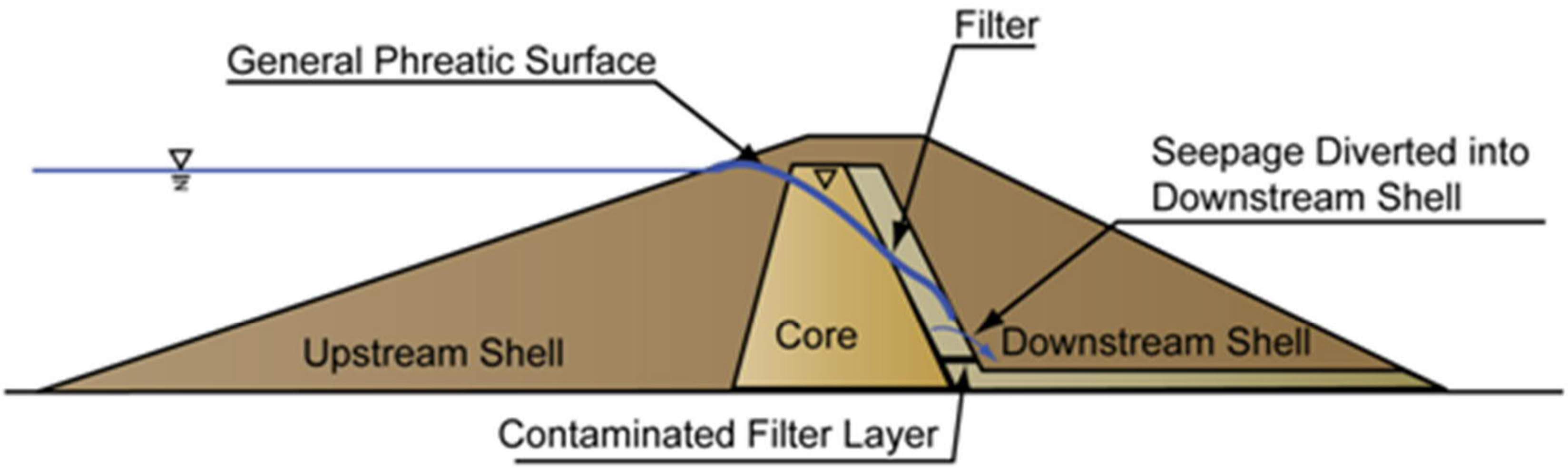
- Provides capacity to handle large flow
- Addresses potential negative effects of filter contamination

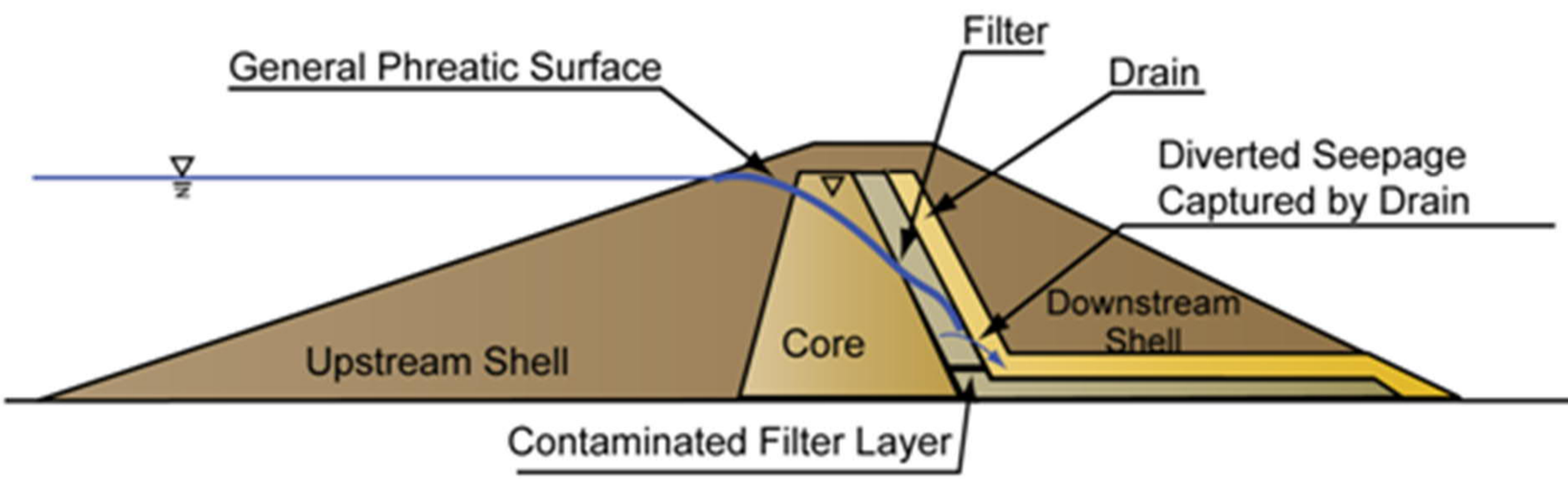
Prevent Concentrated Flows from Overwhelming Filter





Negate Effects of Filter Contamination

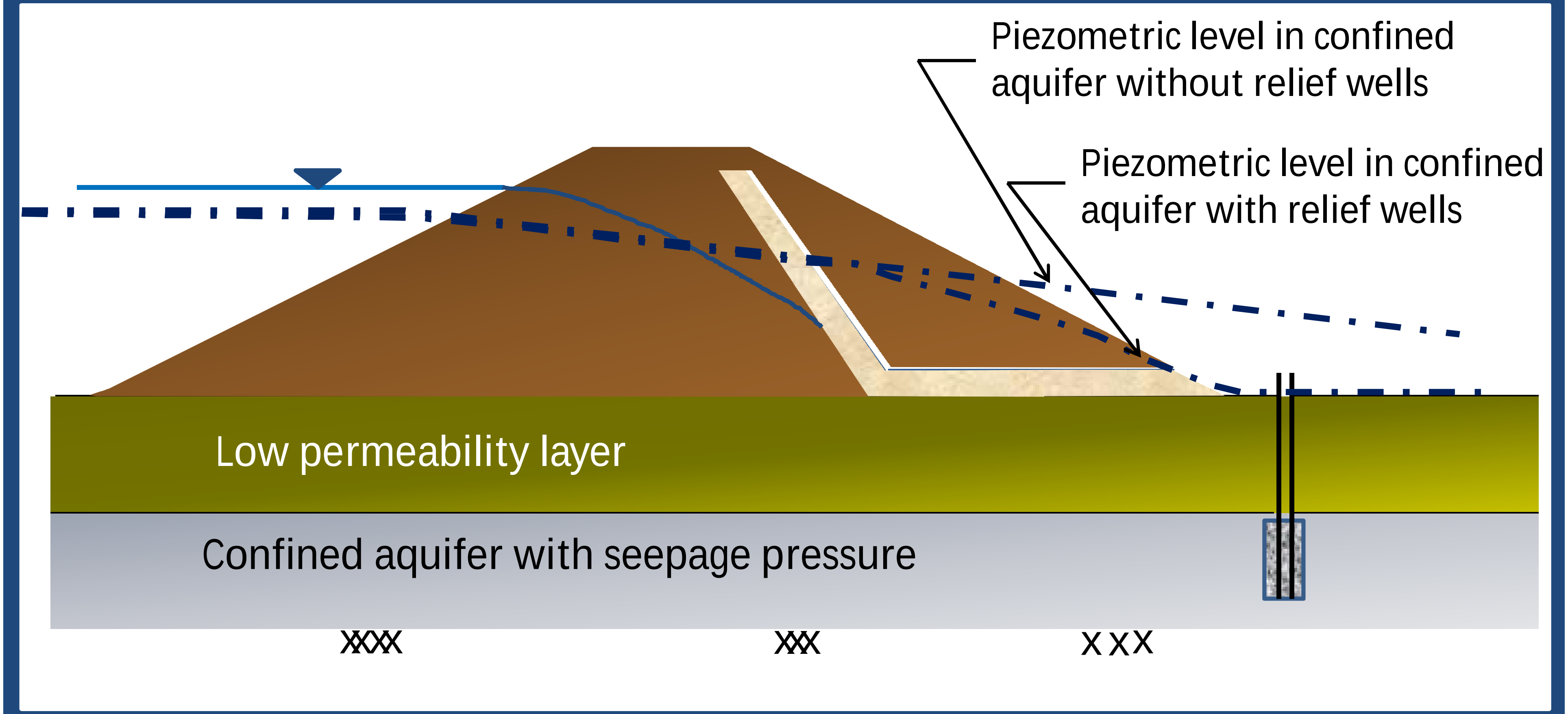




Relief Wells

- Relieve pore pressures and lower piezometric surface within confined pervious foundation strata
- Reduce uplift and improve stability
- Control exit gradients and reduce piping potential
- Maintenance required
- Possible limitation of radius of influence
- Drain trench may be better alternative

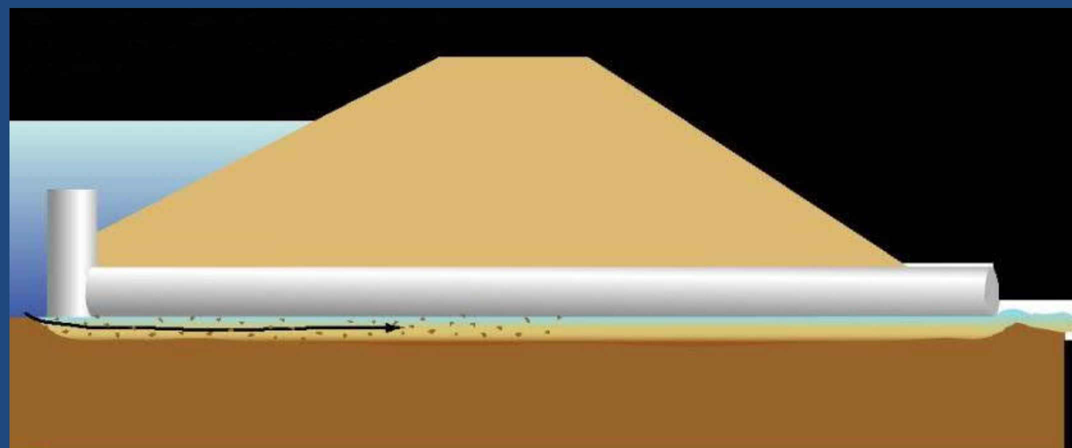
Relief Wells



Seepage Protection for Conduits or Other Embankment Penetrations

- Piping failure along unprotected conduits is a leading cause of dam failure

Outlet Conduit Penetrations



Little Wewoda, Site 17, OK

Courtesy: D. McCook

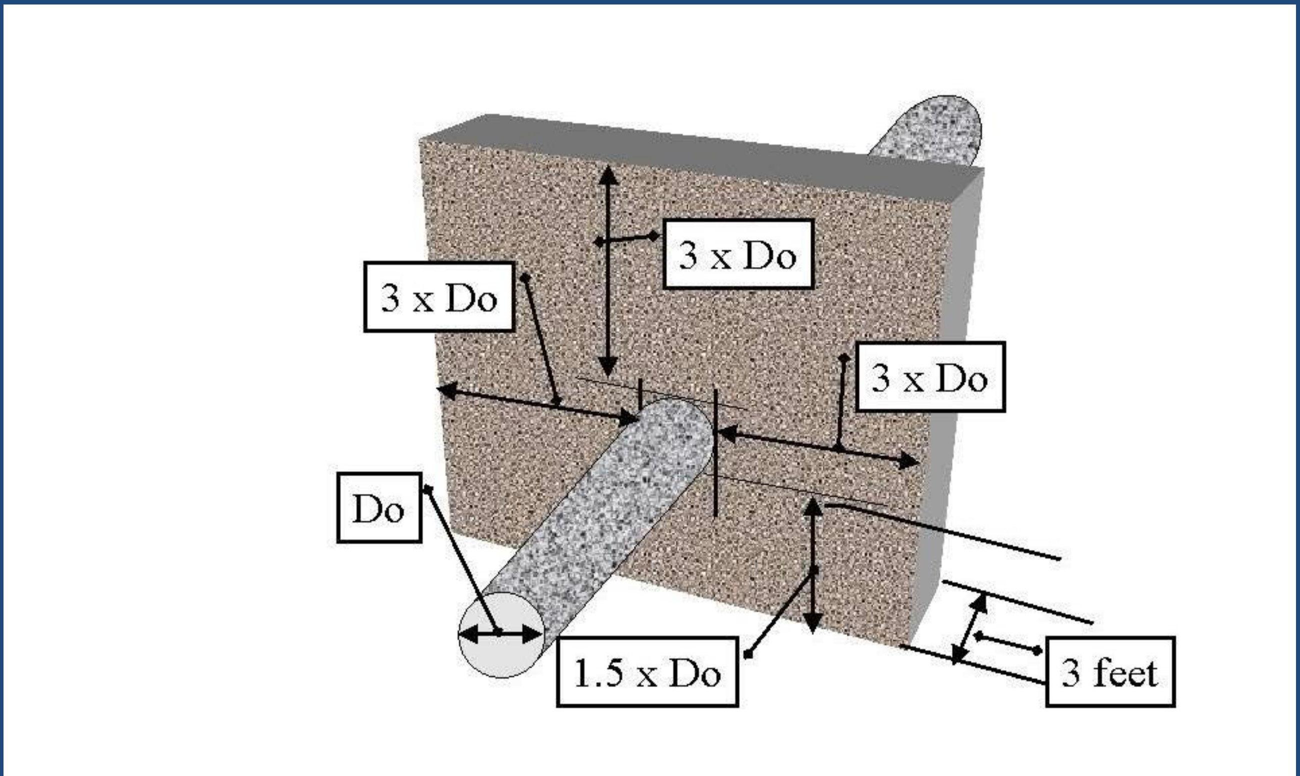
Jackson Mill Creek, Site 1, SC

Courtesy: D. McCook

How is compaction achieved here?

Filter Diaphragm or Collar for Outlet Works

For pipes less than 3 ft in diameter



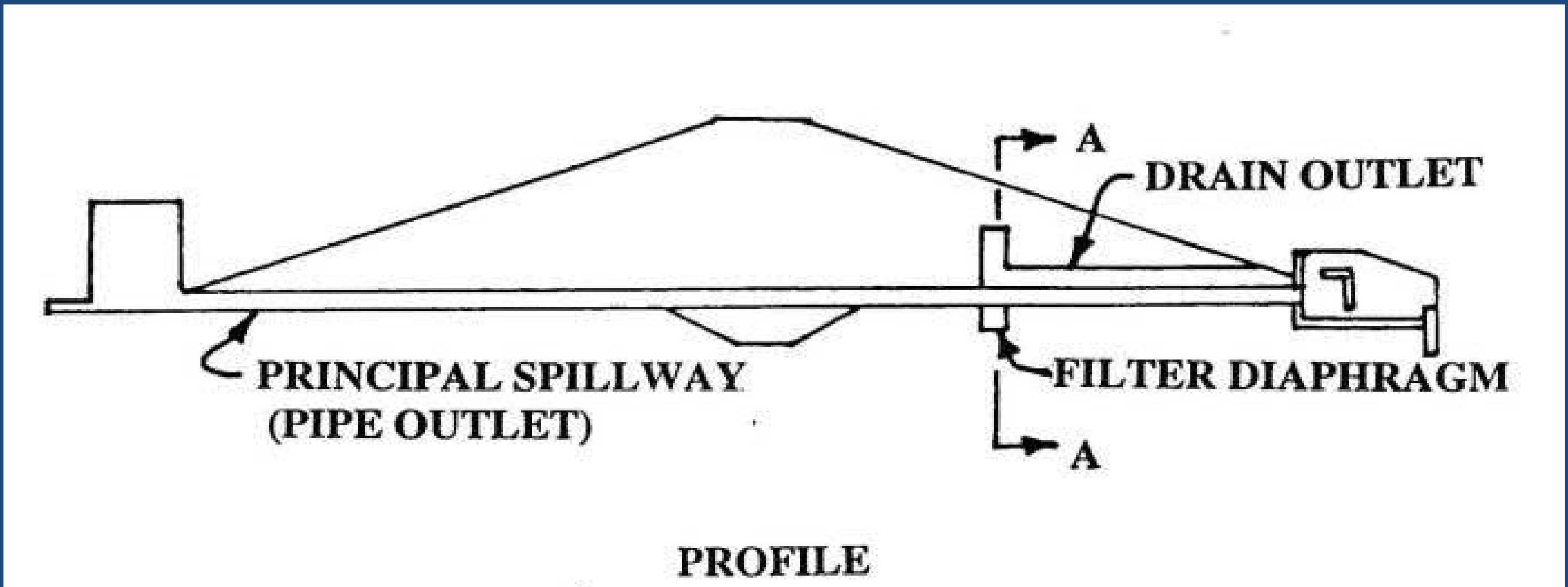
Dimensions recommended by NRCS for filter diaphragms in homogeneous dams with no other internal drainage system such as a chimney drain

Filter Diaphragm or Collar for Outlet Works

FEMA Filter Design Around Conduits

Inside Diameter	Minimum Dimensions			
	Sides	Top	Below	Thickness (upstream to downstream)
< 2.5 ft	3 diameters	3 diameters	1.5 diameters	3 ft
> 2.5 ft	8 ft	8 ft	4 ft	8 ft

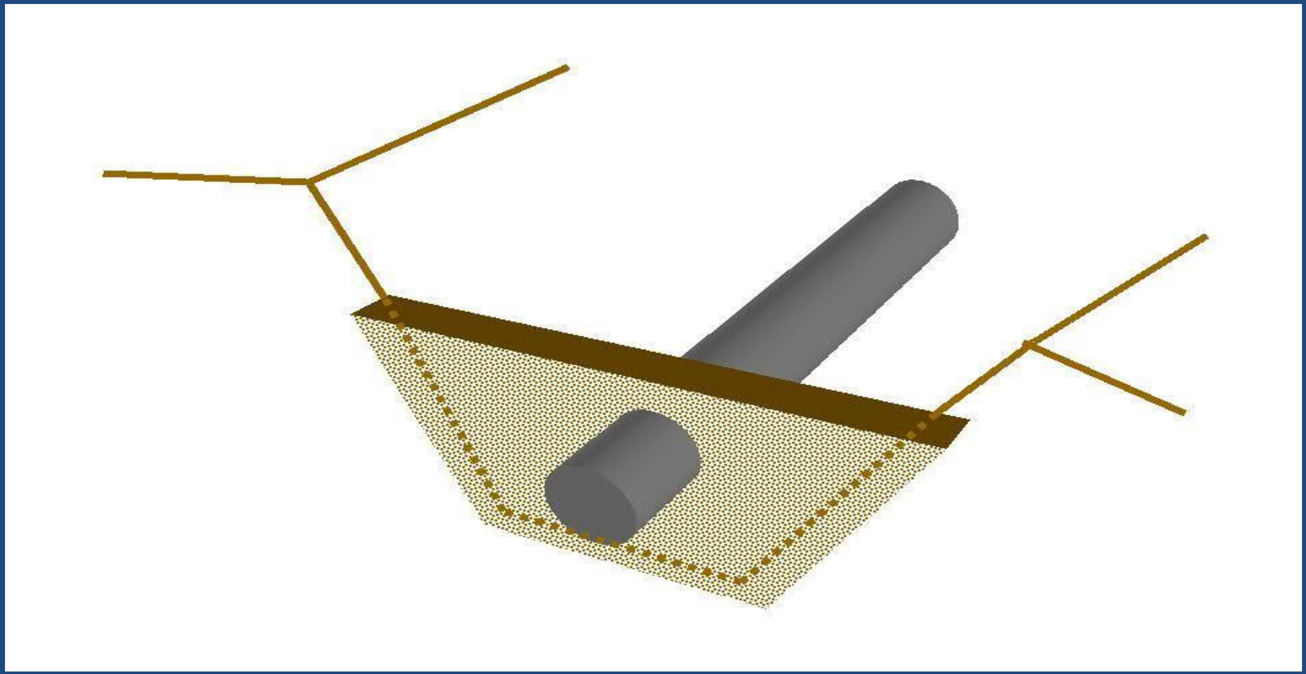
Filter Diaphragm or Collar for Outlet Works



For a small homogeneous dam with no chimney drain, NRCS recommends a filter diaphragm (collar) around the outlet works conduit approximately 2/3 distance through the dam with outlet to the downstream toe for discharging collected seepage water

Filter Diaphragm Placement

Filter Diaphragm for Outlet Works



If the outlet works is located in a trench below the foundation level, the filter diaphragm should extend a short distance into the slopes of the excavation to intercept seepage that may follow the contact between earthfill and the natural foundation soil

Some Practicalities

- Natural vs. processed materials
- Use of standard gradations
- Drain pipe gravel envelopes
- Geotextiles

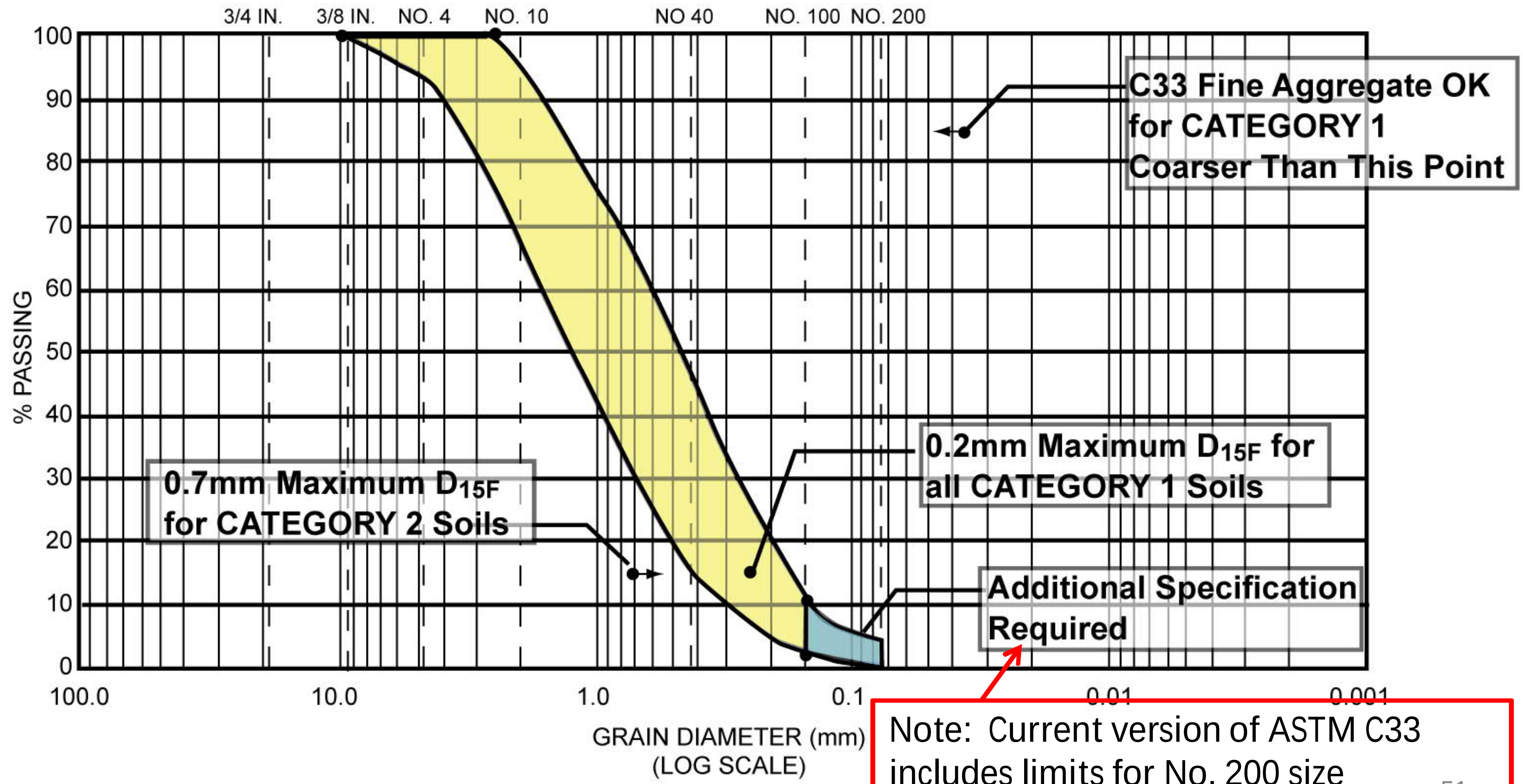
Natural vs. Processed Materials

- Rare to find natural soils suitable for filters
  – Not "clean" enough
  – Can be gap graded
  – Gradations can vary significantly within the deposit
  – Can contain excessive coarse particles - segregation
- Readily available ASTM C33 fine aggregate is an excellent filter in almost all cases

ASTM C33 Fine Aggregate

- Suitable for most base soils
- Readily available
- Similar gradations can be used, if available at less cost
- Not suitable for some clays and silts (some Category 1 base soils) – soils with more than 85% finer than about 0.045 mm

ASTM C33 Fine Aggregate as a Filter

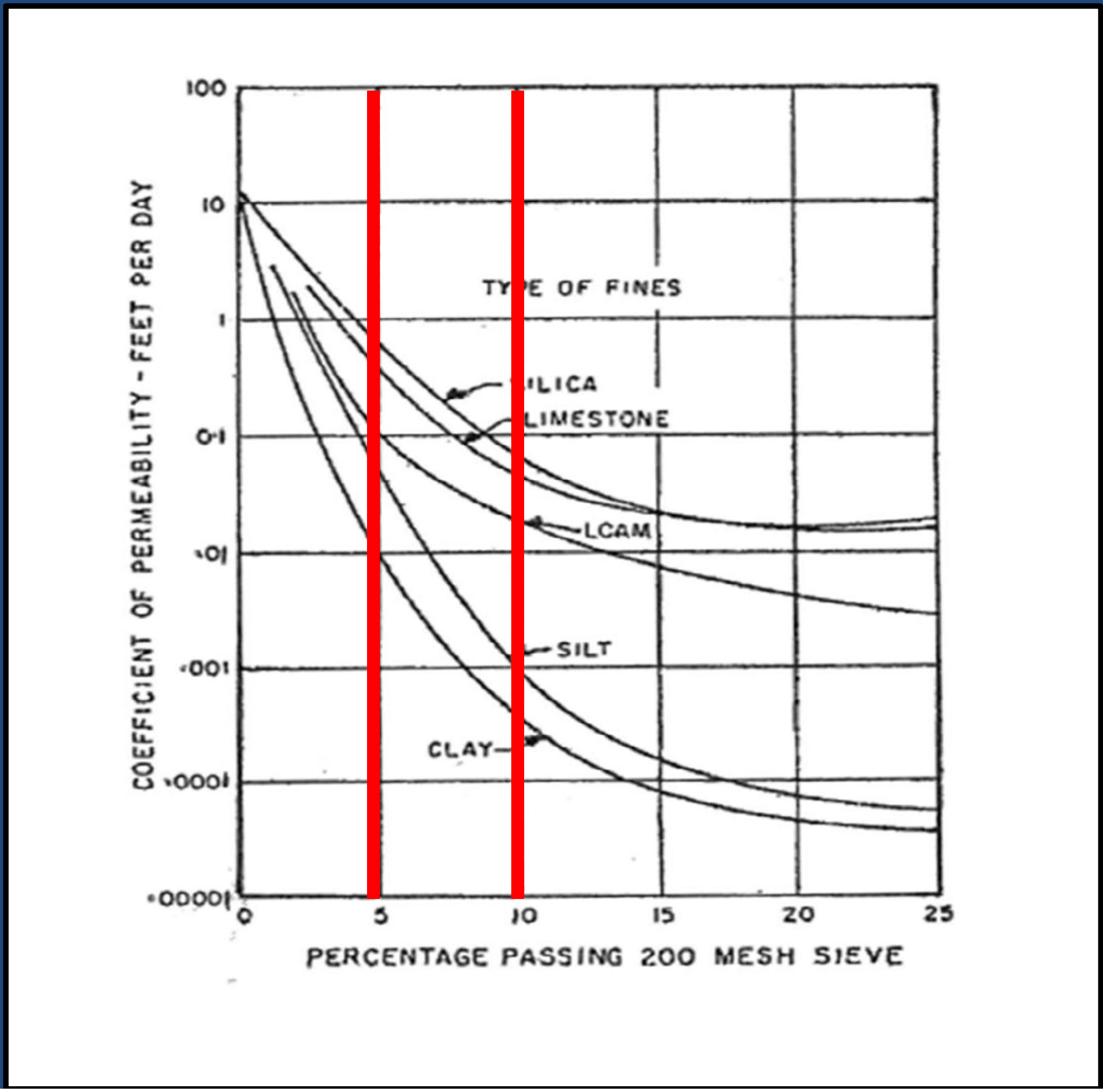


Note: Current version of ASTM C33 includes limits for No. 200 size

Fines Contents for Filters and Drains

- Recommend ≤2 to 3% in stockpile and ≤5% in place
- Some breakdown should be expected
- Permeability decreases dramatically with fines contents greater than 5%

Effect of Fines Content



Standard Gradations

- Economical for small quantities
- Specify locally available sand and gravel materials that fall within the latitude of the filter requirements
- Potential sources:
  - State DOT specifications
  - AASHTO gradations
  - ASTM gradations
  - Products of local aggregate producers
- Verify local availability
- Avoid cohesive fines

Gravel Envelopes Around Drain Pipes

- Slotted pipes embedded in filter sand often become plugged
- Full pipe capacity is not realized

Clogging of Slotted Drain Pipe Embedded in Sand Filter

Criteria for Pipe Perforations or Slots

Bureau of Reclamation and Corps of Engineers	$D_{50} \geq$ max. opening size
Natural Resources Conservation Service	Non-critical: $D_{85} \geq$ max. opening size Critical: $D_{15} \geq$ max. opening size

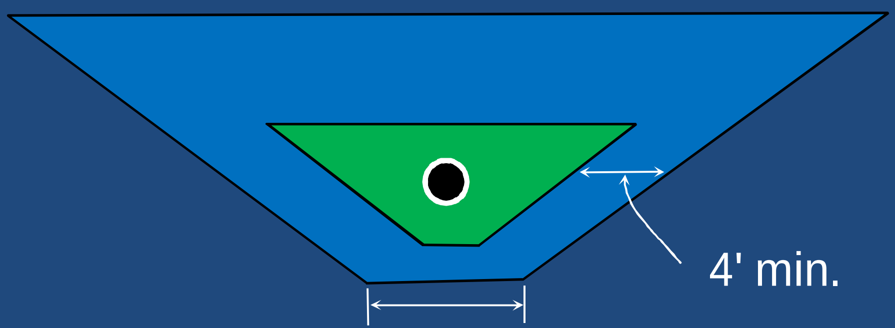
D_{85} = 85% size of aggregate surrounding pipe

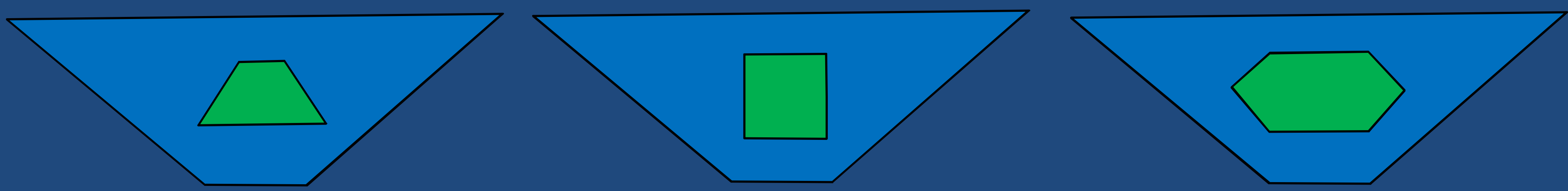
D_{15} = 15% size of aggregate surrounding pipe

Slots or Holes

- Slots are preferred – less chance of clogging
- Not that important – either should work if sized correctly

Gravel Envelope Configurations





Other Configurations

Pipe Size

Pipe size is controlled by the most stringent of the following criteria:

- Minimum inner diameter
  - This requirement is for access for future camera inspection
- Estimated maximum flow rate should not exceed a flow depth of 75% of the pipe height.
  - This requirement is to account for post construction sags in the pipe alignment due to differential settlement.
  - Pipes should not flow full or be pressurized.

Geotextiles

- Susceptible to installation damage
- May clog or deteriorate
- Use in critical locations not allowed by USACE and Reclamation
- Published position of the NDSRB:
  - "It is the policy of the National Dam Safety Review Board that geotextiles should not be used in locations that are critical to the safety of the dam." [1]

[1] Geotextiles in Embankment Dams, Status Report on the Use of Geotextiles in Embankment Dam Construction and Rehabilitation, FEMA, 2008

Seepage “Cut Off” Methods

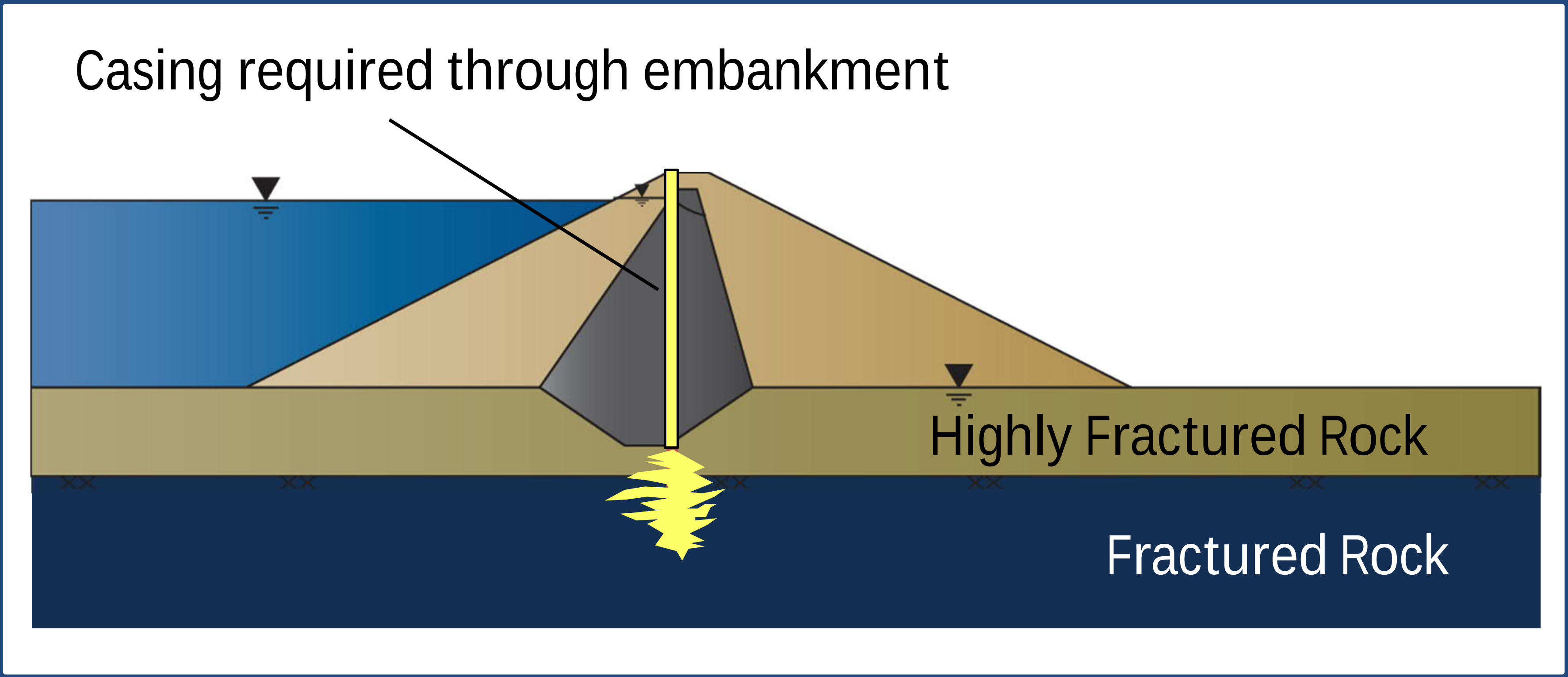
- Grouting
- Low Permeability Blankets
- Barrier Walls

Note: Cut off is in quotes, because it is very difficult to truly cut off seepage – seepage reduction or seepage barriers may be better terms.

Some Cut Off (Barrier) Considerations

- Based on estimated seepage flow paths – how well are these known?
- Often involves underground construction, which cannot be directly observed.
- May create new seepage issues (e.g. high gradients at the bottom or edges of a barrier wall).
- May not require significant reservoir lowering.
- May not require dewatering.

Grouting

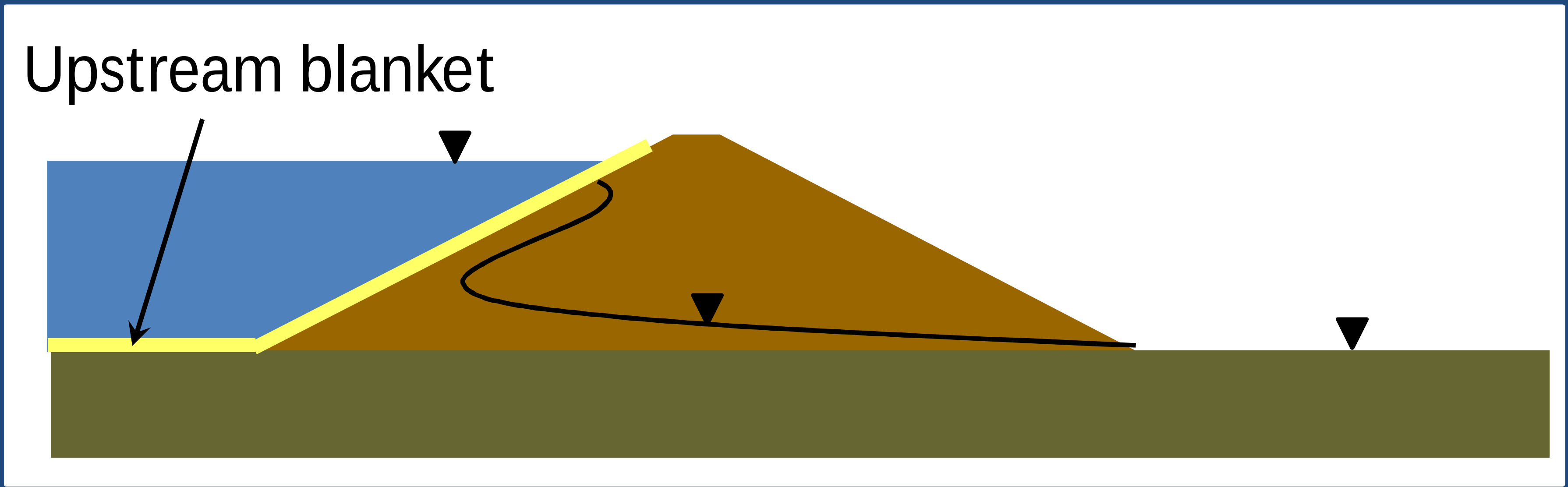


Note: For existing dams, grouting in soils is NOT generally recommended due to potential hydraulic fracturing issues; caution needs to be exercised near top of rock and in weathered rock.

Grouting Cautions

- Limited soils for which grouting is effective.
- Soils (and soft rock) can be hydrofractured.
- Current practice is multiple lines.
- In rock, grout only penetrates water- and air-filled features – potential future erosion of remaining infilling.
- Grout may deteriorate over time.
- Grouting is sometimes considered to be a temporary solution.

Low Permeability Blankets



- Soil Blankets
- Geomembranes

Possible need for connection to existing water barrier in the embankment.

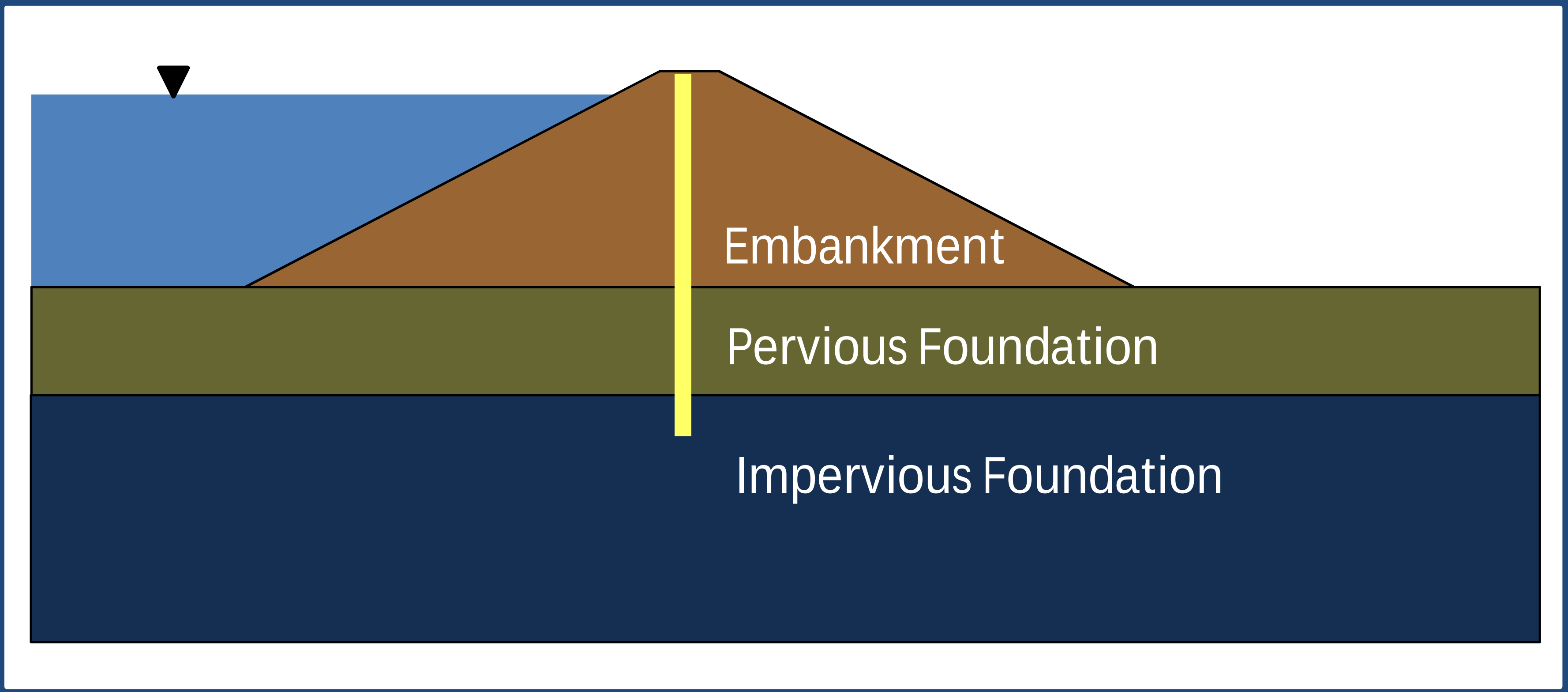
Low Permeability Blankets: Example 2

Ochoco Dam: Geomembrane – Surface Preparation

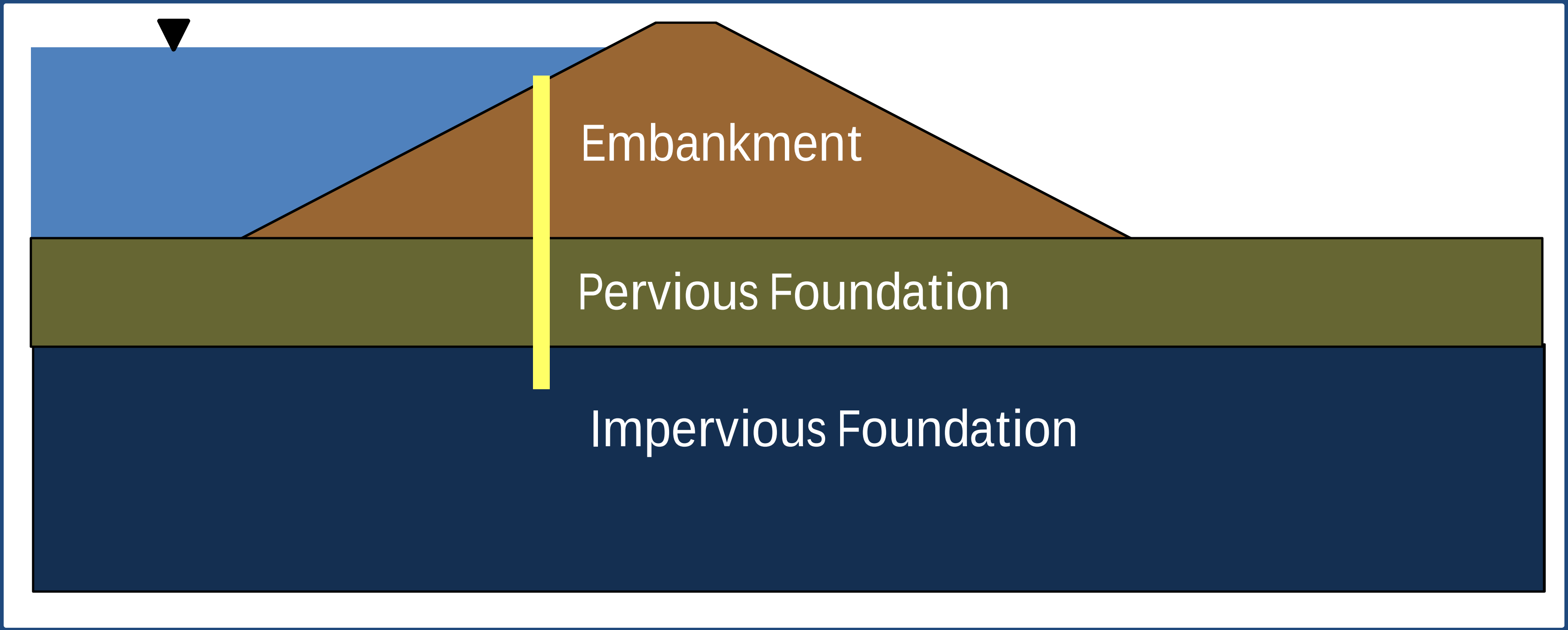
Placing the Membrane

Placing Protective Cover

Seepage Barrier Walls: Foundation and Embankment

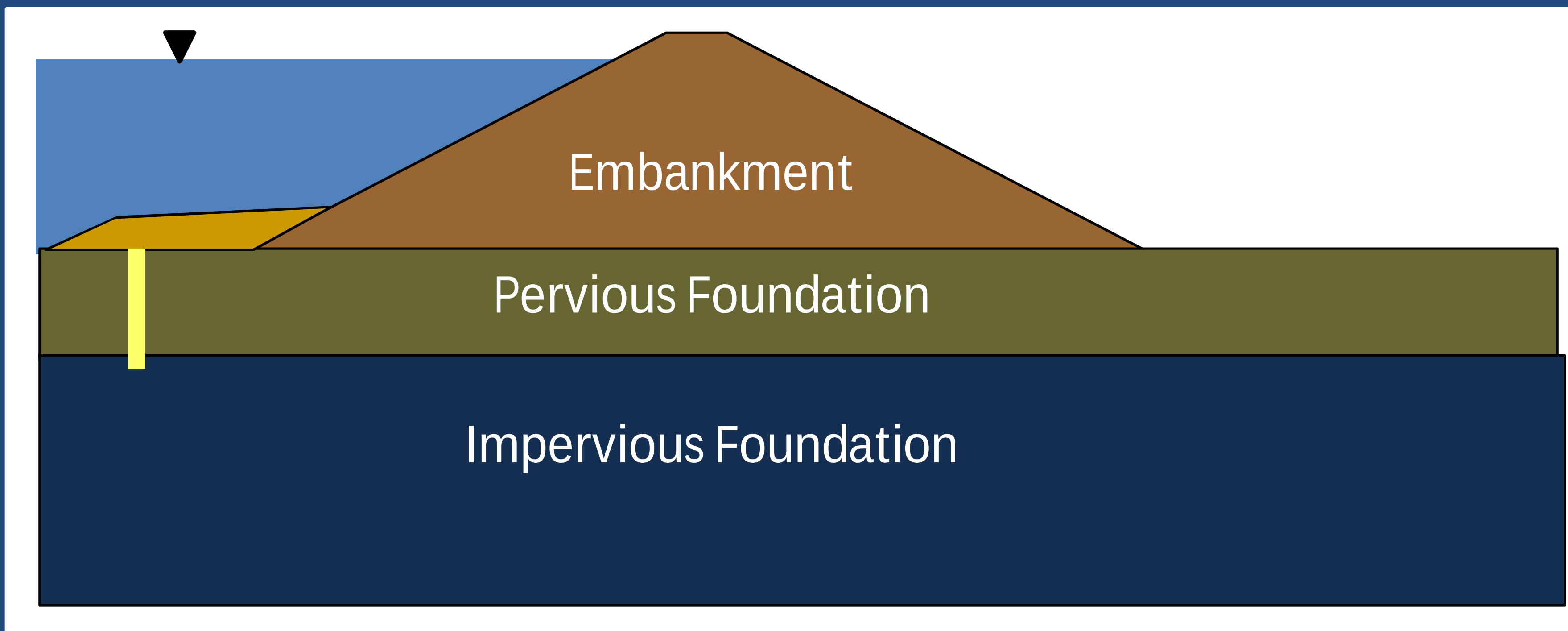


Seepage Barrier Walls: Foundation and Partial Embankment



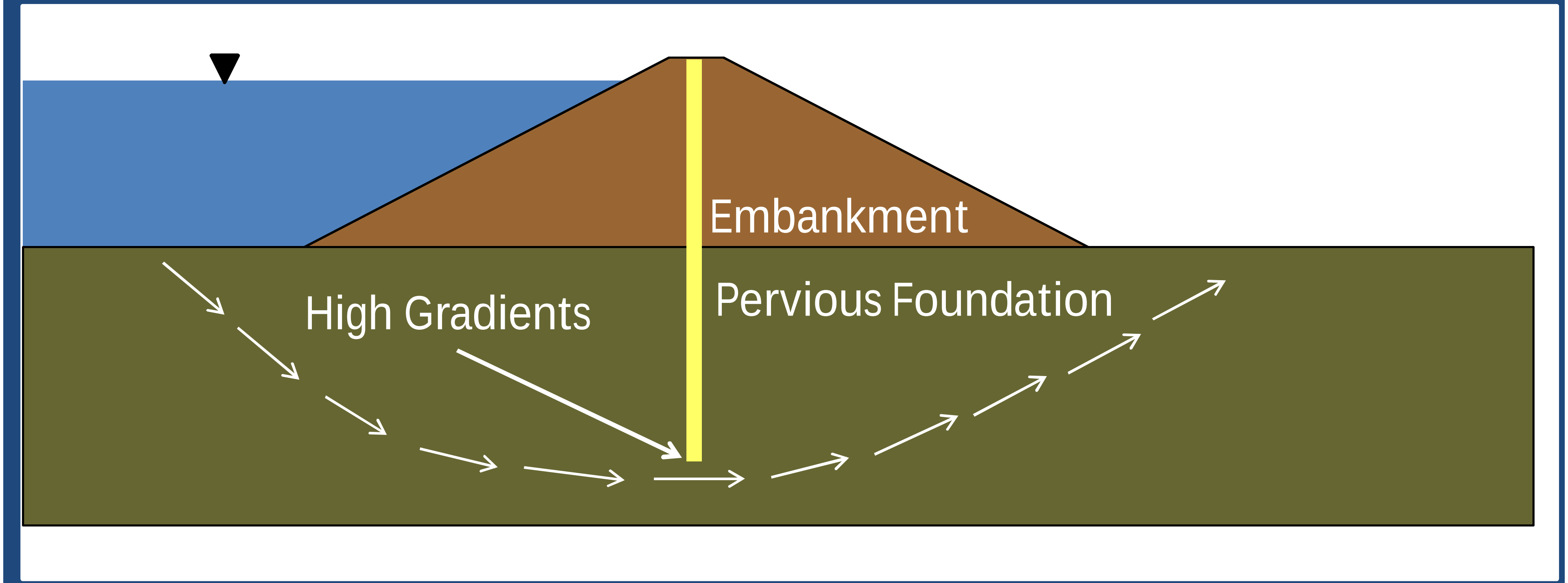
Wall needs to connect to water barrier in the embankment.

Seepage Barrier Walls: Foundation Only



Wall needs to connect to water barrier in the embankment.

Seepage Barrier Walls: Partial Cutoff

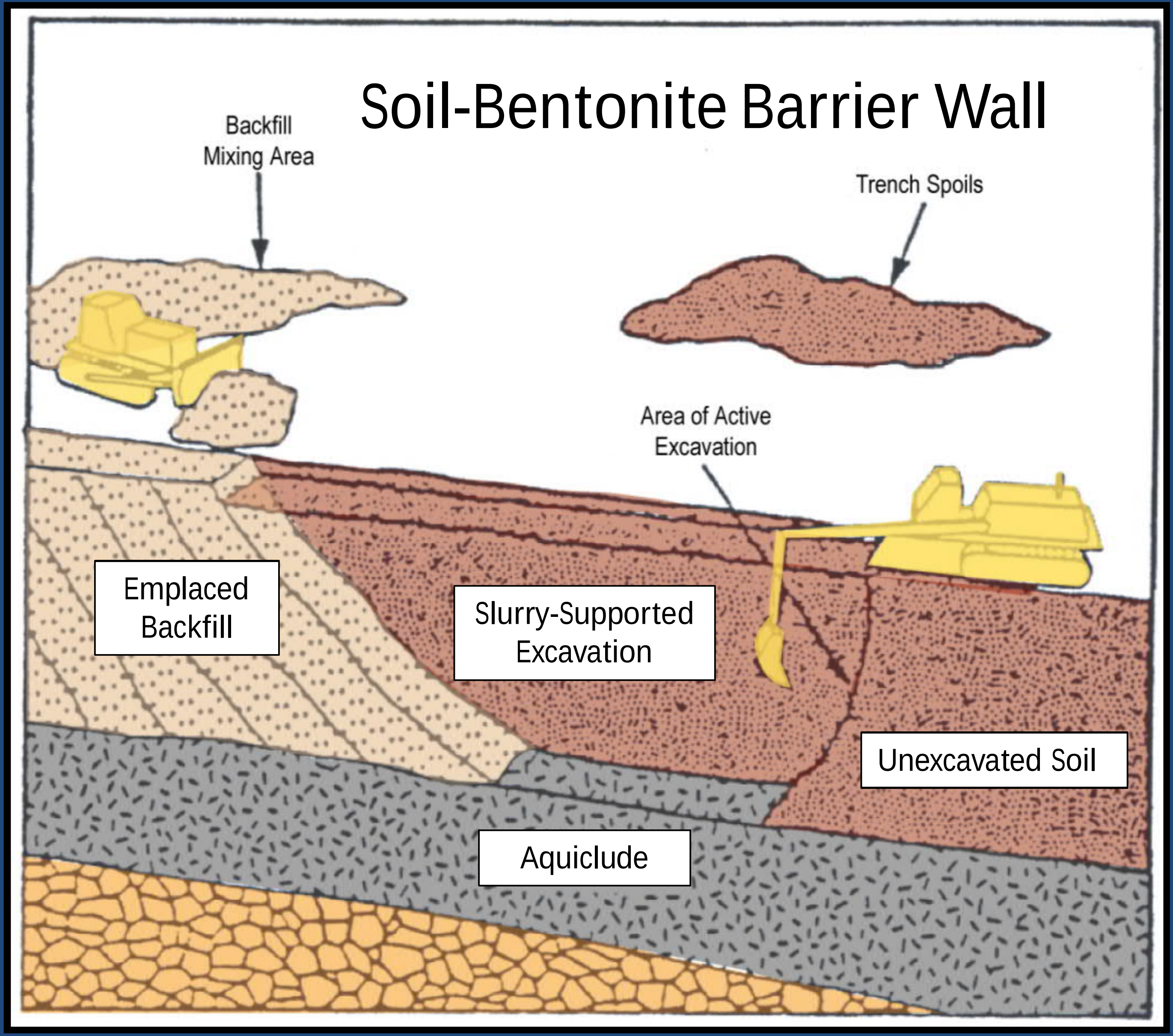


90% penetration allows almost 40% of original flow.

Seepage Barrier Walls

- Continuous Trench Walls
- Soil Mix Walls
- Single Pass Walls
- Element Walls (Panels and Secant Piles)
- Jet Grouting Walls
- Sheet Pile Walls

Continuous Trench Wall Construction



Continuous Trench Barrier Walls

Salient Features

- Low Cost/Rapid Const.
- Slurry Supported Excavation
- No Backfill Joints
- Non-Structural
- Low Permeability
- Depth up to ~85 feet with Backhoe

Typical Backfills

- Soil-Bentonite (SB)
- Cement-Bentonite (CB)
- Soil-Cement-Bentonite (SCB)

Excavators

- Long Boom/Long Stick Excavator
- Clamshell / Grab

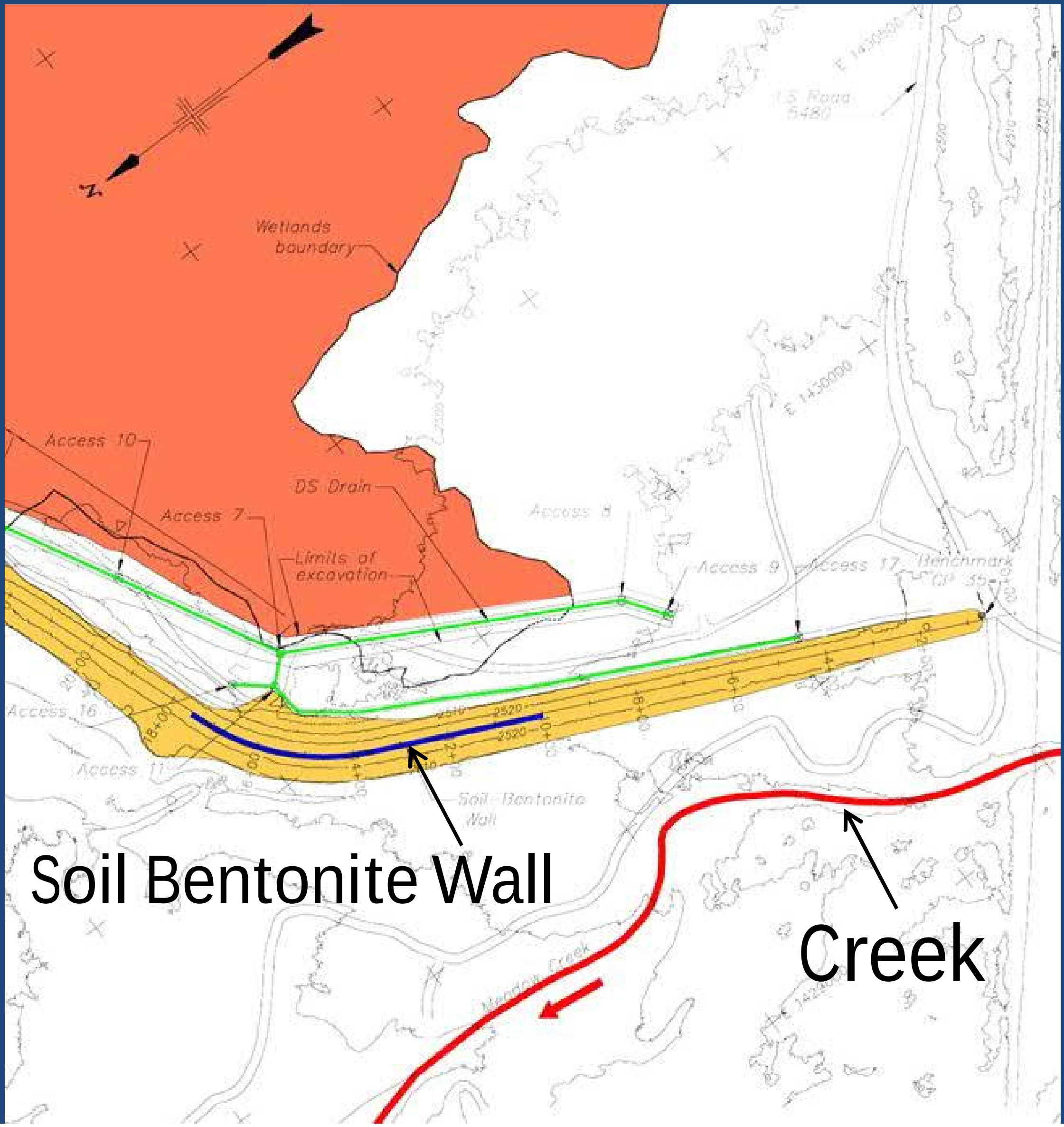
Backfill Equipment

- Bulldozer and Excavator
- Mixing Box
- CB Mix Plant
- No Tremie Placement
  (except for unusual depths)

Keechelus Dam

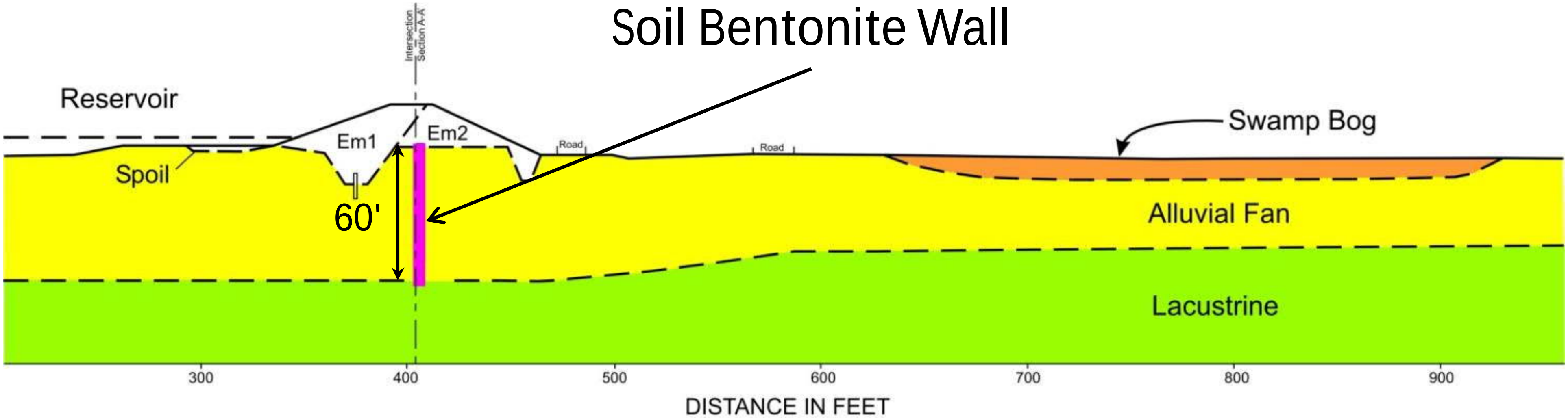
- Modified in 2002 for seepage and internal erosion deficiencies.
- Soil-bentonite wall installed near right end of dam as part of larger modifications.
- Foundation (alluvial fan) sand and gravel deposits.
- Soil amended with fines for 'soil' part of S-B Wall.

Keechelus Dam



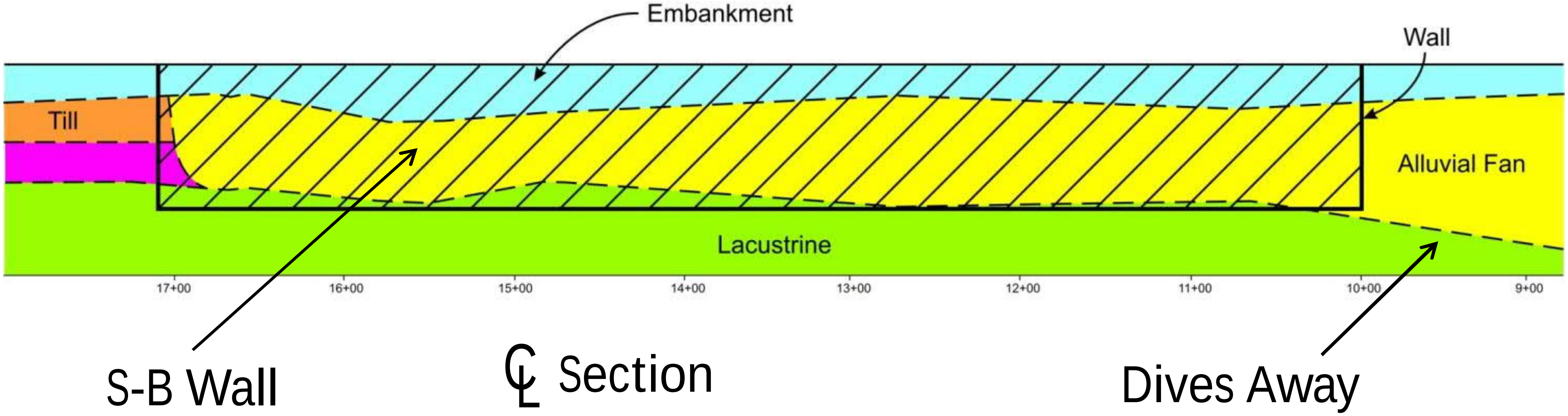
Keechelus Dam

Soil Bentonite Wall



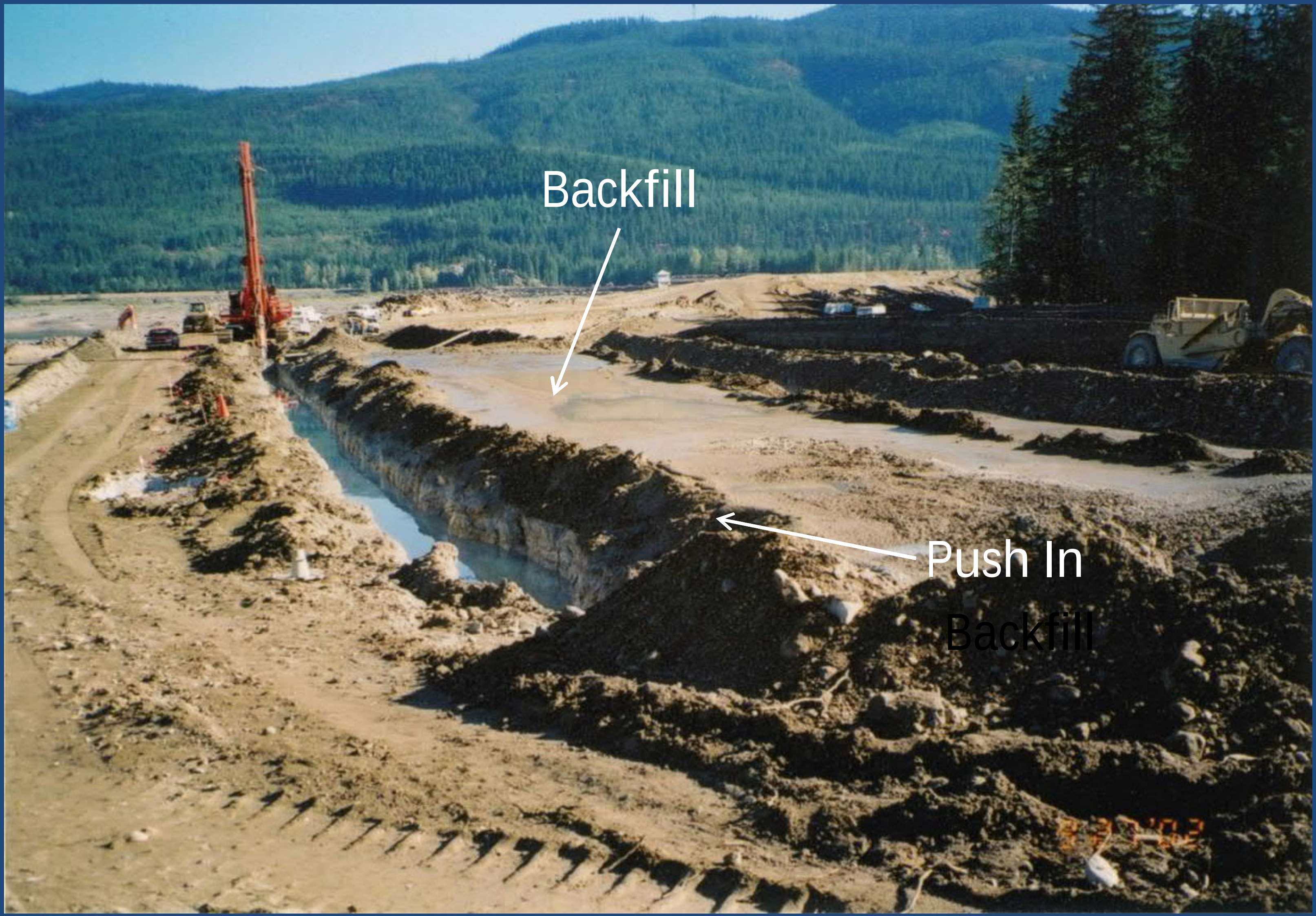
Cross Section - Left

Keechelus Dam



Keechelus Dam – Excavator

Keechelus Dam: Trench Excavation



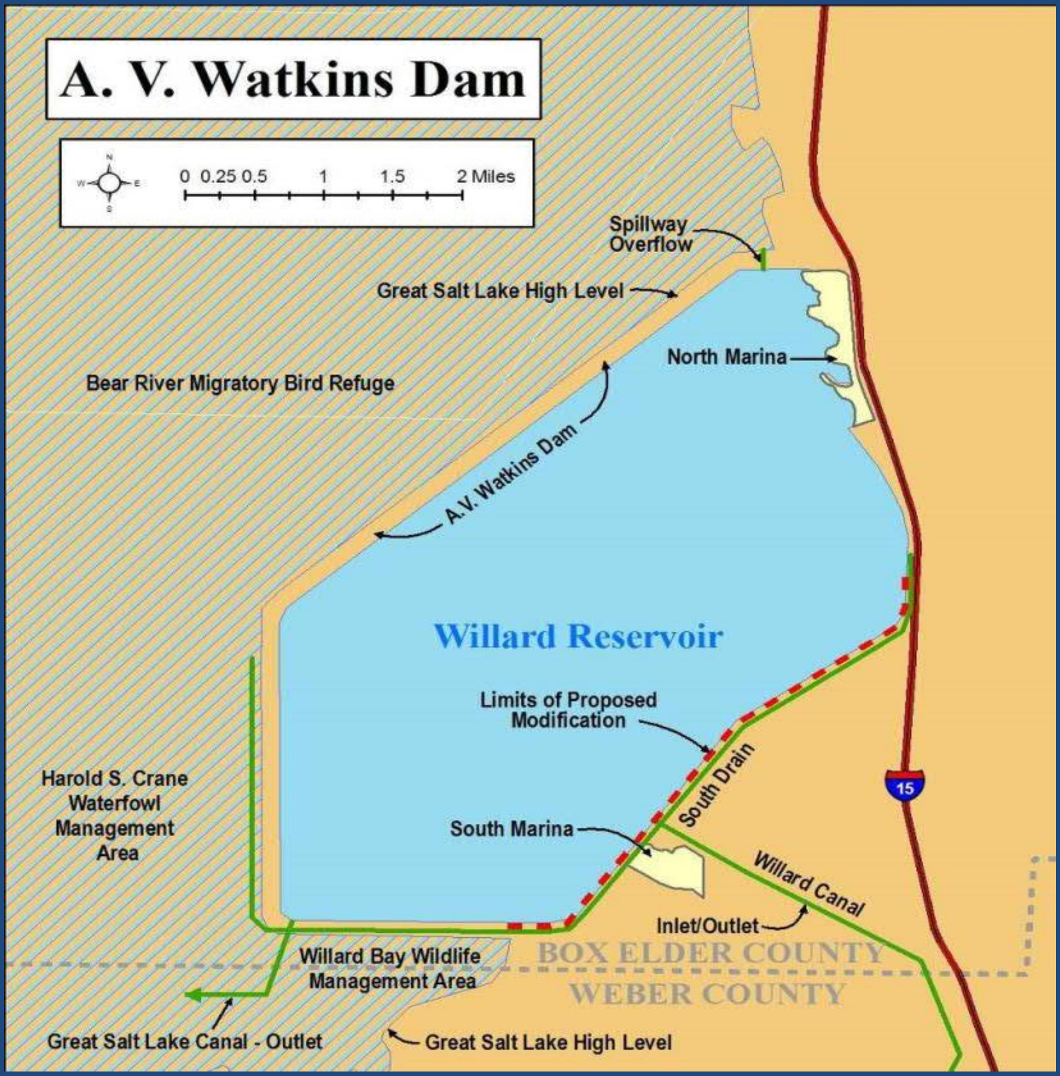
Keechelus Dam: Delivery of 'Fines' Soil

Keechelus Dam: Fines Stock Pile

Keechelus Dam: Mixing

A.V. Watkins Dam – CB Wall

- Impounds Willard Reservoir.
- Dam is 14 miles long.
- Earthfill Structure.
- Maximum Ht. = 36 ft (approx. 20 ft in incident area).
- November 13, 2006; active piping was noticed at approx. sta. 639+00.
- Intervention was successful in preventing failure.



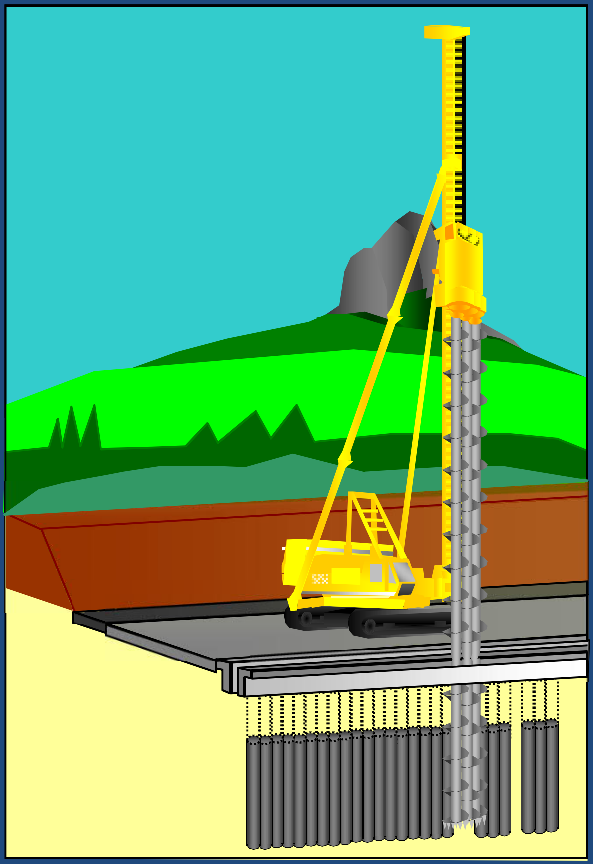
Cement Deep Soil Mixing (CDSM*)

Mixing in situ soils with cement grout or other slurries

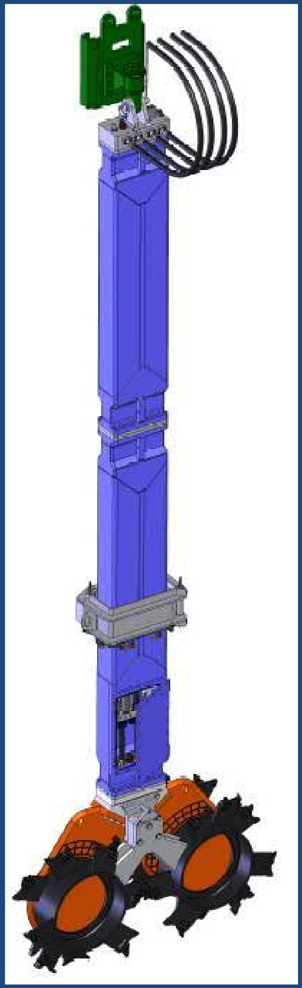
- Multiple shaft mixing tools with cutting heads and mixing paddles, or
- Wheels on horizontal axis or trenching techniques
- Depths currently somewhat more than 100 feet

* aka DSM, DMM – some names are trademarked

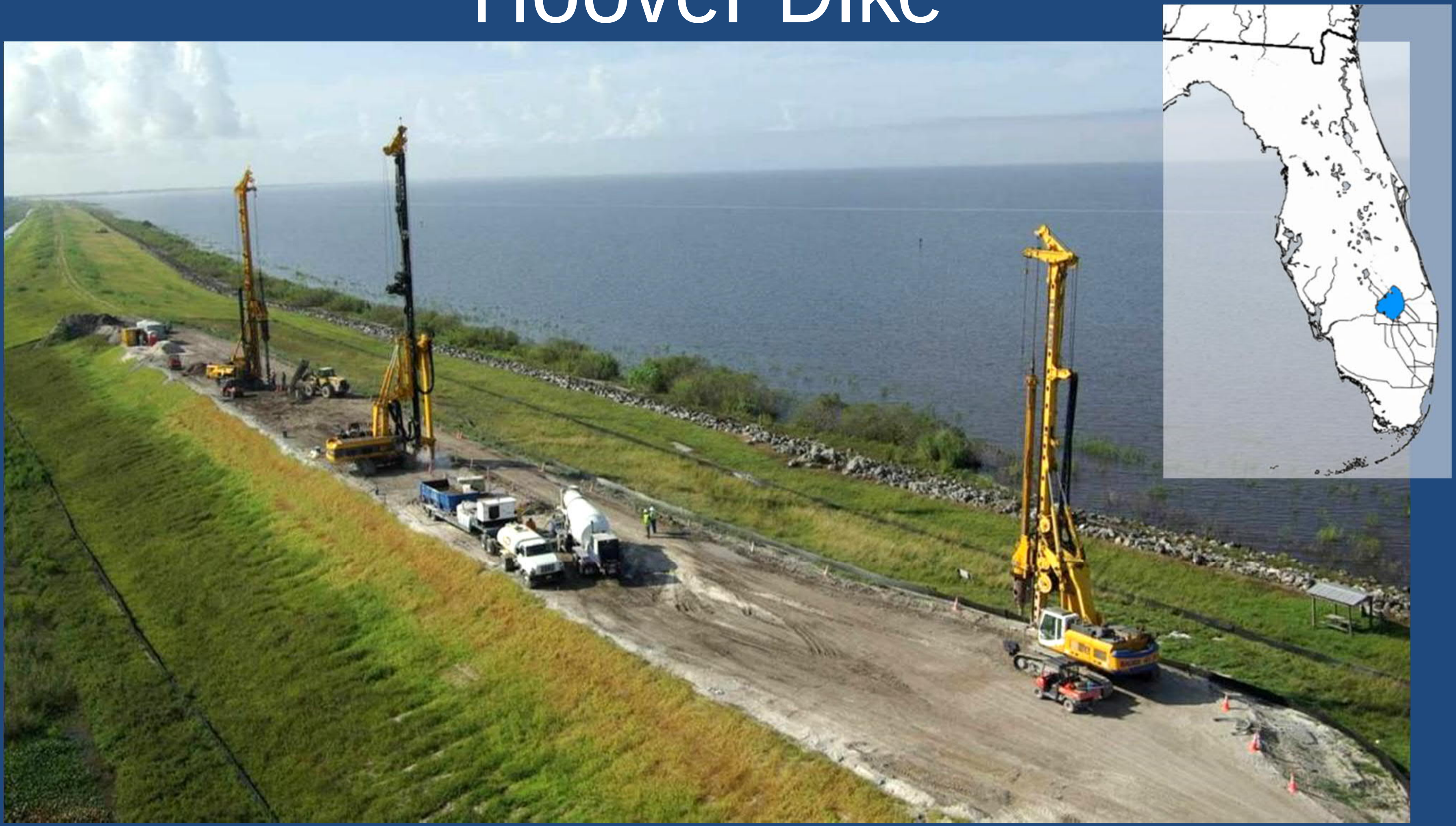
RSW (Triple Auger)



Cutter Soil Mixing (CSM)



Cutter Soil Mixing (CSM) – Herbert Hoover Dike

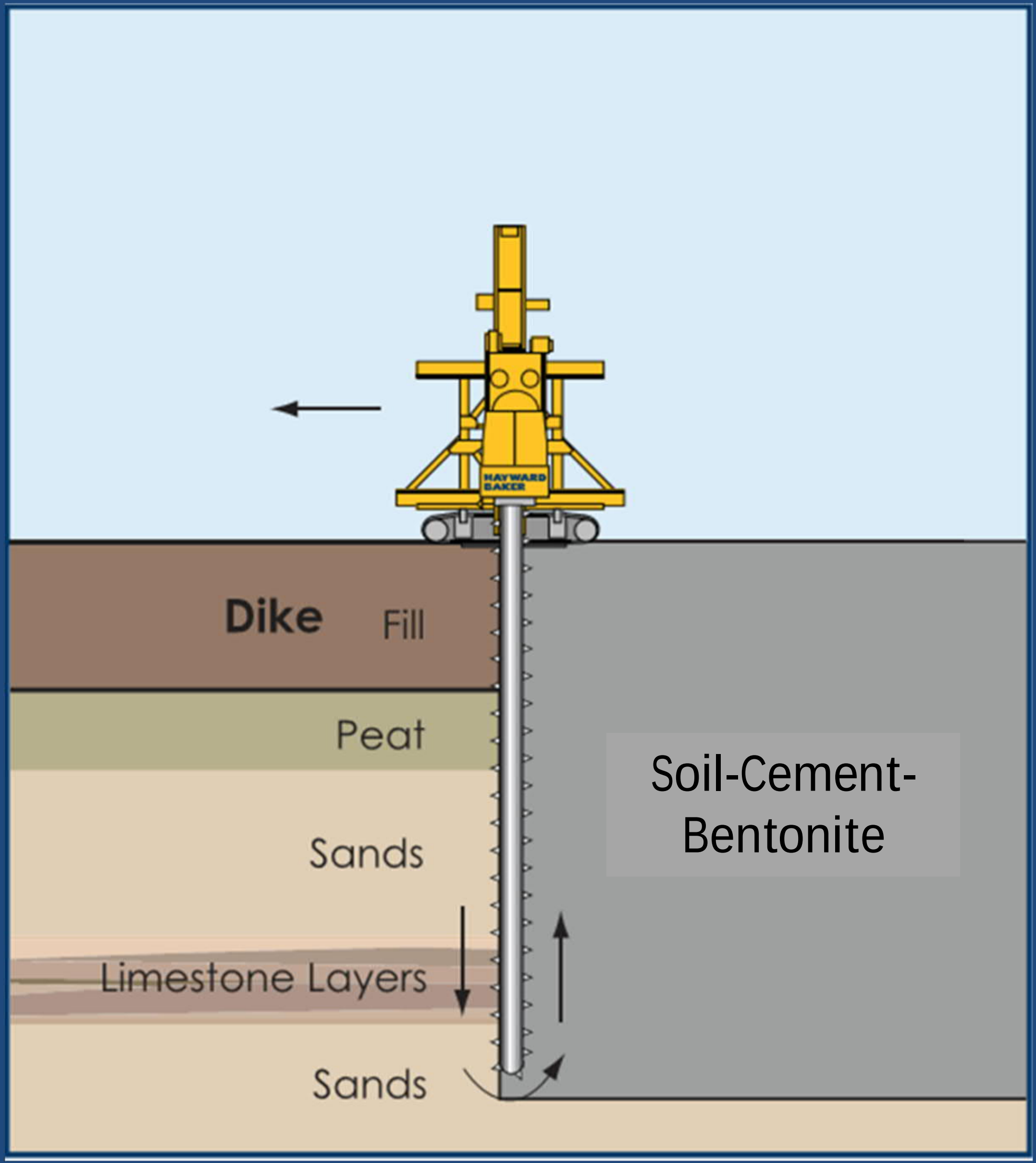


Single Pass Methods

- Trench Cutting Remixing Deep (TRD) Wall Method
- DeWind OnePass Method

Depths currently somewhat more than 100 feet; working on machines for up to 150 feet.

TRD Method



HAYWARD BAKER
Dike
Fill
Peat
Sands
Limestone Layers
Sands
Soil-Cement-Bentonite

TRD Wall Construction - Herbert Hoover Dike

Top of Exposed TRD Wall - Herbert Hoover Dike

Top of Wall

Side of Exposed TRD Wall - Herbert Hoover Dike

DeWind OnePass

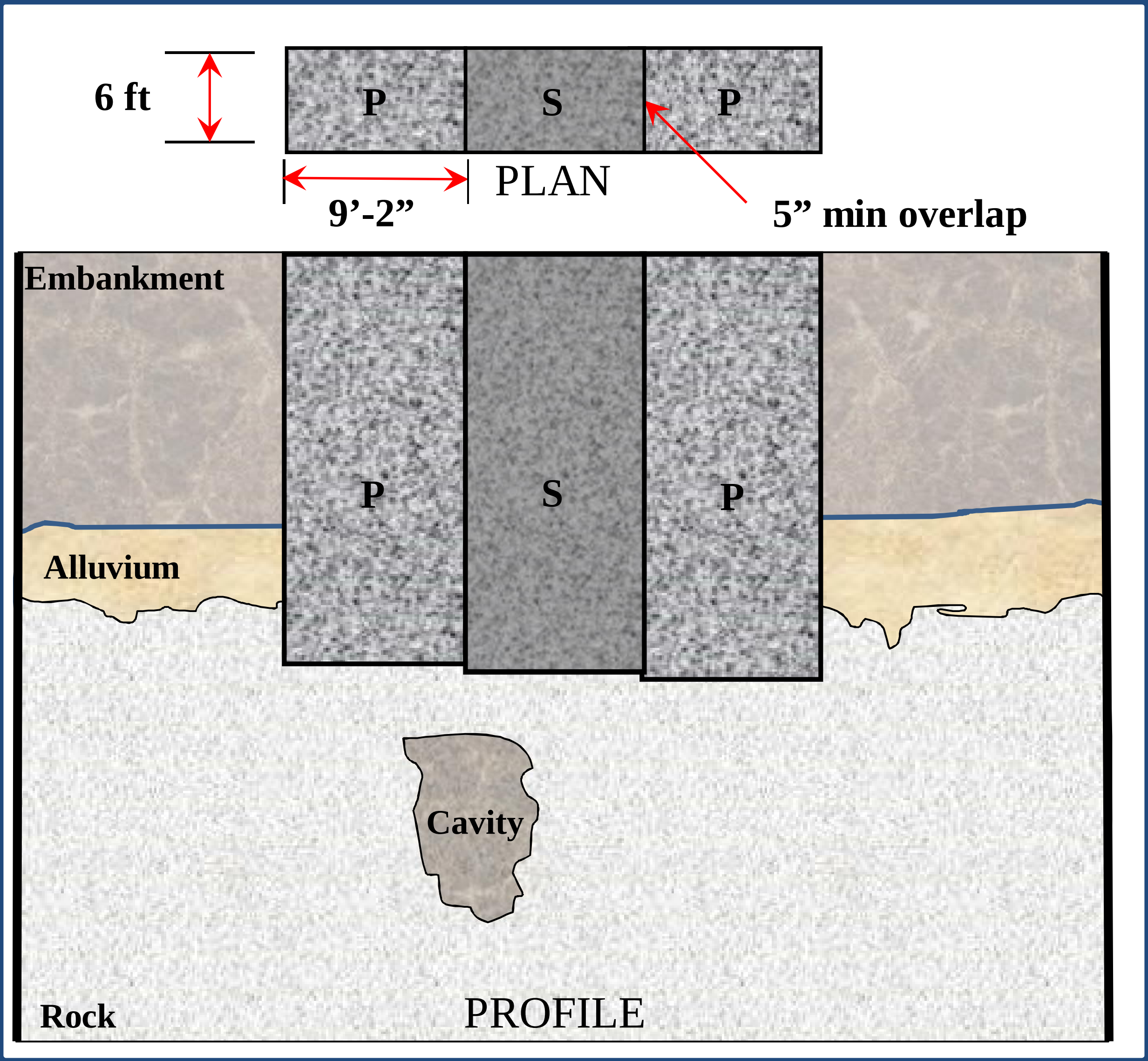
DeWind OnePass

DeWind OnePass

Element Barrier Walls

- Installed in primary / secondary sequence.
- Panels and secant piles are common elements.
- Can extend to great depths, but alignment control, joint integrity, and backfill quality can be challenging.
  - Pilot holes and guided equipment have been used to address alignment.

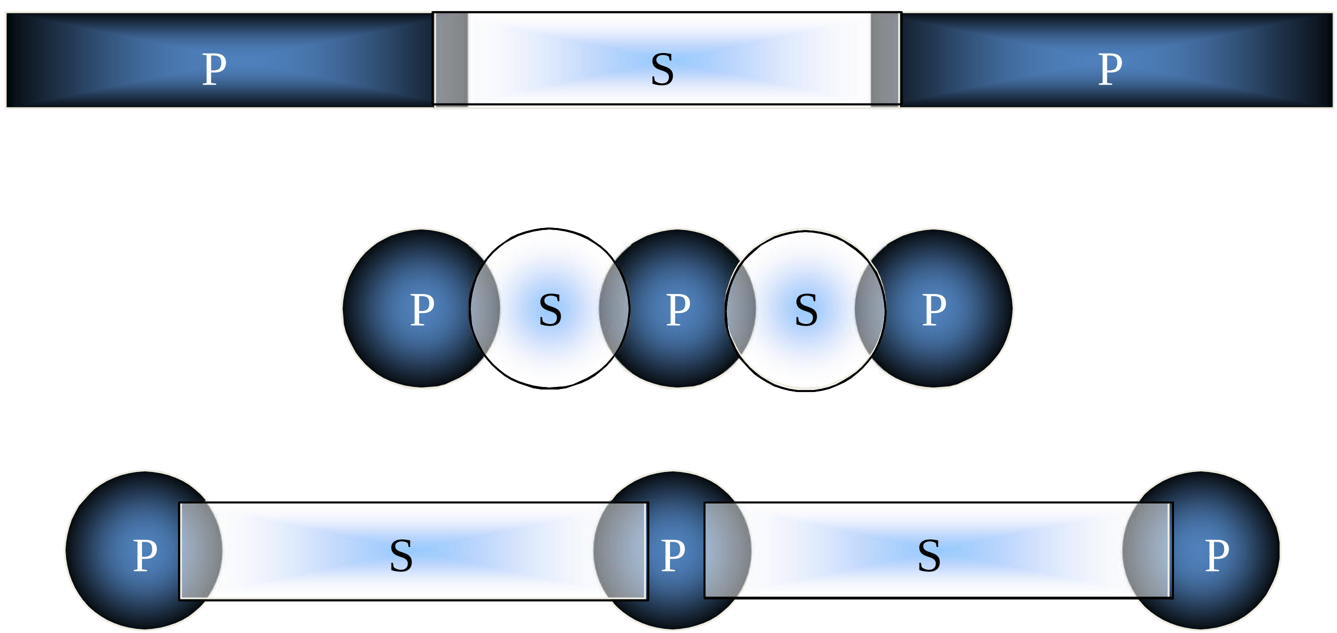
Primary / Secondary Sequence



Element Wall Configurations

Primary Elements
Installed First

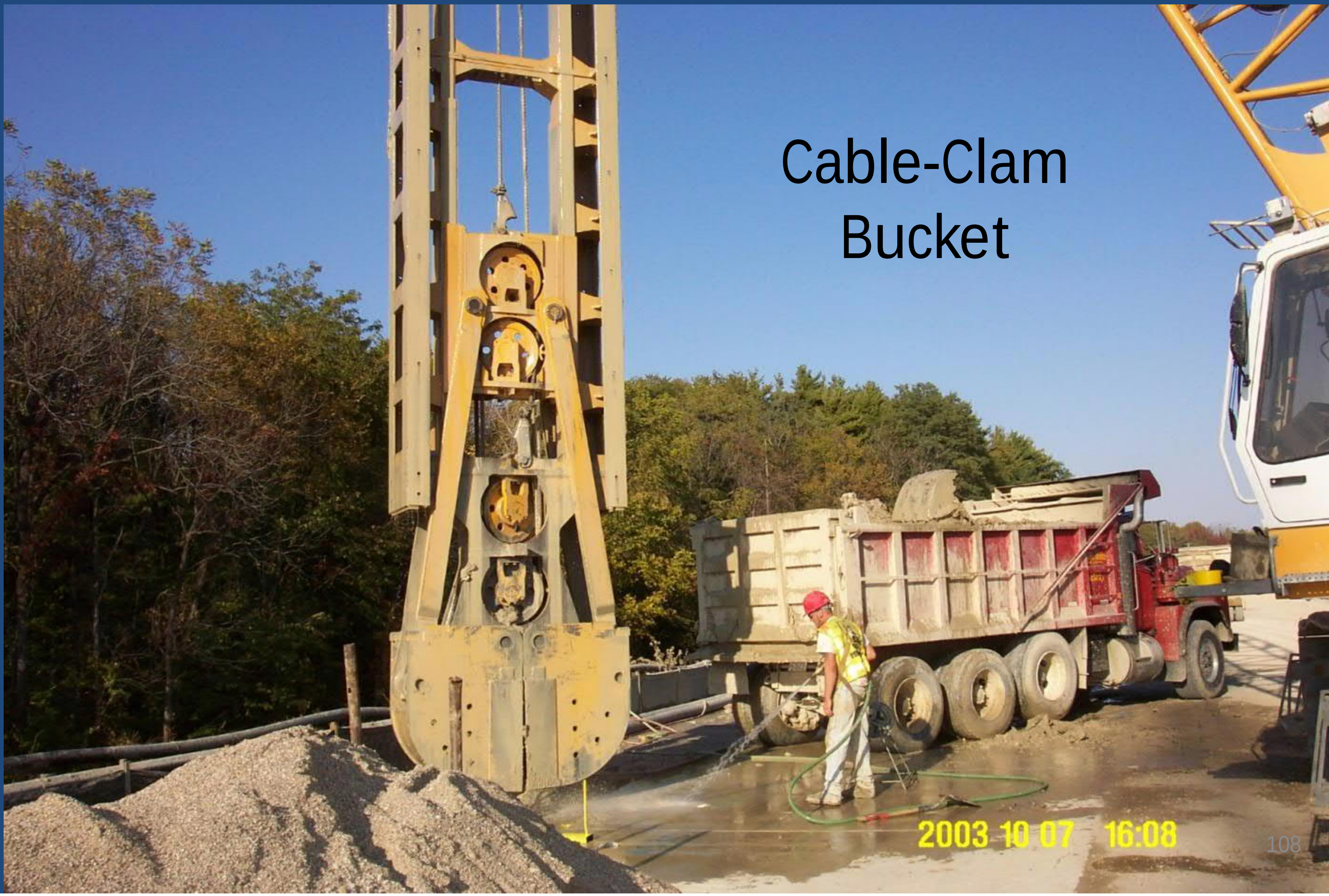
Secondary Elements
Fill Between



Panel Element Equipment

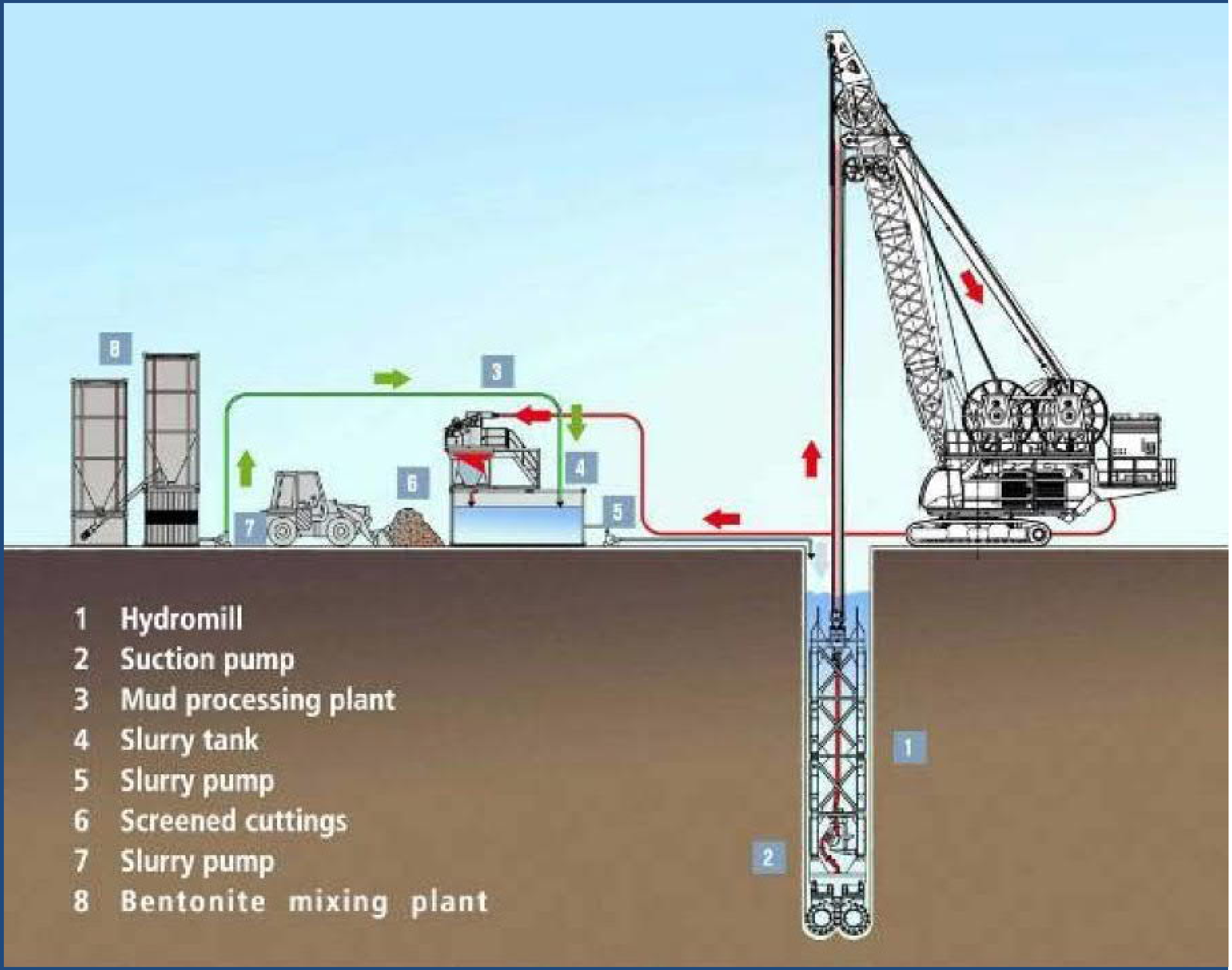
Grab or Clam Shell

Panel Element Equipment

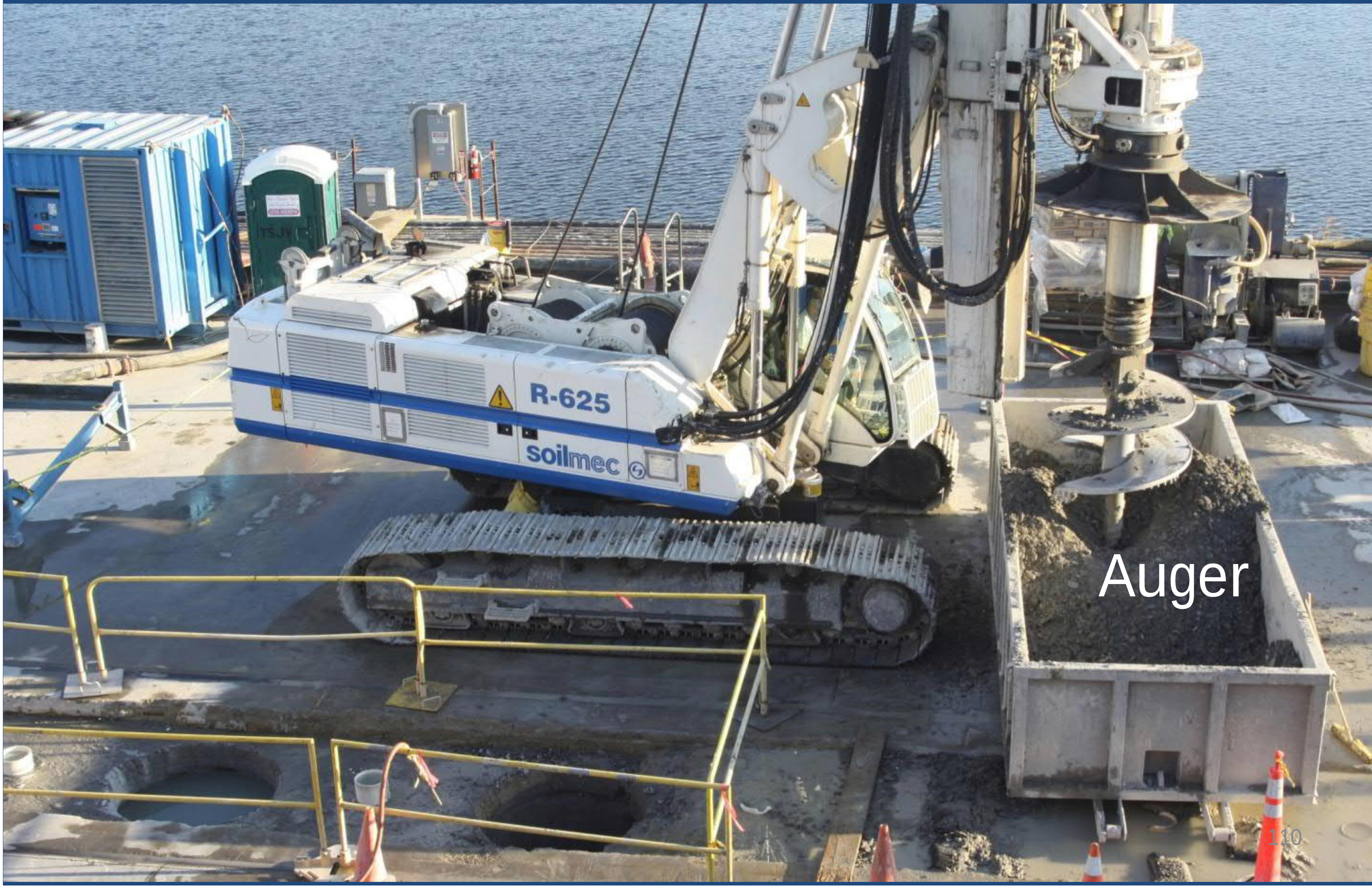


Panel Element Equipment

Hydromill (Hydrofraise)



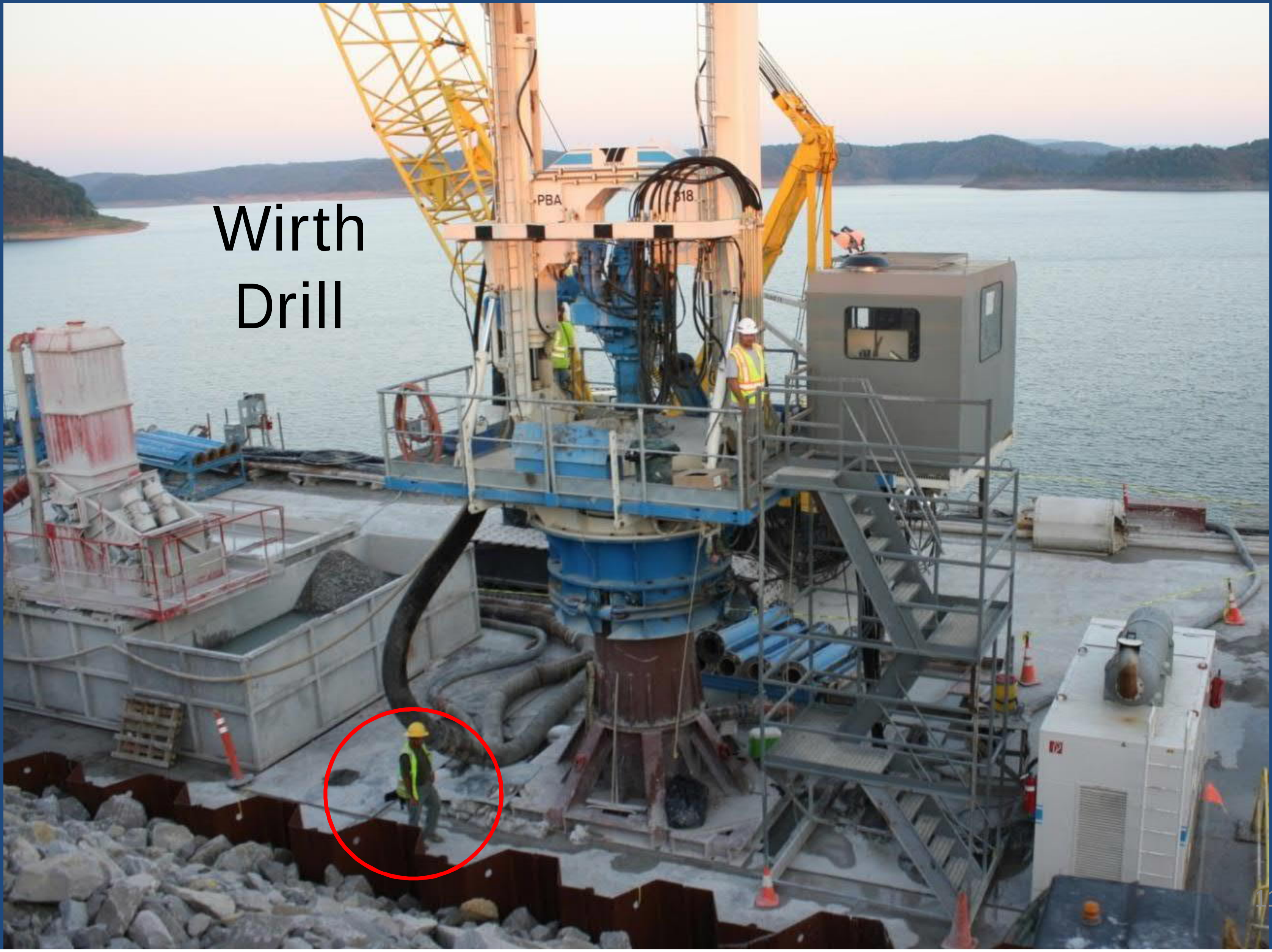
Secant Pile Element Equipment



Secant Pile Element Equipment

Secant Pile Element Equipment

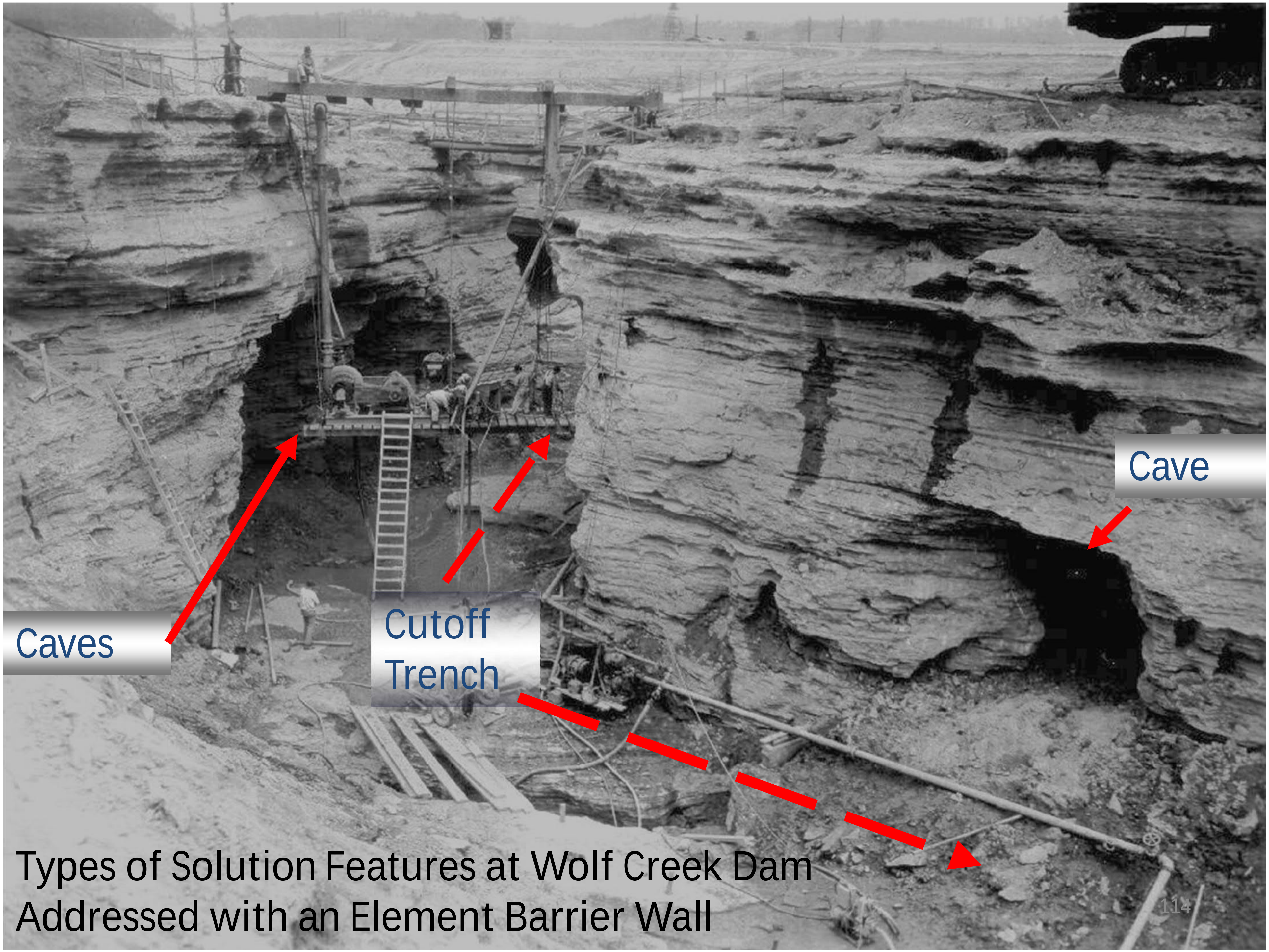
Wirth
Drill



Some Notable Element Barrier Walls

- Wolf Creek Dam – Kentucky (270’)
- Beaver Dam– Arkansas
- Mud Mountain Dam – Washington (420’)
- Walter F. George Dam – Alabama (210’)
- Navajo Dam- New Mexico (400’)
- Fontenelle Dam (180’)
- Center Hill Dam

About 400’ deepest to date, but technology is advancing.



Types of Solution Features at Wolf Creek Dam
Addressed with an Element Barrier Wall

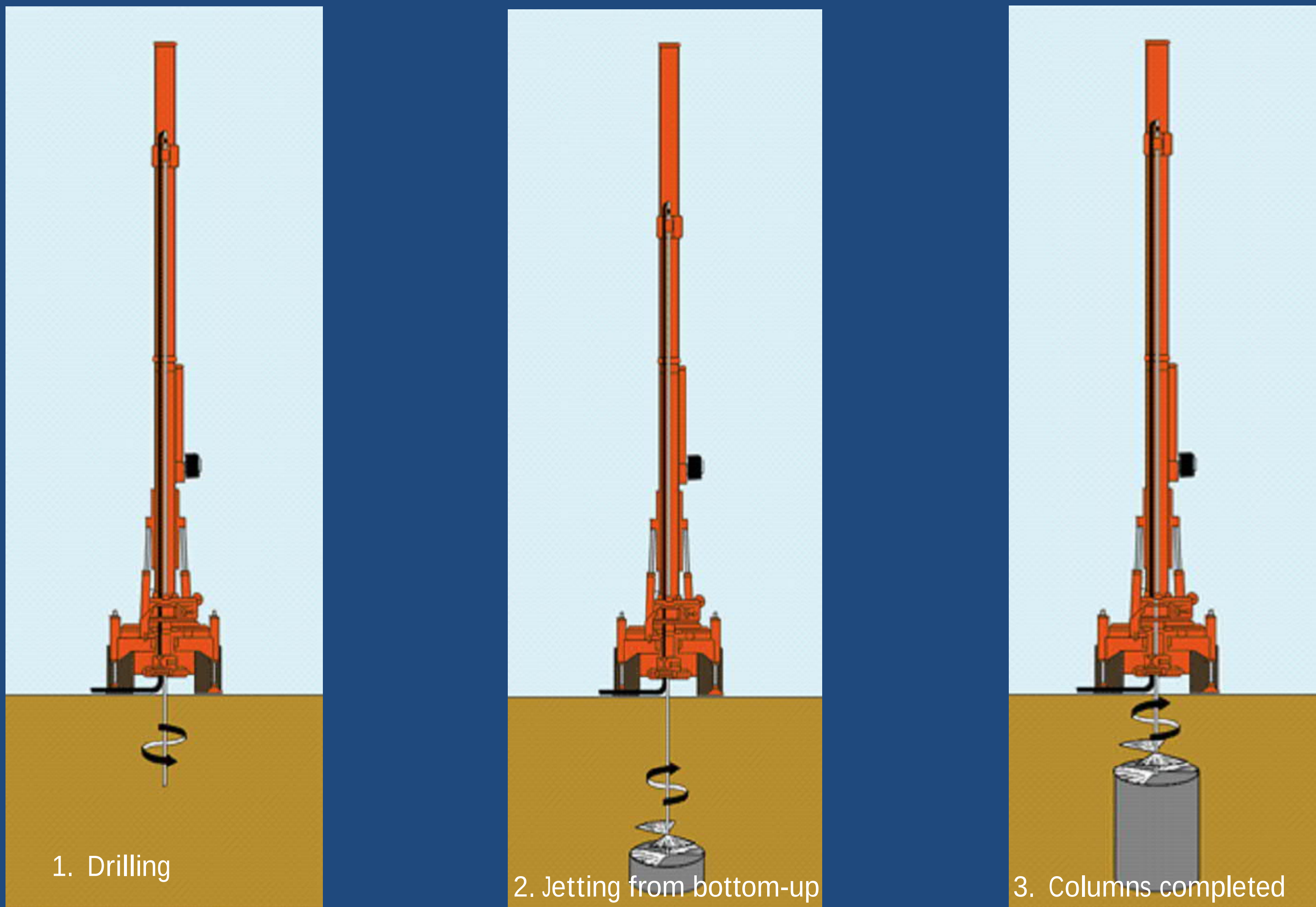
Jet Grouting - Features

- Suitable in a wide range of soils and applications.
- Columns with diameters ranging from 60 cm up to 250 cm (and perhaps more), by using small size drilled holes.
- Capability to overpass pre-existing masonry, boulders, rocky layers and obstructions.
- Use of light weight and small-sized drilling rigs able to operate in limited working areas.

Jet Grouting - Commentary

- Jet grouting is a soil improvement method.
- Jet grouted soil can work in compression and shear, not in tension.
- Jet grouted soil can be reinforced, but it is not a concrete structure.
- Depth limited only by drilling capability, but alignment and continuity will be a concern at large depths.
- Expensive on a per volume basis.

Jet Grout Working Sequence

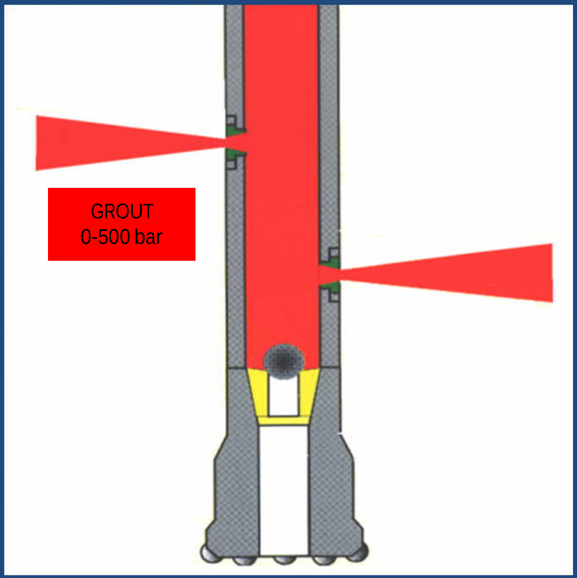


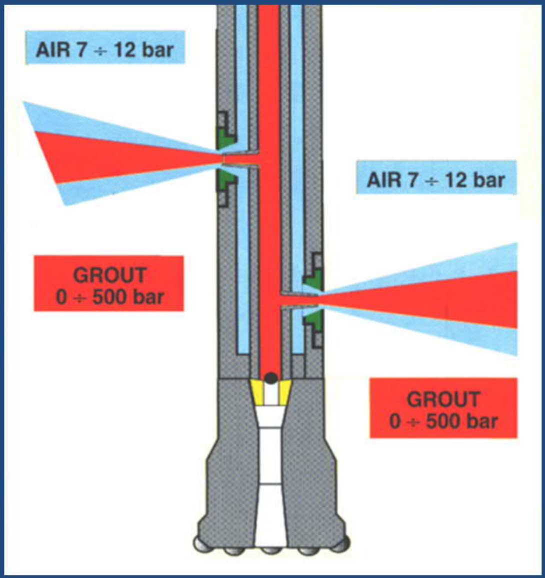
Three Categories of Jet Grouting

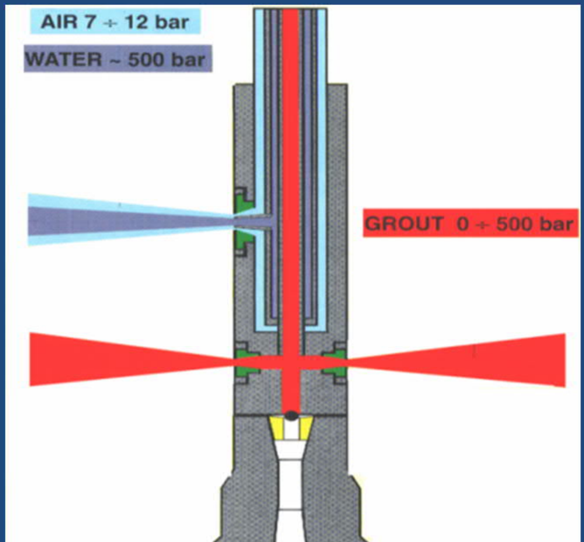
- SINGLE FLUID System: cement grout is used as disaggregating and consolidating fluid (T1) – standard diameter achievable 40-100 cm.

- DOUBLE FLUID System: cement grout plus air are used as disaggregating and consolidating fluid (T1/S) – standard diameter achievable 80-250 cm.

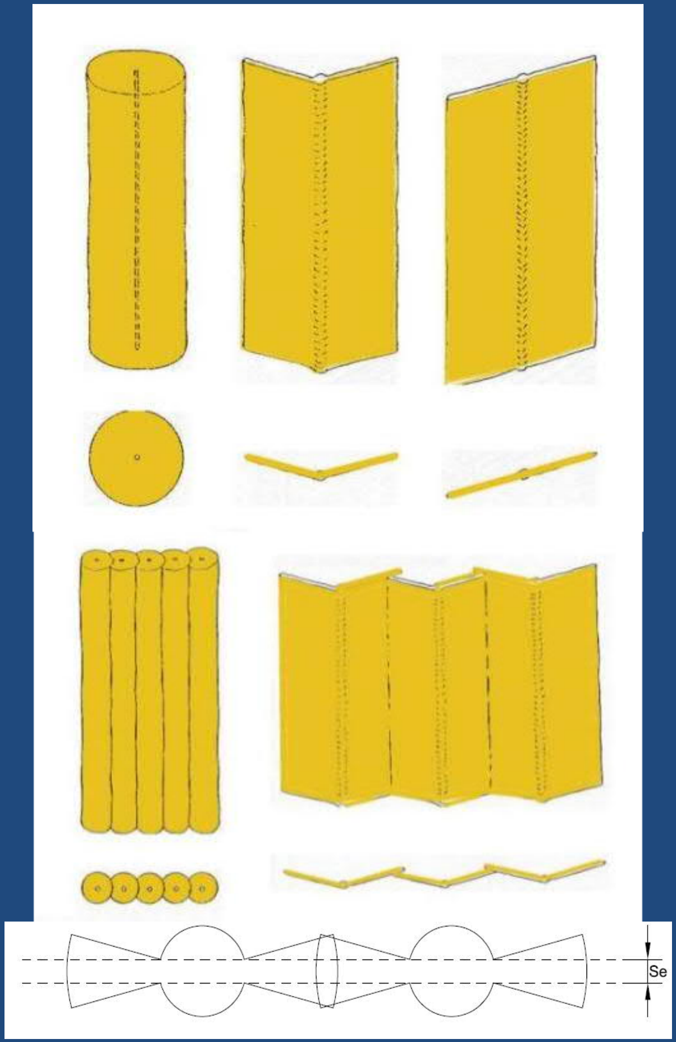
- TRIPLE FLUID System: water plus air are used as disaggregating fluid, while cement grout is used as consolidating fluid (T2) – standard diameter achievable 120-300 cm.



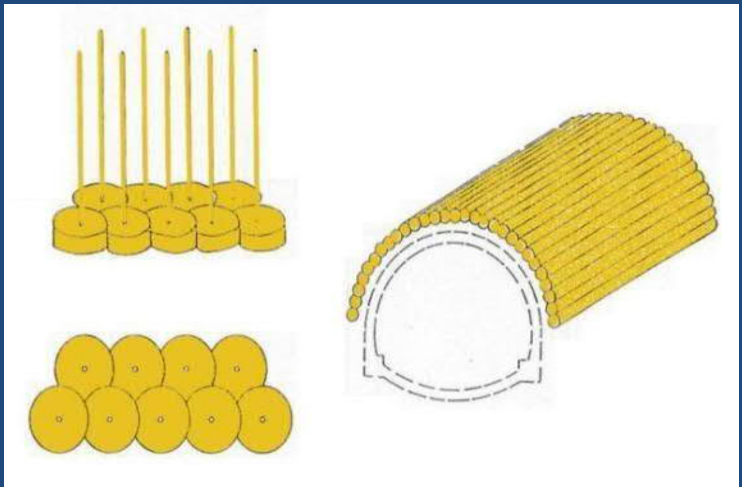




Jet Grouting Shapes



Elements are generally either columns or panels, obtained by retrieving the jetting monitor with simultaneous rotation or with no rotation, respectively.

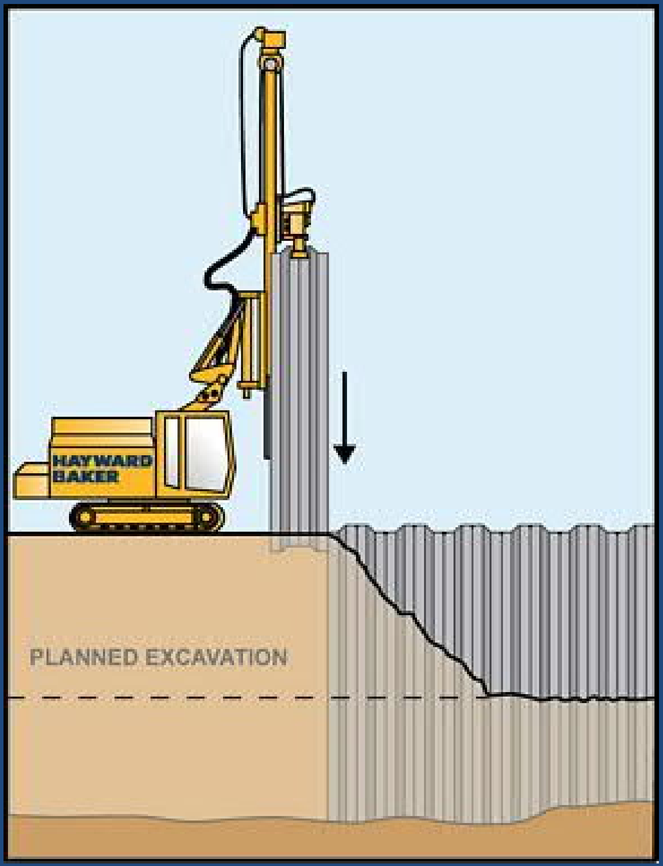


Sheetpiles

Conventional sheetpiles can be used for temporary or permanent seepage barriers.

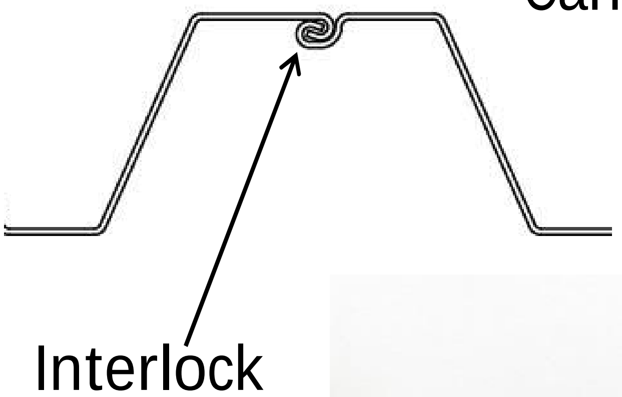
- Sheetpiles can be either steel or plastic (vinyl).
- Issues include:
  - corrosion of steel sheetpile.
  - buckling of steel or plastic sheetpile.
  - lack of advancement.
  - interlock separation.
  - interlock leakage.
- Realistic depths of 100 feet or less.

Sheetpiles



Sheetpiles

Can be treated to reduce leakage.



Vinyl Piles

Vinyl Piles

Deer Flat Dam

Deer Flat Dam

Steel sheetpiles used as a temporary water barrier in a sand and gravel cofferdam.

Deer Flat Dam

Closing

- Dam engineers have a wide range of tools available for seepage rehabilitation.
- The challenge is to consider, with an open mind, the range of options and select the "best" choice for a particular dam.
- Robustness, redundancy, and resiliency should be duly considered in the selection.

Questions?