RECLAMATION

Managing Water in the West

Methods to mitigate internal erosion risks in existing embankment dams

U.S. Department of the Interior
Bureau of Reclamation

ICSE6 Paris
August 2012

Seepage vs. Internal Erosion

- In general, mitigating for internal erosion means mitigating for potentially harmful seepage flows
- However, it is critical to understand that the focus should not necessarily be to reduce seepage but rather to reduce the potential for internal erosion
- This seems obvious, but there are examples in failure case histories where a focus on treating seepage actually worsened the potential for internal erosion

Two Basic Types of Internal Mitigation Measures

- Seepage control
  - Designed to collect or direct seepage into engineered features where it can be controlled to minimize adverse behavior such as high gradients, unfiltered exits, etc.

- Seepage reduction
  - Designed to reduce seepage by means of extending the seepage path through the use of vertical or horizontal barriers and thus reduce gradients and flows

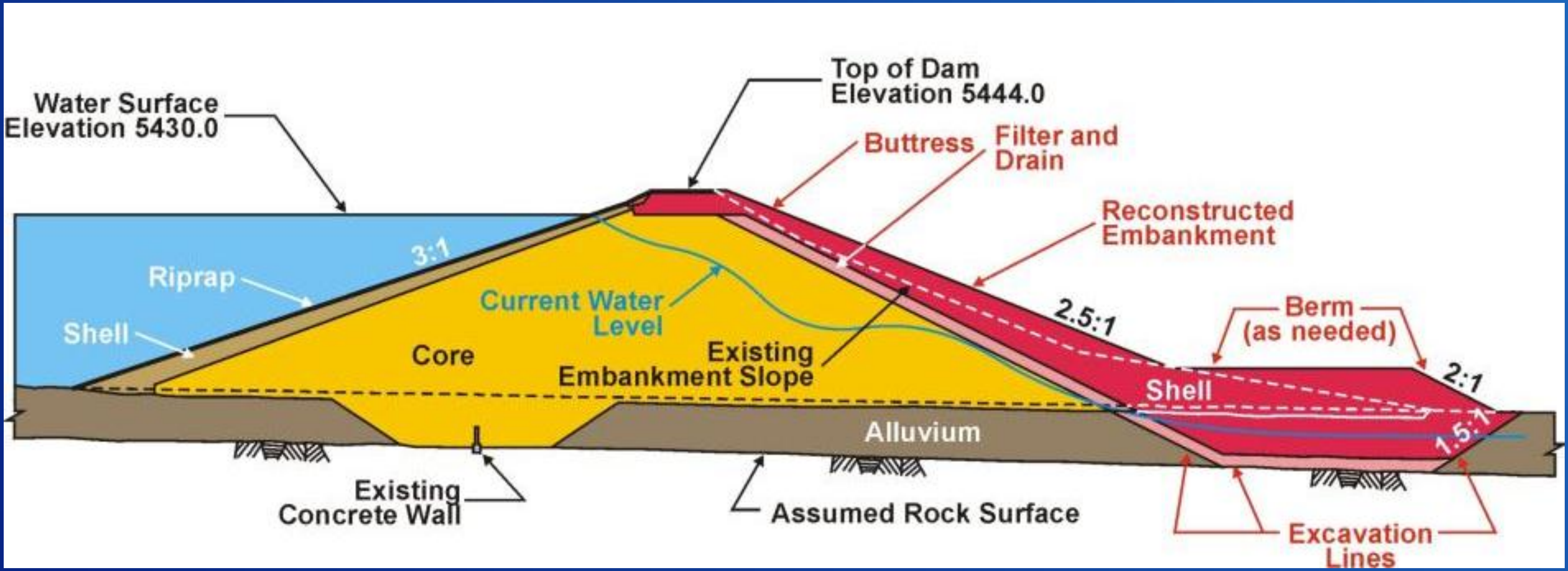
Seepage Control Measures

- Internal filters and drains
- Toe drains
- Drainage trenches at downstream toe
- Relief wells
- Horizontal drains
- Drainage galleries or tunnels
- Filter envelopes around conduits

Example Filter and Drain Modification (with processed sands & gravels)

- Failure mode associated with internal erosion through the dam and potentially from dam into foundation
  - Dam immediately upstream of a large city did not have original chimney filter nor any modern foundation treatment measures
- Modification
  - Two-stage chimney filter/drain of processed sand and gravel, as well as foundation filter and overlying seepage berm

Example Filter and Drain Modification (with processed sands & gravels)



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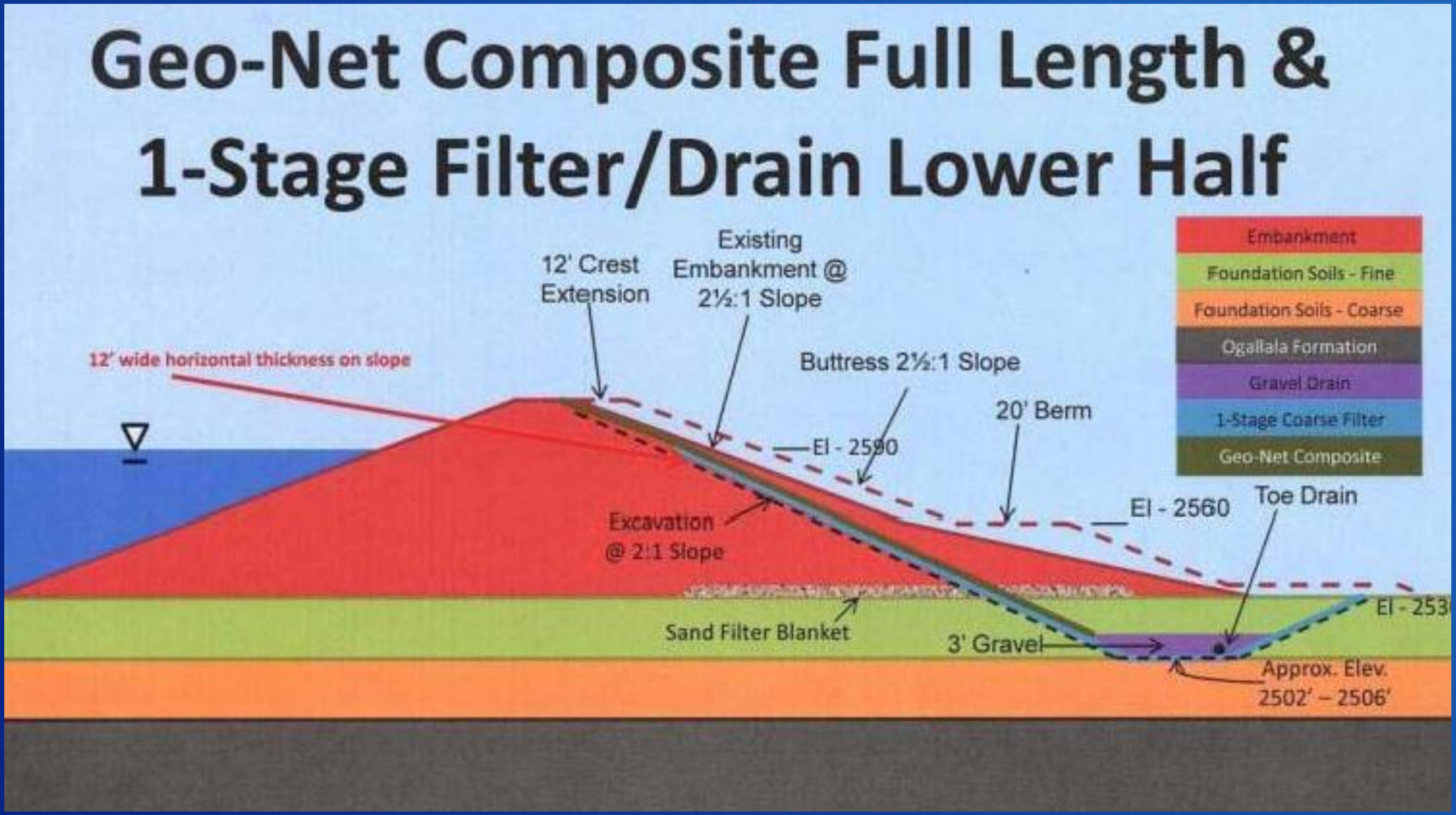
Example Filter and Drain Modification (processed sands & geosynthetics)

- **Failure mode associated with internal erosion through the dam**
  - Embankment was discovered to have transverse crack through nearly full height, with openings up to 5 cm
- **Modification**
  - Chimney filter consisting of geosynthetic filter/drain overlain by processed sand filter, including horizontal drain and toe drain

Example Filter and Drain Modification (processed sands & geosynthetics)



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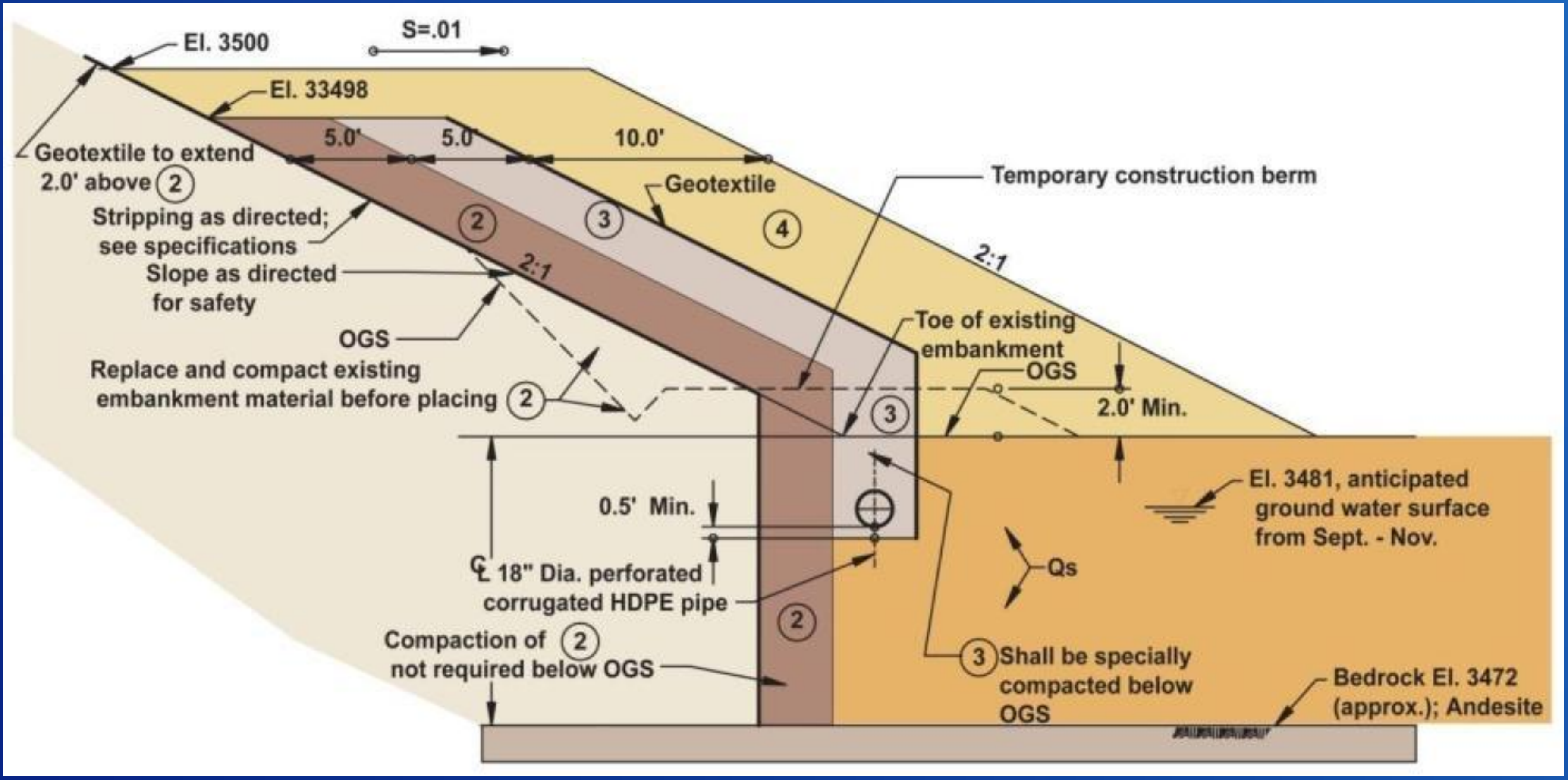
Example Downstream Drainage Trench (using biodegradable slurry)

- Failure mode associated with internal erosion through the dam and/or foundation (along foundation contact)
  - Re-worked moraine and outwash deposits in foundation may not have been completely removed during construction

- Modification
  - Vertical interceptor filter trench to bedrock (sand installed with biodegradable slurry trench), chimney filter, and filtered downstream toe drain and berm

Example Downstream Drainage Trench (using biodegradable slurry)



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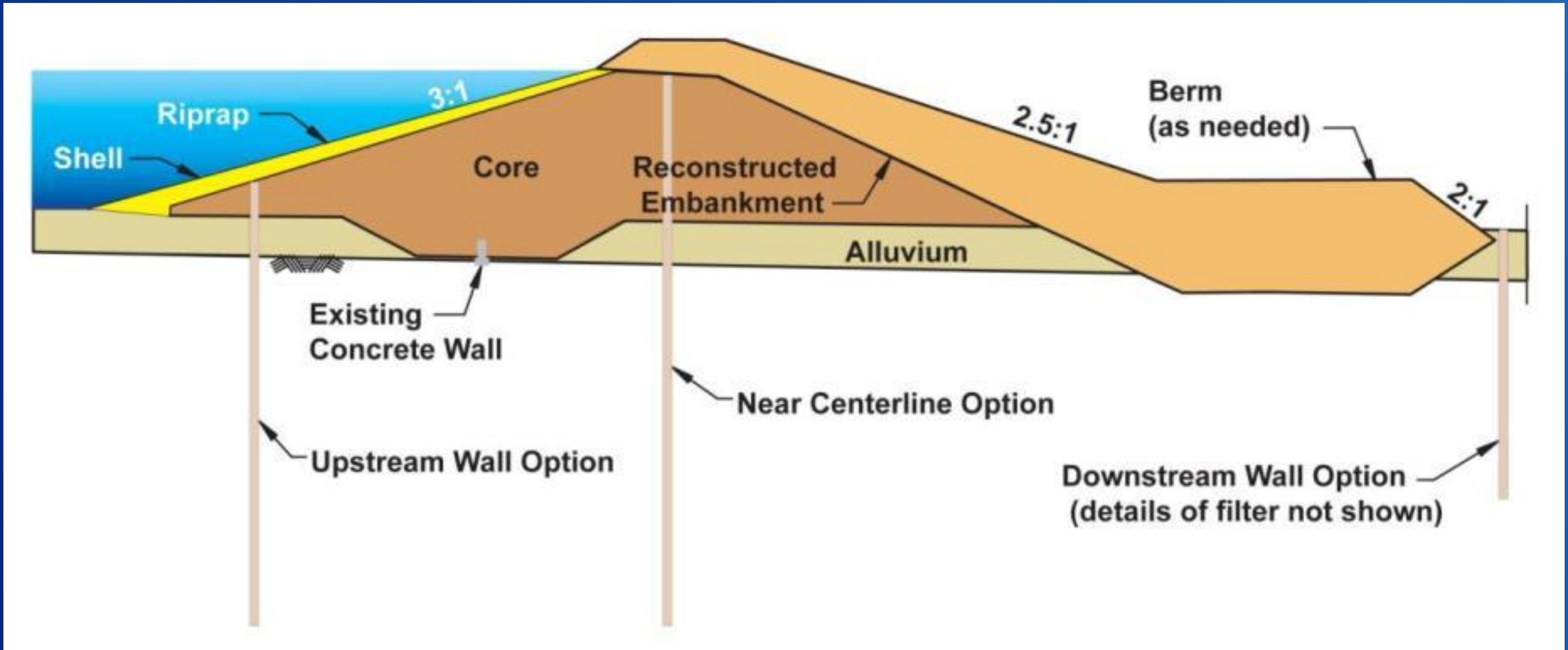
Example Downstream Drainage Trench (using biodegradable slurry)

Seepage Reduction Measures

- Slurry trench cutoff walls
- Sheet pile walls
- Secant pile cutoff walls
- Grout curtains
- Upstream blankets

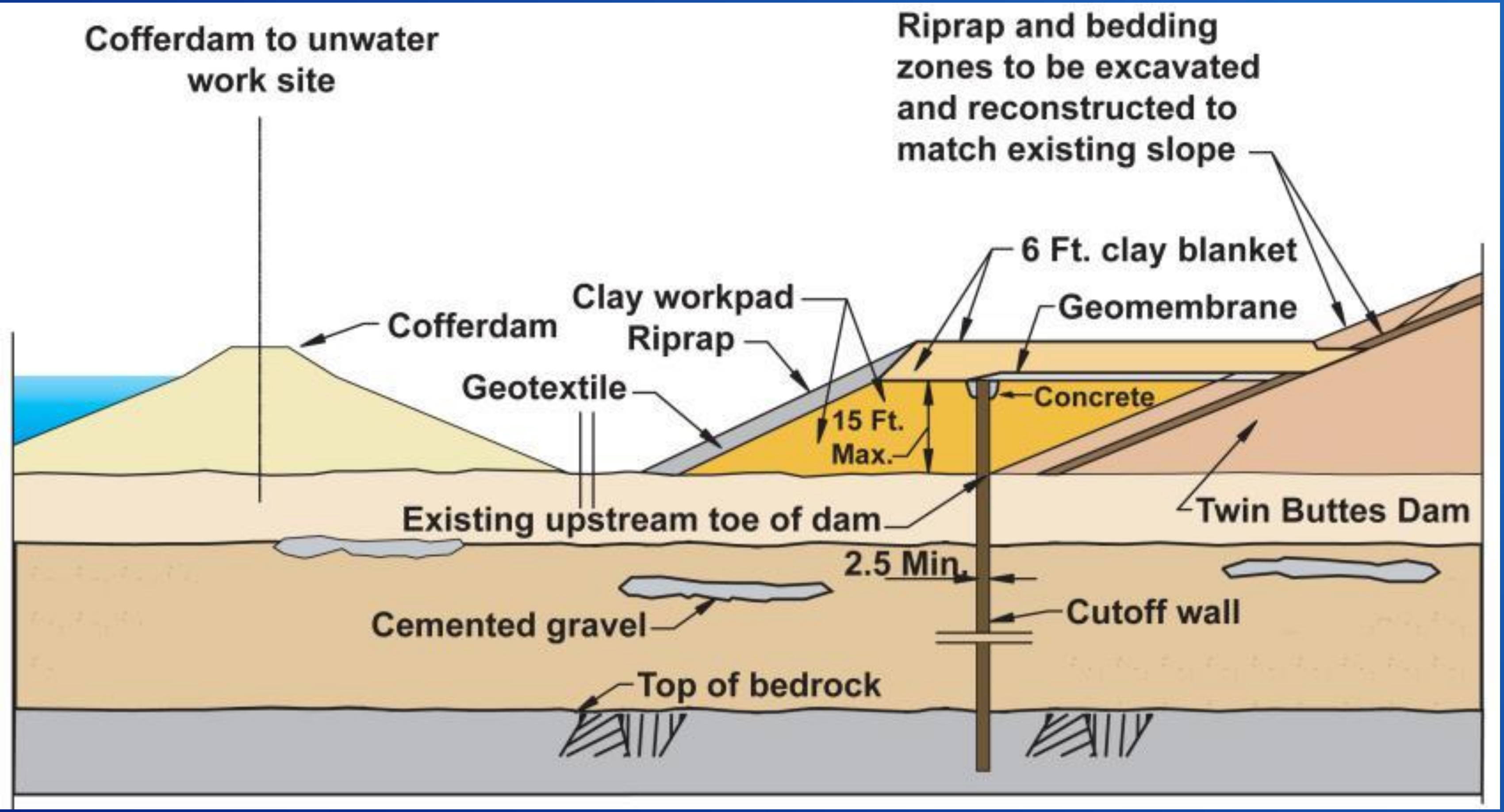
Cutoff Wall Locations



Example Cutoff Wall (using soil-cement backfill)

- Failure mode associated with internal erosion through the foundation
  - Excessive downstream seepage, with signs of increasing flows with time
- Modification
  - Vertical cutoff wall installed at upstream toe, tied into embankment core and backfilled with a mixture of soil, bentonite, and cement

Example Cutoff Wall (using soil-cement backfill)



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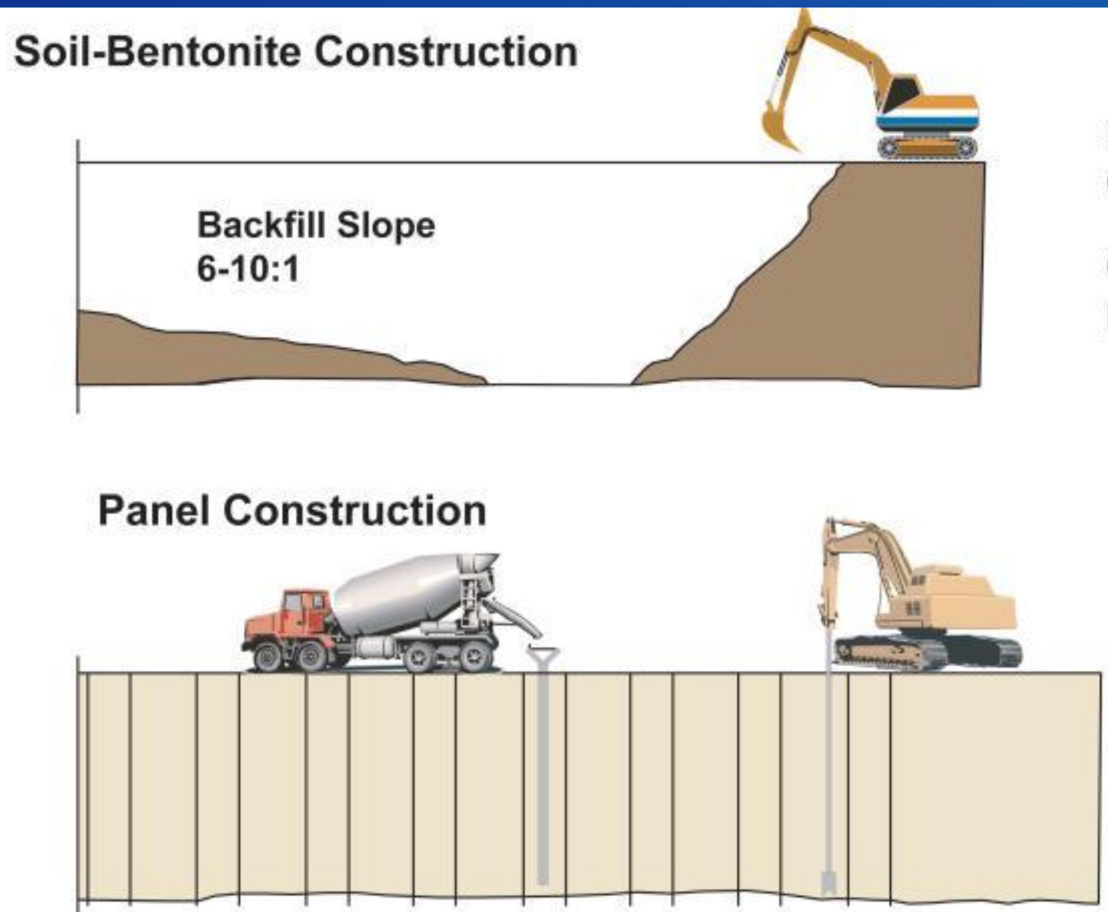
Example Cutoff Wall (using soil-cement backfill)



Long trench and dozing backfill creating sloping backfill

Concerns with the material setting prior to completion

THEREFORE

Determined Panel excavation method would be only way to assure good product

Example Cutoff Wall (multiple trenching methods)

Chisel

Clamshell

Rock Mill

Example Cutoff Wall (using soil-cement backfill)

Example Cutoff Wall (using soil-cement backfill)

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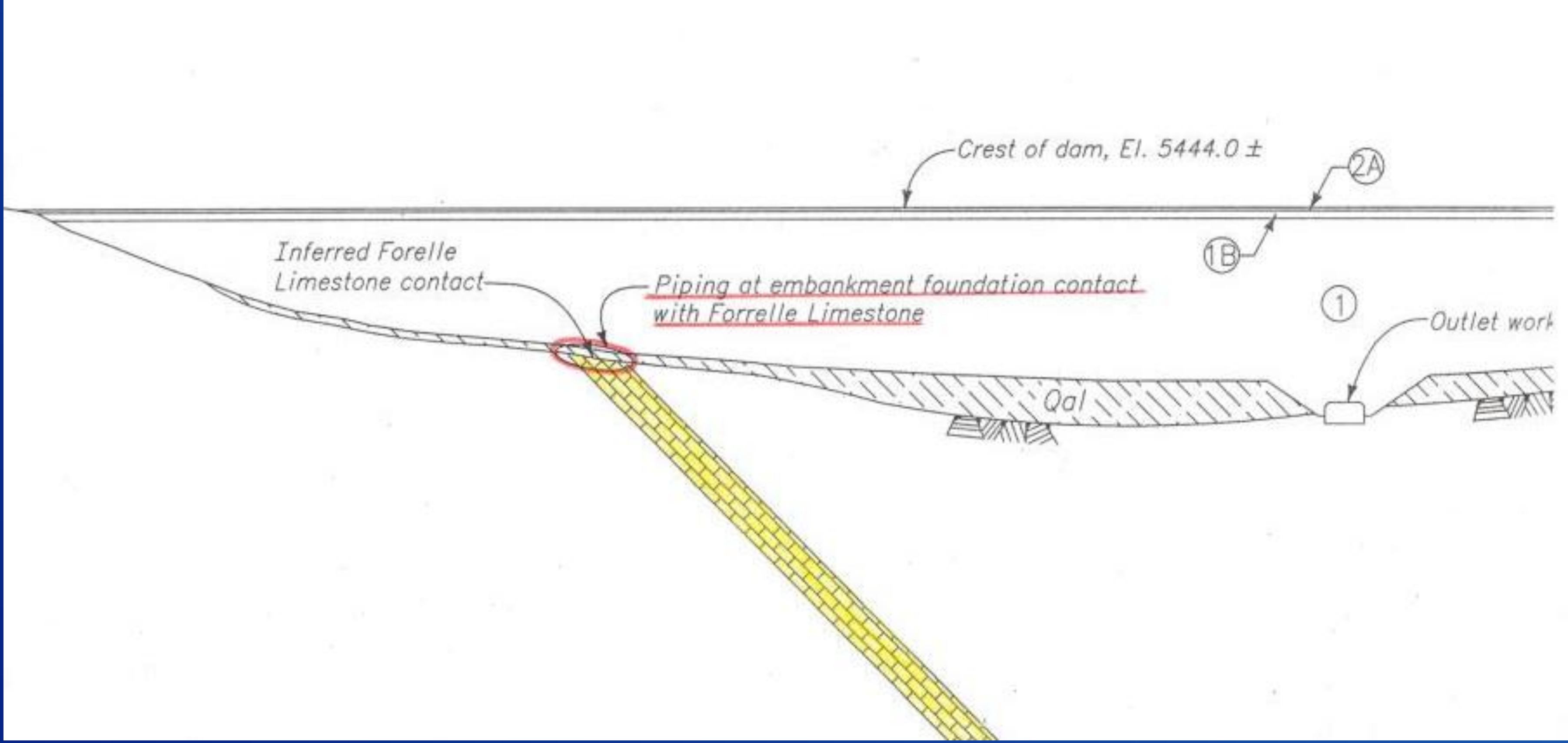
Example Upstream Horizontal Blanket (using geomembrane)

- Failure mode associated with internal erosion through a solutioned foundation bedrock unit
  - Sinkhole had been discovered upstream in reservoir
- Modification
  - Horizontal impermeable blanket consisting of geomembrane with soil cover, placed over upstream exposure of bedrock unit of concern

Example Upstream Horizontal Blanket (using geomembrane)



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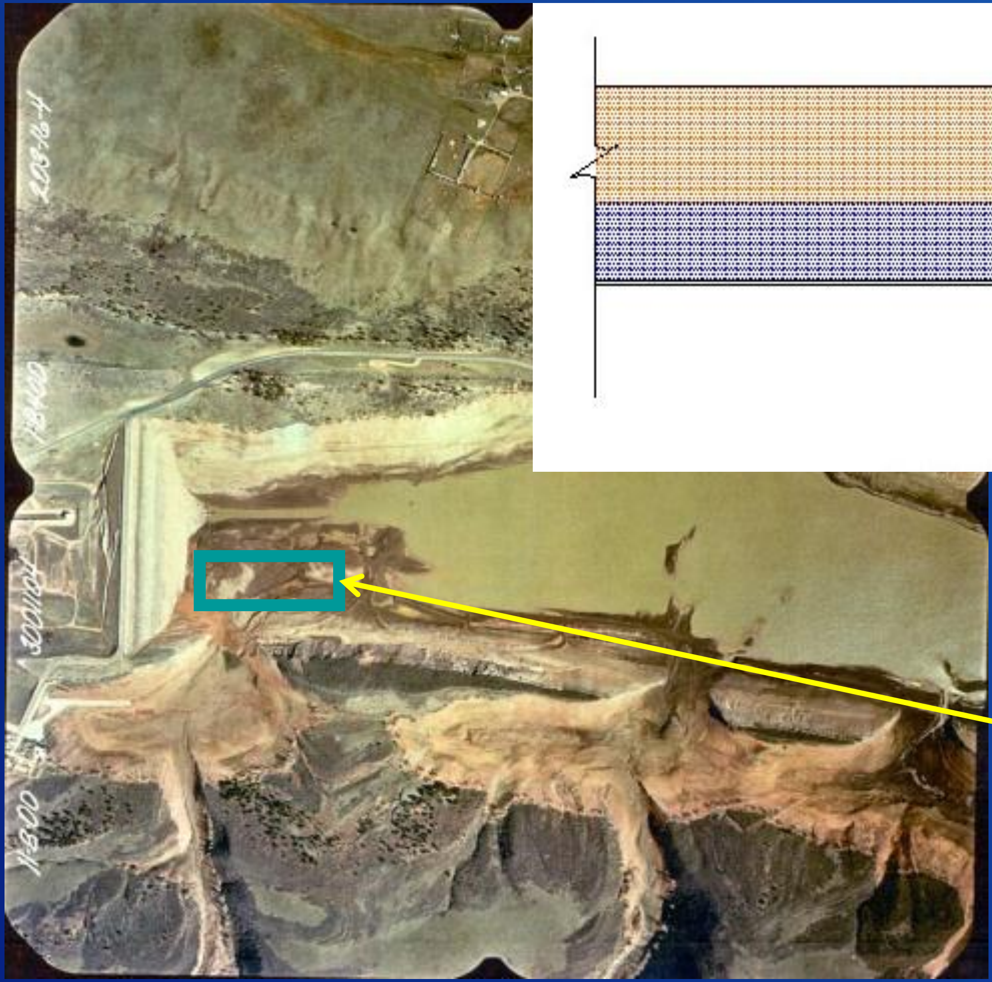
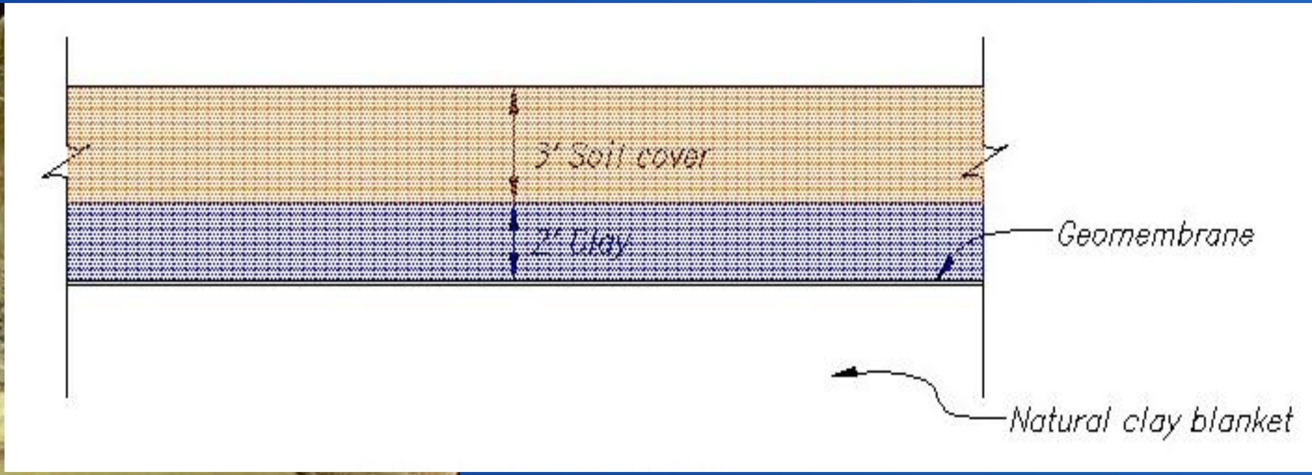
Example Upstream Horizontal Blanket (using geomembrane)





Approximate limits of upstream blanket

Example Upstream Horizontal Blanket (using geomembrane)

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Example Upstream Horizontal Blanket (using geomembrane)

Selection of a Preferred Alternative

- Selection of a seepage control alternative or a seepage reduction alternative can depend on several factors
  - Cost*
  - Degree of risk reduction*
  - Construction risks
  - Length of construction
  - Temporary loss of project benefits
  - Constructability

* Often the most important considerations

Selection of a Preferred Alternative

- The preferred alternative is usually based on a consideration of all these factors, and requires careful deliberation

- The paper includes a table that lists:
  – Mitigation methods
  – Technical advantages
  – Technical disadvantages
  – Construction considerations
  – Relative construction costs

Mitigation Method	Technical Advantages	Technical Disadvantages	Construction Considerations	Construction Cost
Seepage Control Measures				
Internal filter/drain	Can include multiple stage filter/drain Exposes materials (can see potential issues) Can tie to monitoring system (toe drain)	May require lowering of reservoir	Typically requires slope steepening, which can reduce slope stability during construction Employs standard earthwork practices	Moderate cost
Toe drain	Permits means of monitoring seepage Can include multiple stage filter/drain	Cannot provide drainage for deep seepage	Typically easy to construct	Generally low cost
Drainage trench	Increased depth over toe drain Lessens or eliminates need for dewatering	Limited to one stage filter/drain	Will likely need to provide for trench stability (bracing, slurry trench, etc.)	Generally low cost
Relief wells	Can reduce pressures in deeper aquifers Can design filter pack to prevent piping	Requires periodic maintenance Not a "continuous" feature	Number of wells; designs need to be flexible	Low to moderate cost
Horizontal drains	Can be an effective measure at an existing facility	Requires particular attention to filtering	Can be constructed in both soil and rock Often need many drains	Low to moderate cost
Drainage gallery	Can be a means of reducing pressures at different locations beneath a facility (during original construction)	Requires particular attention to filtering Generally has limited application at existing facilities	Can use tunnel or concrete conduit Requires drilling in a confined space	Moderate to high cost
Conduit filter envelope	Provides filtering at a location that has traditionally been problematic	May lose capability to evacuate reservoir during construction period	May require removal of an existing conduit section to construct filter below the conduit	Generally low cost; could be moderate if it requires extensive excavation at existing dam

Mitigation Method	Technical Advantages	Technical Disadvantages	Construction Considerations	Construction Cost
Seepage Reduction Measures				
Slurry trench cutoff wall	Can construct while reservoir is full Reasonable confidence of a continuous wall	Creates high gradients at bottom/ends of wall Potential for uncontrolled slurry loss	"Blind" operation Requires specialty contractor Trench stability needs attention May need a special detail to tie into existing structure	Generally high cost
Sheet pile wall	Simple, low cost solution Can construct while reservoir is full	May have gaps or "windows" where seepage may concentrate	Problematic in coarse-grained soils Presence of water can lead to corrosion issues	Generally low cost
Secant pile wall	At relatively shallow depths, good confidence that wall is continuous Can construct while reservoir is full	With deep walls, can be difficult to maintain vertical alignment, which could create gaps	Requires specialty contractor May need a special detail to tie into existing structure	Moderate cost
Soil mixing or jet grouting	Can construct while reservoir is full	May have "windows" – less likely to be continuous than other wall types Generally limited to downstream area (unless drilling through embankment)	Requires specialty contractor "Blind" operation	Moderate cost
Grout curtain	Have used this technique for decades Can construct while reservoir is full	May have "windows" Grout can degrade Drilling through embankment may cause hydraulic fracturing	Need to carefully monitor grout pressures "Blind" operation	Low to moderate cost
Upstream blanket	Can reduce seepage at sites where vertical walls are impracticable	Requires lowering of reservoir	Can use natural or geosynthetic products	Generally low cost

Selection of a Preferred Alternative

- A personal preference, if all else is equal, would be <u>seepage control</u>
  - Usually features standard earthwork construction methods
  - Uncovers the embankment and/or foundation and allows one to view existing conditions
  - Enhances installation of monitoring devices
  - Less likely to lead to concentrated gradients as seen in a cutoff wall

- Remember the fundamental precept of **"First, do no harm"**

Thank you
for your attention