Basics of Geotechnical Investigations

Never Boring…

MDE Dam Owners Workshop

18 March 2021

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Maryland Department of the Environment

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HOW MANY HOLES?

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SERIOUS BUSINESS

Cannonsville Dam Incident

New York, 2015

- Drilling at toe punctured known confined aquifer
- EAP Activated, 24/7 monitoring
- Drained reservoir
- Relief well and grouting program
- $$$$

What Can Go Wrong? – General Advice

- Drilling into or in close proximity to a dam or levee embankment is an inherently risky activity and there have been many incidents of damage to embankments and foundations caused by improper drilling operations.
- Industry Consensus: Avoid drilling into the core of the dam unless absolutely needed
- Industry Consensus: Drilling or test pitting at downstream toe of a dam is very risky. You must have materials and trained personnel on-site in case of emergency
- Industry Consensus: Avoid installing piezometers in the core of the dam. In most cases, piezometers in the core do not provide significant additional understanding.

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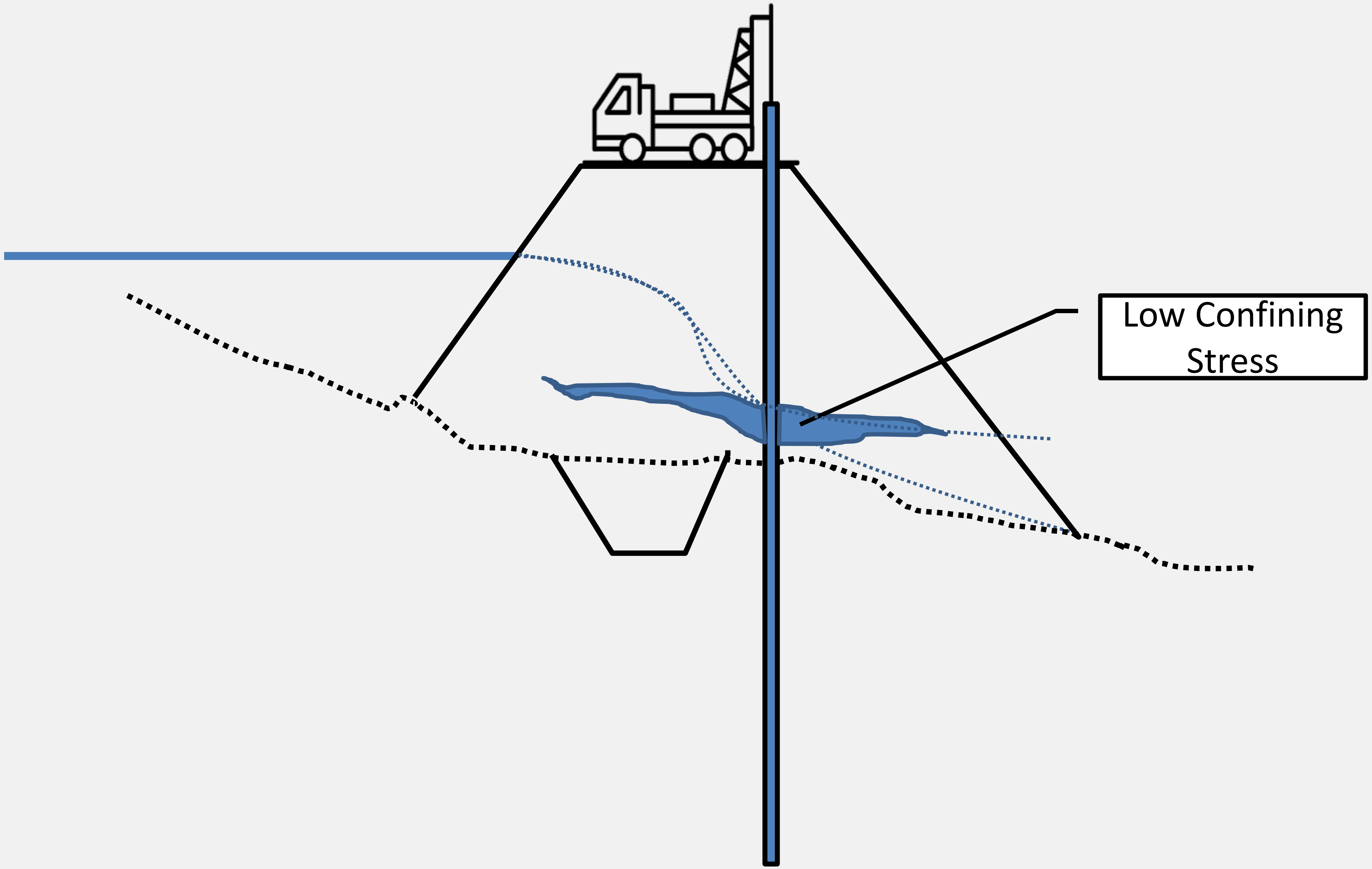
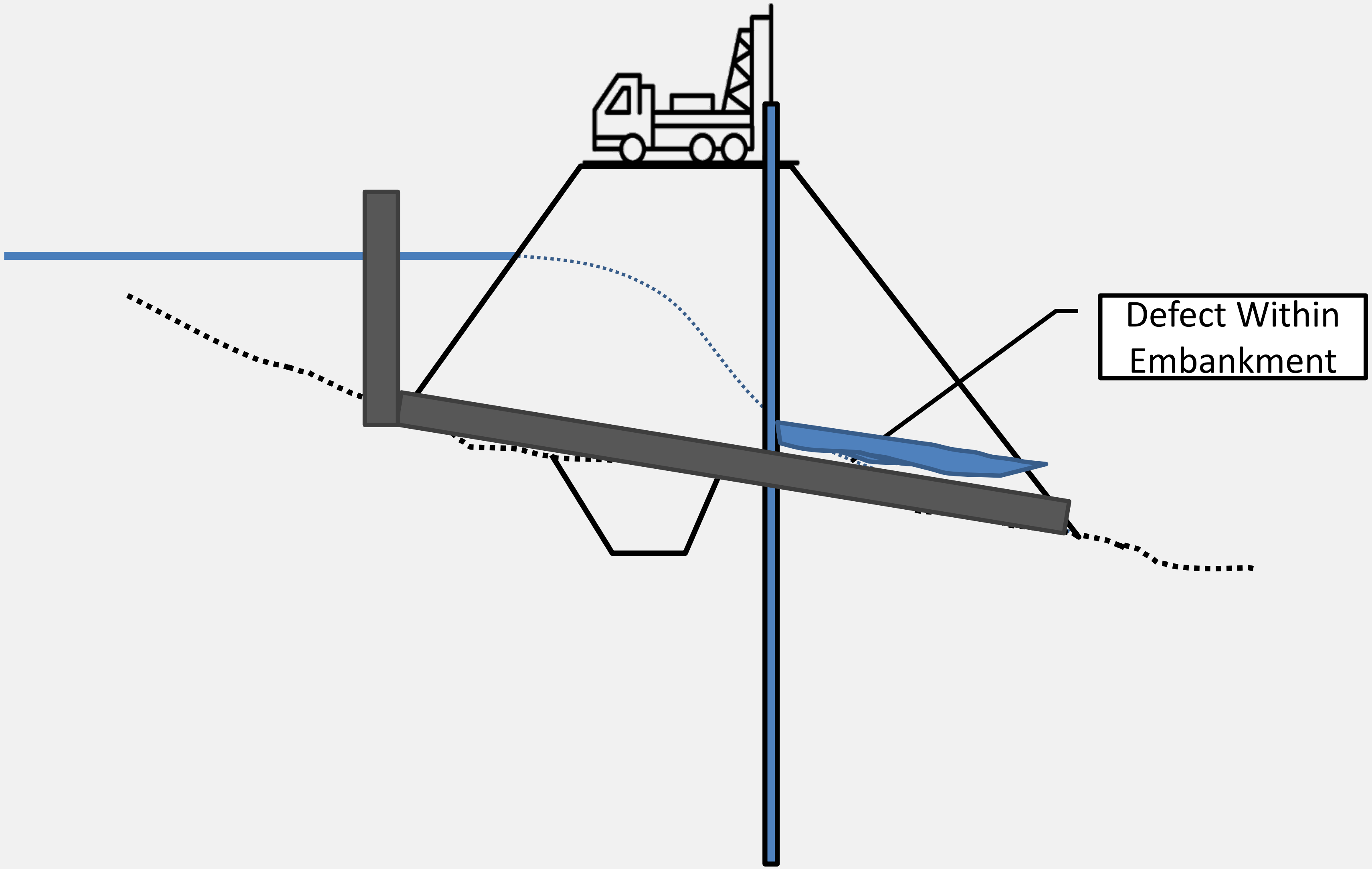
What Can Go Wrong? – Hydraulic Fracturing



What Can Go Wrong? – Hydraulic Fracturing

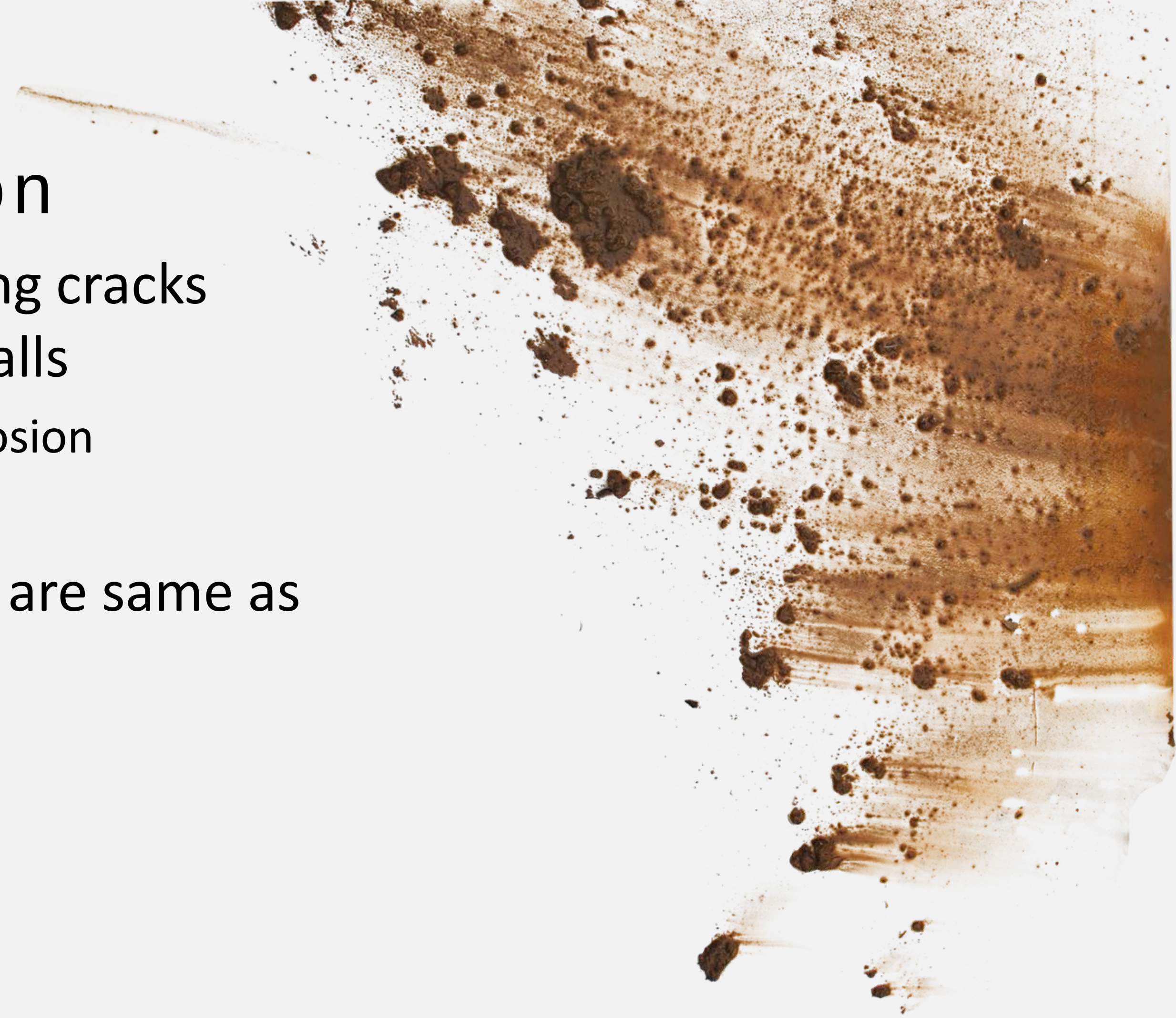
- Among primary reasons fluids are unadvisable when drilling in embankments
  - Fluids can be water, mud, air, grout
- Can occur when fluid pressure in borehole exceeds confining pressure in soil
- Cohesive, cohesionless soils and bedrock are all susceptible
- Can have detrimental effects if occurs in embankment or foundation soils
- Evidenced by loss of fluid circulation, blowouts into adjacent boreholes, seepage on face or toe of embankment
- Locations in dams that are particularly sensitive to low confining stresses are adjacent to steep abutments, near spillway conduits

What Can Go Wrong? – Erosion

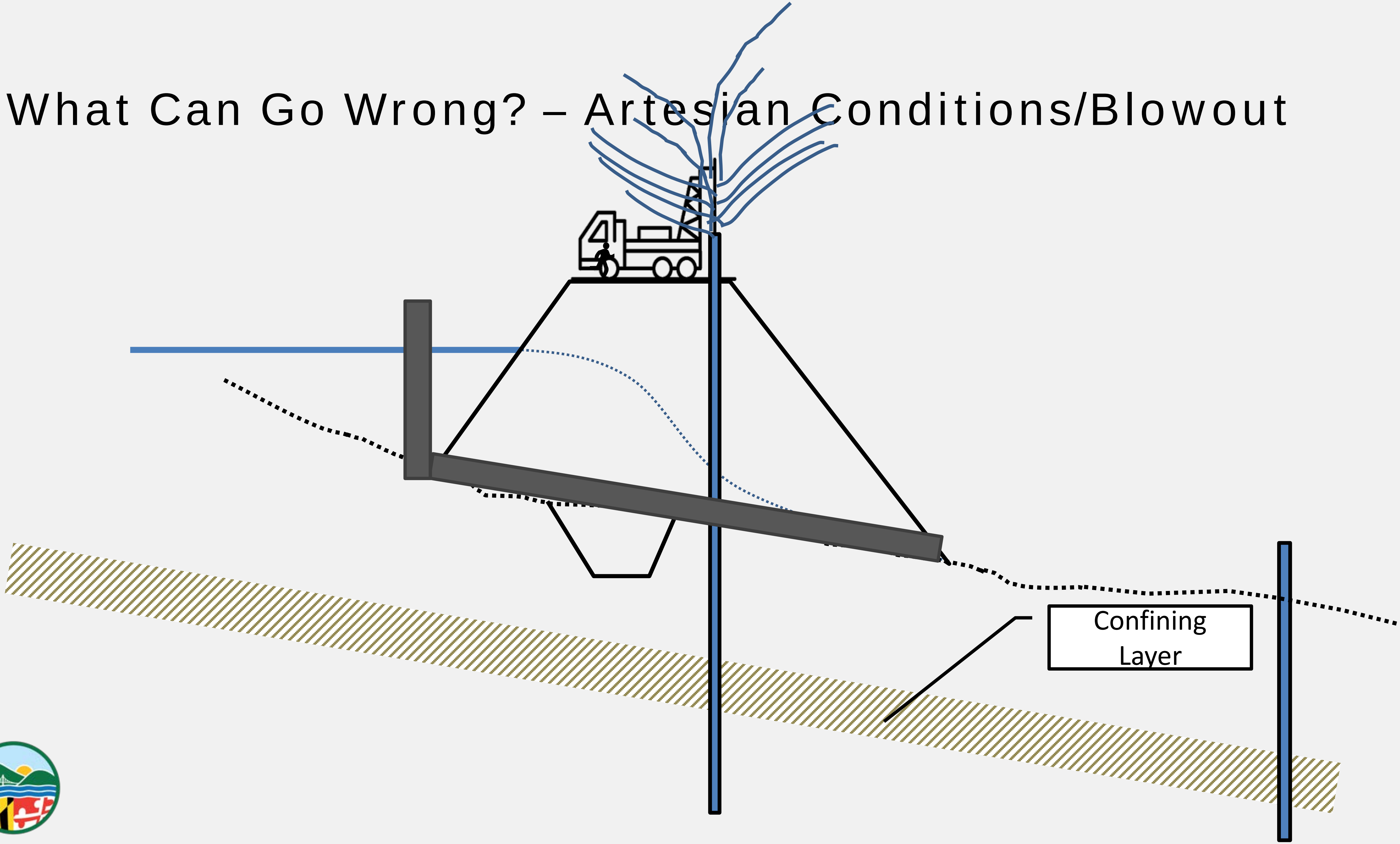


What Can Go Wrong? - Erosion

- Introduction of drilling fluids into existing cracks or defects can cause erosion of crack walls
  - Leads to increased potential for internal erosion
  - Particularly where no drain/filter present
- Locations where defects are most likely are same as areas susceptible to hydraulic fracture



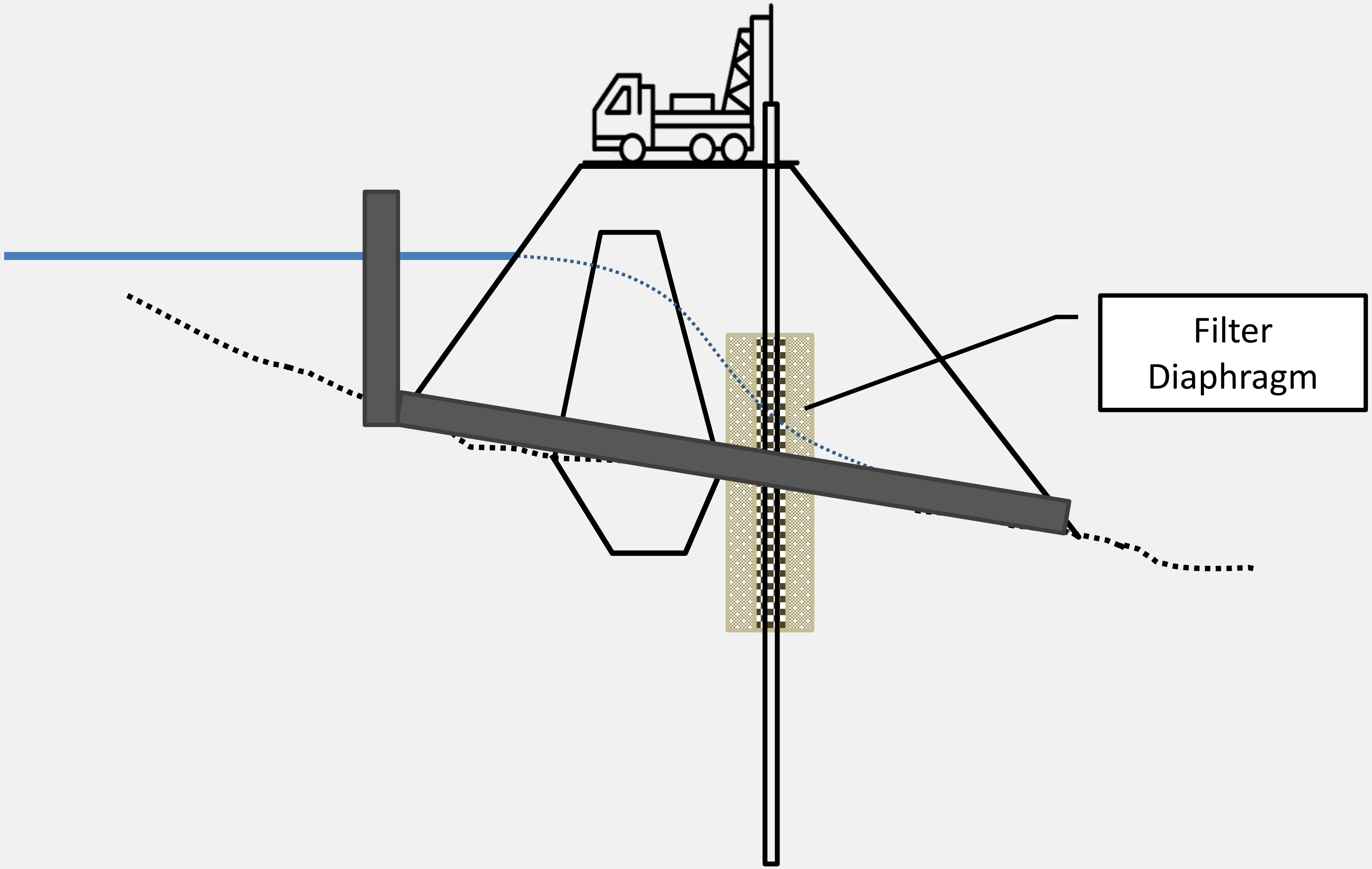
What Can Go Wrong? – Artesian Conditions/Blowout



What Can Go Wrong? – Artesian Conditions/Blowout

- Particularly a concern at downstream toe where upward gradients exist.
- Also a concern where confined, pressurized aquifers are located
- Drilling plan needs to consider means to keep a positive head in drill string
- Very difficult to stabilize once a blowout has occurred

What Can Go Wrong? – Filter/Drain Contamination



What Can Go Wrong? – Filter/Drain Contamination

- Contamination can occur in borings with and without fluids
  - But more likely with fluid
- Drill fluid or sealing grout can migrate into filter and clog materials
- If necessary to penetrate a filter/drain special precautions must be taken and special closure provisions included

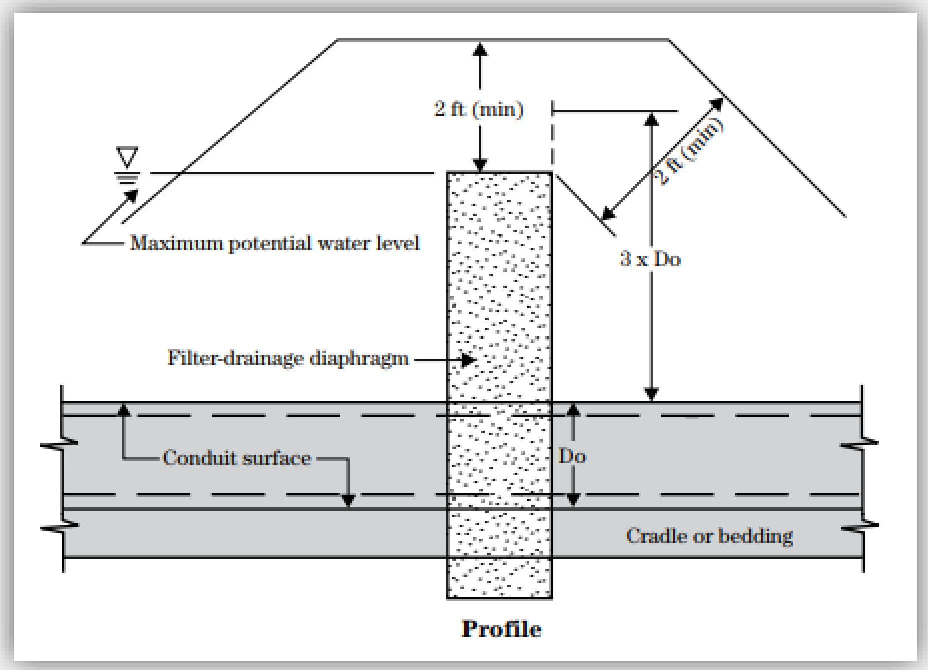


Image NRCS

What Can Go Wrong? – Heave

- When upward seepage/groundwater gradients are present
  - Excavation or soil borings reduce confining stress, so soils will heave upwards
  - Can cause sample disturbance, resulting in invalid data
  - Can result in excavation blowout

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DEFINING SCOPE

First, Define Problem to be Solved

- First step in preparing a subsurface investigation program is to ask:
  - What problem(s) need to be solved (e.g., seepage issue, slope stability, design strengths)
  - Document your objective
- Next, what methods are available to solve your problem(s)
  - Some may be better suited than others
  - For example, a soil boring will only provide information at a discrete location
- Compile, review and summarize all relevant information
  - Does this information solve problems, or reduce uncertainty?
  - Adapt scope based on available data
- Use this process to develop preliminary plan of action (types of testing, sampling, instrumentation, etc.)

Next, Weigh Risks vs. Rewards

- Remember to link drilling plan to potential failure modes
  - PFM: Seepage through foundation, new construction. Investigate soils/geology below dam for highly previous soils, appropriate cutoff depths. Relatively low risk.
  - PFM: Slope failure on existing dam. Investigate embankment and foundation soils, obtain information to assess strength and composition of materials. Moderate risk, could investigation worsen failure?
  - PFM: Seepage at existing dam, uncertain if impervious core constructed. Consider if damage to core by drilling is worth risk, design upstream cutoff instead. Consider use of geophysical (non-invasive) methods first. High risk.
  - PFM: Seepage existing downstream face. Piezometer only gives information at one location. Consider multiple piezometers, geophysics, looking at response in piezometers to pool levels. Can you safely drill? Variable risk depending on site conditions.
- Known unknowns and unknown unknowns: Build room for adaptation/scope change
- Seek to avoid invasive drilling where possible

Then, Determine Appropriate Hazard Mitigation Steps

- Appropriate hazard mitigation steps depend on each site and drilling plan
  - Discussed in next section
- If active monitoring of the dam, or other duties are identified as hazard mitigation steps, identify a responsible person
- Document, document, document
  - Subsurface Investigation Plan
  - Scalable to dam, scope of work, and risk

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Lastly, Execute Program Per Plan

– Ensure everyone is familiar with Subsurface Investigation Plan (SIP) and knows their role
– Understand that there may need to be adaptability, consider including some “what-if” statements in the SIP
– Have an understanding that deviation from plan without considering all prior steps exposes everyone to greater risk

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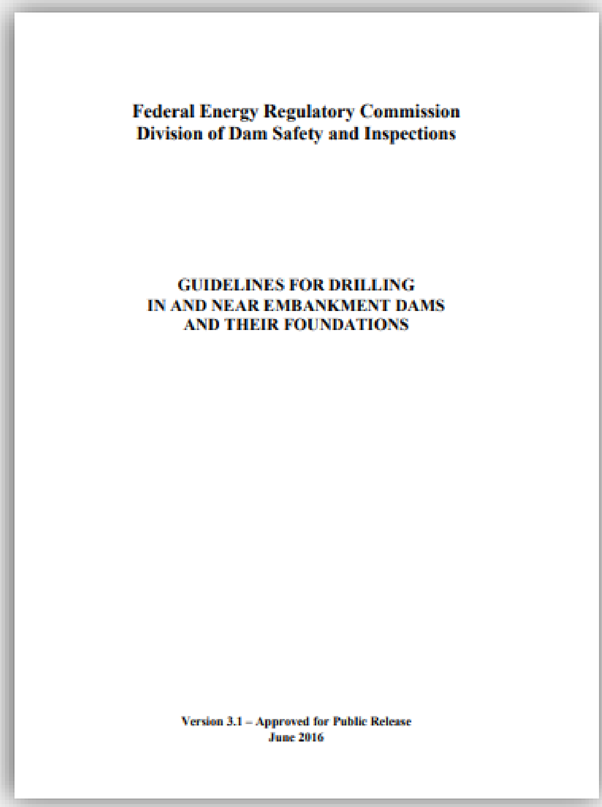
HAZARD MITIGATION

Permitting

- Review and approval by MDE Dam Safety program or local Soil Conservation District
  - Benefit from experience of reviewers with dams in the state
- Permitting is required when drilling in dam, appurtenant structures, and adjacent to dams
  - Any borings within 15 feet of toe, and
  - Borings where depth of drilling is greater than distance from dam

Follow Available Guidance

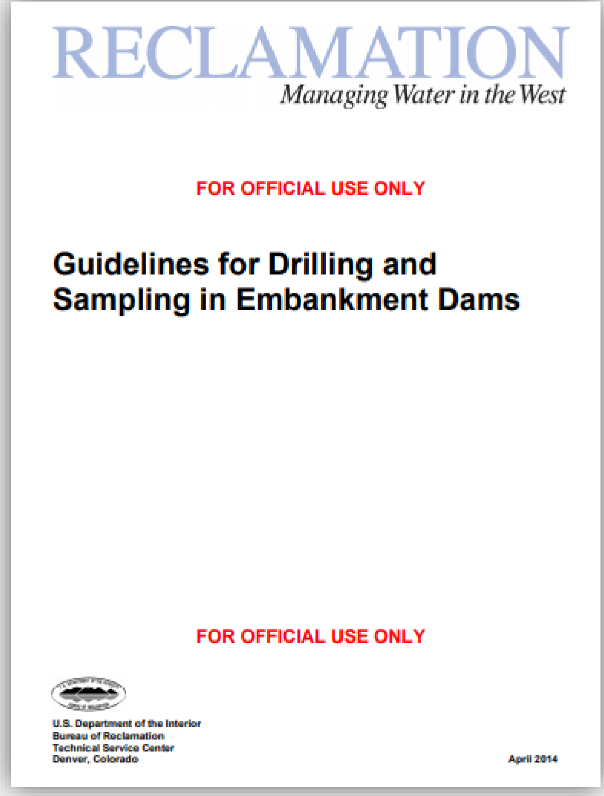
- USACE, FERC, and USBR all have guidelines for drilling in dams
  - Recommendations are largely the same between documents
  - MDE has no preference, but leans to USACE since USBR has a western states mindset and FERC has a hydro mindset



Federal Energy Regulatory Commission
Division of Dam Safety and Inspections

GUIDELINES FOR DRILLING
IN AND NEAR EMBANKMENT DAMS
AND THEIR FOUNDATIONS

Version 3.1 – Approved for Public Release
June 2016



RECLAMATION
Managing Water in the West

FOR OFFICIAL USE ONLY

Guidelines for Drilling and Sampling in Embankment Dams

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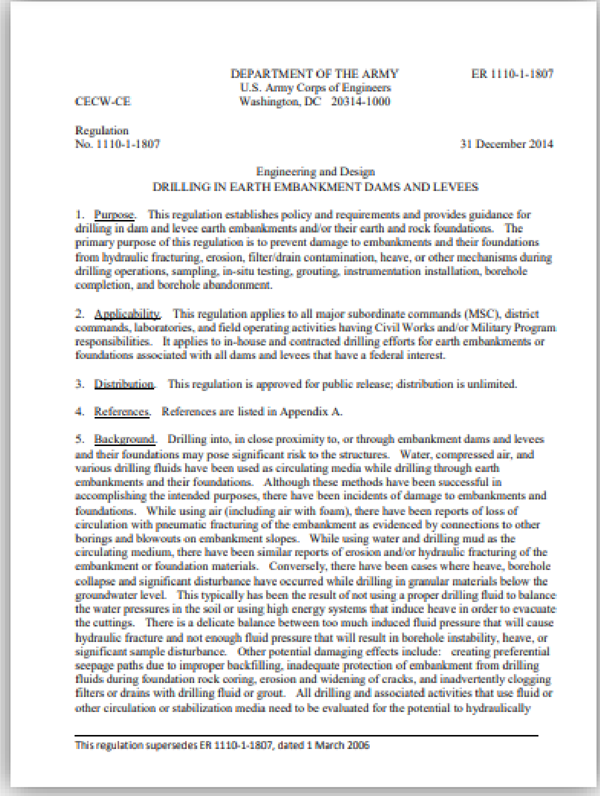
U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

April 2014



DEPARTMENT OF THE ARMY — ER 1110-1-1807
U.S. Army Corps of Engineers
CECW-CE — Washington, DC 20314-1000

Regulation
No. 1110-1-1807 — 31 December 2014

Engineering and Design
DRILLING IN EARTH EMBANKMENT DAMS AND LEVEES

1. Purpose. This regulation establishes policy and requirements and provides guidance for drilling in dam and levee earth embankments and/or their earth and rock foundations. The primary purpose of this regulation is to prevent damage to embankments and their foundations from hydraulic fracturing, erosion, filter/drain contamination, heave, or other mechanisms during drilling operations, sampling, in-situ testing, grouting, instrumentation installation, borehole completion, and borehole abandonment.

2. Applicability. This regulation applies to all major subordinate commands (MSC), district commands, laboratories, and field operating activities having Civil Works and/or Military Program responsibilities. It applies to in-house and contracted drilling efforts for earth embankments or foundations associated with all dams and levees that have a federal interest.

3. Distribution. This regulation is approved for public release; distribution is unlimited.

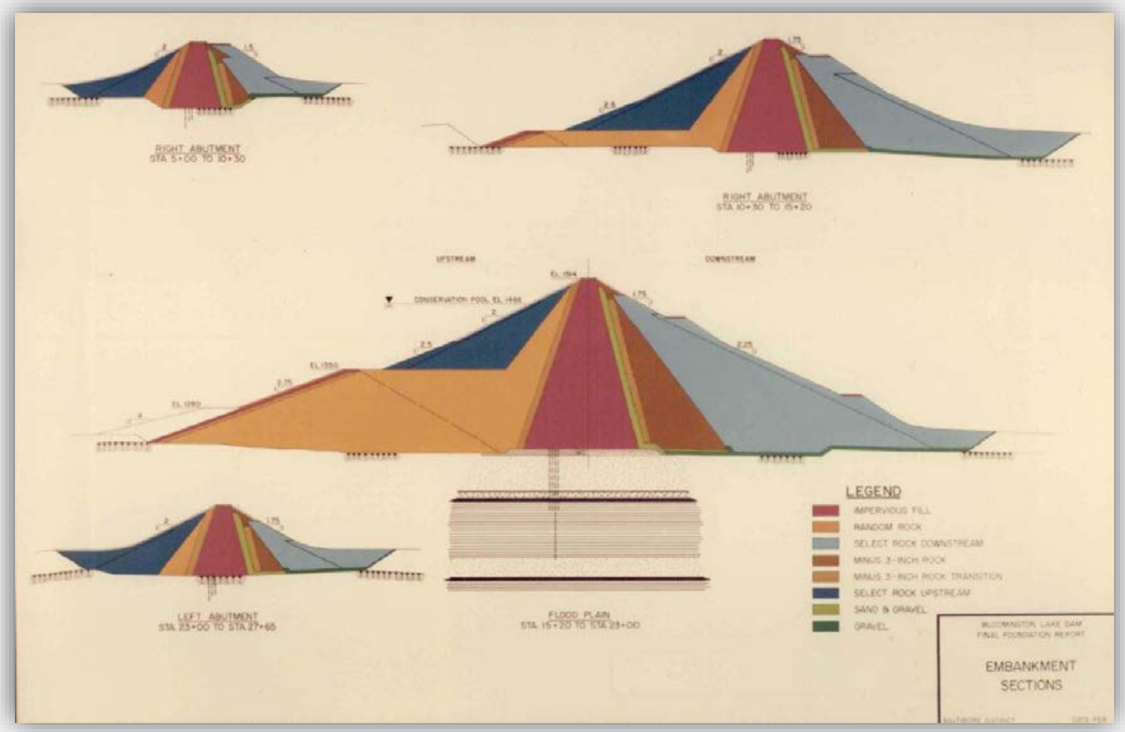
4. References. References are listed in Appendix A.

5. Background. Drilling into, in close proximity to, or through embankment dams and levees and their foundations may pose significant risk to the structures. Water, compressed air, and various drilling fluids have been used as circulating media while drilling through earth embankments and their foundations. Although these methods have been successful in accomplishing the intended purposes, there have been incidents of damage to embankments and foundations. While using air (including air with foam), there have been reports of loss of circulation with pneumatic fracturing of the embankment as evidenced by connections to other borings and blowouts on embankment slopes. While using water and drilling mud as the circulating medium, there have been similar reports of erosion and/or hydraulic fracturing of the embankment or foundation materials. Conversely, there have been cases where heave, borehole collapse and significant disturbance have occurred while drilling in granular materials below the groundwater level. This typically has been the result of not using a proper drilling fluid to balance the water pressures in the soil or using high energy systems that induce heave in order to evacuate the cuttings. There is a delicate balance between too much induced fluid pressure that will cause hydraulic fracture and not enough fluid pressure that will result in borehole instability, heave, or significant sample disturbance. Other potential damaging effects include: creating preferential seepage paths due to improper backfilling, inadequate protection of embankment from drilling fluids during foundation rock coring, erosion and widening of cracks, and inadvertently clogging filters or drains with drilling fluid or grout. All drilling and associated activities that use fluid or other circulation or stabilization media need to be evaluated for the potential to hydraulically

This regulation supersedes ER 1110-1-1807, dated 1 March 2006

Study Dam Construction and Local Geology

– Applies not just to those developing Subsurface Investigation Plan
  - Drillers
  - Engineers/Geologists on-site
– “Know Before You Go”
  - Be aware of internal dam features that must be avoided
  - Understand local geology, and how dam construction may have changed that
– Builds awareness of expected versus unexpected conditions



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Appropriate Drilling Methods

- Fluids (air, water, mud) must be avoided
- Hollow stem augers is generally most appropriate method
  - Can add water to counteract vertical gradients
  - Raise and lower tools slowly
- Sonic Drilling is often accepted
  - Bulk soil samples easily obtained, but SPT less to
- Wireline NQ/NX rock coring when necessary
  - Double or triple barrel
  - Suggest sealing soil/rock interface
  - Must monitor pressures and fluid return closely
- Air Rotary / ODEX
  - Acceptable in open graded rock shells only

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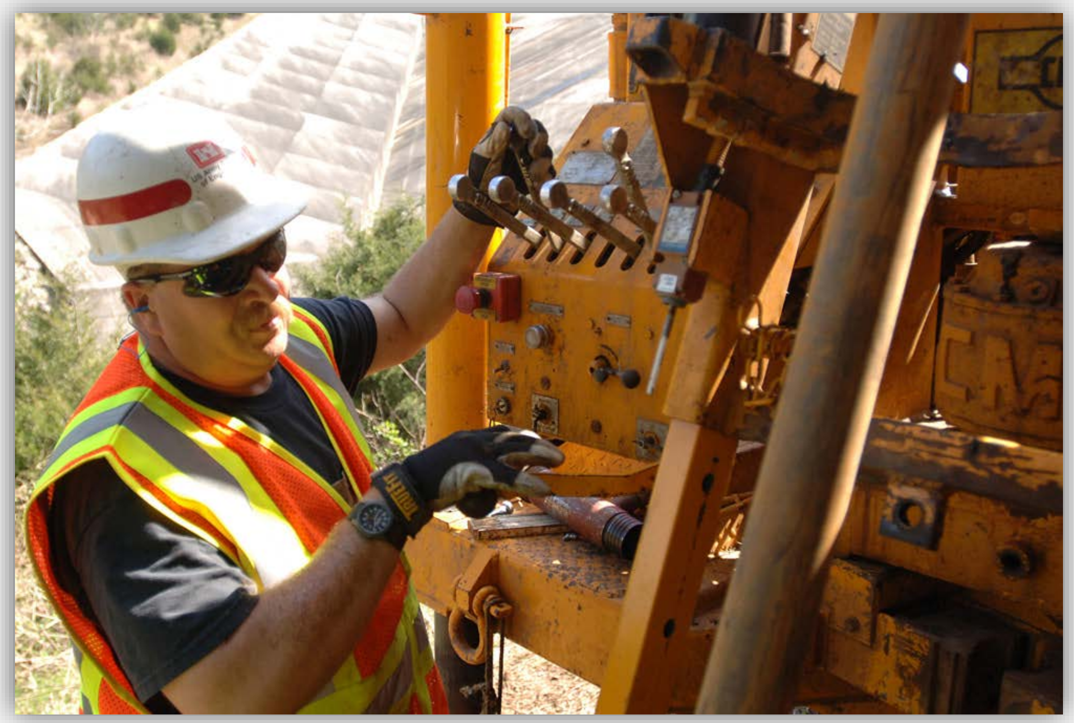
Qualified Drilling Personnel

- Applicable experience matters
- 5-years experience drilling in dams is preferred
- Experience with proposed drilling equipment and methods preferred
- Documented understanding of appropriate guidance is suggested



Qualified Engineers/Geologists

- Applicable experience matters
  - May have extensive drilling/logging experience, but limited knowledge of dams and hazards
- On-site personnel must exercise judgement to ensure work is performed in safe manner

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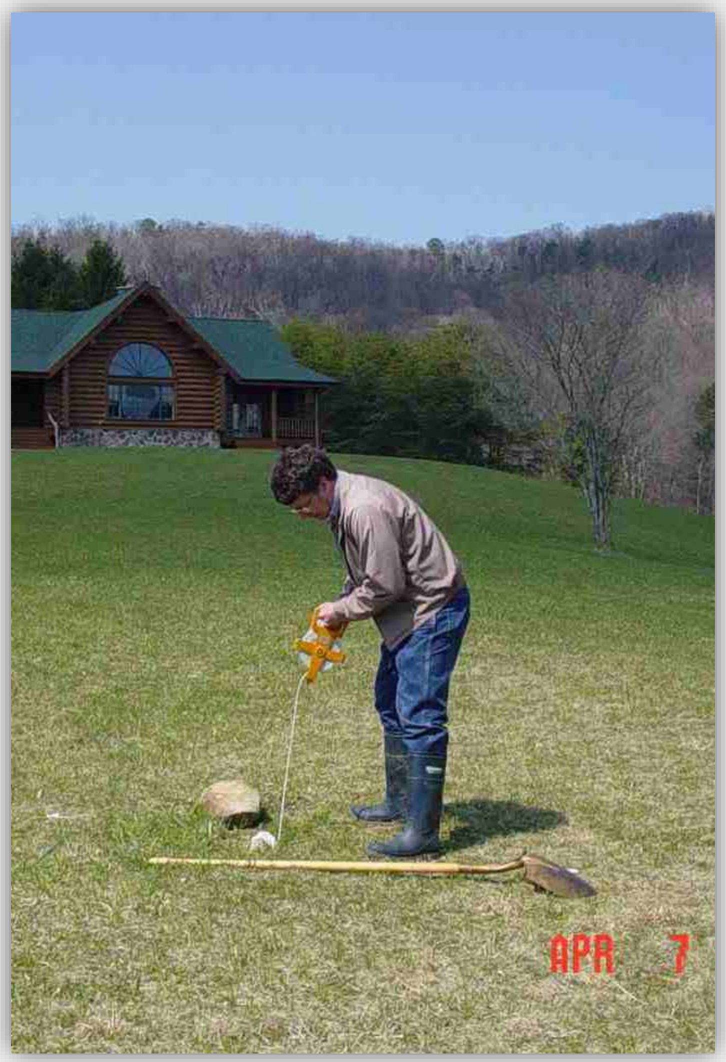
Qualified Engineers/Geologists

– Suggested Minimum Qualifications

Factor	Low Hazard	Significant or High Hazard
Education	Minimum B.S. in Civil Engineering, Geology, or related field. OR licensed as a professional engineer, professional geologist, or certified engineering geologist	
Training	Independent study or formal training in the identification and mitigation of drilling hazards in embankment dams	
Experience	Minimum of two (2) years of general drilling experience	Minimum of four (4) years of embankment dam drilling experience

Proper Borehole Completion

- Boreholes must be sealed after completion
  - Packing in cuttings is <u>not</u> acceptable
- Tremie grouting with high-solids bentonite or cement-bentonite grout is appropriate
  - Be aware of borehole volume vs. grout take
  - Tremie place clean sand/gravel if penetrate filter zone
  - Biodegradable drilling mud (Revert) is not ok
- Maintain logs of borehole completion details
  - Especially when completion involves instrumentation
- Beware: Grouting can induce hydraulic fractures
  - Take it slow
  - Fill in stages



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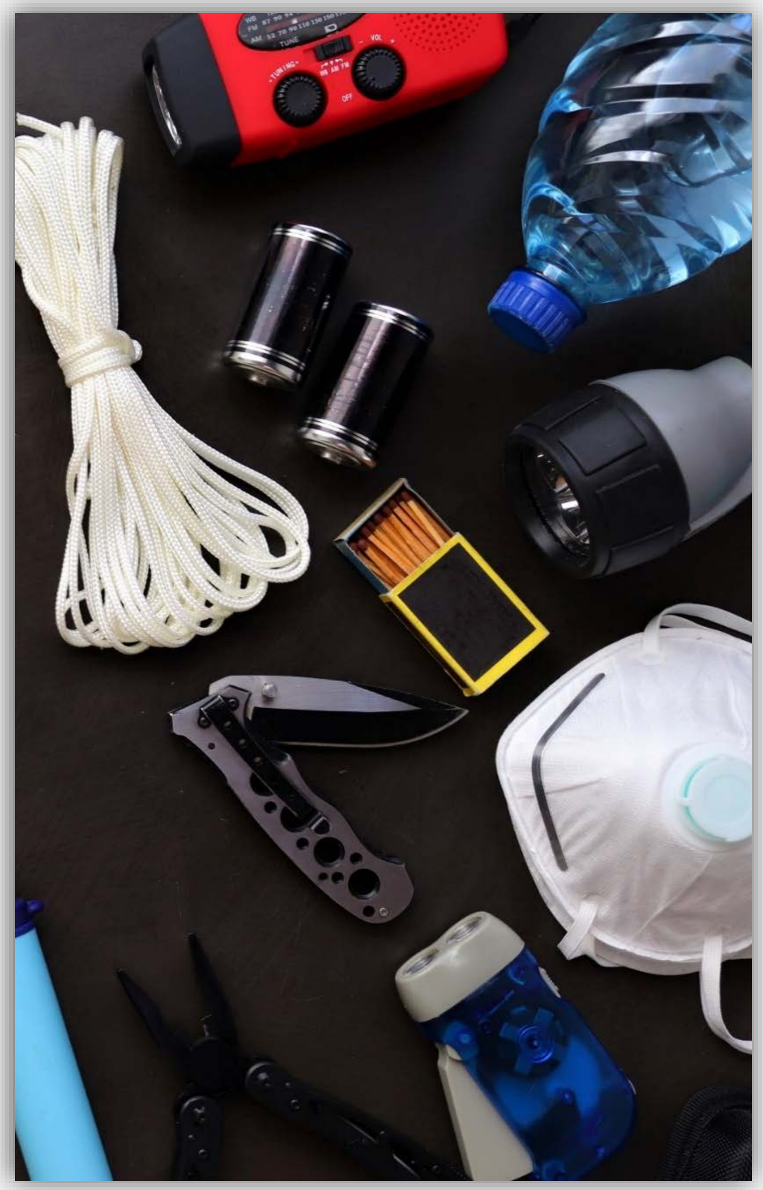
Prepare for Emergencies

- Ensure that EAP is updated <u>and</u> on-site
- Monitor the dam during drilling
  - Check instruments daily
  - Walk embankment at beginning and end of shift
- Ensure that there is a plan and materials in place in event of emergency
  - Sandbags, sand, aggregates to control seepage
  - Packers to isolate zones/cut off artesian conditions
- Consider notifying local emergency response agencies in advance of work for situational awareness



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Document Planning Efforts

- – Subsurface Investigation Plan (SIP) must be prepared for any exploration drilling, instrument installation, or remediation drilling
- – SIP should be prepared and reviewed by experienced geotechnical engineers and/or engineering geologists familiar with subsurface exploration techniques and methods.
- – SIP can be scalable to hazard class and extent of investigation

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Document Planning Efforts

– SIP Outline
  - Purpose of site disturbing activity.
  - Description of the proposed site exploration activity (drilling, test pitting, etc.).
  - Describe proposed equipment, methods, and processes.
  - Identify project personnel and qualifications/experience.
  - Risk identification and mitigation plan.
  - Provide an overall schedule and duration of drilling activities.

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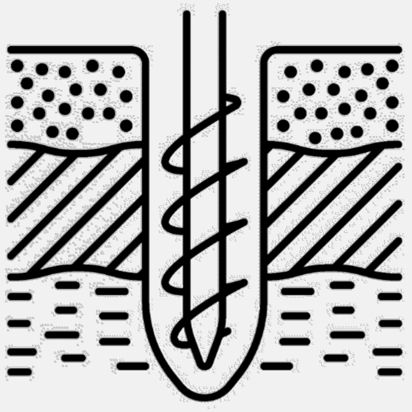
WHAT TO INCLUDE IN A PERMIT APPLICATION

Items to include in a drilling application

- Subsurface Investigation Plan
  - As described earlier
- Investigation location plan
- Table of planned investigation depths and details
  - Will certain locations be finished as piezometers, inclinometers, etc?
  - If rock may be encountered, how much coring?
  - Purpose of boring
- Boring / Test Pit completion details
- Drillers license and qualifications
- Engineers representative qualifications
- Emergency Action Plan (High or Significant Hazard)
- Typical Permit Documents (EIC Affidavit, MLR, adjacent property notifications)



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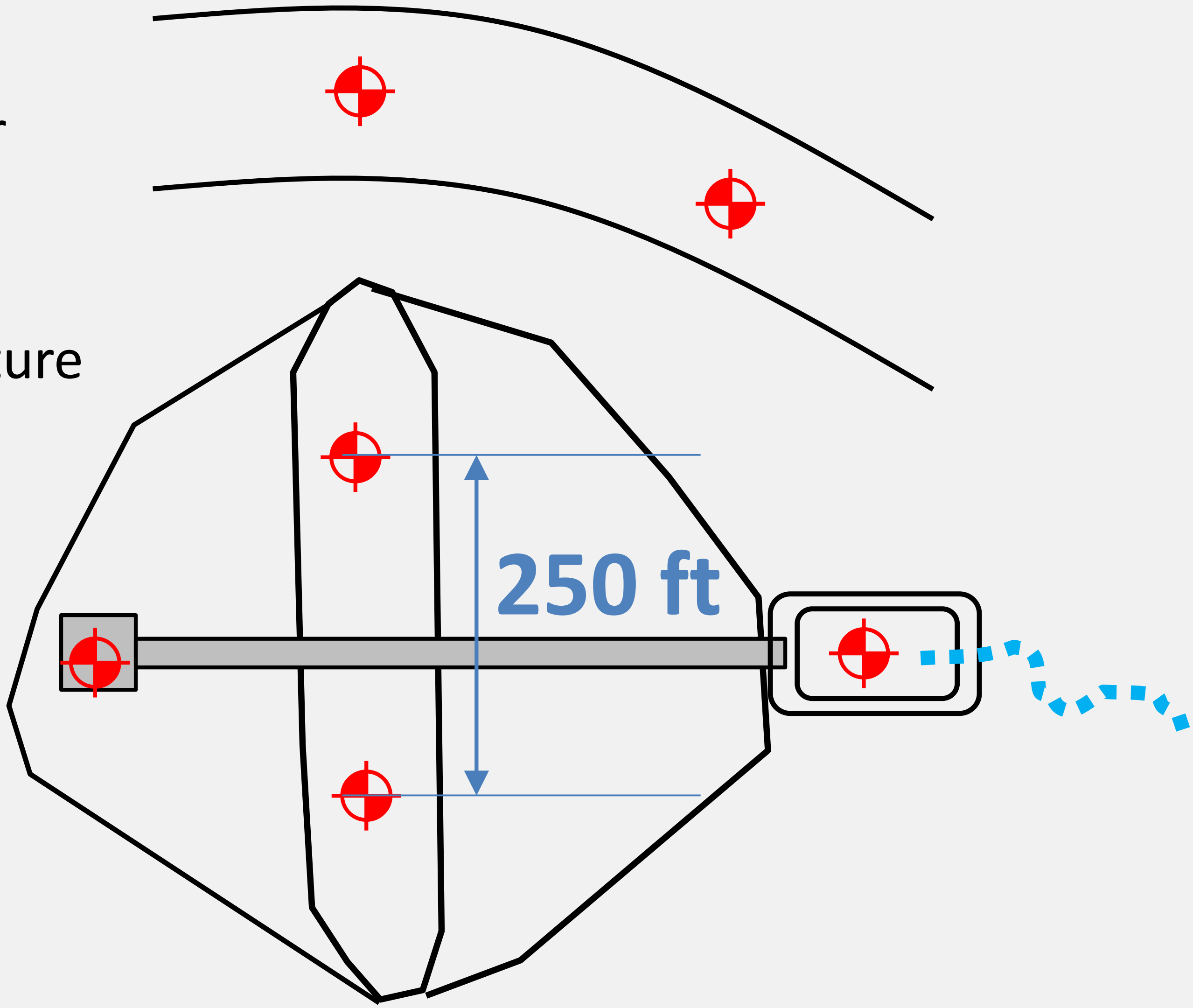
BACK TO THE FIRST QUESTION: HOW MANY HOLES?

Boring Locations (Typical)

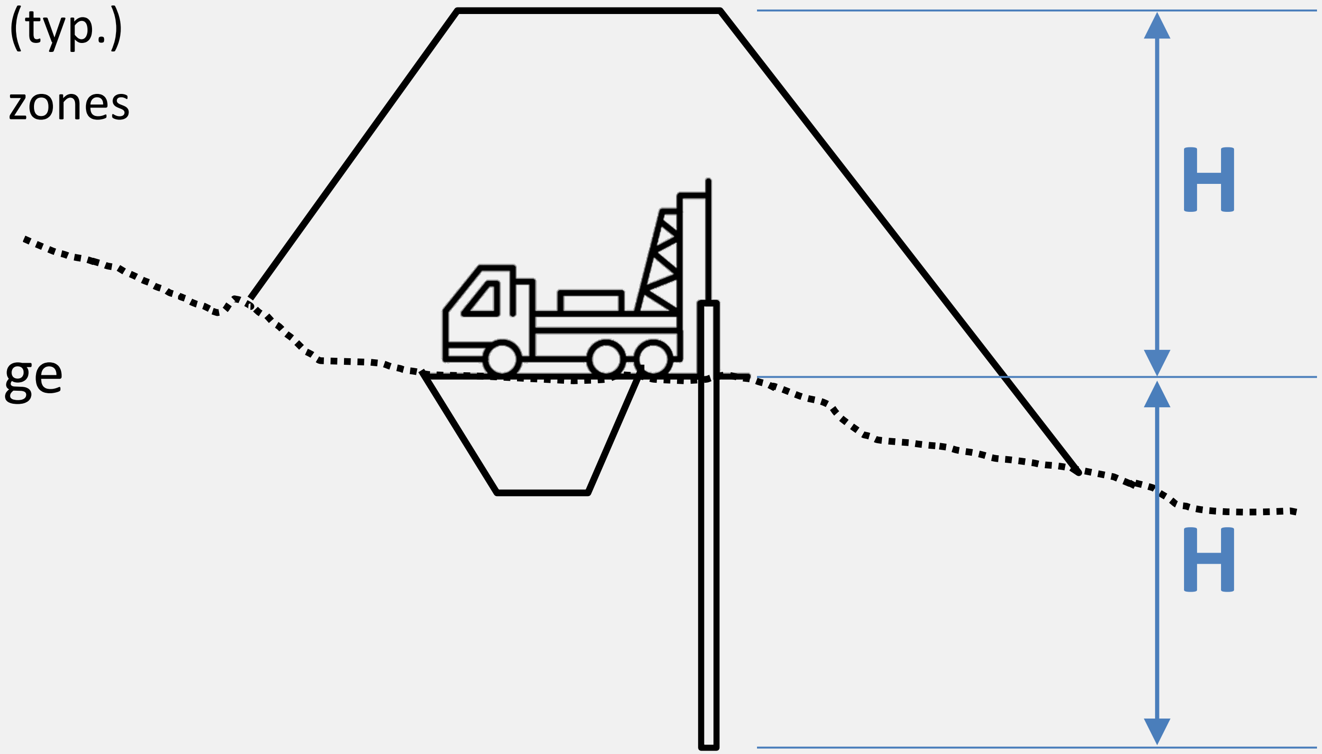
- Knowledgeable geotechnical engineer should set scope
  - Owner, civil designer should not dictate
- Quantity and locations depend on nature of project, size of dam, geologic uncertainty
- For New Construction
  - Riser location
  - Plunge pool
  - Along C_L (Max. 250 ft spacing)
  - Aux. spillway control section
  - Abutments
  - US/DS toes
  - Aux. spillway (additional)

} Depends on site



Boring Depths (Typical)

- Depths depend on geologic conditions
  - Shallow bedrock, shallower depths (typ.)
    - Recommend 10 ft. min. rock core
  - Should extend to impervious stratum (typ.)
  - Extend beyond soft/loose/unsuitable zones
- Riser and Plunge Pool ~ 20 ft.
- Embankment – as shown
- Aux. spillway – match bottom plunge pool



Thank You

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