METALLURGICAL
COAL PRODUCERS ASSOCIATION

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IMPOUNDMENT CAPPING PROBLEMS DURING ABANDONMENT

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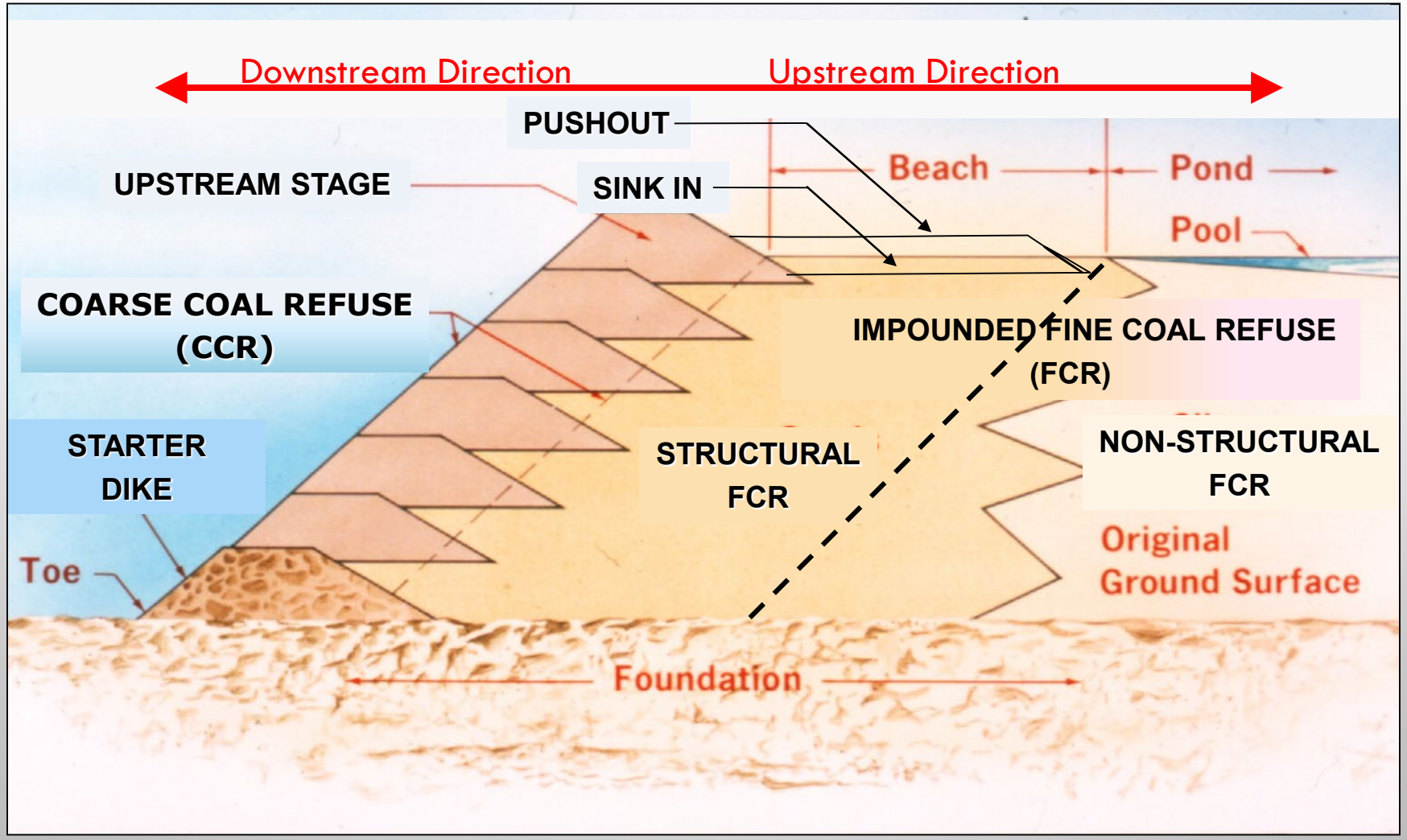
UPSTREAM CONSTRUCTION TERMINOLOGY



TERMINOLOGY

- PUSHOUT – an initial lift of coarse coal refuse (CCR) pushed out over the fine coal refuse (FCR) using a bulldozer.
  - Also called initial pushout.
  - 4 and 6 feet thick with the lower end of this range more desirable for minimizing *displacement* of the FCR.
- SINK IN – a zone of *loose* CCR that displaces (fails) the FCR during the pushout.
  - Also called displacement, mixed zone, assimilated zone…
  - Depth of sink in is a clear indicator of the FCR strength.
  - The greater the CCR sink in; the lower the FCR strength.

IMPOUNDMENT CAPPING PROBLEMS

IMPOUNDMENT CAPPING PROBLEMS

- VERY SOFT/WEAK FCR
- CAPPING INSTABILITY/FAILURE
- FCR HEAVE
- LOSS OF STORAGE DUE TO FCR HEAVE
- EXCESSIVE TIME TO ELIMINATE THE IMPOUNDMENT

FCR STRENGTH

UNDRAINED SHEAR STRENGTH (CONTD.)

- *CAN DENT SLIGHTLY WITH THUMB…* *3000-4000 PSF*
- *CAN MOLD WITH STRONG FINGER PRESSURE…* *1000-2000 PSF*
- *CAN MOLD EASILY WITH FINGER PRESSURE…* *500-1000 PSF*
- *CAN WALK ON (WITHOUT SINKING TOO MUCH)…* *150-200 PSF*
- *NEED A BIG BOARD TO SAFELY CROSS…* *15-50 PSF*

PUSHOUT AND CAP FAILURES

PUSHOUT FAILURE

PUSHOUT FAILURE

CAP FAILURE

CAP FAILURE

CAP INSTABILITY

CAP INSTABILITY

CAP INSTABILITY

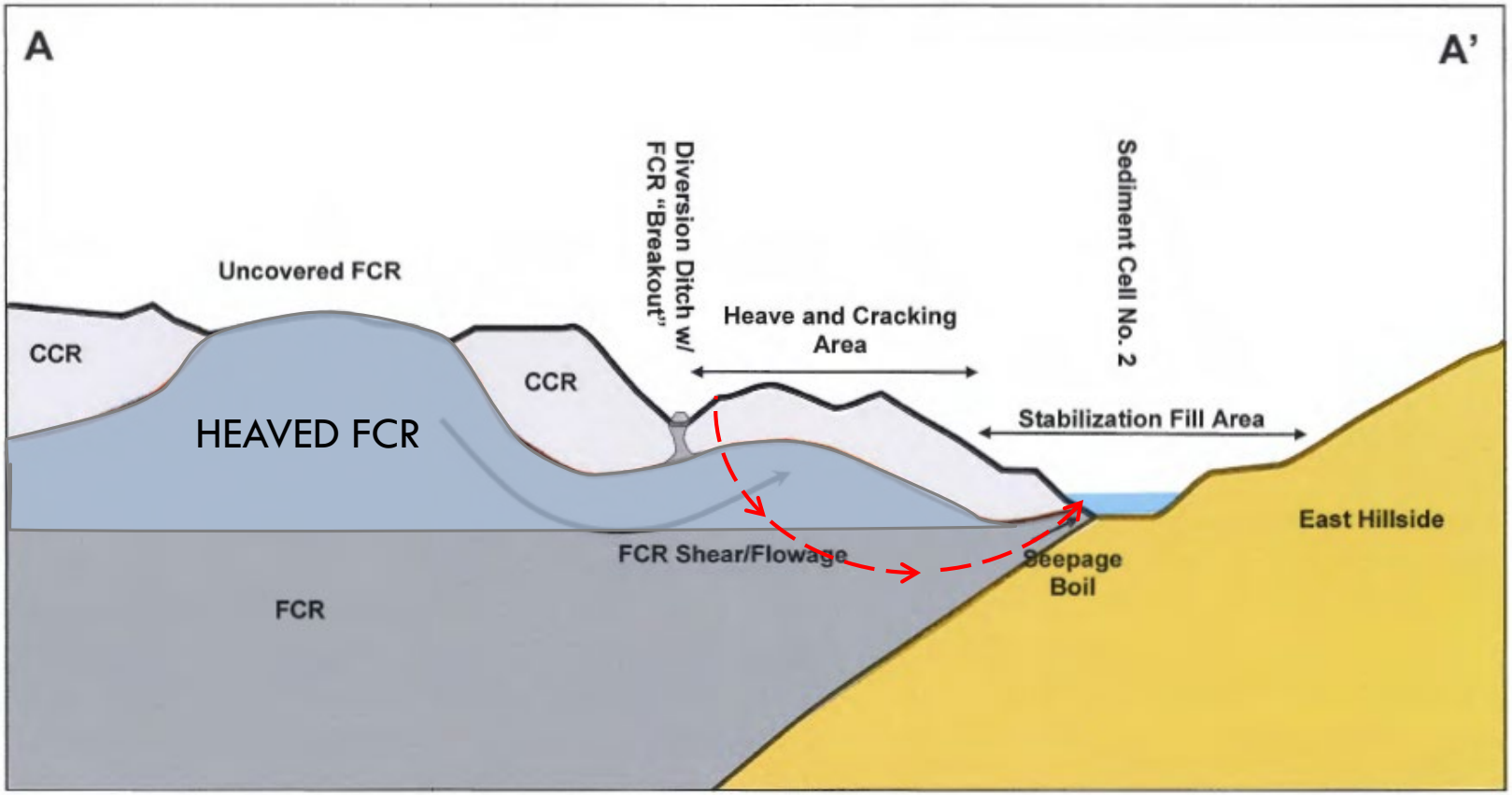


Figure No. 2: Interpreted cross section A-A' through the unstable east edge of cap and sediment control features (some vertical exaggeration - not to scale).

ANATOMY OF HEAVE

WHAT IS HEAVE

- Heave is the upward thrust of the fine coal refuse in the impoundment area caused by bearing capacity **failure** during CCR pushout or subsequent fill placement.
- Due to the relative unit weights of CCR and FCR, CCR will sink down if the FCR is not strong enough to support it. Displaced FCR is typically pushed forward and thrust upward resulting in heave.
- Normal/nominal heave of the fine refuse occurs near the leading edge of the pushout.
- Heave further into pool or "middle of the impoundment" is an unfavorable condition likely indicating a deep-seated failure.
- Additional heave of the FCR during fill placement is really undesirable and an indication of potential instability.

EXCESSIVE HEAVE

DEALING WITH HEAVE DURING PUSHOUTS

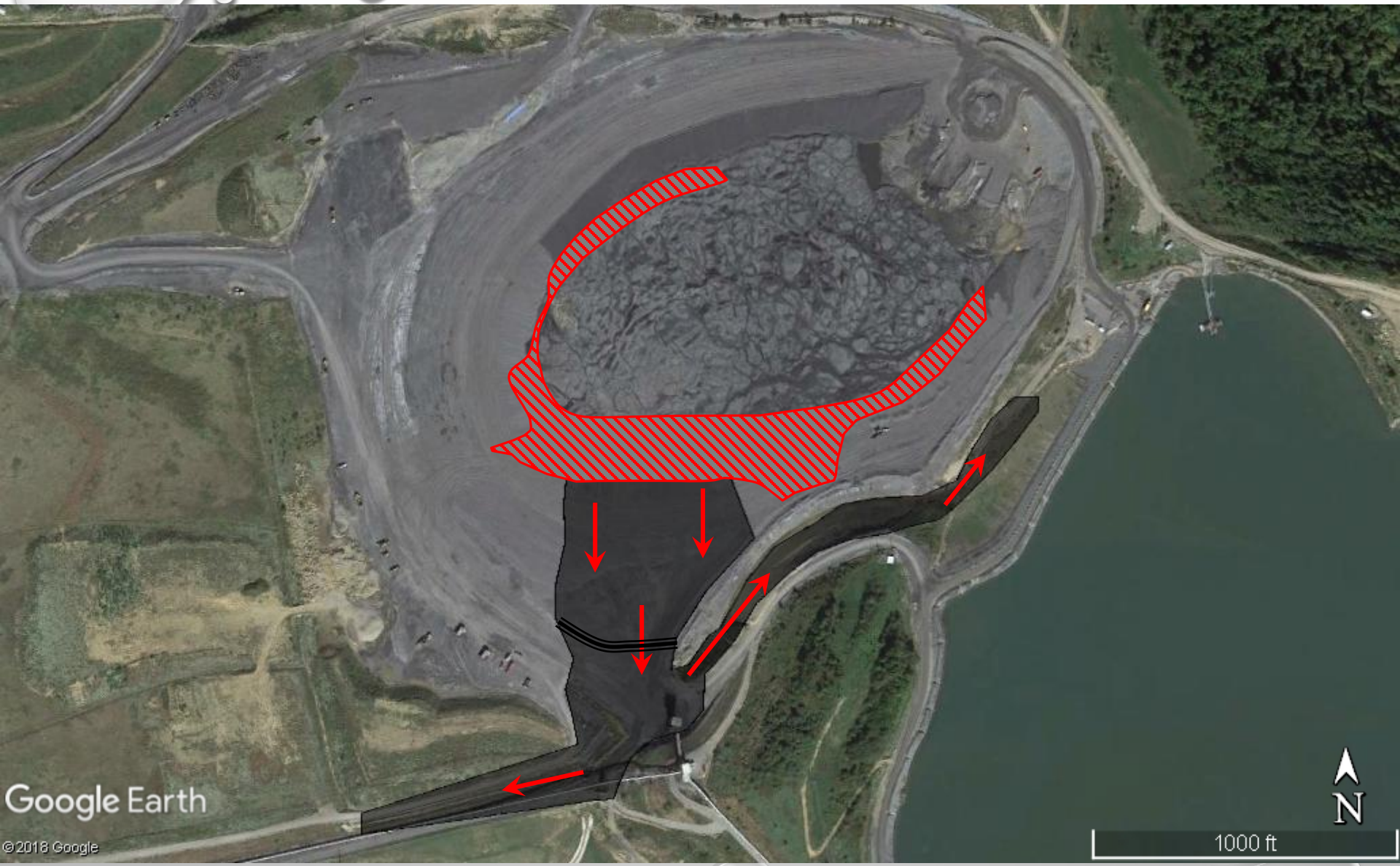
- Should displacement (heave) of fine refuse occur during pushout consider:
  - reducing the pushout thickness,
  - slowing the advance of the pushout,
  - additional dewatering,
  - improving drainage,
  - stabilization or reinforcement of the fine refuse
  - using smaller equipment
- Do not place thick subsequent lifts

SLURRY RELEASE

THICK CRUST OF DRIED FINE REFUSE

UNDERLYING FINE REFUSE REMAINS SOFT

CAP FAILURE AND RELEASE

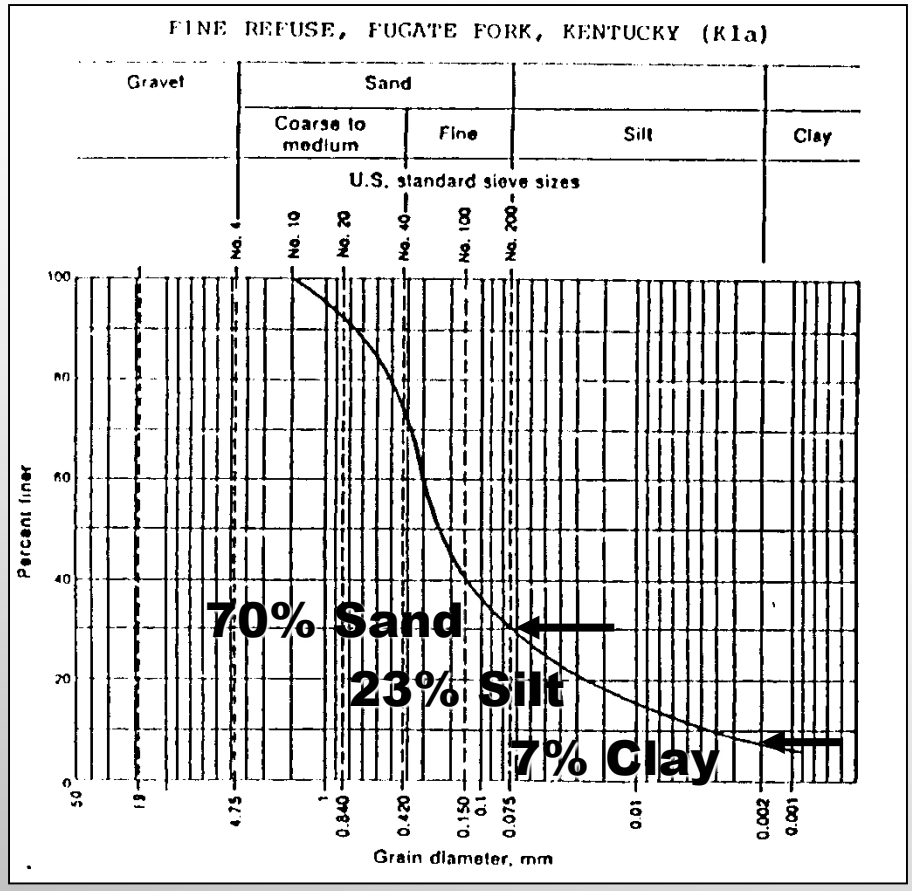


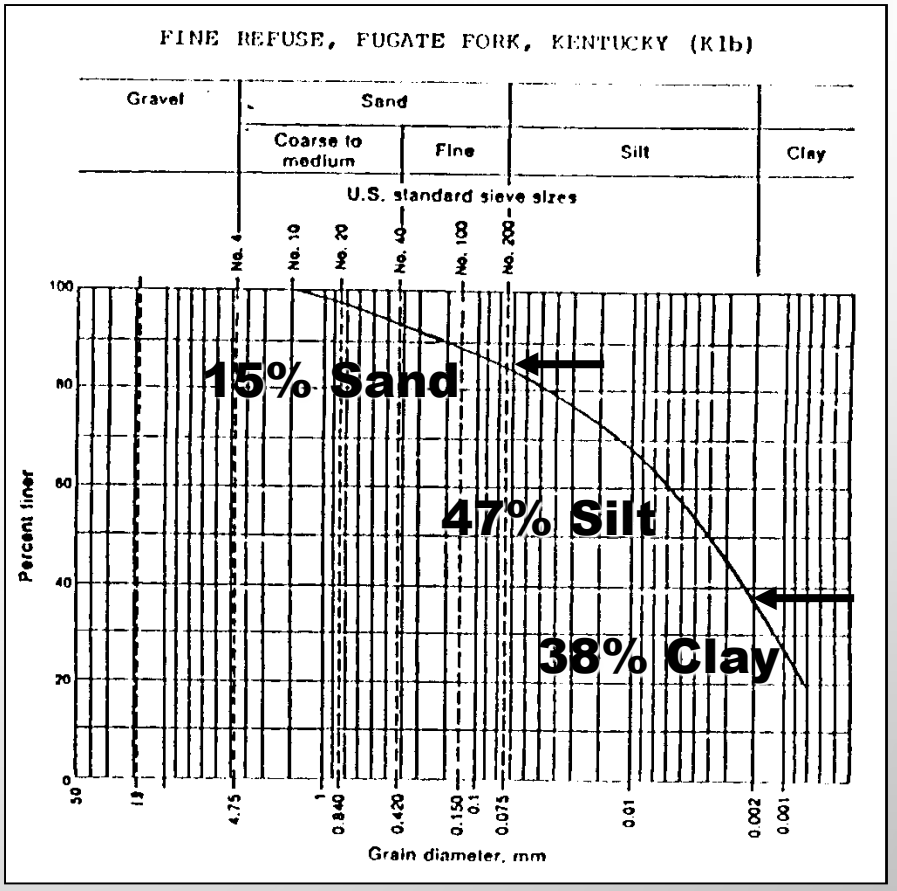
“IT FLOWED LIKE SOUP”

ISSUES CONTRIBUTING TO IMPOUNDMENT CAPPING PROBLEMS

- LACK OF SAND-SIZED MATERIAL IN THE FCR
- INCREASED PRODUCTION & RATE OF CONSTRUCTION
- HIGHER DAMS LEAD TO THICKER FCR DEPOSITS
- HIGHER OPERATING POOL BEFORE ABANDONMENT
- NOT DRAWING ALL THE WATER OFF DURING CAPPING
- FEWER UNDER DRAINS AND INTERNAL DRAINS
- FUTURE CONCERNS:
  - LINERS
  - MORE OF ALL OF THE ABOVE

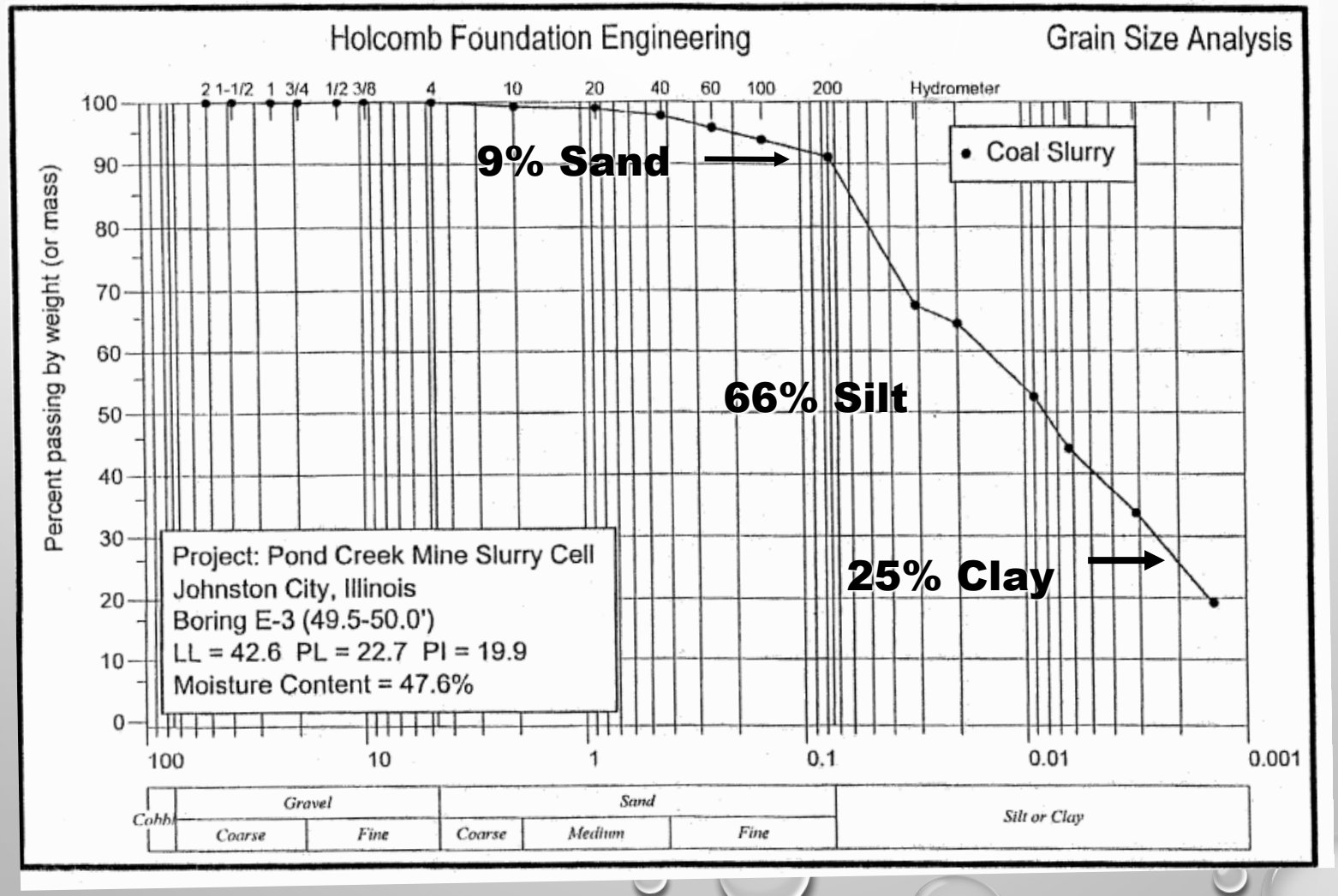
"OLDER" FINE COAL REFUSE



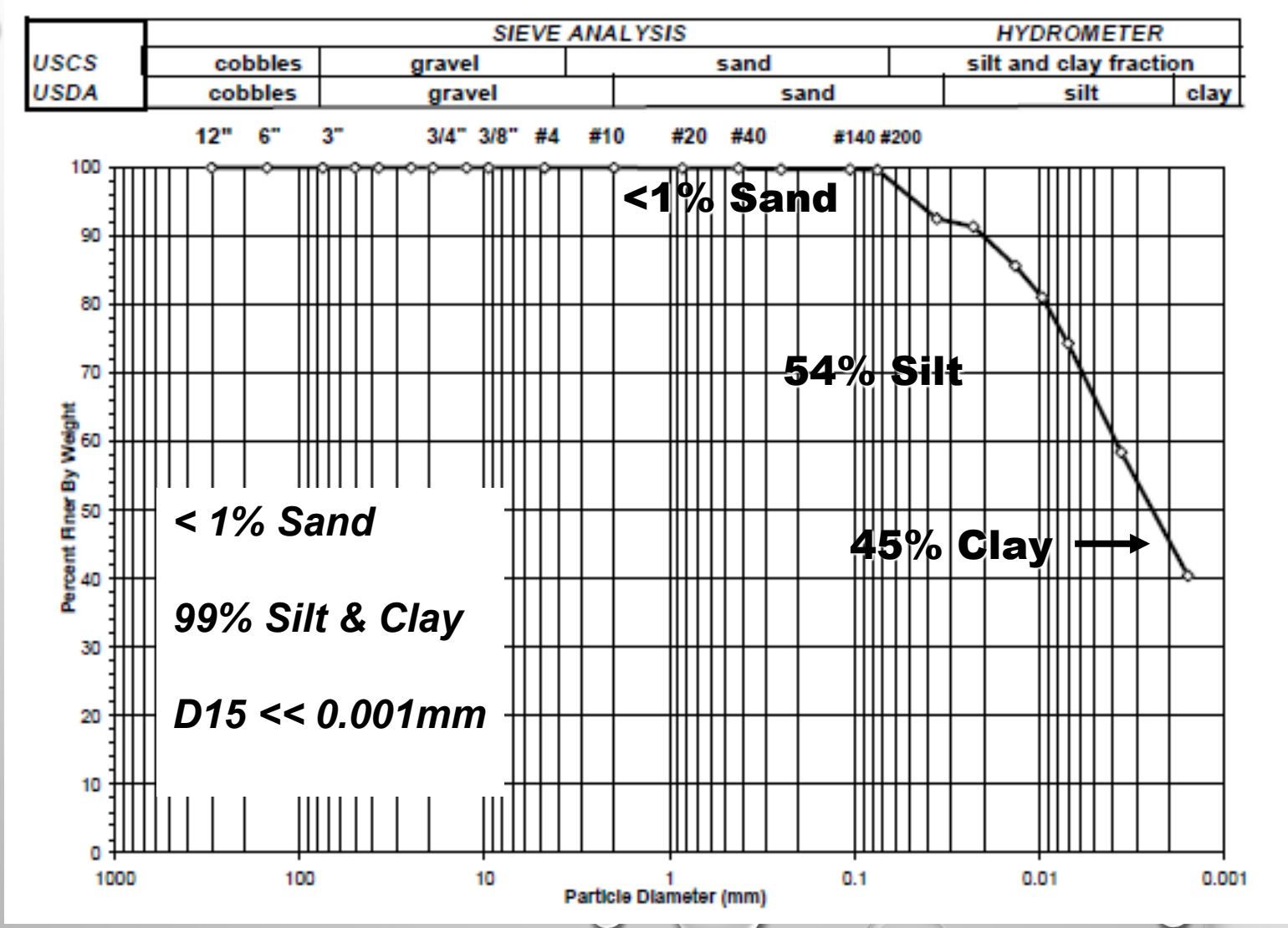


Source: Huang, Li & Weeratunga (April 1987) "Strength and Consolidation Characteristics Of Fine Coal Refuse" Univ. of KY Dept. of Civil Engineering

"NEWER" FINE COAL REFUSE

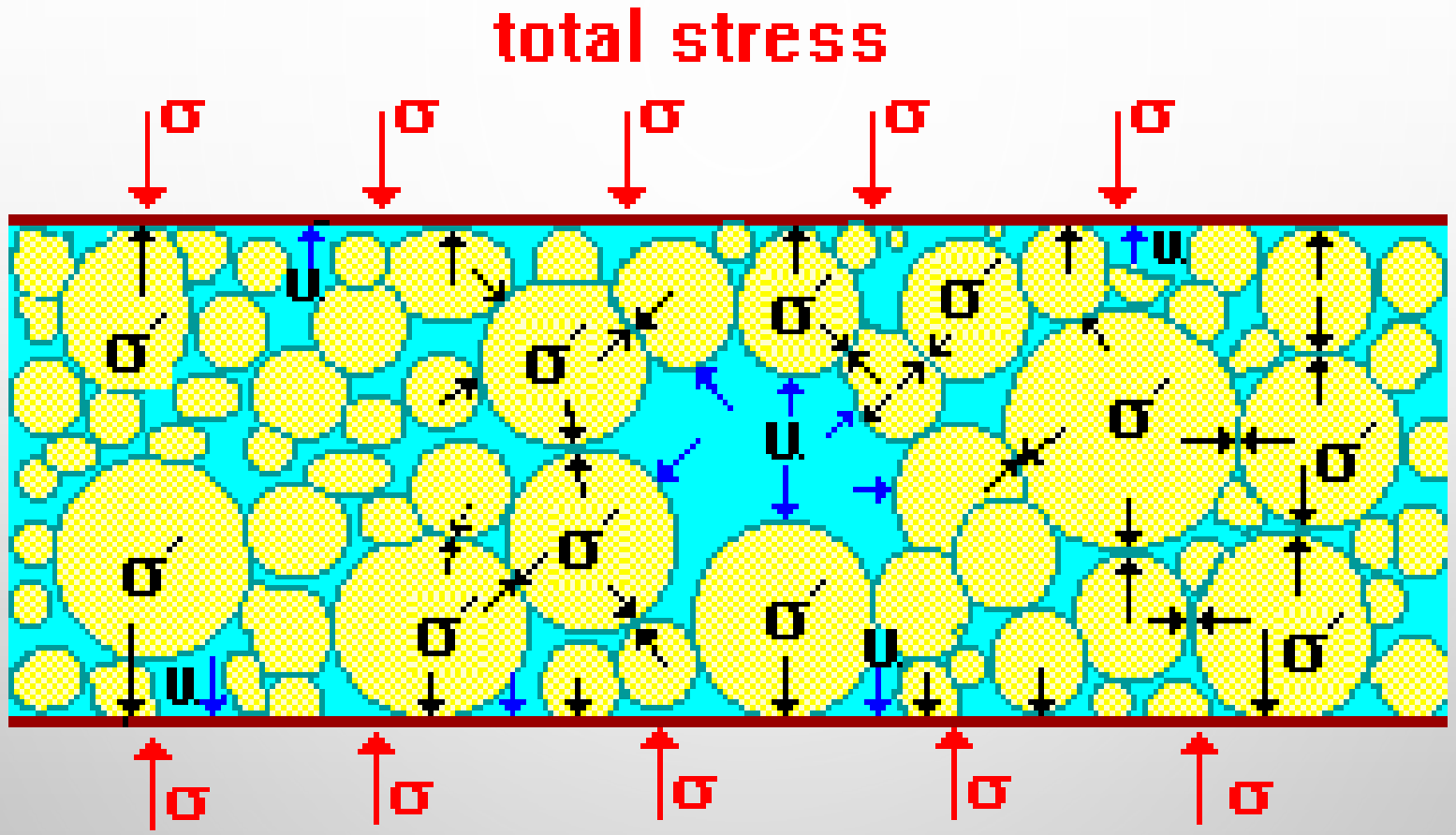


FCR from Saddle Dike Area



THE IMPORTANCE OF DRAINAGE AND CONSOLIDATION

Soil strength properties are a function of effective stress



Effective Stress = Total Stress - Pore Pressure

NOTES ON PORE PRESSURE

1. STEADY-STATE (AND HYDROSTATIC) PORE PRESSURES.

   predictable by seepage analyses and measurable in situ with piezometers

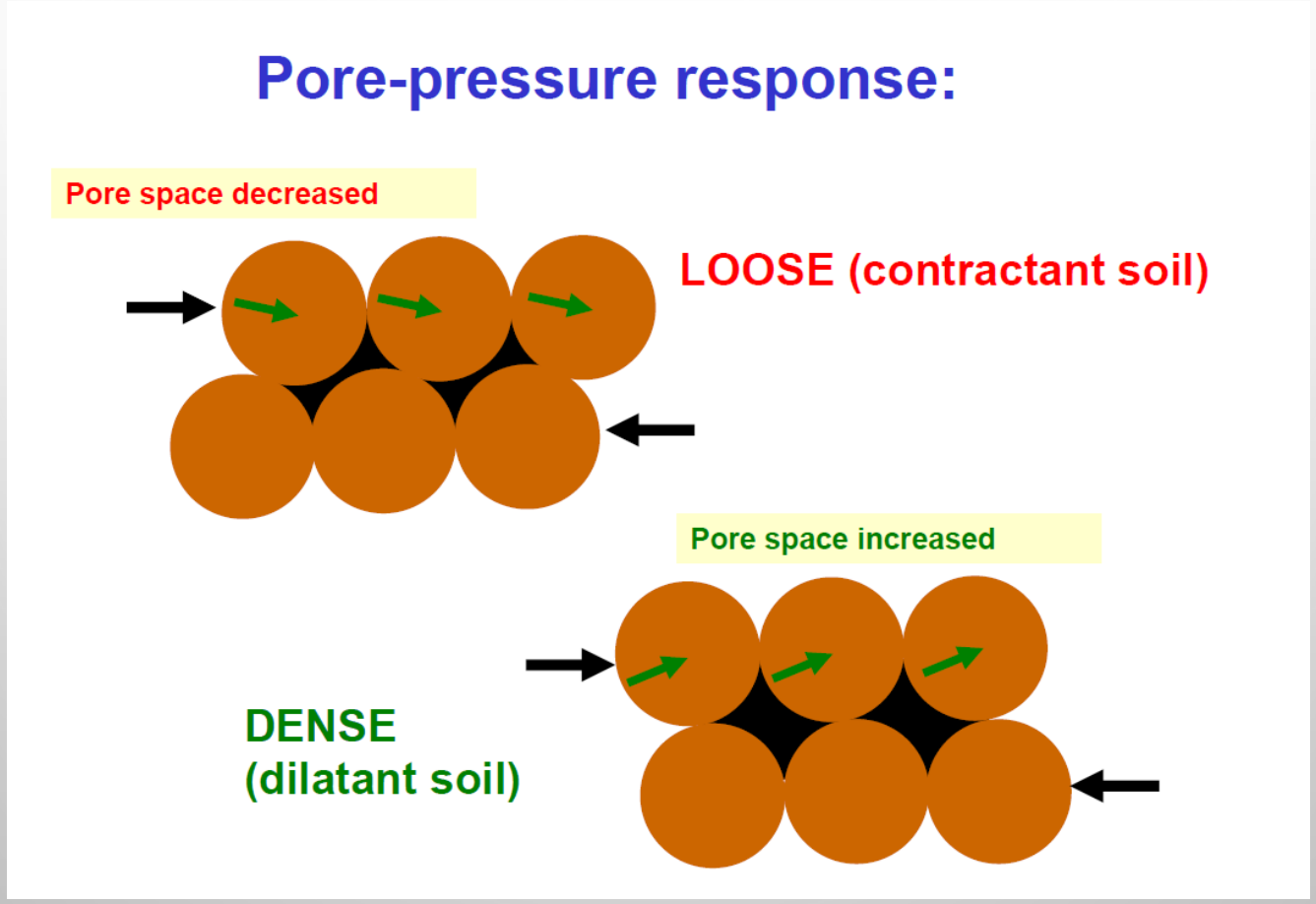
2. EXCESS PORE PRESSURES DUE TO UNDER-CONSOLIDATION.

   predictable by consolidation analyses and measureable in situ using rapid response piezometers, such as pneumatic or vibrating wire

3. PORE PRESSURES DUE TO UNDRAINED SHEAR.

   not measured in the field, but are estimated from the laboratory strength testing

CONTRACTANT VS. DILATANT

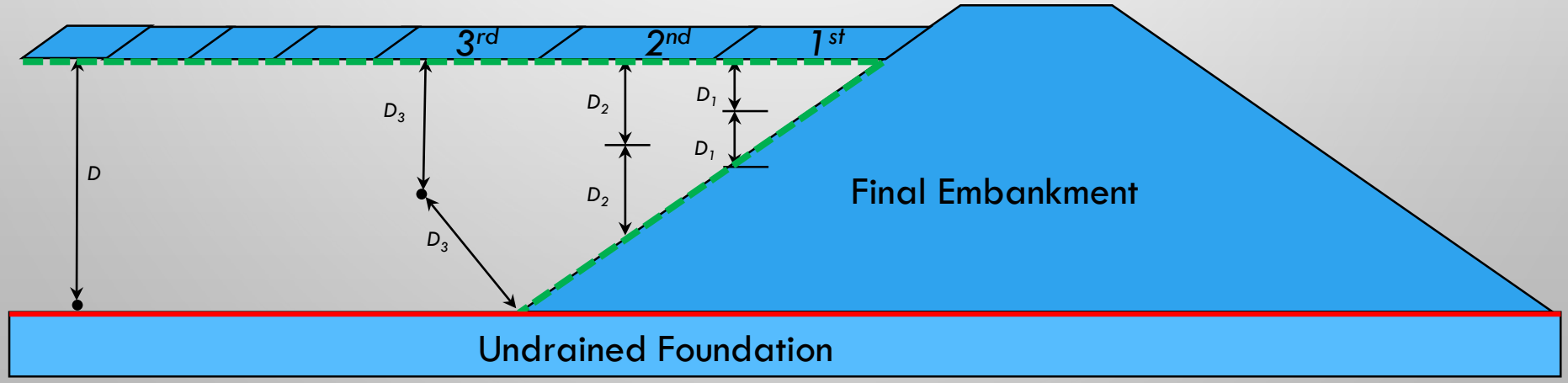


CONSOLIDATION

- GRADUAL PROCESS BY WHICH WATER IS SQUEEZED FROM A SOIL MATERIAL WHEN A VERTICAL LOAD IS APPLIED.
  - THE INITIAL LOAD RESULTS IN ELEVATED (EXCESS) PORE-WATER PRESSURE
  - DELAYS THE INCREASE IN EFFECTIVE STRESS AND DELAYS STRENGTH GAIN
  - DELAYED SETTLEMENT
- PORE-WATER FLOWS TOWARD DRAINAGE BOUNDARIES.
- DISSIPATION OF PORE-WATER ALLOWS A GRADUAL INCREASE IN EFFECTIVE CONSOLIDATION PRESSURE,
- WHICH GRADUALLY INCREASES SHEAR STRENGTH.

DRAINAGE PATHS

- The time needed to fully consolidate increases, exponentially, with a longer drainage path (e.g., Depth of FCR).
- Double the drainage path and the consolidation time increases by 4 times.
- The time needed to consolidate the FCR under the pushout/cap becomes longer the further upstream it extends.



TIME OF CONSOLIDATION

- The time needed to fully consolidate also increases with a smaller coefficient of consolidation (c_v) and
- The coefficient of consolidation (c_v) decreases with lower permeability (finer material)
- The FCR becomes finer further from the crest of the dam
- The time needed to consolidate becomes longer.
- Note that these effects are cumulative.

PRACTICAL AND INNOVATIVE IDEAS FOR PREVENTING OR MITIGATING ADVERSE CAPPING ISSUES

IDEAS FOR EARLY PREVENTION

- If your FCR does not have sufficient sand content, can you change that?
- From the beginning: install drains along the valley bottom to the back of the impoundment.
- More internal drains in the embankment
- Maintain the operational pool as low as practical
- Innovative: periodically move FCR discharge to the back.

BEFORE AND DURING ABANDONMENT

- During final stage(s) through early abandonment, provide additional drainage of the FCR, particularly near the back.
  - Place coarse refuse around to the back of the pool area.
  - Install horizontal wick drains.
- Hydraulically place sand-sized (FCR or CCR) material over the FCR in the back of the pool.
- Draw all free water off the impoundment.
  - Install a sump area to pump water down below the FCR.

MITIGATION

- When approaching wet areas or the FCR starts to exhibit heave:
  - Try placing a layer of CCR over the FCR with a long reach excavator in advance of dozers advancing the pushout. Maintain this upstream layer well in advance – time (needed for consolidation) and distance (buttressing effect) – of the pushout.
- Vertical wick drains through the cap
- Deep soil mixing or geotextile reinforcement

SUMMARY & CONCLUSION

- DRAINAGE, DRAINAGE, DRAINAGE – CONSIDER MORE DRAINS
- TRY TO IMPROVE CONSOLIDATION AND PREVENT FCR HEAVE
- DEWATER, DEWATER, DEWATER – SUMP BELOW THE FCR
- ADVANCE THE CAP SLOWLY – IN SMALL INCREMENTS
- DO NOT RAISE THE CAP TOO SOON OR FAST – ONLY ONE PUSHOUT
- AVOID CAPPING FROM 3 OR MORE SIDES
- AVOID CHASING THE FCR HEAVE

QUESTIONS AND DISCUSSION

ADDITIONAL RESOURCES

MSHA'S ENGINEERING AND DESIGN MANUAL

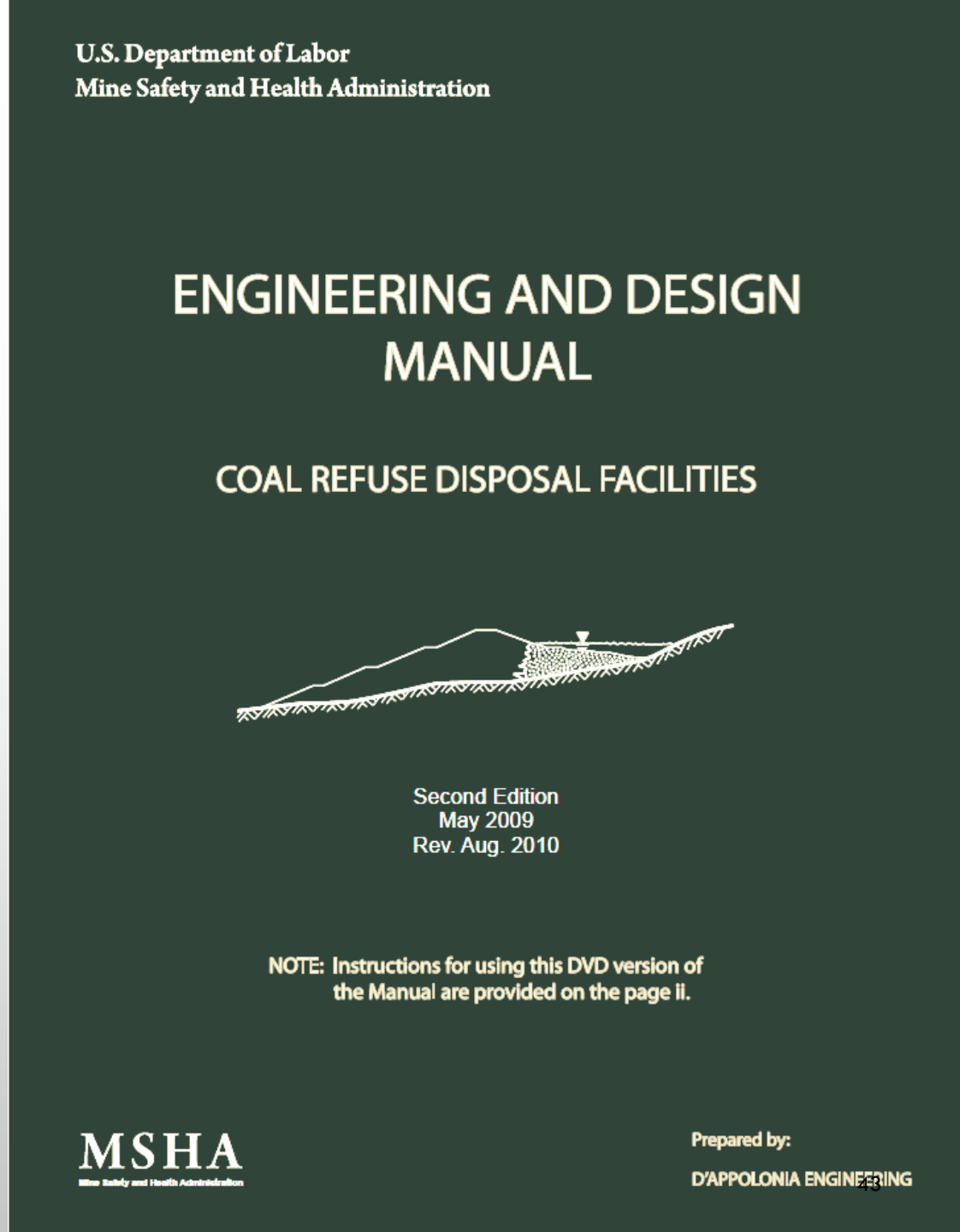
THE NEW "GREEN MONSTER"

PUBLISHED: 2009

REVISION DATE: AUG. 2010

HTTPS://ARLWEB.MSHA.GOV/IMPOUNDMENTS/DESIGNMANUAL/2009IMPOUNDMENTDESIGNMANUAL.PDF

SEARCH KEYWORDS: "PUSHOUTS"
"UPSTREAM CONSTRUCTION"
"IMPOUNDMENT ELIMINATION"



ENGINEERING AND DESIGN MANUAL
COAL REFUSE DISPOSAL FACILITIES

5.9 RECLAMATION, ABANDONMENT AND POST-MINING LAND USE

General provisions for and plans related to abandonment of a coal refuse embankment are part of the final operational stage of the disposal facility and should address elimination of the impoundment…

During the final periods of disposal and progressive elimination of the impoundment capacity, the outlet works such as the decant structure or spillway should remain operational until impoundment regrading is complete.

ENGINEERING AND DESIGN MANUAL
COAL REFUSE DISPOSAL FACILITIES

9.5.1 DESIGN STORMS FOR IMPOUNDMENTS

The impounding capability should be eliminated within two years after the impoundment can no longer accommodate the long-term design storm, and the work should be phased so that the facility is capable of accommodating less than the short-term storm for no more than one year.

ENGINEERING AND DESIGN MANUAL
COAL REFUSE DISPOSAL FACILITIES

10.5.3 IMPOUNDMENT ELIMINATION

The impoundment surface may be dry, desiccated, or vegetated, but the underlying fine refuse typically remains soft and can exhibit sudden shearing under equipment operation.

Preparation of an impoundment elimination plan may require characterization of the fine refuse materials (including drainage and consolidation properties)…

Section 11.5.2 provides guidance for upstream construction that should be considered in developing and implementing plans for capping.