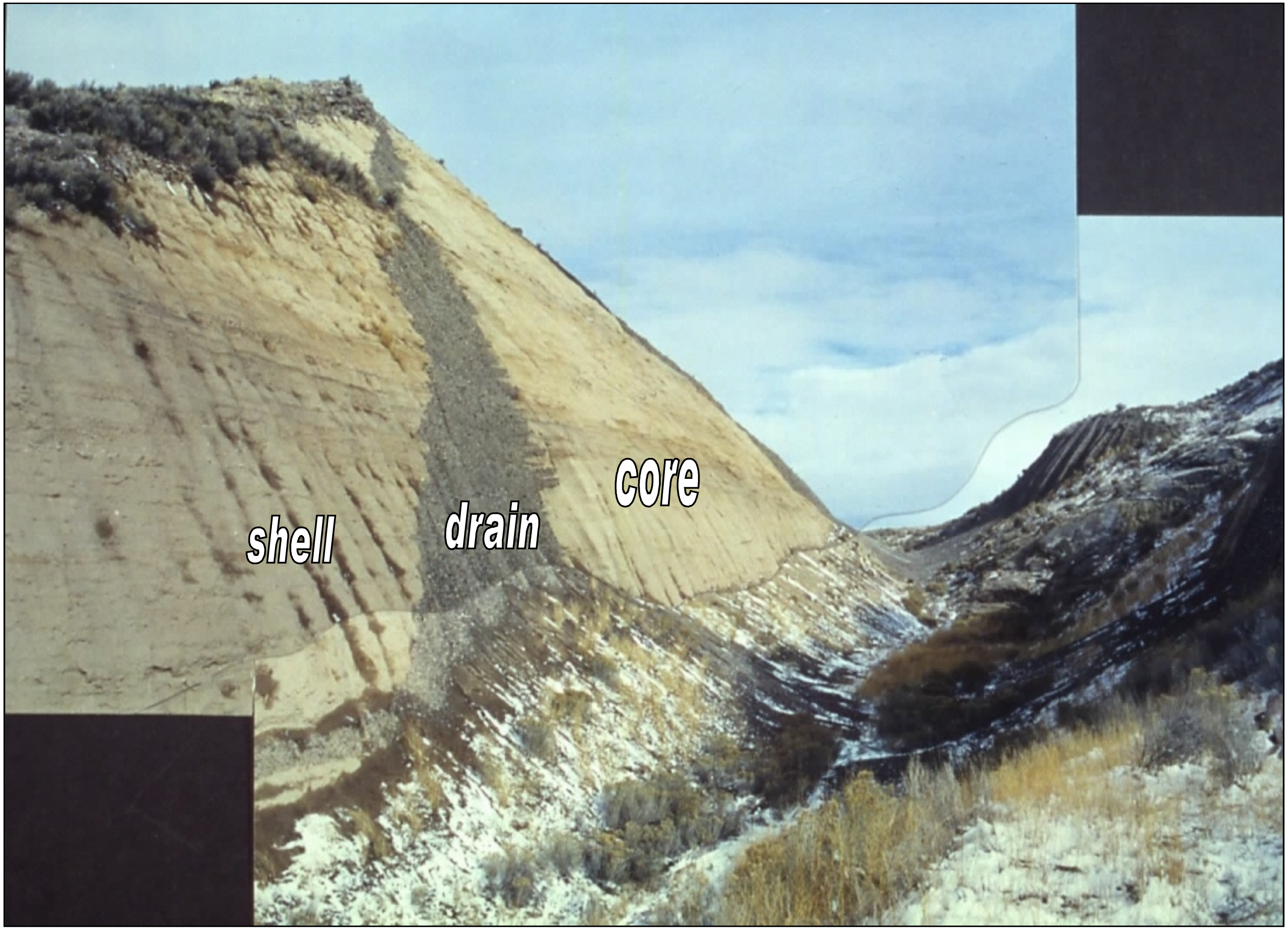
Part 6

SEEPAGE FILTERS

VU-5-882-3-51 01CC NOy Contracts - 27 March 1951 - Fena River Dam - Placing and Compacting Zone #1 Material - Project 210 - Contract NOy-13931

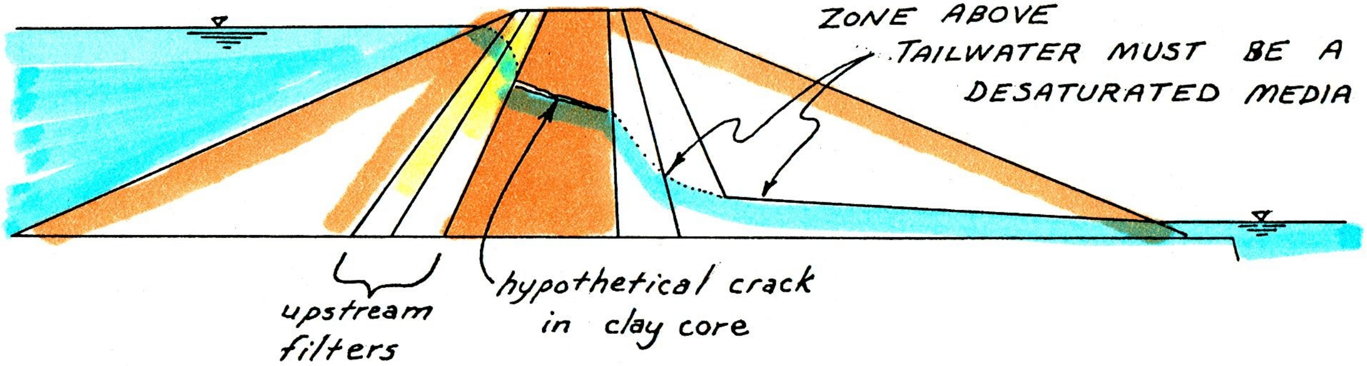
- **Placement of earthen clay core, up and downstream filters, and rockfill shells at Fena Dam on Guam by Navy Seabees in 1951. Upstream is to the right.**

- Hydraulic piping/soil erosion can be prevented by the placement of filter layers of intermediate size material between the soil and the drain rock, if their particle sizes are dramatically different. This is a common precaution when constructing earth dams, like that shown here (Sabena Yegua Dam in the Dominican Republic).



- **Inclined chimney drain comprised of coarse gravel at Teton Dam, between the loess core and the loess shell**

GENERAL ASPECTS OF THE CRACKSTOPPER THEORY

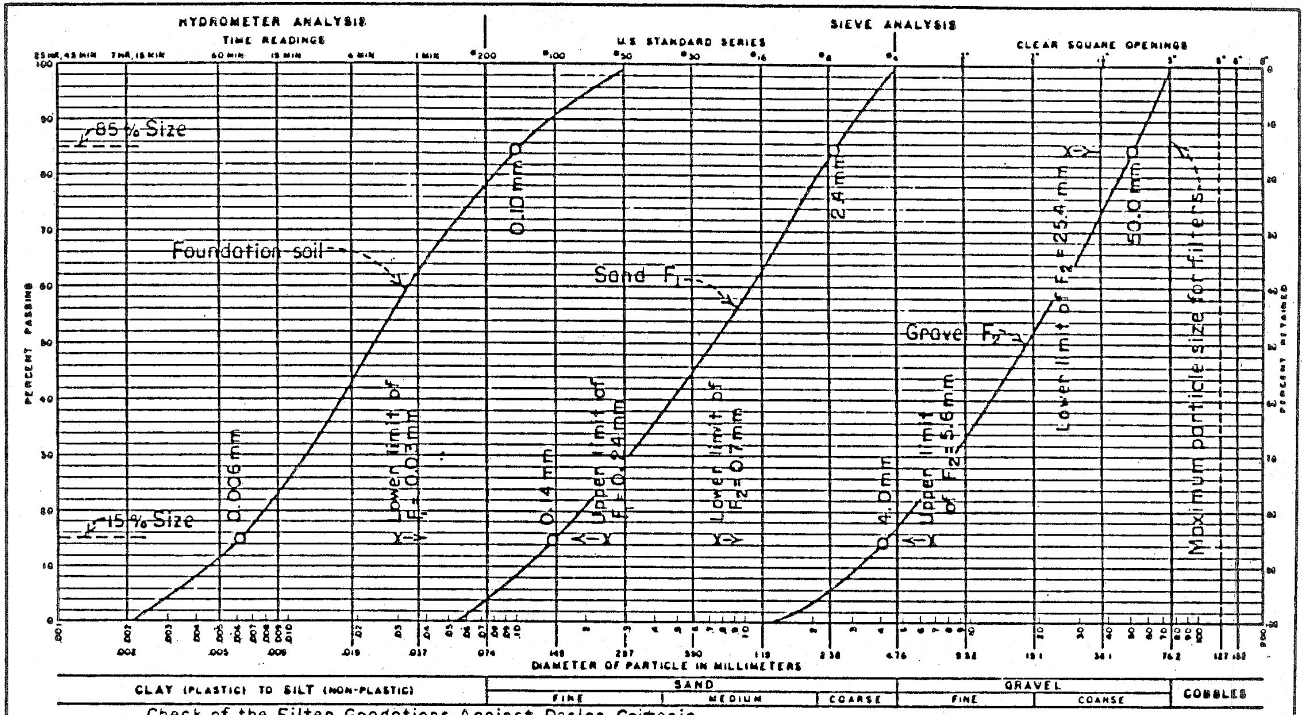


TWO ESSENTIAL ELEMENTS

1. CRACK WON'T GET LARGER
2. CRACK WILL PLUG WITH FILTER MTL.

— NO GUARANTEE OF VALIDITY —

- **The “Crackstopper Theory” was advanced in by the Corps of Engineers in the early 1940s;**
- **It assumes that progressively larger particles will infill a adjoining fissure and plug it, preventing hydraulic piping**



Check of the Filter Gradations Against Design Criteria

For Filter F_1:

$$\frac{D_{15} \text{ of } F_1}{D_{15} \text{ of Foundation}} = \frac{0.14}{0.006} = 23;\ 5 < 23 < 40, \text{ O.K.}$$

$$\frac{D_{15} \text{ of } F_1}{D_{85} \text{ of Foundation}} = \frac{0.14}{0.10} = 1.4;\ 1.4 < 5, \text{ O.K.}$$

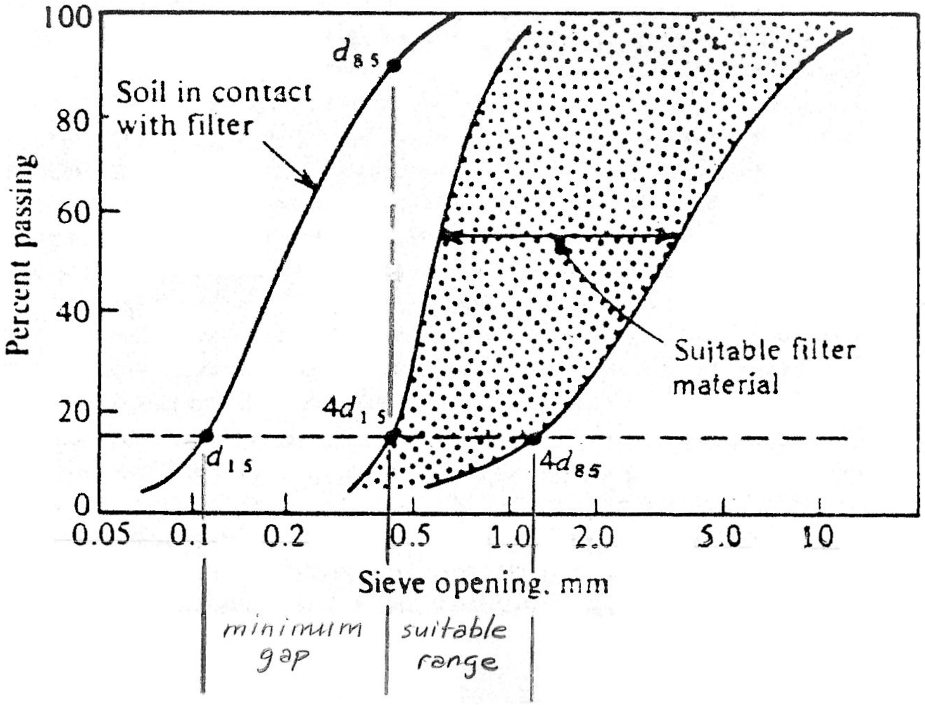
For Filter F_2:

$$\frac{D_{15} \text{ of } F_2}{D_{15} \text{ of } F_1} = \frac{4.0}{0.14} = 29;\ 5 < 29 < 40, \text{ O.K.}$$

$$\frac{D_{15} \text{ of } F_2}{D_{85} \text{ of } F_1} = \frac{4.0}{2.4} = 1.7;\ 1.7 < 5, \text{ O.K.}$$

D_{85} of F_2 = 50 mm; 50 mm > 25.4 mm, O.K.

- The Bureau of Reclamation limits filter aggregate to 3 inches diameter and demands:
- The ratio D_{15}(filter)/D_{85}(soil) must always be less than 5



The basic filter criteria are given as:

- D_{15} (filter)/D_{85} (soil) < 4 to 5 < D_{15} (filter)/D_{15} (soil)
- D_{15} (filter) must not be more than 4 or 5 X D_{85} (soil)
- The ratio D_{15} (filter)/D_{85} (soil) is the *piping ratio*
- The D_{15} (filter) must be 4 to 5X the D_{15} (soil being protected)

Abutment Seepage

Abutment seepage at Starvation Dam and Reservoir near Duchesne, Utah, as viewed in 1977. This dam had recently been built by the Bureau of Reclamation, between 1967-70. The Bureau of Reclamation undertook a thorough study of the seepage problems and corrected them in the 1980s.

- Most seepage-related failures of dams have occurred via percolation through fractured bedrock abutments, or along outlet conduits. This concrete-faced earthfill dam near Lima, Peru failed upon its initial filling because of inadequate seepage collars along the outlet works conduit on the right abutment.


Piping occurred in the abutment, not within the embankment

Piping occurred along a branch of the Newport-Inglewood fault, shown below

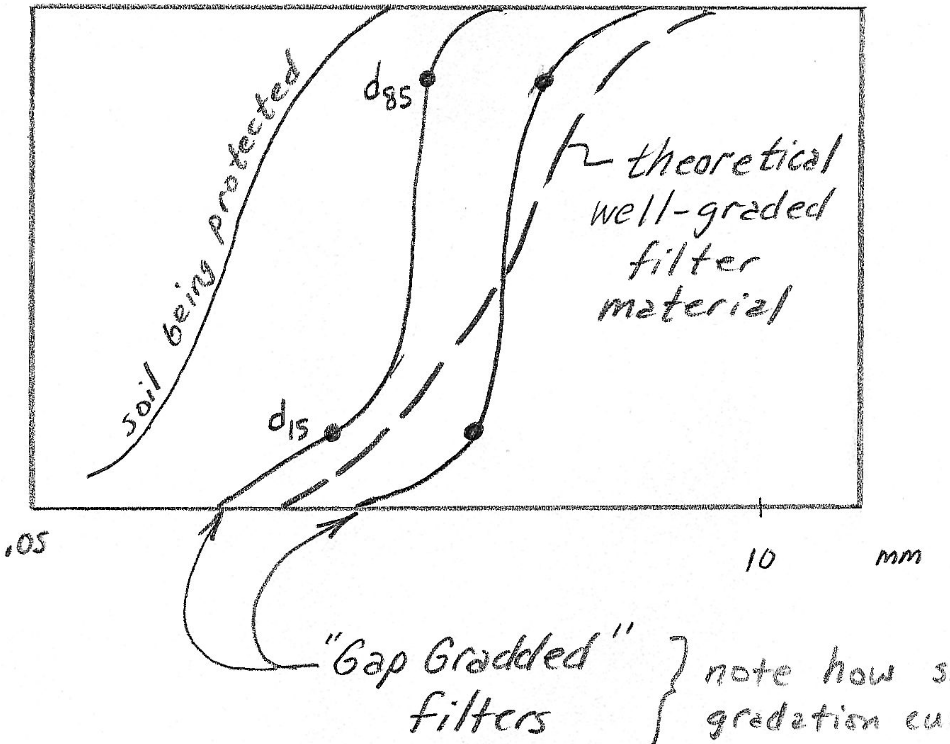

Water streaming from the reservoir's abutment, shortly before breach of the embankment

- **The Baldwin Hills Reservoir in Los Angeles failed in Dec. 1963 by hydraulic piping through the rock abutment, along an active fault that had shifted about 1.5 feet over the previous decade**

- **Fontinelle Dam** was constructed by the US Bureau of Reclamation on the Green River in Wyoming in 1961-65, with a single line grout curtain.
- In September 1965 a serious piping failure occurred on the right abutment where reservoir water passed through valley-side stress relief joints in the sandstone (with only 46 feet of head). The dam came dangerously close to failing, as shown here.

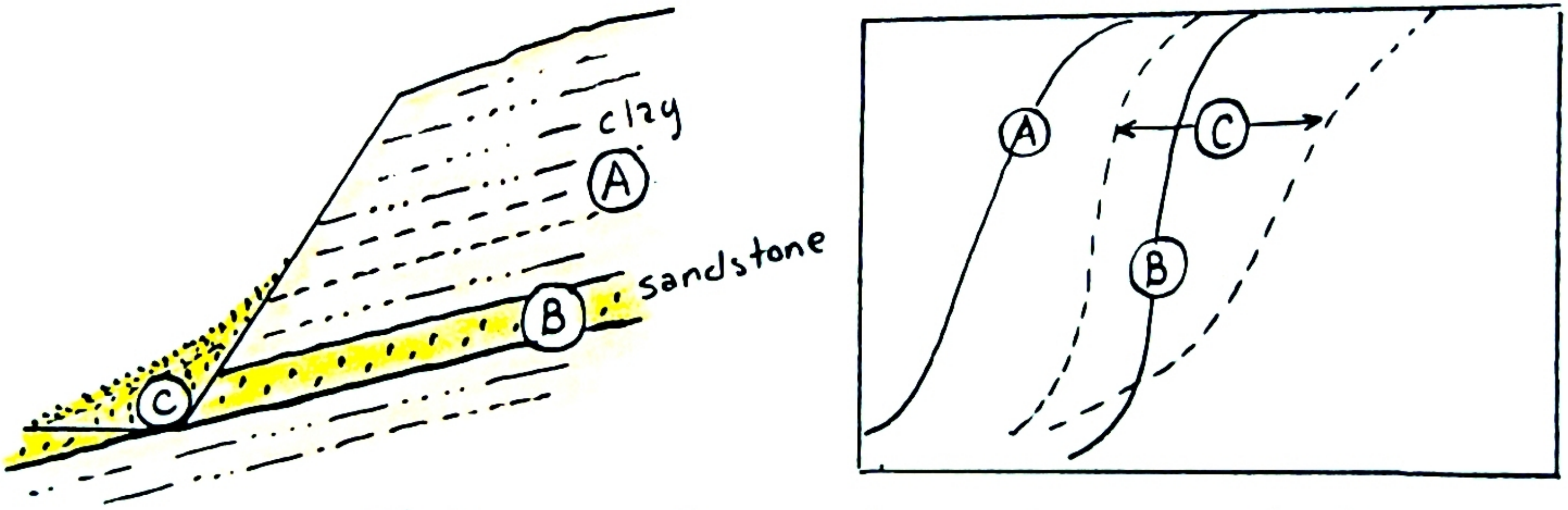
8 rows of grout curtains were installed on the right abutment and the entire dam was subsequently retrofitted with a vertical diaphragm seepage cutoff wall.

- The **Teton Dam** near Rexburg, Idaho failed by hydraulic piping through the fractured rhyolitic ignimbrite in the right abutment keyway on June 5, 1976, during its initial filling.
- This could have been prevented by installing a filter between the fill and the fractured rhyolite exposed in the right abutment keyway.



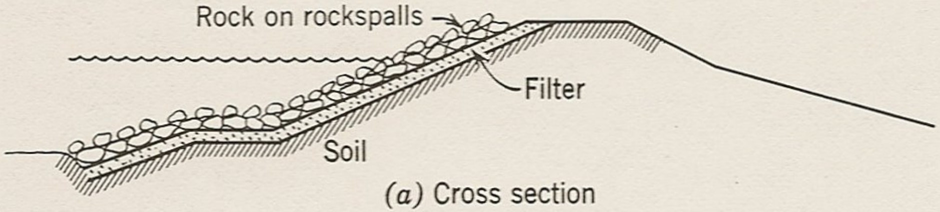
note how shape of the gradation curve varies from the soil being protected

- **One of the problems with D_{15} and D_{85} filter criteria is "gap gradation", caused by well sorted (river run) material. Filters should always be comprised of well-graded mixtures, with a graduated range of particle sizes.**

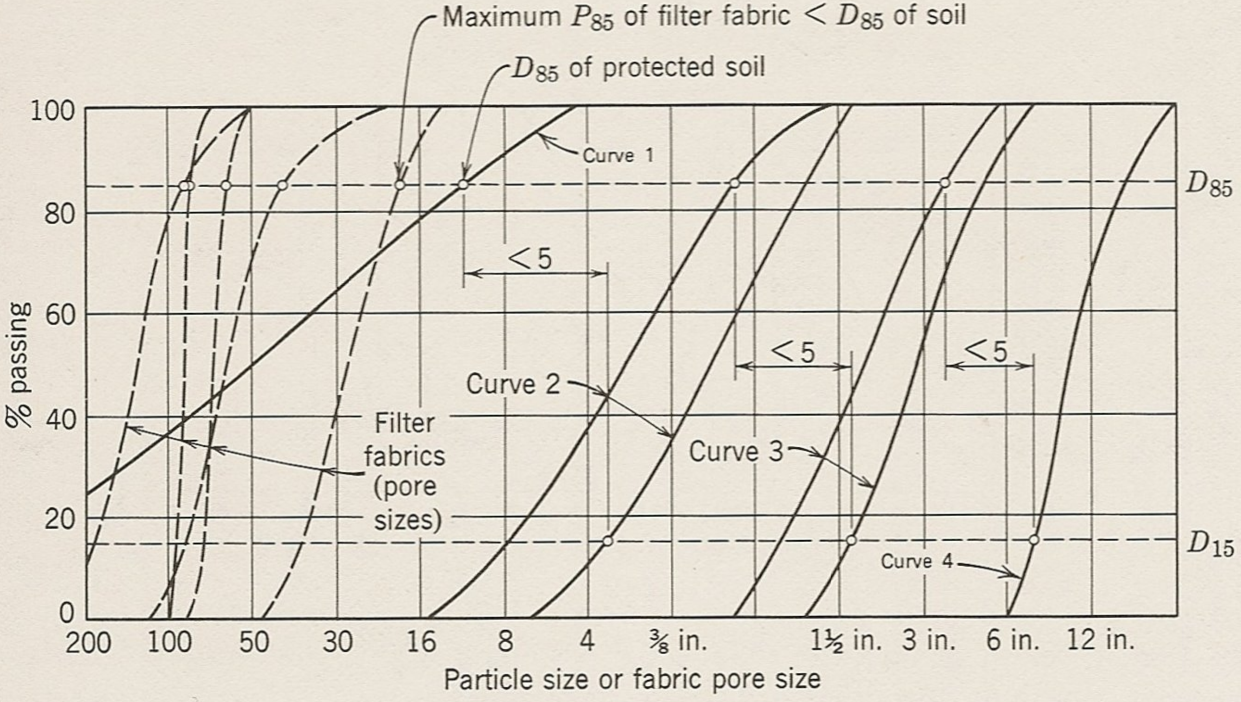


If the groundwater is coming out of the sandstone and not the clay, match filter to the sandstone.

- **Filter criteria** should be compared between the aquifers producing seepage and the soil being protected. In this case, the sandstone (B) is producing seepage and the subdrain is comprised of Material C. Material A (shale) may not be a factor if it does not produce moisture



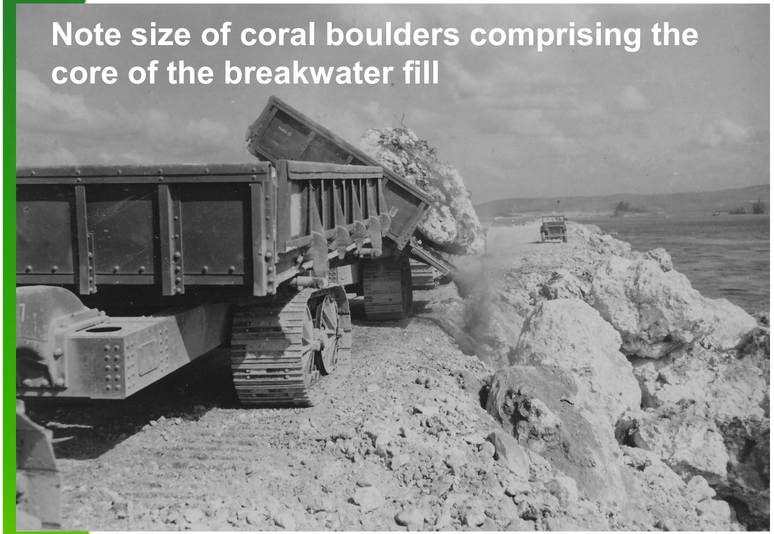
(*a*) Cross section



(*b*) Grading curves

Filter criteria for riprap slope protection of earthen embankments, from Cedergren (1989). Intermediate Filter Curve 2 prevents soil of Curve 1 from washing through the rock cushion (Curve 3) or through the armor rock (Curve 4)

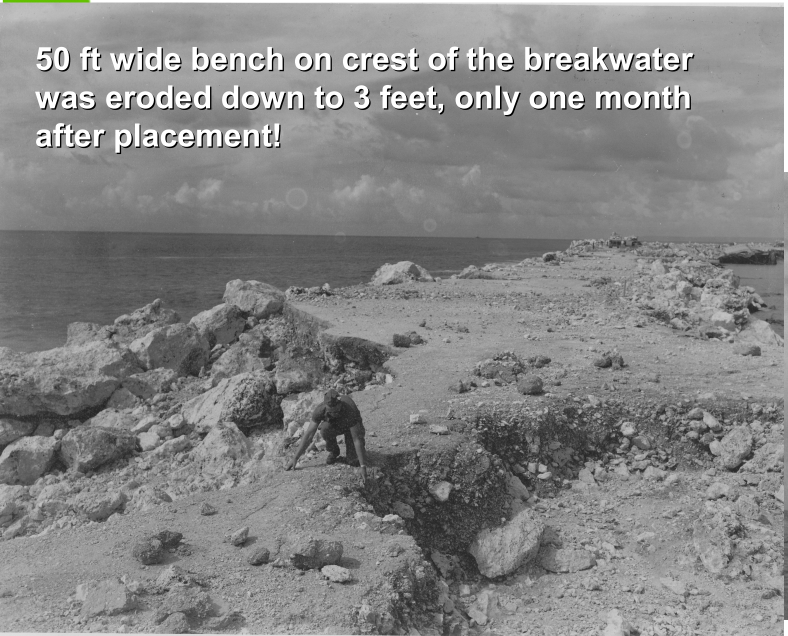
Filters essential for breakwaters



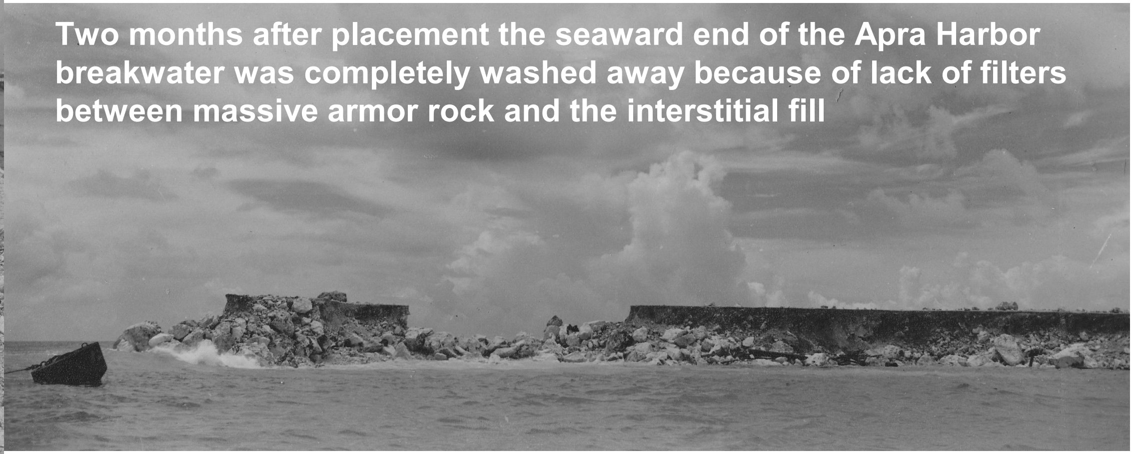
Note size of coral boulders comprising the core of the breakwater fill

The Apra Harbor breakwater on Guam constructed by the Navy’s 76th NCB in July 1945 – lasted just one month

Fines are easily expunged from a heterogenous rockfill by the pumping action of waves pounding against the breakwater, as seen at right.



50 ft wide bench on crest of the breakwater was eroded down to 3 feet, only one month after placement!



Two months after placement the seaward end of the Apra Harbor breakwater was completely washed away because of lack of filters between massive armor rock and the interstitial fill

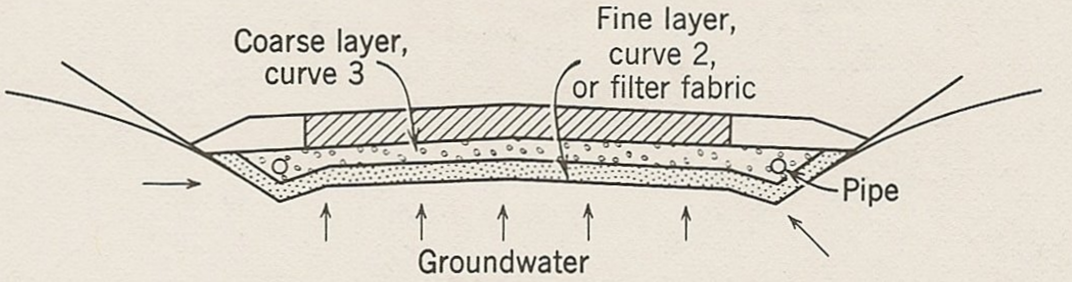
Riprap face protection

- **Upper left**: If riprap is to protect against near-constant wave action, it should be carefully placed, *stacked to interlock*.
- **Lower left**: Rip rap is often *loose dumped* and spread over the downstream face of embankment dams and levees where it is assumed the it retard face erosion, if and when the structure is overtopped
- **Lower right**: *Vegetated boulder revetments*, like this one in Madison, Wisconsin, can be constructed to provide adequate protection and be aesthetically pleasing, important in an urban environment.

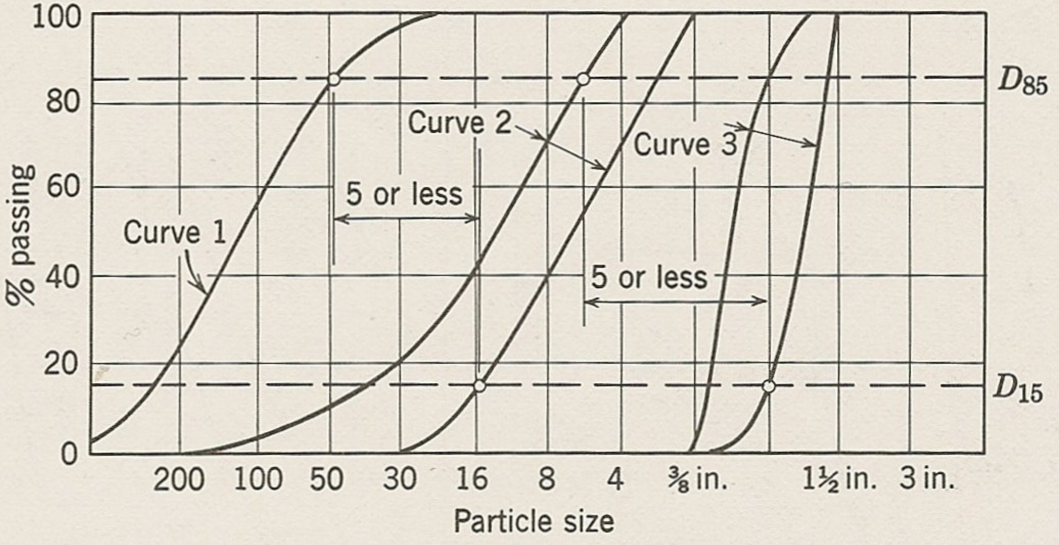

Stacked riprap creates interlocked blocks


Loose-dumped riprap facing on Coyote Dam


Vegetated boulder revetment



(*a*) Cross section

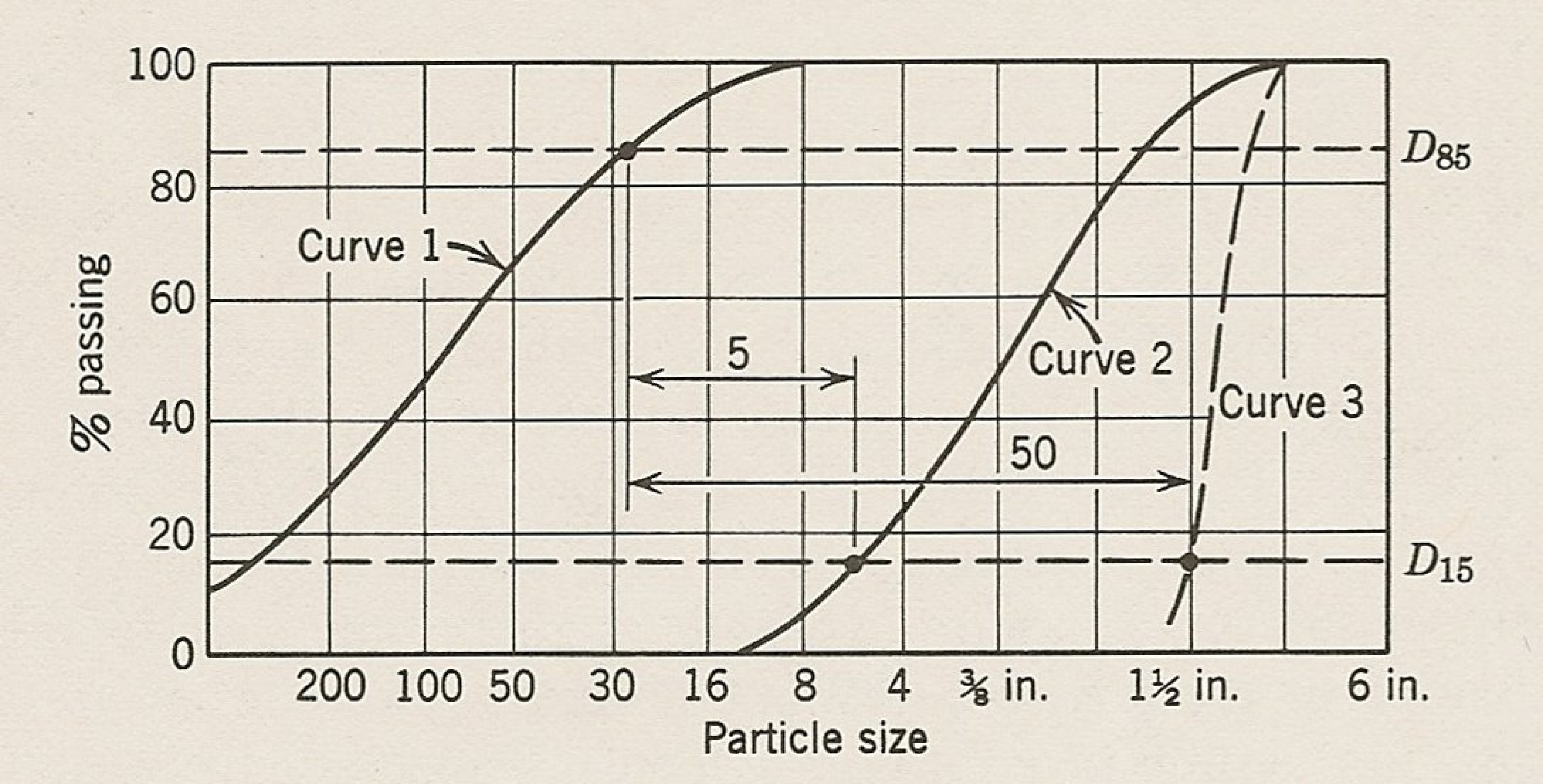


(*b*) Grading curves

Filter criteria for pavements, from Cedergren (1989). Fine filter (Curve 2) prevents native soils (Curve 1) from pumping into open-graded drainrock (Curve 3). This sort of protection is essential in areas with high groundwater

Pavement Distress is almost always related to a lack of subdrainage

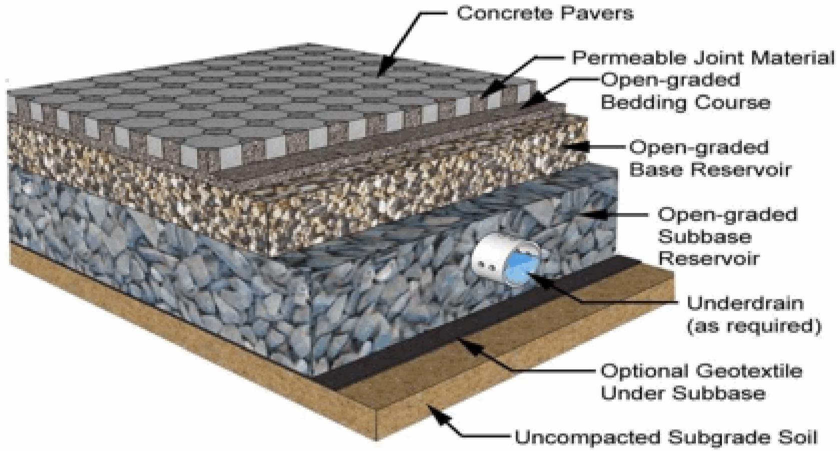
- When we see *water seeping up out of the pavement*, this indicates an **inadequate pavement design.** This is particularly problematic in shales and clayey soils.



Segregated filter materials are very common if the material is excavated from a river or stream bed. Segregated materials can also cause problems. The D_{15} of the unsegregated filter aggregate (Curve 2) should be no more than $5D_{85}$ of the soil (Curve 1), but the D_{15} of segregated pockets of coarse filter material (curve 3) is actually $50D_{85}$ of the soil! This problem occurs more often than most engineers realize, and leads to poor pavement performance.

Pervious pavement subgrade

Pervious pavement subgrade beneath paving stones by Vermont DOT




Porous pavements


Pervious basecourse over geotextile Port of Portland Terminal 6


Pervious subgrade layer laid over black geotextile (at right), prior to placement of Continuous Reinforced Concrete Pavement of Interstate 40 in Oklahoma City