Filter and Drain Design and Construction Details

Presented by
John W. France, PE, D.GE, D.WRE
JWF Consulting LLC

October 21, 2021

USSD

AGENDA

- Introduction and Definitions
- Filter and Drain Configurations and Components
- Filter History
- Filter Gradation Design – Including Design Latitude
- Evaluation of Existing Dams Without Designed Filters
- Filter Sand Compaction
- Some Other Considerations for Filter / Drain Design and Construction

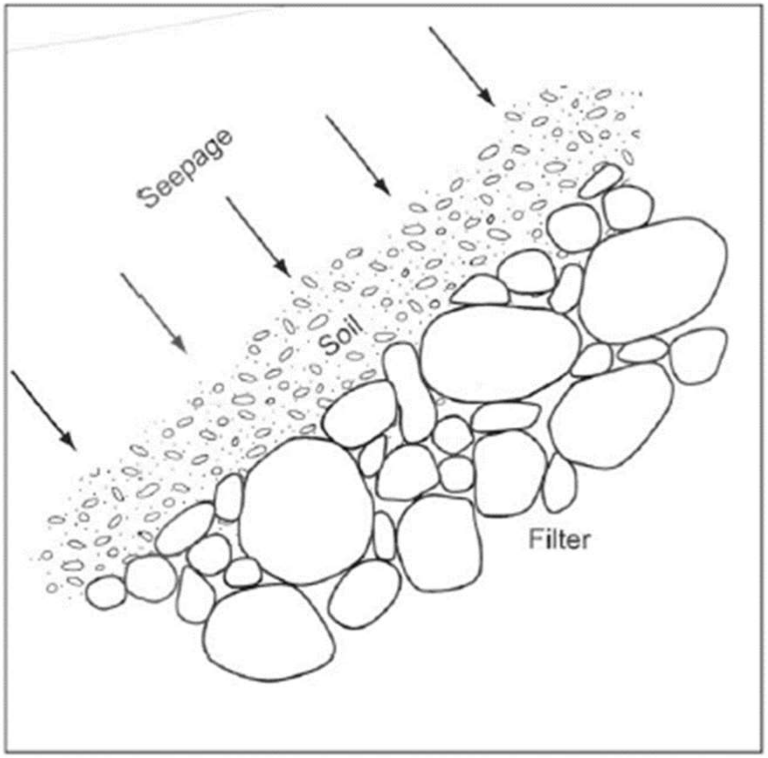
Seepage Control – Filters and Drains

- Purposes of filters and drains:
  - Prevent internal erosion ⬅
  - Reduce pressures in the embankment and / or foundation – increase stability

Seepage and Filters

Seepage does not threaten dam safety, . . .

when it is directed through a filtered exit.



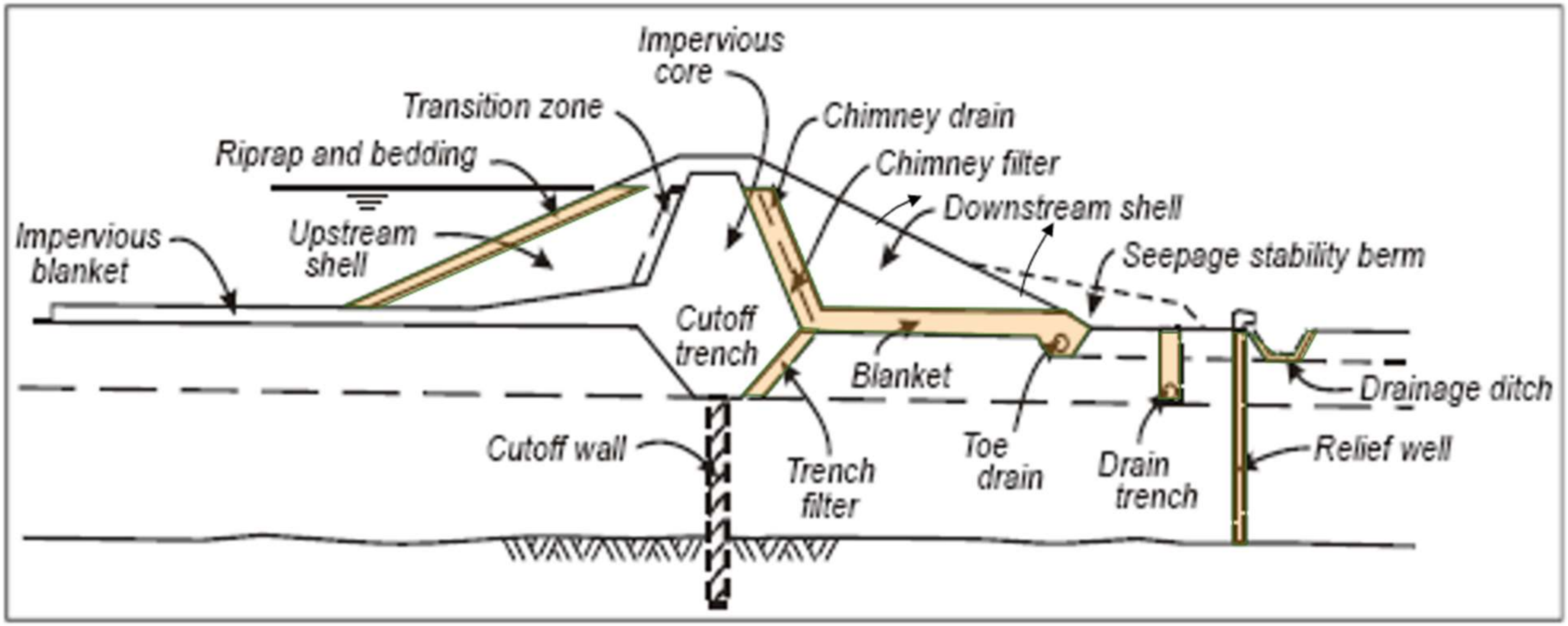
Filter - Definition

- An engineered material that is designed to retain the base soils, as well as have a significantly higher permeability than the base soils being protected. In some cases, a single filter layer retains the base soils and performs as the drain. In these instances, the permeability requirement is imperative to ensure low seepage forces near the exit. Filters are commonly constructed of sand materials (SP or SW). (From Redlinger et al, 2016)
- Filters are sometimes supplemented with separate drain zones

Drain - Definition

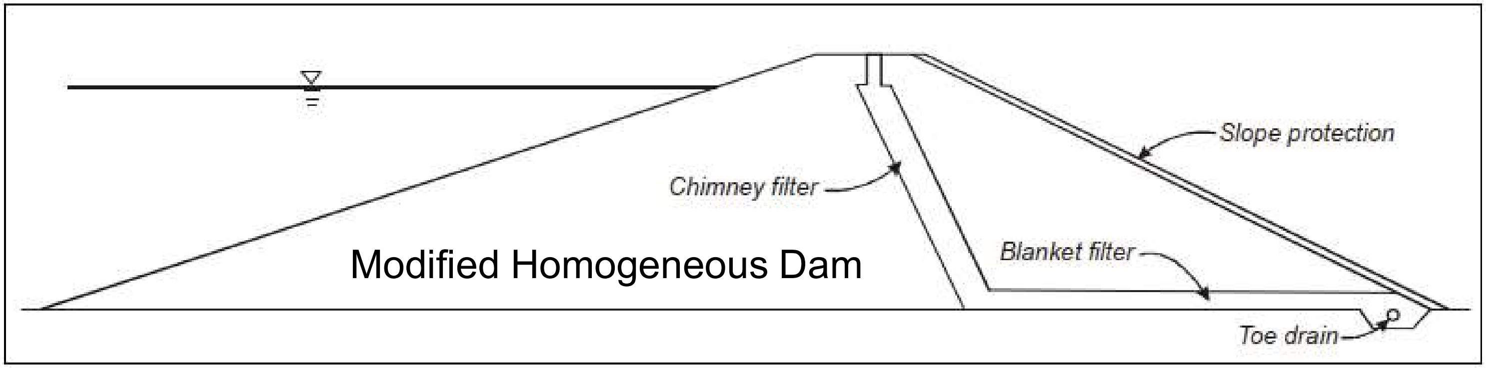
- An engineered material with a primary function of capturing seepage and conveying it safely to the downstream toe. A drain typically is provided as a second layer, or stage, for filter protection of the filter layer and drains away the majority of the seepage that passes through the filter.Commonly constructed of gravel materials (GP or GW). (From Redlinger et al, 2016)
- May include perforated or slotted pipes
  - Allows measurement and monitoring of seepage quantities and sediment transport
  - Can be installed to isolate zones or features such as abutments or foundation

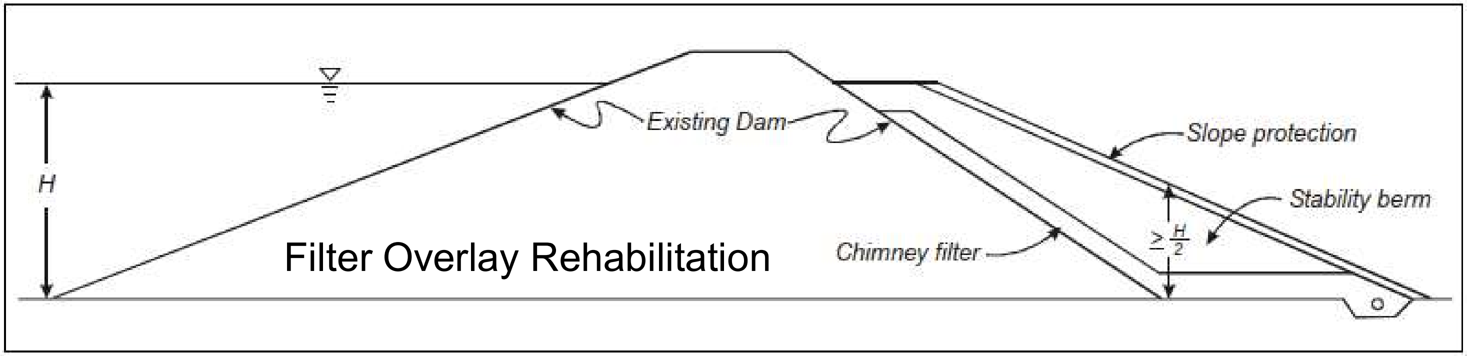
Possible Filter / Drain Locations – New Dams



Not all of these features would likely be used in any one dam

Internal Chimney Filter / Drain


Modified Homogeneous Dam


Filter Overlay Rehabilitation

- Figures from FEMA (2011)
- Other dam and rehabilitation configurations provided in FEMA (2011) and other publications

Poll Question #1

- Approximately when was the concept of a soil filter to prevent piping (internal erosion) first developed?

  - 1800
  - 1890
  - 1920
  - 1930
  - 1950
  - 1960

Poll Question #2

- When was the first equation for required soil filter gradations published?
  - 1920s
  - 1930s
  - 1940s
  - 1950s
  - 1960s
  - 1970s

Poll Question #3

- Approximately when were the criteria that we currently use for soil filter gradations developed?
  - 1930s
  - 1940s
  - 1950s
  - 1960s
  - 1970s
  - 1980s

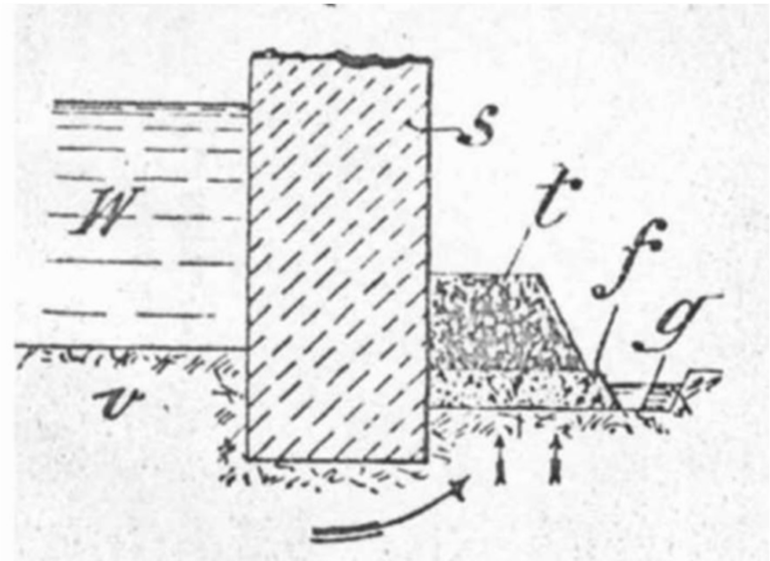
USSD

Filter History

- Early work by Terzaghi – from Fannin (2008)
- Terzaghi’s publication of first equation – from Fannin (2008)
- Sherard, Dunnigan, and Talbot (1984a and 1984b)
- Foster and Fell (2001)
- USACE practice – from Redlinger et al (2016)

Terzaghi Correspondence circa 1920

“Subsurface erosion can reliably be prevented by covering the discharge points of water veins with a…loaded inverted filter”



Figur 3.

Taken from Fannin (2008)

Terzaghi’s U.S. Patent #1,499,956 of 1924

“The characteristic feature of the invention consists in arranging...a filter of such a characteristic, that it will permit the free outflow of the underground-water but prevent the passage through of constituents or parts of the soil, and whereby the filter is loaded or weighted in such a manner, that the layers located underneath the filter and through which the leakage water flows cannot be driven upwardly...”

Taken from Fannin (2008)

Terzaghi Consulting Report[1] - 1926

"…to prevent the finer particles of the downstream section of the dam from being washed out through the downstream toe, a filter should be provided between the dam proper and the toe. The effective size of the filter should not exceed ten times the average grain size of the dam construction material."

Implies $D_{10f} = 10D_{50b}$

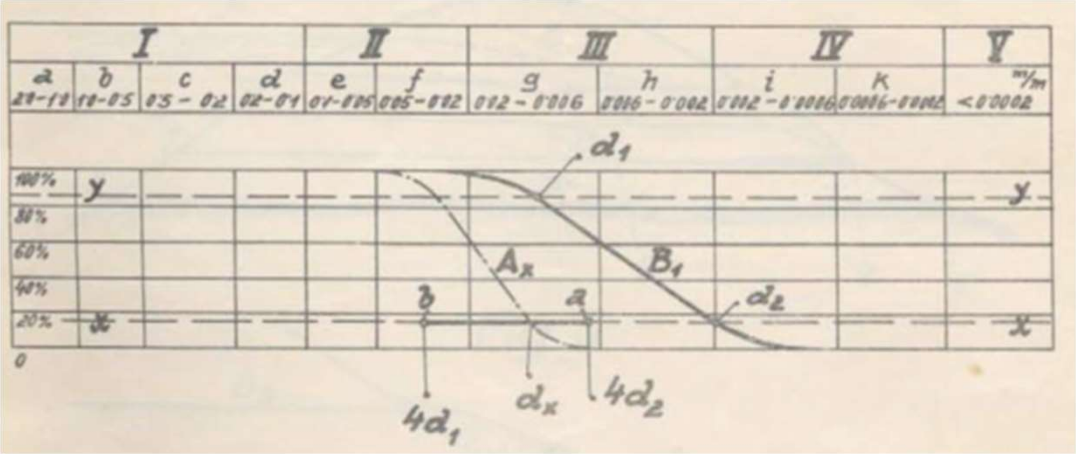
[1] Consulting report to the company of Fay, Spofford and Thorndike concerning the proposed Granville storage dam at Westfield, Mass.

Taken from Fannin (2008)

Terzaghi and Pfletschinger Patent Application – circa 1931-35

$d_x > 4d_1$ - where $d_x = D_{15f}$ and $d_1 = D_{85b}$

“…the pore size of a broadly-graded filter comprises at maximum 1/5th of the diameter of the biggest grain of the finest fraction of the filter materials.”

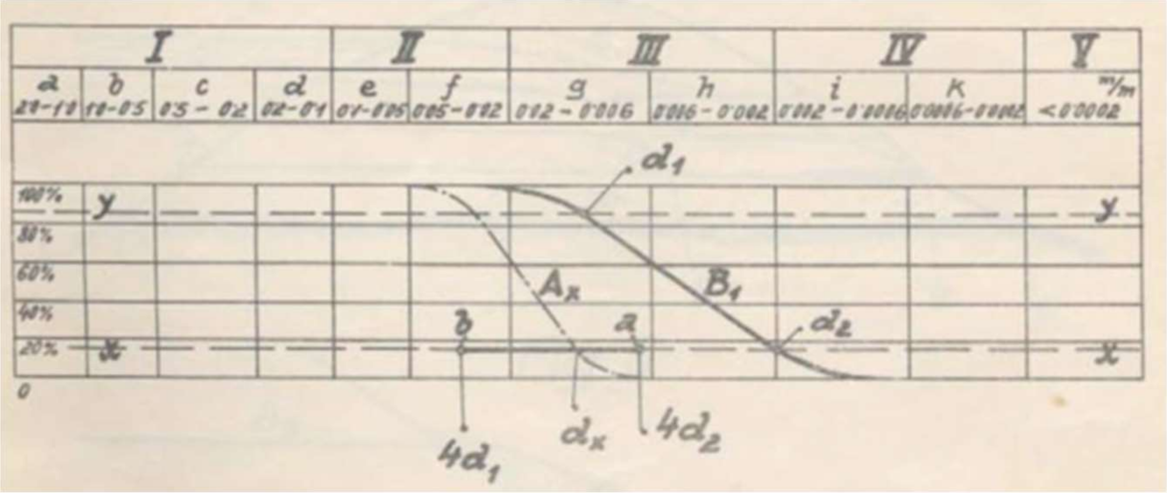


Taken from Fannin (2008)

Terzaghi and Pfletschinger Patent Application – 1931-35

$d_x < 4d_2$ - where $d_x = D_{15f}$ and $d_2 = D_{15b}$

…permeability “is proportional to the square of the finest grain size, 10 to15% by mass” and hence “the filter is essentially (10 to 20 times) more permeable than the soil.”

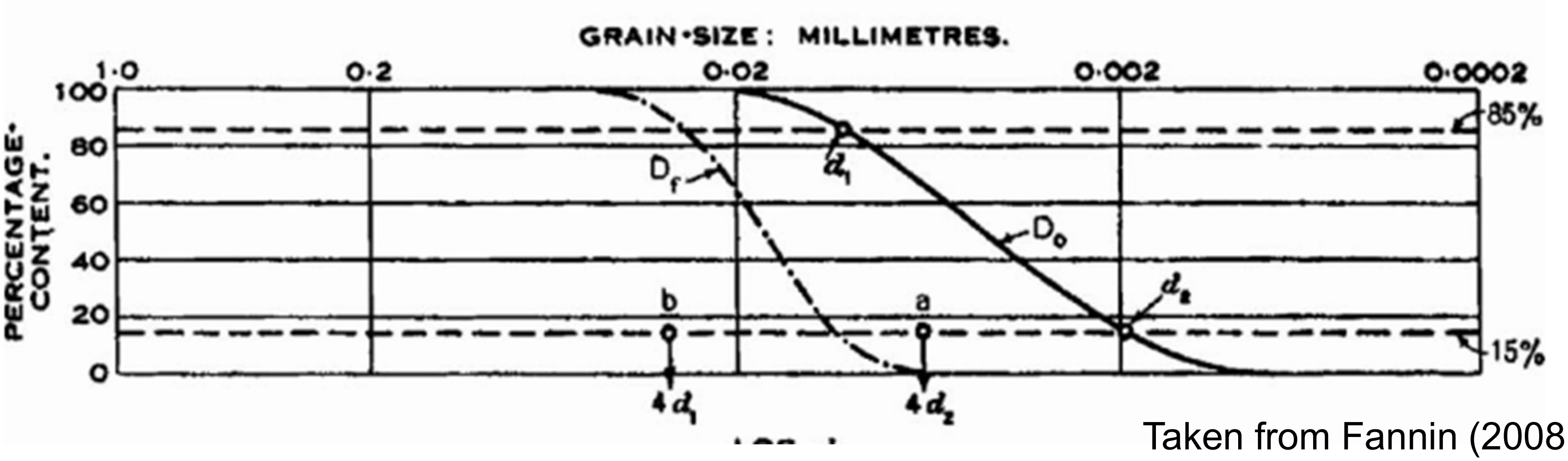


Taken from Fannin (2008)

Equations First Published - 1939

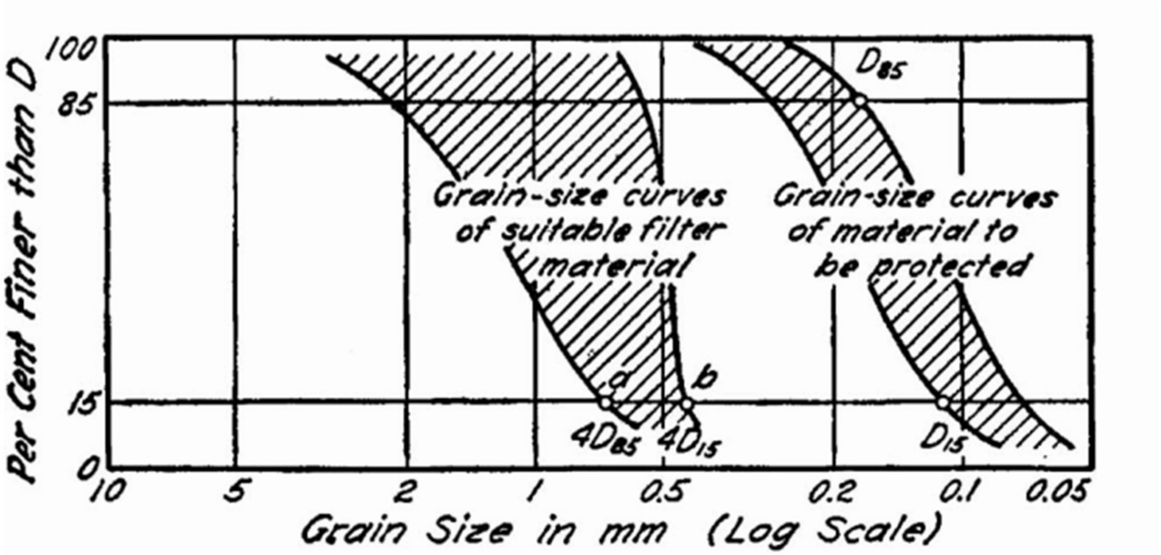
Terzaghi's James Forrest Lecture to the Institution of Civil Engineers at London in 1939

$4D_{85b} > D_{15f} > 4D_{15b}$



Taken from Fannin (2008)

Soil Mechanics in Engineering Practice (Terzaghi and Peck 1948)



With references to the experimental study of Bertram at Harvard, which in turn made reference to an unpublished report for the Bou Hanifia Dam.

Taken from Fannin (2008)

Sherard et al (1984a and 1984b)

- Reviewed prior filter research and guidelines
- Completed filter tests for a range of base soils – silts and clays to sands and gravels
- Confirmed Terzaghi criteria for sands and gravels
- Found criteria for silts and clays to be different
- Developed recommendations for filter gradation design for four different categories of base soil
- Established the basis for our modern filter design criteria

Foster and Fell (2001)

- Researchers from University of New South Wales, Australia
  - Obtained all NRCS data and continued the study, including additional laboratory tests
  - Generally verified results, except for slightly more conservative criteria for highly dispersive soils
  - Added guidance for evaluation of existing conditions not designed with Sherard et al criteria

USACE Research in the 1940s

- Confirmed Terzaghi’s equation
- Added another requirement – “In addition to meeting the above size specification, the grain size curves for filter and base materials should be approximately parallel in order to minimize washing of the fine base material into the filter material.” – No longer used

Taken from Redlinger et al (2016)

Bureau of Reclamation Research in the 1940s and 1950s

- Suggested that filter criteria were best established based on the D_{50} ratio – later found to be in error by Sherard et al (1984a)
- Provided three other important recommendations:
  - Limit maximum particle size to limit segregation
  - Limit fines content to five percent
  - Regrade the base soil on the No. 4 sieve to correct for gap graded soils

Taken from Redlinger et al (2016)

General Trends in USACE Practice

- Prior to the 1940s – homogeneous cross sections with toe drains
- In the 1940s – implementation of blanket drains
- In the 1950s – recognition of the need for chimney drains to cracking and internal erosion
- In the 1960s – realization that filters must continue into the cutoff trench

This evolution resulted from tough lessons learned through failures and near failures.

Taken from Redlinger et al (2016)

Filter Gradation Design

- Current gradation design guidance is based on Sherard et al (1984a and 1984b) and Foster and Fell (2001)
- All U.S. federal government agencies have adopted those basic criteria
- 2011 FEMA manual, *Filters for Embankment Dams, Best Practices for Design and Construction* – google “FEMA filter manual”
- Other federal agencies (USACE, Reclamation, NRCS) still maintain their own filter design guidance documents – see specific references in France et al (2020) – copy provided – and in provided reference list

Current Filter Gradation Design Guidance

- Step by Step Process
- Base Soil Selection
- Mathematical Regrading
- Maximum D_{15F} for Particle Retention
- Minimum D_{15F} for Permeability
- Results of Step by Step Process
- Flexibility within the Calculated Control Points

Filter Gradation Design - Goal

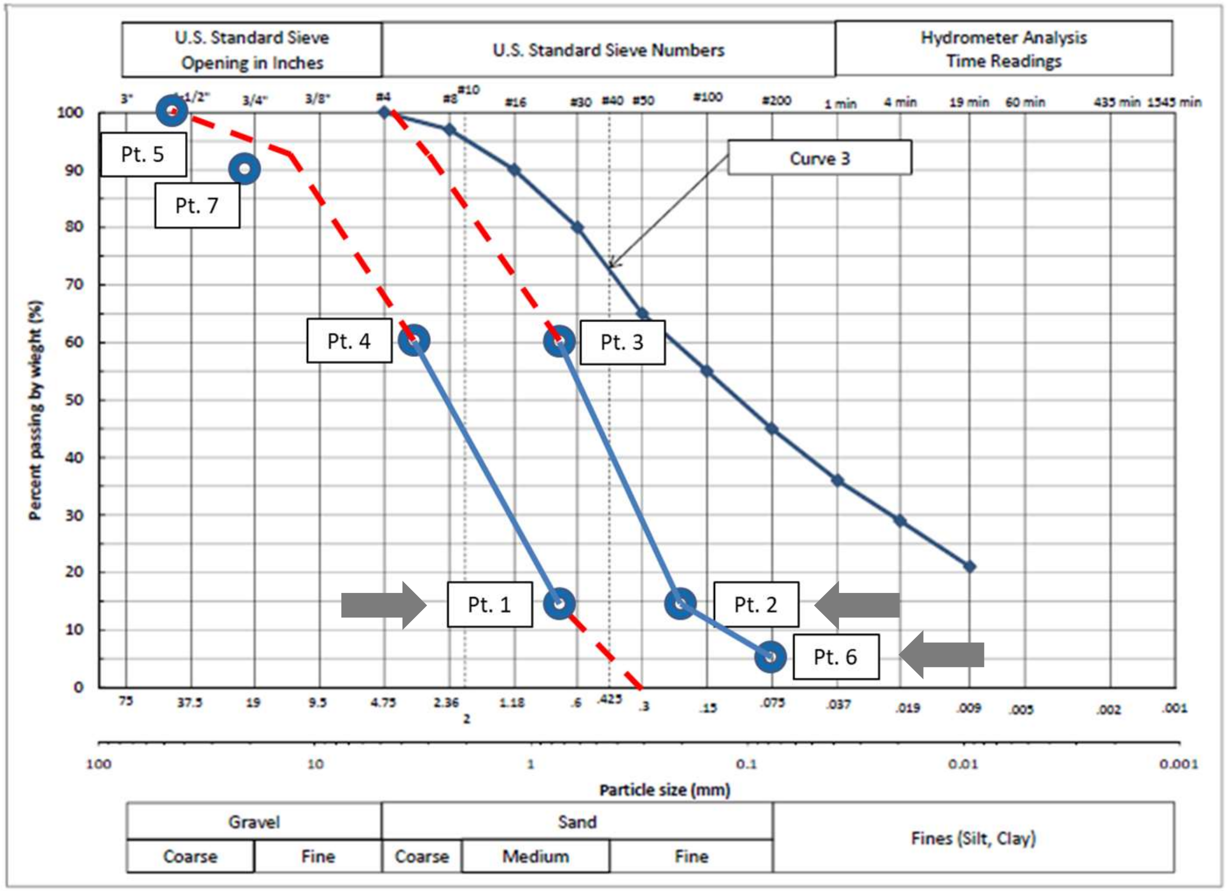
- To select filter gradation limits that will be:
  - Fine enough to filter properly
  - Coarse enough to have <u>needed</u> permeability
  - Graded to prevent internal instability and limit susceptibility to segregation during handling and placement

Step by Step Process

- Define “base soil” – the soil to be filtered or protected
- Establish maximum $D_{15F(Filter)}$ to prevent particle movement (to filter)
- Establish minimum D_{15F} to provide permeability
- Establish other control points to prevent internal instability[1] and limit susceptibility to segregation

[1] Finer portion of the soil can be washed through voids in coarser portion – discussed more in France et al (2020)

Gradation Design Example



Point 1 is to satisfy particle retention requirements – prevent internal erosion
Point 2 is to satisfy permeability requirements
Point 6 is to limit fines content (also permeability related)
All other points are to prevent internal instability and segregation

Control points establish the limits for a filter. Any gradation within the control points, and possibly slightly outside, provides an acceptable filter.

Step by Step Process

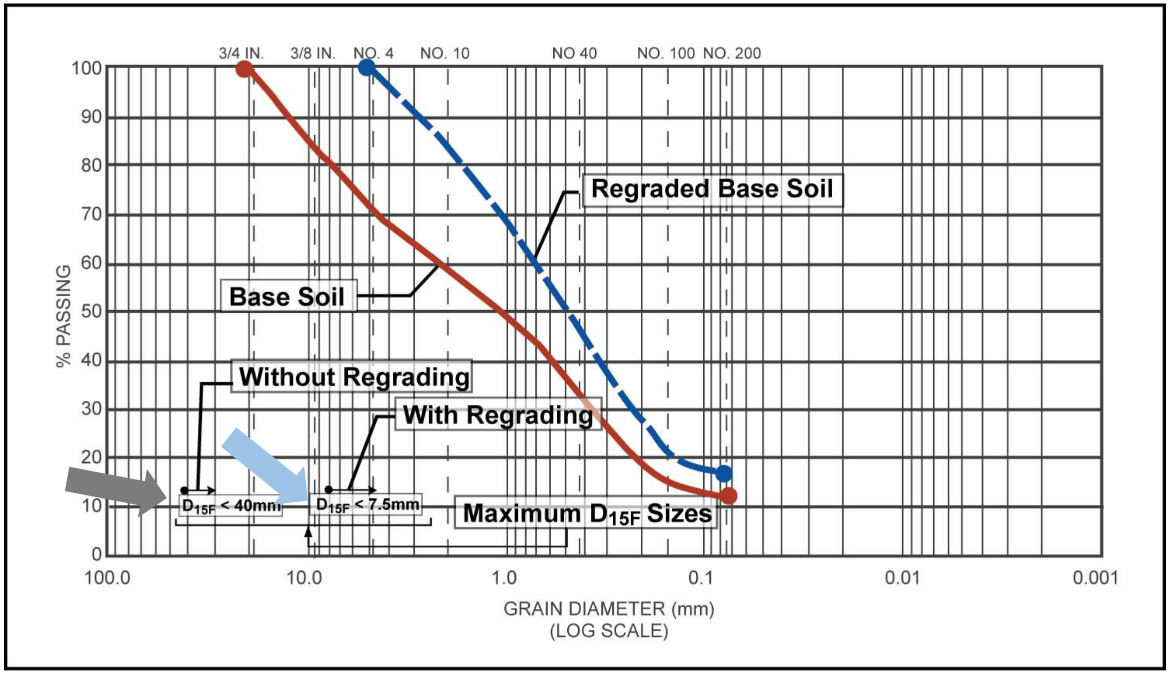
- Advantage of Step by Step Process is uniformity of filter designs by different designers
- Disadvantage is that users may not understand reasons for steps – use spreadsheets with caution
- Important to know background and 1) reasons for the steps and 2) flexibility in selecting a filter gradation

Base Soil Selection

- Define "base soil" – the soil to be filtered or protected
- Often the finest gradation is selected from the gradations available for the material to be protected
- Instances when selecting the finest gradation may not be necessary:
  - Mixing of borrow materials anticipated for new construction
  - Significant variation in gradations and outliers represent pockets or lenses not part of a viable seepage pathway
- See Pabst and France (2010) and Reclamation (2011) for further information about base soil selection

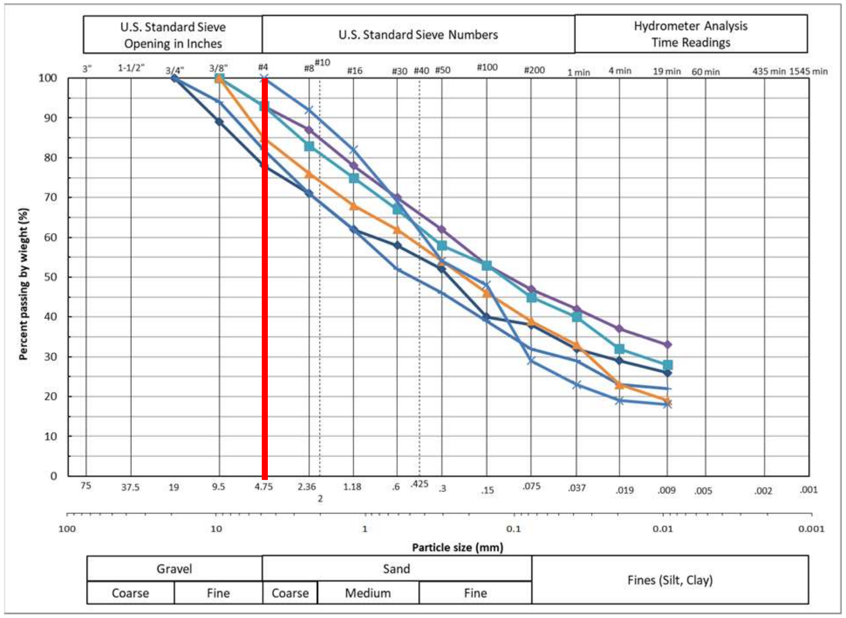
Mathematical Regrading of Base Soil

- Fine filters are designed for the portion passing the No. 4 sieve
- Required in all current filter design guidance – **not previously required**
- Provides particle retention for critical finer portion of the base soil
- Failure to mathematically regrade can result in an inadequate filter
- Gap graded and internally unstable, broadly graded soils need to be treated differently – see NRCS (2017) and Reclamation (2011)
- Reclamation (2011) provides flowchart to determine if regrading is necessary – discussed more later



Mathematical Regrading

Regrade if base soil has any particles larger than the #4 sieve (gravel size)



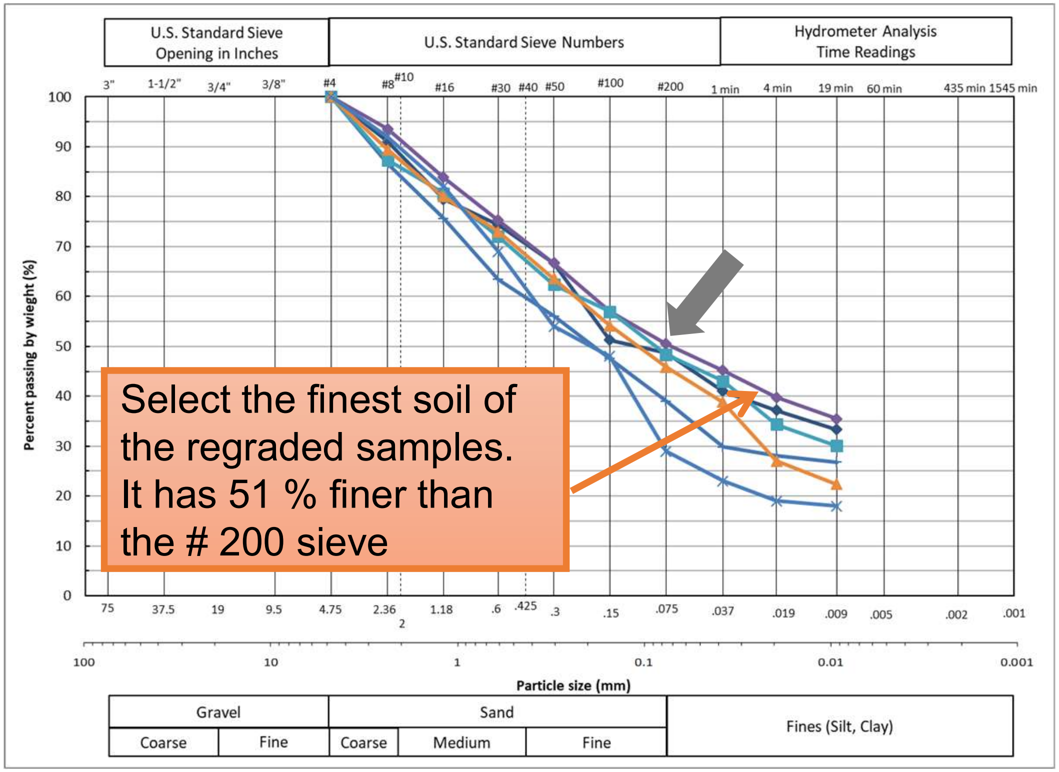
Sieve	Size	Percent Finer	Percent Finer
¾”	19.1	100	
½”	12.7	100	
3/8”	9.5	100	
#4	4.75	93	100
#8	2.36	87	94
#16	1.18	78	84
# 30	0.6	70	75
# 50	0.3	62	67
# 100	0.15	53	57
# 200	0.075	47	51

Multiply by 1.08.
100/.93 = 1.08

Regrading and Categorization

- Plot all of the regraded base soils and determine the % finer than the #200 sieve of the finest soil or soil to be used as the representative base soil
- The finest soil (greatest percentage passing the #200 sieve) is the most critical for filter design (it will require the finest filter)

Base Soil Categorization



Select the finest soil of the regraded samples. It has 51 % finer than the # 200 sieve

Percent Finer than # 200 Sieve	Category of Base Soil
> 85	1
40-85	2
15-39	3
< 15	4

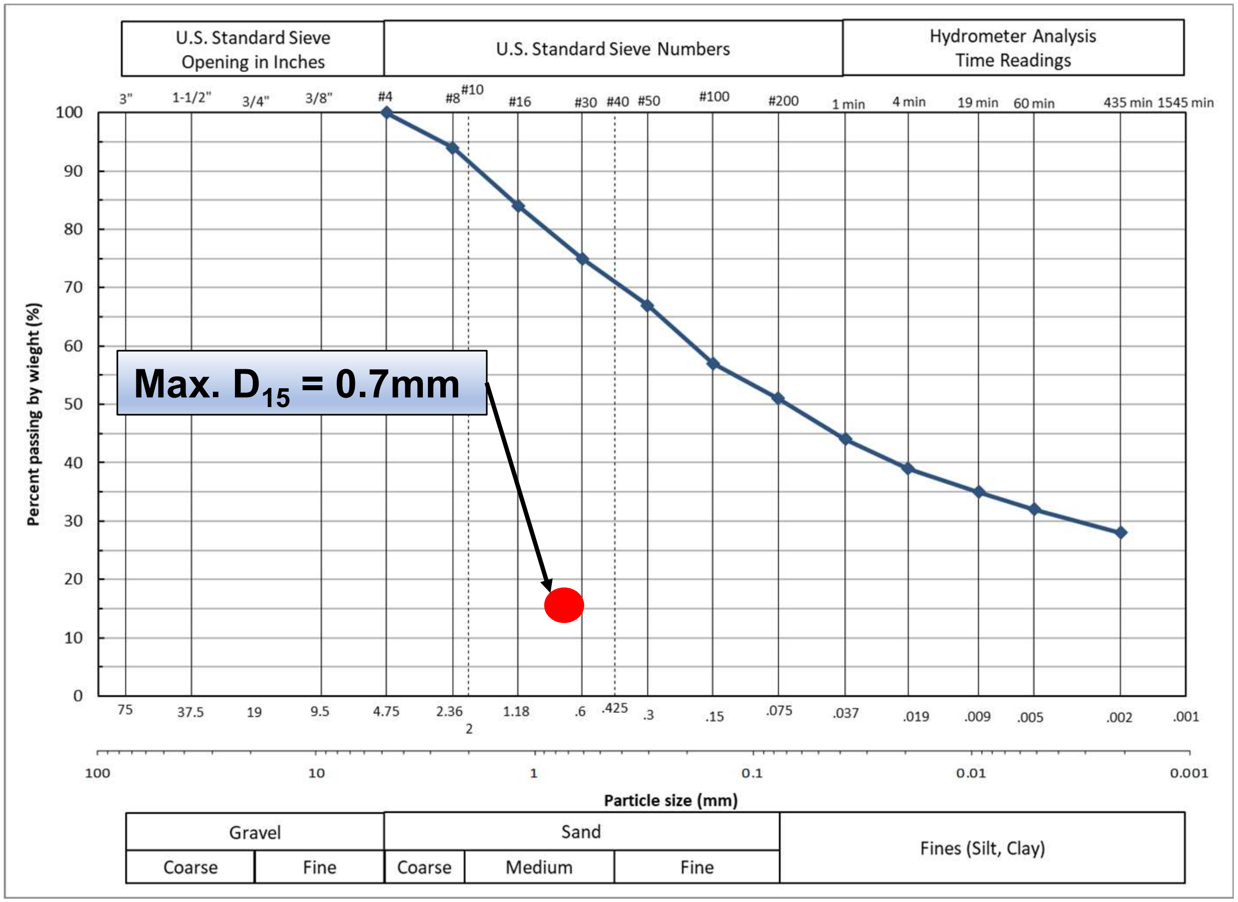
Many base soils that you encounter for fine filter design will be Category 2

Control Point for Particle Retention, Maximum D_{15F}

Base Soil Category	Percent Finer Than No. 200 sieve (A)	Base Soil Description	Filter Criteria
1	>85	Fines silt and clays	D_{15F} = 9 x D_{85B}, but not < 0.2mm, unless dispersive, then D_{15F} = 6.5 x D_{85B}, but not < 0.2mm
2	40 - 85	Sands, silts, clays, and silty and clayey sands	D_{15F} = 0.7mm, unless dispersive, then D_{15F} = 0.5mm
3	15 - 39	Silty and clayey sands and gravels	$D_{15F} = 0.7\text{mm}^* + \frac{(40 - A)(4 \times D_{85B} - 0.7\text{mm}^*)}{25}$ A = % passing No. 200 sieve When A < 4 x D_{85B}, use 0.7 mm* *If dispersive, use 0.5mm instead of 0.7mm
4	<15	Sands and gravels	D_{15F} = 4 x D_{85B}

D_{15F} = 15% size of filter
D_{85B} = 85% size of base being protected, after mathematical regrading

Particle Retention Point

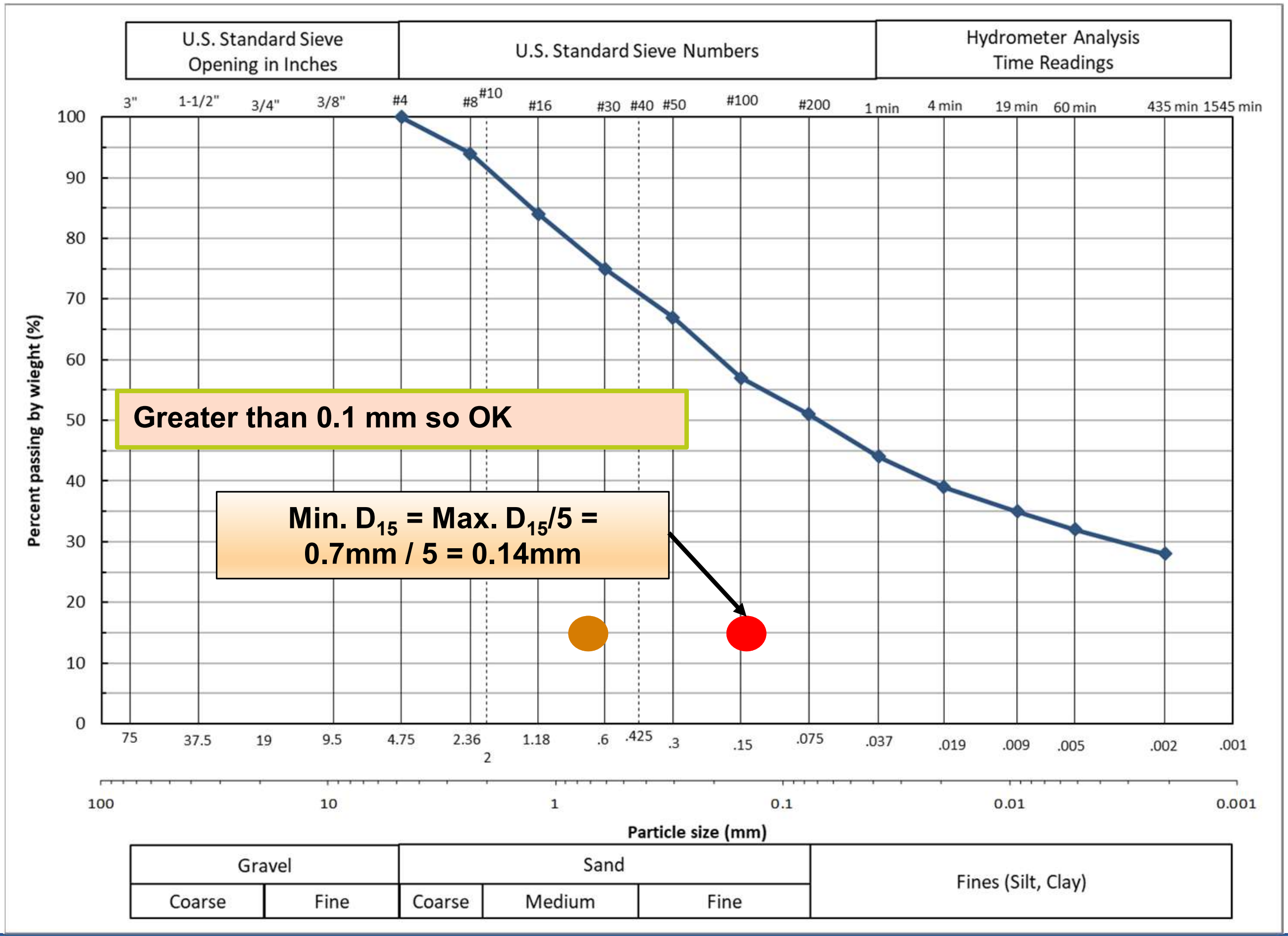


Max. D_{15} = 0.7mm

Control Point for Particle Retention, Maximum D15F

- Determine Minimum D_{15} of filter
- Use the greater of
  - the Maximum D_{15} size ÷ 5
  - or 0.1 mm
- For permeability, it is desirable for the Minimum D_{15} of the filter to be > 4 to 5 x the D_{15} of the coarsest base soil – check for this - evaluate for coarsest base soil before regrading
- In some applications permeability of the fine filter may not be critical

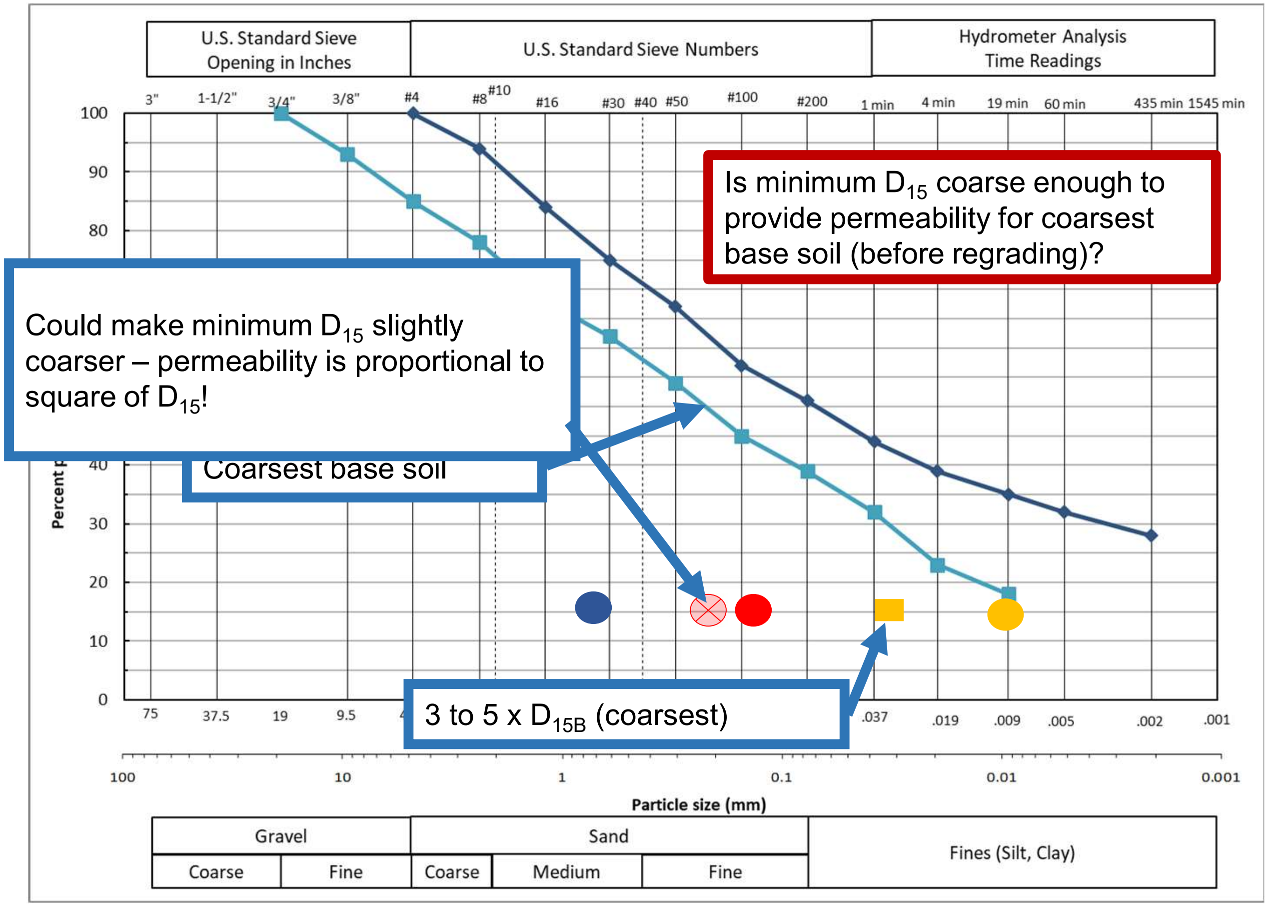
Permeability Control Point



Greater than 0.1 mm so OK

Min. D_{15} = Max. $D_{15}/5$ = 0.7mm / 5 = 0.14mm

Check on Permeability Control Point



Is minimum D_{15} coarse enough to provide permeability for coarsest base soil (before regrading)?

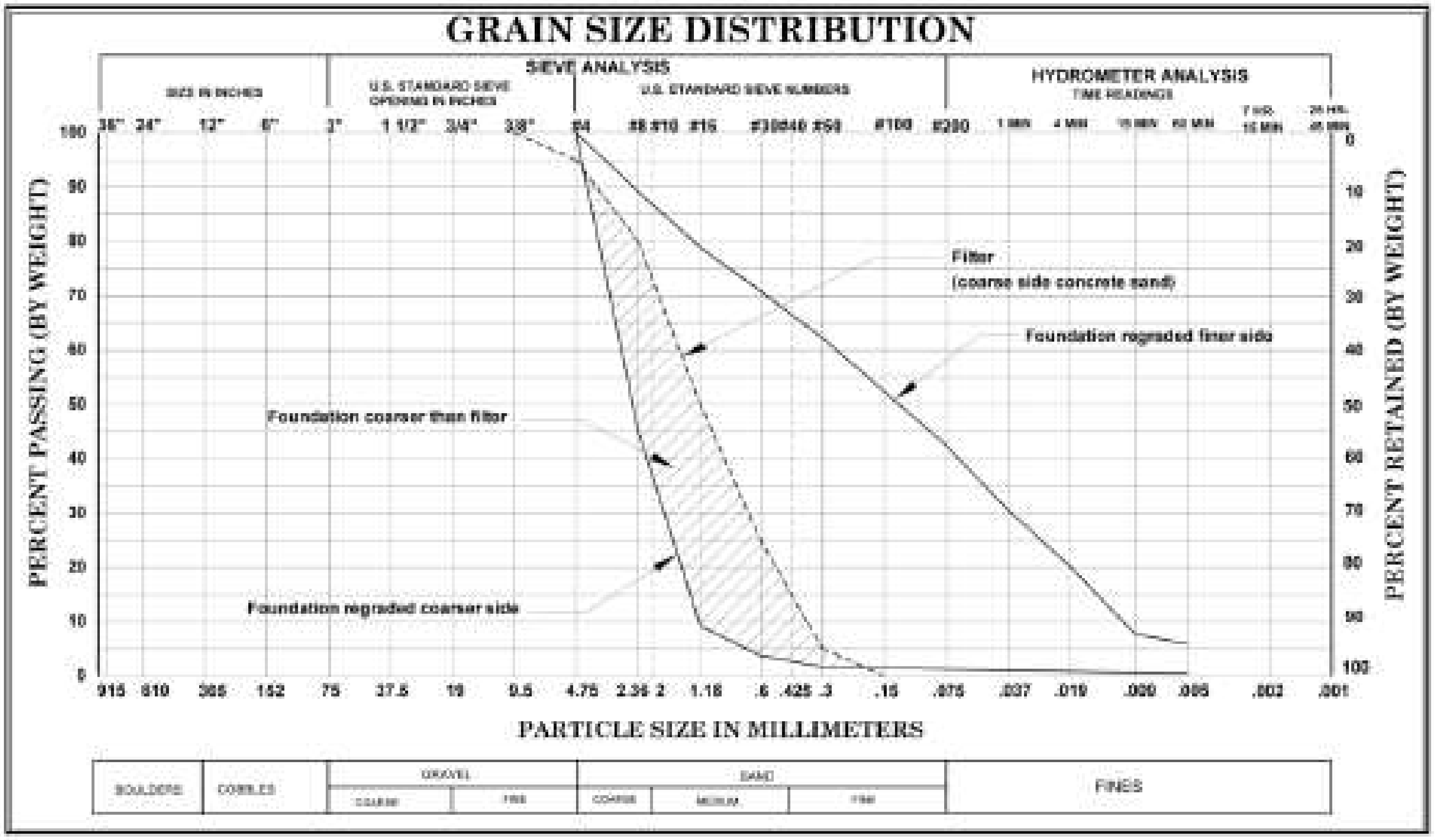
Could make minimum D_{15} slightly coarser – permeability is proportional to square of D_{15}!

Coarsest base soil

3 to 5 x D_{15B} (coarsest)

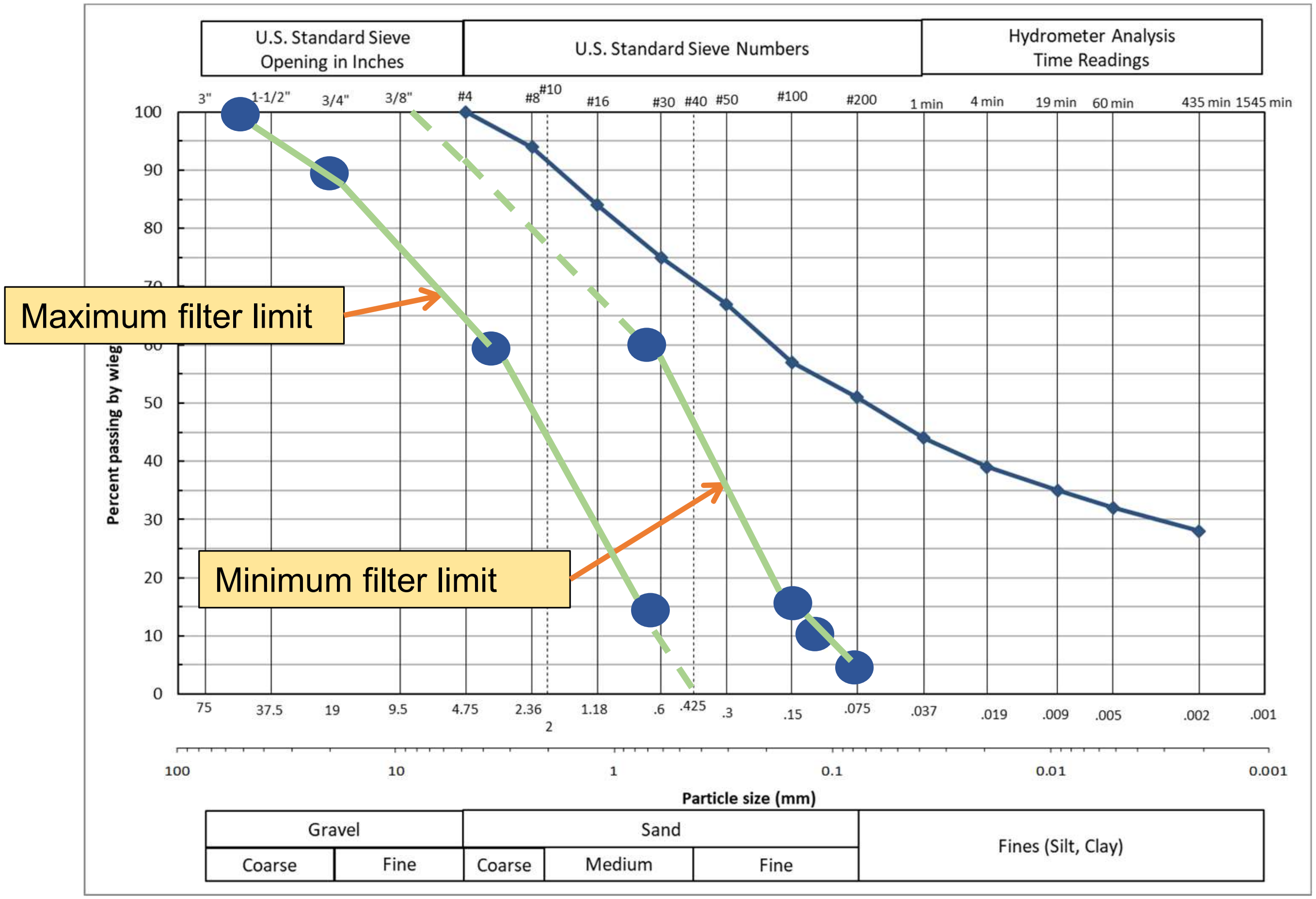
Determination of other control points is discussed in the various guidance documents and France et al (2020)

Permeability Control Point



This step can lead to some contradictory situations requiring judgment – consider the case illustrated here

Results of Step by Step Process



Maximum filter limit

Minimum filter limit

Can select specification limits based on yellow lines

But there is latitude beyond the yellow lines

Poll Question #4

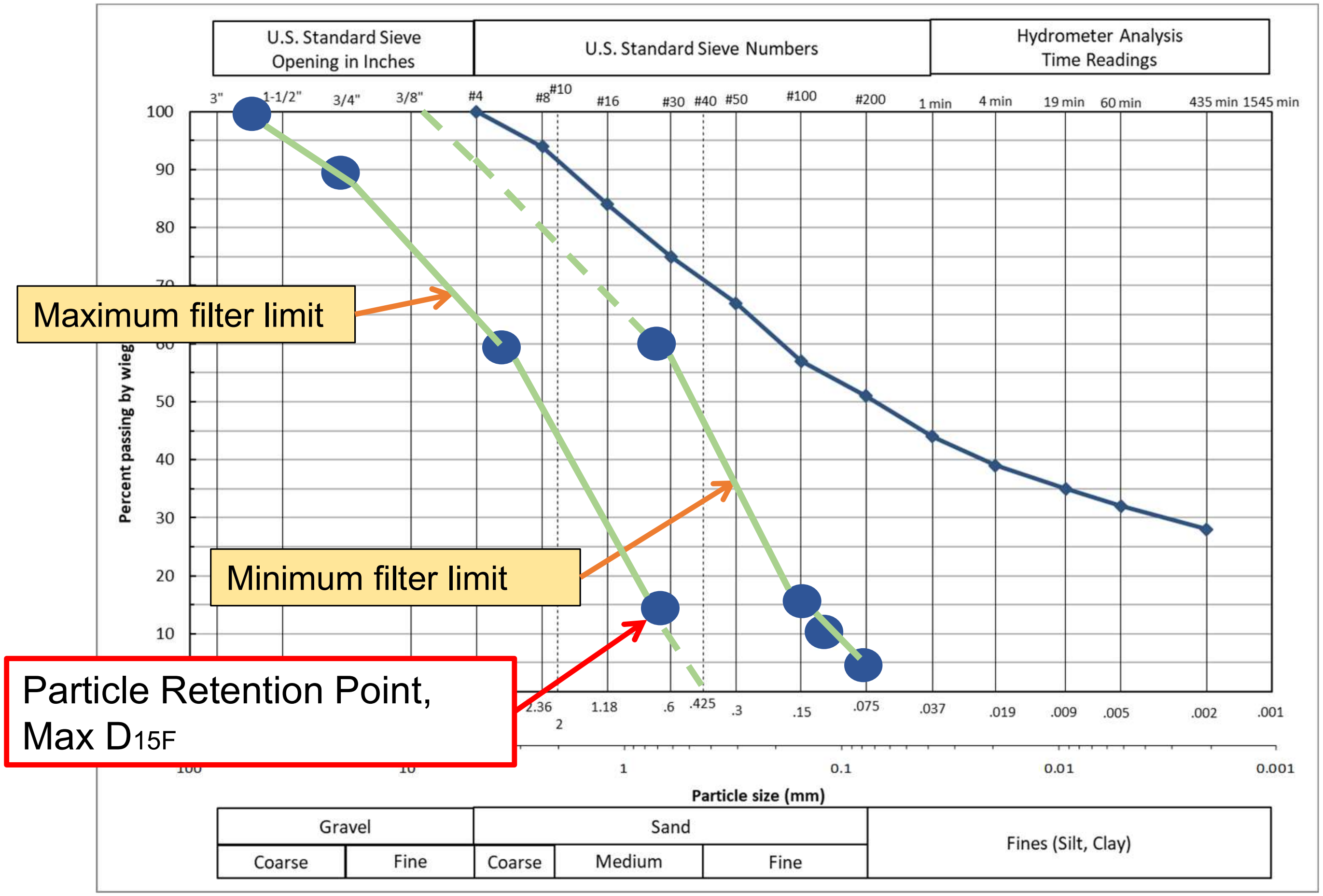
Of the various filter control points, which is the critical point for filter function (particle retention)?

- Maximum D_{15F}
- Minimum D_{15F}
- Maximum D_{60F}
- Minimum D_{60F}
- < 5% finer than #200 sieve

Latitude in Specification Selection

- From NRCS (2017) guidelines:
  - However, in some cases, adjustments to the preliminary design band are made to accommodate standard readily available gradations
- For particle retention (filtering), the critical point is the maximum D_{15F}

Results of Step by Step Process



Maximum filter limit

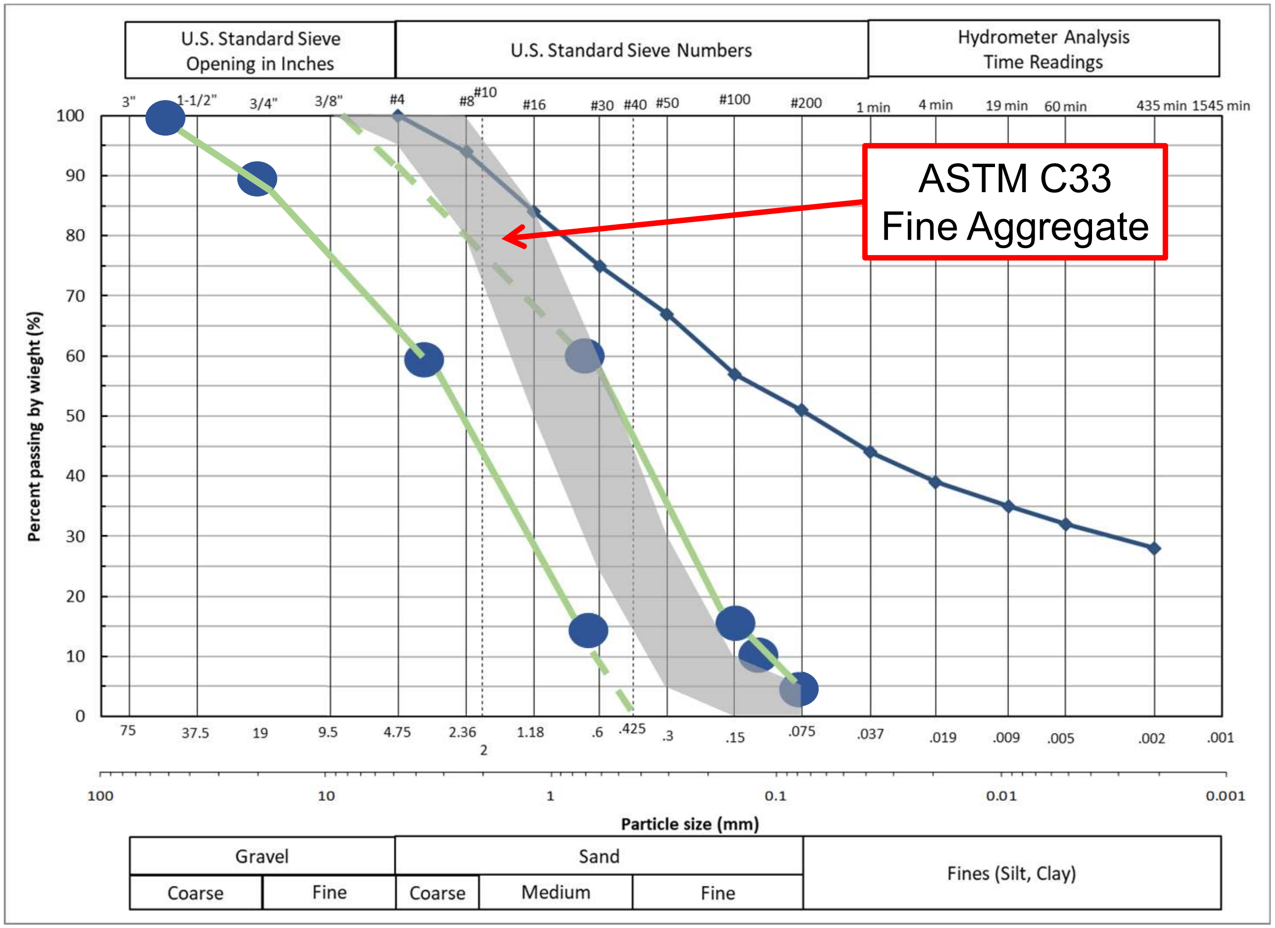
Minimum filter limit

Particle Retention Point, Max D_{15F}

Can select specification limits based on green lines

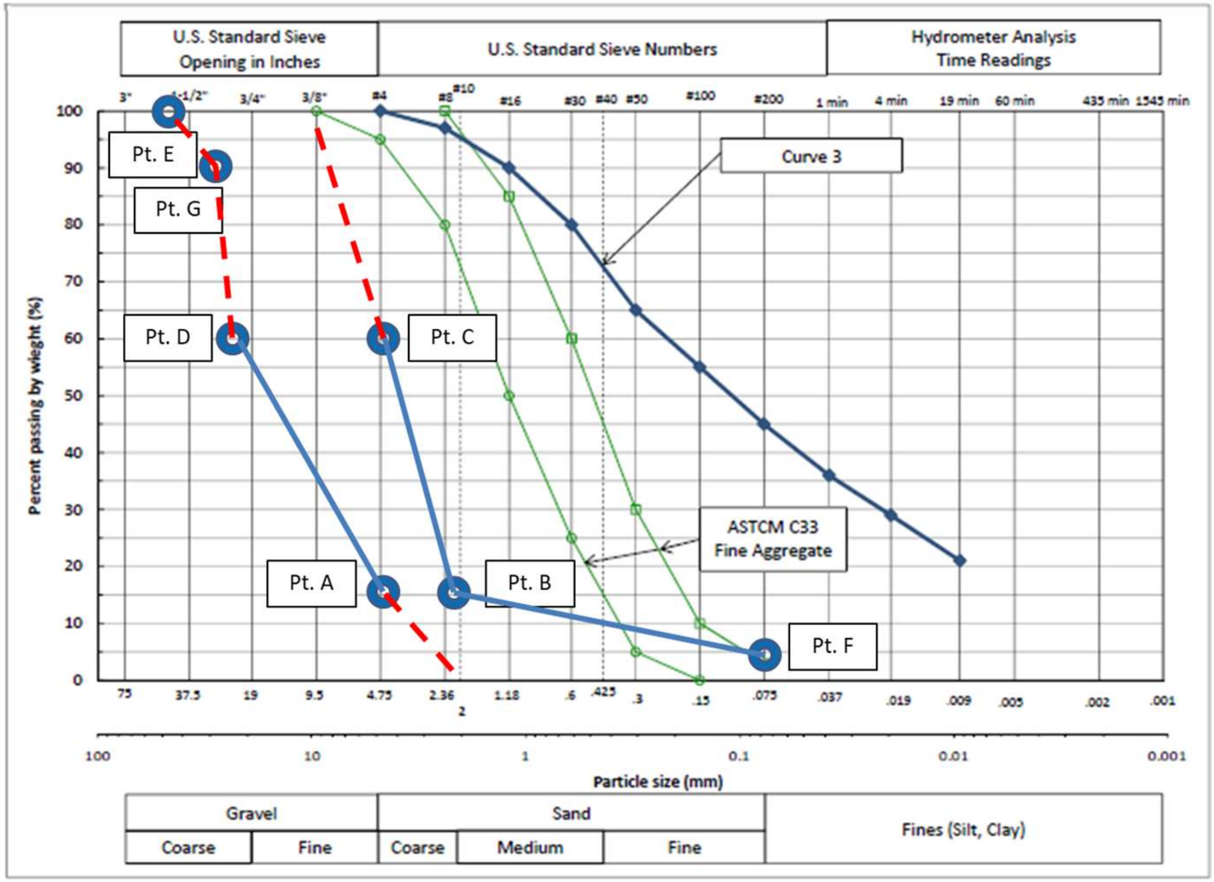
But there is latitude beyond the green lines

Consider ASTM C33 Fine Aggregate

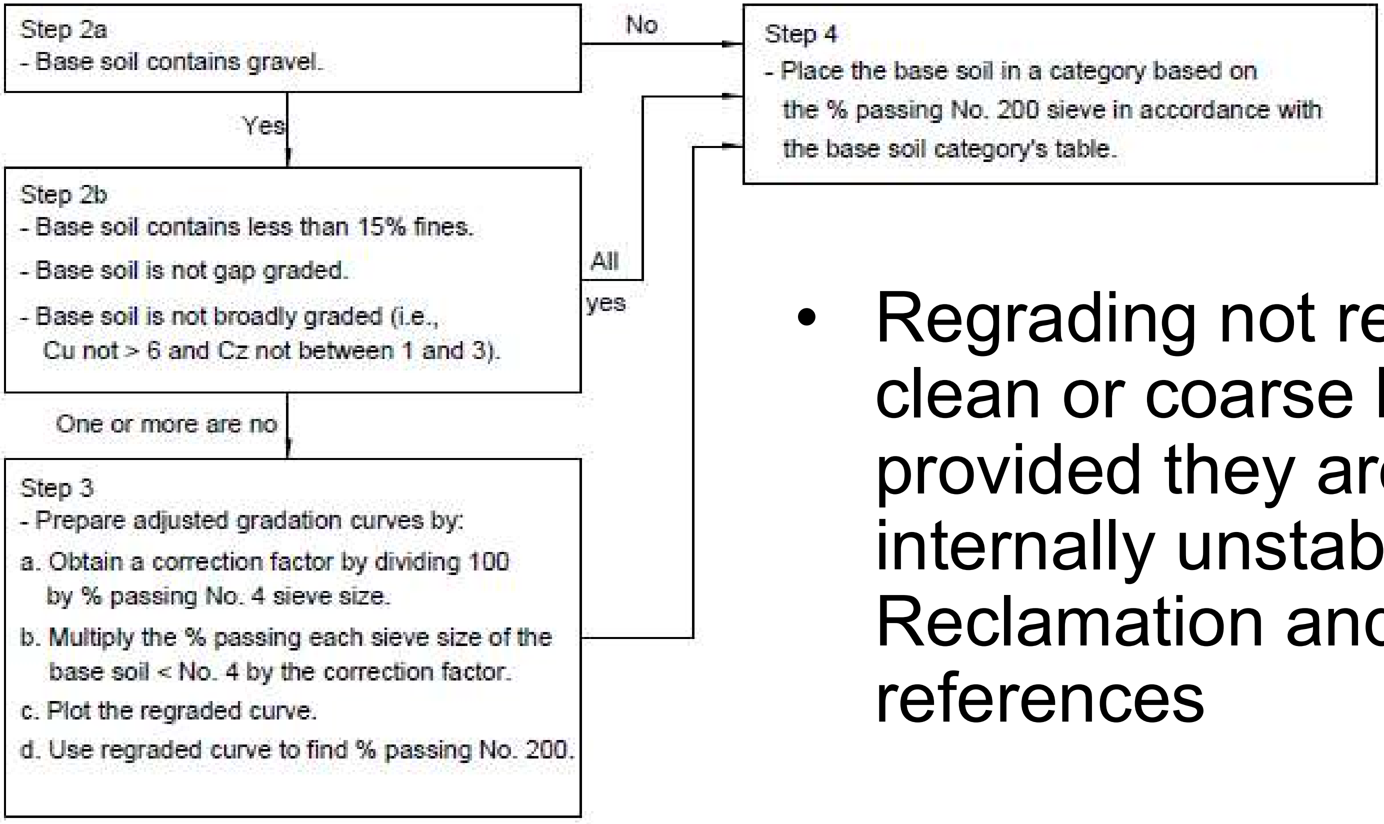


Filter gradation specification could be selected to accommodate ASTM C33 Fine Aggregate

Gradation for a Drain as a Filter for ASTM C33 FA



Regrading Requirements



Step 2a
- Base soil contains gravel.

Step 2b
- Base soil contains less than 15% fines.
- Base soil is not gap graded.
- Base soil is not broadly graded (i.e., Cu not > 6 and Cz not between 1 and 3).

Step 3
- Prepare adjusted gradation curves by:

a. Obtain a correction factor by dividing 100 by % passing No. 4 sieve size.
b. Multiply the % passing each sieve size of the base soil < No. 4 by the correction factor.
c. Plot the regraded curve.
d. Use regraded curve to find % passing No. 200.

Step 4
- Place the base soil in a category based on the % passing No. 200 sieve in accordance with the base soil category's table.

From Reclamation (2011)

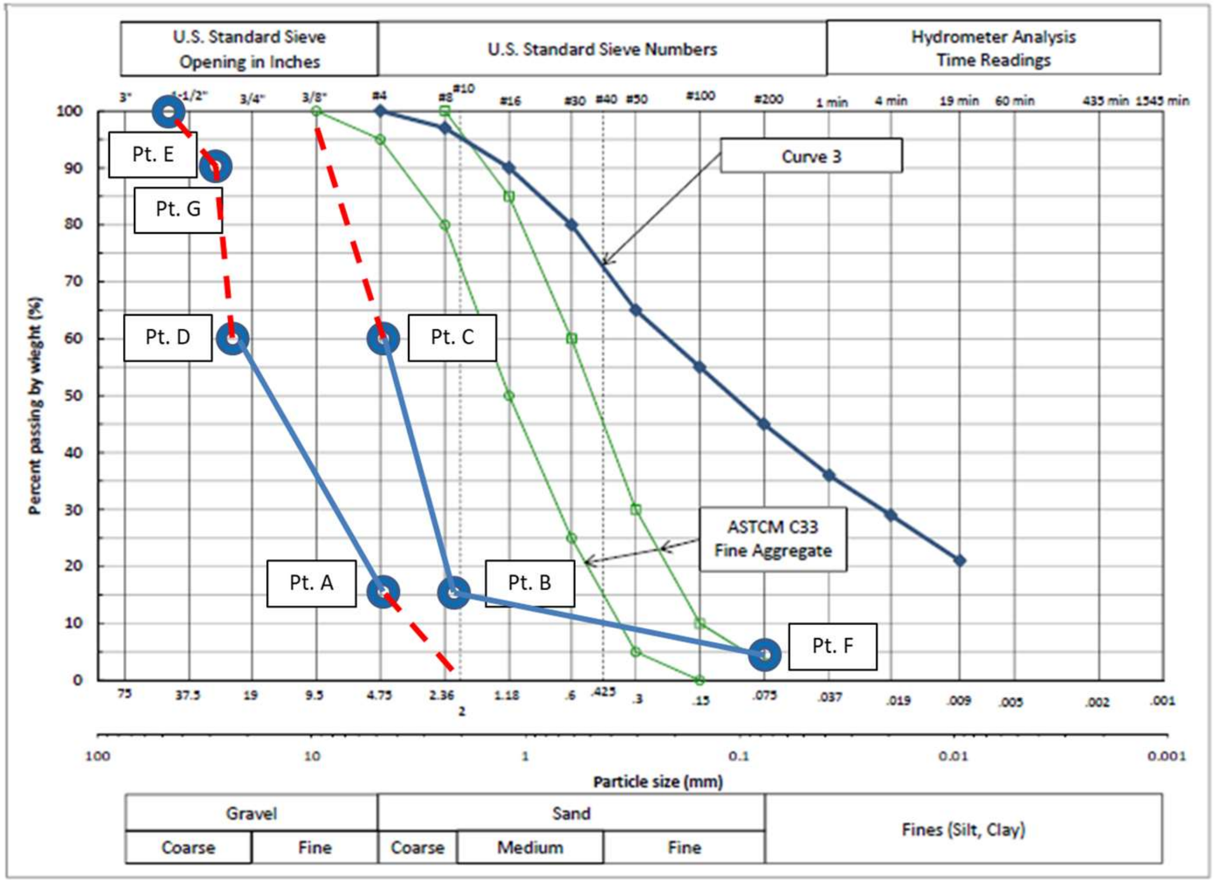
- Regrading not required for clean or coarse base soils, provided they are not internally unstable – see Reclamation and NRCS references

As Filter/ Drain Layers Become More Coarse, Guideline Limits on Maximum Sizes Do Not Work

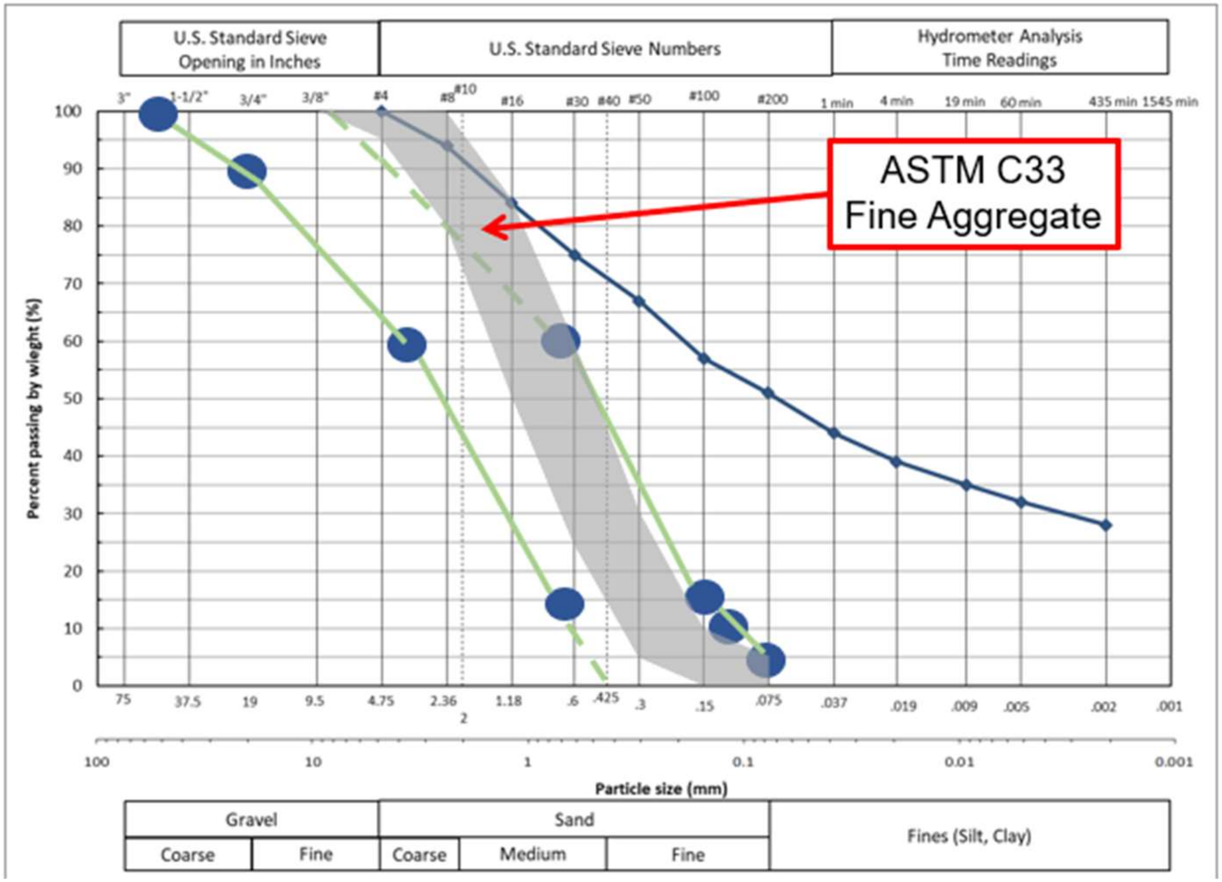
- Maximum particle size = 2 inch
- D_{90} according to the following table:

Base Soil Category	**If D_{10} is (mm)**	**Then Maximum D_{90} is, (mm)**
ALL CATEGORIES	< 0.5	20
	0.5-1.0	25
	1.0-2.0	30
	2.0-5.0	40
	5.0-10	50
	> 10	60

Gradation for a Drain as a Filter for ASTM C33 FA



Question and Answer Session #1

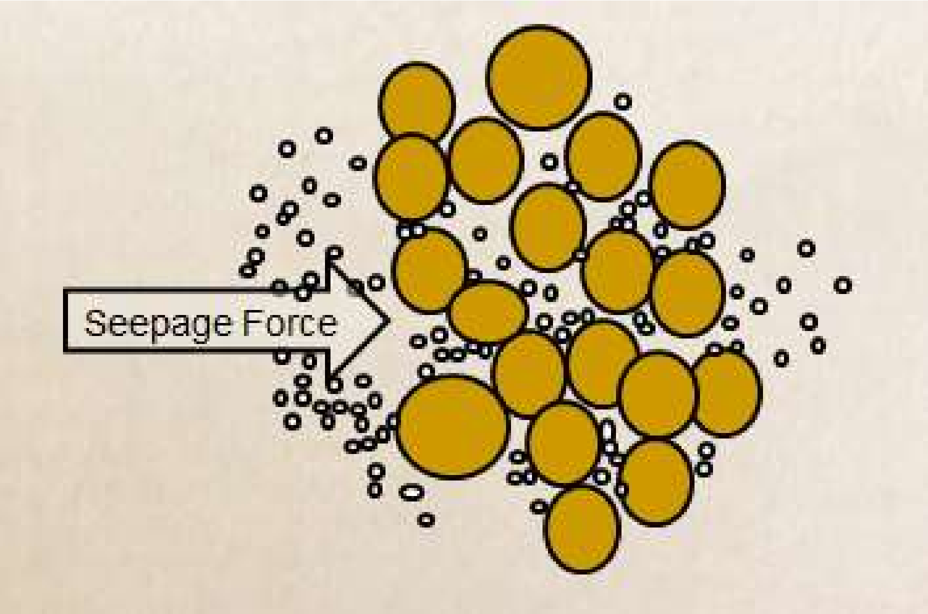


ASTM C33
Fine Aggregate

Filter Compatibility for Existing Dams

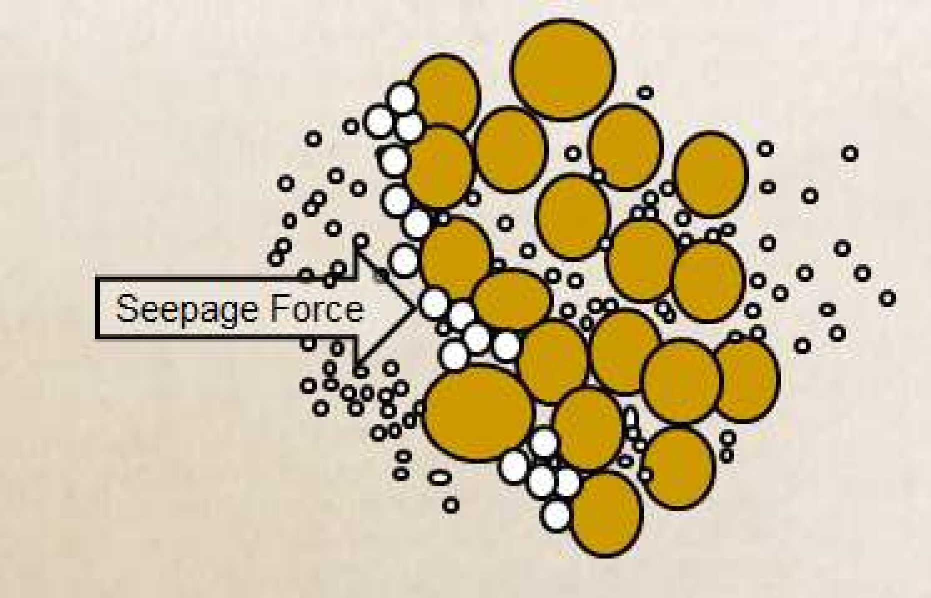
- What if filter is coarser than required by modern filter criteria?
  - Some dams constructed before about 1990 have filter/drainage zones that are coarser than current criteria
  - Other dams were not constructed with designed filters
- Foster and Fell (2001) developed concepts of some erosion, excessive erosion, and continuing erosion
  - Function of how much erosion occurs before erosion process stops

Continuing Erosion



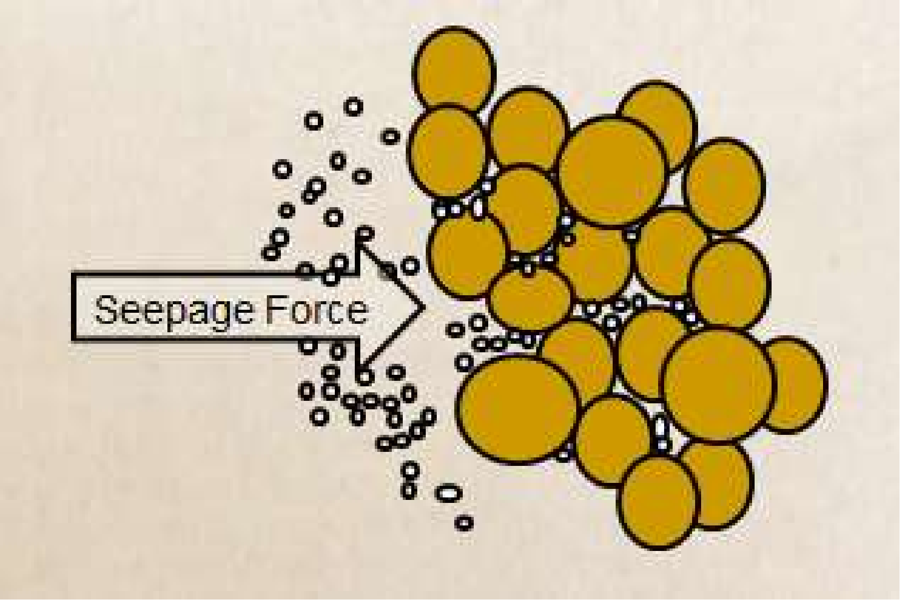
Filter material too coarse to stop erosion of base material, unabated continuing erosion occurs

Excessive Erosion



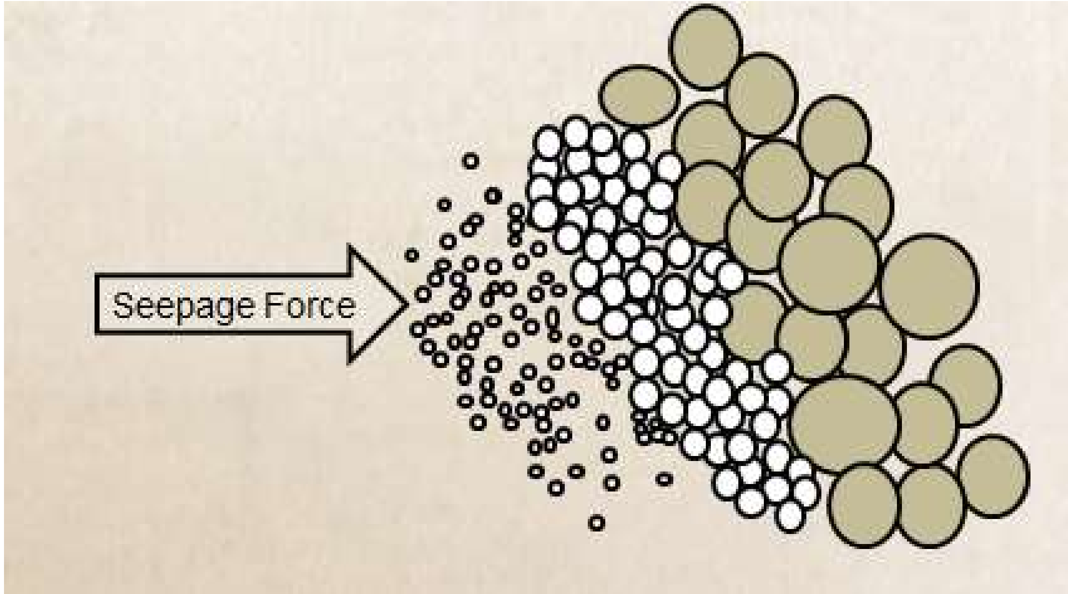
Filter material allows erosion of base material, but seals up after excessive erosion (possibly sufficient to cause sinkholes and/or pipe through core)

Some Erosion



Filter material initially allows erosion of base material, but seals up (self-heals) after some erosion

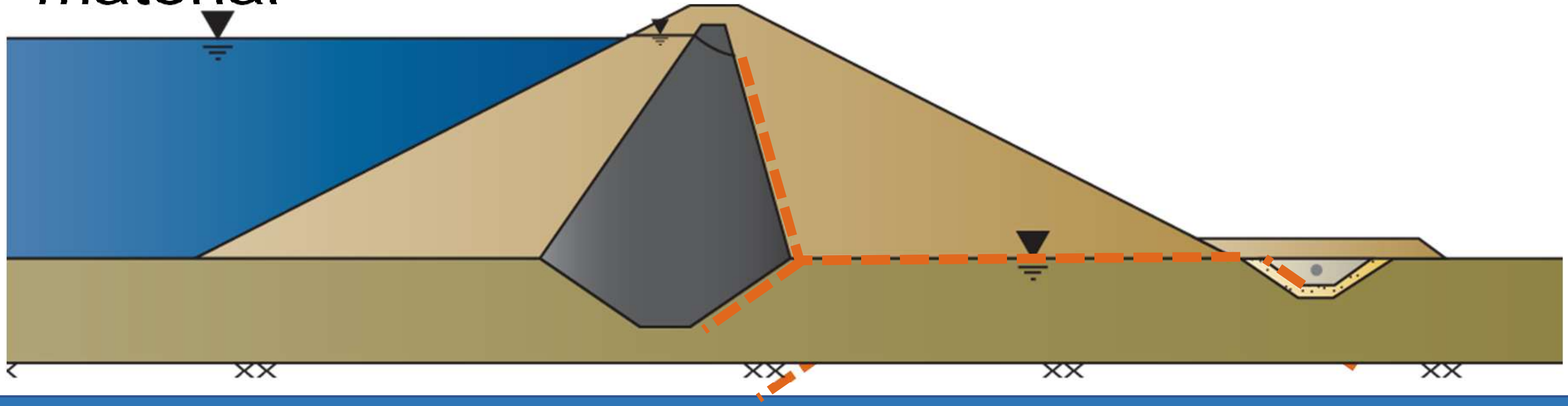
No Erosion



Filter material stops erosion with no or little erosion of base material (soil filter is protecting base) – meets modern filter design guidance

Filter Evaluation of Existing Dams

- Key influential factor in internal erosion evaluations
- Determine zoning and material interfaces
- Determine gradations and plasticity of zoned material



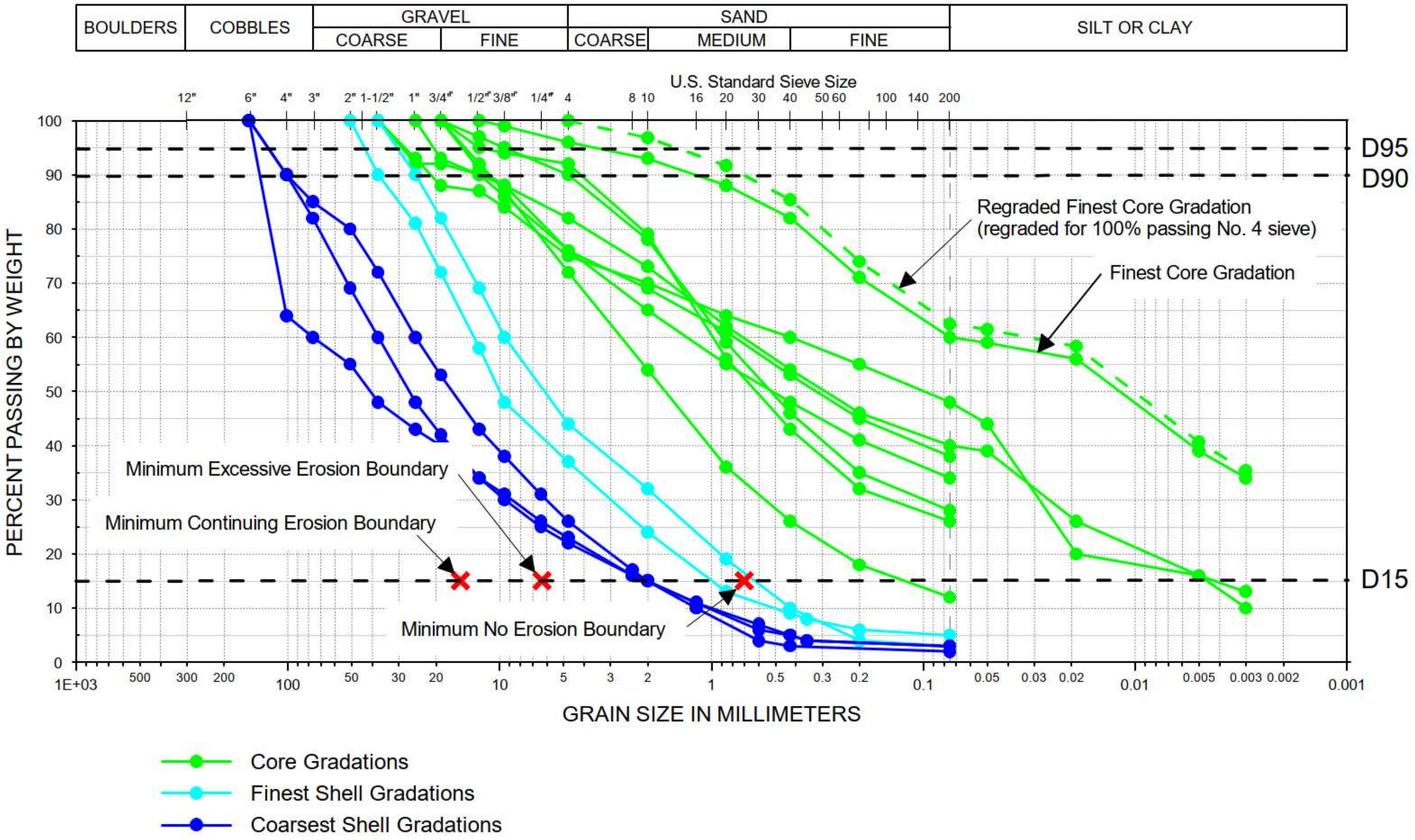
Filter Compatibility of Existing Dams

Base Soil	Foster-Fell Criteria for Excessive Erosion Boundary
$D_{95}B \leq 0.3$ mm	$D_{15}F > 9(D_{95}B)$
0.3 mm $< D_{95}B \leq 2$ mm	$D_{15}F > 9(D_{90}B)$
$D_{95}B > 2$ mm and FC $\leq$ 15 percent	$D_{15}F > 9(D_{85}B)$
$D_{95}B > 2$ mm and 15 percent < FC $\leq$ 35 percent	$D_{15}F > 2.5[(4(D_{85}B) – 0.7) \times ((35 – FC)/20) + 0.7]$
$D_{95}B > 2$ mm and FC $\geq$ 35 percent	$D_{15}F >$ ($D_{15}F$ value for erosion loss of 0.25 g/cm^2 in the CEF test

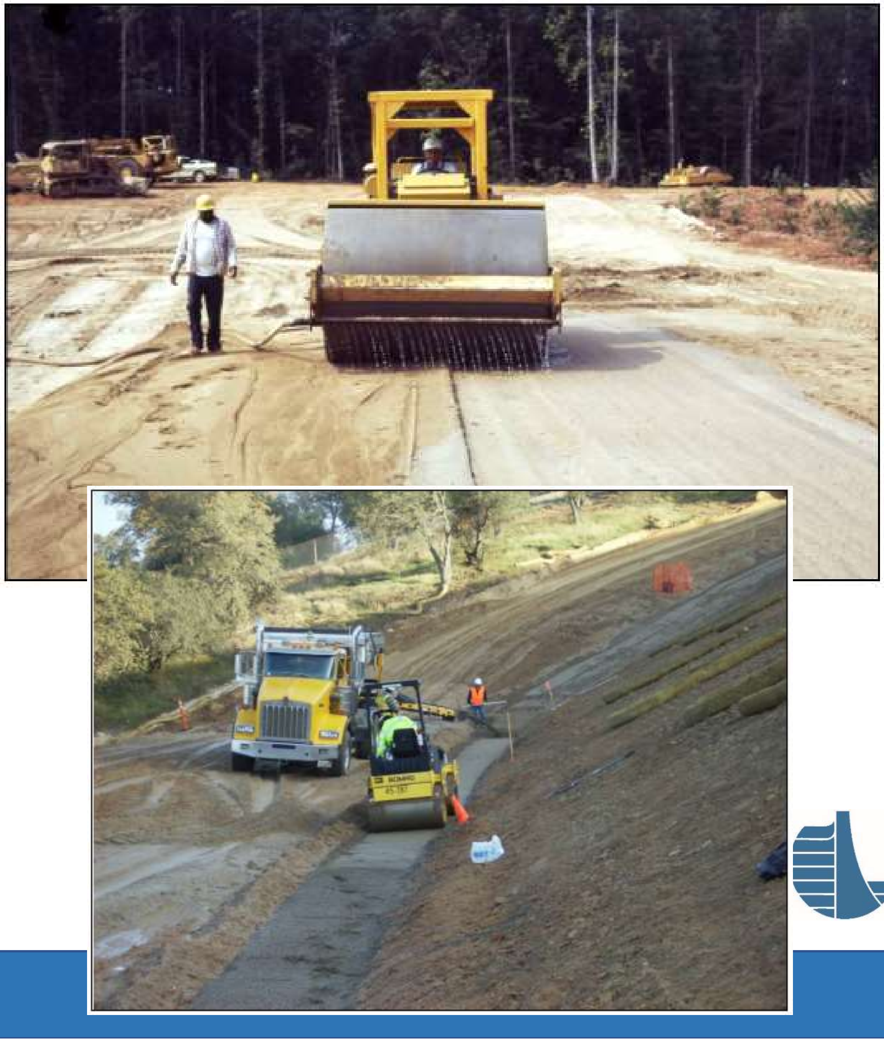
Notes: Criteria are directly applicable to soils with $D_{95}B$ up to 4.75 mm. For soils with coarser particles, determine $D_{85}B$, $D_{90}B$, and $D_{95}B$ using gradation curves adjusted to give a maximum size of 4.75 mm.

Foster-Fell Criteria for Continuing Erosion Boundary
For all soils, $D_{15}F > 9(D_{95}B)$

Foster and Fell (2001) Criteria



Filter Sand Compaction



Purpose of Filter Sand Compaction

From FEMA (2011)

- So that they will not settle excessively on wetting.
- So that a design shear strength will be achieved.
- To provide adequate flow capacity
- To provide self healing properties
- To aid in obtaining strain compatibility with adjacent zones in the dam
- To provide particle retention capability as-compacted.
- To preclude liquefaction or excessive deformation when loaded seismically

Poll Question #5

Are there disadvantages resulting from compacting a filter sand too much?

- Yes
- No

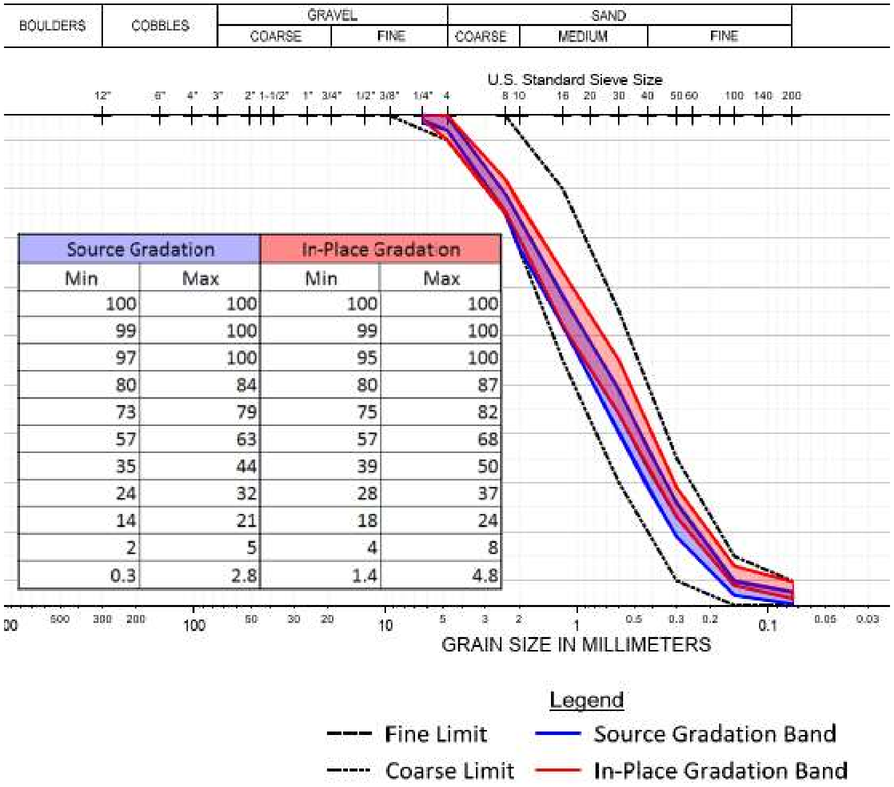
Potential Disadvantages to Overcompacting Filter Sand

- Excessive particle breakdown – decreasing permeability
- Increased possibility of the filter sand holding a crack
- Increased stiffness compatibility with core material

FEMA (2011) recommends against overcompacting filter sand, but does not quantify overcompaction

Particle Breakdown

- Breakage occurs during compaction
- Typical increase in fines content (minus #200) between 1% and 3% (FEMA, 2011)
- Gradation will also change slightly, increasing maximum dry density



Source Gradation		In-Place Gradation	
Min	Max	Min	Max
100	100	100	100
99	100	99	100
97	100	95	100
80	84	80	87
73	79	75	82
57	63	57	68
35	44	39	50
24	32	28	37
14	21	18	24
2	5	4	8
0.3	2.8	1.4	4.8

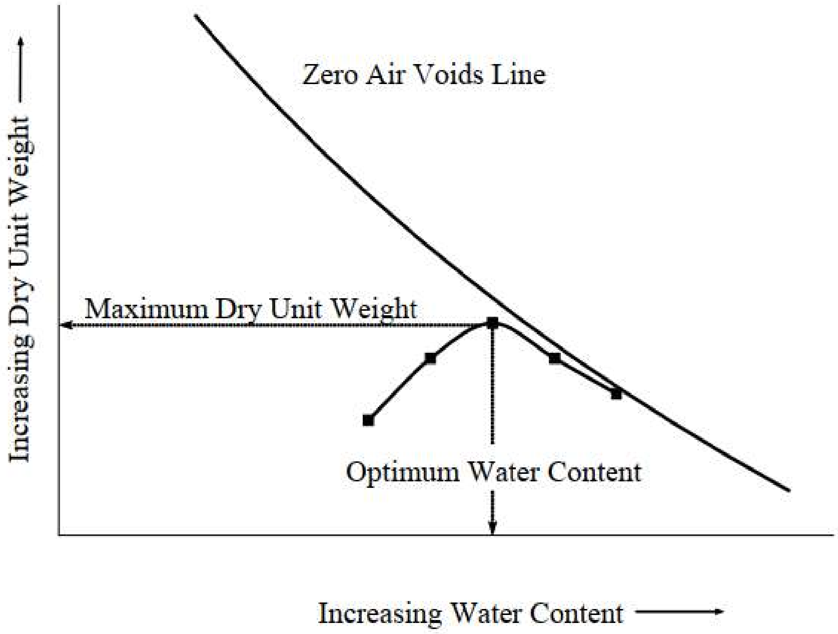
Poll Question #6

Are the compaction characteristics of filter sand the same as those of sandy silts and clays?

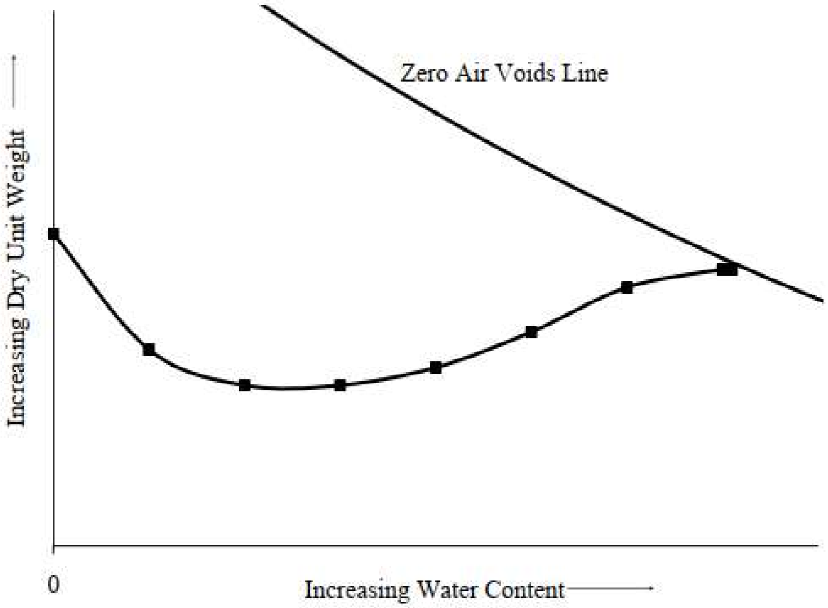
- Yes
- No

Compaction Characteristics

Conventional compaction curve



Filter sand compaction curve



Moisture Conditioning

- Filter sand moisture content changes
  - During compaction
  - After compaction

- High moisture content during compaction will
  - Increase compaction efficiency
  - May decrease breakage

Filter Sand Compaction Control

Method Specification

Procedural

- Layer thickness
- Moisture conditioning
- Number of passes
- Equipment specifications

Performance Specification

End product

- Relative Compaction or
- Relative Density

Poll Question #7

Do maximum density values from laboratory tests represent physical limits on maximum density for and individual soil – i.e. must the field density of a soil be no greater than the laboratory maximum density?

- Yes
- No

All Laboratory Maximum and Minimum Density Test Should Be Considered Index Tests

- Maximum and minimum densities are test procedure dependent
- Densities greater than laboratory maximum densities and less than laboratory minimum densities are physically possible

Basic Tests for Minimum and Maximum Index Densities

Min Index
ASTM
D4254

Max Index
ASTM
D4253

Standard Proctor
/Modified Proctor
One-Point Tests
ASTM D698 /
D1557

Vibrating
Hammer
ASTM D7382

Filter Sand Compaction Specifications

- *Relative Compaction*

$$RC = \frac{\gamma_d}{\gamma_{dmax}} * 100\%$$

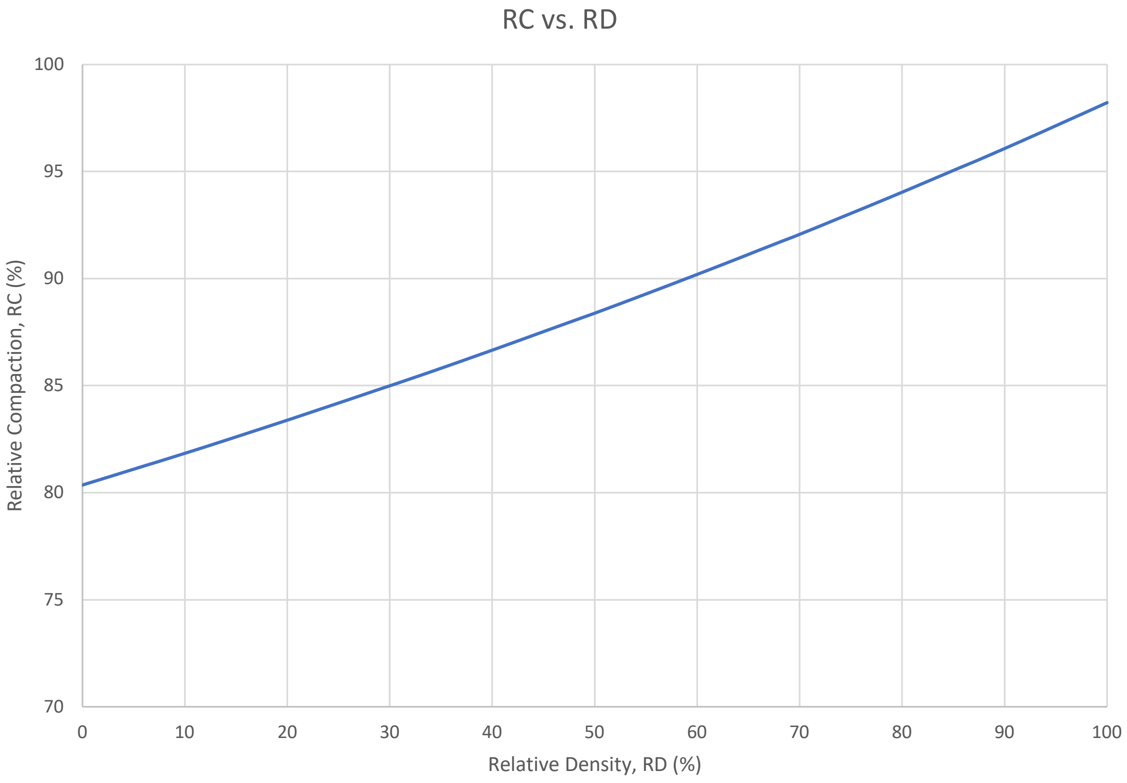
- Standard Proctor (ASTM D698)
- Modified Proctor (ASTM D1557)
- Vibratory hammer (ASTM D7382),
- or Vibratory table (ASTM D4253)

- *Relative Density*

$$RD = \frac{\gamma_{dmax}}{\gamma_d} * \frac{\gamma_d - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}} * 100\%$$

- Minimum and Maximum Index Density (ASTM D4254 and D4253, respectively)

Relative Compaction vs. Relative Density



- RC vs. RD is unique to the soil and laboratory methods
- 100% RC ≠ 100% RD (typically)
- Preliminary evaluation: RC = 80 + 0.2*RD (Lee and Singh, 1971) – but only approximate – the actual relationship is soil specific

Poll Question #8

Is there a consensus within the dam safety community on filter sand compaction practices?

- Yes
- No

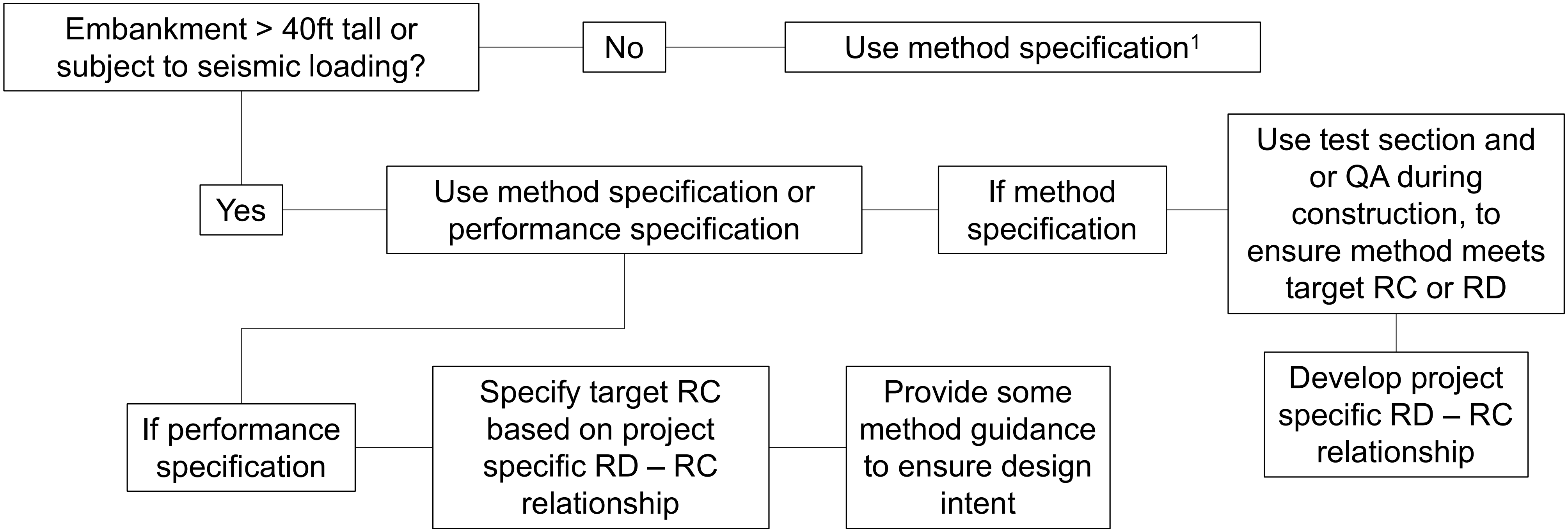
Industry Practices Survey

- No clear consensus on practices
- Most use method specifications with or without verification testing
- Others use performance specification
- Consensus that over-compaction is not desirable
- RD for seismic loading varied from about 65% to >80%
- Near consensus on wetting sand during construction
- Near consensus that RD is very difficult to use for construction control

Guidance from NRCS (1992 and 2016)

- For dams up to 40 feet in height, a method specification has a high likelihood of achieving at least 50% RD, which should be satisfactory for low dams in non-seismic settings
- For dams taller than 40 feet in height, a method specification is recommended with a target of 70% RD
- For dams subject to seismic loading a RD of 70% or greater is recommended

Presenter’s Recommendations[1]



Embankment > 40ft tall or subject to seismic loading?

No

Use method specification[1]

Yes

Use method specification or performance specification

If method specification

Use test section and or QA during construction, to ensure method meets target RC or RD

Develop project specific RD – RC relationship

If performance specification

Specify target RC based on project specific RD – RC relationship

Provide some method guidance to ensure design intent

[1] Include test section or check testing, if desired

[1] Not accepted or endorsed by any organization

Recommended Method Specification[1]

- With heavy vibratory drum compactors (heavier than 10-tons), a loose (before compaction) lift thickness up to 12 inches
- For lighter vibratory drum compactors, the loose lift thickness should be reduced to 8 inches; and for small plate compactors the loose lift thickness should be further reduced to 6 inches. If hand operated impact compactors (jumping jacks) are used in difficult to access locations, even thinner lifts may be required.
- Each lift should be compacted with three or four passes or coverages
- Moisture should be applied to the sand filter as it is compacted, to achieve a moisture content during compaction near saturation.

[1] Recommended by the presenter, not accepted or endorsed by any organization

Filter and Drain Construction – Some Other Considerations

- Natural vs. Processed Materials
- Standard Gradations
- Handling and Construction
- Filter / Drain Dimensions
- Two-stage Filter / Drain Systems
- Toe Drains
- Toe Drain Pipes
- Camera Inspection
- Geotextiles

Not an exhaustive list – other topics addressed in the references.

Natural vs. Processed Materials

- Rare to find natural soils suitable for filters
  - Not “clean” enough
  - Can be gap graded
  - Variable gradations
  - Can contain excessive coarse particles
- Readily available ASTM C33 fine aggregate is an excellent filter in almost all cases

Standard Gradations

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

Handling and Construction

Avoiding Contamination

- Protect filter / drain from contamination during construction to ensure design intent
  - Control surface runoff
  - Control equipment crossings
- When contamination of a filter / drain occurs for whatever reason, all contaminated material must be removed and replaced

Handling and Construction

Avoiding Segregation

- Filter / drain materials must conform to the specified gradation after being placed and compacted.
    - Filter gradation criteria are designed to reduce segregation
    - Specify proper stockpiling and handling procedures
    - Moistened sand segregates less during handling than dry sand

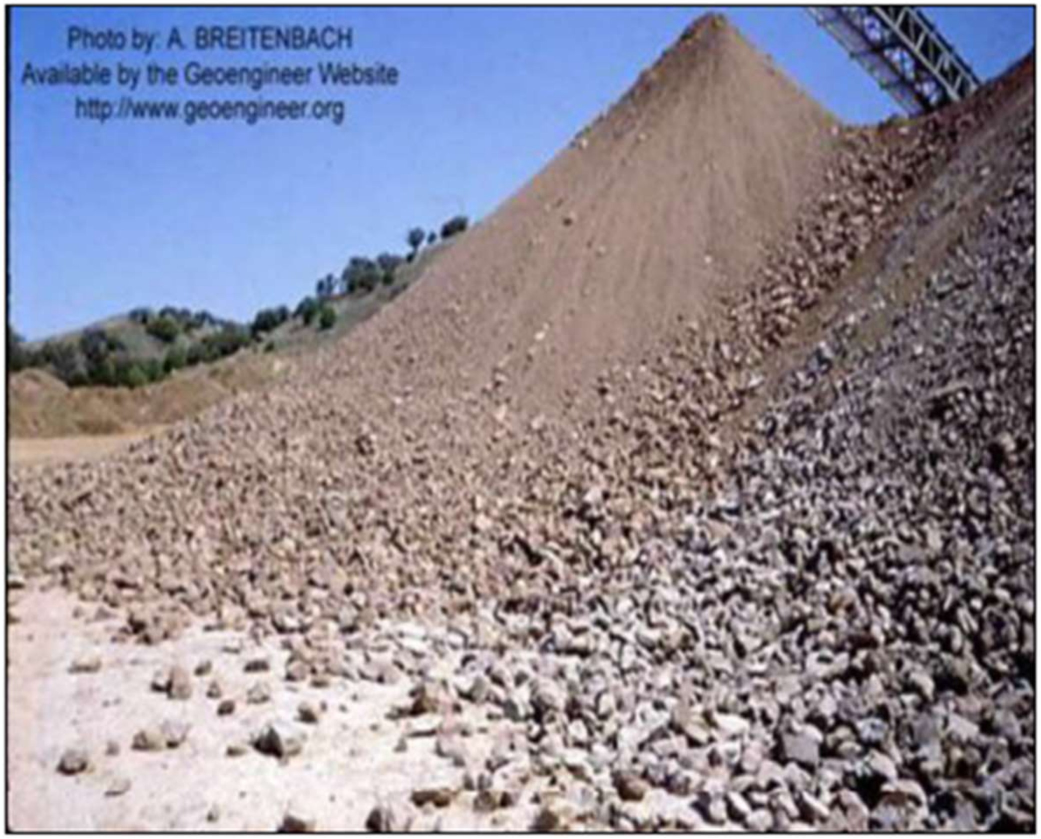
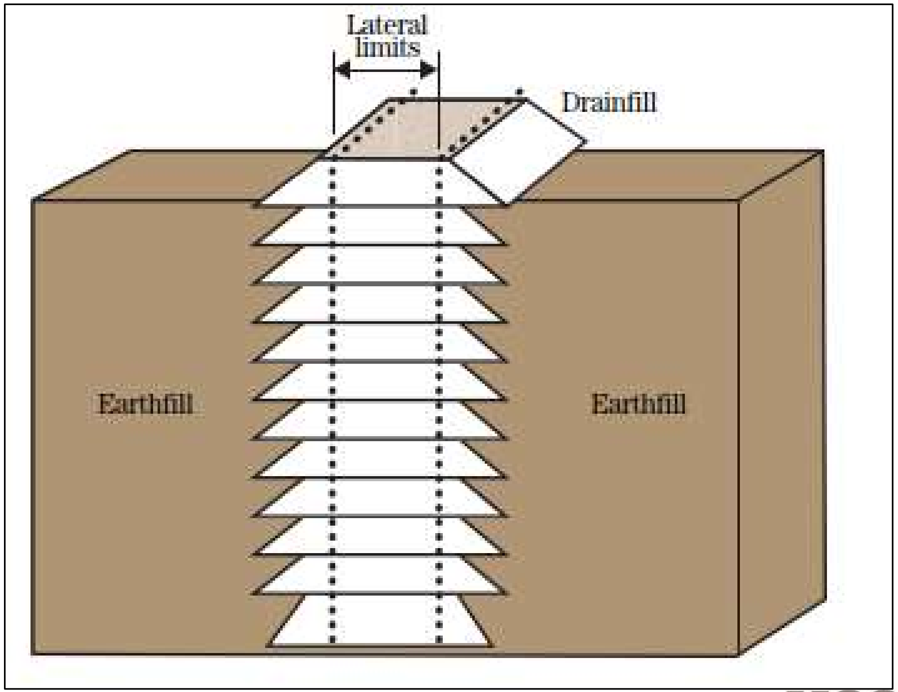


Photo by: A. BREITENBACH
Available by the Geoengineer Website
http://www.geoengineer.org

Handling and Construction

Construction Sequencing

- Continuity of filter/ drain materials through the embankment ensures the design intent is met
    - Maintain filter / drain one lift above of adjacent zones

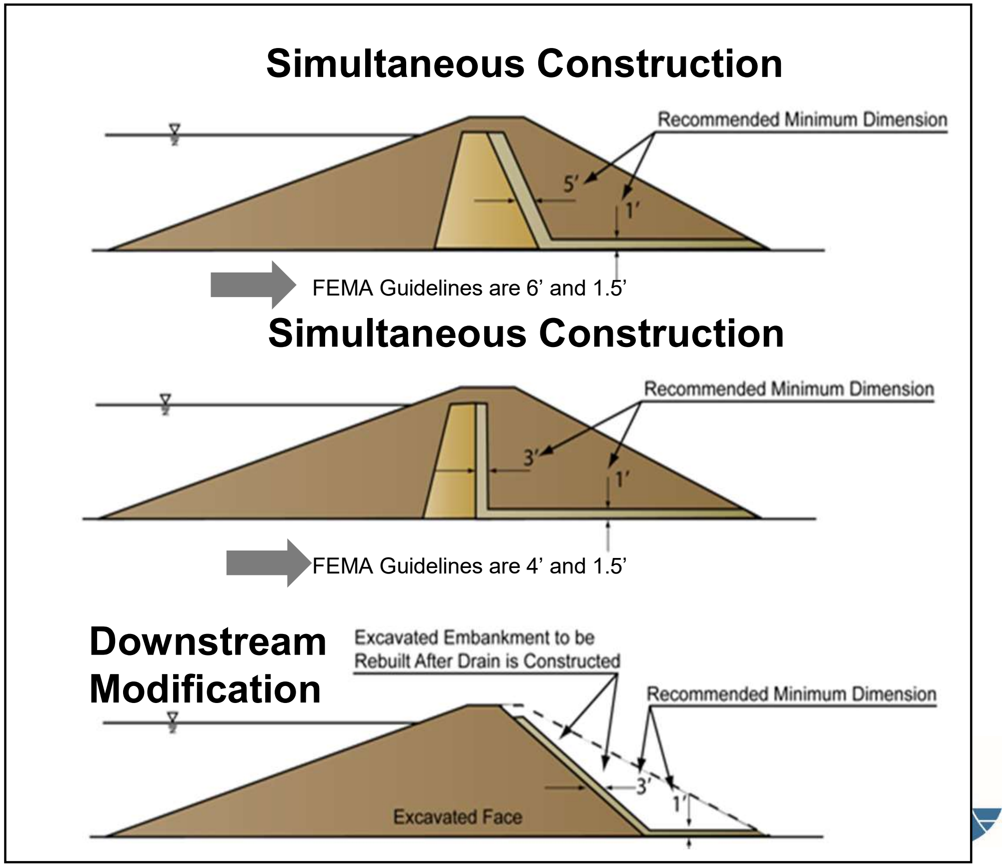


Considerations in Selection of Filter / Drain Zone Dimensions

- Permeability requirements
  - In many cases calculated seepage quantities do not require large filter thicknesses
- Material availability
- Construction equipment / procedures
- Constructability will most often control filter dimensions

Suggested Chimney Filter Dimensions

- Top elevation
  - Historic practice – top of estimated phreatic surface
  - Current practice – often top of maximum flood pool
- Width
  - Orientation of the filter – vertical or inclined



Simultaneous Construction

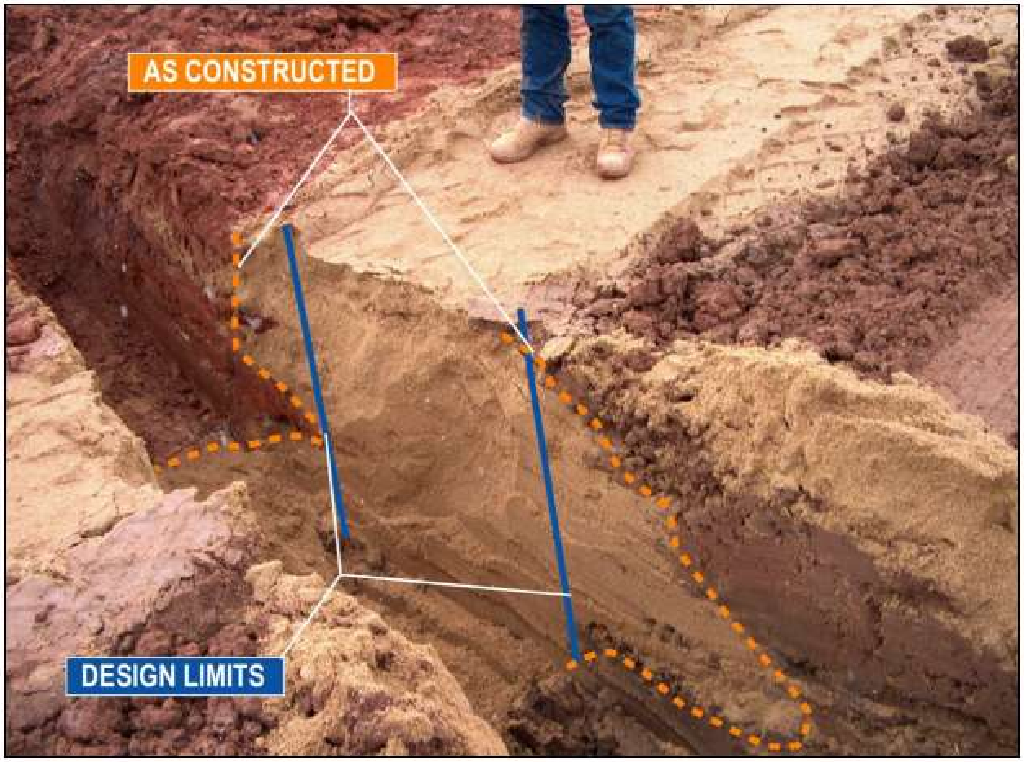
FEMA Guidelines are 6’ and 1.5’

Simultaneous Construction

FEMA Guidelines are 4’ and 1.5’

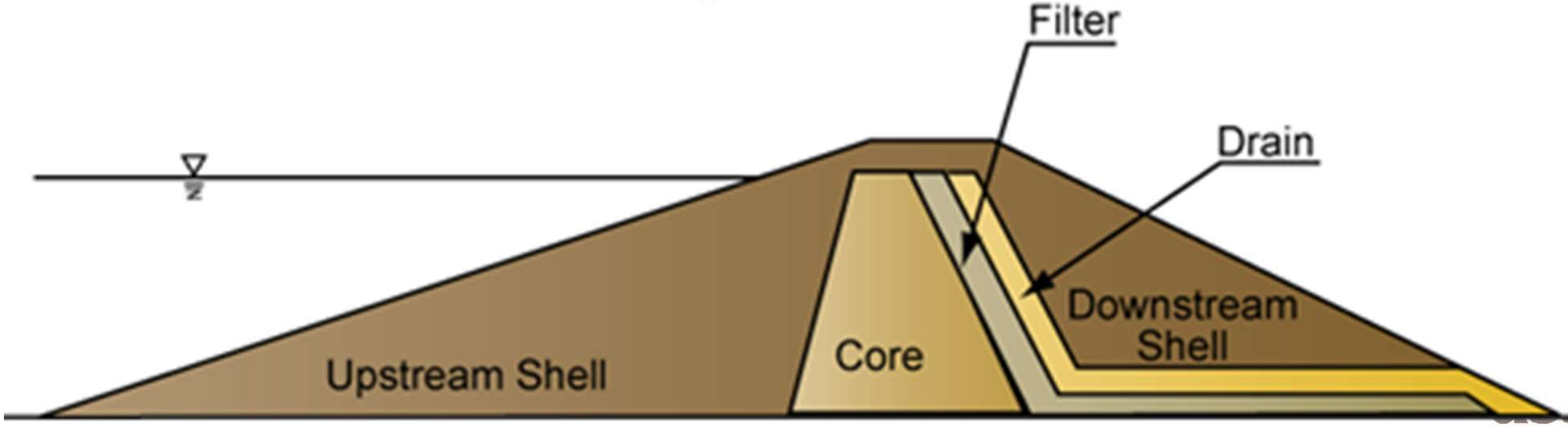
Downstream Modification

“Christmas Tree” Effect from Placement of Inclined Chimneys

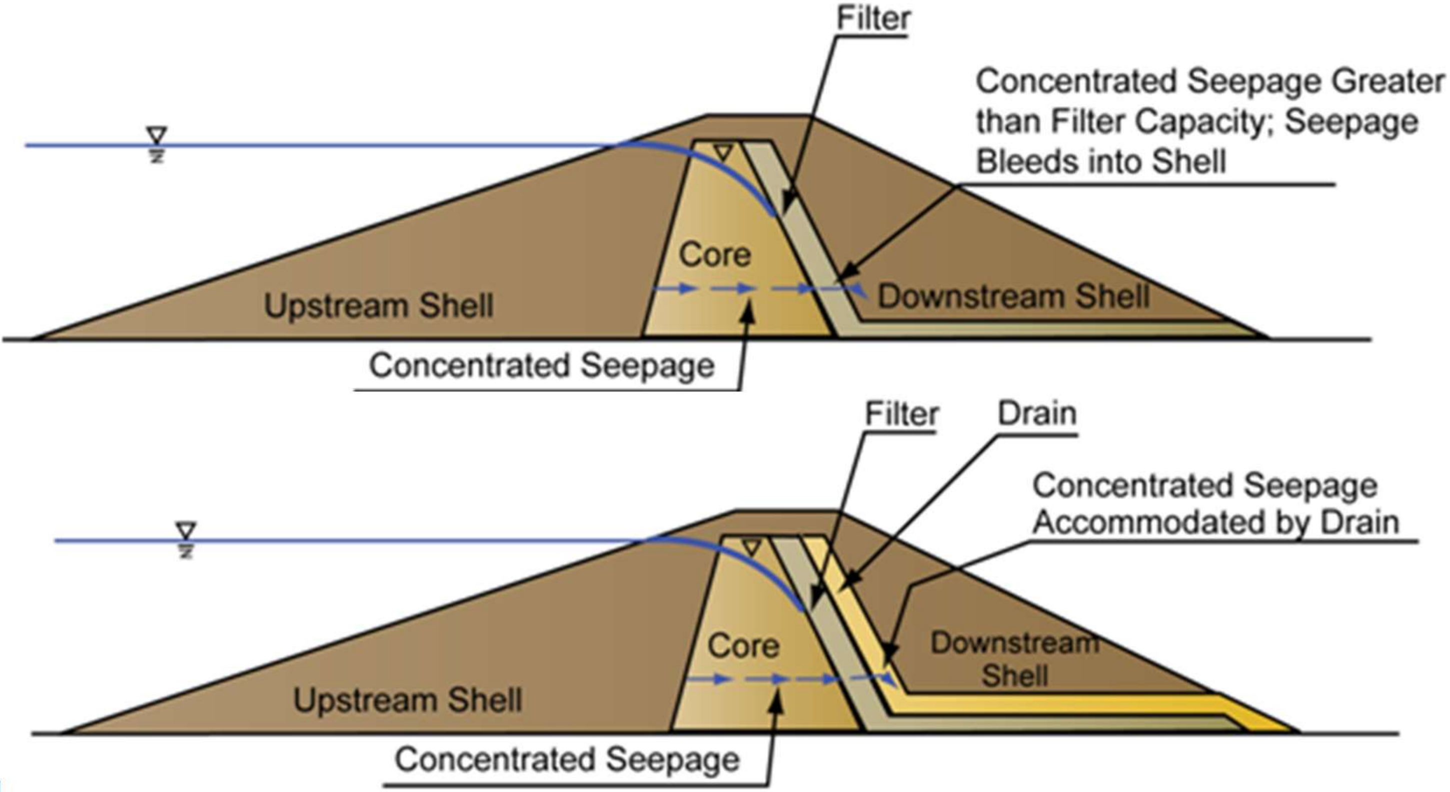


One-Stage vs. Two-Stage Chimneys

- Two-stage:
  - Provides capacity to handle large flow
  - Negates effects of filter contamination
  - Better self-healing of cracks



Prevent Concentrated Flows from Overwhelming Filter



Toe Drains

Purpose

- Convey seepage from the chimney and blanket drains
- Collect foundation seepage

Location

- Near downstream toe of the embankment

Single-Stage versus Two-Stage

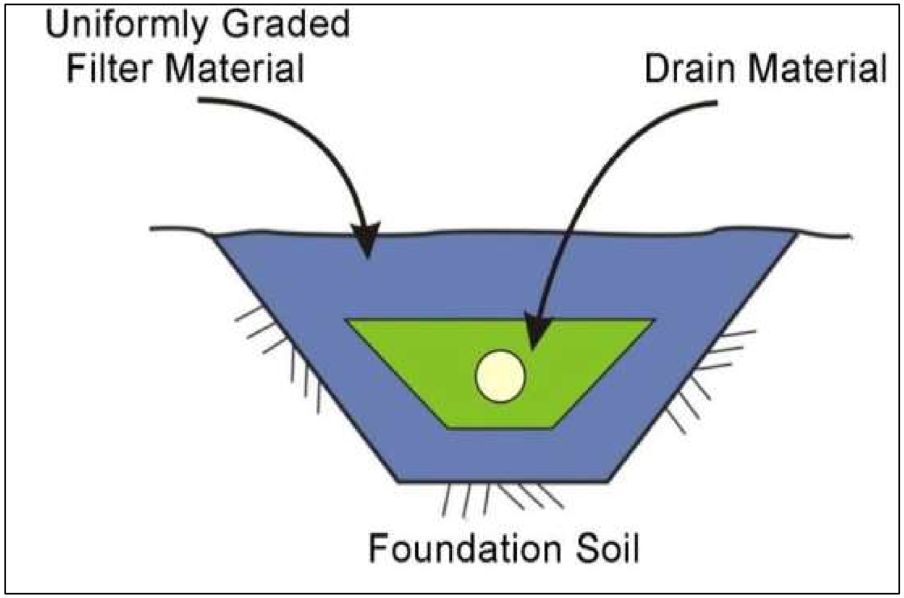


Figure from FEMA (2011)

Clogging of Slotted Drain Pipe Embedded in Sand Filter

Three Examples of Changes in Flow With Addition of Gravel Pipe Envelopes

- Washakie Dam, WY
  - Flow increased from about 50 gpm to about 500 gpm
- Antero Dam, CO
  - Flow increased from about 5 gpm to about 50 gpm
- Rampart Dam, CO
  - Increased from no flow to active collection of flow

Plastic Pipe Materials

Product	Type		Advantage	Disadvantage	Recommended?
HDPE	Solid		Strong, welded joints, flexibility of perforation size and type	Highest cost, special ordered or hand drilled perforations	Highly
	Corrugated	Single - Wall	Economical	Poor historic performance, weak	No
		Double - Wall	Economical, successful applications, large perforation sizes	Low strength, careful installation required	Moderately
PVC	Solid	Well Screen	Strong	Small perforation aperture	Moderately
		Dain Pipe	Economical	Weak, brittle	No
	Corrugated	Double - Wall	Economical	Weak, Brittle	No

Report DSO-09-01, Physical Properties of Plastic Pipe Used in Reclamation Toe Drains, Bureau of Reclamation, September 2009

Camera Inspection

- Numerous cases of damage during construction
- Camera inspection during construction
  - After initial burial, 3 to 5 feet
  - After completion of construction
- Design considerations for inspection
  - Pipe diameter
  - Access points
  - Pipe slope

Geotextiles

- Susceptible to installation damage
- May clog or deteriorate
- Use in critical locations not recommended by USACE, USBR, and NRCS
- Can be used in non-critical locations – e.g. on downstream side of internal filter/drain or as a separator
- Can be used for emergency response – e.g. with heavy seepage

Geotextiles

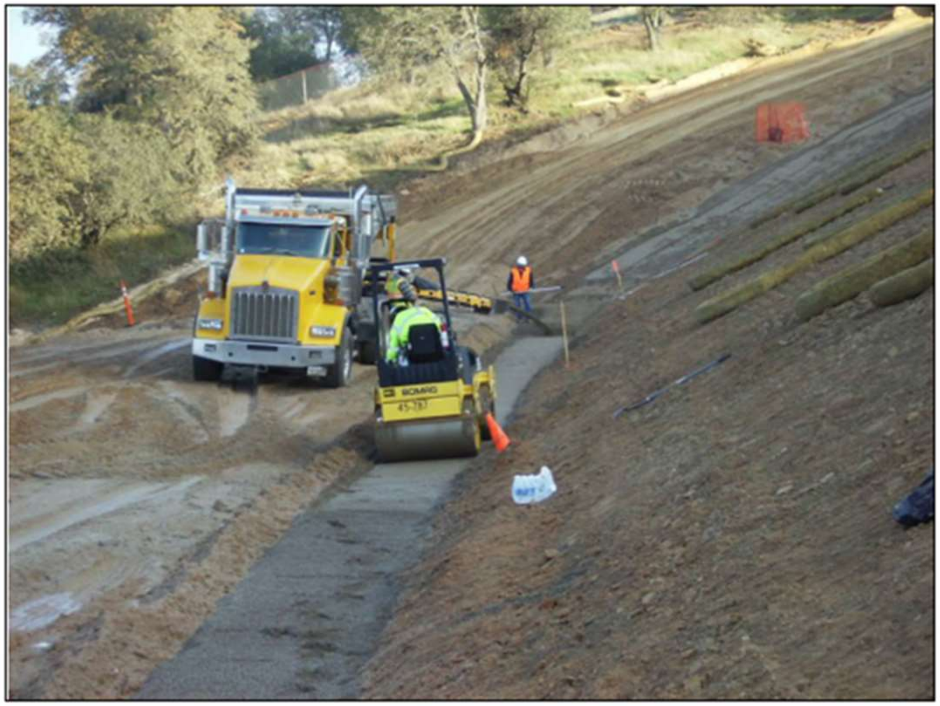
Statement taken from "Filters for Embankment Dams – Best Practices for Design and Construction," FEMA, October 2011:

Because geotextiles are prone to installation damage and have a potential for clogging, their reliability remains uncertain. Many organizations forbid their use in embankment dams in critical applications where poor performance could lead to failure of the dam or require costly repairs. Designers are cautioned to consider the potential problems associated with using a geotextile as a critical design element in a non-redundant manner deeply buried in a dam.

It is the policy of the National Dam Safety Review Board that geotextiles should not be used in locations that are both critical to safety and inaccessible for replacement.

Question and Answer Session #2


2008/04/11



Key Takeaways

- There is a century long history of filter development, but current criteria were developed in the 1980s
- There is some flexibility in application of current gradation criteria – maximum D_{15F} is critical
- Foster and Fell (2001) provides guidance to evaluate filter compatibility in existing older dams
- Compaction characteristics of filter sand are different than those of sands and clays – compaction near saturation is most effective
- There are disadvantages to over-compacting filter sand
- There is not industry-wide consensus on compaction of filter sand
- Beyond gradation and compaction, there are numerous details that need to be considered in design and construction of filters and drains