Granular Filters in Embankment Dams

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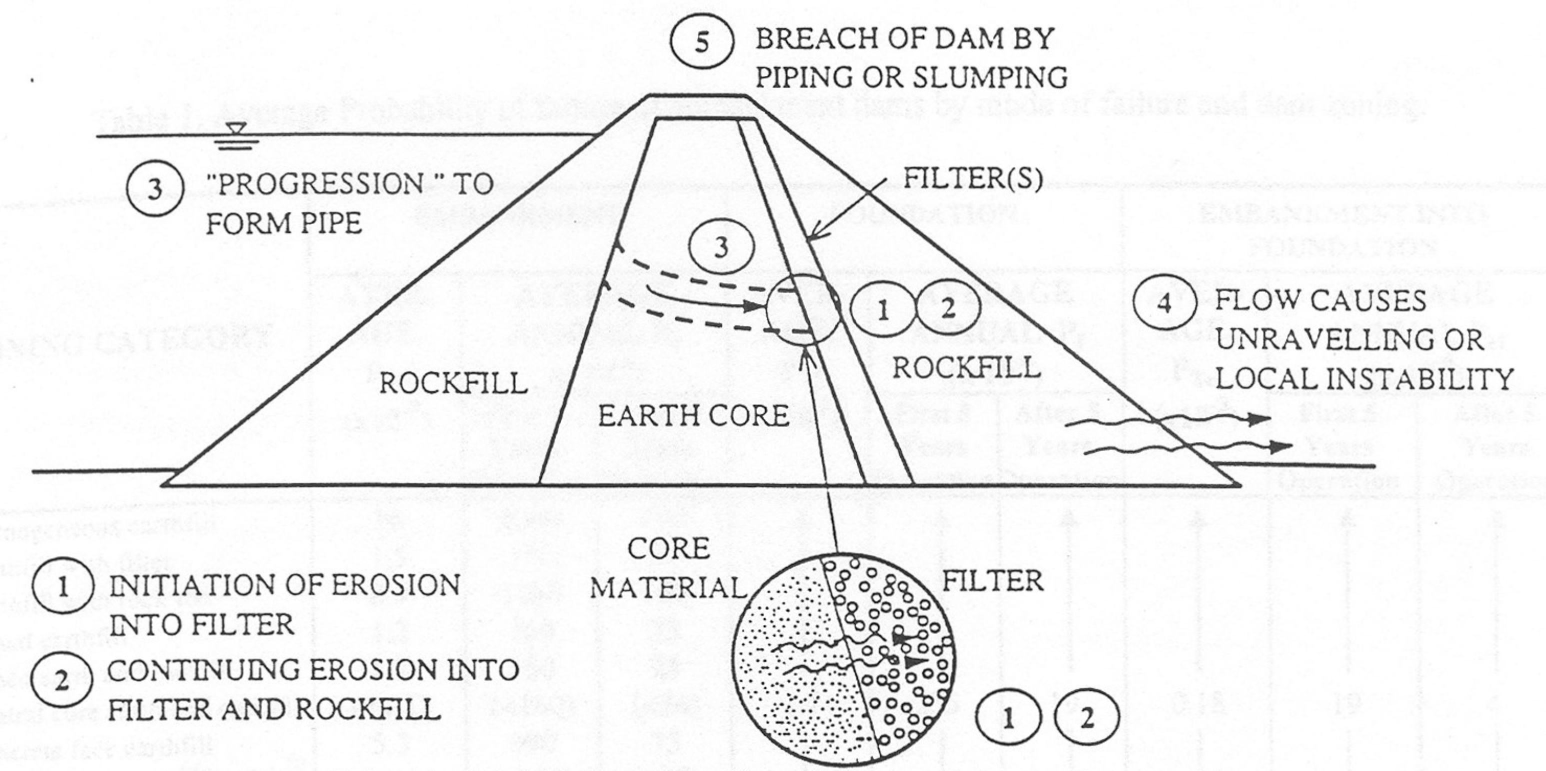
SMEC

Presented by

Dr Gamini Adikari
Principal Engineer Dams
SMEC Australia

Development Stages in a Piping Failure



Stages in the development of breaching by piping in the embankment.

Assessment of filter suitability

- Ability of sandy gravel to prevent erosion of the earth core
- Internal stability of filtering medium
- Impact of substantial proportion of fines on performance of filter - cracking
- Drainage capacity of downstream rockfill in terms of a concentrated leak through core

Types of Filters and their Applications

- Critical filters
- Less critical and non-critical filters
- Filters under rip-rap
- Assessing filter and transition zones in existing dams

Design of Critical filters

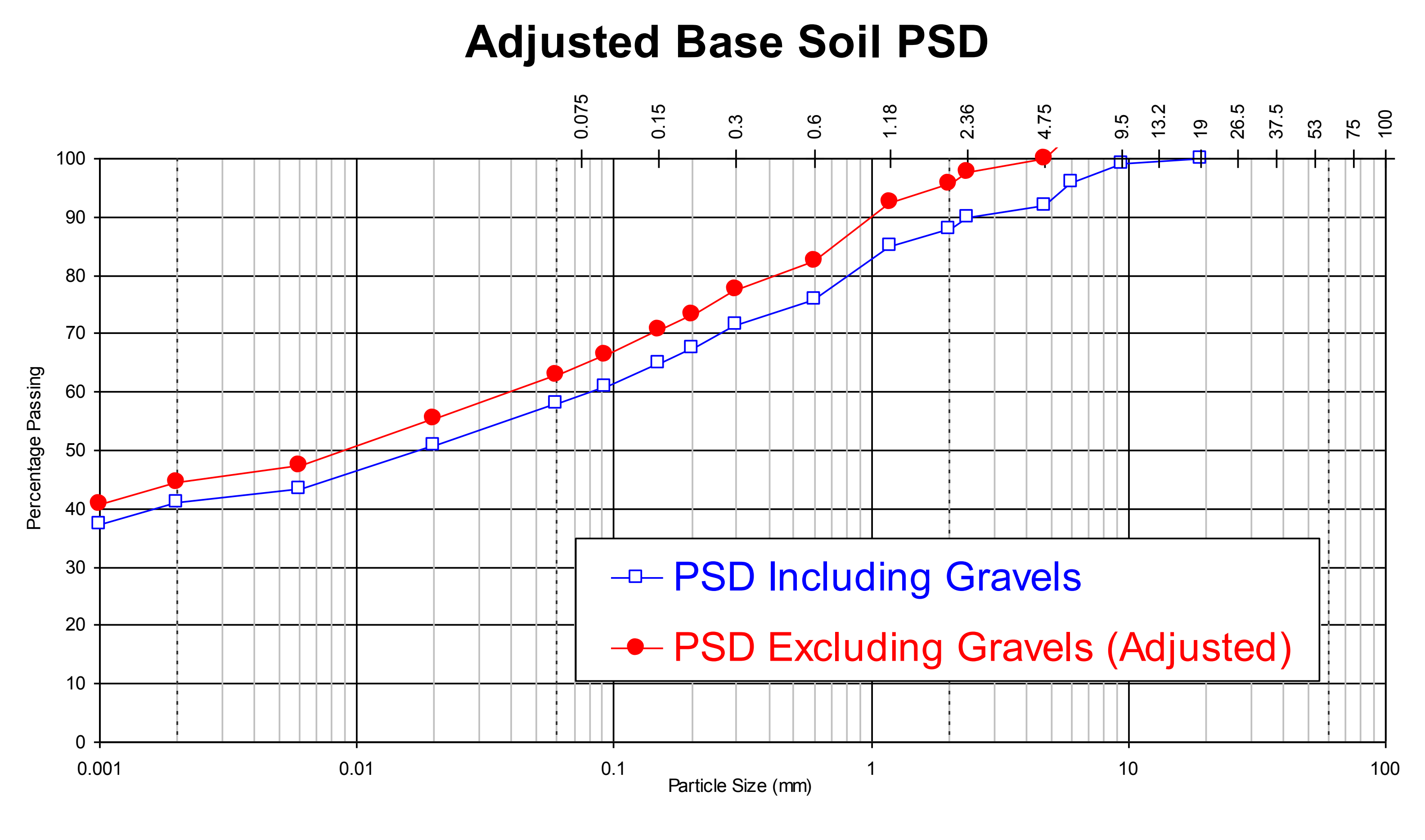
Basic Approach ….

- Design 2A filters considering earthfill as the base material
- Design 2B filters considering 2A filter as the base material
- Design 3A zone considering 2B filter as the base material

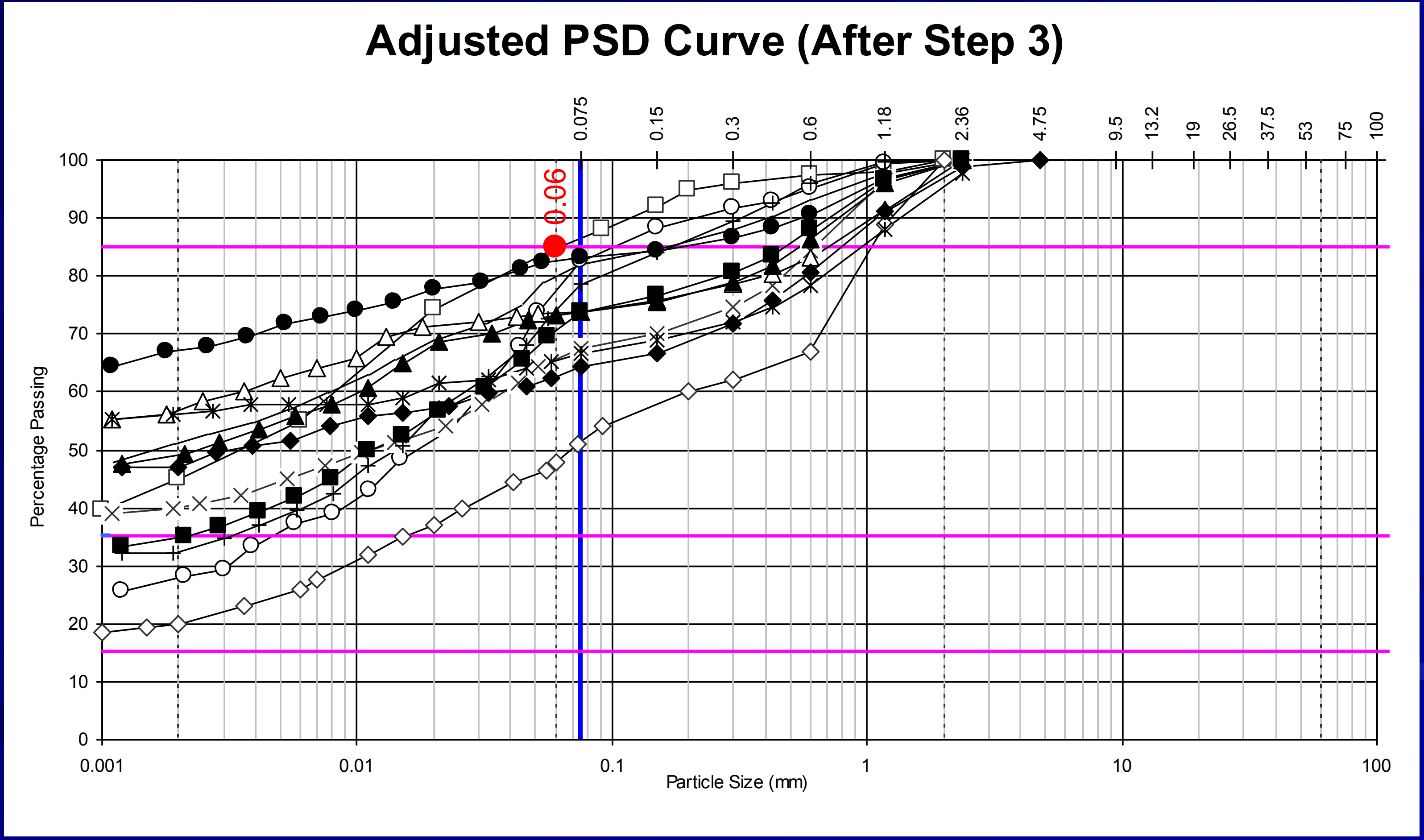
Steps in Filter Design

- Step 1 – Plot the PSD curve of base soil; Determine dispersivity
- Step 2 – Proceed to Step 4, if the base soil is finer than 4.75mm (no gravel)
- Step 3 –Adjust PSD curve to remove the fraction greater than 4.75mm; Determine $D85_B$ from the finer boundary of the grading envelope

Adjusting the PSD curve for base soils that have particles > 4.75mm



Determine $D85_B$ from the finer boundary of the adjusted PSD envelope



Step 4 – Determine the base soil category

Base Soil Category	% finer than 0.075mm	Base Soil Description
1	> 85	Fine silts and clays
2A	35 – 85	silty and clayey sands, sandy clays etc
4A	15 – 35	silty and clayey sands and gravels
3	< 15	sands and gravels

Step 5 – To satisfy the filtration requirement, determine the maximum allowable $D15_F$ of filter

Base soil category	Filtering criteria
1	=< 9 $D85_B$, but not less than 0.2 mm; 6 $D85_B$, for dispersive soils
2A	=< 0.7mm (0.5mm for dispersive soils)
3	Linear interpolation between soil category 2A and 4A
4A	=< 4 $D85_B$

Step 6 – Ensure the filter is sufficiently permeable

- For all soil categories, the minimum $D15_F$ should be => 4 $D15_B$ of base soil “before” re-grading;
- <=2% (or at most 5%) fines passing 0.075mm sieve
- Non-plastic fines in the filter

Step 7

- The width of the filter band should be narrow to prevent the use of gap-graded filter but should be wide enough to allow manufacture
- Ratio of coarse to fine sizes should be =< 5 for % passing 60 or less
- D60/ D10 to be 6 or less on both fine and coarse limits

Step 8 – To minimize segregation during construction

- Max size 75mm for filter zones not less than 2m wide and 0.5m thick
- Max size 37mm or 50mm, for narrower and thinner filter zones
- Specify the maximum D90

How to determine Maximum D90. For all soil categories …….

If $D10_F$ (coarse) is	Max $D90_F$ (coarse) should be
< 0.5 mm	20 mm
0.5 – 1.0 mm	25 mm
1.0 – 2.0 mm	30 mm
2.0 – 5.0 mm	40 mm
5.0 – 10.0 mm	50 mm
> 10.0 mm	60 mm

Step 9

- Connect the control points to form a preliminary design for the finer and coarse limits
- Extrapolate the finer and coarse curves to 100% passing

Design of Less- Critical and Non-Critical Filters

Typical Examples

- Filters upstream of the dam core
- Filters under rip-rap

Filters upstream of the dam core

- Generally not subjected continuous seepage gradients
- If reservoir drawdown is critical, design as critical filters

Filters Under Rip-Rap

- should be coarse enough not to wash out of the rip-rap
- should be fine enough to prevent erosion of the soil beneath the filter
- Generally two layers of filters may be required
- If proper protection is required, no-erosion filter criterion should be satisfied

Assessing filter and transition zones in existing dams

For existing embankment, a two stage approach ….

- Stage 1 - Assessment of various material zones outlined above against current filter design criteria in accordance with Sherard and Dunnigan (1985) and USBR (1987). Where the successive material zones meet this criteria, no further assessment is required.

- Stage 2 - Where the various material zones do not comply with Sherard and Dunnigan / USBR, the ability of the filters to prevent excessive erosion of the base soil, and the internal stability of the filter medium, is assessed using procedure published by Foster and Fell (2001).

Information required …

- Not sufficient to rely on the specification and the “design” drawings
- Assess the results of the “Record Tests” undertaken during construction
- “As Constructed” drawings
- Construction photos
- Construct test pits, log and PSD from samples

Four Erosion Zones

- No Erosion – filter seals with practically no erosion of base material;
- Some Erosion – filter seals after “some” erosion;
- Excessive Erosion – erosion of base soil is excessive before filter seals;
- Continuing Erosion – filter is too coarse to allow eroded base material to seal the filter allowing unrestricted erosion of the base material;

Filter assessment is based on four (4) erosion performance levels and three (3) verification criteria as outlined below:

(1) Continuing Erosion

Continuing-Erosion Filter (CEF) boundary

(2) Excessive erosion

Excessive-Erosion Filter (EEF) boundary

(3) Some erosion

No-Erosion Filter (NEF) boundary

(4) No erosion

Gap graded filters and internal stability

- Internal stability of a filter material is a function of the grading of the material which is generally represented by the uniformity coefficient, $Cu = D_{60} / D_{10}$ of the grading
- However, this procedure assesses the internal stability at D_{60} based on the D_{10} values only, whereas there could be unacceptable gradings in between D_{60} and D_{10}

Internal Stability of Filter Medium

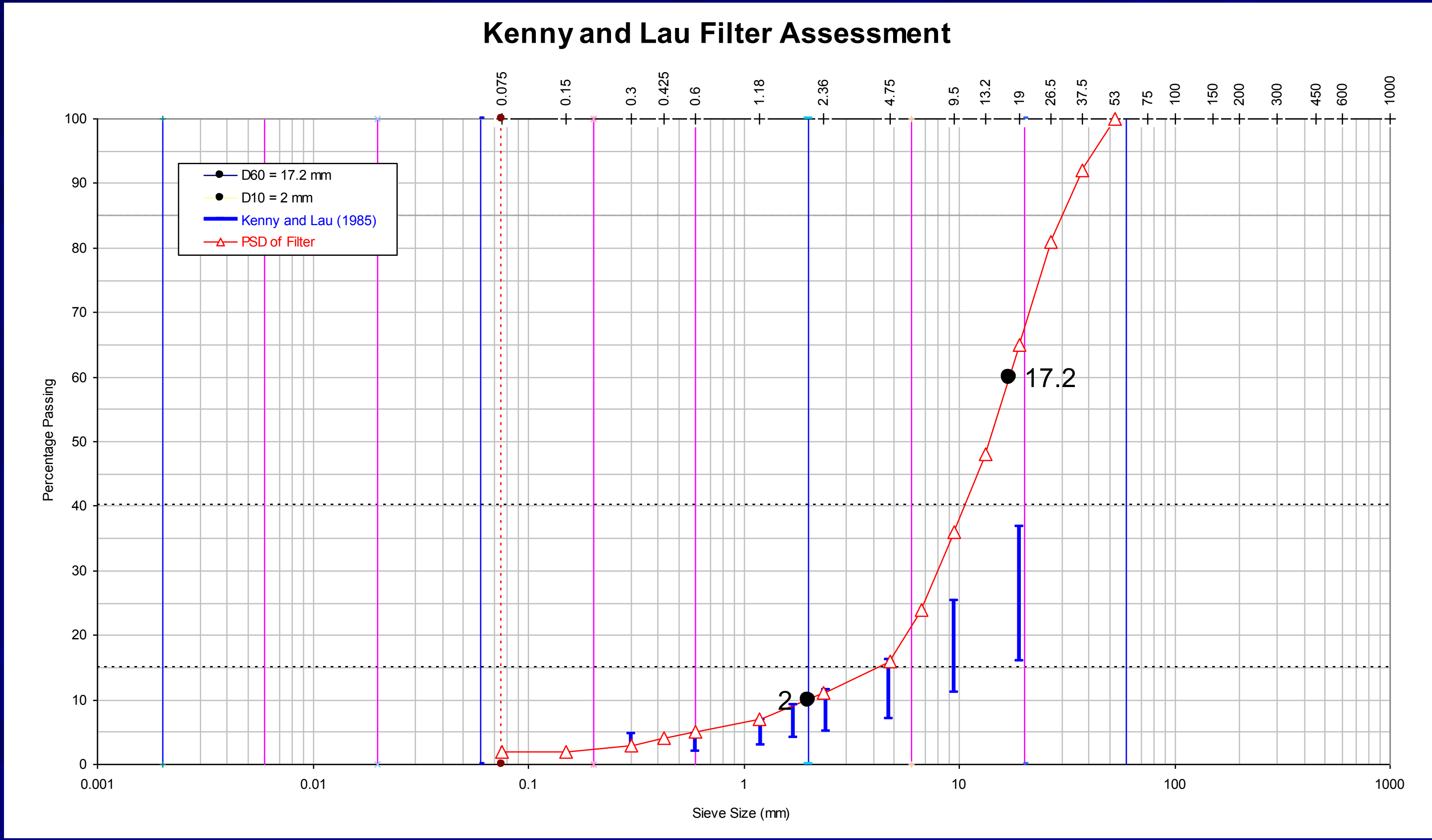
- The Kenny & Lau approach assesses the potential instability of the filter based on the grading of the whole filter and the potential for fine particles in the filter to move through the material due to a deficiency in the number of particles of a particular size

- Kenny & Lau identify that for a given particle size, “D”, in the bottom 20% of the material, there must be sufficient particles in the range “D to 4xD” to restrict the pore sizes such that particle “D” cannot travel through the pores

The Kenny & Lau relationship

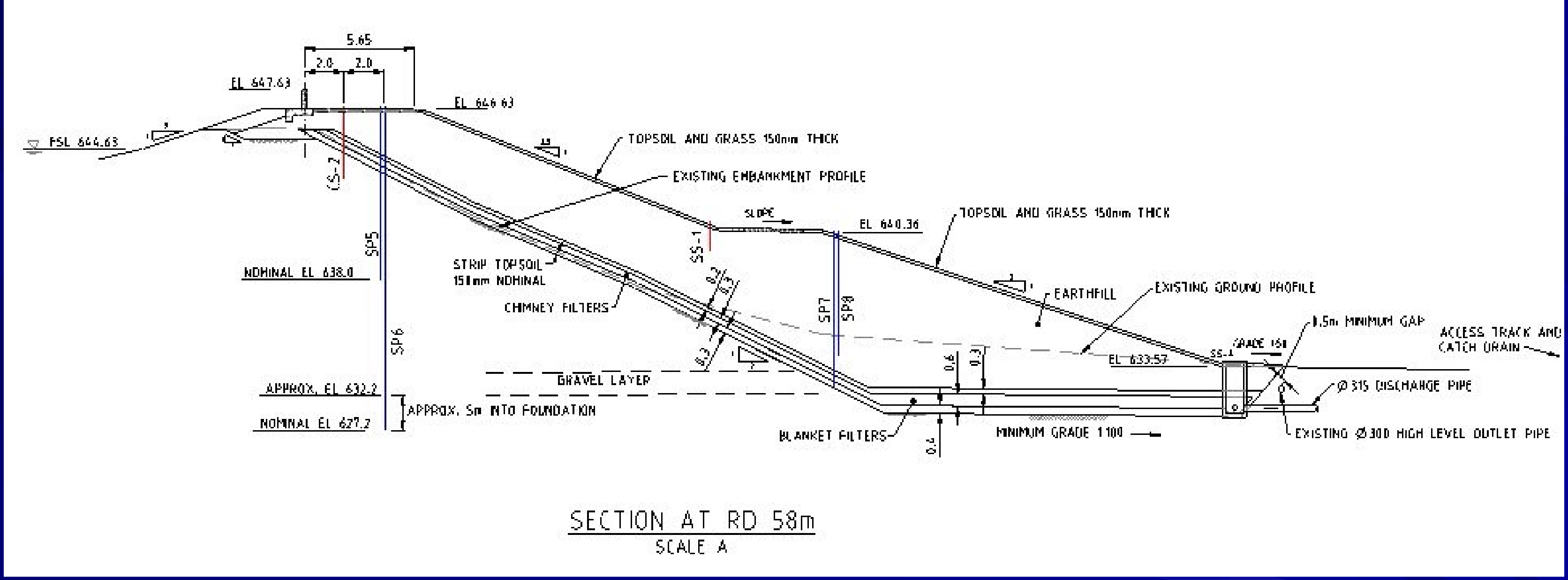
- $H \geq 1.3F$ where:
- F is the percentage of material finer than size D; and
- H = F4D – FD, ie. the percentage of material in the filter between sizes D and 4xD

For a filter to be internally stable, the PSD must plot above the Kenney & Lau percentage bars



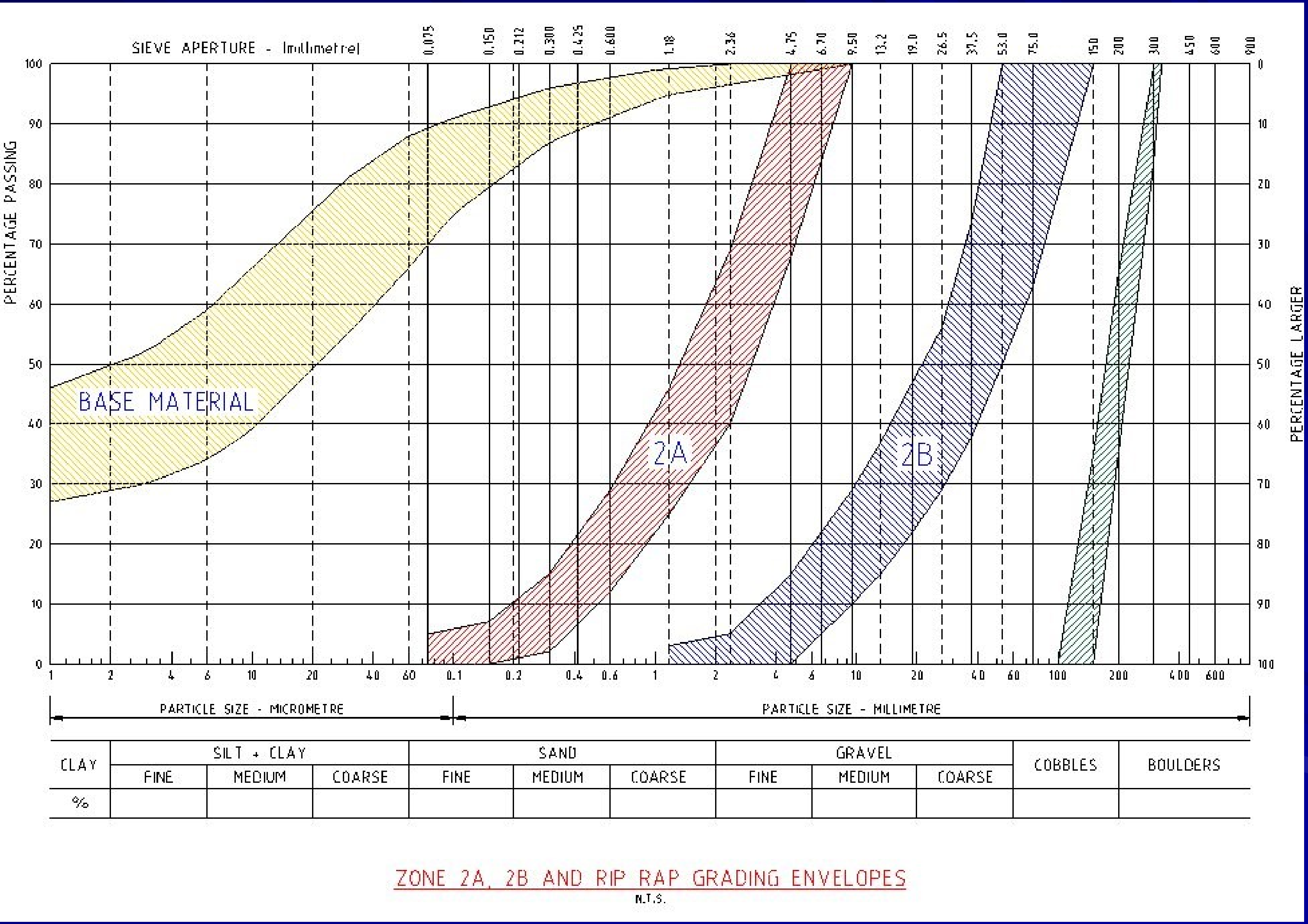
Case Studies

Kerferd Dam - Typical Cross Section



Case Study 1 - Kerferd Dam

Kerferd Dam - Filter Grading Limits



Kerferd Dam

Kerferd Dam

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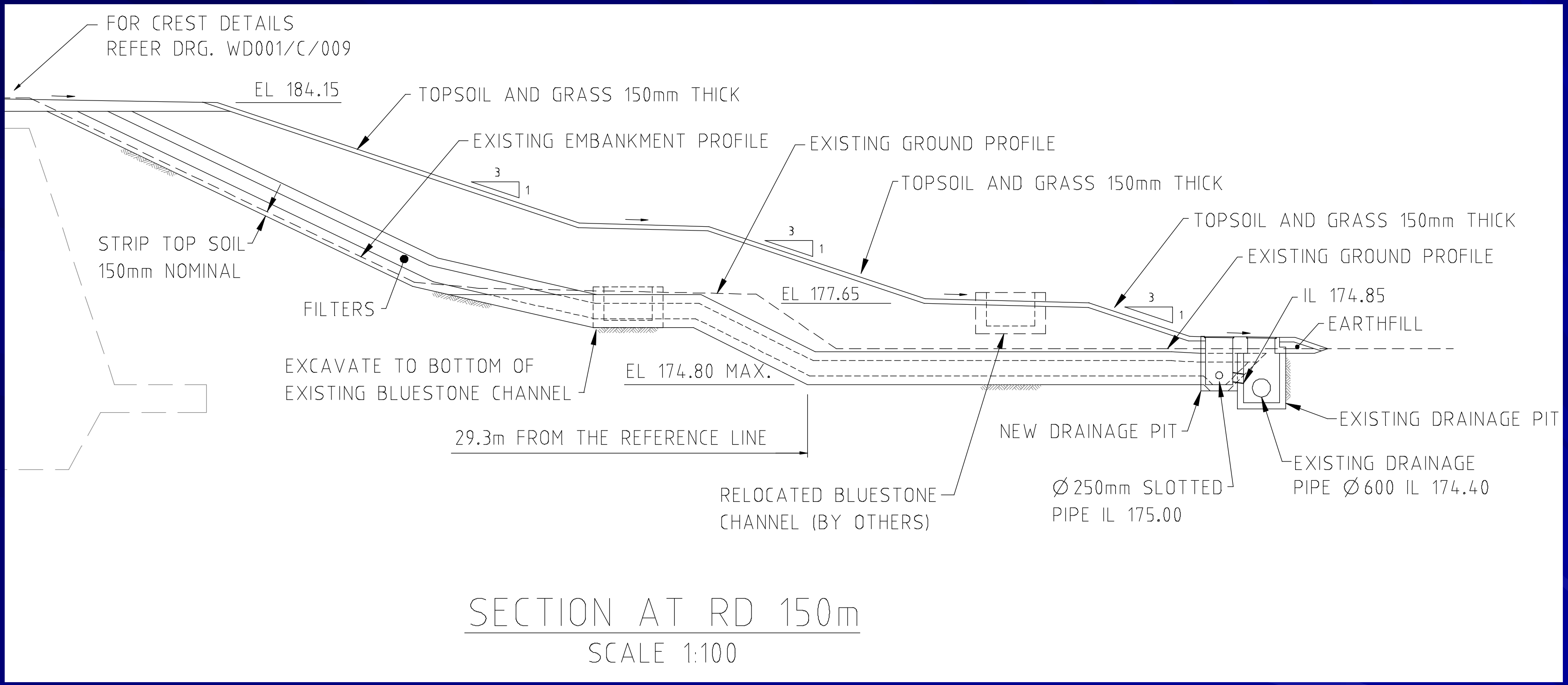
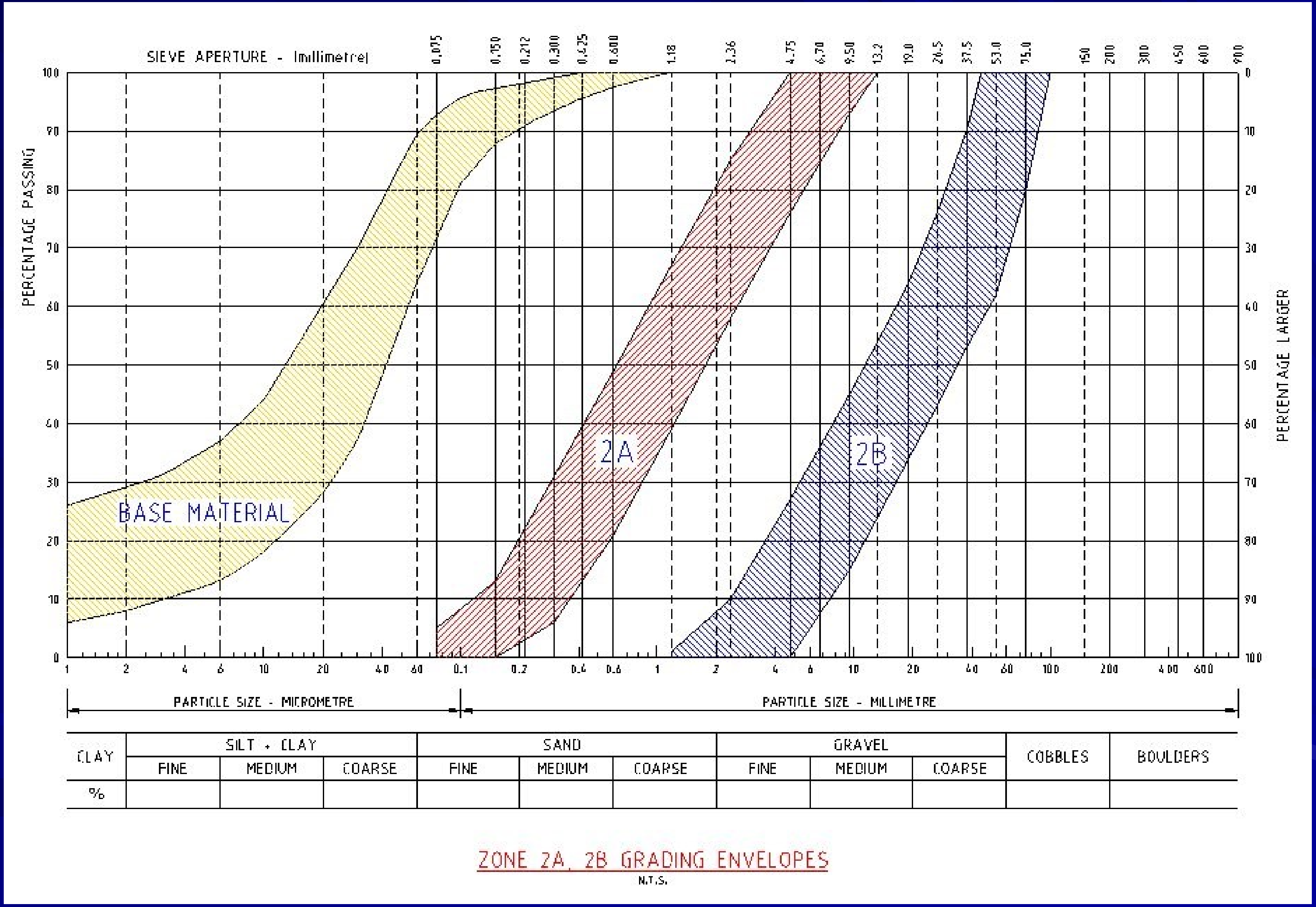
Case Study 2 - Yan Yean Dam

Yan Yean Dam - Typical Cross Section



Yan Yean Dam - Filter Grading Limits



Yan Yean Dam

Yan Yean Dam

Yan Yean Dam

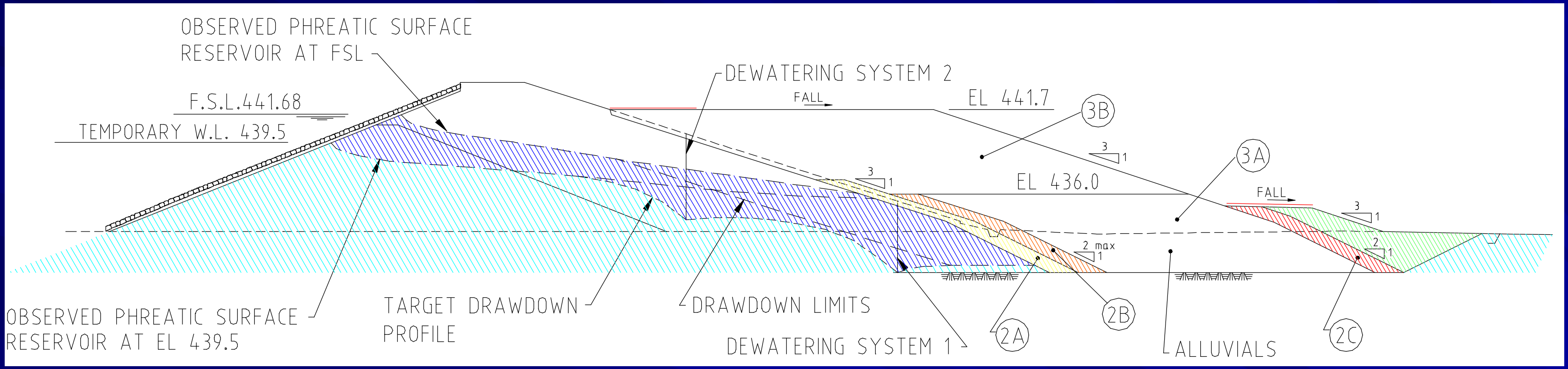
Yan Yean Dam

Yan Yean Dam

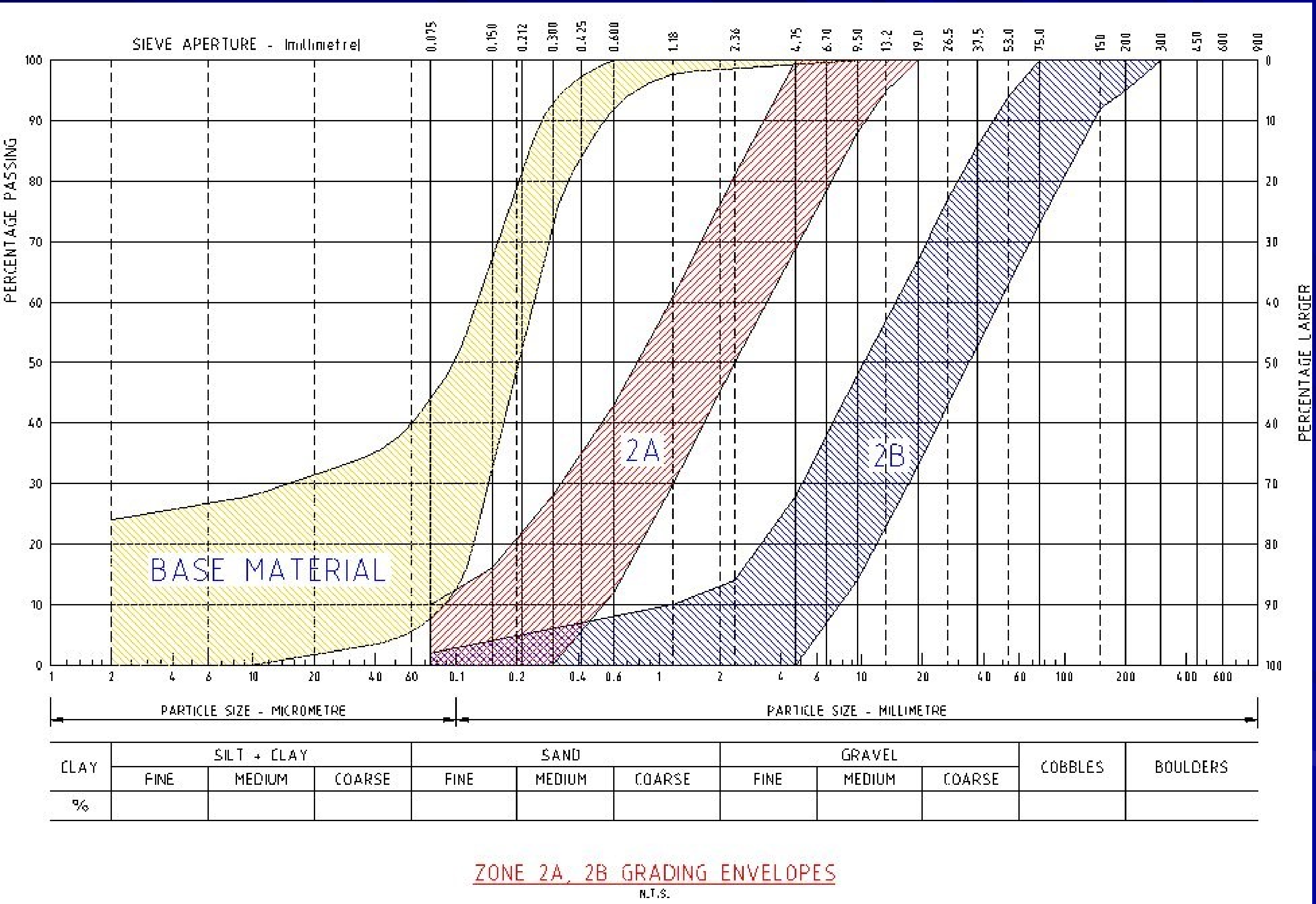
Case Study 3 - Wartook Dam

Wartook Dam

Wartook Dam - Typical Cross Section



Wartook Dam - Filter Grading Limits



Wartook Dam

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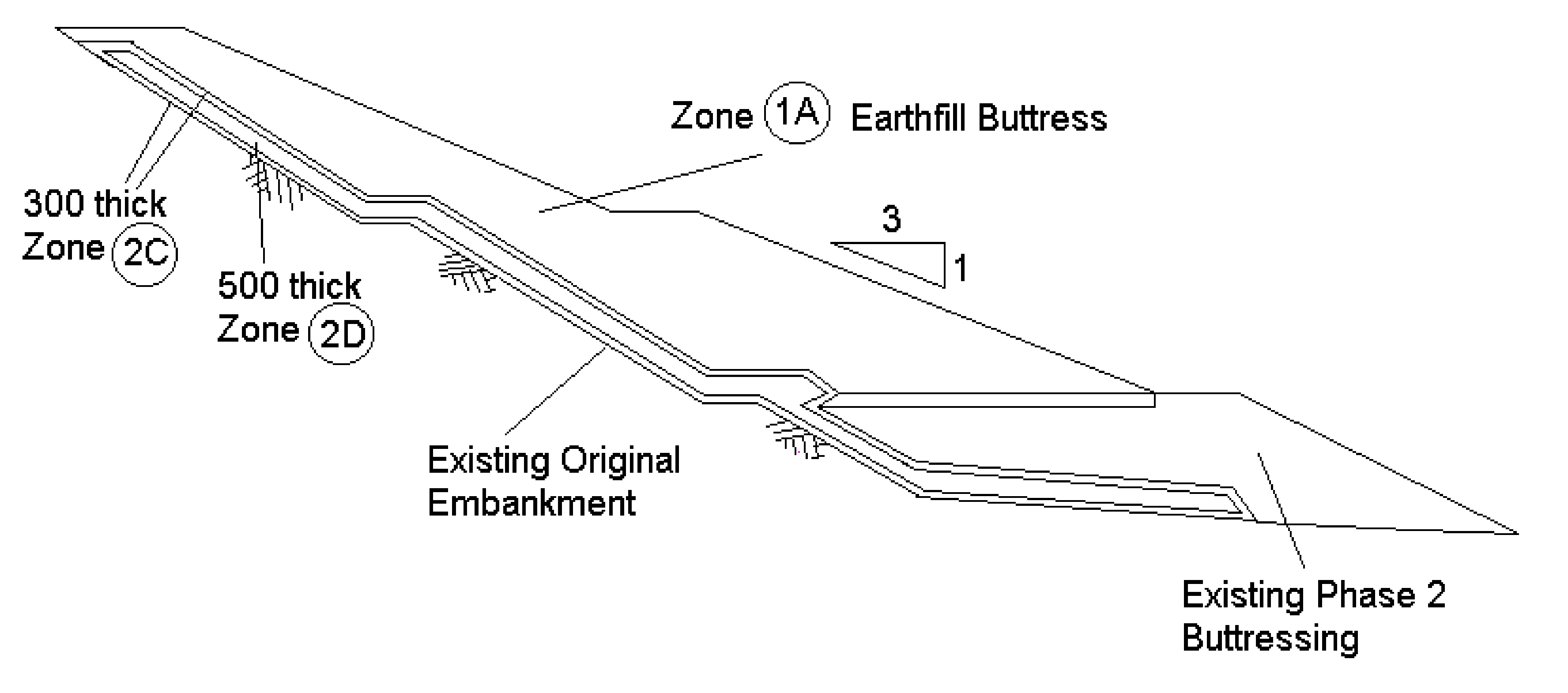
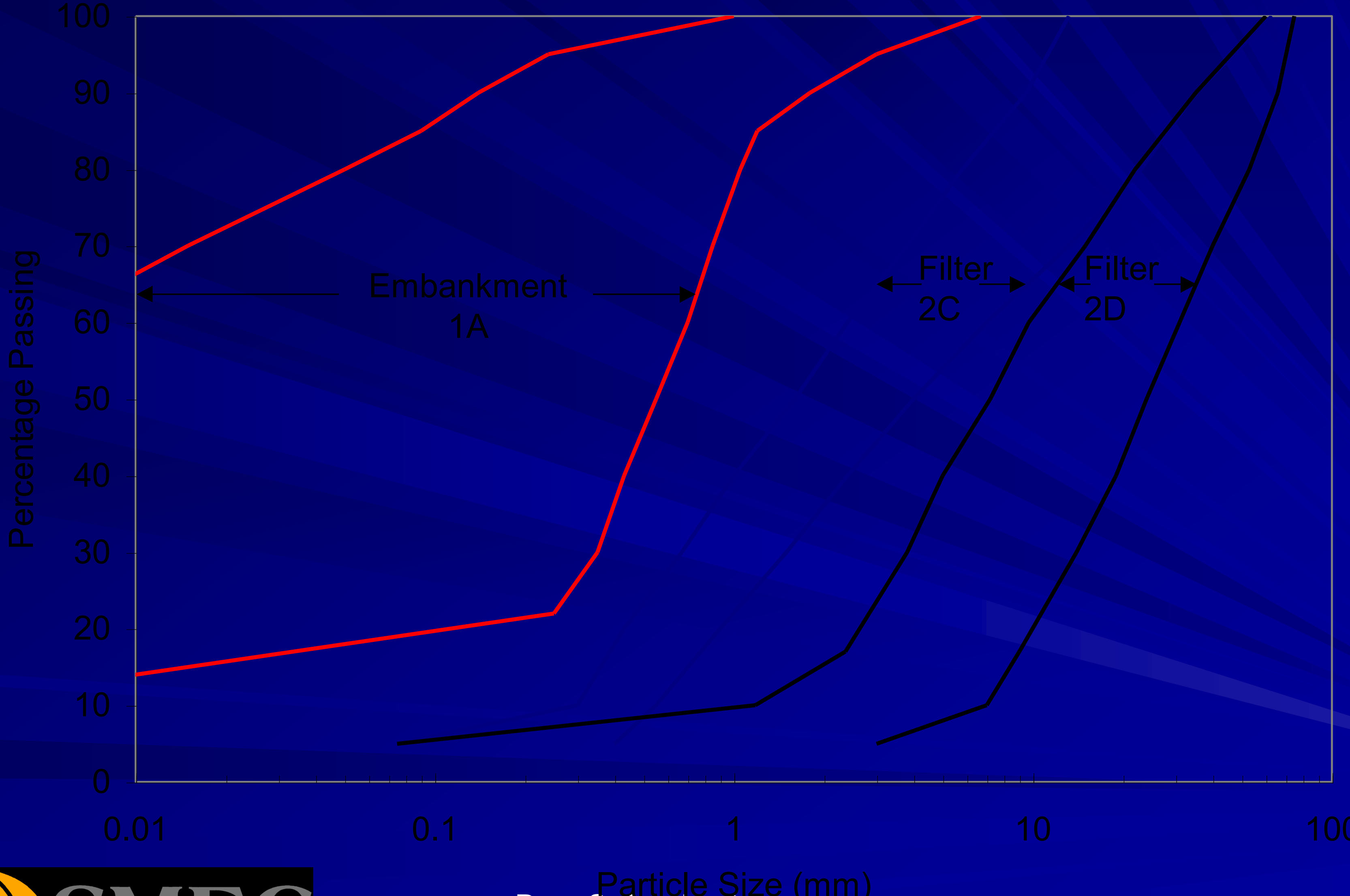
Wartook Dam

Case Study 4 - Hume Dam

Hume Dam - Typical Cross Section



Hume Dam - Filter Grading Limits



Hume Dam

Hume Dam

Hume Dam

Hume Dam

Hume Dam

Hume Dam

Hume Dam

Assessment of Filters in Existing Dams

Sandy Gravel Filter Material

Comparison with Current Design Criteria

Property	*Sandy Gravel Material*	*Required by Design Criteria*
Maximum Size	100-200mm	50mm
D_{40}	0.3-14mm	4.75mm max.
D_{15}	0.02-0.7mm	0.7mm max.
%<0.075mm	5%-21%	5%
C_u	28-650	20 max.

- Filter is too broadly graded
- Potential for wash-out of filter fines and increase in D_{15} size
- Filter after loss of fines may not be able to retain core