SUB-ATTACHMENT G

NRCS FILTER CRITERIA

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Chapter 26 Gradation Design of Sand and Gravel Filters

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633.2600 Purpose

Chapter 26 presents criteria for determining the grain-size distribution (gradation) of sand and gravel filters needed to prevent internal erosion or piping of soil in embankments or foundations of hydraulic structures.

These criteria are based on results of an extensive laboratory filter study carried out by the Soil Conservation Service at the Soil Mechanics Laboratory in Lincoln, Nebraska, from 1980 to 1985. (See Section 633.2605, References, for published reports.)

Refer to section 633.2604 for definitions used in this chapter.

633.2601 Basic purpose of filters and drains

Filters are placed in embankment zones, foundations, or other areas of hydraulic structures for two purposes:

- To intercept water flowing through cracks or openings in a base soil and block the movement of eroding soil particles into the filter. Soil particles are caught at the filter face, reducing the flow of water through cracks or openings and preventing further erosion and enlargement of the cracks or openings.
- To intercept water flowing through the pores of the base soil, allowing passage of the water while preventing movement of base soil particles. Without filters, piping of susceptible base soils can occur when seepage gradients or pressures are high enough to produce erosive discharge velocities in the base soil. The filter zone is generally placed upstream of the discharge point where sufficient confinement prevents uplift or blow-out of the filter.

Drains consist of sand, gravel, or a sand and gravel mixture placed in embankments, foundations, and backfill of hydraulic structures, or in other locations to reduce seepage pressure. A drain's most important design feature is its capacity to collect and carry water to a safe outlet at a low gradient or without pressure build-up. Drains are often used downstream of or in addition to a filter to provide outlet capacity.

Combined filters and drains are commonly used. The filter is designed to function as a filter and as a drain.

633.2602 Permeability and capacity

The laboratory filter study clearly demonstrated that graded filters designed in accordance with these criteria will seal a crack. The sealing begins when water flows through a crack or opening and carries soil particles eroded from the sides of the openings. Eroding soil particles collect on the face of the filter and seal the crack at the interface. Any subsequent flow is through the pores of the soil. If filters are designed to intercept cracks, the permeability required in the filter zone should be based on the steady state seepage flow through the pores of the base soil alone. The hydraulic capacity of any cracks need not be considered in designing the filter because the cracks have been shown to seal.

Where saturated steady-state seepage flow will not develop, for instance in dry dams for flood control having a normal drawdown time of 10 days or less, filter capacity need only be nominal. Filters designed either to protect against steady state seepage or internal erosion through cracks are to be thick enough to compensate for potential segregation and contamination of the filter zones during construction. They must also be thick enough that cracks cannot extend through the filter zone during any possible differential movements.

A zone of coarser materials immediately downstream or below the filter, or both, provides additional capacity to collect and convey seepage to a controlled outlet. In some cases a strip drain is used, and in others a perforated collector pipe is employed to outlet the collected seepage. To prevent movement of the filter materials into the coarse drain materials, the coarse drain materials must be designed for the proper gradation using procedures in this subchapter. Perforations in collector pipes must also be sized properly to prevent movement of the coarse drain materials into the perforations.

633.2603 Determining filter gradation limits

Determine filter gradation limits using the following steps:

Step 1: Plot the gradation curve (grain-size distribution) of the base soil material. Use enough samples to define the range of grain sizes for the base soil or soils. Design the filter using the base soil that requires the smallest D_{15} size for filtering purposes. Base the design for drainage purposes on the base soil that has the largest D_{15} size.

Step 2: Proceed to step 4 if the base soil contains no gravel (material larger than No. 4 sieve).

Step 3: Prepare adjusted gradation curves for base soils that have particles larger than the No. 4 (4.75 mm) sieve.

- Obtain a correction factor by dividing 100 by the percent passing the No. 4 (4.75 mm) sieve.
- Multiply the percentage passing each sieve size of the base soil smaller than No. 4 (4.75 mm) sieve by the correction factor determined above.
- Plot these adjusted percentages to obtain a new gradation curve.
- Use the adjusted curve to determine the percentage passing the No. 200 (0.075 mm) sieve in step 4.

Step 4: Place the base soil in a category determined by the percent passing the No. 200 (0.075 mm) sieve from the regraded gradation curve data according to table 26–1.

Step 5: To satisfy filtration requirements, determine the maximum allowable D_{15} size for the filter in accordance with the table 26–2.

If desired, the maximum D_{15} may be adjusted for certain noncritical uses of filters where significant hydraulic gradients are not predicted, such as bedding beneath riprap and concrete slabs. For fine clay base soil that has d_{85} sizes between 0.03 and 0.1 mm, a maximum D_{15} of $\leq$ 0.5 mm is still conservative. For fine-grained silt that has low sand content, plotting below the "A" line, a maximum D_{15} of 0.3 mm may be used.

Step 6: If permeability is a requirement (see section 633.2602), **determine the minimum allowable D_{15} in accordance with table 26–3.** Note: The permeability requirement is determined from the d_{15} size of the base soil gradation before regrading.

Step 7: The width of the allowable filter design band must be kept relatively narrow to prevent the use of possibly gap-graded filters. Adjust the maximum and minimum D_{15} sizes for the filter band determined in steps 5 and 6 so that the ratio is 5 or less at any given percentage passing of 60 or less. Criteria are summarized in table 26–4.

Table 26–1 Regraded gradation curve data

Base soil category	% finer than No. 200 sieve (0.075 mm) (after regrading, where applicable)	Base soil description
1	> 85	Fine silt and clays
2	40 – 85	Sands, silts, clays, and silty & clayey sands
3	15 – 39	Silty & clayey sands and gravel
4	< 15	Sands and gravel

Table 26–2 Filtering criteria — Maximum D_{15}

Base soil category	Filtering criteria
1	$\leq 9 \times d_{85}$ but not less than 0.2 mm
2	≤ 0.7 mm
3	$\leq \left(\frac{40-A}{40-15}\right)\left[\left(4 \times d_{85}\right) - 0.7\text{mm}\right] + 0.7\text{mm}$ A = % passing #200 sieve after regrading (If 4 x d_{85} is less than 0.7 mm, use 0.7 mm)
4	$\leq 4 \times d_{85}$ of base soil after regrading
4	$\leq 5 \times d_{85}$ (EM 1110-2-1901, App D)

This step is required to avoid the use of gap-graded filters. The use of a broad range of particle sizes to specify a filter gradation could result in allowing the use of gap-graded (skip-graded) materials. These materials have a grain size distribution curve with sharp breaks or other undesirable characteristics. Materials that have a broad range of particle sizes may also be susceptible to segregation during placement. The requirements of step 9 should prevent segregation, but other steps are needed to eliminate the use of any gap-graded filters.

Gap-graded materials generally can be recognized by simply looking at their grain size distribution curve. However, for specification purposes, more precise controls are needed. In designing an acceptable filter band using the preliminary control points obtained in steps 1 through 6, the following additional requirements should be followed to decrease the probability of using a gap-graded filter.

Table 26–3 Permeability criteria

Base soil category	Minimum D_{15}
All categories	$\geq 4 \times d_{15}$ of the base soil before regrading, but not less than 0.1 mm ≥ 3 to $5\ d_{15}$ (EM 1110-2-1901 App D)

Table 26–4 Other filter design criteria

Design element	Criteria
To prevent gap-graded filters	The width of the designed filter band should be such that the ratio of the maximum diameter to the minimum diameter at any given percent passing value ≤ 60% is ≤ 5.
Filter band limits	Coarse and fine limits of a filter band should each have a coefficient of uniformity of 6 or less.

First, calculate the ratio of the maximum D_{15} to the minimum D_{15} sizes determined in steps 5 and 6. If this ratio is greater than 5, adjust the values of these control points so that the ratio of the maximum D_{15} to the minimum D_{15} is no greater than 5. If the ratio is 5 or less, no adjustments are necessary. Label the maximum D_{15} size as Control point 1 and the minimum D_{15} size as Control point 2. Proceed to step 8.

The decision on where to locate the final D_{15} sizes within the range established with previous criteria should be based on one of the following considerations:

1. Locate the design filter band at the maximum D_{15} side of the range if the filter will be required to transmit large quantities of water (serve as a drain as well as a filter). With the maximum D_{15} size as the control point, establish a new minimum D_{15} size by dividing the maximum D_{15} size by 5, and locate a new minimum D_{15} size. Label the maximum D_{15} size Control point 1 and the minimum D_{15} size Control point 2.

2. Locate the band at the minimum D_{15} side of the range if it is probable there are finer base materials than those sampled and filtering is the most important function of the zone. With the minimum D_{15} size as the control point, establish a new maximum D_{15} size by multiplying the minimum D_{15} size by 5, and locate a new maximum D_{15} size. Label the maximum D_{15} size Control point 1 and the minimum D_{15} size Control point 2.

3. The most important consideration may be to locate the maximum and minimum D_{15} sizes, within the acceptable range of sizes determined in steps 5 and 6, so that a standard gradation available from a commercial source or other gradations from a natural source near the site would fall within the limits. Locate a new maximum D_{15} and minimum D_{15} within the permissible range to coincide with the readily available material. Ensure that the ratio of these sizes is 5 or less. Label the maximum D_{15} size Control point 1 and the minimum D_{15} size Control point 2.

Step 8: The designed filter band must not have an extremely broad range of particle sizes to prevent the use of possibly gap-graded filters. Adjust the limits of the design filter band so that the coarse and fine sides have a coefficient of uniformity of 6 or less. The width of the filter band should be such that the ratio of maximum to minimum diameters is less than or equal to 5 for all percent passing values of 60 or less.

Other filter design criteria in step 8

To prevent gap-graded filters—Both sides of the design filter band will have a coefficient of uniformity, defined as:

$$CU = \frac{D_{60}}{D_{10}} \leq 6$$

Initial design filter bands by this step will have CU values of 6. For final design, filter bands may be adjusted to a steeper configuration, with CU values less than 6, if needed. This is acceptable so long as other filter and permeability criteria are satisfied.

Calculate a maximum D_{10} value equal to the maximum D_{15} size divided by 1.2. (This factor of 1.2 is based on the assumption that the slope of the line connecting D_{15} and D_{10} should be on a coefficient of uniformity of about 6.) Calculate the maximum permissible D_{60} size by multiplying the maximum D_{10} value by 6. Label this Control point 3.

Determine the minimum allowable D_{60} size for the fine side of the band by dividing the determined maximum D_{60} size by 5. Label this Control point 4.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5. Label as Control points 5 and 6, respectively.

Table 26–5 Maximum and minimum particle size criteria*

Base soil category	Maximum D_{100}	Minimum D_5, mm
All categories	≤ 3 inches (75 mm)	0.075 mm (No. 200 sieve)

* The minus No. 40 (.425 mm) material for all filters must be nonplastic as determined in accordance with ASTM D4318.

Step 10: To minimize segregation during construction, the relationship between the maximum D_{90} and the minimum D_{10} of the filter is important. Calculate a preliminary minimum D_{10} size by dividing the minimum D_{15} size by 1.2. (This factor of 1.2 is based on the assumption that the slope of the line connecting D_{15} and D_{10} should be on a coefficient of uniformity of about 6.) Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Sand filters that have a D_{90} less than about 20 mm generally do not require special adjustments for the broadness of the filter band. For coarser filters and gravel zones that serve both as filters and drains, the ratio of D_{90}/D_{10} should decrease rapidly with increasing D_{10} sizes.

Step 11: Connect Control points 4, 2, and 5 to form a partial design for the fine side of the filter band. Connect Control points 6, 7, 3, and 1 to form a design for the coarse side of the filter band. This results in a preliminary design for a filter band. Complete the design by extrapolating the coarse and fine curves to the 100 percent finer value. For purposes of writing specifications, select appropriate sieves and corresponding percent finer values that best reconstruct the design band and tabulate the values.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than shown in table 26–7. For critical structure drains where rapid gradient reversal (surging) is probable, it is recommended that the D_{15} size of the material surrounding the pipe be no smaller than the perforation size.

Additional design considerations: Note that these steps provide a filter band design that is as well graded as possible and still meets criteria. This generally provides the most desirable filter characteristics. However, in some cases a more poorly graded filter band may be preferable; for example, if more readily available standard gradations are needed or where onsite filters are used for economy.

The design filter band obtained in steps 1 through 12 may be adjusted to a steeper configuration in such cases. The width of the filter band should be maintained so that the ratio of the maximum diameters to the minimum diameters at a given percent finer is no greater than 5 below the 60 percent finer value.

Only the portion of the design filter band above the previously established minimum and maximum D_{15} sizes should be adjusted. The design band may be adjusted so that the coefficients of uniformity of both the coarse and fine sides of the design band are less than 6, but not less than 2, to prevent use of very poorly graded filters.

Table 26–6 Segregation criteria

Base soil category	If D_{10} is :	Then maximum D_{90} is:
	(mm)	(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

Table 26–7 Criteria for filters used adjacent to perforated collector pipe

Noncritical drains where surging or gradient reversal is not anticipated	The filter D_{85} must be greater than or equal to the perforation size
Critical drains where surging or gradient reversal is anticipated	The filter D_{15} must be greater than or equal to the perforation size.

Note that the requirements for coefficient of uniformity apply only to the coarse and fine limits of the design filter band. It is possible that an individual, acceptable filter whose gradation plots completely within the specified limits could have a coefficient of uniformity greater than 6 and still be perfectly acceptable. The design steps of this procedure will prevent acceptance of gap-graded filters, which is the main concern associated with filters having a high coefficient of uniformity, and it is not necessary to closely examine the coefficient of uniformity of a particular filter as long as it plots within the design filter band.

Illustrations of these filter design steps are in the following examples. The steps in the filter design process are summarized in appendix 26A. The summary is useful to follow as the example problems are reviewed.