Gradation Design of Sand and Gravel Filters used in Embankments and Hydraulic Structures

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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

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

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.

Example 26–1 Fine clay base soil—Category 1

Given: The most important function of the filter being designed is to act as a filter.

Step 1: Plot the gradation curve of the base soil material.

Refer to figure 26–1 for the plotted grain size distribution curve for this example clay base soil, labeled Base soil. The plotted curve is from the following data:

Sieve size	% passing
No 10	100
No. 200	90
0.05 mm	80
0.02 mm	60
0.005 mm	40
0.002 mm	32

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

The example base soil has 100 percent finer than the No. 4 sieve, and the grain size distribution curve does not need to be regraded. Proceed to step 4.

Step 3: Not applicable because the base soil contains no particles larger than the No. 4 sieve

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.

The example soil has 90 percent finer than the No. 200 sieve. From table 26–1, the soil is in category 1.

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

The filtering criteria for base soil category 1 is (table 26–2): The maximum D_{15} of the filter will be less than or equal to 9 times the d_{85} of the base soil, but not less than 0.2 mm.

The d_{85} size of the base soil is 0.06 mm. Thus, the maximum D_{15} of the filter is

$$\leq 9 \times 0.06 = 0.54 \text{ mm (not} < 0.2 \text{ mm)}$$

This is labeled as Maximum D_{15} in figure 26–1.

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

The permeability criterion for all categories of base soils is that the filter will have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but will not be less than 0.1 mm in any case.

The example 26–1 base soil does not have a meaningful d_{15} size. The data show that the base soil has 32 percent finer than 0.002 mm, the smallest commonly determined particle size. Therefore, use the default value of 0.1 mm for the minimum D_{15} of the filter. This value is the preliminary value for minimum D_{15}. Proceed to step 7 for any needed adjustments.

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 previous steps 5 and 6 so that the ratio is 5 or less, at any given percent passing of 60 or less. Adjustments may be required based on the following considerations.

For example 26–1, the ratio of the maximum D_{15} to the minimum D_{15} sizes is equal to 0.54 / 0.1 = 5.4. Because the value is slightly greater than 5, a slight adjustment is needed in this step. The minimum D_{15} is the control because filtering is stated as the most important purpose. Label this as Control point 2. Determine an adjusted maximum D_{15} size for the final design filter band as equal to the minimum D_{15} size, 0.10 x 5 = 0.50 mm. This is the final Control point 1 labeled in figure 26–1. Go to step 8.

Step 8: The designed filter band must not have an extremely broad range of particle sizes to prevent using possibly gap-graded filters. Adjust the limits of the design filter band so that coarse and fine sides of the filter band have a coefficient of uniformity of 6 or less. 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.

For example 26–1, calculate a value for maximum D_{10} by dividing the maximum D_{15} size of 0.5 mm (determined in step 7) by 1.2 = 0.42 mm. Determine the value for the maximum D_{60} size by multiplying the value of D_{10} by 6 = 0.42 x 6 = 2.5 mm. Label this as 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:

$$\frac{D_{60}}{5} = \frac{2.5}{5} = 0.50$$

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.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–1.

It also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–1.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Calculate the minimum D_{10} size of the preliminary filter band as equal to the minimum D_{15} value of 0.1 mm (obtained in step 6) divided by 1.2:

$$0.10 / 1.2 = 0.083 \text{ mm}$$

Table 26–6 lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Because the D_{10} value is less than 0.5 mm, the maximum D_{90} size is 20 mm. Label this value as Control point 7 in figure 26–1.

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 partial design for the coarse side of the filter band.

Complete the design of the filter band 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.

Refer to figure 26–1 for an illustration of the complete filter design. Note that adjustments have been made in straight line portions of the design band to intercept even values for percent passing at standard sieve sizes and to prevent the use of very broadly graded filters. The final design specified gradation is shown in table 26–8.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

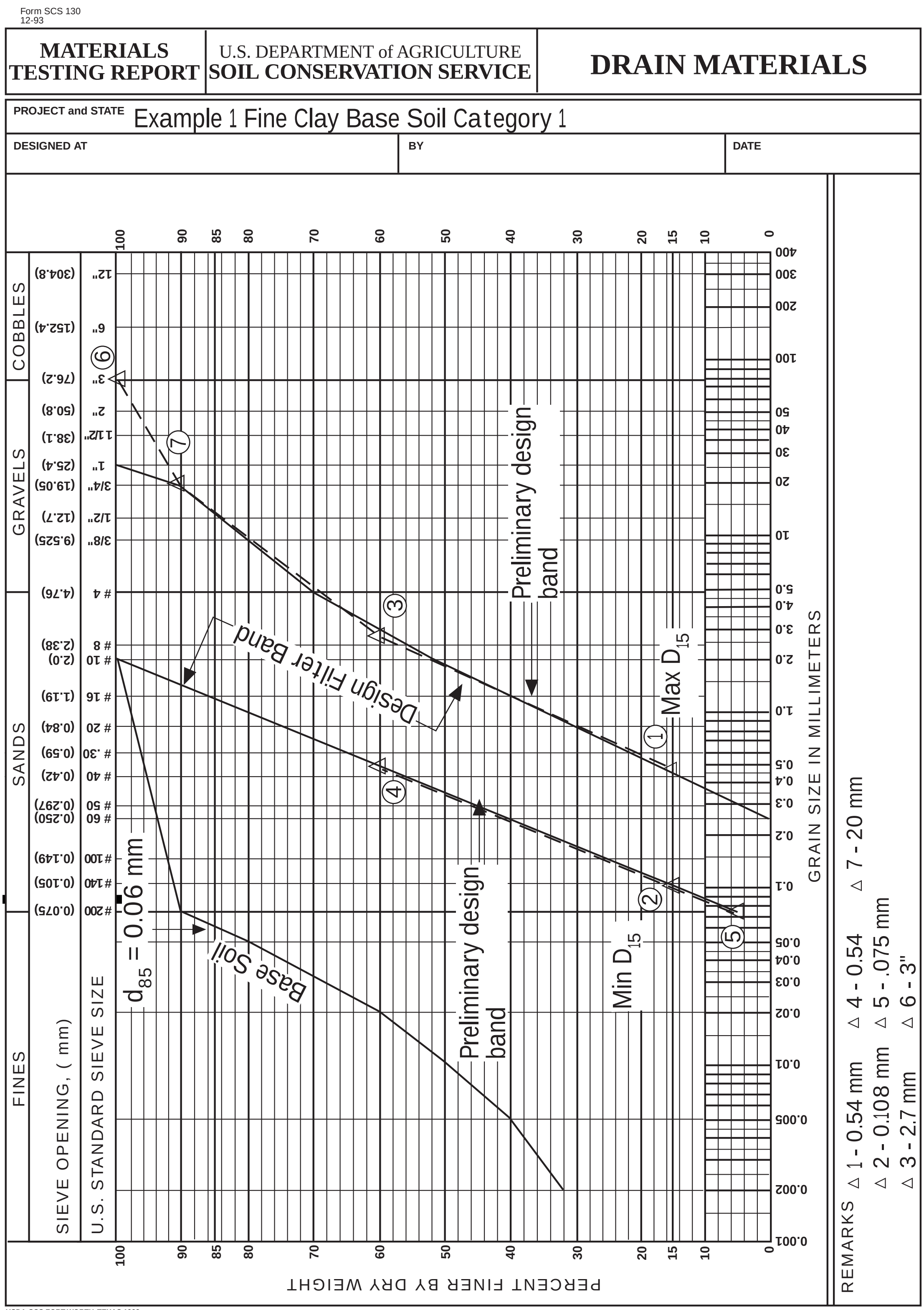
For this example, the filter will not be used around a perforated collector pipe, so step 12 is not applicable.

Additional design considerations: For this example, ASTM C-33 concrete sand falls well within the design band. Because this is a fairly standard, readily available gradation, no adjustments in the design band appear warranted. Selected ASTM Aggregate Specifications are given in appendix 26B.

Table 26–8 Design specification gradation for example 26–1 soil

Sieve size	% passing
1 inch	100
3/4 inch	90–100
No. 4	70–100
No. 10	52–100
No. 20	30–75
No. 60	0–40
No. 140	0–15
No. 200	0–5

Figure 26–1 Grain size distribution curve for fine clay base soil



Example 26–2 Silty sand with gravel base soil—Category 3

Given: The most important function of the filter being designed in this example is to act as a drain.

Step 1: Plot the gradation curve of the base soil material.

Refer to figure 26–2 for the plotted grain size distribution curve for this example silty sand with gravel base soil. The plotted curve is from the following data:

Sieve size	% passing
3 inch	100
1 inch	90
3/8 inch	82
No 4	78
No. 10	72
No. 20	66
No. 40	54
No. 100	32
No. 200	20
0.005 mm	4
0.002 mm	2

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

The example 26–2 base soil has particles larger than the No. 4 sieve, so the grain size distribution curve should be regraded on the No. 4 sieve. Proceed to step 3:

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

Determine the regrading factor by dividing the value 100 by the percent passing the No. 4 (4.75 mm) sieve size. The regrading factor is:

$$\frac{100\%}{78\%} = 1.28$$

Using the original gradation analysis, plot a regraded curve for 100 percent passing the No. 4 (4.75 mm) sieve. The regraded percent passing values are equal to the original percent passing values times the regrading factor.

Sieve size	Original % passing	Regraded % passing
3 inch	100	—
1 inch	90	—
3/8 inch	82	—
No 4	78	100
No. 10	72	92
No. 20	66	85
No. 40	54	69
No. 100	32	41
No. 200	20	26
0.005 mm	4	5
0.002 mm	2	3

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.

The example soil after regrading has 26 percent finer than the No. 200 sieve. From table 26–1, the soil is in category 3.

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

The filtering criteria for base soil category 3 is (table 26–2): The maximum D_{15} of the filter will be less than or equal that given by the following expression:

$$D_{15} \leq \left[\frac{(40 - A)}{(40 - 15)}\right]\left[(4)(d_{85}) - 0.7\text{ mm}\right] + 0.7\text{ mm}$$

Determine from the gradation curve of the regraded base soil that the d_{85} size is 0.84 mm. From the regraded curve, the value of A is 26 percent. Then the maximum D_{15} of the filter by the equation above is:

$$D_{15} \le \left[\frac{(40-26)}{(40-15)}\right]\left[(4)(0.84) - 0.7\text{ mm}\right] + 0.7\text{ mm}$$
$$\le 2.2\text{ mm}$$

This is labeled as Maximum D_{15} in figure 26–2.

Step 6: If permeability is a requirement (section 633.2603), determine the minimum allowable D_{15} according to table 26–3. Note: The permeability requirement is determined from the d_{15} size of the base soil gradation before regrading.

The permeability criterion for all categories of base soils is that the filter have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but not be less than 0.1 mm in any case.

The example 26–2 base soil has a d_{15} size of 0.032 before regrading. The minimum D_{15} of the filter is 4 x 0.032 = 0.128 (acceptable because it is larger than 0.1 mm). Label this value as Minimum D_{15} in figure 26–2.

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 previous steps 5 and 6 so that the ratio is 5 or less at any given percent passing of 60 or less. Adjustments may be required based on the following considerations:

Determine the ratio of the maximum D_{15} size to the minimum D_{15} sizes determined in previous steps. This ratio is:

$$\frac{2.2\text{ mm}}{0.13\text{ mm}} = 16.9$$

Because this ratio exceeds the criterion ratio of 5, adjustments are required in the values.

It was given that the most important function of the filter is to serve as a drain, so the maximum D_{15} is selected as the control point, equal to 2.2 mm. Label this value as Control point 1. To satisfy criteria, determine that the minimum D_{15} value is 1/5 of this value.

The minimum D_{15} value is then:

$$\frac{2.2\text{ mm}}{5} = 0.44\text{ mm}$$

Label this as Control point 2 in figure 26–2.

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 of the filter band 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.

The value for maximum D_{10} is calculated to be the maximum D_{15} size determine in step 7, divided by 1.2:

$$\frac{D_{15}}{1.2} = \frac{2.2}{1.2} = 1.83\text{ mm}$$

Calculate a value for the maximum D_{60}. The maximum D_{10} size times 6 is 1.83 x 6 = 11 mm. Label the maximum D_{60} size as Control point 3.

The minimum allowable D_{60} size is equal to the maximum D_{60} size divided by 5.

$$\frac{11}{5} = 2.2\text{ mm}$$

Label this as Control point 4 in figure 26–2.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26.5.

This table requires filters to have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–2.

It also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–2.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Determine that the minimum D_{10} size is equal to the minimum D_{15} size (determined in step 7) of 0.44 divided by 1.2:

$$\frac{0.44}{1.2} = 0.37 \text{ mm}$$

Because the value of minimum D_{10} size is less than 0.5 mm, the maximum D_{90} size is 20 mm (table 26–6). Label this value as Control point 7 in figure 26–4.

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.

Complete the design of the filter band 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.

Refer to figure 26–2 for the completed filter band design. Table 26–9 gives the final design specified gradation. Note that all the control points are considered and that sieve sizes and corresponding percent finer values are selected to best fit the design band.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

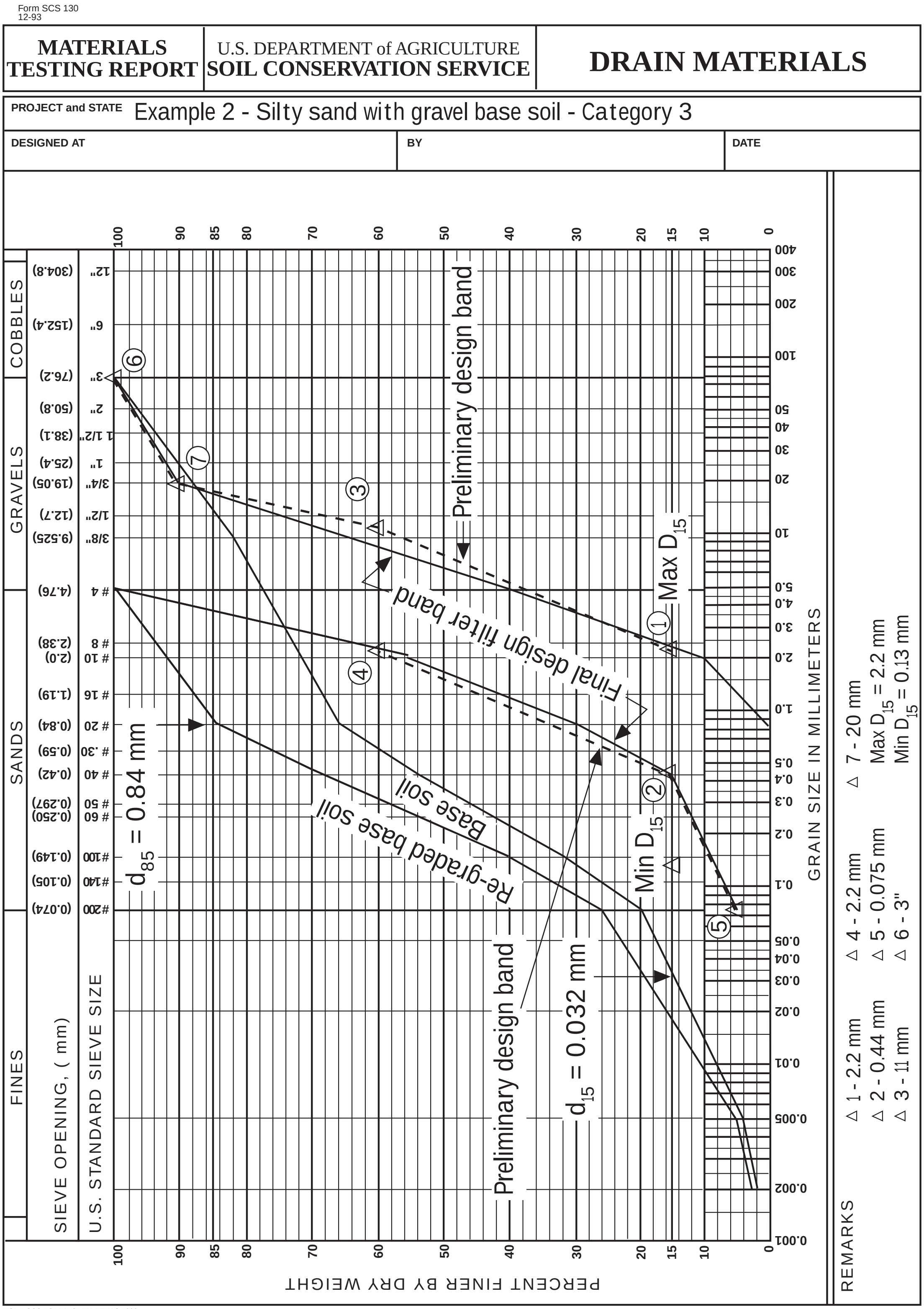
It is not given that this filter is to be used around a collector pipe, so this criterion is not applicable.

Additional design considerations: The design filter band does not coincide with standard, readily available aggregate gradations. Probably, a blend of standard aggregate gradations would be required to meet this design. Adjustments to the filter according to this step would not improve the availability. See following examples where this adjustment would be applicable. Using the design filter band, prepare the following tabular listing of the design.

Table 26–9 Design specification gradation for example 26–2 soil

Sieve size	% passing
3 inch	100
3/4 inch	90–100
1/2 inch	75–100
No. 4	40–100
No. 10	10–55
No. 20	0–30
No. 40	0–15
No. 100	0–9
No. 200	0–5

Figure 26–2 Grain size distribution curve for silty sand with gravel base soil—Category 3



Example 26–2A Silty sand with gravel base soil—Category 3

This example uses the same base soil as that in example 26–2. It is assumed that the most important function of the filter being designed is to act as a filter. Example 26–2 assumed the most important function was to act as a drain. Note the differences in the design steps.

Step 1: Plot the gradation curve of the base soil material. This step is the same as that in example 26–2. Refer to figure 26–2A for the plotted grain size distribution curve for this example silty sand with gravel base soil.

Step 2: Proceed to step 4 if the base soil contains no gravel (material larger than the No. 4 sieve). Because the example 26–2 base soil has particles larger than the No. 4 sieve, the grain size distribution curve should be regraded on the No. 4 sieve. Proceed to step 3.

Step 3: Prepare adjusted gradation curves for base soils with particles larger than the No. 4 (4.75 mm) sieve. This step is the same as that for example 26–2. Refer to that example and see figure 26–2A.

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. This step is the same as that for example 26–2. The soil is in category 3.

Step 5: To satisfy filtration requirements, determine the maximum allowable D_{15} size for the filter according to table 26–2. This step is the same as that for example 26–2. The maximum D_{15} size is 2.2 mm. This is labeled as Maximum D_{15} in figure 26–2A.

Step 6: If permeability is a requirement (section 633.2603), determine the minimum allowable D_{15} according to table 26–3. Note: The permeability requirement is determined from the d_{15} size of the base soil gradation before regrading.

The example 26–2A base soil has a d_{15} size of 0.032 mm before regrading. The value of minimum D_{15} of the filter is 4 x 0.032 = 0.128 mm (acceptable because it is larger than 0.1 mm). Label this value as Minimum D_{15} in figure 26–2A.

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 percent passing of 60 or less. Adjustments may be required based on the following considerations.

Determine the ratio of the maximum D_{15} size to the minimum D_{15} sizes determined in previous steps:

$$\frac{2.2\text{ mm}}{0.13\text{ mm}} = 16.9$$

Because this ratio exceeds the criterion ratio of 5, adjustments are required in the values.

The most important function of the filter is to serve as a filter, so the minimum D_{15} is selected as the control point, equal to 0.13 mm. Label this Control point 2. To satisfy criteria, determine that the maximum D_{15} value is 5 times this value. The maximum D_{15} value is:

$$0.13 \times 5 = 0.65\text{ mm}$$

Label this as Control point 1 in figure 26–2A.

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 of the filter band 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.

A value for maximum D_{10} is calculated by dividing the maximum D_{15} size (determine in step 7) by 1.2.

$$\frac{0.65}{1.2} = 0.54\text{ mm}$$

Calculate a value for the maximum D60 by multiplying the maximum D_{10} size times 6:

$$0.54 \times 6 = 3.24\text{ mm}$$

Label the maximum D_{60} size as Control point 3.

The minimum allowable D_{60} size is equal to the maximum D_{60} size divided by 5:

$$\frac{3.24}{5} = 0.65 \text{ mm}$$

Label this as Control point 4 in figure 26–2A.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–2A.

It also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–2A.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

This table lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Calculate the minimum D_{10} size as equal to the minimum D_{15} size (determined in step 7) of 0.13 mm divided by 1.2:

$$\frac{0.13}{1.2} = 0.11 \text{ mm}$$

Because the value is less than 0.5 mm, the maximum D_{90} size is 20 mm (table 26–6). Label this value as Control point 7 in figure 26–2A.

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.

Complete the design of the filter band 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.

Refer to figure 26–2A for the completed filter band design. The design is also tabulated in table 26–10.

Note that the control points are considered and that relatively even percent finer values are selected for standard sieve sizes for ease in writing specifications.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

It is not given that this filter is to be used around a collector pipe, so this criterion is not applicable.

Additional design considerations: The design filter band coincides fairly well with a standard, readily available aggregate gradation, ASTM C-33 fine aggregate for concrete. However, a slight adjustment in the filter design would make it more compatible with this standard gradation. The filter band can be adjusted to a more poorly graded configuration, a CU value of less than 6. Note that this is accomplished without violating other filtering or permeability criteria. Figure 26–2B shows how the original filter band design shown in figure 26–2A could be slightly altered to a steeper sloping band for the filter limits without violating any of the criteria previously covered.

The final filter design specification limits selected for example 26–2A, before and after possible adjustment, are shown in table 26–10.

Table 26–10 Design specification gradation for example 26–2A soil

Sieve size	Fig. 26–2A before adjustment (% passing)	Fig. 26–2B after adjustment (% passing)
3 inch	100	
3/4 inch	90–100	
1/2 inch	85–100	100
No. 4	70–100	80–100
No. 10	45–100	60–100
No. 20	20–65	20–100
No. 40	0–45	0–60
No. 60	0–30	0–35
No. 100	0–17	0–17
No. 200	0–5	0–5

Figure 26–2A Grain size distribution curve for silty sand with gravel base soil where primary function is filter

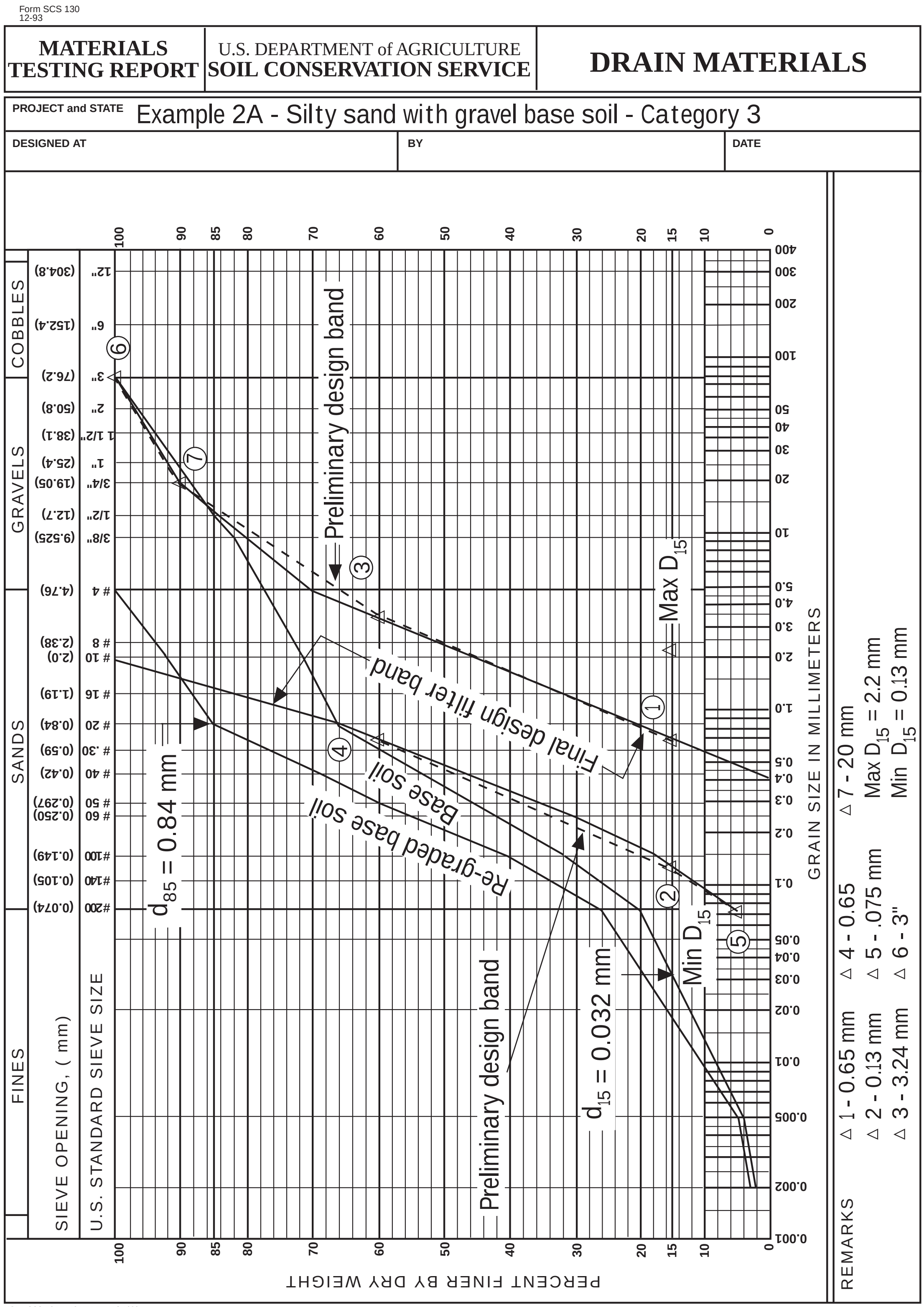
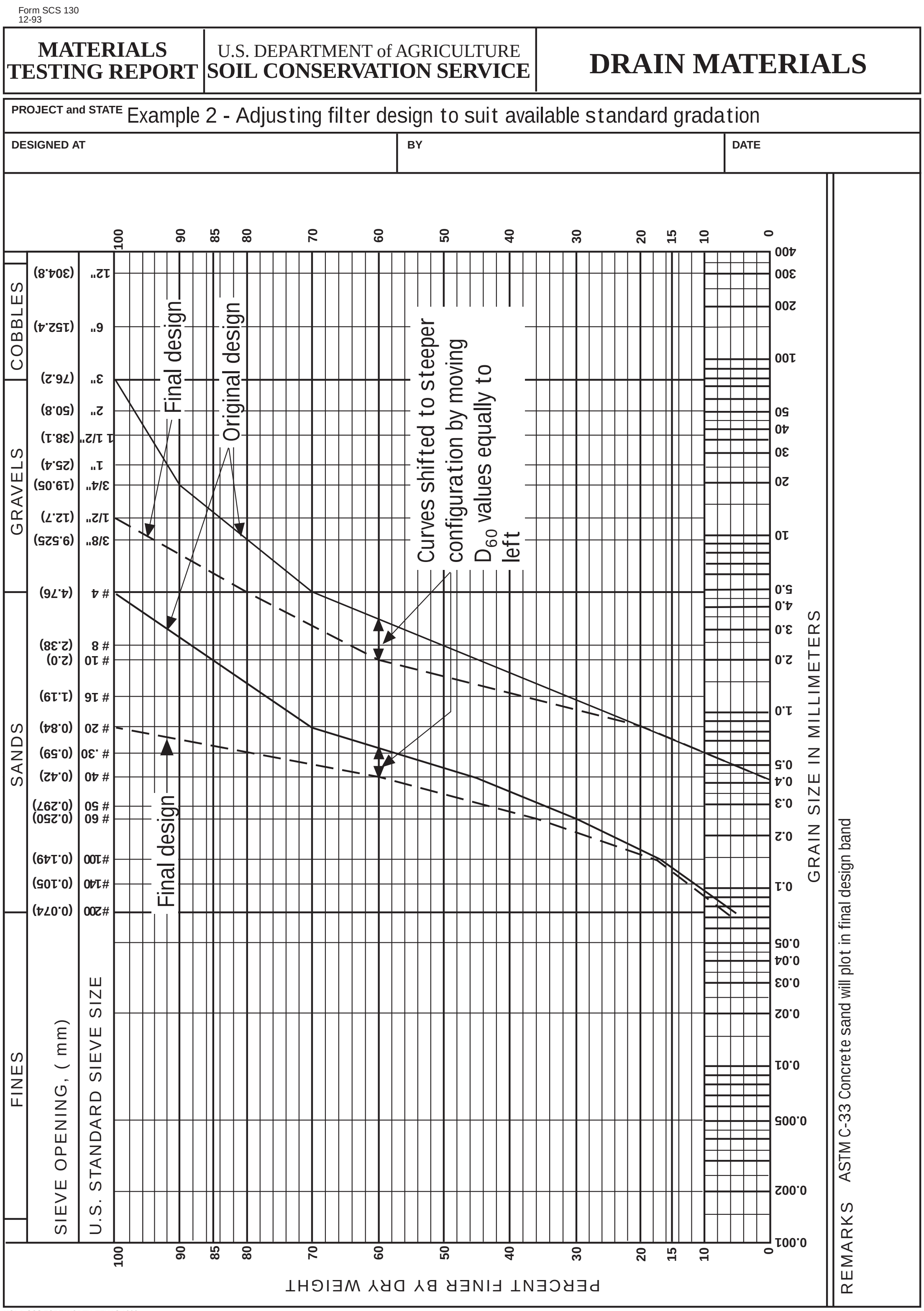


Figure 26–2B Grain size distribution curve for silty sand with gravel base soil (adjusting limits)



Example 26–3 Clayey gravel base soil—Category 2

Given: The most important function of the filter being designed is to act as a filter.

Step 1: Plot the gradation curve of the base soil material.

Refer to figure 26–3 for the plotted grain size distribution curve for this example clayey gravel base soil, labeled Base soil. The plotted curve is from the following data:

Sieve size	% passing
3 inch	100
1 inch	73
3/4 inch	66
1/2 inch	59
No. 4	47
No. 40	34
No. 60	31
No. 200	28
0.05 mm	26
0.02 mm	25
0.005 mm	18
0.002 mm	13

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

Because the example 26–3 base soil has particles larger than the No. 4 sieve, the grain size distribution curve should be regraded on the No. 4 sieve. Proceed to step 3.

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

Determine the regrading factor by dividing the value 100 by the percent passing the No. 4 (4.75 mm) sieve size. The regrading factor is

$$\frac{100\%}{47\%} = 2.13$$

Using the original gradation analysis, plot a regraded curve for 100 percent passing the No. 4 (4.75 mm) sieve. The regraded percent passing values are equal to the original percent passing values times the regrading factor.

Sieve size	Original % passing	Regraded % passing
3 inch	100	—
1 inch	73	—
3/4 inch	66	—
1/2 inch	59	—
No. 4	47	100
No. 40	34	72
No. 60	31	66
No. 200	28	60
0.05 mm	26	55
0.02 mm	25	53
0.005 mm	18	38
0.002 mm	13	28

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.

The example 26–3 base soil after regrading has 60 percent finer than the No. 200 sieve. From table 26–1, the soil is in category 2.

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

This table shows the filtering criteria for base soil category 2 as follows. The maximum D_{15} of the filter will be less than or equal to 0.7 mm. This is labeled as Maximum D_{15} in figure 26–3.

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

The permeability criterion for all categories of base soils is that the filter have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but will not be less than 0.1 mm in any case.

The example 26–3 base soil has a d_{15} size of about 0.0028 mm before regrading. Using the criterion, the minimum D_{15} of the filter would be 4 x 0.0028 = 0.011 mm. However, table 26–3 also shows that the minimum D_{15} is 0.1 mm. Label this value as minimum D_{15} in figure 26–3.

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 percent passing of 60 or less. Adjustments may be required based on the following considerations:

Determine the ratio of the maximum D_{15} to the minimum D_{15} sizes:

$$\frac{0.7\text{ mm}}{0.1\text{ mm}} = 7$$

Because this value exceeds the criterion of 5, adjustment in the values is required. The most important function of this design filter is to act as a filter, so the minimum D_{15} value becomes controlling and is unchanged. Label this value Control point 2 in figure 26–3. Then, the maximum D_{15} value is 5 times this, or 5 x 0.1 mm = 0.5 mm. Label this as Control point 1 in figure 26–3.

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 of the filter band 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

Calculate a value for the maximum D_{10} size as equal to the maximum D_{15} size determined in Step 7 divided by 1.2:

$$\frac{0.5}{1.2} = 0.42\text{ mm}$$

The value for the maximum D_{60} is calculated using the maximum D_{10} size times 6:

$$0.42 \times 6 = 2.52\text{ mm}$$

Label the maximum D_{60} size as Control point 3.

The minimum allowable D_{60} size is then:

$$\frac{D_{60}}{5} = \frac{2.52}{5} = 0.50\text{ mm}$$

Label this as Control point 4 in figure 26–3.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–3.

Table 26–5 also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–3.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Table 26–6 lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Calculate a value for minimum D_{10} size by dividing the minimum D_{15} size determined in Step 7 by 1.2:

$$\frac{0.1}{1.2} = 0.083\text{ mm}$$

Because the value is less than 0.5 mm, the maximum D_{90} size is 20 mm (table 26–6). Label this value as Control point 7 in figure 26–3.

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. Complete the design of the filter band 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.

See figure 26–3 for the final filter band design.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

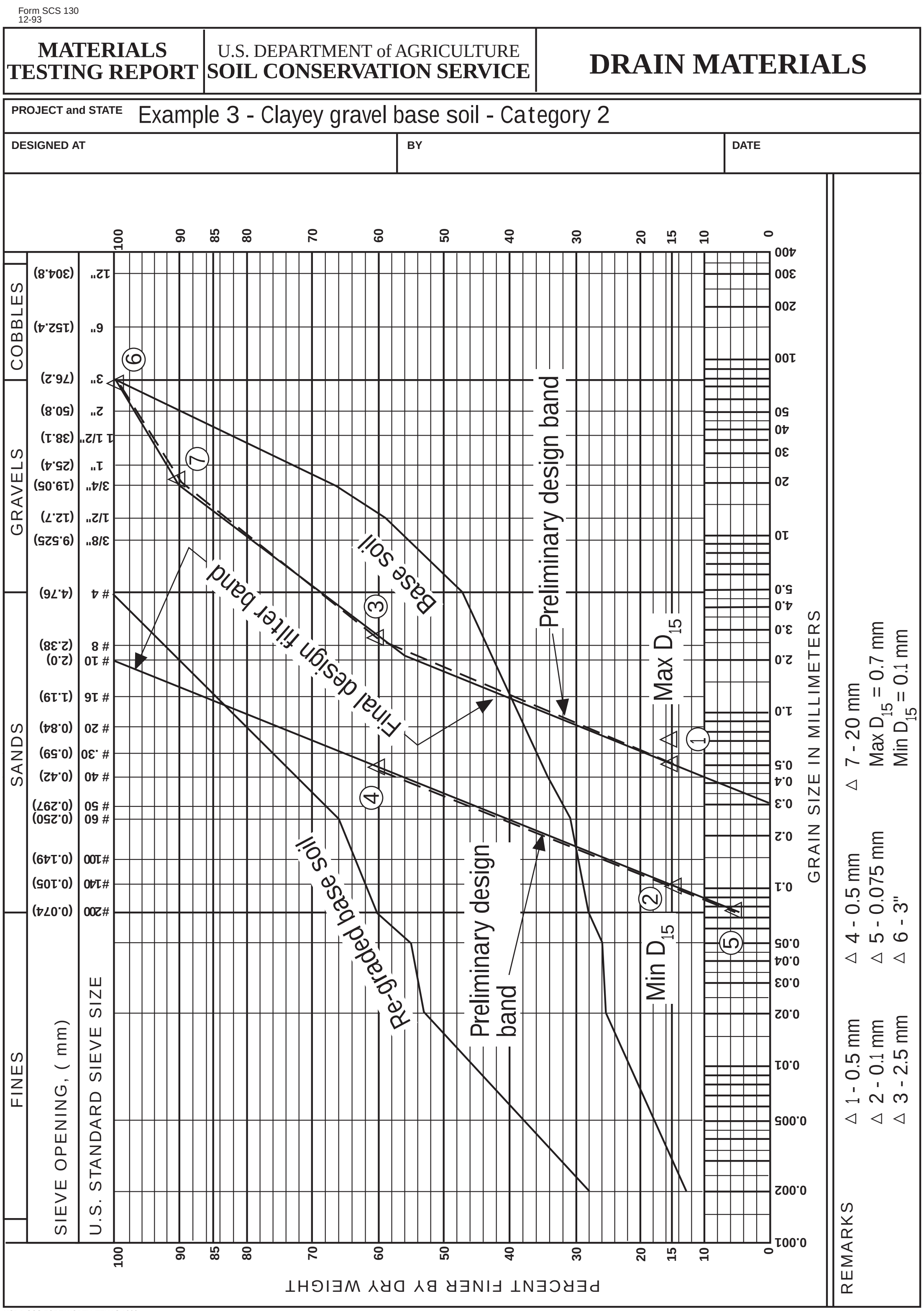
It is not given that this filter is to be used around a collector pipe, so this criterion is not applicable.

Additional design considerations: Standard Concrete Sand, ASTM C–33, plots within this final design band, so one may consider the design acceptable with no further modifications. If onsite sand or other cheaper filters could be located, some modification could be considered. Possible specification limits are shown in table 26–11.

Table 26–11 Design specification limits for clayey gravel base soil

Sieve size	% passing (1)
3 inch	100
3/4 inch	90–100
No. 4	70–100
No. 10	55–100
No. 20	30–75
No. 40	10–55
No. 50	0–45
No. 100	0–25
No. 200	0–5

Figure 26–3 Grain size distribution curve for clayey gravel base soil



Example 26–4 Silty sand base soil—Category 4

Given: The most important function of the filter being designed is to act as a filter.

Step 1: Plot the gradation curve of the base soil material.

Refer to figure 26–4 for the plotted grain size distribution curve for this example silty sand base soil, labeled Base soil. The plotted curve is from the following data.

Sieve size	% passing
No. 20	100
No. 40	94
No. 60	44
No. 140	14
0.05 mm	12
0.02 mm	10
0.005 mm	7
0.002 mm	4

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

Because the example 26–4 base soil has 100 percent of its particles finer than the No. 20 sieve, it has no particles larger than the No. 4 sieve. Therefore, the grain size distribution curve does not have to be regraded. Proceed to step 4.

Step 3: This step is not applicable because the base soil contains no particles larger than the No. 4 sieve. Go to 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.

The example 26–4 base soil has 13 percent finer than the No. 200 sieve, determined from examination of the plotted grain size distribution curve in figure 26–4. From table 26–1, the soil is in category 4.

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

The filtering criterion for base soil category 4 (table 26–2) is that the maximum D_{15} of the filter will be less than or equal to 4 times the d_{85} of the base soil.

The d_{85} of the base soil from the plotted grain size distribution curve in figure 26–4 is 0.39 mm. The maximum D_{15} is:

$$4 \times 0.39 \text{ mm} = 1.56 \text{ mm}$$

Label this as Maximum D_{15} in figure 26–4.

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

The permeability criterion for all categories of base soils is that the filter have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but not be less than 0.1 mm in any case.

The example 26–4 base soil has a d_{15} size of 0.12 mm before regrading. Using the criterion, the minimum D_{15} of the filter would be 4 x 0.12 = 0.48. This is greater than the minimum required D_{15} of 0.1 mm, so it is acceptable. Label this value as Minimum D_{15} in figure 26–4.

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 percent passing of 60 or less. Adjustments may be required based on the following considerations.

The ratio of the maximum D_{15} to the minimum D_{15} is:

$$\frac{1.56}{0.48} = 3.3$$

Because this value is less than the criterion value of 5, no adjustment is necessary. Label the maximum D_{15} and minimum D_{15} sizes as Control points 1 and 2, respectively, and proceed to the next consideration.

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 of the filter band 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.

Calculate a value for the maximum D_{10} size as equal to the maximum D_{15} size (determined in Step 7) divided by 1.2:

$$\frac{1.56}{1.2} = 1.3 \text{ mm}$$

Calculate a value for the maximum D_{60} by multiplying the maximum D_{10} size times 6:

$$1.3 \times 6 = 7.8 \text{ mm}$$

Label the maximum D_{60} size as Control point 3.

The minimum allowable D_{60} size is:

$$\frac{7.8}{5} = 1.56 \text{ mm}$$

Label this as Control point 4 in figure 26–4.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–4.

The table also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–4.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Table 26–6 lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Calculate a value for minimum D_{10} size by dividing the minimum D_{15} size determined in step 7 by 1.2:

$$\frac{0.48}{1.2} = 0.40 \text{ mm}$$

Because the D_{10} size is less than 0.5 mm, the maximum D_{90} size is 20 mm (table 26–6). Label this value as Control point 7 in figure 26–4.

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. Complete the design of the filter band 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.

Refer to figure 26–4 for the selected filter band drawn. Table 26–12 lists the sieve/percent finer values selected.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

The filter is not being used adjacent to a collector pipe, so this step is not applicable.

Additional design considerations: The specified filter band does not meet standard aggregate gradations. The band is more coarse than C–33 concrete sand, and it is finer than the standard gravel gradations (see appendix 26B). Possibly, the required filter gradation could be met by blending standard available gradations.

Consider adjustments in the steepness of the final design filter band shown in figure 26–4 if these adjustments would allow the use of such blends or other readily available gradations. The filter band may be adjusted to a steeper configuration, with a coefficient of uniformity of less than 6, but all the other criteria must still be met. Example 26–2A illustrated such an adjustment in the design filter band.

Table 26–12 The final selected design filter band gradation for silty sand base soil

Sieve size	% passing
3 inch	100
3/4 inch	90–100
No. 4	50–100
No. 10	25–70
No. 20	0–35
No. 40	0–14
No. 60	0–10
No. 200	0–5

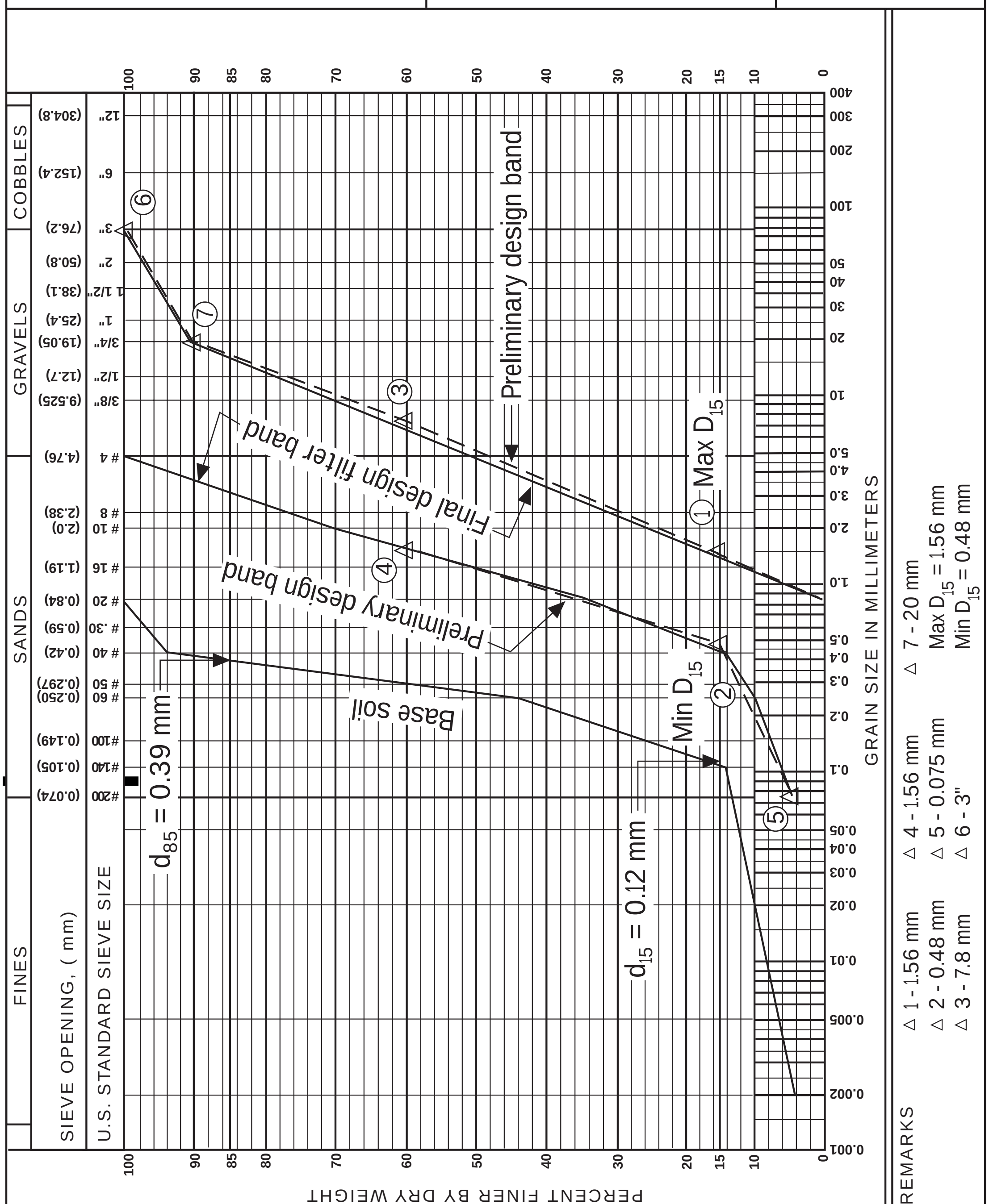
Figure 26–4 Grain size distribution curve for silty sand base soil

Form SCS 130
12-93

MATERIALS TESTING REPORT	U.S. DEPARTMENT of AGRICULTURE SOIL CONSERVATION SERVICE	DRAIN MATERIALS

PROJECT and STATE Example 4 - Silty sand base soil - Category 4

DESIGNED AT | BY | DATE



USDA-SCS FORT WORTH, TEXAS 1993

Example 26–5 Design of a coarse filter to be compatible with a previously designed fine filter and used around a perforated pipe

The base soil for this example is the filter band obtained in the design for example 26–1. The base soil in this case is actually a band of soil gradations specifying a suitable sand filter. The sand filter was designed to protect a silty clay base soil.

Example 26–5 illustrates how to design a gravel filter band to be compatible with the finer sand filter previously designed. In the first part of this example it is understood that the gravel filter will not be used around perforated collector pipe, but some other type of outlet of seepage is employed. The second part of this example illustrates how the design of a coarse filter is changed if perforated pipe is used.

Step 1: Plot the gradation curve of the base soil material. In example 26–5, the base soil is actually a band of possible filter gradations. The filter band that was obtained in example 26–1 is used. Refer to the plotted grain size distribution curve for this example, labeled Fine filter in figure 26–5. The plotted band is from the following data:

Sieve size	% passing
1 inch	100
3/4 inch	90–100
No. 4	70–100
No. 10	52–100
No. 20	30–75
No. 60	0–40
No. 140	0–15
No. 200	0–5

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

Only the fine side of the specified filter band need be considered for this step because the finest base soil controls the filter criteria. Because the fine side of the filter band has no particles larger than the No. 4 sieve, step 3 is skipped. Proceed to step 4.

Step 3: Not applicable because the base soil contains no particles larger than the No. 4 Sieve.

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.

Example 26–5 base filter band has from 0 to 5 percent finer than the No. 200 sieve, determined from examination of the plotted grain size distribution curve in figure 26–5. From table 26–1, the soil is in category 4.

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

This table states the filtering criteria for base soil category 4 as: The maximum D_{15} of the filter will be less than or equal 4 times the d_{85} of the base soil.

The finest gradation from the range of gradations given by the base filter band will be controlling under this criterion. The d_{85} of the fine side of the base filter band from the plotted grain size distribution curve in figure 26–5 is 1.2 mm. Then, 4 x 1.2 mm = 4.8 mm. This is labeled as Maximum D_{15} in figure 26–5.

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

The permeability criterion for all categories of base soils is that the filter have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but not be less than 0.1 mm in any case.

The coarse limit of the base filter band will control under this criterion. Determine that the coarse limit line for the base filter band has a maximum d_{15} size of 0.45 mm. Using the criterion, the minimum D_{15} of the filter would be 4 x 0.45 = 1.8 mm. Label this value as Minimum D_{15} in figure 26–5.

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 percent passing of 60 or less. Adjustments may be required based on the following considerations.

The ratio of the maximum D_{15} to the minimum D_{15} is:

$$\frac{4.8}{1.8} = 2.7$$

Because this value is less than the criterion value of 5, no adjustment is necessary. Label the values of maximum D_{15} and minimum D_{15} as Control points 1 and 2, respectively, and proceed to step 8

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 of the filter band 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.

Calculate a value for the maximum D_{10} size by dividing the maximum D_{15} size determined in Step 7 by 1.2:

$$\frac{4.8}{1.2} = 4.0 \text{ mm}$$

Calculate a value for the maximum D_{60} by multiplying the maximum D_{10} size times 6:

$$4.0 \times 6 = 24 \text{ mm}$$

Label the maximum D_{60} size as Control point 3.

To prevent an overly broad range of particle sizes in the filter, consider the requirement in step 7 that the ratio of maximum to minimum diameters be less than 5 for all percent passing values less than 60. The minimum allowable D_{60} size is:

$$\frac{24.0}{5} = 4.8 \text{ mm}$$

Label this as Control point 4 in figure 26–5.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–5.

Table 26–5 also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–5.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

This table lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Calculate the minimum D_{10} size by dividing the minimum D_{15} size determined in step 7 by 1.2:

$$\frac{1.8}{1.2} = 1.5$$

Because the D_{10} size is between 1.0 and 2.0 mm, the maximum D_{90} size is 30 mm (table 26–6). Label this value as Control point 7 in figure 26–5.

Step 11: Connect Control points 4, 2, and 5 to form a partial design for the fine limits of the filter band being designed. Connect Control points 6, 7, 3, and 1 to form the preliminary coarse limits of the filter band being designed. Complete the design of the filter band 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.

Refer to figure 26–5 for the final coarse filter band designed for the condition of no perforated pipe being used. Note that the filter selected for final design has coefficient of uniformity values for the fine and coarse sides of the design bands slightly less than 6. The Control points 3 and 7 were shifted to the left slightly to have a smoother band shape. The data used for the designed filter band is given in table 26–13.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

For the second part of this example, it is assumed that the gravel filter being designed is for use around standard perforated drain pipe and is not for a critical drain. It is also given that rapid gradient reversal or surging is not predicted.

Standard perforations in drain pipe are 1/4 inch, plus-or-minus 1/16 inch. The maximum size of perforation that must be protected is then 5/16 inch, or about 8 mm. If the gravel filter being designed is to be used surrounding perforated pipe, an additional control point as defined by step 12 is necessary.

Design steps 1 through 11 are unchanged and not repeated here. The additional requirement of step 12 is that the D_{85} size of the filter may be no smaller than the perforation size for designs of noncritical drains where gradient reversal or surging is not predicted.

The additional design step 12 results in an additional control point labeled Control point 8. This is plotted in figure 26–5A. This additional control point is a minimum D_{85} size for the filter being designed and is equal to 8 mm, the maximum perforation size possible. Using Control point 8 does not significantly change the design for the coarse filter band.

Step 12 has different criteria if the coarse filter is designed for critical structure drains or for a situation where gradient reversal and surging were predicted with collector pipes. For this situation the coarse filter must have a D_{15} size no less the perforation size, 8 mm for the example. (For noncritical drains where surging is not predicted, the requirement is based on D_{85}.) In other words, this requirement is that the filter must be relatively coarse to prevent intrusion of the filter into the perforations in the high stresses present. However, filtering criteria require the gravel band to be a satisfactory filter for the sand filter (step 5) as well.

To accomplish this filtration function, the gravel must have a D_{15} of less than 4.8 mm. It is obvious then that one gravel filter cannot be used to satisfy both functions because both the criteria cannot be met. Another coarser filter that has a D_{15} greater than 8 mm must be designed to surround the perforations in the pipe and at the same time filter the gravel filter just designed. This is an example of the need for a 3-stage filter that could arise in critical flow situations.

Additional design considerations: Examine the limits of the gravel filter band constructed in figure 26–5. Note that the band is somewhat narrow at the lower percent passing sizes. Some designers have used an extended coarse filter limit as part of the specifications of the coarse filter band design to make it easier to supply the required filters (figure 26–5A).

The extended upper limits for a coarse filter are acceptable contingent upon the fine filter material actually used or delivered to a construction site, from the range of possible fine filters specified in the band being protected.

A gravel filter with a D_{15} size larger than the design filter band is acceptable if the fine sand filter actually delivered to a site has a d_{85} size larger than the minimum size possible within the design band of the fine sand filter. The coarse gravel filter actually used on the site must have a D_{15} less than or equal to 4 times the d_{85} size of the fine filter actually supplied from within the design band, based on the criteria in table 26–2 for Category 4 soils.

An extended coarse filter limit in the design band is used to provide maximum flexibility in obtaining filter materials. Where possible, specifications should fit readily available gradations from concrete aggregate suppliers to reduce cost of obtaining specially manufactured filter materials. However, criteria should not be relaxed because filter zones are important to the safe functioning of many structures.

Table 26–13 Data for designed filter band

Sieve size	% passing
3 inch	100
1 inch	90–100
1/2 inch	45–100
No. 4	15–60
No. 10	0–15
No. 20	0–10
No. 200	< 5

Figure 26–5 Gravel filter band design

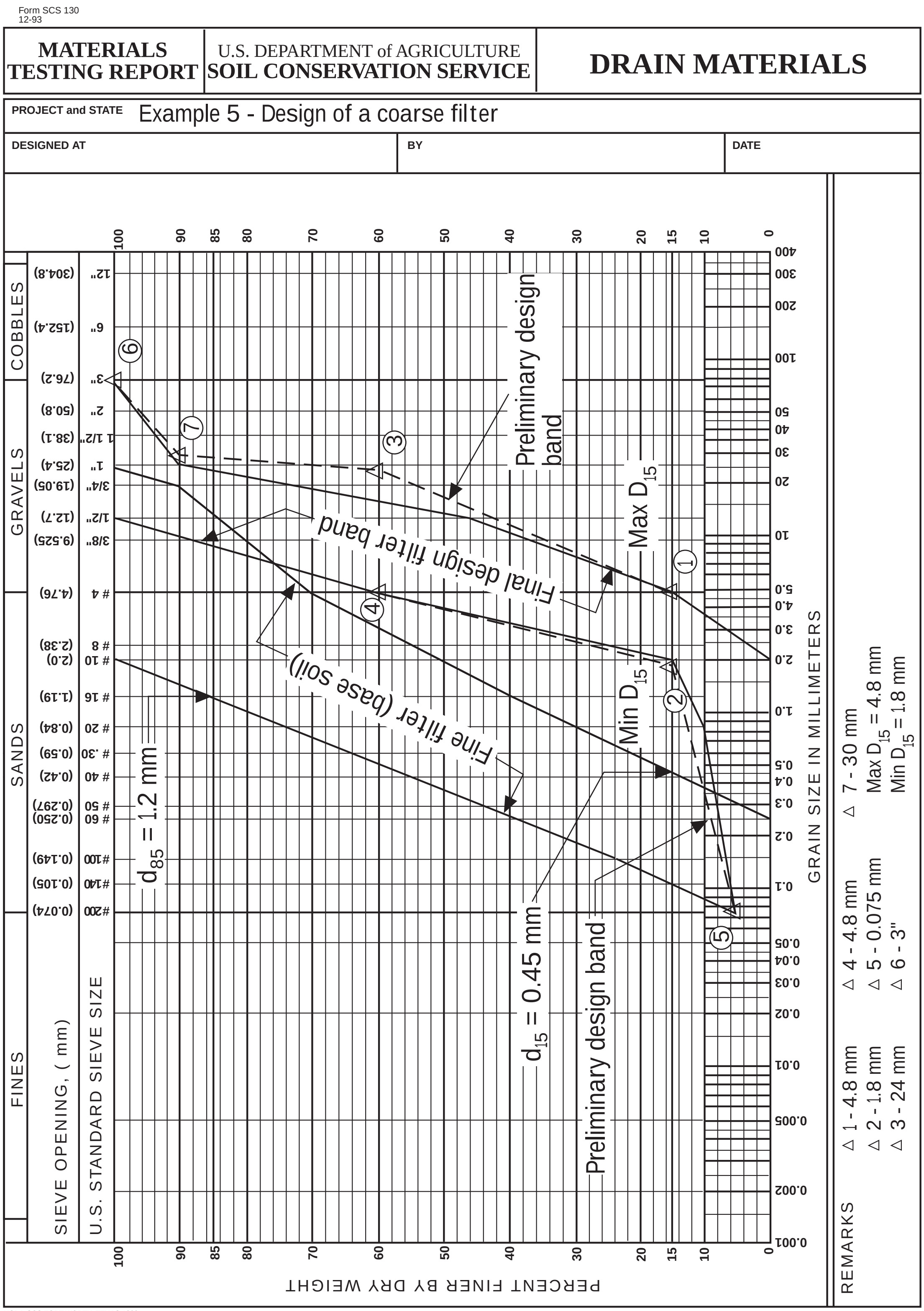
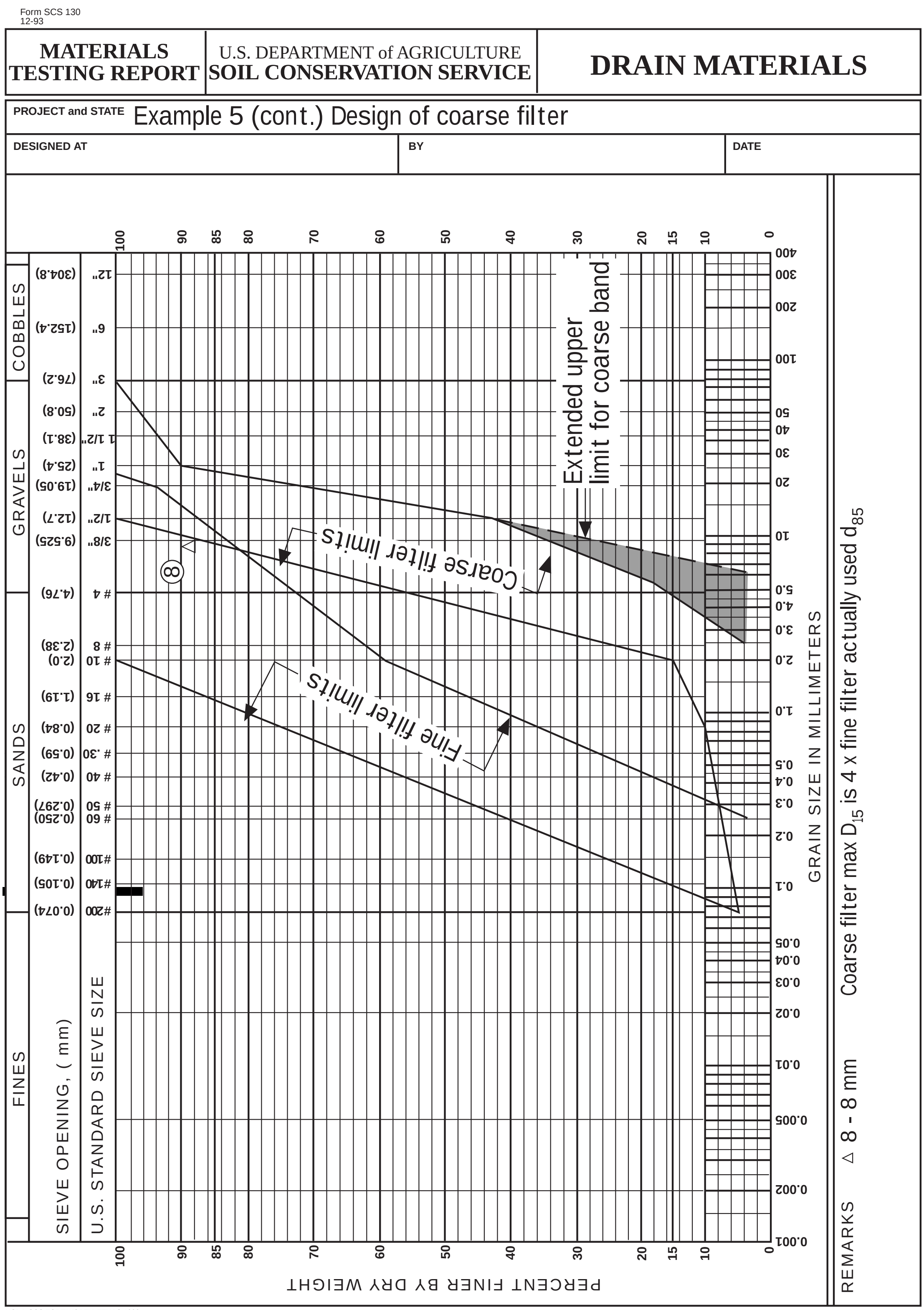


Figure 26–5A Gravel filter band design using an extended coarse filter limit



Example 26–6 Very fine clay base soil—Category 1

Given: The most important function of the filter being designed is to act as a filter.

Step 1: Plot the gradation curve of the base soil material.

Refer to figure 26–6 for the plotted grain size distribution curve for this example clay base soil, labeled Base soil. The plotted curve is from the following data:

Sieve size	% passing
No 4	100
No. 200	96
0.02 mm	90
0.005 mm	60
0.002 mm	34

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

The example 26–6 base soil has 100 percent finer than the No. 4 sieve, and the grain size distribution curve does not have to be regraded. Proceed to step 4.

Step 3: Not applicable because the base soil contains no particles larger than the No. 4 sieve

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.

The example 26–6 base soil has 96 percent finer than the No. 200 sieve. The soil is in category 1 (table 26–1).

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

This table shows the filtering criteria for base soil category 1 as: The maximum D_{15} of the filter will be less than or equal to 9 times the d_{85} of the base soil, but not less than 0.2 mm.

The d_{85} size of the base soil is 0.016 mm. Then, the maximum D_{15} of the filter will be less than or equal to 9 x 0.016 = 0.14 mm, but not less than 0.2 mm. Therefore, the maximum D_{15} of the filter is 0.2 mm. This is labeled Maximum D_{15} in figure 26–6.

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

The permeability criterion for all categories of base soils is that the filter have a minimum D_{15} of no less than 4 times the d_{15} of the base soil (before any regrading of the base soil), but not be less than 0.1 mm in any case.

The example 26–6 base soil does not have a meaningful d_{15} size. The data shows that the base soil has 34 percent finer than 0.002 mm, the smallest commonly determined particle size. Therefore, use the default value of 0.1 mm for the minimum D_{15} of the filter. Label this value Minimum D_{15} in figure 26–6.

Step 7: 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 percent passing of 60 or less. Adjustments may be required based on the following considerations.

For example 26–6, the ratio of the maximum D_{15} to the minimum D_{15} sizes is:

$$\frac{0.2}{0.1} = 2$$

Because the value is less than 5, no adjustment is needed in this step. The sizes selected become the maximum D_{15} and minimum D_{15} sizes for the final design filter band. These are labeled Control points 1 and 2, respectively, in figure 26–6. Go to step 8.

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 of the filter band 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

For example 26–6, calculate a value for maximum D_{10} by dividing the maximum D_{15} size of 0.2 mm determined in step 5 by 1.2:

$$\frac{0.2}{1.2} = 0.17 \text{ mm}$$

Calculate a value for the maximum allowable D_{60} size by multiplying the maximum D_{10} size by 6:

$$6 \times 0.17 = 1.02 \text{ mm}$$

Label this value as Control point 3 in figure 26–6.

Determine the minimum allowable D_{60} size for the fine side of the band by dividing the determined maximum D_{60} size by 5:

$$\frac{1.02}{5} = 0.20 \text{ mm}$$

Label this Control point 4 in figure 26–6.

Step 9: Determine the minimum D_5 and maximum D_{100} sizes of the filter according to table 26–5.

This table shows that filters must have a D_5 greater than or equal to 0.075 mm, equal to the No. 200 sieve size. Label this value as Control point 5 in figure 26–6.

Table 26–5 also shows that filters must have a D_{100} of less than or equal to 3 inches. Label this value as Control point 6 in figure 26–6.

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. Determine the maximum D_{90} using table 26–6. Label this as Control point 7.

Calculate the minimum D_{10} size of the preliminary filter band as equal to the minimum D_{15} value of 0.1 mm (obtained in step 6) divided by 1.2:

$$\frac{0.1}{1.2} = 0.083 \text{ mm}$$

Table 26–6 lists maximum D_{90} sizes for filters for a range of D_{10} sizes. Because the D_{10} value is less than 0.5 mm, the maximum D_{90} size is 20 mm (table 26–6). Label this value as Control point 7 in figure 26–6.

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 partial design for the coarse side of the filter band. Complete the design of the filter band 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.

Refer to figure 26–6 for an illustration of the complete filter design. Note that adjustments have been made in straight line portions of the design band to intercept even values for percent passing at standard sieve sizes. See the selected specified gradation in table 26–14.

Step 12: Design filters adjacent to perforated pipe to have a D_{85} size no smaller than the perforation size. 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.

Table 26–14 Design filter band data for example 26–6 soil

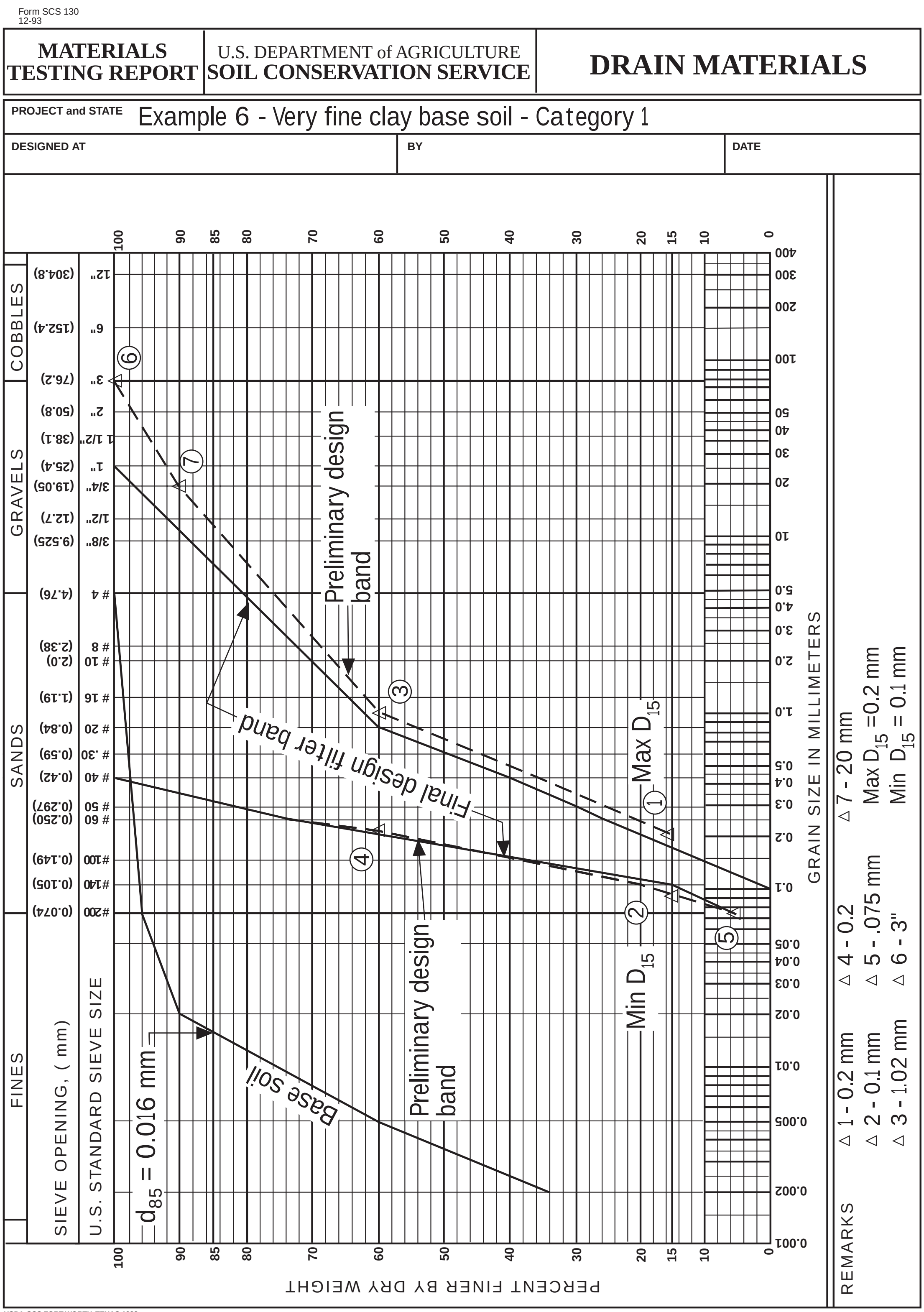
Sieve size	% passing
1 inch	100
No. 4	80–100
No. 10	70–100
No. 20	60–100
No. 40	40–100
No. 60	25–75
No. 140	0–15
No. 200	0–5

This step is then not applicable for this example because the filter will not be used around a perforated collector pipe. Table 26–14 lists the design filter band data obtained from the steps of this example.

Additional design considerations: ASTM C–33 fine concrete aggregate often meets the filter gradation requirements for many silts and clays. The base soil in example 26–6, however, is an unusual case in which the base soil is so fine that a filter finer than C–33 fine aggregate is required. Several alternatives are suggested for such situations:

- If a base soil having a d_{85} of 0.05 mm or larger is available at the site, using this soil in a core zone or in a transition zone between the core zone and the filter zone may be more economical. A more coarse filter could then be designed for the new base soil with the larger d_{85} size, and it is more likely that the specified gradation could be met with standard supplier sources.
- Attempt to locate a standard gradation that may fit the specified filter band. An example of such a gradation that might be located is ASTM D1073, Bituminous Mixture, Gradation No. 3. ASTM D1073 specifications for selected gradations are shown in appendix 26B.

Figure 26–6 Grain size distribution curve for very fine clay base soil



633.2604 Definitions

Base soil—The soil immediately adjacent to a filter or drainage zone through which water may pass. This movement of water may have a potential for moving particles from the base soil into or through the filter or drain materials.

d_{15}, d_{85}, and d_{100} sizes—Particle sizes (mm) corresponding respectively to 15, 85, and 100 percent finer by dry weight from the gradation curve of the base soil.

D_5, D_{10}, D_{15}, D_{30}, D_{60}, D_{85}, D_{90}, and D_{100} sizes—Particle sizes (mm) corresponding to the 5, 10, 15, 30, 60, 85, 90, and 100 percent finer by dry weight from the gradation curve of the filter.

Gradation curve (grain-size distribution)—Plot of the distribution of particle sizes in a base soil or material used for filters or drains.

Drain—A designed pervious zone, layer, or other feature used to reduce seepage pressures and carry water.

Filter—Sand or sand and gravel having a gradation designed to prevent movement of soil particles from a base soil by flowing water. Guidance on design using geotextiles and other nonsoil filter materials is not included.

Fines—That portion of a soil finer than a No. 200 (0.075 mm) U.S. Standard sieve as explained in table 26–1.

Soil category—One of four types of base soil material based on the percentage finer than the No. 200 (0.075 mm) U.S. Standard sieve as explained in table 26–1.

633.2605 References

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Appendix 26A Steps in Filter Design

1. Plot the gradations of base soils for which a filter is being designed on Form SCS-130 or acceptable alternative.

2. Determine the finest base soil that will control filter requirements. Also determine the soil with the most coarse limits that will control permeability requirements for the filter.

3. If the finest base soil has particles larger than the No. 4 sieve, regrade the soil on the No. 4 sieve.

4. Determine within which base soil category the regraded sample falls.

5. Determine the maximum D_{15} size based on filter criterion in criteria tables for that base soil category using the finest soil of the category plotted.

6. Determine the minimum D_{15} size based on permeability criterion in criteria tables, considering the coarsest sample plotted.

7. Calculate the ratio of the maximum D_{15} to the minimum D_{15} sizes from steps 5 and 6. If the ratio is less than or equal to 5, label the points Control points 1 and 2, respectively, on Form SCS-130, and continue to step 8. If the ratio is greater than 5, determine whether filtering or drainage is the most important function of the filter being designed. If filtering is most important, go to step 7A. If permeability is the most important consideration, go to step 7B.

7A. Filtering controls—Label the minimum D_{15} size as control point 2. Multiply minimum D_{15} by 5. This is the maximum D_{15} size; plot on Form 130 and label as control point 1. Go to Step 8.

7B. Permeability controls design—Label the maximum D_{15} size as Control point 1. Divide the maximum D_{15} size by 5. This is the minimum D_{15} size; plot on Form 130 and label as Control point 2. Go to Step 8.

8. Calculate a value for the maximum D_{10} size by dividing the maximum D_{15} size (Control point 1) determined in step 7 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 a value for maximum D_{60} by multiplying the maximum D_{10} size by 6. Label this as 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.

9. Plot the minimum D_5 (for all filters) as equal to 0.075 mm (the No. 200 sieve). Label as Control point 5 on Form 130. Plot the maximum D_{100} (for all filters) as equal to 3 inches. Label as Control point 6 on Form 130.

10. Calculate a value for the minimum D_{10} size by dividing the minimum D_{15} size (Control point 2) determined in step 7 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.)

Based on the determined value of minimum D_{10} size, obtain from table 26–6 the maximum allowable D_{90} size for the filter. Plot this value on Form 130 and label it as Control point 7.

11. Connect Control points 6, 7, 3, and 1 to form the coarse side of the initial filter design band. Connect Control points 4, 2, and 5 to form the fine side of the initial filter design band. Extrapolate the previously drawn lines to complete the preliminary fine and coarse limits of the preliminary filter band to 0 and 100 percent passing values. Adjust these limits to intercept relatively even values of percent passing at standard sieve sizes to simplify specifications (generally rounded at the nearest 5 on the percent passing scale) staying within the preliminary band. In most cases avoid sharp breaks in the design envelopes that might allow too broadly graded filter materials to be used in this final design step. If necessary to meet available gradations, adjust Control points 3 and 4 to the left, maintaining the ratio of diameters at 5, then draw other preliminary fine and coarse limits.

12. Design filters surrounding perforated pipe with an additional control point, determined as the minimum D_{85} size of the filter according to criteria tables. Label this value as Control point 8, and re-examine the design obtained in step 11.

A summary of the important criteria associated with the filter design process follows.

Base Soil Categories Summary

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

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 No. 200 sieve after regrading (If $4 \times d_{85}$ is less than 0.7 mm, use 0.7 mm)
4	$\leq 4 \times d_{85}$ of base soil after regrading

Other Filter Design 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 less than or equal to 60 percent, is less than or equal to 5. 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 these steps have CU value of 6. For final design, filter bands may be adjusted so that CU values less than 6 result. This is acceptable as long as other filter and permeability criteria are satisfied.

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

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 according to ASTM D4318.)

Segregation Criteria

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

Criteria for Filters Used Adjacent to Perforated Collector Pipe

For noncritical drains where surging or gradient reversal is not anticipated, the filter D_{85} must be greater than or equal to the perforation size.

For critical drains, or where surging or gradient reversal is anticipated, the filter D_{15} must be greater than or equal to the perforation size.

Appendix 26B Standard ASTM Aggregate Specifications

Standard gradations for aggregates used in production of concrete are established by the American Society for Testing and Materials (ASTM). These aggregates are also commonly used for filter and drain zones in embankments, retaining walls, and other applications. Selected representative standard aggregates are listed in following tables for reference.

ASTM C-33—Standard Specification for Concrete Aggregates, lists standard gradations for both fine and coarse aggregates.

ASTM D-448—Standard Classification for Sizes of Aggregate for Road and Bridge Construction, lists standard gradations for only coarse aggregates.

ASTM D-1073—Lists standard gradations for Bituminous Mixtures.

In the interest of brevity, only selected representative standard gradations from the C–33 and D–1073 standards are listed in table 26B–1. A few gradations that may be useful are listed in D–448 and not in C– 33, but many of the gradations listed in the two standards are identical. Both of these ASTM standards are in Volume 04.02, Concrete and Aggregates.

Figure 26B–1 has plotted gradation bands for selected aggregates from the table.

Note: ASTM standards are periodically reviewed and updated, so use the latest version of the Standards for writing specifications. Refer to the latest ASTM standards volume to ensure that the gradations have not changed from those listed in table 26B–1 or to determine other standard gradations not listed. This table only lists selected representative gradations.

Table 26B–1 Selected standard aggregate gradations

Fine aggregate—ASTM C–33

ASTM	- - - Percent finer than sieve no. - - -							
size	#200	#100	#50	#30	#16	#8	#4	3/8"
Fine	3-5*	2–10	10–30	25–60	50–85	80–100	95–100	100

Coarse aggregates—ASTM C–33

ASTM	- - - Percent finer than sieve no. - - -									
size	#16	#8	#4	3/8"	1/2"	3/4"	1"	1-1/2"	2"	3"
357	—	—	0–5	—	10–30	—	35–70	—	95–100	100
56	—	—	0–5	0–15	10–40	40–85	90–100	100		
57	—	0–5	0–10	—	25–60	—	95–100	100		
67	—	0–5	0–10	20–55	—	90–100	100			
7	—	0-5	0-15	40-70	90-100	100				
8	0–5	0–10	10–30	85–100	100					

See the footnote at the end of the table.

Table 26B–1 Selected standard aggregate gradations—Continued

Bituminous mixtures—ASTM D–1073

ASTM mix	Percent finer than sieve no.							
	#200	#100	#50	#30	#16	#8	#4	3/8"
2	0–5	0–12	8–30	28–52	50–74	75–100	100	
3	0–5	5–25	30–60	65–90	85–100	95–100	100	
4	0–10	2–20	7–40	20–65	40–80	65–100	80-100	100

* For concrete aggregate, the permissible percentage finer than the No. 200 sieve is 3 to 5 percent, depending on the abrasion resistance desired for the manufactured concrete. In the case of manufactured sand, if the material finer than the No. 200 sieve consists of the dust of fracture, essentially free of clay or shale, these limits may be increased to 5 and 7 percent respectively. For drain and filter applications, the percentage finer than the No. 200 sieve is specified according to SM Note 1 as less than or equal to 5 percent, and an additional requirement is that the fines (minus No. 40 sieve) are nonplastic.

Figure 26B–1 Standard aggregate gradations