VII. DETENTION AND FILTERING STRUCTURES

7.1 General

When sediment laden water is slowed or ponded, its ability to transport sediment is greatly reduced. Under these conditions, sediment will settle out of the water and deposit. The efficiency of a detention structure will depend on the amount of time the flow remains in the detention area. Larger size particles settle quickly while small size particles require a much longer time to settle. Figure 7.1 shows the settling distance for the different diameter particles used in this manual for a 30-minute time interval. Detention structures presented in this manual will only pond one to two feet of water and, as can be seen in Figure 7.1, the three largest sizes will quickly reach this depth while the smallest size will take several hours.

Filtering structures also pool water allowing sediment to settle out and deposit. In addition to detaining sediment laden water, a number of filter barriers are available for removing sediment from moving water. Filtering is accomplished by allowing the sediment laden water to flow slowly through the small pores of a filter material.

Synthetic fabrics have become the dominant material used in the design of filtering structures. The fabrics are permeable and have numerous small pores which trap sediments, both woven and nonwoven fabrics, are in use. These fabrics have a low permeability which means that water will pool behind a filter structure. Because of this low permeability filter structures will not be suitable for use where high concentrations of water occur such as channels or gullies. Filter fabrics will trap all sand size particles and 60 to 80 percent of silt and clay size particles. Large particle sizes will tend to settle out before they are filtered but the distinction is not necessary since all of these sizes will be removed in either case.

Detention and filtering structures are an effective means of reducing the sediment yield from an area. Several factors can decrease their performance over a short period of time, however, and maintenance of the structures is important. First, since these structures are very efficient sediment traps, they will accumulate large deposits of sediment after rainfall. These structures must be cleaned frequently or else their efficiency will be reduced. The structures must be accessible to maintenance equipment for cleaning and should not be installed in locations where maintenance equipment access is

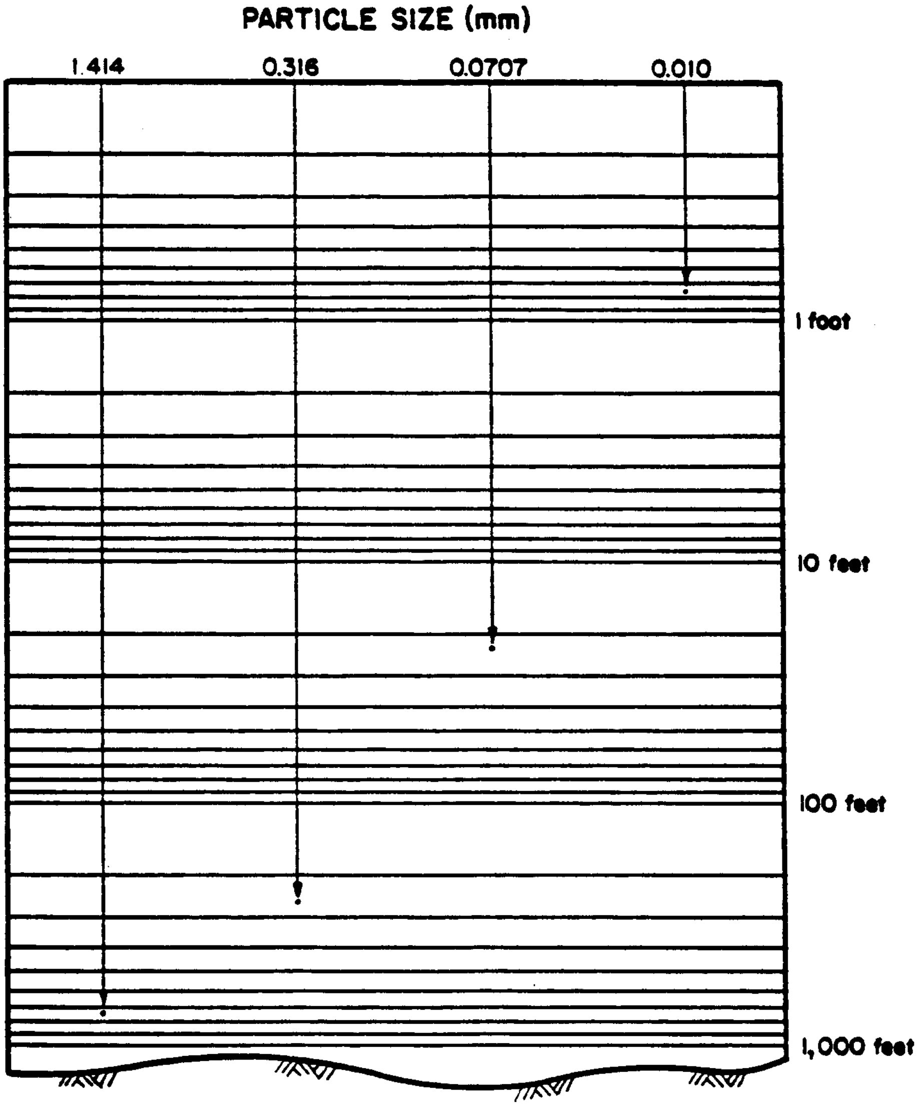


Figure 7.1. Settling distance for different diameter particles based on a 30-minute time interval.

limited. Second, erosion can jeopardize the effectiveness of these structures. Common problems are channels which form under or around structures and/or the clogging of filter materials. Synthetic filter fabric is also susceptible to deterioration from ultraviolet radiation. Structures should be inspected frequently and repairs made promptly when damage has occurred.

7.2 Procedural Guide

The sediment trapping efficiency of both detention and filtering structures can be evaluated using the following procedure. The height of ponded water is limited to two feet for both of these structures. This height reduces the possibility of various structural problems (undercutting or channeling around) and allows room for storage of sediment. Large sediment deposition behind these structures should be avoided since it greatly reduces the trapping efficiency of the structure. The procedure consists of the following five major steps:

1. Determination of total water and sediment yield to the structure.
2. Determination of structure length.
3. Determination of the amount of trapped sediment.
4. Determination of effluent settleable solids concentration.
5. Determination of the required structure height.

Worksheet 7.1 is provided to aid in executing the detention and filtering structure procedure.

Step One: Determine total water and sediment yield to the structure.

The procedure guide for Chapter IV computes water and sediment yield from an area. The step three worksheet gives total rainfall excess in inches (last value in column 4) and the step seven worksheet gives the total sediment yield in tons (sum of column 5). The total volume of water and sediment yield to the detention structure is given by the following equation:

$$V_{sw} = 3630\ P_e A + 20.2\ G_y \qquad (7.1)$$

where: V_{sw} = volume of sediment and water, cubic feet

P_e = rainfall excess, inches

Worksheet 7.1. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = ______________ inches

Catchment Area, A = ______________ acres

Actual Sediment Yield, G_y = ______________ tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$

=

= ________________ cu.ft.

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = ______________ feet

Duration of runoff, t_e = ______________ hours

Flow rate per unit area, K_a = ______________ ft/hr

Upland slope, S_x = ______________

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$

=

= ______________

Structure Length Coefficient, C_f = ______________

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$

=

= ______________ feet

Actual structure length used, L_d = ______________ feet

Worksheet 7.1. (continued).

Volume of sediment deposition

$$\forall_s = 20.2\ G_d$$

= ____________ cu.ft.

Depth of sediment deposition

$$d_d = \sqrt{2\forall_s S_x / L_d}$$

=

= ____________ feet

Step Four: Mean Concentration of Effluent

$$C_s = 8{,}830\ (G_y - G_d)/P_e A$$

=

= ______________ ppm

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$$d_f = d_d - 0.5$$

= ____________ feet

Total height

$$\text{Structure Height, } H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f$$

=

= ____________ feet

A = area in acres

G_y = total sediment yield in tons

Step Two: Determination of structure length.

The length of a detention or filtering structure will depend on the flow rate through the structure, the duration of runoff, and the height of the structure. The flow rates through straw bales, synthetic fabrics, and rock outlets are given in Table 7.1. The flow rate of synthetic fabrics can be determined by the Filtering Efficiency and Flow Rate Test (Test #1, developed by Virginia Highway and Research Council, 1980). These flow rates are generally not available from manufacturers. The permeability of the fabric as measured using either a fall head or constant head permeameter should not be used for flow rate.

The duration of runoff is determined by calculating the time of initial rainfall excess (see task three of step three in Chapter IV) and subtracting that time from the storm duration. The maximum depth of water which can pool behind a structure is 2.0 feet for detention structures and filter fence, 1.5 feet for brush filter barrier, and 1.0 feet for straw bale barrier.

Knowing the flow rate through the structure, the duration of runoff, and the structure height, a detention parameter, K_f, is determined from the following equation

$$K_f = 1/2\ K_a t_e d_{max} \tag{7.2}$$

where: K_a = flow rate per unit area for the structure in ft/hr

t_e = duration of runoff in hours

d_{max} = maximum allowable ponded depth in feet.

Using the detention parameter K_f and slope of the land surface above the structure, the structure length coefficient, C_f, is found using the nomograph in Figure 7.2. The minimum structure length is given by the following equation:

$$L_{min} = \frac{\forall_{sw}}{C_f} \tag{7.3}$$

The total amount of sediment trapped by the detention structure is given by summing the results of Equation 7.7 for each particle size. The volume of deposition is given by:

$$\forall_s = 20.2\ G_d \tag{7.8}$$

and the depth of deposition by:

$$d_d = \sqrt{\frac{2\ \forall_s\ S_x}{L_d}} \tag{7.9}$$

where: $\forall_s$ = deposited volume, cubic feet

d_d = deposition depth, feet

Step Four: Determine Settleable Solids Concentration

The concentration of settleable solids in the water leaving a detention structure is given by the following equation:

$$C_s = 8830\ \frac{(G_y - G_d)}{P_e\ A} \tag{7.10}$$

where: C_s = the mean concentration of settleable solids, ppm

G_y = actual sediment yield into the detention structure in tons

G_d = sediment trapped in the detention structure in tons

P_e = rainfall excess in inches

A = area above structure in acres

Step Five: Determination of the Required Structure Height

A detention structure should have at least 0.5 feet of freeboard above the depth of water and sediment. If the depth of sediment trapped is greater than 0.5 feet, then additional freeboard is recommended where the additional freeboard is given by:

$$d_f = d_d - 0.5 \tag{7.11}$$

where: d_f = additional freeboard in feet if the sediment deposition is greater than 0.5 feet

d_d = deposition depth, feet

The required height of the detention structure is:

$$H_d = \sqrt{\frac{L_{min}}{L_d}\ d_{max}} + 0.5 + d_f \tag{7.12}$$

Worksheet 7.1. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = ______________ inches

Catchment Area, A = ______________ acres

Actual Sediment Yield, G_y = ______________ tons

$V_{sw} = 3{,}630\ P_e A + 20.2\ G_y$

=

= ________________ cu.ft.

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = ______________ feet

Duration of runoff, t_e = ______________ hours

Flow rate per unit area, K_a = ______________ ft/hr

Upland slope, S_x = ______________

Detention Parameter

$K_f = 1/2\ K_a\ t_e\ d_{max}$

=

= ______________

Structure Length Coefficient, C_f = ______________

Minimum Structure Length

$L_{min} = V_{sw}/C_f$

=

= ______________ feet

Actual structure length used, L_d = ______________ feet

Worksheet 7.1. (continued).

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual Sediment Yield[1] G_y (tons)	Fall Velocity[2] w(ft/sec)	Trap Efficiency[3] e_s	Sediment Trapped[4] G_d (tons)
0.010				
0.0707				
0.316				
1.414				
Total		/////////	/////////	

[1] From input data

[2] See Table 7.1 (Not needed for filter structures)

[3] For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$$e_s = 1 - 4\ (K_a/w)\ (L_f/L_d)\ S_x$$

Rock outlet flow rate, K_a = ______________ ft/sec

Rock outlet length, L_f = ______________ feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4}\ L_d}{K_a L_f S_x}$$

= ________________

$e_s = p_s$ from Figure 6.11

[4] $G_d = e_s G_y$

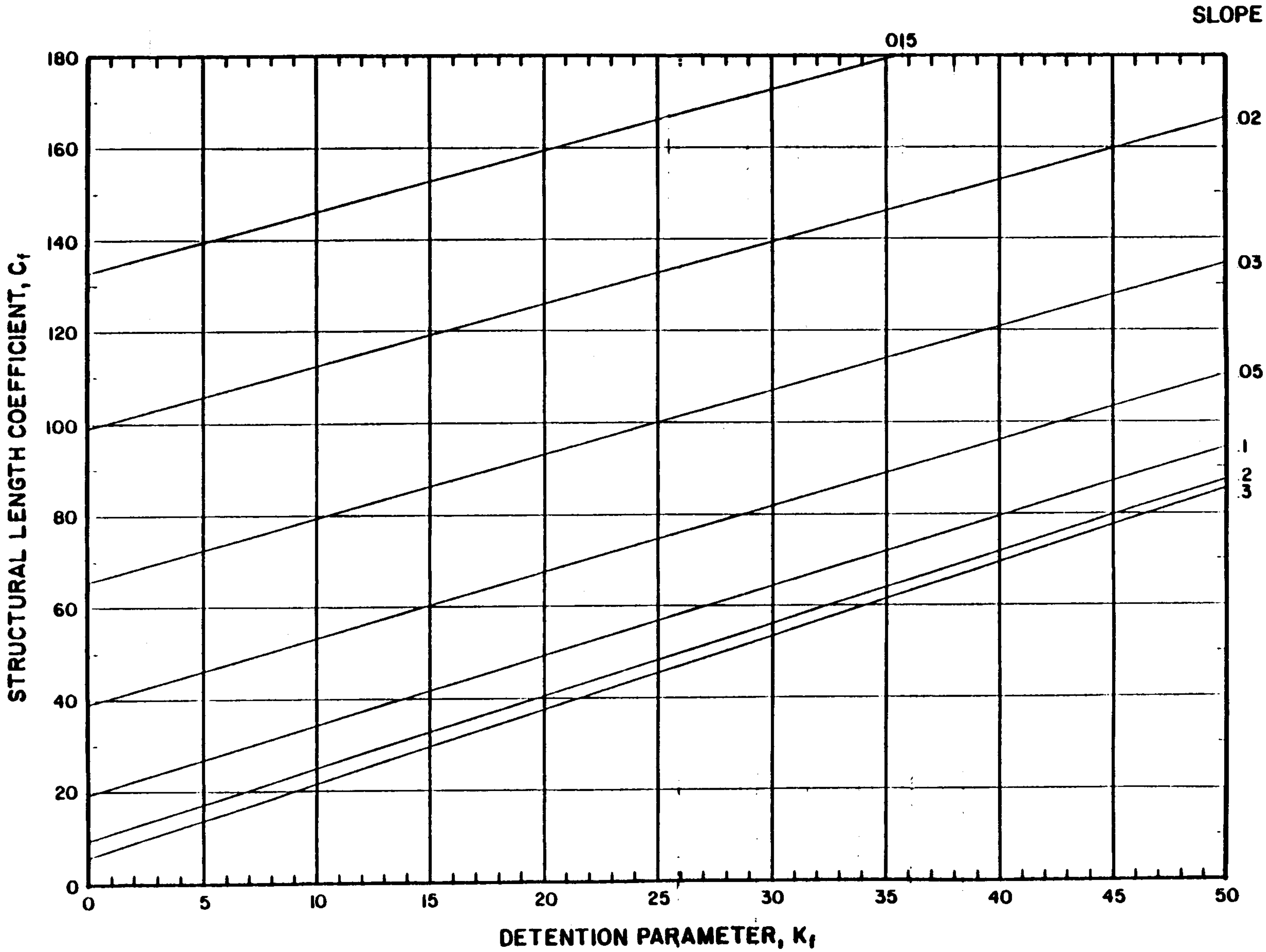


Figure 7.2. Structural length coefficient nomograph (from Simons, Li & Associates, Inc., 1982).

where: L_{min} = minimum structure length, feet

$\forall_{sw}$ = volume of sediment and water, cubic feet

C_f = structure length coefficient

If the topography of the site for the structure cannot accommodate the necessary minimum length, a new location should be selected. It is important to keep in mind that detention and filtering structures must be constructed parallel to the contours of a slope. The required structure length can be reduced by selecting a fabric with an increased unit area flow rate or by selecting a structure with increased height. The length can also be reduced by selecting a site with a flatter upland slope. The actual design length of the structure is denoted by L_d .

Permeable Rock Outlets

The flow rate through a permeable rock outlet is much greater than that for synthetic fabrics. Detention structures consist of an earth berm and a permeable rock outlet. The procedure for determining the length of a detention structure is as follows:

1. Divide the rock outlet flow rate (Table 7.1) by the estimated ratio of berm length to rock outlet length.

2. Use this flow rate to determine the detention parameter (Equation 7.2) and in determining the structure length coefficient (Figure 7.2).

3. Calculate the detention structure length using Equation 7.3. The rock outlet length can be found by dividing the structure length by the estimated ratio of berm length to rock outlet length.

The trapping efficiency of detention structures improves as the ratio of berm length to rock outlet length increases (see next step). The rock outlet length can be varied to find the most efficient outlet size for a site.

Step Three: Sediment Trapping Efficiency

Flow through a detention structure is controlled by a permeable rock outlet. The rate at which the pool drains can be controlled by varying the length of the rock outlet or the type of rock used (riprap or gravel). The faster the pool drains, the fewer fine sediment sizes will be trapped.

Trapping efficiency of a detention structure for a sand size material is given by the following equation:

$$e_s = 1 - 4 \frac{K_a}{w} \frac{L_f}{L_d} S_x \qquad (7.4)$$

where: e_s = trap efficiency for a given sediment size

K = flow rate of the rock outlet in ft/sec

w = fall velocity of the particle in ft/sec

L_f = rock outlet length, feet

L_d = structure length, feet

If e_s from Equation 7.4 is negative, then the trapping efficiency will be zero for that sediment size. Table 7.1a gives of fall velocity for each particle size and Table 7.1b flow rates for rock outlets.

For silt size sediment, the trap efficiency is based on the procedure in Chapter VI for determining silt yield from diversion structures (Step 5). This procedure is simplified for diversion structures.

First, the settling parameter is given as,

$$C_w = \frac{2.2 \times 10^{-4} L_d}{K_a L_f S_x} \qquad (7.5)$$

Second, the trap efficiency will equal the ratio of sediment settling to the volume of sediment available to settle, or

$$e_s = p_s \qquad (7.6)$$

For filtering structures, the trapping efficiency of the structure for the sand sizes equals 1.0 (100 percent) and will vary for the silt size (0.010 mm) depending on the percentage of silt in the incoming sediment yield to the filter structure. Figure 7.3 gives the trapping efficiency (for synthetic fibers and straw bales) for silt size particles as a function of the percent of silt.

The amount of sediment trapped for a particular size is:

$$G_d = e_s G_y \qquad (7.7)$$

where: G_d = amount of sediment trapped in tons

G_y = sediment yield for a particle size (sum of colums 1-4, respectively from the Step Seven worksheet, Chapter IV) in tons

Table 7.1a. Particle Fall Velocity and Rock Outlet and Structure Flow Rates.

Particle Size (mm)	Fall Velocity (ft/sec)
0.010	4.40×10^{-4}
0.0707	.0115
0.316	.129
1.414	0.391

Table 7.1b. Unit Area Flow Rates for Various Structure Types.

Synthetic Fabrics (ave) Structure Type	Flow Rate (ft/sec)	Flow Rate (ft/hr)
Rock Outlet:		
Riprap	0.061	220.0
Coarse Aggregate	0.044	158.0
Synthetic Fabrics (ave)	--	2.4
Straw Bales	--	45.0

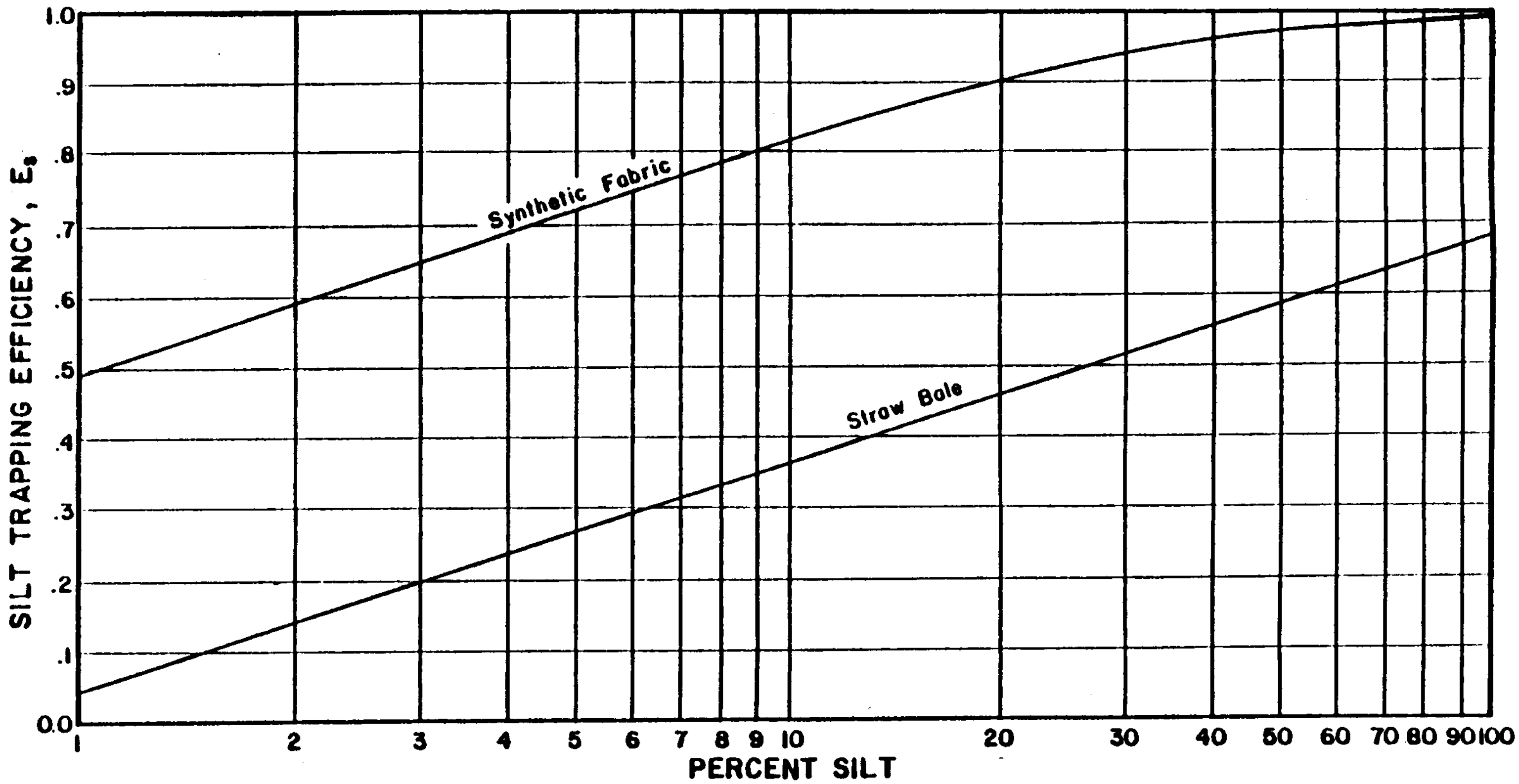


Figure 7.3. Silt trapping efficiency (from Simons, Li & Associates, Inc., 1982).

where: H_d = structure height, feet

The height of the rock outlet for the detention structure should equal the structure height without freeboard.

7.3 Design of Detention Structures

A detention structure is a temporary ridge of compacted soil located at the base of a disturbed area. It is constructed on the contour of a slope and provides a linear sediment trapping area. Water is discharged from the detention structure through a permeable rock outlet to a stabilized outlet channel. Detention structures are easily combined with diversion and conveyance structures to form a complete sediment trapping system (see Figure 7.4). These structures are designed to retain the entire storm volume which is then released slowly. Fairly long detention times can be developed in these structures which result in a high sediment trapping efficiency.

Design Information

A detention structure consists of two components: 1) a perimeter berm of compacted soil, and 2) a permeable rock outlet. General design criteria for the perimeter berm are given in Table 7.2, and Figure 7.5 shows a typical cross section of a perimeter berm. General design criteria for a permeable rock outlet are given in Table 7.3. Figure 7.6 shows a typical permeable rock outlet.

Planning Considerations

A detention structure is intended to collect sediment laden sheet flow and provide adequate sediment settling time. These structures are generally used at the base of a slope to trap sediment and protect adjacent downslope land.

If the perimeter berm is to remain in place for longer than 30 days, the berm should be stabilized with temporary or permanent vegetation. The lateral slope of the berm should be nearly zero for maximum ponding length to develop. It is desirable to maintain a slight gradient toward the rock outlet to facilitate drainage.

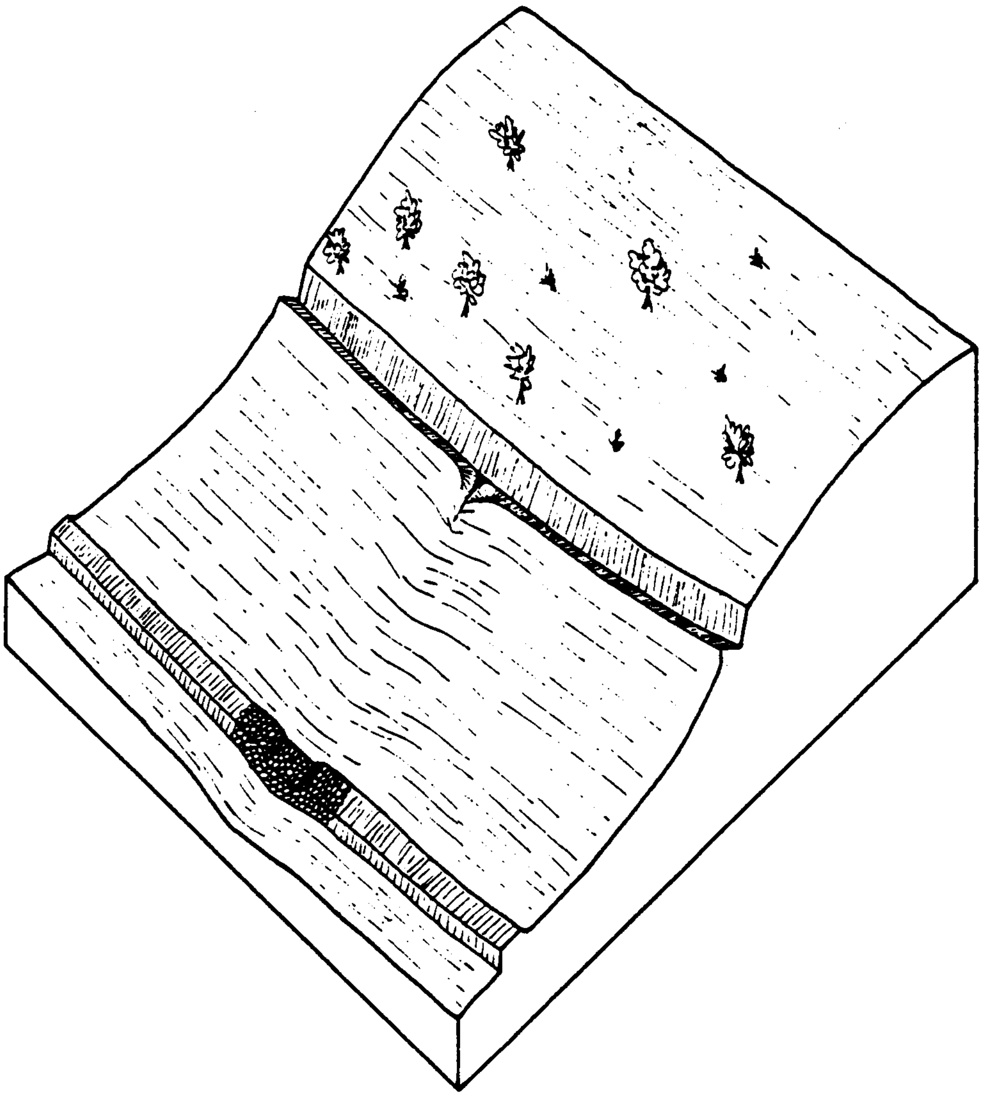


Figure 7.4. Detention berm with rock outlet.

Table 7.2. General Design Criteria for a Perimeter Berm.

Height:	1.5 feet minimum measured from upslope side of berm
Topwidth:	2.0 feet minimum
Side Slopes:	2:1 or flatter
Compaction:	Required. Compaction using the wheels or tracks of heavy equipment is adequate.
Grade:	Zero. Perimeter berm should be constructed parallel to the contour of the upland slope.

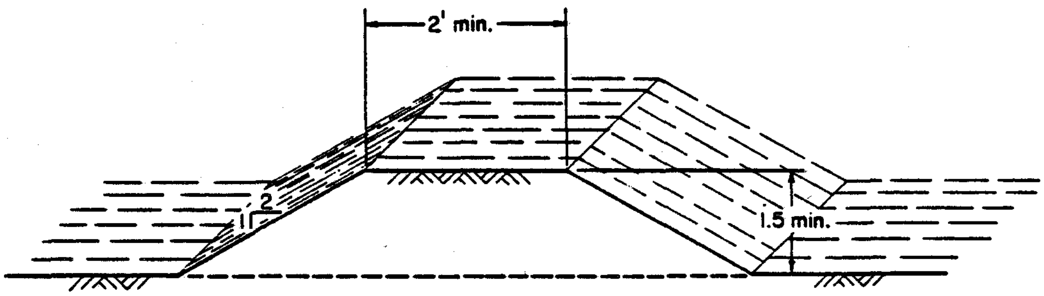
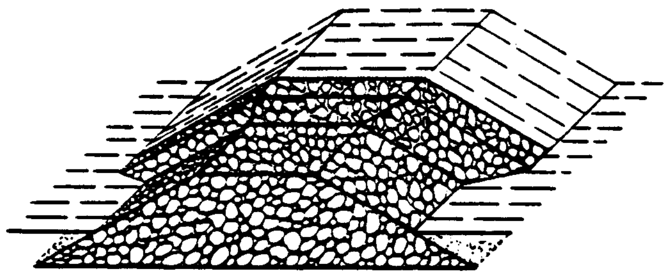


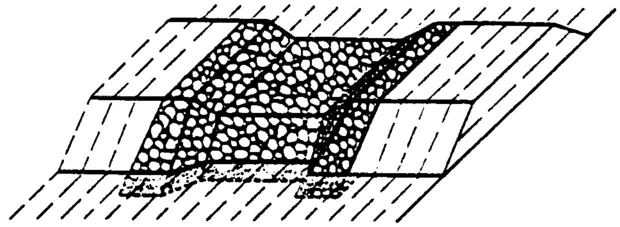
Figure 7.5. Typcial cross section of a perimeter berm.

Table 7.3. General Design Criteria for a Rock Outlet.

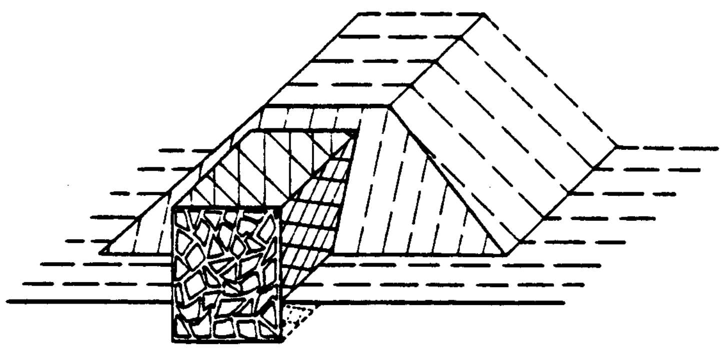
Height:	Minimum of 0.5 feet lower than the top of the perimeter berm
Topwidth:	2.0 feet minimum
Side Slopes:	2:1 or flatter
Material:	Riprap, 6 to 12 inches in diameter when high flows are possible, or crushed stone 2.0 inches or larger when only low flows are expected.



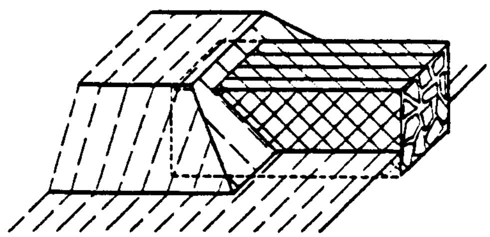
Typical riprap or gravel cross section



Riprap or gravel outlet



Typical gabion cross section



Gabion outlet

Figure 7.6. Rock outlet types.

Whenever possible, the detention structure should be built before other construction begins. The berm should be adequately compacted to prevent failure and stabilized with mulch and vegetation. The detention structure should be located in active mining areas to minimize possible damages by mining and reclamation operations. Deposited sediment should be removed from behind the structure after major storms or when one-third of the pond volume has been filled with sediment.

Rock outlets used with detention structures are permeable and should be expected to leak. They are not intended to trap sediments in the pore openings of the rock. The outflow rate can be greatly reduced by adding synthetic filter fabric over the rock (see Figure 7.7). Filter fabric will clog rapidly under these conditions and therefore must be inspected frequently and replaced when clogging is evident. Filter fabric should never be incorporated within a rock outlet since maintenance and inspection would be difficult.

In-Service Performance

Deposited sediment should be removed from behind the detention structure after major storms or when one-third of the pond volume has been filled with sediment. The detention structure should be designed with adequate room behind the structure to allow for easy access by equipment for cleaning. Detention structures should not be installed in locations where access by maintenance equipment is difficult.

When sediment is removed from a detention structure, the berm and rock outlet should be clearly marked to prevent damage to these areas by equipment. Flagged stakes should be placed along the inside edge of the berm (see Figure 7.8) so that the equipment operator can clearly gage the location of the berm and rock outlet.

If filter fabric is used in conjunction with a rock outlet, it should be replaced when sediment is removed from the pond. Filter fabric should be inspected after major storms for clogging.

Specifications

Materials used in the construction of detention structures are earth embankment, gravel, riprap, or gabions. Specifications for embankment for berm construction and gravel for rock outlets are given in section 6.6. Specifications for riprap and gabions used for constructing rock outlets are given on the following pages.

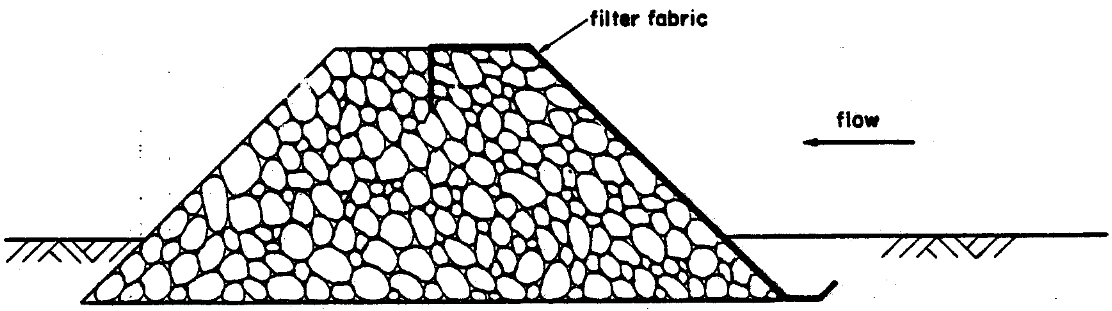


Figure 7.7. Rock outlet with filter fabric.

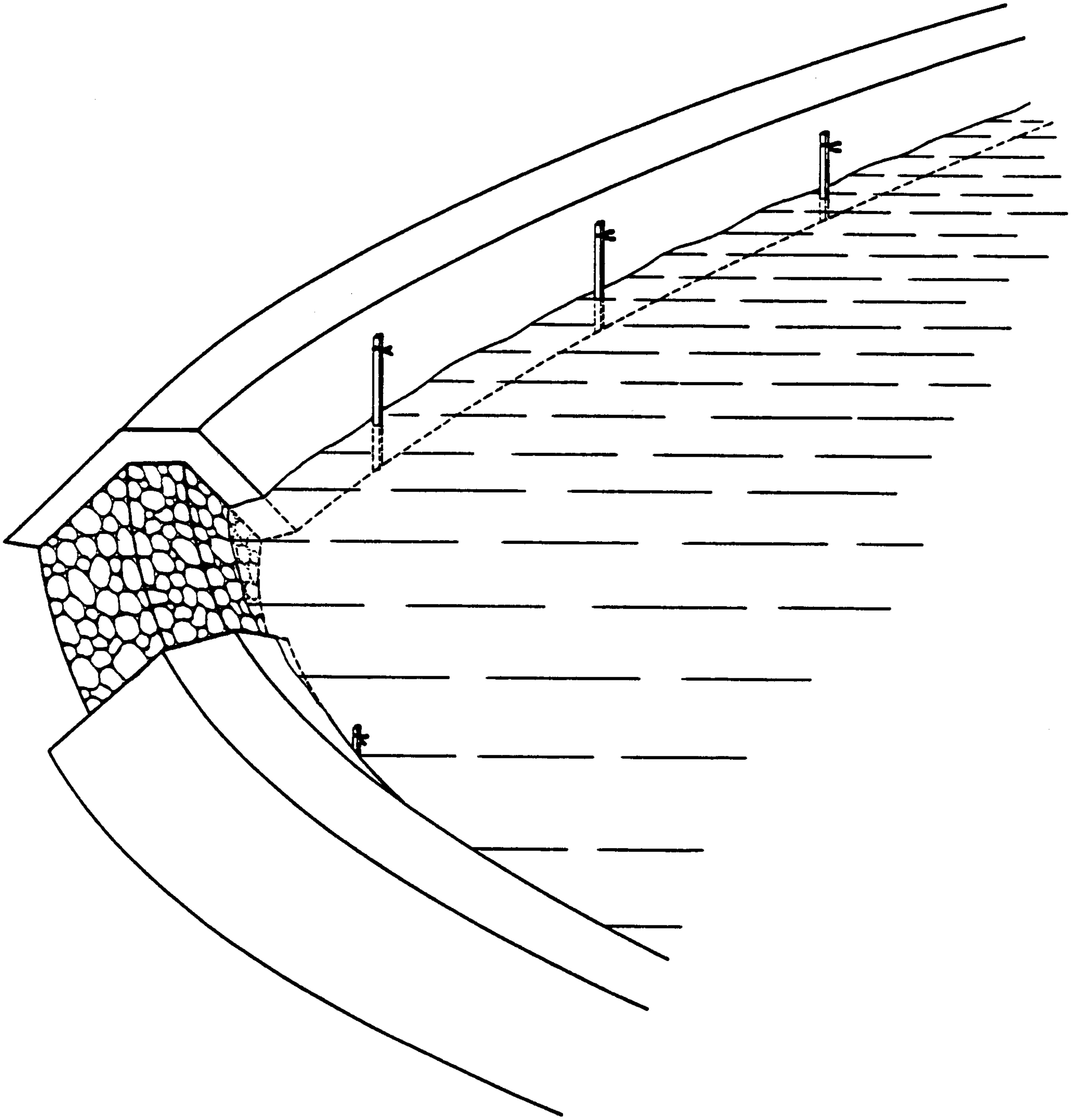


Figure 7.8. Flagging to protect berm and rock outlet during maintenance.

Specification - Riprap for Rock Outlets

Description. This work shall consist of construction of riprap in accordance with these specifications as shown on the plans or as directed.

Materials. Riprap shall consist of hard, dense, sound, rough fractured stone as nearly cubical as parcticable. Thin slab type stones and flaking rock shall not be used. The stone shall have a specific gravity of at least 2.25. Removed concrete may be used for riprap provided it meets the other requirements of this section and if approved. The size requirements for the two items of riprap are as follows:

Guide for Size Determination

Stone Size*	Volume (cu.ft.)	Weight (lbs)
6 in.	0.065	10
9 in.	0.22	30

*equivalent spherical diameter

Size of stone and arrangement of riprap shall be as shown on plans. Stone shall be well graded in order that the voids can be filled, and at least 50 percent of the mass shall be stones equal to or larger than the stone size called for on the plans. Stone size shall not be larger than twice the mean diameter of the riprap.

Construction Requirements. Riprap shall be placed to conform to the plan details. The spaces between the larger stones shall be filled with smaller stone of a suitable size. Riprap may be machine-placed with sufficient hand work to accomplish requirements of this specification.

Method of Measurement. Riprap will be measured by the cubic yard by the method of average end areas based on dimensions shown on the plans or ordered.

Basis of Payment. The accepted quantities will be paid for at the contract unit price for each of the pay items listed below that appear in the bid schedule.

Payment will be made under:

PAY ITEM	PAY UNIT
Riprap	Cubic Yard

Structure excavation will be measured and paid for separately.

Specification - Gabions

Description. This work shall consist of the construction of riprap in wire mesh gabions in accordance with these specifications as shown on the plans or directed.

Materials. Wire - All wire used in the manufacture and assembly of the mesh shall equal or exceed Federal Specification QQ-W-461G, Wire, Steel, Carbon (Round, Bare and Coated) including the following specific requirements: finish 5, class 3 weight of zinc coating. Wire mesh for Gabions (cage thickness 12 inches and greater) shall be 11 gage (U.S.), soft temper.

Tie and connecting wire shall be supplied for securely fastening all edges of the gabions and diaphrams. Gabions shall be provided with 4 cross connecting wires in each cell 1/2 unit high and 8 in each cell one unit high. Gabions shall also have inner tie wires connecting the front face to the rear face at approximate spacing of 12 inches in both vertical and horizontal dimensions. Tie wire shall meet the same specifications for wire used in the mesh except that tie wire for gabion cages shall not be more than 2 gages lighter.

All wire used, including tie and connecting wire, shall be certified by mill test report(s) showing compliance with specificatin requirements.

Riprap - Riprap shall consist of hard, dense, sound, rough fractured stone or local sandstone, as nearly cubical as practicable. Thin slab type stones and flaking rock shall not be used. Stone shall have a specific gravity of at least 2.25 and shall be resistant to the action of air and water. Flaking or fragmental rock will not be permitted.

The sizes of riprap stone for gabions and slope mattresses shall conform to the following:

	Stone Size
Gabions (cage thickness 12 inches or greater)	4 to 8 inches

Construction Requirements: Gabions shall be placed to conform with plan details. Riprap material shall be placed in close contact in the unit so that maximum fill is obtained. The units may be filled by machine with sufficient hand work to accomplish requirements of this specification.

Where the length of the unit exceeds its horizontal width, the gabion is to be equally divided by diaphragms, of the same mesh and gauge as the body, into cells whose length does not exceed the horizontal width. The unit shall be furnished with the necessary diaphragms secured in proper position on the base section in such a manner that no additional tying at this juncture will be necessary.

All perimeter edges of gabions are to be securely bound so that the joints formed by tying have approximately the same strength as the body of the mesh.

All gabion units shall be tied together each to its neighbor along all contacting edges in order to form a continuous connecting structure.

Method of Measurement. The quantity to be measured under this item will be the number of cubic yards of riprap required to fill the gabions in accordance with the dimensions shown on plans, or as ordered, completed and accepted.

Basis of Payment. The accepted quantity measured as provided above will be paid for at the contract unit price per cubic yard for gabions.

Payment will be made under:

PAY ITEM	PAY UNIT
Gabions	Cubic yards

Structure excavation and structure backfill will be measured and paid for separately.

7.4 Design of Filter Structures

Filter structures are temporary sediment barriers consisting of synthetic filter fabric or straw bales placed along the contour of a slope. Several designs are in common use and are presented in this manual. Filter fence is a linear filter barrier constructed of synthetic filter fabric, posts and, depending on the strength of the fabric used, wire fence. Brush barrier is a linear filter barrier which makes use of residue materials available from clearing and grubbing operations covered by synthetic filter fabric. A straw bale barrier consists of a row of entrenched and anchored straw bales.

Filter structures can be easily combined with other sediment control practices to form a complete sediment control system. These structures are very effective at reducing the amount of suspended sediment from an area. Filter fabrics have a low permeability and are limited to situations where unconcentrated, overland flows are expected. Filter structures are not able to handle the volumes of water generated by channel flows.

Design Information

Improperly constructed filter structures will have poor sediment trapping efficiency and high failure rates. Undercutting and end flow are two major problems with this type of structure. Careful installation and adequate maintenance are essential to the effectiveness of these sediment filters. Improper installation can result in increased erosion and damage from sediment. In general synthetic filter structures are easier to install correctly compared to straw bale barriers and may be preferable in many cases.

Installation procedures are presented for both synthetic fabric structures (filter fence and brush filter barrier) and straw bale barriers. All installations should be carefully inspected for defects after construction.

Installation Procedure - Filter Structures

In most cases the fabric should not extend to a height greater than 36 inches; higher heights may back up volumes of water sufficient to cause failure of the structure.

The procedure for installing filter fences are given below.

1. Set wood or steel posts securely at intervals no greater than 10 feet apart. Wood posts should be at least 3 inches in diameter; with steel, only the T-shaped posts should be used.

2. Fasten fence wire securely to the upstream side of the posts. Wire should extend into the soil a minimum of 2 inches, and be a minimum of 36 inches in height.

3. Excavate a trench 6 inches wide by 6 inches deep along the upstream base of the fence.

4. Staple or wire the filter fabric to the fence, allowing the fabric to extend into the trench as shown in Figure 7.9. The fabric should not extend over 36 inches above the original ground on the wire fence.

5. Backfill and compact the soil over the fabric extending into the trench.

6. If a filter fence is to be constructed across a ditch line or drainageway of low flow, the barrier should be of sufficient length to contain the design storm volume from the upland area.

7. The fence should be constructed parallel to the contours of the slope. The ends of the fence should bend upslope a sufficient distance to eliminate end flow as shown in Figure 7.10.

The procedures for installing brush filter barriers is similar to that for filter fence and is illustrated in Figure 7.11.

Installation Procedure - Straw Bale Barrier

The installation procedures for straw bale barriers are given below and are illustrated in Figure 7.12.

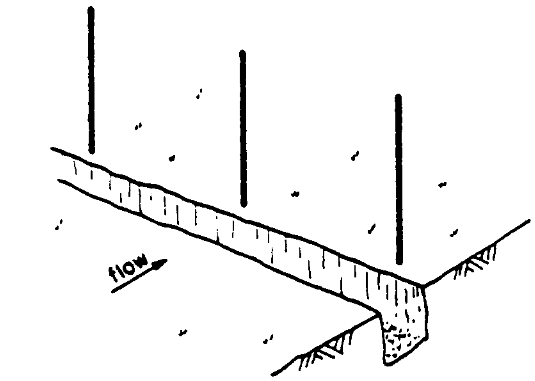
1. Excavate a trench the width of a bale and the length of the proposed barrier to a minimum depth of four inches.

2. Place bales tightly together in the trench. Drive two sturdy wooden stakes or steel rods through each bale and into the ground to a depth sufficient to securely anchor the bales.

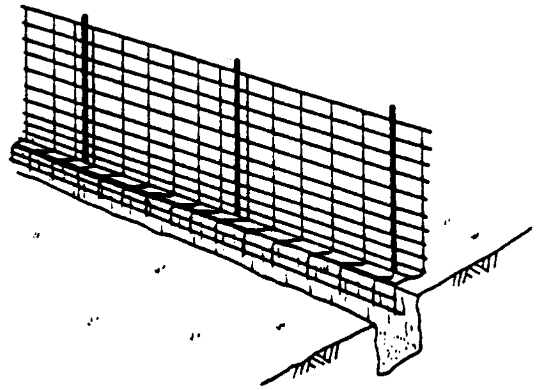
3. Wedge loose straw tightly between bales after staking.

4. Backfill and compact the excavated soil against the barrier. Backfilled soil should conform to ground level on the downstream side and should be built up to 4 inches against the upstream side of the barrier.

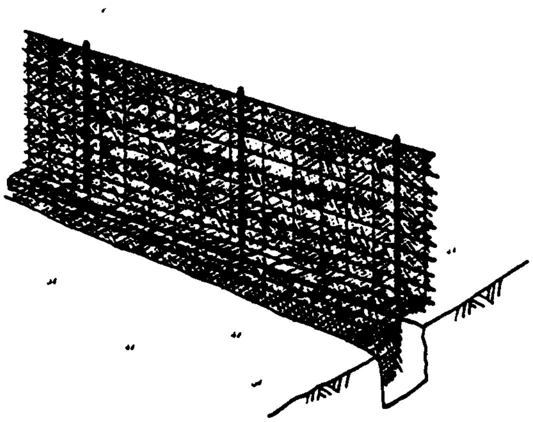
5. The straw bale barrier should be constructed parallel to the contours of the slope. The ends of the barrier should bend upslope a sufficient distance to eliminate end flow.



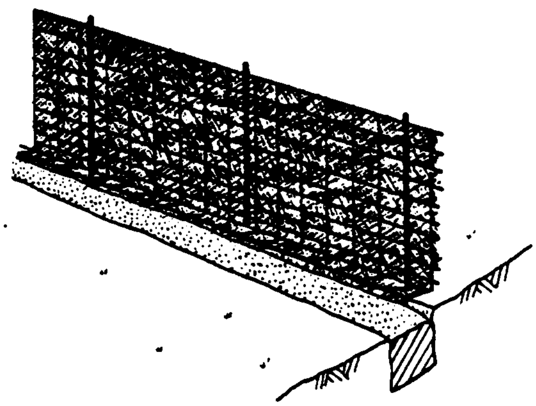
1. Set posts and excavate trench.



2. Tie wire fencing to posts



3. **Attach filter fabric to wire fence, allowing extension into trench as shown.**



4. Backfill and compact excavated soil.

Figure 7.9. Building a filter fence (after Virginia Soil and Water Conservation Commission, 1980).

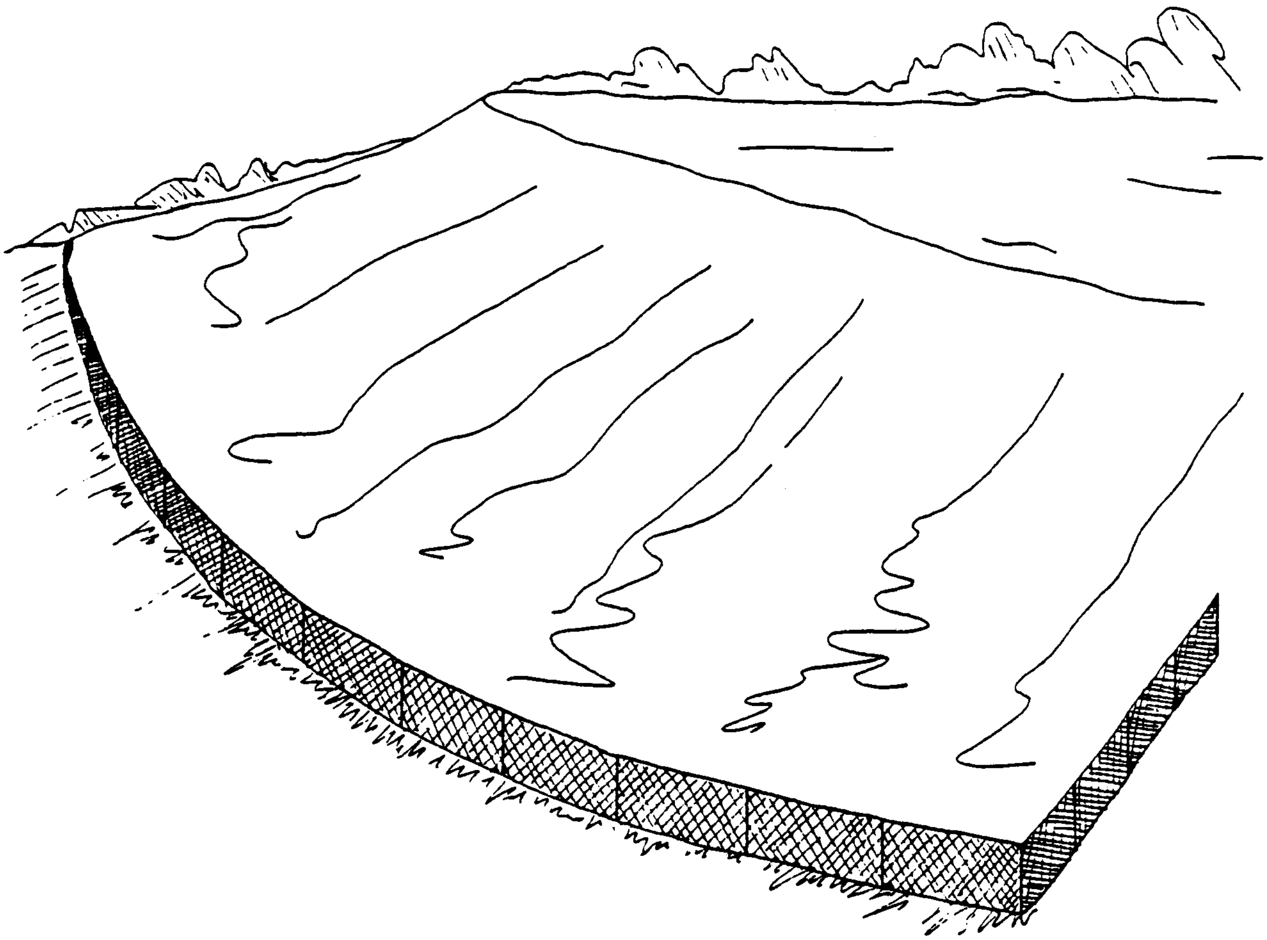
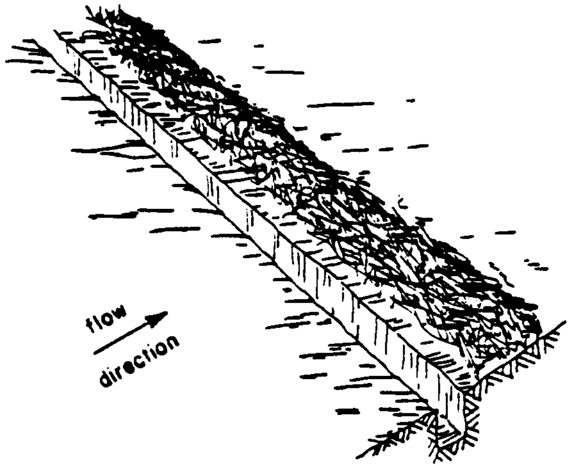
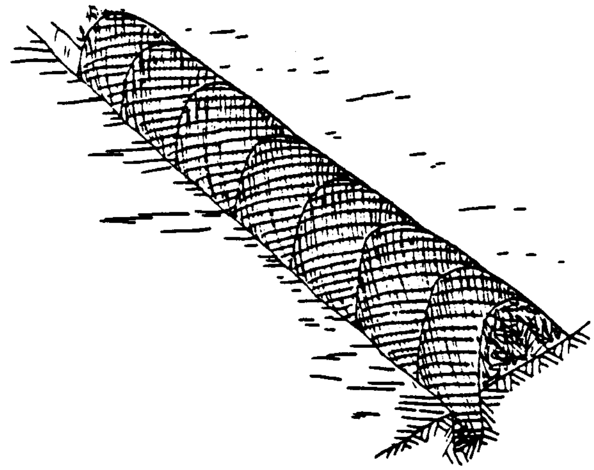


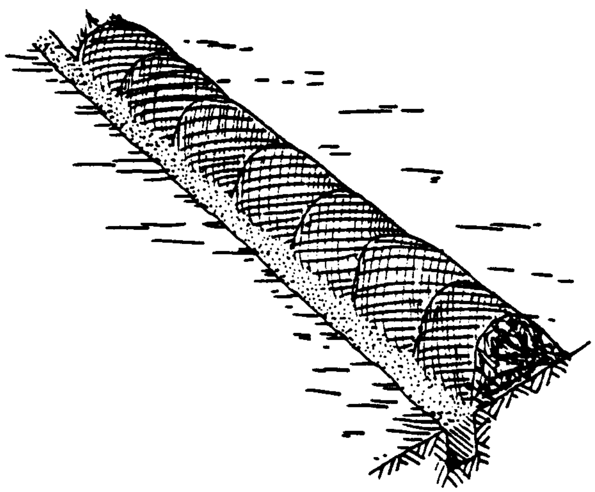
Figure 7.10. Filter fence application showing proper termination to prevent end flow.



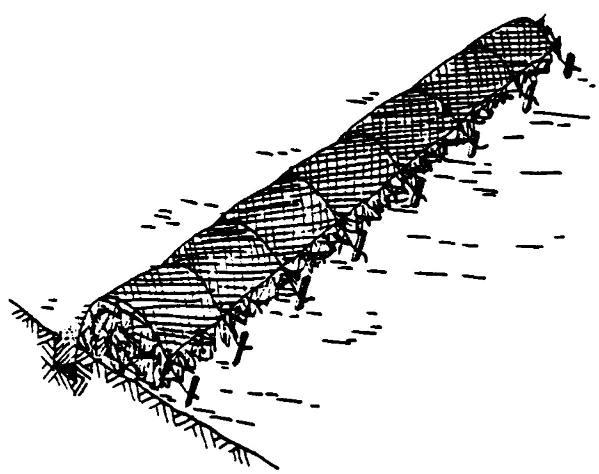
1. Excavate trench along uphill edge of brush barrier.



2. Drape filter fabric over brush barrier and into the trench.



3. Backfill and compact excavated soil.



4. Set stakes and tie down filter fabric along the downhill edge of the brush barrier.

Figure 7.11. Building a brush filter barrier (after Virginia Soil and Water Conservation Commission, 1980).

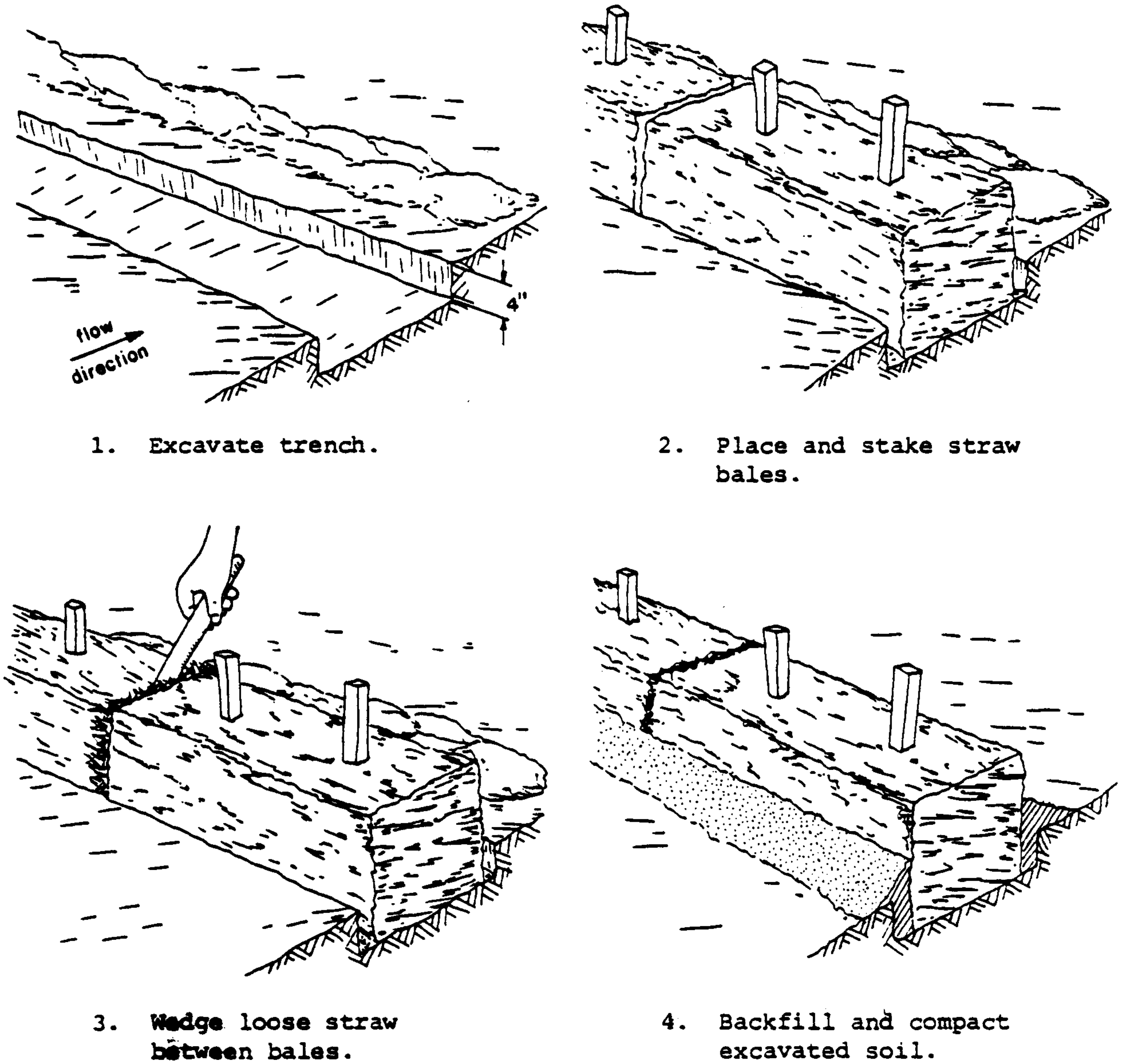


Figure 7.12. Installation of straw barrier (after Virginia Soil and Water Conservation Commission, 1980).

Planning Considerations

The use of filter structures must be limited to situations in which only low or moderate flows are to be intercepted. Use of these structures is specifically excluded for situations in which water is to be concentrated in a channel or drainageway. Experience has shown that use of straw bales as check structures in ditches has resulted in high failure rates. Rock check structures are recommended (see Chapter VI). It must be emphasized that while these structures are efficient sediment filters, they require more inspection and maintenance than most sediment control structures.

The filtering efficiency of straw bales is lower than that for synthetic fabric (see Figure 7.3). Filter structures may be preferable to straw bales because they are capable of ponding sediment laden water to a greater depth, therefore reducing the required length of the structure. Failure rates are lower for synthetic fabric structures compared to straw bale barriers, but poorly constructed fabric structures are not uncommon. Installation procedures must be followed carefully.

In-Service Performance

Deposited sediment should be removed from behind a filter structure after major storms or when one-third of the sediment trapping volume has been reached. Filter structures should not be installed in locations where access by maintenance equipment is difficult. Filter fabric should be checked after major storms for clogging and damage. Filter fabric will deteriorate from exposure to ultraviolet radiation and should be checked at regular intervals for reduced strength or tears.

During cleaning operations, care should be taken with equipment to prevent damage to the filter structure. If damage occurs, it should be repaired promptly. Repaired sections of filter fabric should be overlapped and bonded to existing sections to prevent leakage.

Specifications

This section gives specifications for filter fabric structures. The specification for synthetic fabric requires that fabric pass two tests developed by the Virginia Department of Transportation to determine filtering efficiency, flow rate, and strength. Since these are nonstandard tests, the procedures for conducting the test are given. Manufacturers are currently aware of these tests and some give the results in their published performance data or will comply with requests for this information.

No detailed specification is given for straw bales since these may vary with the type of machinery and straw used to form the bale. General guides to selecting a durable straw bale are: 1) the bale should be wire-bound around the sides, and 2) old or water logged bales should be avoided. Straw bales should be secured with wooden stakes (2 inches x 2 inches minimum) or rebar.

Specification - Filter Fence and Brush Filter Barrier

Description. This work shall consist of furnishing and installing filter fences and brush filter barriers in accordance with this provision and in reasonably close conformity with the lines, grades and details shown on the plans or established by the Engineer.

Materials. Filter cloth fabric shall be a pervious sheet of propylene, nylon, ester or ethylene yarn and shall be certified by the manufacturer or supplier as conforming to the following requirements:

PHYSICAL PROPERTY	TEST	REQUIREMENTS
Filtering Efficiency	Test 1	90% (Min.)
Flow Rate	Test 1	0.3 Gal./Sq.Ft./Min. (Min.)
*Tensile Strength @ 20% (Max.) Elongation	Test 2	Extra Strength 50 Lbs. per Linear Inch (Min.) Standard Strength 30 Lbs. per Linear Inch (Min.)

*Requirements reduced by 50% after 6 months of installation.

Filter cloth fabric for above ground use shall contain ultraviolet ray inhibitors and stabilizers to provide a minimum of 6 months of expected usable construction life at a temperature range of 0°F to 120°F.

Posts for filter fence shall be rough or finish 4 inches by 4 inches wood, 3 inches (minimum) diameter wood, or 1.33 pounds per linear foot (minimum) steel with a minimum length of 5 feet.

Wire fence reinforcement for filter fence using standard strength filter cloth fabric shall be a minimum of 36 inches in height, a minimum of 14-1/2 gage and shall have a mesh spacing of 6 inches or less.

Construction Requirements. Filter Fence shall be erected at locations shown on the plans or as approved or determined by the Engineer. The Contractor shall have the option to provide extra strength filter cloth fabric or to provide standard strength filter cloth fabric with a wire fence reinforcement. When standard strength filter cloth fabric is used for filter fence, the filter cloth fabric shall be reinforced with wire fence, and the post spacings shall not exceed 10 feet. When extra strength filter cloth fabric is used for filter fence, the post spacings shall not exceed 6 feet and the wire fence will not be required. Posts shall be uniformly installed with not less than 2° and not more than 20° inclination toward the potential silt load area. The attachment of fence fabric to existing trees will not be permitted unless approved by the Engineer. The filter fence shall be maintained in an effective condition at all times while in use.

Filter cloth fabric shall be a minimum of 45 inches wide and shall be secured to the post or fence by suitable staples, tie wire or hog rings in such a manner as to prevent tearing of the fabric. The bottom of the filter cloth shall be entrenched into the ground a minimum of 8 inches to prevent water from flowing under the fence. Filter cloth fabric shall be spliced together only at support posts with a minimum of 6 inch overlap and securely sealed. The top of the filter cloth fabric shall be installed with a 1 inch tuck or with a reinforced to end section.

In the event the filter cloth fabric has decomposed or becomes ineffective prior to 6 months after installation, the filter cloth fabric shall be replaced at the Contractor's expense to original design. In the event the filter cloth fabric has decomposed after 6 months from the installation date and the filter fence is still required as determined by the Engineer, the filter cloth fabric shall be replaced with equal material and will be paid for at one-half the contract unit price for the filter fence. Filter fence materials shall be removed when no longer required, as determined by the Engineer, and shall be disposed of by the Contractor.

Brush Filter Barriers: Brush barriers used along the down hill side of slopes shall have standard strength filter cloth fabric attached at specified locations to form a brush filter barrier. The bottom of the filter cloth shall be entrenched into the ground a minimum of 8 inches and the top of the filter cloth shall be installed with a 1 inch tuck or with a reinforced top end section.

Brush for brush filter barriers shall be installed prior to any major earth-disturbing activity and shall be trimmed sufficiently to prevent tearing or puncturing of the filter cloth. The top of the filter cloth shall be tied, stapled or otherwise secured to the top or slope of brush barrier such that the integrity of the silt barrier will be sound. Intermediate attachment of the filter cloth shall be with suitable ties or staples. A 6 inch overlap of cloth for vertical and horizontal splicing shall be maintained and tightly sealed.

The filter cloth fabric shall be maintained in accordance with the requirements for filter fence. When brush filter barriers are no longer required, as determined by the Engineer, the fabric shall be cut at ground height and disposed of by the Contractor.

Inspection and Maintenance: All filter fences and brush filter barriers shall be inspected immediately after each rainfall and at least daily during prolonged rainfall. Any deficiencies shall be immediately corrected. In addition, a daily review of the location for filter fences and brush filter barriers shall be made in areas where construction activity changes the earth contour and drainage runoff to ensure that the filter fences or brush filter barriers are properly located for effectiveness. Where deficiencies exist, additional filter fences or brush filter barriers shall be installed as approved or directed by the Engineer.

Sediment deposits shall be removed when the deposit reaches approximately one-third of the volume capacity of the filter fence or brush filter barrier as approved or directed by the Engineer and disposed of as directed by the Engineer. Any sediment deposits remaining in place after the temporary filter fence or brush filter barrier is no longer required shall be dressed to conform with the existing grade, prepared and seeded.

Method of Measurement. Filter fences will be measured in linear feet, complete-in-place. When the filter cloth fabric is required to be replaced after 6 months from the installation date, the replacement filter cloth fabric will be measured in linear feet of filter fence and paid for at one-half the contract unit price for filter fence.

Brush filter barriers will be measured in square yards of filter cloth complete-in-place, excluding laps. The brush filter barrier will not be measured for payment under this provision, but will be paid for separately.

Basis of Payment. The accepted quantity measured as provided above will be paid for at the contract unit price.

Payment will be made under:

PAY ITEM	PAY UNIT
Filter Fence	Linear foot
Brush Filter Barrier	Square yard

When silt cleanout is approved or directed by the Engineer, silt removal will be measured in cubic yards of vehicular measurement of haul and paid for separately.

Seeding materials will be measured and paid for separately.

TEST 1 - FILTERING EFFICIENCY AND FLOW RATE TEST

LABORATORY

1. Scope

This method is used to determine the filtering efficiency and flow rate of a filter fabric in the laboratory.

2. Apparatus

a. A flume 48 inches long by 32 inches wide by 12 inches high with a gutter attached to one side (see Figures 7.13 and 7.14).

b. Two 20-gallon containers.

c. A stirrer on a 1/4 inch portable drill.

d. Stopwatch.

e. A DH-48 integrated water sampler with ten 500 ml bottles.

3. Procedure

a. Stretch a sample of the fabric 39 inches long by 12 inches wide across the flume opening 32 inches wide and fasten securely in place to assure that all the sediment-laden water passes through the sample. Note: The flume opening is the standard length of a straw bale.

b. Elevate the flume to an 8 percent slope.

c. Take a depth integrated, suspended solids sample from an untreated, fairly sediment-free water supply. Continuously agitate the supply for uniformity during the sampling process.

d. Prewet the fabric by passing 50 litres of untreated, fairly sediment-free water through it.

e. Mix 150 grams of minus 10 material of a silty soil (see gradation curve, Figure 7.15) in 50 litres of the untreated water placed in one of the 20-gallon containers. Thoroughly agitate the solution with the stirrer on the 1/4 inche portable drill to obtain a uniform mix.

f. After uniformly mixing the solution, quickly dump the solution behind the fabric sample in the flume. Start the timer at dumping.

g. Rinse the mixing container with 1 to 2 litres of the filtrate and dump into the flume.

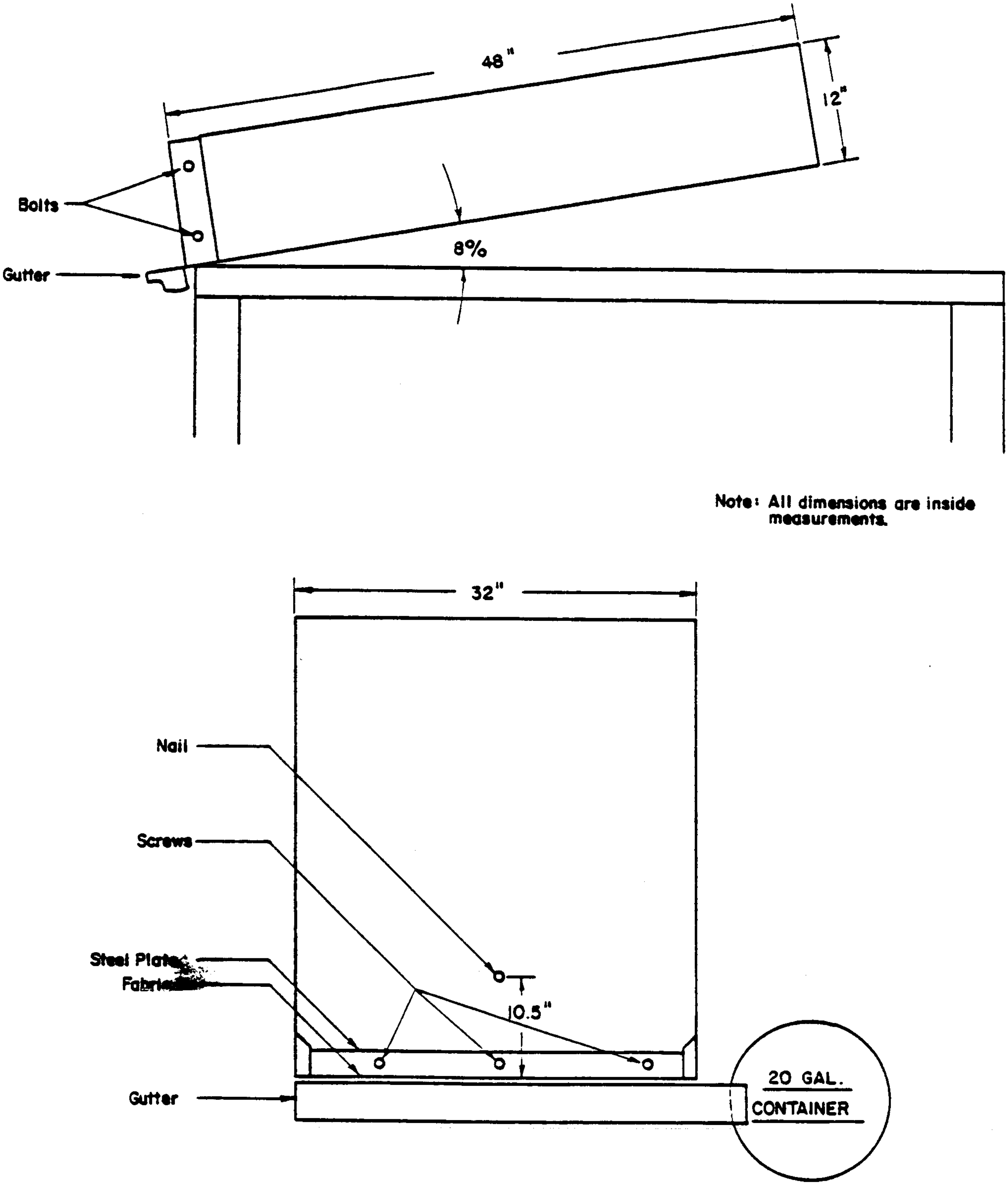
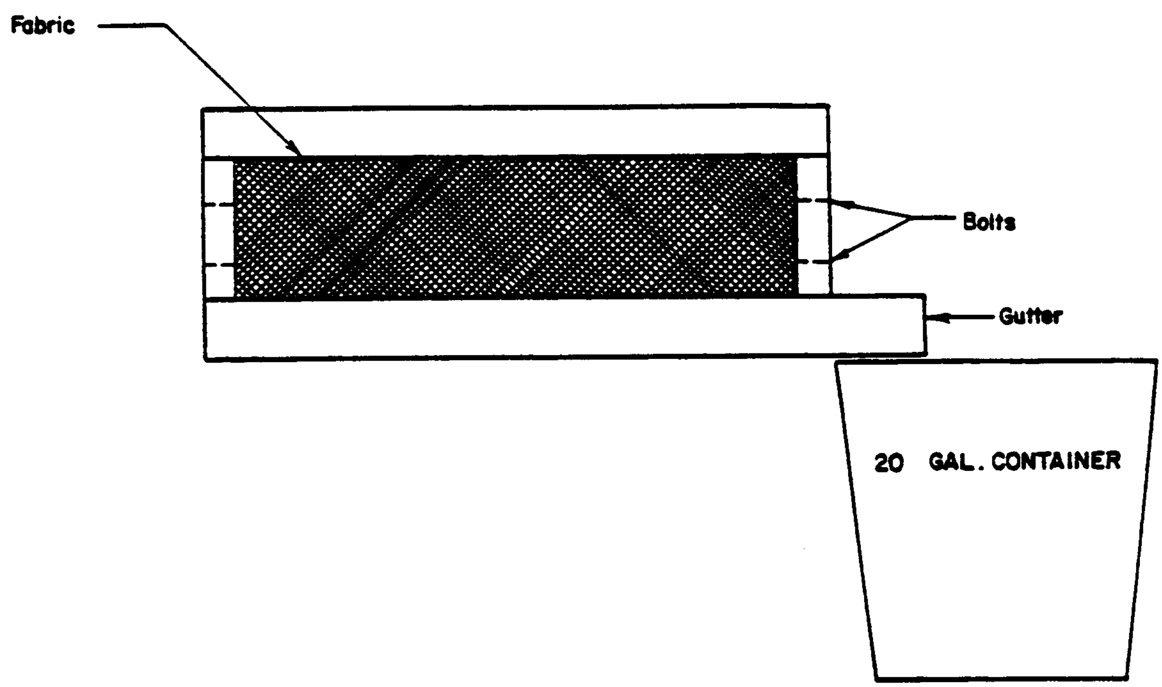


Figure 7.13. Side view (upper sketch) and top view of flume (after Virginia Soil and Water Conservation Commission, 1980).



Note: 2 Side plates and a bottom plate are used to fasten the sample of fabric in place.

Figure 7.14. End view of flume (after Virginia Soil and Water Conservation Commission, 1980).

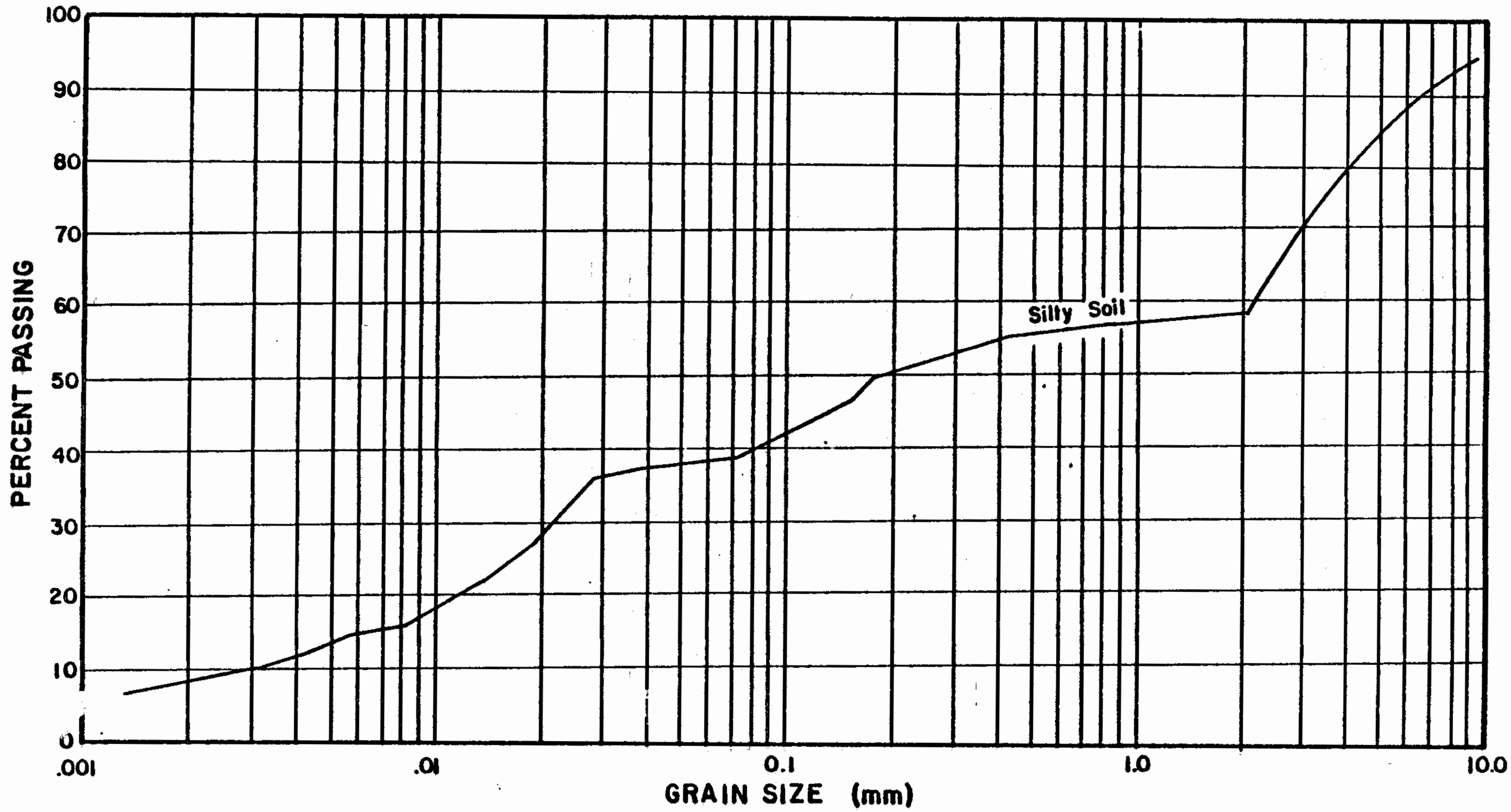


Figure 7.15. Gradation curve for soil used (after Virginia Soil and Water Conservation Commission, 1980).

h. Time the flow of water through the fabric until the water level drops to a point 10.5 inches behind the fabric. At this point the flow has essentially ceased.

i. Collect all filtrate in a second mixing container.

j. At the completion of the test, agitate the collected filtrate until the mixture is uniformly mixed. Obtain a depth integrated, suspended solids sample from the mixture during agitation.

k. Process the two suspended solids samples by the "nonfilterable residue" procedure described by the American Public Health Association, et al. (1981.

l. Calculate the filtering efficiency (FE) of the fabric as follows:

$$FE\ (\%) = \frac{(SS_{bg} + 3{,}000) - SS_{after}}{(SS_{bg} + 3{,}000)} \times 100,$$

where SS_{after} and SS_{bg} are the suspended solids value after filtration and the background level, respectively.

m. Calculate the flow rate of the fabric as follows:

$$\text{Flow rate (gal./ft.}^2\text{/min)} = 14.85/\text{time (min.)}$$

n. Repeat steps e through l for the same fabric sample twice more.

TEST 2 - STRENGTH TEST

1. Scope

This test determines the stress-strain relationship of a filter fabric.

2. Apparatus

A tensile test device with a capacity of approximately 2,500 lb. equipped with a dial that can be read in increments of 10 lb. or less. The device should have a rate of travel of 13 percent ± 2 percent of the gage length of the fabric per minute. The device shall have a travel distance of 20 inches minimum and hold a 7 inch wide sample.

3. Procedure

a. Cut a sample of the fabric in the direction perpendicular to the axis of the roll. The sample should be 27 inches long by 7 inches wide.

b. Securely fasten the sample of the fabric in the clamps of the testing device so the length of the fabric between the clamps is 14 inches.

c. Place the secured sample in the testing device.

d. Start the testing device and stopwatch simultaneously.

e. Take load and elongation readings every 15 seconds up to 2-1/2 minutes, or until failure has occurred, whichever comes first.

f. Plot the load on the vertical axis versus its corresponding elongation on the horizontal axis.

g. Determine the peak load value, if it occurs prior to 20 percent or 2.8 inches elongation. If the peak load does not occur before 20 percent elongation, then record the load at 20 percent elongation.

h. Repeat steps a through g for a sample cut in the direction perpendicular to the axis of the roll with a 1/2 inch long tear crossways in the middle of the sample.

i. Repeat steps a through g for a sample cut in the direction parallel to the axis of the roll.

7.5 Example Problems

Example Problem 7.1

Design a detention structure to control the sediment yield from the mechanically treated slope given in Example Problem 5.7. The topography of the area will allow a maximum detention structure length of 660 feet. The slope of the area immediately uphill of the planned structure location is 0.030. A ratio of berm length to rock outlet length of 100 will be used for a riprap rock outlet. All computations for this example problem are carried out on the attached worksheet.

Example Problem 7.1. Worksheet - Detention Structure.

Step One: Volume of Water and Sediment Yield

Rainfall Excess, P_e = 2.12 inches

Catchment Area, A = 10 acres

Actual Sediment Yield, G_y = 37.1 tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$= 3{,}630(2.12)(10) + 20.2(37.1)$$
$$= 77{,}705 \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = 2.0 feet

Duration of runoff, t_c = 17.0 hours

Flow rate per unit area, K_a = 2.20 ft/hr

Upland slope, S_x = 0.03

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$= 1/2(2.2)(17.0)(2.0)$$
$$= 37.4$$

Structure Length Coefficient, C_f = 118

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$
$$= 77{,}705/118$$
$$= 659 \text{ feet}$$

Actual structure length used, L_d = 660 feet

Example Problem 7.1. (continued)

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual[(1)] Sediment Yield G_y (tons)	Fall[(2)] Velocity w(ft/sec)	Trap[(3)] Efficiency e_s	Sediment[(4)] Trapped G_d (tons)
0.010	35.6	0.000227	0.75	26.7
0.0707	1.5	0.0115	0.99	1.5
0.316	0.0	0.129	1.00	0.0
1.414	0.0	0.391	1.00	0.0
Total	37.1	/////////	/////////	28.2

(1) From input data

(2) See Table 7.1 (Note needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4 (K_a/w) (L_f/L_d) S_x$

Rock outlet flow rate, K_a = 0.061 ft/sec

Rock outlet length, L_f = 6.6 feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4} L_d}{K_a L_f S_x}$$

$$= 12.0$$

$e_s = P_s$ from Figure 6.11

(4) $G_d = e_s G_y$

Example Problem 7.1. (continued)

Volume of sediment deposition

$\forall_s = 20.2\ G_d$

$= \underline{\quad 570 \quad}$ cu.ft.

Depth of sediment deposition

$d_d = \sqrt{2\forall_s S_x / L_d}$

$= \sqrt{2(570)(0.03)/660}$

$= \underline{0.228 \quad}$ feet

Step Four: Mean Concentration of Effluent

$C_s = 8{,}830\ (G_y - G_d)/P_e A$

$= 8{,}830(37.1 - 28.2)/(2.12)(10)$

$= \underline{3{,}560 \quad}$ ppm

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$d_f = d_d - 0.5$

$= \underline{\quad 0.0 \quad}$ feet

Total height

$H_d = d_{sw} + 0.5 + d_f$

$$H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f$$

$= 2.0 + 0.5 + 0.0$

$= \underline{2.5 \quad}$ feet

Example Problem 7.2

Design a filter fence structure to control sediment yield from the mechanically treated slope given in Example Problem 5.1. The topography of the area will allow a maximum filter fence length of 660 feet. The slope of the area immediately uphill of the planned structure location is 0.03. Computations for this example are given on the attached worksheet.

Example Problem 7.2. Detention and Filtering Structures.

Step One: Volume of Water and Sediment Yield

Total Rainfall Excess, P_e = 2.12 inches

Catchment Area, A = 10 acres

Total Sediment Yield, G_y = 37.1 tons

$$\forall_{sw} = 3{,}630\ P_e A + 20.2\ G_y$$
$$= 3{,}630(2.12)(10) + 20.2(37.1)$$
$$= 77{,}705 \text{ cu.ft.}$$

Step Two: Minimum Structure Length

Maximum Allowable Ponded Depth, d_{max} = 2.0 feet

Duration of runoff, t_c = 17.0 hours

Flow rate per unit area, K_a = 2.4 ft/hr

Upland slope, S_x = 0.03

Detention Parameter

$$K_f = 1/2\ K_a\ t_e\ d_{max}$$
$$= 1/2(2.4)(17.0)(2.0)$$
$$= 40.8$$

Structure Length Coefficient, C_f = 122

Minimum Structure Length

$$L_{min} = \forall_{sw}/C_f$$
$$= 77{,}705/122$$
$$= 636 \text{ feet}$$

Actual structure length used, L_d = 660 feet

Example Problem 7.2. (continued).

Step Three: Sediment Trapping Efficiency

Sediment Size (mm)	Actual Sediment Yield G_y (tons) [1]	Fall Velocity w(ft/sec) [2]	Trap Efficiency e_s [3]	Sediment Trapped G_d (tons) [4]
0.010	35.6	---	0.98	34.9
0.0707	1.5	---	1.00	1.5
0.316	0.0	---	1.00	0.0
1.414	0.0	---	1.00	0.0
Total	37.1	/////////	/////////	36.4

(1) From input data

(2) See Table 7.1 (Note needed for filter structures)

(3) For Filter Structures see Figure 7.2

For Detention Structures:

For Sand Sizes:

$e_s = 1 - 4 (K_a/w) (L_f/L_d) S_x$

Rock outlet flow rate, K_a = ___---___ ft/sec

Rock outlet length, L_f = ___---___ feet

For the silt size:

$$C_w = \frac{2.2 \times 10^{-4} L_d}{K_a L_f S_x}$$

= ___---___

$e_s = P_s$ from Figure 6.11

(4) $G_d = e_s G_y$

Example Problem 7.2. (continued).

Volume of sediment deposition

$\forall_s = 20.2\ G_d$

Depth of sediment deposition

$d_d = \sqrt{2\forall_s S_x / L_d}$

$= \sqrt{2(570)(0.03)/660}$

$=$ <u>0.18</u> feet

Step Four: Mean Concentration of Effluent

$C_s = 8{,}830\ (G_y - G_d)/P_e A$

$= 8{,}830(37.1 - 36.4)/(2.12)(10)$

$=$ <u>292</u> ppm

Step Five: Required Structure Height

If d_d is greater than 0.5 feet then add additional freeboard, d_f

$d_f = d_d - 0.5$

$=$ <u>0.0</u> feet

Total height

$$H_d = \sqrt{\frac{L_{min}}{L_d}}\ d_{max} + 0.5 + d_f$$

$$= \sqrt{\frac{636}{660}}\ (2.0) + 0.5$$

$=$ <u>2.46</u> feet

Discussion of Example Problem Results

The sediment yield for the two previous problems was primarily in the silt size range. The gravel rock outlet reduces outflow from the detention structure and provides a silt detention efficiency of 24 percent. The filter fence traps silt in the pore openings of the fabric and provides a 62 percent filter efficiency. The five-foot long gravel rock outlet used in Problem 7.1 is the smallest size outlet structure which could be realistically constructed and properly maintained.

In general, the cost of a detention structure will be less than that of a filter structure since materials for construction are readily available. Sediment trapping efficiency of filter structures, however, is much higher.

7.6 References

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