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INDEX

RUNOFF CONVEYANCE MEASURES

6.30

GL

GRASS-LINED CHANNELS

Definition

A channel with vegetative lining constructed to design cross section and grade for conveyance of runoff.

Purpose

To convey and dispose of concentrated surface runoff without damage from erosion, deposition, or flooding.

Conditions Where Practice Applies

This practice applies to construction sites where:

- concentrated runoff will cause damage from erosion or flooding;
- a vegetative lining can provide sufficient stability for the channel cross section and grade;
- slopes are generally less than 5%; and
- space is available for a relatively large cross section.

Typical uses include roadside ditches, channels at property boundaries, outlets for diversions, and other channels and drainage of low areas.

Planning Considerations

LOCATION

Generally, channels should be located to conform with and use the natural drainage system. Channels may also be needed along development boundaries, roadways, and backlot lines. Avoid channels crossing watershed boundaries or ridges.

Plan the course of the channel to avoid sharp changes in direction or grade. Site development should conform to natural features of the land and use natural drainageways rather than drastically reshape the land surface. Major reconfiguration of the drainage system often entails increased maintenance and risk of failure.

Grass-lined channels must not be subject to sedimentation from disturbed areas.

An established grass-lined channel resembles natural drainage systems and, therefore, is usually preferred if design velocities are below 5 ft/sec. Velocities up to 6 ft/sec can be safely used under certain conditions (Table 8.05a, *Appendix 8.05*).

Establishment of a dense, resistant vegetation is essential. Construct and vegetate grass-lined channels early in the construction schedule before grading and paving increase the rate of runoff.

Geotextile fabrics or special mulch protection such as fiberglass roving or straw and netting provide stability until the vegetation is fully established. These protective liners must be used whenever design velocities exceed 2 ft/sec for bare soil conditions. It may also be necessary to divert water from the channel until vegetation is established, or to line the channel with sod. Sediment traps may be needed at channel inlets and outlets.

V-shaped grass channels generally apply where the quantity of water is small, such as in short reaches along roadsides. The V-shaped cross section is least desirable because it is difficult to stabilize the bottom where velocities may be high.

Parabolic grass channels are often used where larger flows are expected and space is available. The swale-like shape is pleasing and may best fit site conditions.

Trapezoidal grass channels are used where runoff volumes are large and slope is low so that velocities are nonerosive to vegetated linings.

Subsurface drainage, or riprap channel bottoms, may be necessary on sites that are subject to prolonged wet conditions due to long duration flows or high water tables (Practice 6.81, *Subsurface Drain* and Practice 6.31, *Riprap-lined and Paved Channels*).

OUTLETS
Outlets must be stable. Where channel improvement ends, the exit velocity for the design flow must be nonerosive for the existing field conditions. Stability conditions beyond the property boundary should always be considered (Practice 6.41, *Outlet Stabilization Structure*).

AREA
Where urban drainage area exceeds 10 acres, it is recommended that grass-lined channels be designed by an engineer experienced in channel design.

Design Criteria

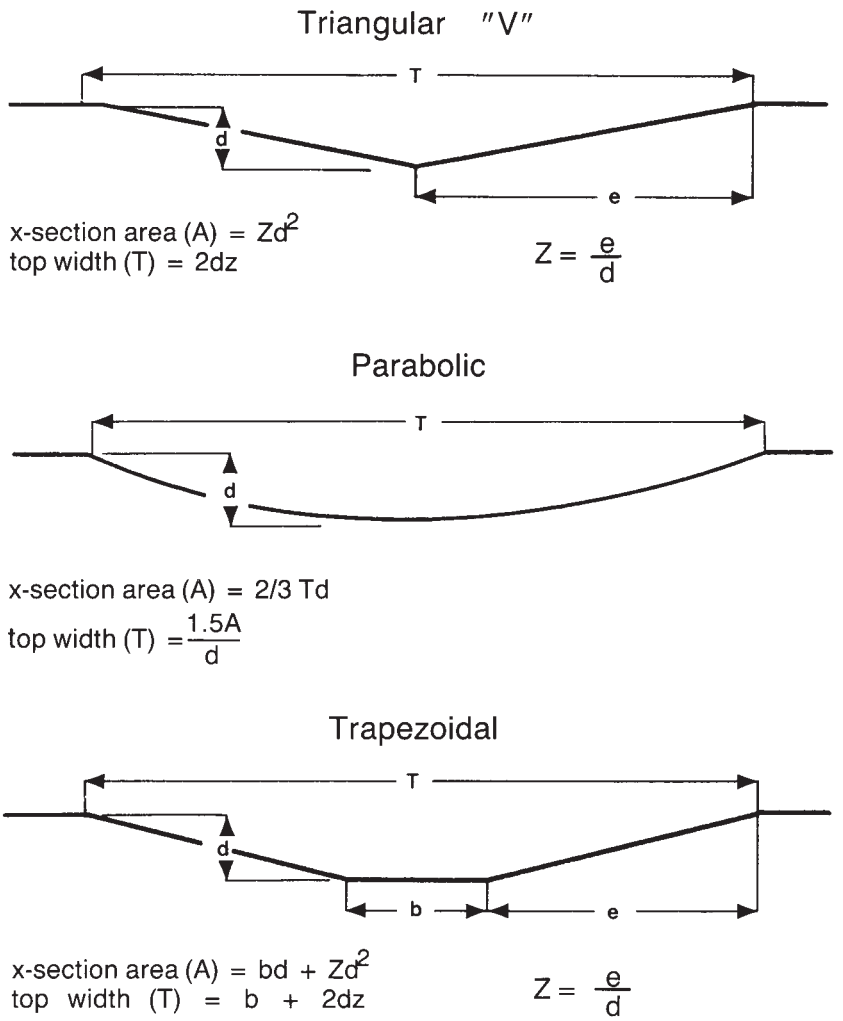
Capacity—At a minimum, grass-lined channels should carry peak runoff from the 10-year storm without eroding. Where flood hazard exists, increase the capacity according to the potential damage. Channel dimensions may be determined by using design tables with appropriate retardance factors or by Manning's formula using an appropriate "n" value. When retardance factors are used, the capacity is usually based on retardance "C" and stability on retardance "D" (*References: Appendix, 8.05*).

Velocity—The allowable design velocity for grass-lined channels is based on soil conditions, type of vegetation, and method of establishment (Table 8.05a, *Appendix 8.05*).

If design velocity of a channel to be vegetated by seeding exceeds 2 ft/sec, a temporary channel liner is required. The design of the liner may be based on peak flow from a 2-year storm. If vegetation is established by sodding, the permissible velocity for established vegetation shown in Table 8.05a may be used and no temporary liner is needed. Whether a temporary lining is required or not permanent channel linings must be stable for the 10-year storm. A design approach based on erosion resistance of various liner materials developed by the Federal Highway Administration is presented in *Appendix 8.05*.

Cross section—The channel shape may be parabolic, trapezoidal, or V-shaped, depending on need and site conditions (Figure 6.30a).

Figure 6.30a Cross section geometry of triangular, parabolic, and trapezoidal channels.



Hydraulic grade line—Examine the design water surface if the channel system becomes complex.

Side slopes—Grassed channel side slopes generally are constructed 3:1 or flatter to aid in the establishment of vegetation and for maintenance. Side slopes of V-shaped channels are usually constructed 6:1 or flatter along roadways for safety.

Depth and width—The channel depth and width are proportioned to meet the needs of drainage, soil conditions, erosion control, carrying capacity, and site conditions. Construct channels a minimum of 0.2 foot larger around the periphery to allow for soil bulking during seedbed preparations and sod buildup.

Grade—Either a uniform or gradually increasing grade is preferred to avoid sedimentation. Where the grade is excessive, grade stabilization structures may be required or channel linings of riprap or paving should be considered (Practice 6.82, *Grade Stabilization Structure*).

Drainage—Install subsurface drains in locations with high water tables or seepage problems that would inhibit establishment of vegetation in the channel. Stone channel bottom lining may be needed where prolonged low flow is anticipated.

Outlets—Evaluate the outlets of all channels for carrying capacity and stability, and protect them from erosion by limiting the exit velocity (Practice 6.41, *Outlet Stabilization Structure*).

Sedimentation protection—Protect permanent grass channels from sediment produced in the watershed, especially during the construction period. This can be accomplished by the effective use of diversions, sediment traps, protected side inlets, and vegetative filter strips along the channel.

Construction Specifications

1. Remove all trees, brush, stumps, and other objectionable material from the foundation area, and dispose of properly.

2. Excavate the channel, and shape it to neat lines and dimensions shown on the plans plus a 0.2-foot overcut around the channel perimeter to allow for bulking during seedbed preparations and sod buildup.

3. Remove and properly dispose of all excess soil so that surface water may enter the channel freely.

4. The procedure used to establish grass in the channel will depend upon the severity of the conditions and selection of species. Protect the channel with mulch or a temporary liner sufficient to withstand anticipated velocities during the establishment period (*Appendix 8.05*).

Maintenance

During the establishment period, check grass-lined channels after every rainfall. After grass is established, periodically check the channel; check it after every heavy rainfall event. Immediately make repairs. It is particularly important to check the channel outlet and all road crossings for bank stability and evidence of piping or scour holes. Remove all significant sediment accumulations to maintain the designed carrying capacity. Keep the grass in a healthy, vigorous condition at all times, since it is the primary erosion protection for the channel (Practice 6.11, *Permanent Seeding*).

References

Surface Stabilization
- 6.11, Permanent Seeding
- 6.12, Sodding
- 6.14, Mulching

Outlet Protection
- 6.41, Outlet Stabilization Structure

Other Related Practices
- 6.81, Subsurface Drain
- 6.82, Grade Stabilization Structure

Appendices

8.02, Vegetation Tables
8.03, Estimating Runoff
8.05, Design of Stable Channels and Diversions

6.31

RIPRAP AND PAVED CHANNELS

Definition

Channels with erosion-resistant linings of riprap, paving, or other structural material designed for the conveyance and safe disposal of excess water.

Purpose

To convey concentrated surface runoff without erosion.

Conditions Where Practice Applies

This practice applies where design flow velocity exceeds 2 ft/sec so that a channel lining is required, but conditions are unsuitable for grass-lined channels. Specific conditions include:

- Channels where slopes over 5% predominate; continuous or prolonged flows occur; potential for damage from traffic (people or vehicles) exists; or soils are erodible, and soil properties are not suitable for vegetative protection.
- Design velocity exceeds that allowable for a grass-lined channel.
- Property value justifies the cost to contain the design runoff in a limited space.
- Channel setting warrants the use of special paving materials.

Planning Considerations

Riprap or paving materials are generally employed as channel liners when design flow velocities exceed the tolerance of grass or where grass lining is inappropriate (Practice 6.30, *Grass-lined Channels*).

Flexible liners are preferred to rigid liners, and riprap is the flexible liner of choice. Riprap is preferred primarily on the basis of cost, but it has several additional advantages such as:

- Riprap liners can be designed to withstand most flow velocities by choosing stable stone size.
- Riprap adjusts to unstable foundation conditions without failure.
- Failure of a riprap liner is not as expensive to repair as a rigid liner would be.
- The roughness of riprap reduces outlet velocity, and tends to reduce flow volume by allowing infiltration.

Rigid liners such as concrete or flagstone can carry large volumes of water without eroding. However, they are more expensive to design and construct, are less forgiving of foundation conditions, and introduce high energies that must be controlled and dissipated to avoid damage to channel outlets and receiving streams.

Channels combining grassed side slopes and riprap or paved bottoms may be used where velocities are within allowable limits for grass lining along the channel sides, but long-duration flows, seepage, or a high velocity flow would damage vegetation in the channel bottom.

Paving blocks and gabions have some of the same characteristics as riprap, and are often used instead of riprap to fit certain site conditions.

Channels with smooth liners, such as concrete or flagstone, usually are not limited by velocity, take up less land area, and can be constructed to fit limited site conditions. In addition, they provide a more formal appearance and usually require less maintenance. Exercise care to see that foundation soils are stable, and proper foundation drainage is installed. Appropriate measures are needed to reduce the exit velocity of the paved channel to protect the receiving channel or outlet.

Where urban drainage area exceeds 10 acres it is recommended that riprap and paved channels be designed by an engineer experienced in channel design.

Design Criteria

Capacity—Design channels to contain the peak runoff from the 10-year storm as a minimum. Where flood damage potential is high, expand the capacity to the extent of the value or hazard involved.

Velocity—Compute velocity using Manning's equation with an appropriate *n* value for the selected lining. Values for Manning's *n* are shown in Table 6.31a.

Table 6.31a
Guide for Selecting Manning *n* Values

Lining Material	*n*
Concrete:	
Trowel finish	0.012-0.014
Float finish	0.013-0.017
Gunite	0.016-0.022
Flagstone	0.020-0.025
Paving blocks	0.025
Riprap	Determine from Table 8.05f
Gabion	0.025-0.030

Channel gradient—When the Froude Number is between 0.7 and 1.3, channel flows may become unstable and the designer should consider modifying the channel slope. Reaches designed for supercritical flow should be straight unless special design procedures are used.

$$FR = \frac{\sqrt{Q^2B}}{gA^3}$$

where:

FR = Froude Number, dimensionless
Q = Discharge, ft^3/sec
B = Water surface width, ft
g = 32.2 ft/sec^2
A = Cross-sectional area, ft^2

Cross section—The cross section may be triangular, parabolic, or trapezoidal. Reinforced concrete or gabions may be rectangular (Figure 6.31a).

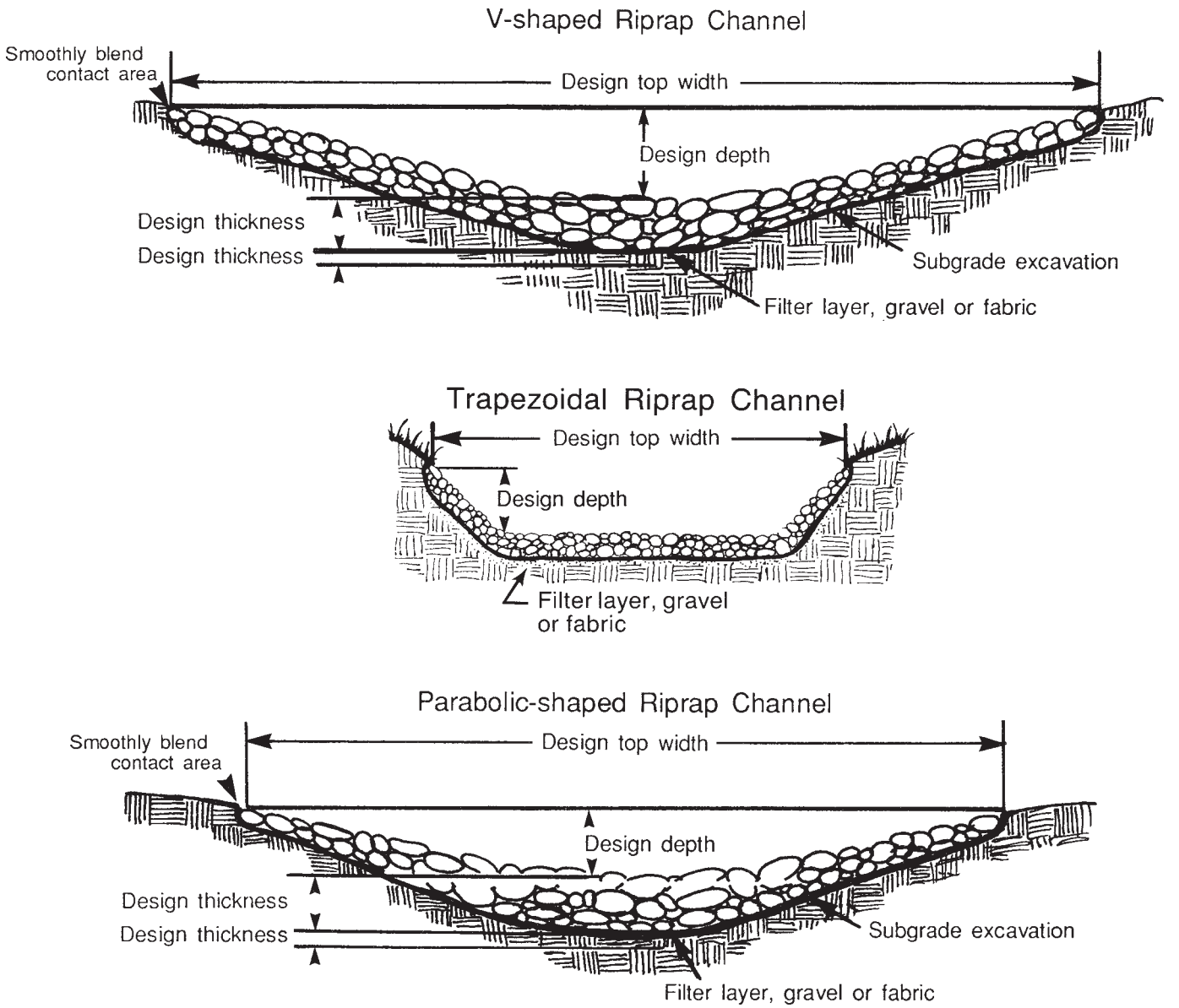


Figure 6.31a Construction detail of riprap channel cross sections.

Side slope—Base side slopes on the materials and placement methods in Table 6.31b.

Hydraulic grade line—Ensure that the design water surface in the channel meets the design flow elevations of tributary channels and diversions. Ensure that it is below safe flood elevations for homes, roads, or other improvements.

Table 6.31b
Guide for Selecting Channel Side Slopes

	Maximum Slope
Nonreinforced Concrete	
Formed Concrete	
Height of lining 1.5 ft or less	vertical
Screeded concrete or flagstone mortared in place	
Height of lining less than 2 ft	1:1
Height of lining more than 2 ft	2:1
Slip form concrete	
Height of lining less than 3 ft	1:1
Riprap and Paving Blocks	2:1

Depth and width—Proportion the channel depth and width to meet the needs of drainage, carrying capacity, foundation limitations, and specific site conditions.

Lining thickness—Minimum lining thickness should be as shown in Table 6.31c.

Filter layer—A sand/gravel filter layer should be used under the channel lining to prevent piping and reduce uplift pressure (*Appendix 8.05*).

Riprap—For the design of riprap channels see *Appendix 8.05*.

Concrete—Concrete for linings should be a dense, durable product sufficiently plastic for thorough consolidation, but stiff enough to stay in place on side slopes. As a minimum, use a mix certified as 3,000 lb/inch^2.

Cutoff—Cutoff walls are needed at the beginning and end of paved or riprapped channel sections to protect against undercutting. Expansion joints and additional cutoff walls may also be needed.

Outlets—Evaluate the capacity and stability of all channel outlets and protect them from erosion by limiting exit velocity (Practices 6.40, *Level Spreader* and 6.41, *Outlet Stabilization Structure*).

Table 6.31c
Channel Lining Thickness

Material	Minimum Thickness
Concrete	4 inches
Rock riprap	1.5 times maximum stone diameter
Flagstone	4 inches including mortar

Construction Specifications

1. Clear the foundation area of trees, stumps, roots, loose rock, and other objectionable material.

2. Excavate the cross section to the lines and grades of the foundation of the liner as shown on the plans. Bring over-excavated areas to grade by increasing the thickness of the liner or by backfilling with moist soil compacted to the density of the surrounding material.

3. Concrete linings:

- Place concrete linings to the thickness shown on the plans and finish them in a workmanlike manner.
- Take adequate precautions to protect freshly placed concrete from extreme temperatures to ensure proper curing.
- Ensure that subgrade is moist when concrete is poured.
- Install foundation drains or weep holes where needed to protect against uplift and piping.
- Provide transverse (contraction) joints to control cracking at approximately 20-feet intervals. These joints may be formed by using a 1/2-inch thick removable template or by sawing to a depth of at least 1 inch.
- Install expansion joints at intervals not to exceed 100 feet.

4. Rock riprap linings: Practice 6.15, *Riprap*.

5. Place filters, beddings, and foundation drains to line and grade in the manner specified. Place filter and bedding materials immediately after slope preparation. For synthetic filter fabrics, overlap the downstream edge by at least 12 inches with the upstream edge which is buried a minimum 12 inches in a trench. See figure 6.14a, page 6.14.6. Space anchor pins every 3 feet along the overlap. Spread granular materials in a uniform layer. When more than one gradation is required, spread the layers so there is minimal mixing. Filter material should consist of at least 3 inches of material on all sides of the drain pipe. The drain pipe conduit should be a minimum of 4 inches in diameter. Acceptable materials include perforated, continuous, closed-joint conduits of clay, concrete, metal, plastic, or other suitable material (Practice 6.81, *Subsurface Drain*).

6. Perform all channel construction to keep erosion and water pollution to a minimum. Immediately upon completion of the channel, vegetate all disturbed areas or otherwise protect them against soil erosion. Where channel construction will take longer than 30 days, stabilize channels by reaches.

Maintenance

Inspect channels at regular intervals as well as after major rains, and make repairs promptly. Give special attention to the outlet and inlet sections and other points where concentrated flow enters. Carefully check stability at road crossings, and look for indications of piping, scour holes, or bank failures. Make repairs immediately. Maintain all vegetation adjacent to the channel in a healthy, vigorous condition to protect the area from erosion and scour during out-of-bank flow.

References

Surface Stabilization
6.11, Permanent Seeding
6.15, Riprap

Runoff Conveyance Measures
6.30, Grass-lined Channels

Outlet Protection
6.41, Outlet Stabilization Structure

Other Related Practices
6.81, Subsurface Drain

Appendices
8.03, Estimating Runoff
8.05, Design of Stable Channels and Diversions

6.32

TSD

TEMPORARY SLOPE DRAINS

Definition

A flexible tubing or conduit extending temporarily from the top to the bottom of a cut or fill slope.

Purpose

To convey concentrated runoff down the face of a cut or fill slope without causing erosion.

Conditions Where Practice Applies

This practice applies to construction areas where stormwater runoff above a cut or fill slope will cause erosion if allowed to flow over the slope. Temporary slope drains are generally used in conjunction with diversions to convey runoff down a slope until permanent water disposal measures can be installed.

Planning Considerations

There is often a significant lag between the time a cut or fill slope is graded and the time it is permanently stabilized. During this period, the slope is very vulnerable to erosion, and temporary slope drains together with temporary diversions can provide valuable protection (Practice 6.20, *Temporary Diversions*).

It is very important that these temporary structures be sized, installed, and maintained properly because their failure will usually result in severe erosion of the slope. The entrance section to the drain should be well entrenched and stable so that surface water can enter freely. The drain should extend downslope beyond the toe of the slope to a stable area or appropriately stabilized outlet.

Other points of concern are failure from overtopping from inadequate pipe inlet capacity and lack of maintenance of diversion channel capacity and ridge height.

Design Criteria

Capacity—Peak runoff from the 10-year storm.

Pipe size—Unless they are individually designed, size drains according to Table 6.32a.

Table 6.32a
Size of Slope Drain

Maximum Drainage Area per Pipe (acres)	Pipe Diameter (inches)
0.50	12
0.75	15
1.00	18
>1.00*	as designed

*Inlet design becomes more complex beyond this size.

Conduit—Construct the slope drain from heavy-duty, flexible materials such as nonperforated, corrugated plastic pipe or specially designed flexible tubing (Figure 6.32a). Install reinforced, hold-down grommets or stakes to anchor the conduit at intervals not to exceed 10 ft with the outlet end securely fastened in place. The conduit must extend beyond the toe of the slope.

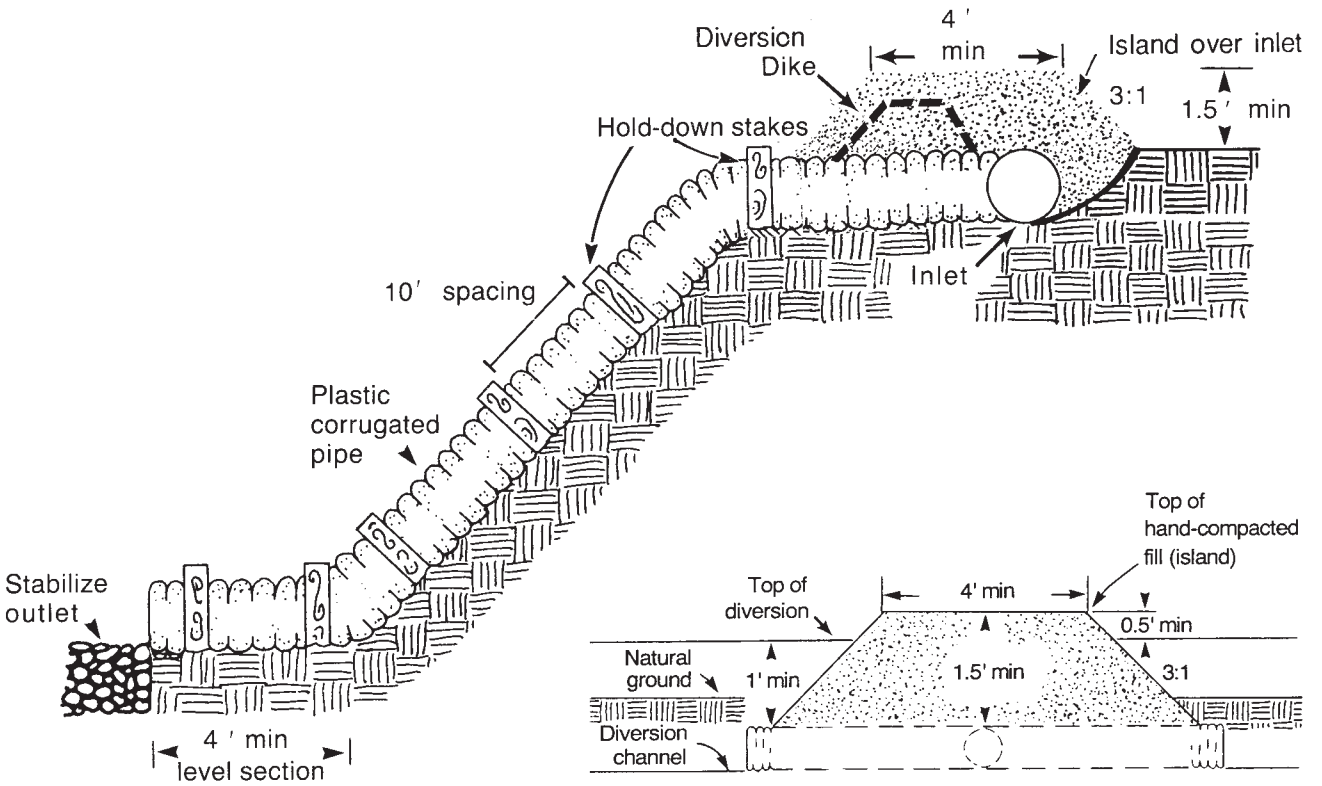


Figure 6.32a Cross section of temporary slope drain.

Entrance—Construct the entrance to the slope drain of a standard flared-end section of pipe with a minimum 6-inch metal toe plate (Figure 6.32a). Make all fittings watertight. A standard T-section fitting may also be used at the inlet.

Temporary diversion—Generally, use an earthen diversion with a dike ridge to direct surface runoff into the temporary slope drain. Make the height of the ridge over the drain conduit a minimum of 1.5 feet and at least 6 inches higher than the adjoining ridge on either side. The lowest point of the diversion ridge should be a minimum of 1 foot above the top of the drain so that design flow can freely enter the pipe.

Outlet protection—Protect the outlet of the slope drain from erosion (Practice 6.41, *Outlet Stabilization Structure*).

Construction Specifications

A common failure of slope drains is caused by water saturating the soil and seeping along the pipe. This creates voids from consolidation and piping and causes washouts. Proper backfilling around and under the pipe "haunches" with stable soil material and hand compacting in 6-inch lifts to achieve firm contact between the pipe and the soil at all points will eliminate this type of failure.

1. Place slope drains on undisturbed soil or well compacted fill at locations and elevations shown on the plan.

2. Slightly slope the section of pipe under the dike toward its outlet.

3. Hand tamp the soil under and around the entrance section in lifts not to exceed 6 inches.

4. Ensure that fill over the drain at the top of the slope has minimum dimensions of 1.5 feet depth, 4 feet top width, and 3:1 side slopes.

5. Ensure that all slope drain connections are watertight.

6. Ensure that all fill material is well-compacted. Securely fasten the exposed section of the drain with grommets or stakes spaced no more than 10 feet apart.

7. Extend the drain beyond the toe of the slope, and adequately protect the outlet from erosion.

8. Make the settled, compacted dike ridge no less than 1 feet above the top of the pipe at every point.

9. Immediately stabilize all disturbed areas following construction.

Maintenance

Inspect the slope drain and supporting diversion after every rainfall, and promptly make necessary repairs. When the protected area has been permanently stabilized, temporary measures may be removed, materials disposed of properly, and all disturbed areas stabilized appropriately.

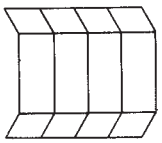
References

Runoff Control Measures
6.20, Temporary Diversions

Outlet Protection
6.41, Outlet Stabilization Structure

6.33

PAVED FLUME (Chutes)



Definition

A small concrete-lined channel to convey water on a relatively steep slope.

Purpose

To conduct concentrated runoff safely down the face of a cut or fill slope without causing erosion.

Conditions Where Practice Applies

Where concentrated storm runoff must be conveyed from the top to the bottom of a cut or fill slope as part of a permanent erosion control system. Paved flumes serve as stable outlets for diversions, drainage channels, or natural drainageways that are located above relatively steep slopes. Restrict paved flumes to slopes of 1.5:1 or flatter.

Planning Considerations

Conveying storm runoff safely down steep slopes is an important consideration when planning permanent erosion control measures for a site (Figure 6.33a). Paved flumes are often selected for this purpose, but other measures such as grassed waterways, riprap channels, and closed storm drains should also be considered. Evaluate the flow volume, velocity and duration of flow, degree of slope, soil and site conditions, visual impacts, construction costs, and maintenance requirements to decide which measure to use.

When planning paved flumes, give special attention to flow entrance conditions, soil stability, outlet energy dissipation, downstream stability, and freeboard or bypass capacity. Setting the flume well into the ground is especially important, particularly on fill slopes.

Paved chutes often have the upper portion of their side slopes grassed. This saves on materials and improves appearance. The paved portion carries the design flow, and the grassed area provides freeboard.

Design Criteria

Capacity—Consider peak runoff from the 10-year storm as a minimum. Provide sufficient freeboard or bypass capacity to safeguard the installation from any peak flow expected during the life of the structure.

Slope—Ensure that the slope of a chute does not exceed 1.5:1 (67%).

Cutoff walls (curtain walls)—Provide cutoff walls at the beginning and end of paved flumes. Make the cutoff wall as wide as the flume, extend it at least 18 inches into the soil below the channel, and keep it a minimum thickness of 6 inches. Reinforce cutoff walls with 3/8-inch reinforcing steel bars placed on 6-inch centers.

Anchor lugs—Space anchor lugs a maximum of 10 feet on the center for the length of the flume. Make anchor lugs as wide as the bottom of the flume, extend them at least 1 foot into the soil below, and keep them a minimum thickness of 6 inches. Reinforce anchor lugs with 3/8-inch steel reinforcing bars placed on 6-inch centers.

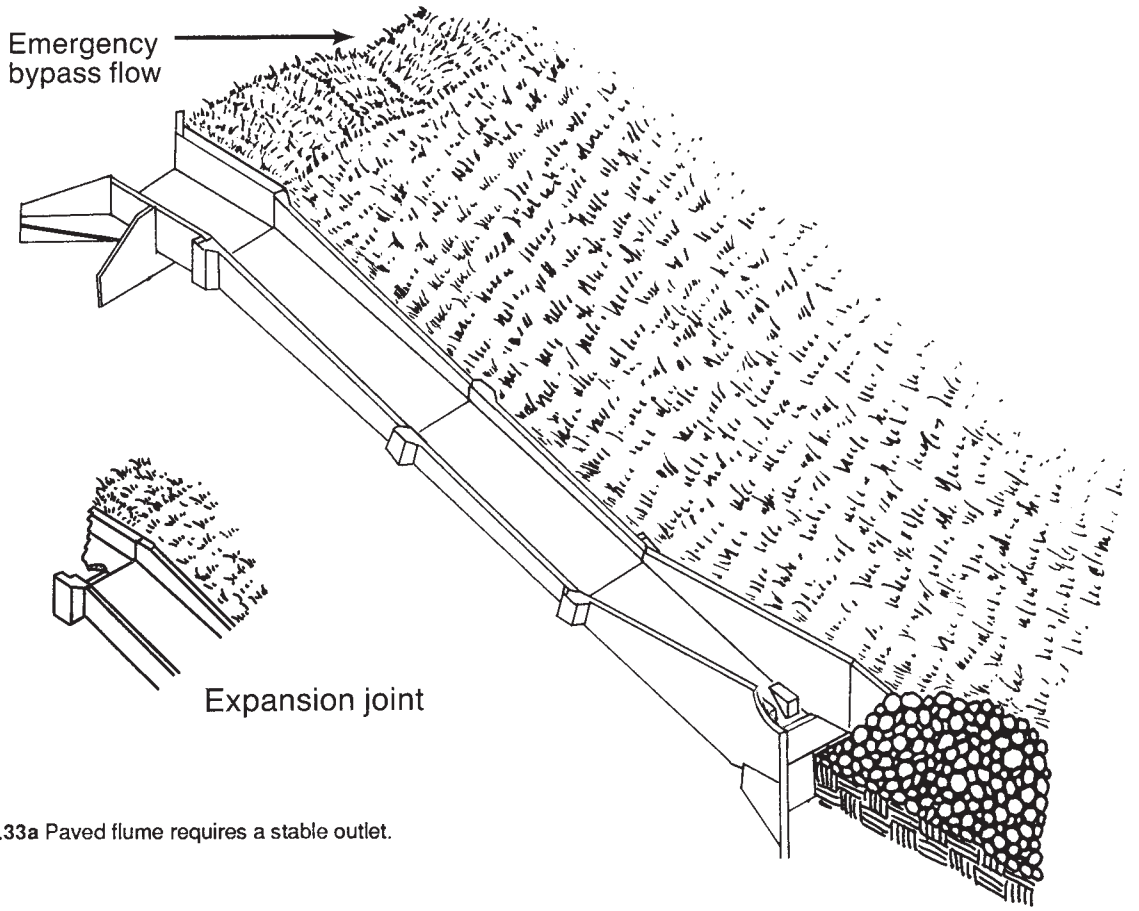


Figure 6.33a Paved flume requires a stable outlet.

Concrete—Keep concrete in the flume channel at least 5 inches thick and reinforce it with 3/8-inch steel bars. Ensure that the concrete used for flumes is a dense, durable product and sufficiently plastic for thorough consolidation but stiff enough to stay in place on steep slopes. As a minimum, use a mix certified as 3,000 lb/inch^2.

Cross section—Ensure that flumes have a minimum depth of 1 foot with 1.5:1 side slopes. Base bottom widths on maximum flow capacity.

Alignment—Keep chute channels straight because they often carry supercritical flow velocities.

Drainage filters—Use a drainage filter to prevent piping and reduce uplift pressure wherever seepage or high water table may occur (*Appendix 8.05*).

Inlet section—Ensure that the inlet to the chute has the following minimum dimensions: side walls 2 feet high, length 6 feet, width equal to the flume channel bottom, and side slope same as flume channel side slopes.

Outlet section—Protect outlets for paved flumes from erosion. Use an energy dissipator to reduce high chute velocities to nonerosive rates. In addition, place riprap at the end of the dissipator to spread the flow evenly over the receiving area. Other measures, such as an impact basin, plunge pool, or rock riprap outlet structure, may also be needed (Practice 6.41, *Outlet Stabilization Structure*).

Table 6.33a
Flume Dimensions

Drainage[1] Area (acres)	Min. Bottom Width (ft)	Min. Inlet Depth (ft)	Min. Channel Depth (ft)	Max. Channel Slope (Ft)	Max. Side Slope (ft)
5	4	2	1.3	1.5:1	1.5:1
10	8	2	1.3	1.5:1	1.5:1

[1]Due to complexity of inlet and outlet design, drainage areas have been limited to 10 acres per flume.

SMALL FLUMES
Where drainage areas are 10 acres or less, the design dimensions for concrete flumes may be selected from Table 6.33a.

Construction Specifications

1. Construct the subgrade to the elevations shown on the plans. Remove all unsuitable material and replace them with stable materials. Compact the subgrade thoroughly and shape it to a smooth, uniform surface. Keep the subgrade moist at the time concrete is poured. On fill slopes, ensure that the soil adjacent to the chute for at least 3 feet is well-compacted.

2. Place concrete for the flume to the thickness shown on the plans and finish it in a workman-like manner.

3. Form, reinforce, and pour together cutoff walls, anchor lugs, and channel linings.

4. Take adequate precautions to protect freshly poured concrete from extreme temperatures to ensure proper curing.

5. Provide transverse (contraction) joints to control cracking at approximately 20-feet intervals. Joints may be formed by using a 1/8-inch thick removable template or by sawing to a depth of at least 1 inch.

6. In very long flumes, install expansion joints at intervals not to exceed 50 feet.

7. Place filters and foundation drains, when required, in the manner specified, and protect them from contamination when pouring the concrete flume.

8. Properly stabilize all disturbed areas immediately after construction.

Maintenance

Inspect flumes after each rainfall until all areas adjoining the flume are permanently stabilized. Repair all damage noted in inspections immediately. After the slopes are stabilized, flumes need only periodic inspection, and inspection after major storm events.

References

Surface Stabilization
6.11, Permanent Seeding

Runoff Conveyance Measures
6.30, Grass-lined Channels
6.31, Riprap-lined and Paved Channels

Outlet Protection
6.40, Level Spreader
6.41, Outlet Stabilization Structure

Other Related Practices
6.81, Subsurface Drain

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8.03, Estimating Runoff
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