# Riprap-lined Swale (RS)

## Practice Description

A riprap-lined swale is a natural or constructed channel with an erosion-resistant rock lining designed to carry concentrated runoff to a stable outlet. This practice applies where grass swales are unsuitable because of conditions such as steep channel grades, prolonged flow areas, or soils that are too erodible or not suitable to support vegetation or insufficient space.

## Planning Considerations

Swales should be carefully built to the design cross section, shape, and dimensions. Swales are hydraulic structures and as such depend upon the hydraulic parameters to serve satisfactorily. Swales may be used to

- Serve as outlets for diversions and sediment control basins and stormwater detention basins.
- Convey water collected by road ditches or discharged through culverts.
- Rehabilitate natural draws and gullies carrying concentrations of runoff.

The design of a swale cross section and lining is based primarily upon the volume and velocity of flow expected in the swale. Riprap-lined swales should be used where velocities are in the range of 5 to 10 ft/sec.

Besides the primary design considerations of capacity and velocity, a number of other important factors should be taken into account when selecting a cross section. These factors include land availability, compatibility with land use and surrounding environment, safety, maintenance requirements, and outlet conditions, etc.

Riprap-lined swales are trapezoidal in shape. Trapezoidal swales are often used where the quantity of water to be carried is large and conditions require that it be carried at a relatively high velocity.

Outlet conditions for all swales should be considered. This is particularly important for the transition from the riprap lining to a vegetative lining. Appropriate measures must be taken to dissipate the energy of the flow to prevent scour of the receiving swale.

## Design Criteria

### Capacity

Lined swales shall be designed to convey the peak rate of runoff from a 10-year 24-hour rainfall event. Adjustments should be made for release rates from structures and other drainage facilities. Swales should also be designed to comply with local stormwater ordinances.

Swales should be designed for greater capacity whenever there is danger of flooding or when out-of-bank flow cannot be tolerated. The maximum capacity of the swale flowing at design depth should be 200 cubic ft/sec.

Peak rates of runoff values used to determine the capacity requirements should be calculated using accepted engineering methods. Some accepted methods are:

- Natural Resources Conservation Service, National Engineering Handbook Series, Part 650, Engineering Field Handbook, Chapter 2, Estimating Runoff.
- Natural Resources Conservation Service (formerly Soil Conservation Service), Technical Release 55, Urban Hydrology for Small Watersheds.
- Other comparable methods – See *Appendix A: Erosion and Stormwater Runoff Calculations* found in the Appendices Volume.

### Cross section

The swale cross section should be trapezoidal in shape. The steepest permissible side slope of the swale should be 2:1 (Horizontal: Vertical). A bottom width should be selected based on area available for installation of the swale and available rock sizes. The bottom width will be used in determining stable rock size and flow depth.

### Depth

Design flow depth should be determined by the following formula:

$z = [n(q)/1.486(S)^{0.50}]^{3/5}$
S = Bed slope, (ft/ft)
z = Flow depth, (ft)
q = Unit discharge, ($ft^3$/s/ft) (Total discharge ÷ Bottom width)
n = Manning's coefficient of roughness (see formula under velocities)

The design water surface elevation of a swale receiving water from other tributary sources should be equal to or less than the design water surface elevation of the contributing source. The design water surface elevation of contributing and receiving waters should be the same, whenever practical. A minimum depth may be necessary to provide adequate outlets for subsurface drains and tributary swales.

## Freeboard

The minimum freeboard is 0.25 foot. Freeboard is not required on swales with less than 1% slope and where out-of-bank flow will not be damaging and can be tolerated from an operational point of view.

## Stable Rock Size

Stable rock sizes, for rock-lined swales having gradients between 2 percent and 40 percent should be determined using the following formulas from *Design of Rock Chutes* by Robinson, Rice, and Kadavy.

For swale slopes between 2% and 10%: $d_{50} = [q\ (S)^{1.5}/4.75(10)^{-3}]^{1/1.89}$

For swale slopes between 10% and 40%: $d_{50} = [q\ (S)^{0.58}/3.93(10)^{-2}]^{1/1.89}$

$d_{50}$ = Particle size for which 50 % of the sample is finer, inch
S = Bed slope, ft/ft
q = Unit discharge, $ft^3/s/ft$
(Total discharge ÷ Bottom width)

After the stable median stone size is determined, the gradation of rock to be used should be specified using Tables RS-1 and RS-2. Table RS-1 is used to determine the weight of the median stone size ($d_{50}$). Using this median weight, a gradation can be selected from Table RS-2, which shows commercially available riprap gradations.

Table RS-1 Size of Riprap Stones

| **Weight (lbs)** | **Mean Spherical Diameter (feet)** | **Rectangular Shape** | |
|---|---|---|---|
| | | Length | Width, Height (feet) |
| **50** | 0.8 | 1.4 | 0.5 |
| **100** | 1.1 | 1.75 | 0.6 |
| **150** | 1.3 | 2.0 | 0.67 |
| **300** | 1.6 | 2.6 | 0.9 |
| **500** | 1.9 | 3.0 | 1.0 |
| **1000** | 2.2 | 3.7 | 1.25 |
| **1500** | 2.6 | 4.7 | 1.5 |
| **2000** | 2.75 | 5.4 | 1.8 |
| **4000** | 3.6 | 6.0 | 2.0 |
| **6000** | 4.0 | 6.9 | 2.3 |
| **8000** | 4.5 | 7.6 | 2.5 |
| **20000** | 6.1 | 10.0 | 3.3 |

Table RS-2 Graded Riprap

| Class | Weight (lbs.) $d_{10}$ | $d_{15}$ | $d_{25}$ | $d_{50}$ | $d_{75}$ | $d_{90}$ |
|---|---|---|---|---|---|---|
| **1** | 10 | - | - | 50 | - | 100 |
| **2** | 10 | - | - | 80 | - | 200 |
| **3** | - | 25 | - | 200 | - | 500 |
| **4** | - | - | 50 | 500 | 1000 | - |
| **5** | - | - | 200 | 1000 | - | 2000 |

### Velocities

Velocities should be computed by using Manning's Formula with a coefficient of roughness, "n," as follows: $n = 0.047(d_{50} \cdot S)^{0.147}$

Applies on slopes between 2 and 40% with a rock mantle thickness of $2 \times d_{50}$ where:
$d_{50}$ = median rock diameter (inch), S = lined section slope (ft/ft) ($0.02 \leq S \leq 0.4$)

Velocities exceeding critical velocity should be restricted to straight reaches.

Waterways or outlets with velocities exceeding critical velocity should discharge into an outlet protection structure to reduce discharge velocity to less than critical (see *Outlet Protection Practice*).

### Lining Thickness

The minimum lining thickness should be equal to the maximum stone size of the specified riprap gradation plus the thickness of any required filter or bedding.

### Lining Durability

Stone for riprap should consist of field stone or rough unhewn quarry stone of approximately rectangular shape. The stone should be hard and angular and of such quality that it will not disintegrate on exposure to water or weathering, and it should be suitable in all other respects for the purpose intended. The specific gravity of the individual stones should be at least 2.5.

### Geotextiles

Geotextiles should be used where appropriate as a separator between rock and soil to prevent migration of soil particles from the subgrade, through the lining material. Geotextiles should be Class I material as selected from Table RS-3.

### Filters or Bedding

Filters or bedding should be used where needed to prevent piping. Filters should be designed according to the requirements contained in the *Subsurface Drain Practice*. The minimum thickness of a filter or bedding should be 6″.

Table RS-3 Requirements for Nonwoven Geotextile

| Property | Test method | Class I | Class II | Class III | Class IV [1] |
|---|---|---|---|---|---|
| **Tensile strength (lb)** [2] | ASTM D 4632 grab test | 180 minimum | 120 minimum | 90 minimum | 115 minimum |
| **Elongation at failure (%)** [2] | ASTM D 4632 | ≥50 | ≥50 | ≥50 | ≥50 |
| **Puncture (pounds)** | ASTM D 4833 | 80 minimum | 60 minimum | 40 minimum | 40 minimum |
| **Ultraviolet light (% residual tensile strength)** | ASTM D 4355 150-hr exposure | 70 minimum | 70 minimum | 70 minimum | 70 minimum |
| **Apparent opening size (AOS)** | ASTM D 4751 | As specified max. no. 40 [3] | As specified max. no. 40 [3] | As specified max. no. 40 [3] | As specified max. no. 40 [3] |
| **Permittivity $sec^{-1}$** | ASTM D 4491 | 0.70 minimum | 0.70 minimum | 0.70 minimum | 0.10 minimum |

Table copied from NRCS Material Specification 592.

1 Heat-bonded or resin-bonded geotextile may be used for Classes III and IV. They are particularly well suited to Class IV. Needle-punched geotextile are required for all other classes.
2 Minimum average roll value (weakest principal direction).
3 U.S. standard sieve size.

# Construction

Prior to start of construction, riprap-lined swales should be designed by a qualified design professional. Plans and specifications should be referred to by field personnel throughout the construction process.

## Site Preparation

Determine exact location of underground utilities (See Appendix C: MS One-Call and 811 Color Coding.)

Remove brush, trees, and other debris from the channel and spoil areas, and dispose of properly.

Grade or excavate cross section to the lines and grades shown in design. Over-excavate to allow for thickness of riprap and filter material. Foundation excavation not deep enough or wide enough may cause riprap to restrict channel flow and result in overflow and erosion. Side slopes are usually 2:1 (Horizontal: Vertical) or flatter.

## Foundation Stabilization

Install geotextile fabric or aggregate in the excavated channel as a foundation for the riprap. Anchor fabric in accordance with design specifications. If the fabric is omitted or damaged during stone placement, there may be settlement failure and bank instability.

### Installation

As soon as the foundation is prepared, place the riprap to the thickness, depth, and elevations shown in the design specifications. It should be a dense, uniform, and well-graded mass with few voids. Riprap should consist of a well-graded mixture of stone (size and gradation as shown in design specifications) that is hard, angular, and highly chemical, and weather resistant. Larger stone should predominate, with sufficient smaller sizes to fill the voids between the stones. The diameter of the largest stone size should be not greater than 1.5 times the $d_{50}$ size. Minimum thickness of riprap liner should be 1.5 times the maximum stone diameter.

Blend the finished rock surface with the surrounding land surface so there are no overfalls, channel constrictions, or obstructions to flow.

### Outlet Stabilization

Stabilize channel inlet and outlet points. Extend riprap as needed.

Stabilize adjacent disturbed areas after construction is completed.

### Construction Verification

Check finished grades and cross sections throughout the length of the channel.

Verify channel cross section dimensions at several locations to avoid flow constrictions.

## Common Problems

*Consult with a qualified design professional if any of the following occur:*

> Variations in topography on site indicate channel will not function as intended; changes in plan may be needed.
>
> Design specifications for riprap sizing, geotextile fabric or aggregate filter cannot be met; substitution may be required. Unapproved substitutions could result in channel erosion.

## Maintenance

Inspect channels at regular intervals and after storm events. Check for rock stability, sediment accumulation, piping, and scour holes throughout the length of the channel.

Look for erosion at inlets and outlets.

When stones have been displaced, remove any debris and replace the stones in such a way as to not restrict the flow of water.

Give special attention to outlets and points where concentrated flow enters the channel and repair eroded areas promptly by extending the riprap as needed.

## References

### BMPs from Volume 1

**Chapter 4**

Outlet Protection (OP) 4-199
Subsurface Drain (SD) 4-218

### Additional Resources

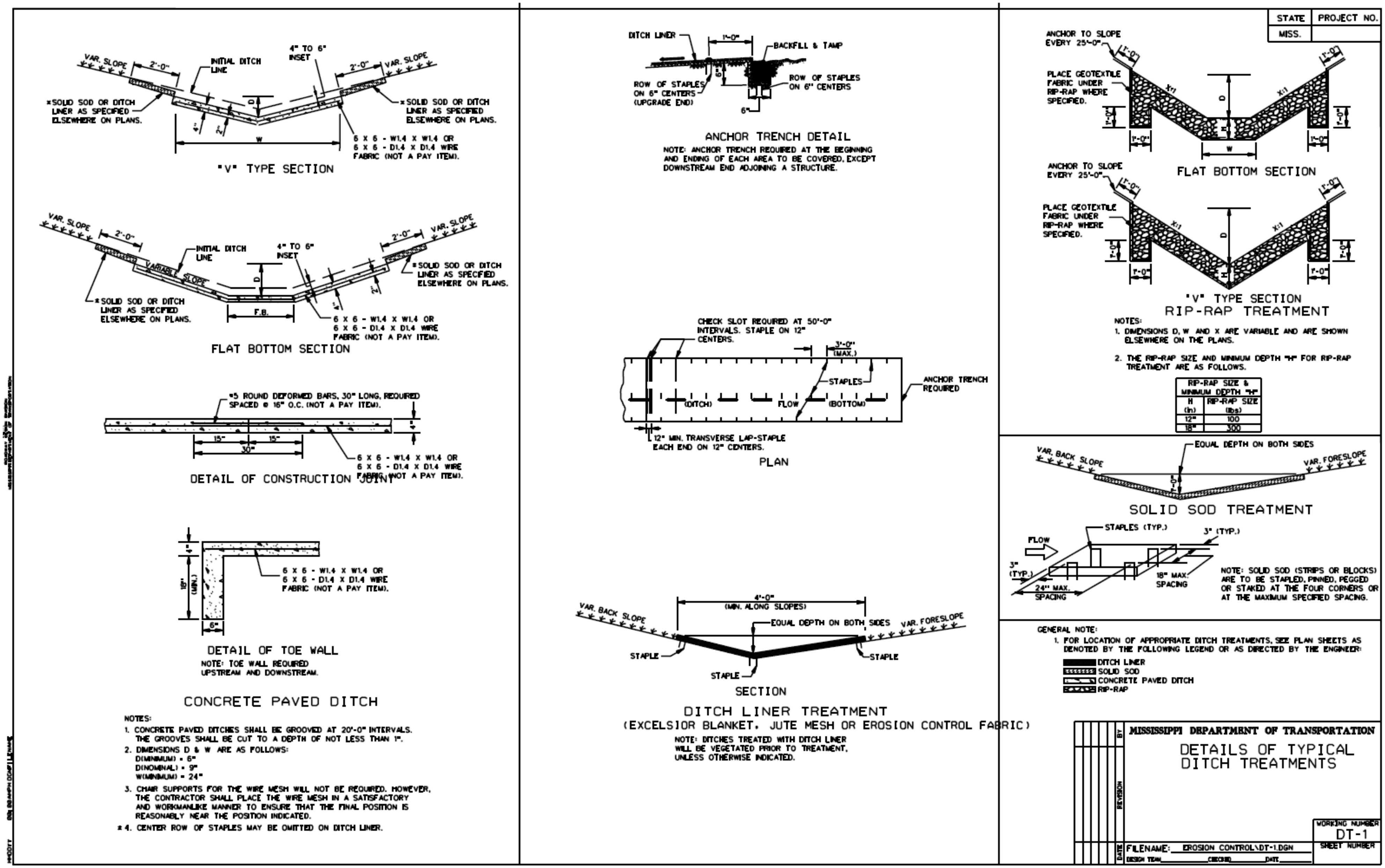
Natural Resources Conservation Service, National Engineering Handbook Series, Part 650, Engineering Field Handbook, Chapter 2, Estimating Runoff.

Natural Resources Conservation Service (formerly Soil Conservation Service), Technical Release 55, Urban Hydrology for Small Watersheds.

Robinson, K.M., Rice, C.E., and Kadavy, K.C., 1998. Design of Rock Chutes. Am. Soc. Agric. Eng. Trans. 41, 621–626.

### MDOT Drawing DT-1

Details of Typical Ditch Treatments 4-217


"V" TYPE SECTION
VAR. SLOPE
2'-0"
INITIAL DITCH LINE
4" TO 6" INSET
*SOLID SOD OR DITCH LINER AS SPECIFIED ELSEWHERE ON PLANS.
6 X 6 - W1.4 X W1.4 OR 6 X 6 - D1.4 X D1.4 WIRE FABRIC (NOT A PAY ITEM).
FLAT BOTTOM SECTION
VARIABLE SLOPE
F.B.
#5 ROUND DEFORMED BARS, 30" LONG, REQUIRED SPACED @ 16" O.C. (NOT A PAY ITEM).
DETAIL OF CONSTRUCTION JOINT
DETAIL OF TOE WALL
NOTE: TOE WALL REQUIRED UPSTREAM AND DOWNSTREAM.
CONCRETE PAVED DITCH
NOTES:
1. CONCRETE PAVED DITCHES SHALL BE GROOVED AT 20'-0" INTERVALS. THE GROOVES SHALL BE CUT TO A DEPTH OF NOT LESS THAN 1".
2. DIMENSIONS D & W ARE AS FOLLOWS:
D(MINIMUM) = 6"
D(NOMINAL) = 9"
W(MINIMUM) = 24"
3. CHAIR SUPPORTS FOR THE WIRE MESH WILL NOT BE REQUIRED. HOWEVER, THE CONTRACTOR SHALL PLACE THE WIRE MESH IN A SATISFACTORY AND WORKMANLIKE MANNER TO ENSURE THAT THE FINAL POSITION IS REASONABLY NEAR THE POSITION INDICATED.
* 4. CENTER ROW OF STAPLES MAY BE OMITTED ON DITCH LINER.
DITCH LINER
1'-0"
BACKFILL & TAMP
ROW OF STAPLES ON 6" CENTERS (UPGRADE END)
ROW OF STAPLES ON 6" CENTERS
ANCHOR TRENCH DETAIL
NOTE: ANCHOR TRENCH REQUIRED AT THE BEGINNING AND ENDING OF EACH AREA TO BE COVERED, EXCEPT DOWNSTREAM END ADJOINING A STRUCTURE.
CHECK SLOT REQUIRED AT 50'-0" INTERVALS. STAPLE ON 12" CENTERS.
3'-0" (MAX.)
STAPLES
(DITCH)
FLOW
(BOTTOM)
ANCHOR TRENCH REQUIRED
12" MIN. TRANSVERSE LAP-STAPLE EACH END ON 12" CENTERS.
PLAN
4'-0" (MIN. ALONG SLOPES)
VAR. BACK SLOPE
EQUAL DEPTH ON BOTH SIDES
VAR. FORESLOPE
STAPLE
SECTION
DITCH LINER TREATMENT
(EXCELSIOR BLANKET, JUTE MESH OR EROSION CONTROL FABRIC)
NOTE: DITCHES TREATED WITH DITCH LINER WILL BE VEGETATED PRIOR TO TREATMENT, UNLESS OTHERWISE INDICATED.
STATE | PROJECT NO.
MISS.
ANCHOR TO SLOPE EVERY 25'-0"
PLACE GEOTEXTILE FABRIC UNDER RIP-RAP WHERE SPECIFIED.
FLAT BOTTOM SECTION
"V" TYPE SECTION
RIP-RAP TREATMENT
NOTES:
1. DIMENSIONS D, W AND X ARE VARIABLE AND ARE SHOWN ELSEWHERE ON THE PLANS.
2. THE RIP-RAP SIZE AND MINIMUM DEPTH "H" FOR RIP-RAP TREATMENT ARE AS FOLLOWS.
RIP-RAP SIZE & MINIMUM DEPTH "H"
H (In) | RIP-RAP SIZE (lbs)
12" | 100
18" | 300
VAR. BACK SLOPE
EQUAL DEPTH ON BOTH SIDES
VAR. FORESLOPE
SOLID SOD TREATMENT
STAPLES (TYP.)
3" (TYP.)
FLOW
24" MAX. SPACING
18" MAX. SPACING
NOTE: SOLID SOD (STRIPS OR BLOCKS) ARE TO BE STAPLED, PINNED, PEGGED OR STAKED AT THE FOUR CORNERS OR AT THE MAXIMUM SPECIFIED SPACING.
GENERAL NOTE:
1. FOR LOCATION OF APPROPRIATE DITCH TREATMENTS, SEE PLAN SHEETS AS DENOTED BY THE FOLLOWING LEGEND OR AS DIRECTED BY THE ENGINEER:
DITCH LINER
SOLID SOD
CONCRETE PAVED DITCH
RIP-RAP
MISSISSIPPI DEPARTMENT OF TRANSPORTATION
DETAILS OF TYPICAL DITCH TREATMENTS
WORKING NUMBER
DT-1
SHEET NUMBER
FILENAME: EROSION CONTROL\DT-1.DGN