The information contained in Chapter Two: Erosion and Sediment Control, dated August 2006, has been updated to reflect the August 2018 Errata. The errata addresses errors, changes in procedure, changes in NDOT department titles, changes in other Roadway Design and Drainage Design Manual chapters and other reference material citations occurring since the latest publication of this chapter.

# Chapter Two
# Erosion and Sediment Control

Soil erosion is a naturally occurring phenomenon where soil particles are displaced and carried away by water, wind or other agents. The rate at which erosion occurs depends upon the properties of the soil, terrain, climate, rainfall intensity and duration, and the volume and characteristics of the water flow.

Sedimentation is the deposition of eroded soil and may occur in lakes, reservoirs, streams, or other drainage ways. Sedimentation may restrict drainage ways, plug culverts, damage property and adversely impact stream ecological systems.

Erosion and sediment control is accomplished by:

- Absorbing the impact of rainfall.
- Slowing water's velocity, dividing water into smaller quantities.
- Infiltration by soil or vegetation.
- Retention or temporary detention.

Highway construction involves disturbance of large land areas. Erosion and sediment control is a major concern in highway construction and is addressed during all phases of the project from planning and design through construction, and continues into maintenance. An erosion and sediment control program includes the plans of action and provision of documents to achieve an acceptable level of erosion and sediment control.

Roadway designers must keep in mind the need for erosion and sediment control throughout the entire design phase. A preliminary erosion control plan should be developed at the earliest phase of design. This will enable the designer to review the design for effectiveness at the Plan-in-Hand Review or other on site visit. Designers should work closely in the early stages of design with the **Roadside Development & Compliance Unit** (**RDC**) in the **Project Development Division** to achieve erosion and sediment control objectives. EXHIBIT 2.1 shows the erosion control design process designers should follow. Development of an early erosion control plan will help improve cost estimates and will aid the final erosion control design by highlighting areas of concern.

Erosion and sediment control plans must comply with applicable federal, state and local (city and county) rules and regulations, including, but not limited to, the requirements of the National Pollutant Discharge Elimination System Construction Site Permit issued by the **Nebraska Department of Environmental Quality.** The **Project Development Division** requests this permit, (See the Roadway Design Manual, Chapter Thirteen: Planning and Project Development, Section 4, Reference 2.16, (http://www.roads.nebraska.gov/business-center/design-consultant/rd-manuals/)).

Since, in general, the effects of water erosion are more severe than the effects of wind erosion on Nebraska construction projects this chapter primarily focuses on water erosion control measures and techniques to achieve desired on-site erosion and sediment control.

The following References have been used extensively throughout this chapter:

- Highway Drainage Guidelines, (Reference 2.1).
- Model Drainage Manual, (Reference 2.2).
- A Guide For Transportation Landscape and Environmental Design, (Reference 2.3).
- Manual of Erosion and Sediment Control and Stormwater Management Standards, (Reference 2.4).
- Erosion and Sediment Control Manual, (Reference 2.5). (http://www.transportation.wv.gov/highways/engineering/files/erosion/erosion2003.pdf).

## 1. EROSION AND SEDIMENT CONTROL OBJECTIVES

An effective erosion and sediment control program must accomplish these four objectives:

- Limit both on-site and off-site impacts to acceptable levels both during and after construction.
- Facilitate project construction while minimizing overall costs.
- Aid in the restabilization of the construction site, reducing the long term maintenance requirements.
- Comply with federal, state and local regulations.
- Require minimal maintenance.

Controlling adverse impacts from all construction activities is an important goal of roadway design. Controlling the effects of erosion on-site may facilitate construction activities and reduce the amount of earth re-work required as a result of runoff.

Erosion control measures should:

- Be simple to construct.
- Minimize interruption to normal construction procedures and operations.
- Be effective in their operation.

In addition to controlling any off-site impacts, the erosion and sediment control program is designed to promote revegetation of the construction sites as quickly as possible and to reduce the maintenance requirements of the roadside over the long term.

The fourth objective for an erosion control program is compliance with federal, state and local regulations. Federal controls are administered by several agencies through various permitting requirements. The **Project Development Division** will coordinate the permitting requirements (See the Roadway Design Manual, Chapter Thirteen: Planning and Project Development, Section 4, (Reference 2.16).

The **Federal Highway Administration (FHWA**) requires erosion and sediment control measures be included in the Plans, Specifications and Estimates (PS&E) package for all federal-aid projects. At a minimum, **FHWA** requires the identification of all erosion and sediment-sensitive areas and identification of the methods to be used for minimizing adverse effects. In addition to the **FHWA** requirements, the “National Pollutant Discharge Elimination System” (NPDES) permit requires erosion and sediment control plans for all sites that are 1 acre (0.4 hectare) or larger in size.

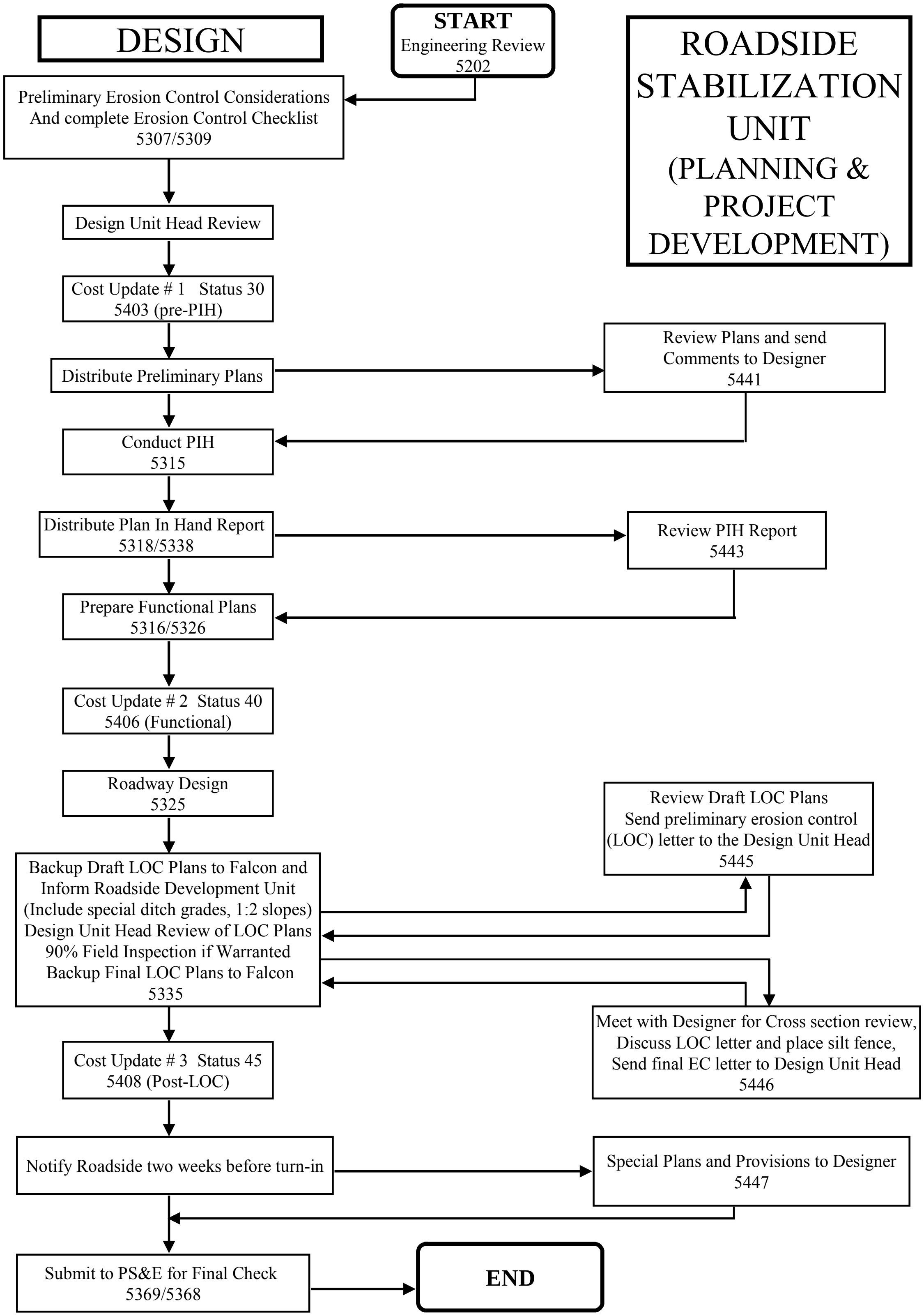



**Exhibit 2.1 Erosion Control Design Process**

## 2. SAFETY AND AESTHETICS

Early consideration of the effects of erosion and the specification of proper countermeasures during the design phase can lessen the amount of future maintenance due to erosion and can prevent potential highway hazards. Erosion control can be incorporated directly into the roadway geometric design (especially in cross section design), in the drainage design, and in the landscaping provisions (See the Roadway Design Manual, Chapter Six: The Typical Roadway Cross-Section, Chapter Ten: Miscellaneous Design Issues, Section 3 (Reference 2.16), and Chapter One: Drainage, of this manual). Erosion, safety hazards and maintenance may be minimized by use of properly designed:

- Flat side slopes that gradually transition to the natural terrain.
- Benching of steep slopes (where the slope is 1:3 or greater and 30 ft. or more in length as measured along the slope).
- Drainage channels - width, depth, cross section, slope alignment and protective treatment.
- Inlets, especially with regard to location and spacing.
- Culvert inlets.
- Culvert outlets.
- Groundwater interception facilities.
- Dikes, berms, etc. to protect backslopes.
- Sedimentation devices such as silt fences, silt traps, ditch checks, etc.

Revegetation practices that focus on native and introduced varieties of vegetation are the basis for our erosion control program. The root structure and vegetation supplied by these plants will be responsible for controlling erosion on the site for years after the construction is complete and will provide a more aesthetic roadway environment. Revegetation should focus on:

- Preservation of existing vegetation where possible.
- The transplanting of existing vegetation if necessary and feasible.
- Planting of new native vegetation or of an introduced species that is highly adaptable to the area.
- Selective clearing and thinning.
- Regeneration of existing native and introduced plant species.
- Salvage and reuse topsoil.

## 3. GENERAL EROSION AND SEDIMENT CONTROL DESIGN CONSIDERATIONS

Erosion is likely to occur at any concentration of flow; however, it occurs most severely in high flow concentrations. Erosion most commonly occurs:

- On longitudinal slopes of more than 1,000 ft. (300 m) (or less depending on the percent slope and soil type.
- On the outer banks of curved channels.
- At a culvert outlet or inlet.
- Where the longitudinal slope of a ditch exceeds 1.5%.
- Where there is sheet flow over a foreslope or backslope.
- At the ends of bridge structures.

The locations of potential erosion throughout the project site should be identified. Consideration should also be given to the general soil type found within the area of the project. Non-cohesive soils (e.g. Loess and sandy soils) are more easily erodable and may require additional erosion control. Soil survey manuals showing soil types with their engineering properties including, susceptibility to erosion, are available in the **NDOT** Library for all Nebraska Counties.

A preliminary erosion and sediment control plan should be completed prior to the Plan-in-Hand site visit. This will give the roadway designer an opportunity to review the plans for effectiveness and to make any necessary design changes. The *Erosion Control Plan-In-Hand Checklist*, **Exhibit F** of the Design Process Outline, (Reference 2.17, http://www.roads.nebraska.gov/media/6761/design-process-outline.pdf), is available to the designer as a tool, used to determine additional items to examine on the Plan-in-Hand. This checklist should be reviewed during the Plan-in-Hand in consultation with the **District Engineer** and **District Construction Engineer**. It should then be sent to the **Roadside Development & Compliance Unit** in the **Project Development Division**, along with the erosion and sediment control plans, for their review and comment prior to the final plan review, (See the Roadway Design Manual, Chapter Two: Roadway Design Process, Section 7, Reference 2.16). The *Erosion Control Plan-In-Hand Checklist* becomes part of the plan-in-hand package and is used for determining appropriate erosion controls as well as for estimating erosion control costs.

## 4. EROSION AND SEDIMENT CONTROL PLANS

Information on erosion and sediment control may be shown on:

- Erosion and Sediment Control plan sheets.
- Plan and Profile sheets.
- Summary of Quantities sheet.
- Removal and Construction plan sheets.
- Drainage sheets.

Based on the complexity of the project, the **Roadside Development & Compliance Unit**, along with the roadway designer, will determine how to properly show the erosion and sediment control design on the plans. Minor grading projects, such as overlays, may be able to show all of the pertinent information on existing plan sheets. Most projects, however, will require separate Erosion and Sediment Control plans such as:

- Temporary Erosion and Sediment Control Plan: The Temporary Erosion and Sediment Control Plan is a dynamic document, which will be adjusted throughout the life of the construction project. This plan will be modified on an as-needed basis, depending on the contractor's phasing scheme and on the local conditions during construction. Currently this plan is to be developed by the contractor, based on localized conditions that occur during the day to day construction of a project. The roadway designer is responsible for determining which temporary erosion control measures will be required on a project and for providing a quantity of materials for bidding purposes.
- Permanent Erosion and Sediment Control Plan: The Permanent Erosion and Sediment Control Plan is composed of the required elements to permanently re-stabilize the site after construction is completed. The items specified on this plan are designed to work in conjunction with the permanent seeding of the project. These plans are to be dynamic and may be adjusted in the field based on the project conditions.

## 5. TEMPORARY EROSION AND SEDIMENT CONTROL MEASURES

Temporary erosion and sediment control measures are for use during construction to maintain the site condition and to prevent off-site erosion and sedimentation. Temporary measures may be used until the permanent erosion control and revegetation measures are established or in conjunction with other permanent erosion control measures. It may be necessary for some temporary measures to be applied on the same site several times over the course of the project.

The roadway designer will be responsible for determining which temporary erosion and sediment control measures will initially be required on the project and for determining the approximate quantities for bidding purposes. It is important to note that this is a dynamic plan and it will change throughout the construction of the project based on the contractors phasing scheme, weather conditions, soil types encountered, etc. The quantities computed by the roadway designer for these items are approximations and will be over-run and under-run based on the actual conditions encountered during construction.

### 5.A Temporary Hydraulic Control Measures

#### 5.A.1 Temporary Slope Drain

A temporary slope drain is a pipe (aboveground or buried) extending from the top to the bottom of a cut or fill slope. It is used to temporarily transport concentrated stormwater runoff safely down the face of a cut or fill slope without causing erosion on or below the slope. It is essential to protect against the potentially high discharge velocity of water at the outlet by using erosion control blankets, riprap or other measures.

Slope drains should be used on cut or fill slopes where there is a potential for flows to go over the face of the slope causing erosion and preventing adequate stabilization. An example of such a case would be the end of a farming terrace removed during phased construction. The slope drain pipe should be sized according to the parameters established in Chapter One: Drainage, and the current pipe material policy (See Appendix C, “Pipe Material Policy”). A culvert cross section will be required. EXHIBIT 2.2 illustrates an aboveground temporary slope drain.

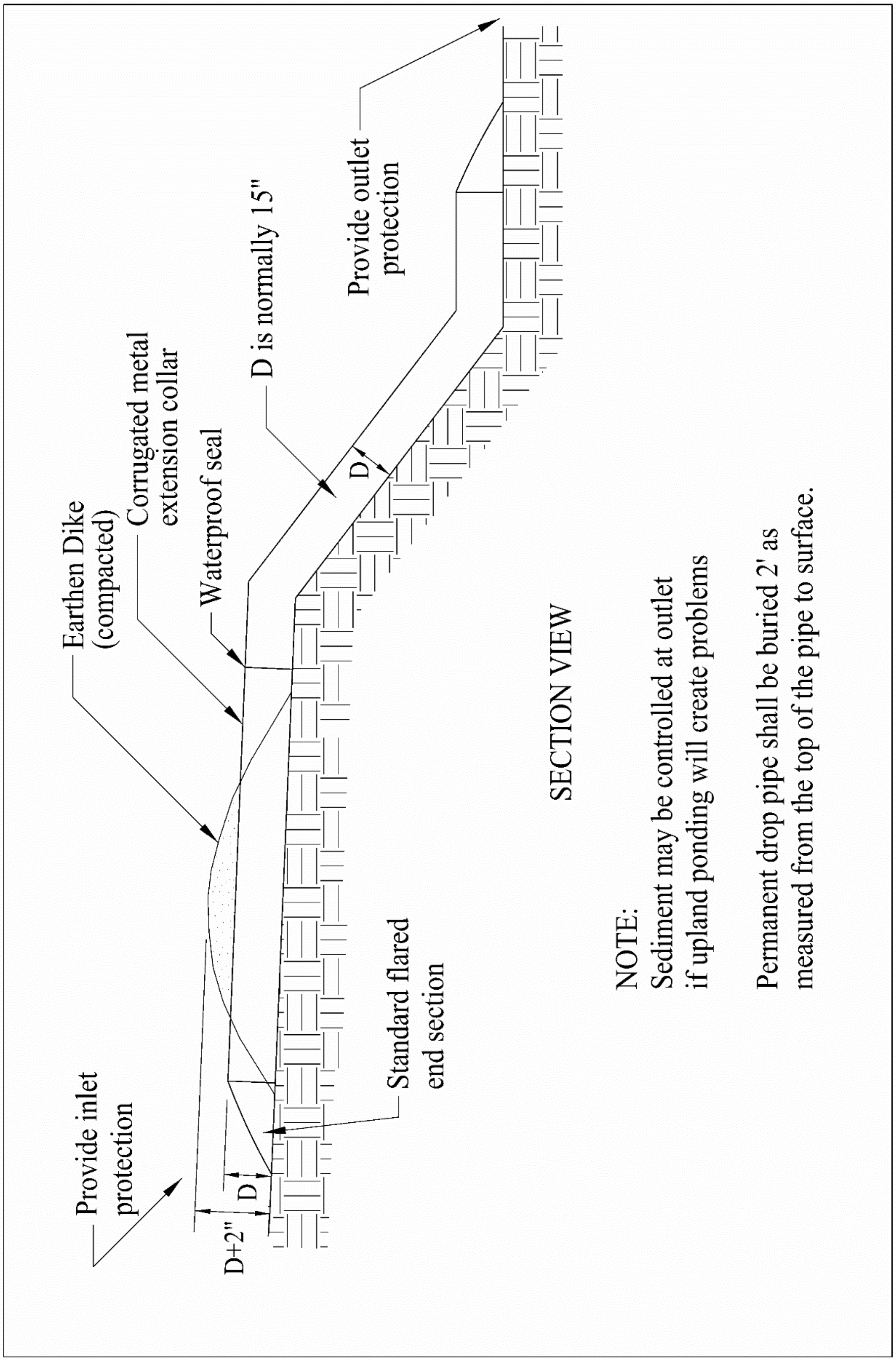



**Exhibit 2.2 Temporary Slope Drain**

## 5.B Temporary Erosion Control Measures

### 5.B.1 Covercrop Seeding

Covercrop Seeding is the establishment of a temporary vegetative cover on disturbed areas with appropriate, rapidly growing annual plants. Covercrops reduce erosion and sedimentation by stabilizing disturbed areas, reduce damage from sedimentation and runoff to downstream or off-site areas, and provide protection to bare soils exposed during construction until permanent vegetation or other erosion control measures can be established.

Covercrop Seeding can be used on surcharge areas, soil stockpiles, dikes, dams, sides of sediment basins, temporary road banks, etc. Covercrop Seeding may also be applied to finish grades as the project progresses to protect the finish grade and reduce erosion. A permanent vegetative cover should be applied as soon as possible upon completion of the finish grading earthwork.

Different species of seed may be used for covercrop during different times of the year. In the spring, for example, oats are planted. Summer seeding may be with foxtail millet or pearl millet. Winter wheat is planted in the fall. Consult the **Roadside Development & Compliance Unit** in the **Project Development Division** for details. Material and application requirements may be found in Section 812 of the Standard Specifications for Highway Construction, (Reference 2.10), (http://roads.nebraska.gov/media/6897/specbook-2007.pdf). Covercrop Seeding should be used in most areas except for where slope protection is required. The area to be covered is measured in acres (hectares) and should be calculated as shown in EXHIBIT 2.4.

Covercrop seeding will be calculated for each phase of the earthwork on projects with phased construction which requires more than one construction season. The 2N sheet will show the quantity of Covercrop Seeding required for each phase, (See the Roadway Design Manual, Chapter Eleven: Plan Preparation, Section 4.G, Reference 2.16).

### 5.B.2 Temporary Seeding

Temporary Seeding is the establishment of permanent vegetation using perennial grasses for a short duration, usually for more than one growing season, but for periods longer than Covercrop Seeding can protect. Temporary Seeding is generally used in staged construction.

### 5.B.3 Temporary Mulching

Temporary Mulching is the application of plant residues or other suitable materials to the soil surface. Temporary Mulch is used by itself or in conjunction with Covercrop and Temporary Seeding to provide temporary protection of the soil surface during construction. Temporary Mulching prevents erosion by protecting the soil surface from raindrop impact and by reducing the velocity of overland flow. Temporary Mulching can be used anytime protection of the soil surface is desired.

Temporary Mulching material shall be either dry cured native prairie hay, native grass hay from seed growing operations, native grass hay from planted warm season grass stands, or threshed grain straw (brome hay is not allowed due to its' shallow root structure). Temporary Mulch is applied at the rate of 1.5 tons/acres (3.35 Mg/ha) for hay, 2.0 tons/acre (4.5 Mg/ha) for straw and 2.5 tons/acre (5.6 Mg/ha) for rushes or similar materials. Temporary Mulching material and application requirements may be found in Section 805 of the Standard Specifications for Highway Construction, (Reference 2.10).

### 5.B.4 Temporary Slope Protection

Temporary Slope Protection is the spreading and crimping of hay on bare soil without seeding. Currently, the use of Temporary Slope Protection is limited to unseeded temporary roads in the Sandhills Region. The hay is used to stabilize the sandy soils and to provide erosion control. The material for Temporary Slope Protection may be hay, straw or rushes and is applied at the rate of 2.0 lbs/sq. yd. (1.1 kg/$m^2$). Refer to Section 810 of the Standard Specifications for Highway Construction, (Reference 2.10). Slope Protection Netting (See Section 6.B.3) should be included whenever with this item is specified.

The Temporary Slope Protection material may be anchored by whatever methods the contractor deems necessary. Temporary Slope Protection material shall be kept in good repair throughout the life of the construction project. The contractor is responsible for its upkeep, no extra payment will be made for the maintenance and repair of Temporary Slope Protection.

### 5.B.5 Contour Field Cultivation of Slopes

Contour Field Cultivation of Slopes is a procedure that is used to roughen the foreslope or backslope grade in horizontal strips to reduce the rill erosion common on non-vegetated slopes. The Contour Field Cultivation creates a rough area, 8 to 12 ft. wide (2.5 to 3.7 m), perpendicular to the down hill flow. This cultivated area intercepts the shallow, concentrated rivulets of water and spreads the water over a wider area and back into sheet flow, reducing or eliminating the rill erosion. A field cultivator shall be used to construct the parallel strips, on the contour, at approximately 25 ft. (7.6 m) centers. The initial cultivated strip will be centered no more than 10 ft. (3 m) from the top of the back slope and the final, bottom cultivated strip centered no more than 25 ft. (7.6 m) from the ditch bottom. The cultivation strips will be rough tilled to a depth of 3 to 4 in. deep (75 to 100 mm).The cultivated strips may also be placed on rough graded slopes that will be left exposed for several weeks or on finished grades.

## 5.C Temporary Sediment Control Measures

### 5.C.1 Temporary Erosion Checks

Temporary Erosion Checks are barriers placed perpendicular to the flow in ditches with slopes steeper than 3% to slow the velocity of the water, causing silt deposition. Erosion Checks are typically used in ditches where rough grading has been completed but finish grading has yet to begin. The spacing of these products depends on the slope of the ditch; the steeper the slope, the closer together the Temporary Erosion Checks should be spaced (See EXHIBIT 2.9). Temporary Erosion Checks may be used in conjunction with Temporary Silt Traps (See Section 5.C.5) to increase their holding capacity. The products used for Temporary Erosion Checks may occasionally be specified for permanent applications.

Erosion Checks are listed on the Approved Products List, Reference 2.19, (http://www.roads.nebraska.gov/business-center/materials/approved-products/) and any item in this category may be used in a temporary application. The Erosion Checks may be biodegradable or non-biodegradable. At the completion of the project, any non-biodegradable Temporary Erosion Checks must be removed and will remain the property of the Contractor. Any biodegradable Temporary Erosion Checks may be left in place.

### 5.C.2 Temporary Earth Checks

Temporary Earth Checks are barriers placed perpendicular to the flow in ditches in order to slow the velocity of water, causing silt deposition. Temporary Earth Checks are used in ditches where rough grading has been completed but finish grading has yet to begin. Temporary Earth Checks are constructed of earth and are placed at locations determined by the Contractor or the **District Project Manager**.

Temporary Earth Checks are used on ditches with slopes of 3% or flatter. The steeper the slope, the closer together these checks are placed. Construction consists of building a small earth berm across a ditch to reduce the velocity of water. Temporary Earth Checks can be used in conjunction with Temporary Silt Traps (See Section 5.C.5) on the upstream side of the ditch to increase their sediment holding capacity.

### 5.C.3 Temporary Rock Checks

Temporary Rock Checks are barriers placed in ditches, perpendicular to the flow, to slow the velocity of the water flow, which causes silt deposition. Temporary Rock Checks are used in ditches where rough grading has been completed but finish grading has not yet begun. Temporary Rock Checks are constructed of rock and are placed at locations determined by the **District Project Manager** or the Contractor.

Temporary Rock Checks are used on steeper ditch slopes, where riprap will be placed as a Permanent Hydraulic Control. The steeper the ditch, the closer the checks are placed to each other. Construction consists of building a small rock berm across the ditch to reduce the velocity of water with rock that is already specified (for riprap construction). Temporary Rock Checks can be used in conjunction with Temporary Silt Traps (See Section 5.C.5) on the upstream side of the ditch to increase the sediment holding capacity.

### 5.C.4 Temporary Silt Fence

Temporary Silt Fence is a barrier that can be placed at the toe of the slope, across ditches, or in any location where silt may have the opportunity to leave the Right-of-Way. The majority of Silt Fence locations will be specified with the permanent erosion control. Temporary Silt Fence is to be used on locations *not* identified with the permanent erosion control.

Temporary Silt Fence may consist of any product on the Approved Products List (Reference 2.19) for Low Porosity or High Porosity Silt Fence, or from any other commercially available source. The silt fence material shall be a minimum of 36 in. (900 mm) in height. When Temporary Silt Fence is being used across a ditch, High Porosity Silt Fence should be used.

### 5.C.5 Temporary Silt Trap

A Silt Trap is a temporary ponding area formed by excavating a basin along the path of the water flow. A Silt Trap may be used alone or in conjunction with a Silt Fence, Erosion Control products and/or Erosion Checks. A Silt Trap is normally 1 ft. (300 mm) deep and 6 ft. (1.8 m) wide with slopes into and out of the depression. Silt Traps generally do not include outlet drains; trapped water either evaporates or percolates into the ground.

## 6. PERMANENT EROSION AND SEDIMENT CONTROL MEASURES

Permanent erosion and sediment control measures are for use during and after construction of the roadway. Permanent measures are designed to limit the amount of erosion that occurs over the life of a project and to maintain the shape of the final embankments, ditches, and channels. Permanent erosion and sediment control measures are selected based on the project design storm and should withstand the majority of storms, (up to and including the design storm), with only minor maintenance. Some sediment control measures, (such as Sediment Basins), will require periodic maintenance to maintain their effectiveness.

The selection of a permanent erosion and sediment control measure is based on the following:

- Location of installation (urban, rural, rest stop, recreation area, etc.).
- Economic analysis of suitable alternatives.
- Principles of agronomy.
- Site-specific requirements.
- Availability of construction materials.
- Future maintenance requirements.
- Wetlands protection.

In addition to the above parameters, the erosion control and sediment measure selected must be able to withstand the expected erosive conditions encountered on the project. One gauge of acceptability is the permissible velocity for water flow over the erosion control measure. EXHIBIT 2.3 shows permissible velocities for various channel linings. It is important to remember that these are maximum velocities developed for flows of short duration. Flows that exceed these values will damage the channel lining and cause erosion.

For additional information, refer to the following **FHWA** publications:

- Hydraulic Design Series No. 4: Design of Roadside Drainage Channels, (Reference 2.7), (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds4.pdf).
- Hydraulic Engineering Circular No. 11: Design of Riprap Revetment, (Reference 2.8), (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hec/hec11sI.pdf).
- Hydraulic Design Series No. 3: Design Charts for Open Channel Flow, (Reference 2.9), (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds3.pdf).

| STRUCTURALLY-LINED CHANNELS | | |
|---|---|---|
| **Lining Material** | **Permissible Velocity * fps (m/s)** | |
| *Cellular Confinement Product*<br>● *Soil and Vegetative Fill*<br>● *Granular Fill*<br>● *Concrete Fill* | *Consult Manufacturer* | |
| *Riprap (See Section 7.A and EXHIBIT 2.13)* | *10* | *(3.0)* |
| *Gabion Baskets and Revet (Reno) Mattress* | *15* | *(4.5)* |
| *Concrete Lining or Interlocking Paver Blocks* | *Greater than 15* | *(4.5)* |

** Designer should confirm maximum permissible velocity with manufacturer.*

**Exhibit 2.3a Permissible Velocity for Structurally-Lined Channels**

| NON-VEGETATED CHANNELS | | | |
|---|---|---|---|
| **Soil Type** | **Channel Slope** | **Permissible Velocity * fps (m/s)** | |
| *Sand* | *0-1%* | *2.5* | *(0.8)* |
| | *1-5%* | *2.0* | *(0.6)* |
| | *over 5%* | *Consider Other Channel Liner Material* | |
| *Silt* | *0-3%* | *2.5* | *(0.8)* |
| | *over 3%* | *2.0* | *(0.6)* |
| *Loam* | *0-1%* | *4.0* | *(1.2)* |
| | *1-3%* | *3.5* | *(1.1)* |
| | *Over 3%* | *3.0* | *(0.9)* |
| *Clay Loam* | *0-2%* | *4.5* | *(1.4)* |
| | *2-5%* | *4.0* | *(1.2)* |
| | *>5%* | *3.5* | *(1.1)* |
| *Clay* | *0-2%* | *5.5* | *(1.7)* |
| | *2-5%* | *5.0* | *(1.5)* |
| | *Over 5%* | *4.5* | *(1.4)* |

** Designer should confirm maximum permissible velocity with manufacturer.*

**Exhibit 2.3b Permissible Velocity for Non-Vegetated Channels**

## 6.A Permanent Erosion Control Measures

Vegetation plays an important role in controlling erosion. Vegetation shields the soil surface from the impact of falling rain, reducing one of the primary methods of soil detachment. It holds soil particles in place through its root structure. Decaying vegetation increases the organic matter of the soil, which along with the living vegetation's root structure improves the soil's capacity to absorb water. A good cover of vegetation can reduce the amount and slow the velocity of stormwater runoff.

Vegetation is the preferred choice in erosion control material for the following reasons:

- It is cost effective.
- It will adjust to nearly all changes in the embankment or channel geometry.
- It will filter sediment and other contaminants from the runoff.
- Local damage or loss is self-healing.
- The appearance is natural and generally pleasing.

### 6.A.1 Seeding

Seeding is the primary method used to provide a permanent vegetative cover to protect against erosion. Permanent seeding is generally initiated at the completion of the project. Types of permanent seeding include:

- Type A Seeding: Permanent placement of seed on the foreslope, ditch, and backslope measured in acres (hectares).
- Type B Seeding: Includes shorter plant varieties that can withstand frequent mowing. Type B Seeding is the permanent placement of seed on the shoulder area and in the median, measured in acres (hectares).
- Type C Seeding: Other seed mixtures as needed for special placement.

See EXHIBIT 2.4 for guidance in the calculation of seeding areas.

### 6.A.2 Mulching

Mulching is the application of plant residues or other suitable materials to the soil surface. Mulch is always used in conjunction with seeding in order to establish vegetation. Mulch helps foster the growth of vegetation by increasing available moisture and by providing insulation against extreme heat and cold. Mulching helps prevent erosion by protecting the soil surface from raindrop impact and by reducing the velocity of overland flow. Mulching can be used anytime protection of the soil surface is desired.

Mulching material shall be either dry cured native prairie hay, native grass hay from seed growing operations, native grass hay from planted warm season grass stands, or threshed grain straw. Brome hay is not allowed. The mulch is applied at the rate of 2 tons/acre (4.5 Mg/ha) for hay and 2.25 ton/acre (5.0 Mg/ha) for straw. Mulching material and application requirements may be found in Section 805 of the Standard Specifications for Highway Construction, (Reference 2.10).

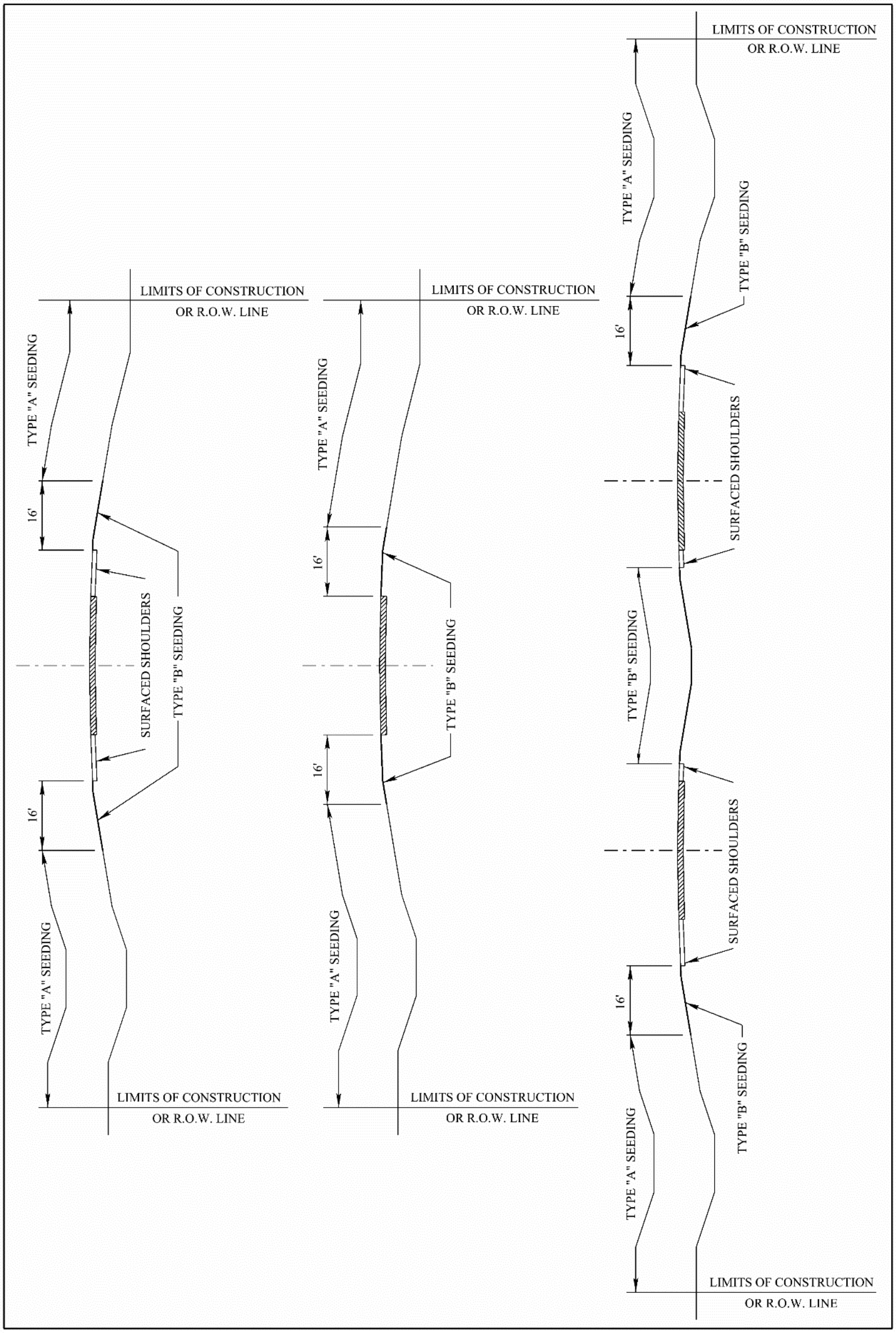



**Exhibit 2.4a Seeding Computations**

**Compute:**

**Type "B" Seeding**

(32 ft. + (Median Width – Inside Surfaced Shoulder Widths)) x Length of Project ÷ 43,560 ft./acre = _____ acres

Or in metric:

(9.8 m + (Median Width – Inside Surfaced Shoulder Widths)) x Length of Project ÷ 10,000 $m^2$/hectare = _____ hectare

**Type "A" Seeding**

**For Projects on Existing or Shifted Alignment:**

(Total area between the L.O.C.'s – Surfacing Area – Type "B" Seeding) x *115% = _____ acres (hectares)

**For Projects on New Alignment:**

(Total R.O.W. Taking – Surfacing Area – Type "B" Seeding) x **90% = _____ acres (hectares)

* The 115% factor includes the area disturbed by the contractor which lies beyond the limits of construction and will require seeding.
** This assumes that 10% of the total ROW area will not be disturbed during construction and will not require seeding. Use a factor of 100% when calculating seeding through cropland and any other areas which will require seeding to the ROW limits.

**Covercrop Seeding:**

Type "B" Seeding Area + Type "A" Seeding Area = _____ acres (hectares)

**Notes:**

1. Seeding should be computed on all projects.
2. Wetland seeding is not included in the above calculations.
3. In the case of a shifted alignment the designer shall ensure that the seeding computations include the area of surfacing removed from the existing alignment which lies outside of the limits of construction.
4. The total R.O.W. taking shown on the R.O.W. Plans may or may not be the correct area to be used in seeding calculations. The designer should check with the R.O.W. designer to determine if the taking area shown on the R.O.W. Plans is to be used.
5. The method used to calculate the Type "A" Seeding (and the appropriate percentage factor) should be noted on the Summary of Quantities Sheet, (See the Roadway Design Manual, Chapter Eleven: Highway Plans Assembly, Section 4.C, Reference 2.16).

**Exhibit 2.4b Seeding Computations**

### 6.A.3 Slope Protection

Slope Protection is the spreading and crimping of hay on bare soil in conjunction with seeding. Slope Protection is used in the Sandhills Region and in other areas with non-cohesive soils. The hay is used to stabilize the sandy soils, provide erosion control, and to establish a protective cover that promotes seed germination and the growth of vegetation. Covercrop Seeding is not required in areas with Slope Protection.

Slope Protection covers the area of disturbed soil that is not surfaced and is measured and paid for in sq. yds. ($m^2$). The material for Slope Protection may be hay, straw, or rushes and is applied at the rate of 2.0 lbs./sq. yd. (1.1 $kg/m^2$), (Refer to Section 810 of the Standard Specifications for Highway Construction, Reference 2.10). Slope Protection Netting (See Section 6.B.3) should be included whenever this item is specified.

### 6.A.4 Contour Field Cultivation of Backslopes

Contour Field Cultivation of backslopes is a procedure that is used to roughen the backslope finish grade in parallel strips to reduce the rill erosion common on non-vegetated slopes. The Contour Field Cultivation creates a rough area, 8 to 12 ft. (2.5 to 3.7 m) wide, perpendicular to the down hill flow. This cultivated area intercepts the shallow, concentrated rivulets of water and spreads their water over a wider area and back into sheet flow, reducing or eliminating the rill erosion. A field cultivator shall be used to construct the parallel (on the contour) cultivation strips at approximately 25 ft. (7.6 m) centers. The initial cultivated strip will be centered no more than 10 ft. (3 m) from the top of the backslope and the final, bottom, cultivated strip will be centered no more than 25 ft. (7.6 m) from the ditch bottom. The cultivation strips will be rough tilled to a depth of 3 to 4 in (75 to 100 mm).

The cultivated strips shall be completed as soon as the finish grade for the backslope has been established. Cultivated strips may also be placed on rough graded slopes that will be left exposed for several weeks.

Contour Field Cultivation of backslopes is paid for by the lin. ft. (m).

### 6.A.5 Sodding

Sodding is the transplanting of grasses. Sodding is done mostly in urban areas and is limited to occupied residential property and business sites. Sod usually comes in rolls, but sometimes slabs and plugs are used. Vacant lots are normally seeded.

Four types of grass are typically used for Sodding:

- Bluegrass: Primarily used on urban projects to match existing lawn conditions where a property owner is available to care for the grass after installation. Occasionally used on rural projects at the request of the property owner. Bluegrass Sodding shall be performed only when weather conditions are favorable. Bluegrass comes in rolls or slabs.
- Fescue: Primarily used on urban projects to match existing lawn conditions where a property owner is available to care for the grass after installation and occasionally used on rural projects at the request of the property owner. Fescue comes in rolls or slabs.
- Buffalograss: Buffalograss is used in medians in urban areas and comes in plugs or slabs.
- Zoysia: Zoysia is planted to match the existing plant material and comes in plugs.

Sodding will not survive without extended care. Sodding is measured and paid for in sq. yd. ($m^2$) of sod placed.

### 6.A.6 Erosion Control "Type_" Products

The various Erosion Control products are protective blankets or Turf Reinforcement that may be installed on prepared planting areas of steep slopes, channels or shorelines. Erosion Control Blankets and Turf Reinforcement Mats control erosion in critical areas by providing a microclimate that protects young vegetation and promotes its establishment. Some types of Erosion Control Blankets and Turf Control Mats also raise the maximum permissible water velocity on or across turf grass stands in channelized areas by reinforcing the turf to resist the forces of erosion during storm events.

Erosion Control Blankets are typically used on steep slopes (1:3 or steeper) where erosion hazard is high and vegetation growth is likely to be too slow to provide adequate protective cover. Erosion Control Blankets should be used in conjunction with Erosion Checks and may also be used in vegetated ditches with slopes of up to 3%. These blankets are composed primarily of straw or coconut and are selected based on the steepness of the slope and the longevity requirements of the product.

Turf Reinforcement Mats are used around splash basins of flumes or along flumes. They are also used on vegetated ditches and channels where the velocity of design flow exceeds the allowable velocity. Erosion Control Blankets or Turf Reinforcement Mats may be used where moving water is likely to wash out new plantings or in areas where the forces of wind prevent standard mulching practices from remaining in place until vegetation becomes established.

There are numerous erosion control products on the market (See EXHIBITS 2.5 THROUGH 2.9). See the Approved Products List (Reference 2.19) for a complete listing of all Erosion Control Products approved for use on **NDOT's** construction projects. The roadway designer should use special provisions to specify any brand name products recommended by the **Roadside Development & Compliance Unit**.

## SLOPE EROSION CONTROL USAGE CHART

| TYPE OF EROSION CONTROL * | SLOPE STEEPNESS | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1:6 or Flatter | | | 1:4 | | | 1:3 | | | 1:2.5 | | | 1:2 | | | 1:1 | | |
| | SLOPE LENGTH | | | SLOPE LENGTH | | | SLOPE LENGTH | | | SLOPE LENGTH | | | SLOPE LENGTH | | | SLOPE LENGTH | | |
| | 0'-30' | 30'-60' | 60'– | 0'-30' | 30'-60' | 60'+ | 0'-30' | 30'-60' | 60'+ | 0'-30' | 30'-60' | 60'+ | 0'-30' | 30'-60' | 60'+ | 0'-30' | 30'-60' | 60'+ |
| Seed with Properly Anchored Mulch | ——— | ——— | ——— | ——— | ——— | ——— | ——— | ——— | | | | | | | | | | |
| Sod | ——— | ——— | ——— | ——— | ——— | ——— | ——— | ——— | | | | | | | | | | |
| Slope Protection (Mulch) | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | | | | | | | | | |
| Type 1A Slope Protection Netting | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | | | | | | | | | |
| Type 1B Lt. Wt. Quick Degrading Erosion Control Blanket | ——— | ——— | ——— | ——— | ——— | ——— | ——— | ——— | | | | | | | | | | |
| Type 1C Lt. Wt. Single Net Erosion Control Blanket | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | ——— | | | | | | | |
| Type 1D Lt. Wt. Double Net Erosion Control Blanket | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | ——— | | | | |
| Type 1E Med. Wt. Double Net Erosion Control Blanket | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | ——— | ——— | | | |
| Type 1F Heavy Duty Erosion Control Blanket | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ········ | ——— | ——— | ——— | ——— |

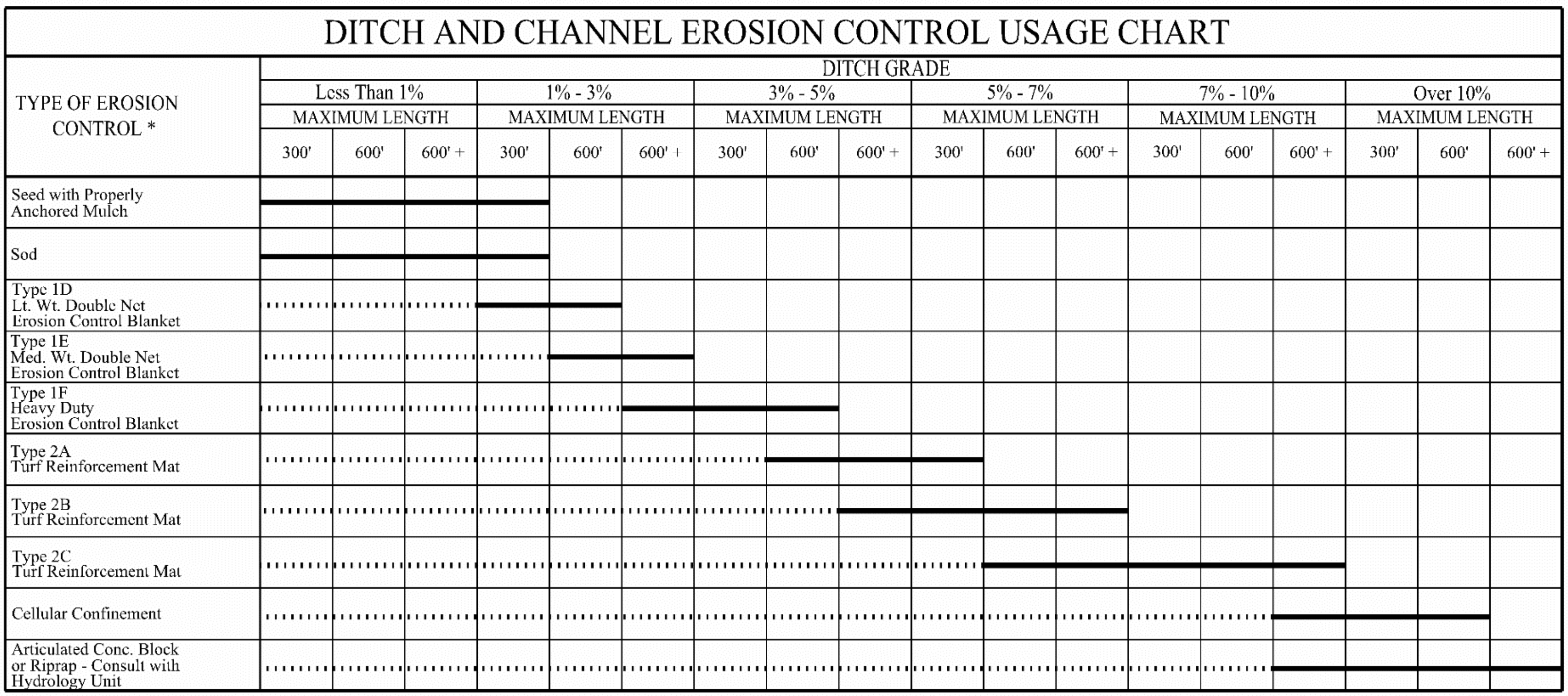
* For a description of the physical properties, see Exhibit 2.7.

——— Designates instances where a particular Erosion Control Type will be used

········ Designates instances where a particular Erosion Control Type may be used

Rill and gully erosion on side slopes is the primary concern when designing slope erosion control. When unprotected, the slopes will erode. Rills and gullies provide channels that further concentrate runoff and greatly increase the rate at which sediment is removed from the slopes. Once formed, they can become costly t correct and dangerous for our maintenance crews. Seeding and Mulching is the primary method of slope erosion control. However, Rolled Erosion Control Products (RECP's) are used based on aesthetic considerations, severity of the slopes, and soil types as well as cost.

**Exhibit 2.5 Slope Erosion Control Usage Chart**




* For a description of the physical properties, see Exhibits 2.7 and 2.8.

——— Designates instances where a particular Erosion Control Type will be used

·········· Designates instances where a particular Erosion Control Type may be used

Ditches and channels on the Right-of-Way carry water from the roadway, the side slopes, as well as runoff from adjacent properties. The energy produced during times of flow, based upon channel length and grade, soil type, and vegitative cover will affect the channel. The concentrated water can create gullies, some of which may continue up gradient and deepen enough to destabilize the side slope and threaten the roadway. In many instances, grasses, once established, can be sufficient to stabilize the ditch. However, as the lengths and grades become greater, the ditches require synthetic reinforcement of the grass to maintain the ditch. The overall philosophy of ditch and channel erosion control is to find the most economical solution over the long term while minimizing the amount of erosion occuring on the Right-of-Way.

**Exhibit 2.6 Ditch and Channel Erosion Control Usage Chart**

| ROLLED EROSION CONTROL PRODUCT PHYSICAL PROPERTIES SPECIFICATION CHART | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| PRODUCT TYPE | PRODUCT DESCRIPTION | MATERIAL COMPOSITION | FUNCTIONAL LONGEVITY | BLANKET SIZE | | ACCEPTABLE MATRIX FILL MATERIAL | PAY ITEM | STD. PLAN NO. |
| | | | | Minimum Roll Width | Minimum Thickness ASTM D 6525 | | | |
| DEGRADABLE BLANKETS | | | | | | | | |
| 1A | Slope Protection Netting | A photodegradable synthetic mesh or woven biodegradable natural fiber netting. | 12 Months | 6.5 ft. | N/A | N/A | SY | 5010 |
| 1B | Lt. Wt. Quick Degrading Erosion Control Blanket | Processed degradable natural and/or polymer fibers mechanically bound by a single rapidly degrading synthetic or natural fiber netting. | 3 Months | 4.0 ft. | 0.30 in. | Straw or Excelsior | SY | 5010 |
| 1C | Lt. Wt. Single Net Erosion Control Blanket | Processed degradable natural fibers mechanically bound together by a single degradable synthetic or natural fiber netting. | 12 Months | 6.5 ft. | 0.30 in. | Straw or Excelsior | SY | 5010 |
| 1D | Lt. Wt. Double Net Erosion Control Blanket | Processed degradable natural fibers mechanically bound together between two degradable synthetic or natural fiber nettings. | 12 Months | 6.5 ft. | 0.30 in. | Straw or Excelsior | SY | 5010 |
| 1E | Med. Wt. Double Net Erosion Control Blanket | An erosion control blanket composed of degradable natural fibers and/or processed slow degrading natural fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix. | 24 Months | 6.5 ft. | 0.30 in. | Straw, Excelsior, or Coconut Fibers | SY | 5010 |
| 1F | Heavy Duty Erosion Control Blanket | An erosion control blanket composed of degradable natural fibers and/or processed slow degrading natural fibers mechanically bound together between two slow degrading synthetic or natural fiber nettings to form a continuous matrix. | 36 Months | 6.5 ft. | 0.30 in. | Excelsior or Coconut Fibers | SY | 5010 |

The information in this table has been derived from information obtained from the Erosion Control Technology Council and from the characteristics of products currently on the NDOT Approved Products list.

**Exhibit 2.7 Rolled Erosion Control Product Properties**
**Degradable Blankets**

| ROLLED EROSION CONTROL PRODUCT PHYSICAL PROPERTIES SPECIFICATION CHART | | | | | | | |
|---|---|---|---|---|---|---|---|
| PRODUCT TYPE | PRODUCT DESCRIPTION | MATERIAL COMPOSITION | BLANKET SIZE | | ACCEPTABLE MATRIX FILL MATERIAL | PAY ITEM | STD. PLAN NO. |
| | | | Minimum Roll Width | Minimum Thickness ASTM D 6525 | | | |
| LONG TERM NON-DEGRADABLE CHANNEL APPLICATIONS | | | | | | | |
| 2A | Turf Reinforcement Mat | Long term, non-degradable rolled erosion control product composed of UV stabilized, non-degradable synthetic fibers, filaments, nettings and/or wire mesh processed into three dimensional reinforcement matrices designed for permanent and critical hydraulic applications where design discharges exert velocities and shear stresses that exceed the limits of mature, natural vegetation. Turf reinforcement mats provide sufficient thickness, strength and void space to permit soil filling and/or retention and the development of vegetation within the matrix. | 6.5 ft. | 0.25 in. | Excelsior, Coconut, or Polymer Fibers. | SY | 5010 |
| 2B | Turf Reinforcement Mat | | 6.5 ft. | 0.50 in. | 100% UV Stabilized Polypropylene Fibers | SY | 5010 |
| 2C | Turf Reinforcement Mat | | 6.5 ft. | 0.50 in. | 100% UV Stabilized Polypropylene Fibers | SY | 5010 |

The information in this table has been derived from information obtained from the Erosion Control Technology Council and from the characteristics of products currently on the NDOT Approved Products list.

**Exhibit 2.8 Rolled Erosion Control Product Properties**
**Long Term Non-Degradable Channel Applications**

## 6.B Permanent Sediment Control Measures

Sediment Control Measures are required with the Permanent Erosion Control to aid in:

- Keeping the soil on the site until final stabilization occurs.
- Reduce the amount of erosion on-site.
- Reduce the long-term maintenance costs.

As with the Permanent Erosion Control, there are numerous techniques and products available to aid in controlling sediment after construction is complete.

### 6.B.1 Erosion Checks

Erosion Checks are hay or straw bales placed in ditches at predetermined intervals to slow the velocity of water and cause silt deposition. Erosion Checks may also be used in conjunction with an Erosion Check-Silt Trap (ST), (See Section 5.C.5). The silt trap versions are used when the expected silt loading will be greater than normal due to sizeable cuts, soil type, etc. The steeper the grade, the closer together the erosion checks should be placed. The designer should refer to EXHIBIT 2.9 for preliminary guidelines regarding placement and spacing of Erosion Checks for the sediment control requirements of their project. The **Roadside Development & Compliance Unit** will review the final Erosion Check locations and intervals for each project.

There are several types of Erosion Checks listed on the Approved Products List (Reference 2.19). Typically, they are used in ditches where the rough grading is complete and before the finish grading is done, however there can be situations where these are used in a permanent capacity.

The roadway designer needs to provide details and calculate the number of bales that will be needed per Erosion Check installation. The Erosion Check design shall extend up the foreslope and backslope of the ditch to effectively contain runoff and to prevent erosion and washout at the edges of the Erosion Check. Erosion Check-ST includes a silt trap on the upstream side of the hay bales. Bale dimensions are typically 14-16 in. H x 18 in. W x 36 in. L (360-400 mm H x 450 mm W x 900 mm L) and are placed in an 6 in. (150 mm) deep trench. See the Erosion Check – Type A, -Type HV and –Type ST Special Plans and the Silt Checks Special Plans in the Standard/Special Plans Book, (Reference 2.12), for further details. EXHIBIT 2.10 illustrates various types of erosion checks.

When used in a ditch, Erosion Checks are typically spaced on 25 ft. (7.6 m), 50 ft. (15.2 m), 75 ft. (22.9 m), or 100 ft. (30.5 m) increments based on the severity of the ditch slope and any local conditions.

| EROSION CHECK USAGE CHART | | | | | |
|---|---|---|---|---|---|
| ***Bid Item*** | ***Product*** | ***Usage*** | ***Ditch Grade*** | ***Placement Guidelines*** | ***Required Plans (Standard/Special Plans Book)*** |
| *Erosion Check* | *Includes: 3 ft., (1 m) Bale, Filter Fabric, and Erosion Control Blanket* | *Used for silt control and to reduce the velocity of water in ditches. Type must match the EC in the ditch.* | *2%* | *100 ft. (30 m) on center* | *Standard Plan 5100 1 E/M* |
| | | | *3-4%* | *50-75ft. (15-23) on center* | |
| | | | *4-6%* | *50-75 ft. (15-23 m) on center* | |
| | | | *6-9%* | *50 ft. (15 m) on center* | |
| *Erosion Check – ST (with silt trap)* | *Includes: 3 ft., (1 m) Bale, Filter Fabric, Erosion Control Blanket, and Silt Trap* | *Used for an expected high silt load. Type must match the EC in the ditch.* | *2%* | *100 ft. (30 m) on center* | *Special Plan 5100 1 E/M* |
| | | | *3-4%* | *75-100 ft. (23-30 m) on center* | |
| | | | *4-6%* | *50-75 ft. (15-23 m) on center* | |
| | | | *6-9%* | *50 ft. (15 m) on center* | |
| *Temporary Silt Check* | *Includes: 7 ft., (2.1 m) Triangular Foam Dike, and Filter Fabric & Other Products* | *Used as a temporary silt retention device while the project is under construction.* | *2%* | *150 ft. (45 m) on center* | *Special Plan 5108 1 E/M* |
| | | | *3-4%* | *100 ft. (30 m) on center* | |
| | | | *4-6%* | *75 ft. (23 m) on center* | |
| | | | *6-9%* | *50 ft. (15 m) on center* | |

**Exhibit 2.9 Erosion Check Usage Chart**

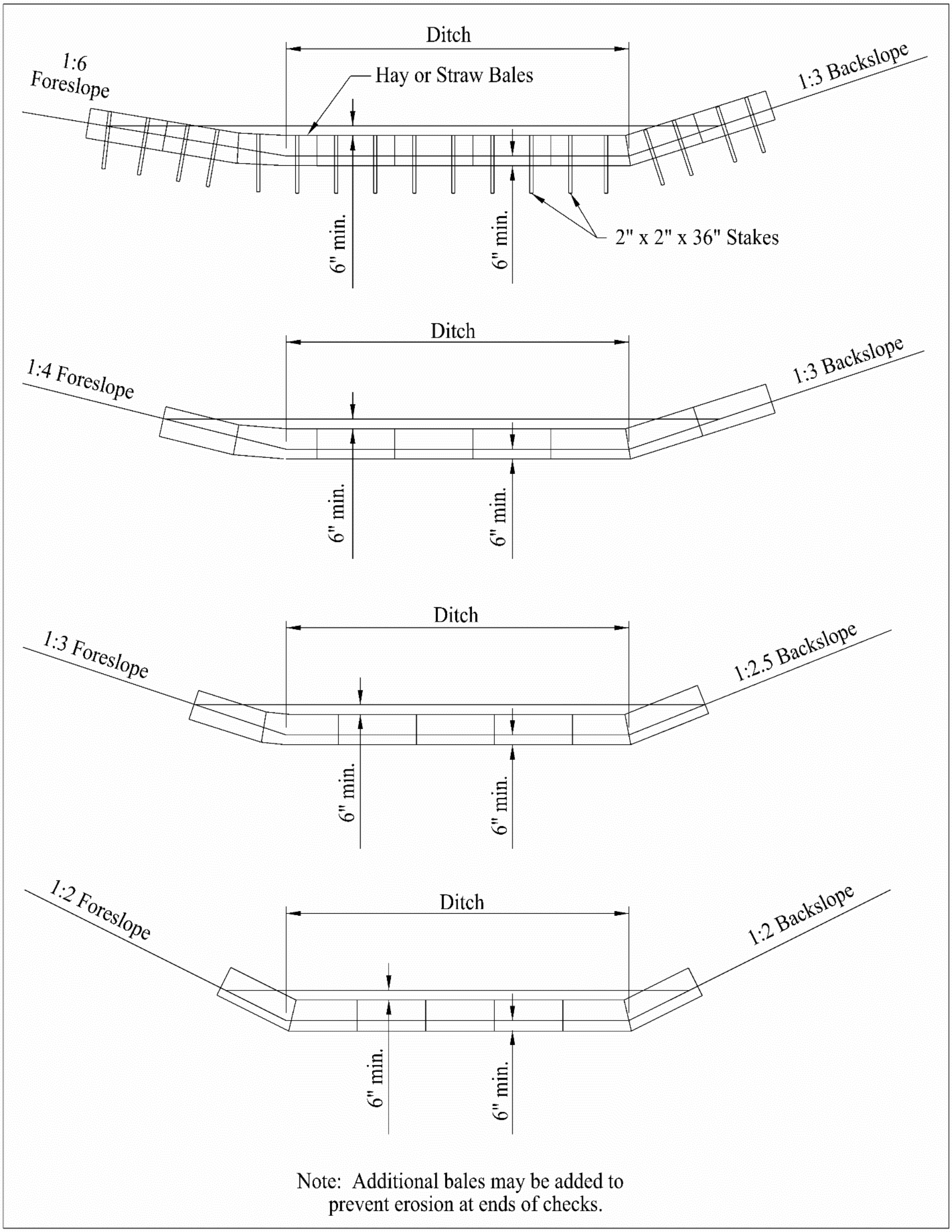



**Exhibit 2.10 Erosion Checks**

### 6.B.2 Silt Fence

A Silt Fence is a sediment barrier consisting of synthetic or natural fabric. The fabric is stretched across and attached to supporting posts. The fabric also is entrenched, (See the Fabric Silt Fence Details in the Standard/Special Plans Book, Reference 2.12). Silt Fence is typically used to intercept and retain small amounts of sediment from disturbed areas of limited extent in order to prevent sediment from leaving the construction site. It essentially filters waterborne soil from the water before it leaves the project site. Silt Fence can be used around area inlets, other drainage structures, and on steep and high slopes. High Porosity Silt Fence can be used in ditches to help slow the velocity of the water, allowing soil particles to drop out.

The Silt Fence fabric may be either high porosity or low porosity, and either full height or low profile. Coir Silt Fence is an organic biodegradable fabric made from coconut fibers. Coir Silt Fence, at regular height and high porosity, may be used in wetlands applications or in areas where the functional life of the Silt Fence will need to meet or exceed two years. Silt Fence is sometimes used with a silt trap on the upstream side to prolong the life of the fence, (See Section 5.C.5). EXHIBIT 2.11 lists the different types of silt fences.

Silt Fence is used on most projects, especially on projects with adjoining wetlands, and may be used to control erosion on side slopes. The roadway designer should establish locations where Silt Fence will be required. The **Roadside Development & Compliance Unit** will provide assistance for preliminary and final Silt Fence placement for specific situations and will aid in determining the appropriate Silt Fence type.

Silt Fence is measured and paid for by the lin. ft. (m).

| ***SILT FENCE USAGE CHART*** | | |
|---|---|---|
| ***Silt Fence Bid Item*** | ***Product Usage*** | ***Required Plans*** |
| *Low Porosity* | *Low flow situations* | *5700 1 E/M* |
| *High Porosity* | *High flow areas - mostly rural, some urban* | |
| *Combination of low and high porosity* | *Area inlets and urban high flow areas* | |
| *Low profile, low or high porosity* | *Low flow structure* | |
| *Combination of low profile, low and high porosity* | *Median drains, area inlets* | |
| *Low Profile Coir Fiber* | *Wetland protection – low silt load* | |
| *Coir Fiber* | *Wetland protection* | |

**Exhibit 2.11 Silt Fence Usage Chart**

### 6.B.3 Slope Protection Netting

Slope Protection Netting, a photo-degradable lightweight flexible netting, is used over Slope Protection (See Section 6.A.3) to protect the slope protection material from excessive loss due to wind. Slope Protection Netting is typically installed in the sandhills on the east and south sides of high fills, see Standard Plan 5010 in the Standard/Special Plans Book, (Reference 2.12), and Section 811 of the Standard Specifications for Highway Construction, (Reference 2.10).

Slope Protection Netting is measured and paid for in sq. yds. ($m^2$), (seeding quantities are also calculated for this same area, see Section 6.A.1).

## 7. PERMANENT HYDRAULIC CONTROL MEASURES

### 7.A Riprap

Riprap is a layer, facing or protective lining of stones placed to prevent erosion, scour or sloughing. Filter fabric is installed beneath the stone in most applications. Riprap can be used for several different applications including:

- Ditch Lining.
- Lining of channel banks.
- Protection of highway embankments.
- Energy dissipation at culvert outlets.

Riprap, as discussed in this section, is limited to dumped riprap including rock and broken concrete. Rock riprap shall be sandstone, limestone, quartzite or other hard stone, clean and free of earth, clay or refuse (See Section 905 of the Standard Specifications for Highway Construction, Reference 2.10). Broken concrete shall be sized appropriately and placed as specified in Section 906 of Reference 2.10. Each load shall be reasonably well graded from the largest to the smallest size specified. The designer should refer to Hydraulic Engineering Circular No. 11, Design of Riprap Revetment, (Reference 2.8) for discussion of hand-placed riprap, grouted riprap, sacked concrete riprap, and broken concrete riprap.

Dumped riprap is graded rock or stone dumped on a prepared slope in such a manner that segregation will not take place. Dumped riprap has several advantages including:

- The lining is flexible and can adjust to foundation settlement.
- The riprap is free draining, which eliminates hydrostatic pressure problems associated with rigid linings.
- Local damage or loss is easily repaired by the placement of additional rock.
- The appearance is natural and generally pleasing.

Riprap can be an effective erosion resistant lining, however, it is susceptible to damage in the following ways:

- The displacement of individual stones by the forces of water.
- The loss of foundation stability by movement of the underlying soil through the riprap layer when no filter layer is placed or is placed improperly.
- Displacement of the entire mass when the filter fabric acts as a sheer plane on steep slopes.

The resistance of the stone to displacement by moving water depends on:

- The weight, size, and shape of the individual stone.
- The gradation of the stone.
- The depth of water over the stone lining (including buoyancy forces).
- The steepness of the protected slope.
- The stability and efficiency of the filter blanket and the embankment on which the stone is placed.
- The velocity of the flowing water against the stone.

### 7.A.1 Sizing Riprap

The design method presented in this section is based on the concept of maximum permissible tractive force. The tractive force approach focuses on stresses developed at the boundary between flowing water and the materials forming the channel boundary. The size of rock riprap required can be determined by computing the shear stress on the channel at the design discharge and comparing the calculated shear stress to the permissible value for the size of stone selected.

### 7.A.2 Tractive Force Theory

The hydrodynamic force of water flowing in a channel is known as the tractive force. The basis for stable channel design with rock riprap is that the flow-induced tractive force should not exceed the permissible or critical shear stress of the lining materials. In a uniform flow, the tractive force is equal to the effective component of the gravitational force acting on the body of water, parallel to the channel bottom. The average tractive force, or shear stress, on the channel is equal to:

$$\tau = \gamma RS \qquad \text{Eq. 2.1}$$

Where:
$\tau$ = Average tractive force shear stress (lbs./sq. ft.);
$\gamma$ = Unit weight of water (62.4 lbs./cu. ft.);
R = Hydraulic radius (ft.);
S = Average bed slope or energy slope.

Studies have shown that shear stress in channels is not uniformly distributed along the wetted perimeter, and that the maximum average shear stress, $\tau_{max}$, for a straight channel occurs on the channel bed, where the maximum flow depth occurs.

The tractive force method is applicable over a wide range of channel slopes and channel shapes. However, channels with extremely steep slopes, (S greater than 0.25 ft./ft.), and channels with steep side slopes (steeper than 1:3) should use the modified tractive force method provided in Hydraulic Engineering Circular No. 15: Design of Roadside Channels with Flexible Linings; (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/05114.pdf), (Reference 2.18).

### 7.A.3 Permissible Shear Stress

The permissible shear stress, $\tau_p$, indicates the force required to initiate movement of the lining material. Prior to movement of the lining, the underlying soil is relatively protected. Therefore permissible shear stress is not significantly affected by the erodibility of the underlying soil.

Values for permissible shear stress for ditch and channel linings are based on research conducted at laboratory facilities and in the field. EXHIBIT 2.12 presents permissible shear stress values for riprap lining type.

| ***PERMISSIBLE SHEAR STRESS FOR RIPRAP*** | | |
|---|---|---|
| *Riprap Type* | *Mean Riprap Stone Size, $D_{50}$ (ft.)* | *Permissible Shear Stress, $\tau_p$ (lbs./sq. ft.)* |
| *Rock Riprap Type A* | *0.77* | *3.08* |
| *Rock Riprap Type B* | *1.02* | *4.08* |
| *Broken Concrete* | *1.10* | *4.40* |
| *Rock Riprap Type C* | *1.28* | *5.12* |

**Exhibit 2.12 Permissible Shear Stress for Riprap**

The permissible shear stress for non-cohesive soils is a function of mean diameter of the channel material. For other stone sizes, the permissible shear stress is given by the following equation:

$$\tau_p = (4.0 \text{ lbs./cu. ft.}) \times D_{50} \div SF \qquad \text{Eq. 2.2}$$

Where: $\tau_p$ = Permissible tractive force shear stress;
4.0 lbs./cu. ft. = A constant provided by **FHWA**;
$D_{50}$ = The mean riprap stone size in ft.;
SF = Safety Factor (usually 1.1).

### 7.A.4 Riprap Size

The basic comparison required in the design procedure is that of permissible to computed shear stress for the riprap. If the permissible shear stress is greater than the computed shear, the riprap size is considered acceptable. Channels lined with riprap on side slopes steeper than 1:3 must be designed using a steep side slope design procedure provided in Hydraulic Engineering Circular No. 15: Design of Roadside Channels with Flexible Linings, (Reference 2.18).

$\tau_{max} < \tau_p$ - Design Size Acceptable
$\tau_{max} > \tau_p$ - Design Size Not acceptable

Example Problem:

30 cfs is directed down a standard 10' wide, a trapezoidal highway ditch which has 1:3 side slopes and a 10% grade. Find a stable Riprap material to line the ditch.

Step 1. Using Manning's Equation (See Chapter One: Drainage, Section 7.C and Eq. 1.5) determine:

Flow depth, $d = 0.74$ ft.
Hydraulic Radius, $R = 0.62$ ft.

Step 2. Using Equation 2.1, determine the maximum average shear stress, $\tau_{max}$:

$\tau_{max} = \gamma RS$ = (62.4 lbs./cu. ft.) x (0.62 ft.) x (0.1 ft./ft.) = 3.87 lbs./sq. ft.

Step 3. Using Equation 2.2 Determine the Permissible Shear Stress:

Type A Rock Riprap: $D_{50}$ = 0.77 ft.

$\tau_p$ = (4.0 lbs./cu. ft.) x 0.77 ft. ÷ 1.1 = 2.80 lbs./sq. ft.

Step 4. Determine the Acceptability of riprap material:

$\tau_{max}$ = 3.87 lbs./sq. ft. > $\tau_p$ = 2.80 lbs./sq. ft.: Design Size Not acceptable.

Repeat Steps 3 and 4 until acceptable riprap material determined:

Type B Rock Riprap: $D_{50}$ = 1.02 ft.

$\tau_p$ = (4.0 lbs./cu. ft.) x 1.02 ft. ÷ 1.1 = 3.71 lbs./sq. ft.

$\tau_{max}$ = 3.87 lbs./sq. ft. > $\tau_p$ = 3.71 lbs./sq. ft.: Design Size Not acceptable.

Type C Rock Riprap: $D_{50}$ = 1.28 ft.

$\tau_p$ = (4.0 lbs./cu. ft.) x 1.28 ft. ÷ 1.1 = 4.65 lbs./sq. ft.

$\tau_{max}$ = 3.87 lbs./sq. ft. < $\tau_p$ = 4.65 lbs./sq. ft.: Design Size Acceptable.

The answer may also be found using EXHIBIT 2.13:

Acceptable Riprap for 30 cfs in a normal ditch section at a 10% (0.10) slope: = Conc. (33 cfs) and Rock Riprap Type C (43 cfs).

| ***RIPRAP - PERMISSIBLE DITCH FLOW (cfs)*** | | | | |
|---|---|---|---|---|
| ***Slope*** | ***Riprap Type*** | | | |
| | *Rock Riprap Type A* | *Rock Riprap Type B* | *Broken Concrete Riprap* | *Rock Riprap Type C* |
| *0.05* | *42* | *70* | *81* | *107* |
| *0.06* | *33* | *55* | *64* | *84* |
| *0.07* | *28* | *45* | *52* | *68* |
| *0.08* | *23* | *38* | *43* | *57* |
| *0.09* | *20* | *33* | *37* | *49* |
| *0.10* | *13* | *28* | *33* | *43* |
| *0.11* | *11* | *25* | *29* | *38* |
| *0.12* | *10* | *22* | *26* | *34* |
| *0.13** | *9* | *20* | *23* | *30* |
| *0.14** | *8* | *14* | *21* | *28* |
| *0.15** | *8* | *13* | *15* | *26* |
| *0.16** | *7* | *12* | *13* | *23* |
| | ***cfs*** | | | |

** Consider flattening ditch slope and using drop structure.*

**Exhibit 2.13 Permissible Ditch Flow (cfs) for a Normal Ditch Section**
**(Based on the Mean Stone Size and the Design Depth Thickness, See Exhibit 2.15)**

### 7.A.5 Channel Bends

On channel bends, the flow around the bend creates secondary currents, which impose higher shear stresses on both the channel sides and bottom compared to the straight channel. The location of this increased shear stress changes across the length of the bend. The shear begins to increase on the inside of the curve and progresses to the outside of the curve as the bend is completed. The maximum shear stress in the bend is a function of the ratio of channel curvature to bottom width, $R_c/B$. As $R_c/B$ decreases, (i.e. the bend becomes sharper), the maximum shear stress increases. The bend shear stress, is determined by multiplying the straight channel shear stress by a constant, $K_b$.

$$\tau_b = (K_b) \times (\tau_{max}) \qquad \text{Eq. 2.3}$$

Where: $\tau_b$ = Bend shear stress;
$K_b$ = A factor for maximum shear stress on channel bends, (See EXHIBIT 2.14);
$\tau_{max}$ = The maximum straight channel shear stress (See Eq. 2.1).

This increased shear stress continues downstream of the bend for a distance, $L_p$.

$$L_p = (0.604) \times (R^{7/6} \div n_b) \qquad \text{Eq. 2.4}$$

Where: $L_p$ = Distance shear stress continues downstream of bend;
R = Hydraulic radius;
$n_b$ = Manning's roughness in the bend.

<u>Example Problem</u>:

A roadside ditch carries 40 cfs from a culvert through a 20' radius bend adjacent to a county road before emptying into a stream. The 10 ft. wide ditch is at a grade of 0.05 ft./ft. and has 1:3 side slopes. Determine the necessary riprap size.

Step 1. Using Manning's Equation (See Chapter One: <u>Drainage</u>, Section 7.C and Eq. 1.5) determine:

Flow depth, $d =$ 0.90 ft.
Hydraulic Radius, $R =$ 0.73 ft.

Step 2. Using Equation 2.1, determine the maximum average shear stress, $\tau_{max}$:

$\tau_{max} = \gamma RS$ = (62.4 lbs./cu. ft.) x (0.73 ft.) x (0.05 ft./ft.) = 2.28 lbs./sq. ft.

Step 3. Using <u>EXHIBIT 2.14</u>, determine the maximum bend shear stress factor, $K_b$:

Radius of Curve ÷ Bed Width, ($R_c$ ÷ B) = 20 ft. ÷ 10 ft. = 2.0

From <u>EXHIBIT 2.14</u>: For ($R_c$ ÷ B) = 2.0, $K_b$ = 2.0

Step 4. Using Equation 2.3, determine the maximum bend shear stress, $\tau_b$:

$\tau_b = (K_b) \times (\tau_{max})$ = (2.0) x (2.28 lbs./sq. ft.) = 4.56 lbs./sq. ft.

Step 5. Using Equation 2.2, determine the Permissible Shear Stress, $\tau_p$:

$\tau_p$ = (4.0 lbs./cu. ft.) x $D_{50}$ ÷ SF

Type A Rock Riprap: $D_{50}$ = 0.77 ft.; SF = 1.1

$\tau_p$ = (4.0 lbs./cu. ft.) x 0.77 ft. ÷ 1.1 = 2.80 lbs./sq. ft.

Type C Rock Riprap: $D_{50}$ = 1.28 ft.; SF = 1.1

$\tau_p$ = (4.0 lbs./cu. ft.) x 1.28 ft. ÷ 1.1 = 4.65 lbs./sq. ft.

Step 6. Determine the Acceptability of riprap material:

$\tau_{max}$ = 2.28 lbs./sq. ft. < $\tau_p$ = 2.80 lbs./sq. ft.: Design Size Acceptable for Straight.

$\tau_b$ = 4.56 lbs./sq. ft. < $\tau_p$ = 4.65 lbs./sq. ft.: Design Size Acceptable for Bend.

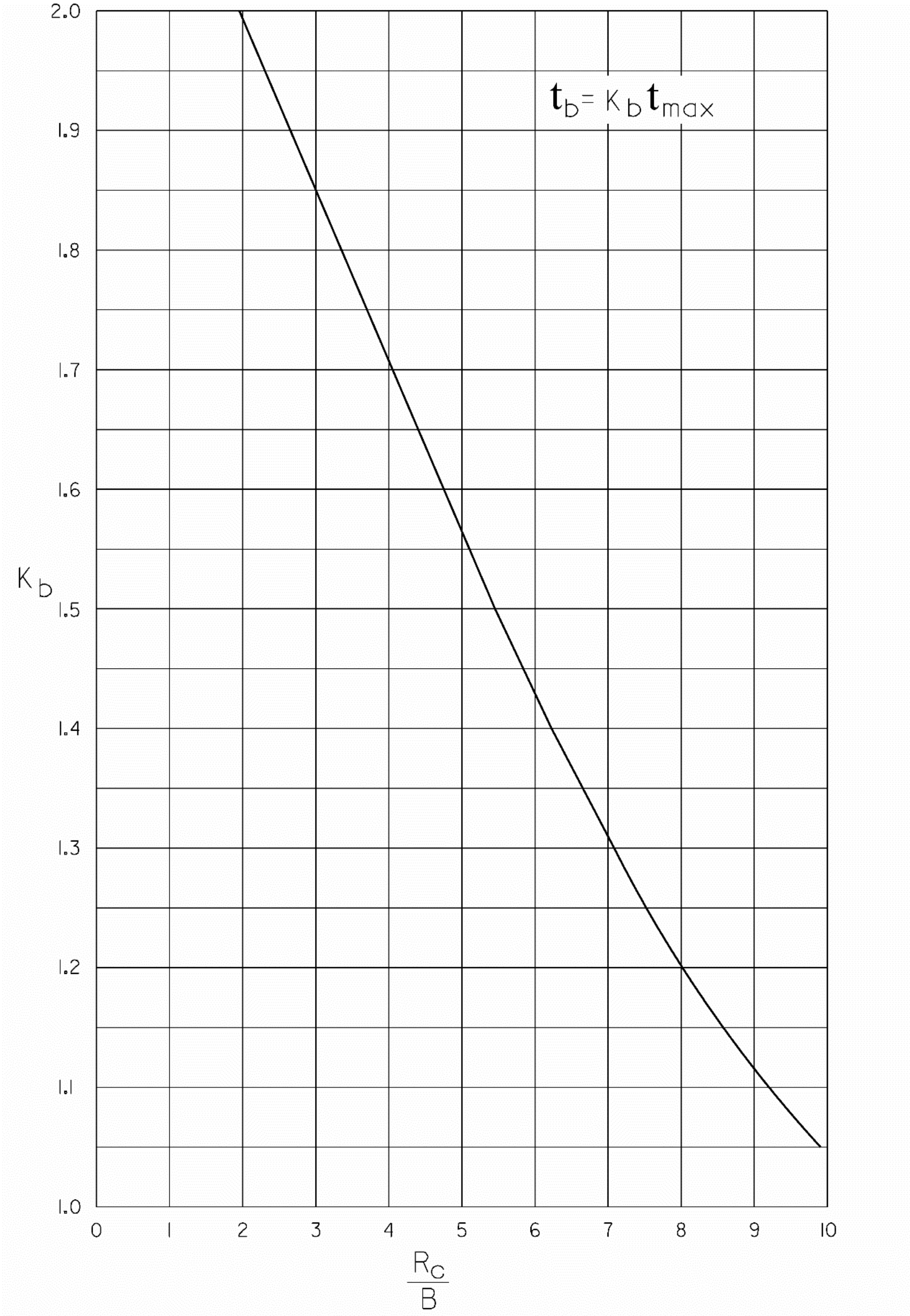



**Exhibit 2.14 $K_b$ Factor for Maximum Shear Stress on Channel Bends**
**(Source: Reference 2.18, Chart 10)**

### 7.A.6 Other Considerations

Two additional design considerations are required for riprap channel linings: Riprap Gradation and Filter Material under rock riprap.

### 7.A.6.a Riprap Gradation and Thickness

Riprap gradation should follow a smooth size distribution curve. Most riprap gradations should fall within the acceptable range where the ratios $D_{100}/D_{50}$ and $D_{50}/D_{20}$ are between 1.5 and 3.0. The most important criterion is a proper distribution of sizes in the gradation so that interstices formed by larger stones are filled with smaller sizes in an interlocking fashion, preventing the formation of open pockets. Flat slab-like stones should be avoided at all times since they are easily dislodged by the flow, and tend to redirect flow into unprotected banks. These gradation requirements apply regardless of the type of filter design used.

### 7.A.6.b Filter Design

When rock riprap is used the need for an underlying filter material must be evaluated. The filter material may be either a granular filter layer or an engineering fabric.

<u>Granular Filter Blanket</u>

For a granular filter blanket, the following criteria must be met:

$$(D_{15} \text{ filter} \div D_{85} \text{ base}) < 5 < (D_{15} \text{ filter} \div D_{15} \text{ base}) < 40$$

$$(D_{50} \text{ filter}) < (D_{50} \text{ base}) < 40$$

This relationship must hold between the filter blanket and base material and between the riprap and filter blanket. The filter blanket criteria may require more than one layer of filtering material to be placed. The thickness of the granular filter blanket should approximate the maximum size in the filter gradation. The minimum thickness for a filter blanket should be 6 in.

<u>Engineering Filter Fabric</u>

The following properties of an engineering filter fabric are required to assure that their performance is adequate as a filter under riprap.

- The fabric must be able to transmit water faster than the soil.
- The following criteria for the apparent opening size (AOS) must be met:
    1. For soil with less than 50 percent of the particles by weight passing a US No 200 sieve, AOS < 0.024 in. (0.6 mm) (greater than a US No 30 sieve).
    2. For soil with more than 50 percent of the particles by weight passing a US No 200 sieve, AOS < 0.012 in. (0.297 mm) (greater than a US No 50 sieve).

### 7.A.7 Placing Riprap

The minimum thickness of the riprap lining placed in a channel is equal to the maximum size stone. EXHIBIT 2.15 provides the various **NDOT** riprap stone sizes and design thicknesses.

| *NDOT RIPRAP PROPERTIES* | | | | |
|---|---|---|---|---|
| *Riprap Type* | *Median Diameter $D_{50}$ (ft.)* | *Maximum Diameter $D_{100}$ (ft.)* | *Minimum Design Depth / Thickness (ft.)* | *Basis of Payment (Ton)* |
| *Rock Riprap Type A* | *0.77* | *1.28* | *1.50* | *1.35 Ton/cu. yd.* |
| *Rock Riprap Type B* | *1.02* | *1.61* | *1.75* | *1.35 Ton/cu. yd.* |
| *Broken Concrete Riprap* | *1.10* | *1.88* | *2.00* | *1.35 Ton/cu. yd.* |
| *Rock Riprap Type C* | *1.28* | *2.12* | *2.25* | *1.35 Ton/cu. yd.* |

**Exhibit 2.15 NDOT Riprap Properties**

#### 7.A.7.a Channel Bank Riprap

Excavation of the channel bottom and sides for the placement of the riprap material is necessary for the stability of the lining. When riprap is placed in the ditch the flowline of the ditch should be the top of the riprap and the earth side slopes above the riprap should match the top of the riprap, (See EXHIBIT 2.16).

On a straight channel, riprap bank protection should begin and end at a stable feature in the bank. If a stable feature does not exist, cutoffs should be provided as shown in EXHIBIT 2.17. Where the protective cover is long, intermediate cutoffs should be provided to reduce the hazard of complete failure of the stone blanket.

For stream channels composed of sand or silt, bank protection should extend a minimum vertical distance of 3 ft. (1 m) below the streambed on a continuous slope with the embankment (See EXHIBIT 2.18). On the outside of curves or sharp bends, scour is particularly severe, and the toe of the bank protection should be placed deeper than in straight reaches. Where a toe trench cannot be excavated, the riprap blanket should terminate in a stone toe at the level of the streambed (See EXHIBIT 2.19). The toe provides material that will fall into a scour hole and thus extend the blanket.

The purpose of the toe protection is to prevent undermining, not to support the riprap blanket. Unless the protection has sufficient stability to support itself on the embankment slope, the protection cannot be considered adequate.

The upper vertical limit of the riprap blanket should extend at least 1 ft. (300 mm) above design high water. This allowance for freeboard depends upon the velocities near the riprap cover and at some locations, on the height of waves that might be generated on the water surface. Established sod above the stone protection will provide considerable protection from floods that overtop the riprap cover.

Details of riprap used for lining channel banks are shown in EXHIBITS 2.16 THROUGH 2.19.

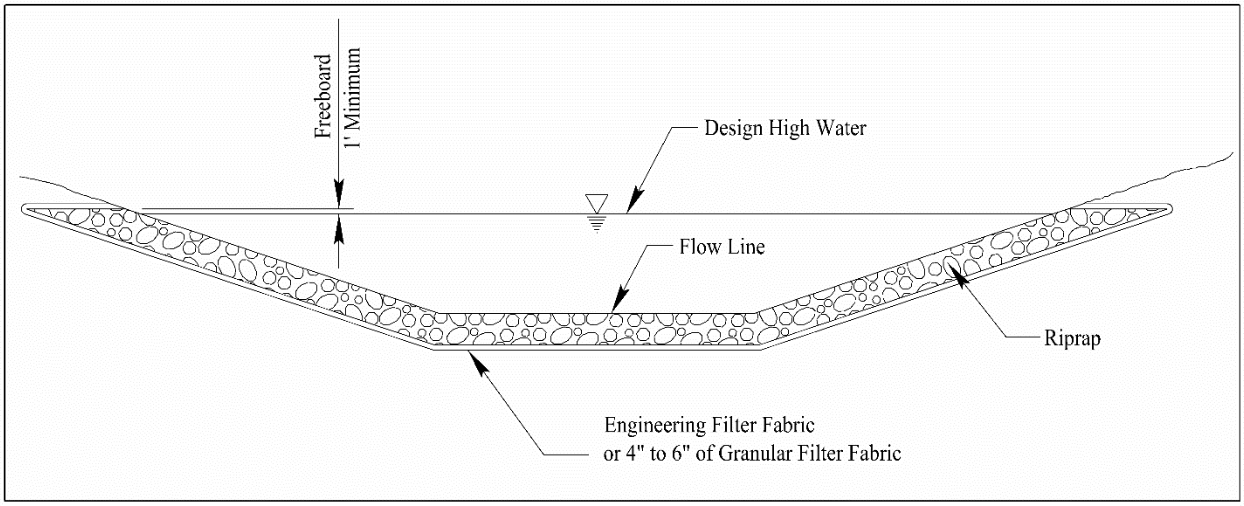



**Exhibit 2.16 Channel Perimeter Riprap**

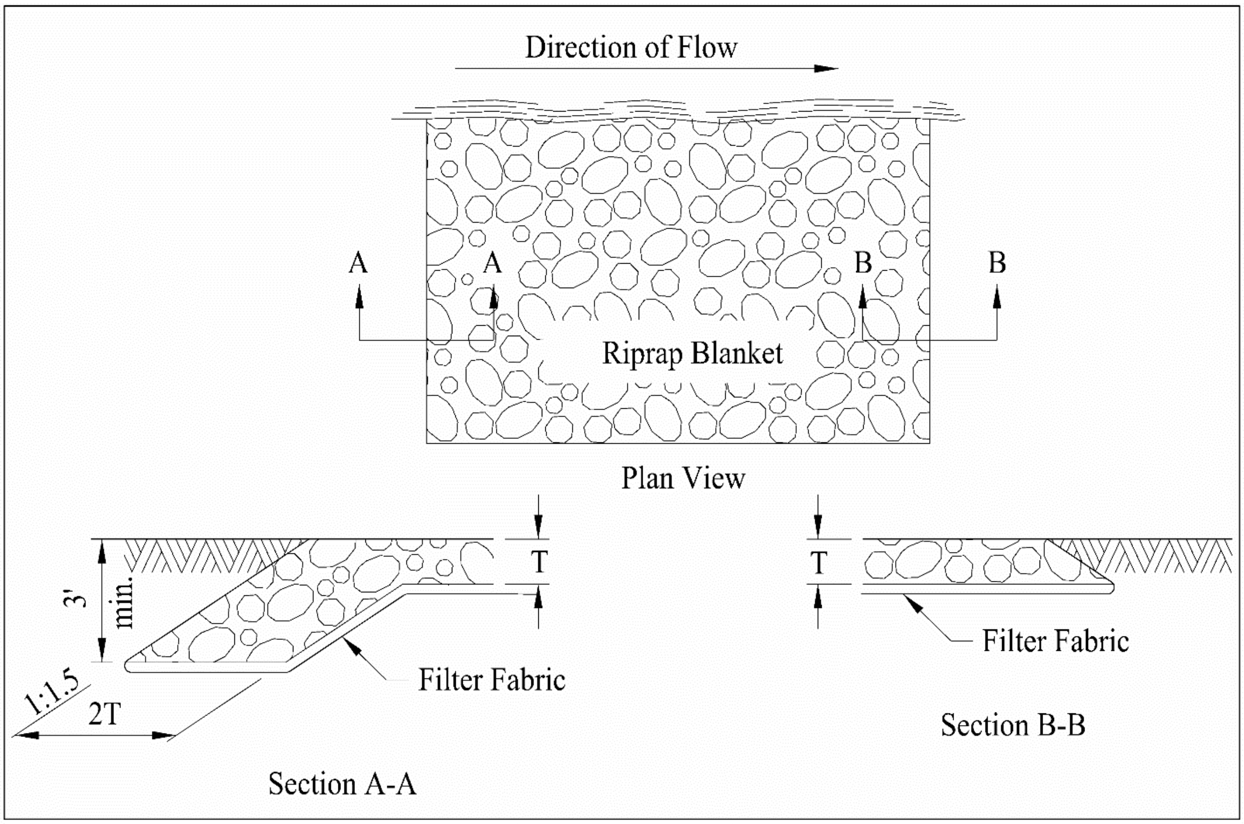



**Exhibit 2.17 Riprap Cutoff Detail**

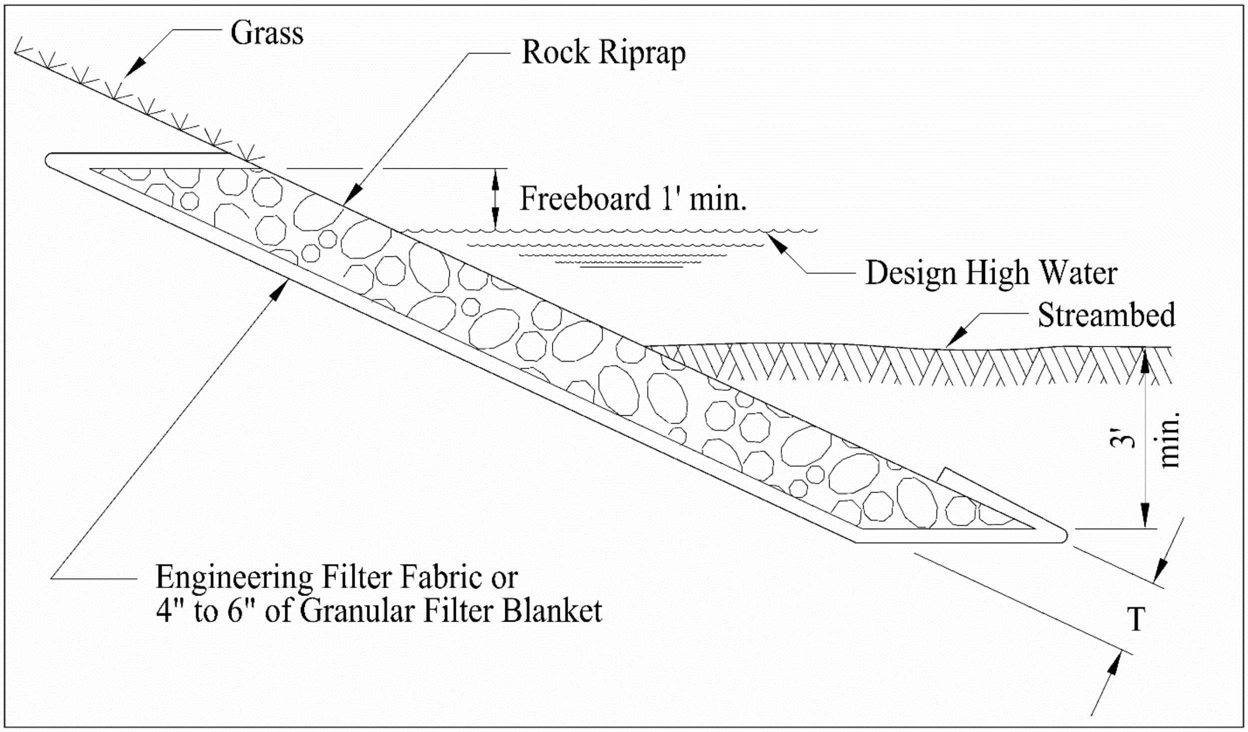



**Exhibit 2.18 Riprap Blanket and Toe Trench Detail**

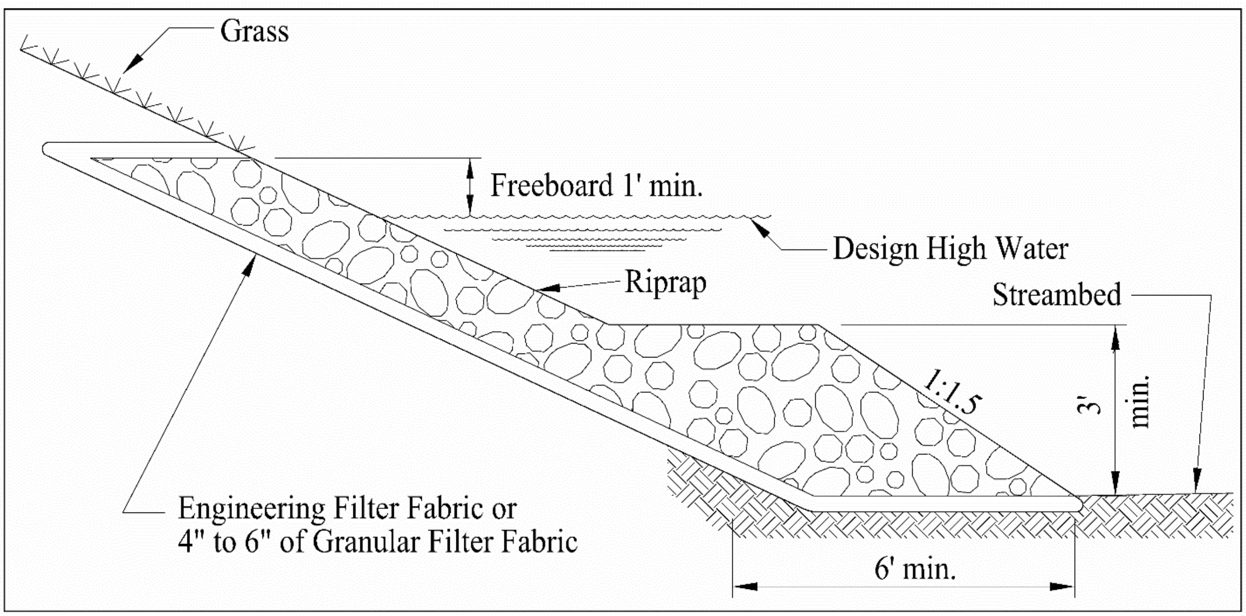



**Exhibit 2.19 Riprap Blanket and Toe Detail**

## 7.B Gabions

Gabions are rectangular, rock-filled wire baskets. These wire baskets can be placed side-by-side and stacked vertically to form an unbroken lining or wall. Gabion baskets are shown in EXHIBIT 2.20. Gabions are suitable for several applications including:

- Lining of high, steep channel banks.
- Channel drop structures.
- Energy dissipation at the outlet of culverts.
- Low-height retaining walls.

Gabion baskets are available from manufacturers in different sizes. The 6 ft. and longer Gabion baskets are usually divided into cells with interior diaphragms that reinforce the basket and facilitate basket assembly in the field. Wire used to fabricate the baskets is normally zinc coated. If the baskets will be installed in a corrosive or polluted environment, a continuous, polyvinyl chloride (PVC) sheath can be applied to the zinc coated wire.

When gabions are used for lining of channel banks, the baskets are laid directly on the banks to be protected and function only as a facing or lining. Accordingly, the slope or bank must itself be stable, and must not be so steep as to cause the basket to slide. The **Materials and Research Division** must be consulted to determine the safe, stable slope for the channel bank.

The stability of gabion structures depends on the following:

- Strength of the basket's wire mesh.
- Thickness of the lining.
- Grading of the stone fill.
- Resistance of the wire baskets to corrosion.
- Resistance of the stone fill to freeze thaw and abrasion.

The thickness of the lining and grading of stone fill is dependent upon the velocity of water in the channel. The “critical velocity” is the velocity at which the gabion basket will remain stable without movement of the stone fill. The “limit velocity” is that which is still acceptable although there is some deformation of the basket due to movement of the stones within the compartment.

Research has indicated that the size of rocks needed for gabion baskets is half that required for riprap for a given hydraulic condition. For the same size stone or rock, the acceptable velocity for gabion baskets is approximately 3-4 times that for riprap. The designer should consult manufacturer's literature that provides required lining thickness and stone sizes for a range of velocities.

If gabions baskets are to function as a retaining wall, the Bridge Division must be contacted to design the retaining wall system. Consideration must be given to scour and potential for undermining the foundation.

Construction specifications for gabions are found in Section 907 of the Standard Specifications for Highway Construction, (Reference 2.10). Gabions are measured according to the number of baskets placed and are paid for by each.

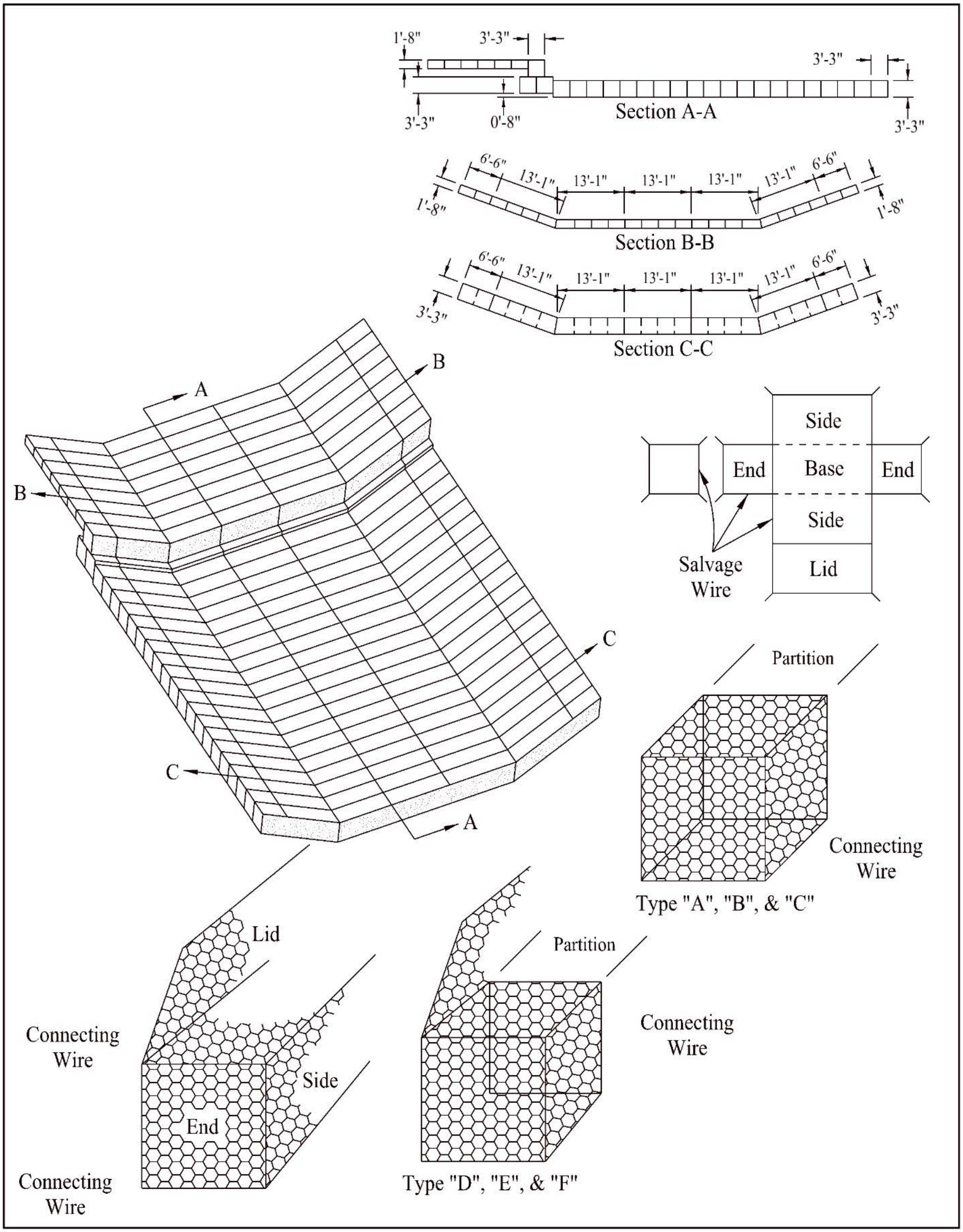



**Exhibit 2.20 Gabions**

## 7.C Revet Mattress

A Revet mattress is a special type of gabion (See Section 7.B) with a large surface area-to-thickness ratio. Revet mattresses are multicell containers with internal diaphragms spaced at 3 ft. (1 m) intervals. Wire used for fabricating revet mattresses is zinc coated, and a PVC coating is also available for corrosive environments. Filter fabric is required under revet mattresses.

Revet mattresses are suitable for several applications including:

- Lining of low, flat channel banks.
- Energy dissipation at the outlet of culverts.
- Protection of highway embankments.

Revet mattresses have requirements for placement, stability, lining, rock size, etc. similar to those for gabions, (See Section 7.B for discussion).

Refer to manufacturer's publications for construction specifications and plans for revet mattresses. Revet mattresses are measured and paid by each, (Refer to Section 907 of the Standard Specifications for Highway Construction, Reference 2.10).

## 7.D Cellular Confinement System

A cellular confinement system consists of a network of three-dimensional cells constructed of High Density Polyethylene (HDPE) plastic. The HDPE sections are shipped as collapsed bundles that are expanded at the job site into thick sheets of varying size and installed. The cellular confinement system provides root reinforcement and increased shear resistance when the cells are filled with native soils and vegetation, but the cells can also act as a ditch lining when filled with various materials including granular materials and concrete. EXHIBIT 2.21 shows a cellular confinement system.

A cellular confinement system can be used for several types of applications including:

- Stabilizing ditch bottoms.
- Lining of stream channel banks.
- Construction of retaining walls.
- Protection of highway embankments.

The cellular system is flexible and can conform readily to changes in subgrade profile. When filled with concrete, the system eliminates the need for forms and expansion joints. The flexible nature of the concrete filled cellular confinement system allows it to respond more favorably to changes in ditch or channel geometry caused by erosion or subsidence than cast-in-place pavements.

The designer should contact the manufacturer to obtain hydraulic design parameters including allowable velocities and Manning's "n" values.

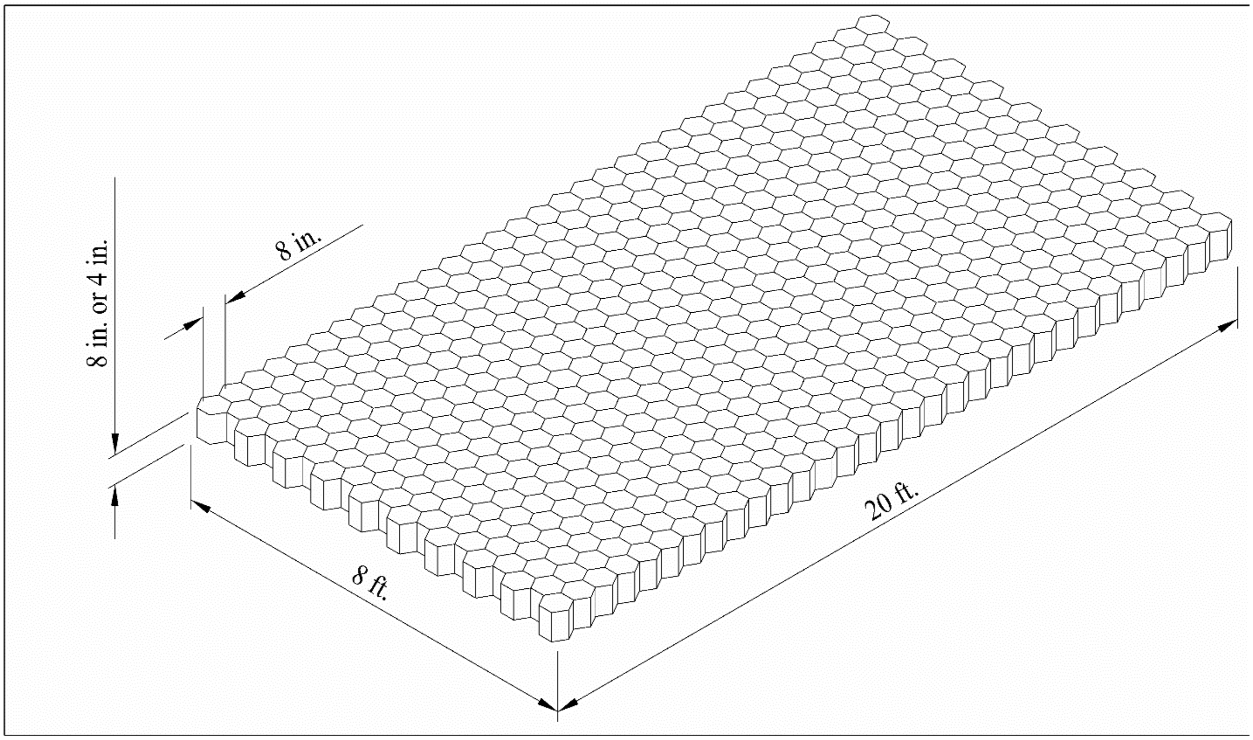



**Exhibit 2.21 Typical Cellular Confinement System**

## 7.E Curb and Flume

### 7.E.1 3 in. (75 mm) Curb

Curb and flumes may be used as a permanent erosion control measure. They may also be used as temporary measures during phasing similar to the ditch lining concept. Use 3 in. (75 mm) curb on:

- Both shoulders of roadways with profile grades steeper than 3%.
- Both shoulders of roadways with profile grades 2.5% and steeper, which are longer than 1500 ft. (450 m).
- Low side of superelevated sections.
- Highly erodible soils.
- Multilane facilities in section when approved by the **Assistant Design Engineer**.
- Large and steep embankments.

A 3 in. (75 mm) curb shall have a minimum 2 ft. (600 mm) turf shoulder behind the curb. The turf shoulder should preferably drain *away* from the curb, desirably at a 4% grade but a flat shoulder slope is acceptable Water flowing in the gutter shall be removed from the roadway before reaching the 3 in. (75 mm) depth using Type I through VIII Concrete Flumes.

### 7.E.2 Concrete Flumes

Concrete flumes are used to collect stormwater runoff from the curbed shoulder and convey it down the foreslope of the highway embankment to the toe of the slope and into a receiving ditch or drainage way. Two types of flumes are used by **NDOT**:

- Above ground spillways - Drop Curb and Concrete Flume Types I and II.
- Buried flume pipe structures - Concrete Flume Types IV through VIII.

The above ground spillways convey the water collected from the gutter down the top of the foreslope in a curbed concrete spillway (See Special Plans 4341 through 4346 in the Standard/Special Plans Book, Reference 2.12). These spillways have a tendency to break and separate on fill depths greater than 4 ft. (1.2 m), as measured from the shoulder, and at breaks in the foreslope where it changes from a 1:6 to a 1:4 or 1:3 slope. The use of Concrete Flume Types I and II should be limited to shallow embankments, 4 ft. (1.2 m) or less, with uniform foreslopes.

The buried flume pipe structures convey the water collected by a grate or area inlet down a 15 in. (375 mm) corrugated metal pipe buried in the foreslope embankment, (Refer to Standard Plans 5470 and 5480 in the Standard/Special Plans Manual, Reference 2.12, http://www.roads.nebraska.gov/business-center/design-consultant/stand-spec-manual/). The buried flume pipe is the preferred method for conveying water down high embankments, greater than 4 ft. (1.2 m), or where breaks occur in the foreslope.

Prior to the plan-in-hand field inspection the designer will create a list of all roadway grades between 2% and 3½% and a list of all roadway grades greater than 3½% for a comparative analysis of erosion control techniques (i.e. curb and flume vs. other erosion control methods).

Spacing of the concrete flumes is based on the 2-Year design storm, $Q_2$, the spread distance of the water on the shoulder, and the 3 in. (75 mm) height of the asphalt curb, (Refer to EXHIBIT 2.22 for a guideline on Concrete Flume Spacing). Not all roadway design situations will fall within the parameters used to establish the above guideline; therefore the roadway designer should check the effect of a 2-Year design storm on the gutter flow for the chosen concrete flume spacing, (See Chapter One: Drainage, Section 10.A).

| ***CONCRETE FLUME SPACING*** | | |
|---|---|---|
| ***Concrete Flumes, Types I & II (For Embankment Heights of 4 ft. (1.2 m) or Less)*** | | |
| *Slope of Roadway Centerline* | *Distance between Flumes* | *Superelevated* |
| *2% - < 2.5% (if longer than 1500 ft. (450m))* | *500 ft. (150 m)* | *400 ft. (120 m)* |
| *2.5% - < 4%* | *500 ft. (150 m)* | *400 ft. (120 m)* |
| *4% - < 5%* | *400 ft. (120 m)* | *300 ft. (90 m)* |
| *5% - < 6%* | *350 ft. (110 m)* | *250 ft. (80 m)* |
| ***Concrete Flumes, Type IV – VIII (For Embankment Heights Greater than 4 ft. (1.2 m)*** | | |
| *Slope of Roadway Centerline* | *Distance between Flumes* | *Superelevated* |
| *2% - < 2.5% (if longer than 1500 ft. (450m))* | *400 ft. (120 m)* | *350 ft. (110 m)* |
| *2.5% - < 4%* | *400 ft. (120 m)* | *350 ft. (110 m)* |
| *4% - < 5%* | *350 ft. (110 m)* | *300 ft. (90 m)* |
| *5% - < 6%* | *300 ft. (90 m)* | *250 ft. (80 m)* |

**Exhibit 2.22 Concrete Flume Spacing Guidelines**

## 7.F Runoff Intercepting Methods

### 7.F.1 Intercepting Earth Dike

An intercepting earth dike is a ridge of soil constructed to divert stormwater runoff at non-erosive velocities to a stabilized outlet or pond. Intercepting earth dikes are commonly located at the uphill side of a disturbed backslope or borrow area. Intercepting earth dikes may also be used to divert sediment-laden drainage runoff from a disturbed area to a sediment trapping facility, (See Section 7.I). Intercepting earth dikes should be considered when:

- Runoff from higher areas may damage property, cause erosion, or interfere with the establishment of vegetation on lower areas.
- Runoff with high sediment loads threatens sensitive wetlands or water bodies.
- It is necessary to maintain a separation between different types of flow such as irrigation and stormwater runoff.

Intercepting earth dikes are frequently used to concentrate and direct water to slope drains (See Section 7.F.3), grade control structures (See Section 7.G) and other outlet structures. When they are used for this purpose, it is important to place the earth dike outlets in a manner that will maintain the existing drainage pattern. Refer to EXHIBIT 2.23 for typical intercepting earth dike designs.

When designing an intercepting earth dike it is important to keep in mind that water may be diverted on both sides of the dike, not just the water on the upslope side.

Temporary intercepting earth dikes may be used whenever stormwater runoff must be temporarily diverted to protect disturbed areas and slopes, or to retain sediment on-site during construction.

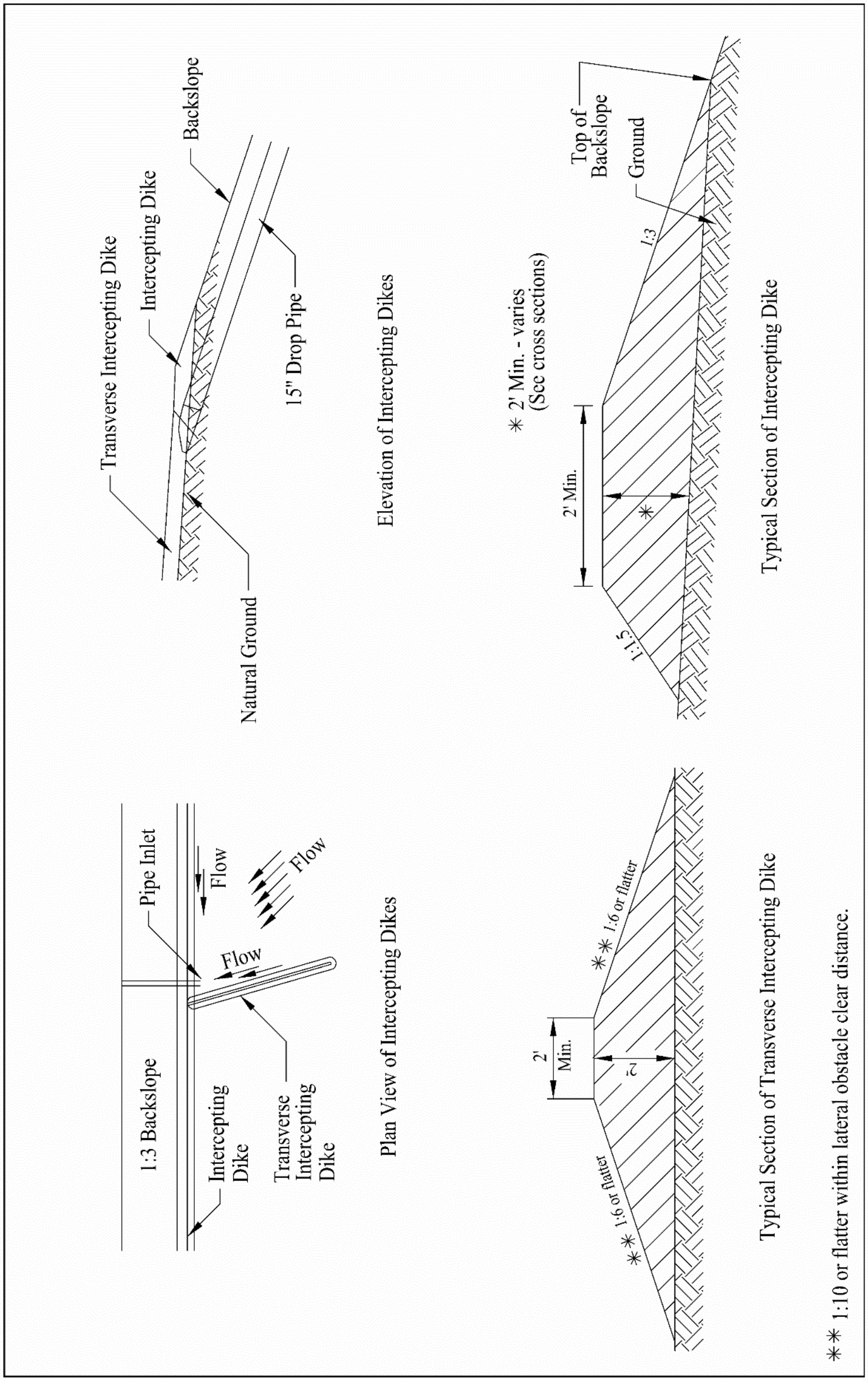



**Exhibit 2.23 Intercepting Earth Dikes**

### 7.F.2 Intercepting Ditch

An intercepting ditch is a channel constructed at the midpoint of deep backslopes. It is used to intercept and convey water at non-erosive velocities to an adequate and stable outlet.

On backslopes where the slope width is in excess of 100 ft. (30 m) measured along the slope and transverse to the top edge of the backslope, an intercepting ditch will be required halfway down the slope and at a maximum of 100 ft. (30 m) intervals. Intercepting ditches can only be utilized on cut slopes. They are not allowed on foreslopes. Temporary intercepting ditches may be used on the lower side of cleared areas that will be excavated. The **Roadside Development & Compliance Unit** in the **Project Development Division** can be consulted and will provide recommendations on the location of intercepting ditches.

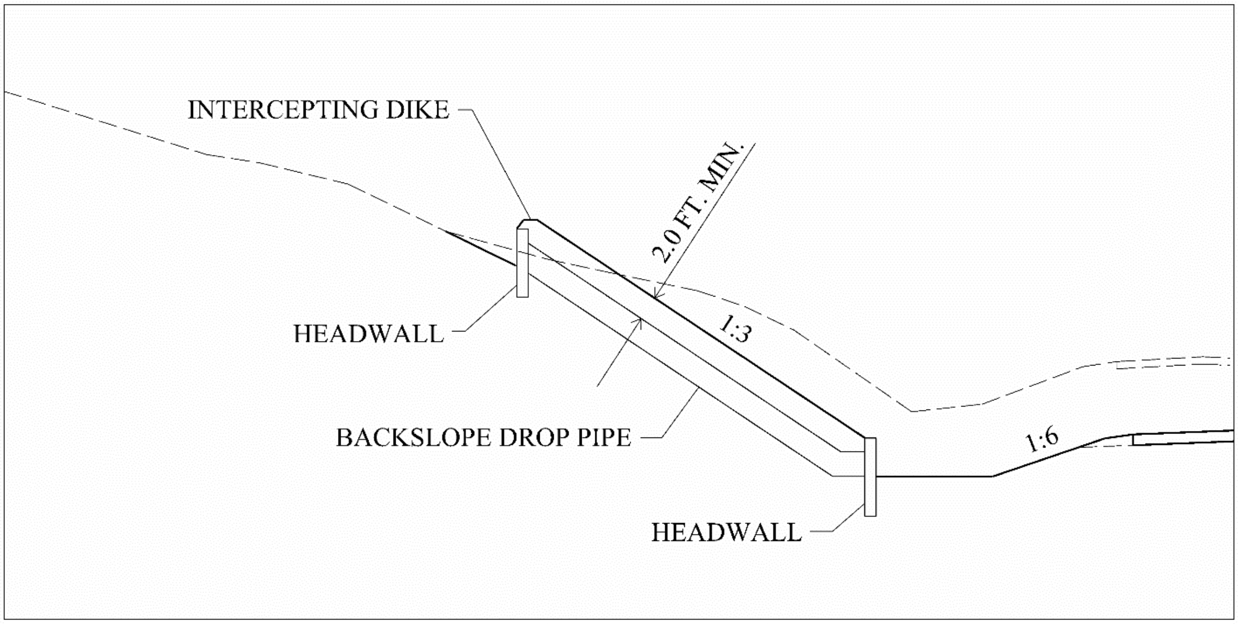
Care must be taken to outlet intercepting ditches into adequately stabilized areas. All intercepting ditches must be seeded in accordance with the guidelines for temporary and permanent vegetation (See Sections 5.B and 6.A, respectively). Intercepting ditches should be protected with the proper erosion control, when necessary.

### 7.F.3 Backslope Drop Pipe

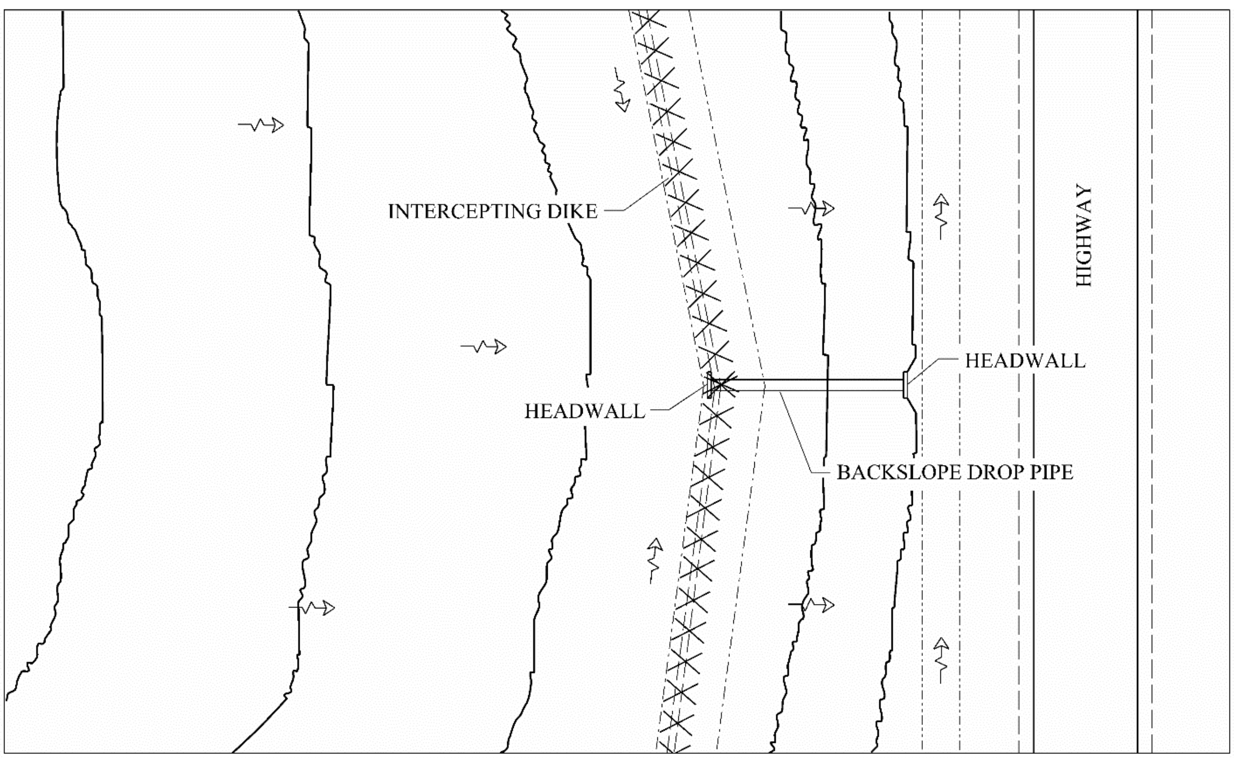
Backslope drop pipes are frequently used to convey water diverted and concentrated by intercepting dikes and ditches without causing erosion on or below the slope. It is essential to protect against the potentially high discharge velocity of water at the outlet by using erosion control blankets, riprap or other measures.

Backslope drop pipes should be used on cut or fill slopes where there is a potential for upstream flows to go over the face of the slope causing erosion and preventing adequate stabilization. An example of such a case would be where a hill slopes down to a highway with a newly lowered profile, causing a 1:3 backslope to be excavated which is 200 ft. (60 m) long and 10 ft. (3 m) deep. An intercepting earth dike is placed to collect runoff before it flows over the backslope. The water concentrated by the dike is diverted to two drop pipes spaced 100 ft. (30 m) apart, which lower the collected water to the road ditch.

Backslope drop pipe should be sized according to the parameters established in Chapter One: Drainage and Appendix C, “Pipe Material Policy”. A culvert cross section will be required. EXHIBIT 2.24 illustrates a backslope drop pipe.




**Cross-Section View**




**Plan View**

**Exhibit 2.24 Backslope Drop Pipe with Intercepting Dike**

## 7.G Ditch Grade Control Structures

Ditch grade control structures are used to prevent degradation of the roadside ditch by scour or head-cutting. The grade control structures consist of various permanent erosion control measures, such as sills or check structures and drop structures, which reduce the flow velocity in the ditch to within acceptable limits.

Sills or check structures consist of earth or stone mounds placed across the ditch with a rise of 1 to 2 ft. (300 to 600 mm) above the flow line of the ditch. The check structures control the scour in the ditch by ponding water behind the structure and slowing the water. To be effective the check structures need to be placed close enough together to control the energy grade line of the water flowing in the ditch.

Drop structures consist of various measures used to convey water down large vertical distances over short lengths. The placement of drop structures controls scour in the ditch by permitting the construction of milder, less erosive, longitudinal slopes, and controls head-cutting of the ditch by conveying the water to the lowered flow line of the downstream body of water in a non-erodible channel, culvert, or other structure. Drop structures can consist of a series of short vertical drops spaced periodically along the length of the ditch or a single large vertical drop at some point along the ditch, usually at the beginning or end of the ditch.

The design of any type of ditch grade control structure must consider the safety of the traveling public. Grade control structures placed within the lateral obstacle clearance zone shall be designed to be traversable, (See the Roadway Design Manual, Chapter Six: The Typical Roadway Cross-Section and Chapter Nine: Guardrail and Roadside Barriers, Reference 2.16).

### 7.G.1 Drop Pipe

Drop pipes are one type of ditch grade control structure, and are commonly found adjacent to bridges where the roadside ditch outlets to a stream that flows at a significantly lower elevation. (Backslope drop pipes are discussed in Section 7.F.3). Where ditches enter into a receiving stream above its base flow elevation, a drop structure should be designed to convey the water from the ditch to the stream.

The typical drop pipe will be a broken-back (BB) culvert that passes through an earthen dike, which closes the ditch, and outlets into a lower ditch or body of water. Headwalls are preferred at the inlet and outlet of the culvert, though flared end sections are acceptable. Headwalls are preferred because they provide a cutoff wall at the inlet that will reduce water movement along the outside of the culvert pipe and they provide physical support at the inlet and outlet to protect against movement of the culvert.

Drop pipe will be designed according to the parameters established in Chapter One: Drainage and Appendix C, “Pipe Material Policy”. A maximum headwater elevation of 1.5 ft. (450 mm) below the shoulder point of the roadway shall be maintained. Where the drop pipe exists in a critical location it may be advisable to design the culvert to a larger storm event than is indicated in Chapter One: Drainage, Section 6. The outlet section of the culvert pipe should be designed to keep the outlet velocity to a minimum. When necessary, an energy dissipator shall be constructed at the outlet.

The earthen dike used to close the ditch should be built to an elevation that provides a 1 ft. (300 mm) freeboard for the design headwater. The foreslope and backslope of the dike shall be designed to meet safety requirements.

EXHIBIT 2.25 shows a typical design for a drop pipe flowing from a ditch into a stream.

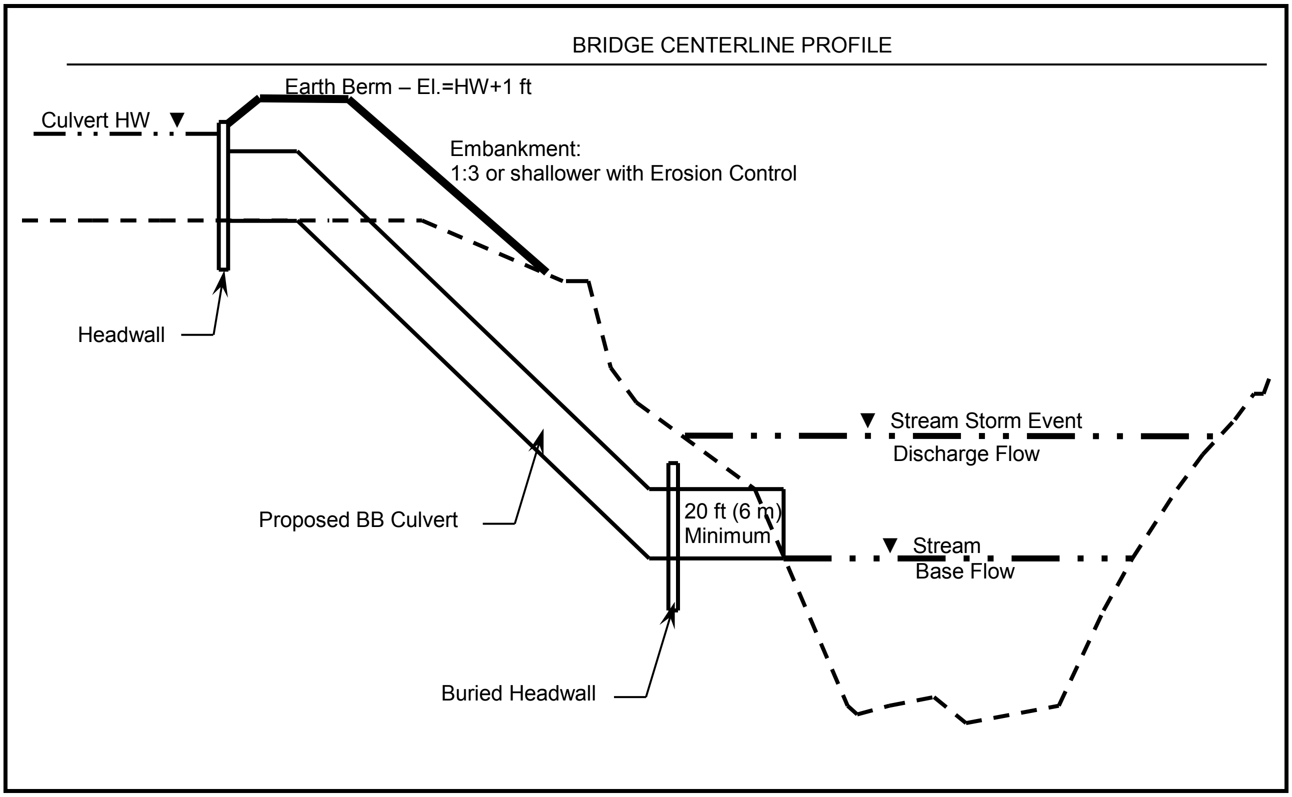



**Exhibit 2.25 Typical Drop Pipe Design from Ditch to Stream**

## 7.H Ditch Lining

Ditch lining, (concrete or bituminous), represents the highest level of erosion control that can be provided for an embankment, ditch or channel. The ditch lining consists of paving an embankment or floor and banks of a ditch or channel with either pre-cast concrete blocks, cast-in-place reinforced concrete pavement, or bituminous pavement. Placement of ditch lining is applicable to locations where the anticipated erosive forces are too great to maintain a grade for vegetation and other erosion control methods prove to be unacceptable. Consideration should be given for concrete ditch linings where slopes are greater than 9%, and in locations where continuous water flow occurs.

### 7.H.1 Articulated Concrete Block Lining

Articulated concrete block linings consist of pre-formed sections that interlock with each other, are attached to each other with wire cable or synthetic fiber rope, or butt together in order to form a continuous blanket or mat. The concrete blocks that make up the various manufacturers' mats differ in shape and method of articulation, but share certain common features. These features include:

- Rapid installation with some flexibility in placement geometry.
- Flexibility to respond to minor changes in ditch or channel geometry without failure.
- Permeable in nature to allow free draining of back slopes and ponded water.
- Provisions for establishment of vegetation within the lining.

Although the design procedure for the articulated concrete block linings is similar to that of riprap linings, the individual manufacture's design procedures should be followed. In any case, filter fabric shall be placed under all installations.

### 7.H.2 Cast-In-Place Concrete Ditch Lining

Cast-in-place concrete ditch linings consist of reinforced concrete pavement placed on a prepared base along the bottom and sides of the ditch. The concrete pavement forms a continuous rigid structure that will handle high velocity flows with little or no deterioration of the lining.

Cast-in-place concrete ditch linings should be considered where the hydraulic efficiency of a smooth channel surface is important, or the width of the ditch must be kept at a minimum. A concrete channel will carry nearly the same amount of water as a grass ditch twice its width, and can be built with vertical walls.

Cast-in place concrete ditch lining can be very maintenance intensive. These linings are rigid structures that do not normally respond favorably to changes in ditch or channel geometry. The designer should be aware that rigid concrete channel lining is susceptible to damage by the following:

- Undercutting.
- Hydrostatic uplift.
- Erosion and scour along the interface between the lining and the natural channel surface.

The loss of even small sections of the supporting base can cause complete failure of the cast-in-place concrete ditch lining.

Cast-in-place concrete ditch lining details are provided in Standard Plan 4550 in the Standard/Special Plans Manual (Reference 2.12) and in Section 908 of the Standard Specifications for Highway Construction, (Reference 2.10).

### 7.H.3 Concrete Slope Protection

Concrete slope protection includes the placement of concrete slabs on bridge embankments to protect the slope from erosion. Concrete slope protection is usually placed on the embankments of bridges over highways. Bridges over rivers generally have riprap placed on the embankments (See Section 7.A). Refer to Section 908 of the Standard Specifications for Highway Construction, (Reference 2.10) and to the project Bridge Plans for details.

## 7.I Sediment Control

### 7.I.1 Sediment Trap

A sediment trap (See EXHIBIT 2.27) is a temporary structure that is used to detain runoff from small drainage areas so the sediment can settle out. These devices are constructed by excavation and by the construction of an embankment that will provide a determined storage volume. The release, or flow from the structure, is controlled by either a rock spillway or pipe outlet. Sediment traps are generally limited to a contributing drainage area of 5 acres (2 hectares).

When properly designed, located, and constructed, sediment traps can remove non-colloidal sediment at efficiencies of up to 80%. Sediment traps are excellent perimeter controls, provided that runoff from the disturbed area drains to one location and that sufficient right-of-way and storage volume are available. Temporary sediment traps may also be constructed upstream of inlets during grading operations, but only if sufficient storage volume can be created.

#### 7.I.1.a Design

The design of sediment traps involves determining the required storage volume, the dimensions of the spillway, and the necessary elevations. In most cases a simple approach is used to determine the storage volume. The length of the spillway can be computed as a function of the drainage area. This design approach is acceptable for small drainage areas, however, a more precisely designed and efficient designed trap may be sized using the procedures for sediment basins (See Section 7.I.2).

#### 7.I.1.b Location

The location of sediment traps is critical in their design and should be determined based on the existing and proposed topography of the site. As a perimeter control the sediment trap should be placed where 2 to 5 acres (0.8 to 2 hectares) drain to one location. The designer should attempt to choose a location where maximum storage can be obtained using the natural topography, reducing the required excavation. The location of the sediment trap should also be at a location which will minimize interference with construction activities and will allow the trap to remain in service until the site is stabilized. The site must be accessible for future clean-out of the sediment. The designer should also consider the consequences should the structure fail.

### 7.I.1.c Storage Volume

In order for a sediment trap to function properly the required storage volume must be provided. This volume is created by excavation of the site and/or the construction of an embankment to detain runoff. The required storage volume equates to 134 cu. yd. per acre (253 $m^3$ per hectare) of drainage area. The drainage area should not exceed 5 acres (2 hectares). This storage volume provides enough space to trap the first 1.0 in. (25 mm) of runoff from the drainage area. If this storage volume cannot be obtained due to site constraints, the maximum available storage volume should be provided. The available storage volume should not fall below a minimum value of 67 cu. yd. per acre (126 $m^3$ per hectare). The storage volume should preferably be designed at a minimum length to width ratio of 2:1.

The total storage volume of the sediment trap should be divided equally between wet and dry storage. The wet storage should consist of a permanent ponding area based on a volume of 67 cu. yd. per acre (126 $m^3$ per hectare), which is either excavated earthwork or placed behind a solid earth berm. The dry storage should consist of a temporary ponding area based on a volume of 67 cu. yd. per acre (126 $m^3$ per hectare), which is behind and below the crest of a self-draining embankment.

When the storage volume falls below the desired 134 cu. yd. per acre (253 $m^3$ per hectare), the dry storage volume of 67 cu. yd. per acre (126 $m^3$ per hectare) shall be maintained. Any loss to the sediment trap volume shall be from the wet storage volume.

When a natural depression is used as the sediment trap, and no other methods of calculating the storage volume is available, the volume can be approximated by the following equation:

Volume = 0.4 x Ponding Surface Area at Crest x Maximum Depth Below Crest

### 7.I.1.d Embankment

The embankment of the structure should be constructed to a maximum height of 5 ft. (1.5 m). The desirable top width of the embankment should be 4 ft. (1.2 m) and the side slopes should be 1:3 or flatter. The embankment berm, once constructed, should be immediately seeded with Temporary Seed (See Section 5.B.2).

### 7.I.1.e Outlet

The outlet for the sediment trap is a self draining embankment, constructed of Rock Riprap Type A. The crest of the self draining embankment shall be constructed 1 ft. (305 mm) below the top of the impermeable soil embankment. The weir length of the spillway is based on the upstream contributing drainage (See EXHIBIT 2.26).

| ***Contributing Drainage Area*** | ***Weir Length*** |
|---|---|
| *1 Acre (0.4 hectare)* | *4 ft. (1.2 m)* |
| *2 Acre (0.8 hectare)* | *5 ft. (1.5 m)* |
| *3 Acre (1.2 hectare)* | *6 ft. (1.8 m)* |
| *4 Acre (1.6 hectare)* | *10 ft. (3.0 m)* |
| *5 Acre (2.0 hectare)* | *12 ft. (3.6 m)* |

**Exhibit 2.26 Weir Lengths for Sediment Trap's Self Draining Embankment**

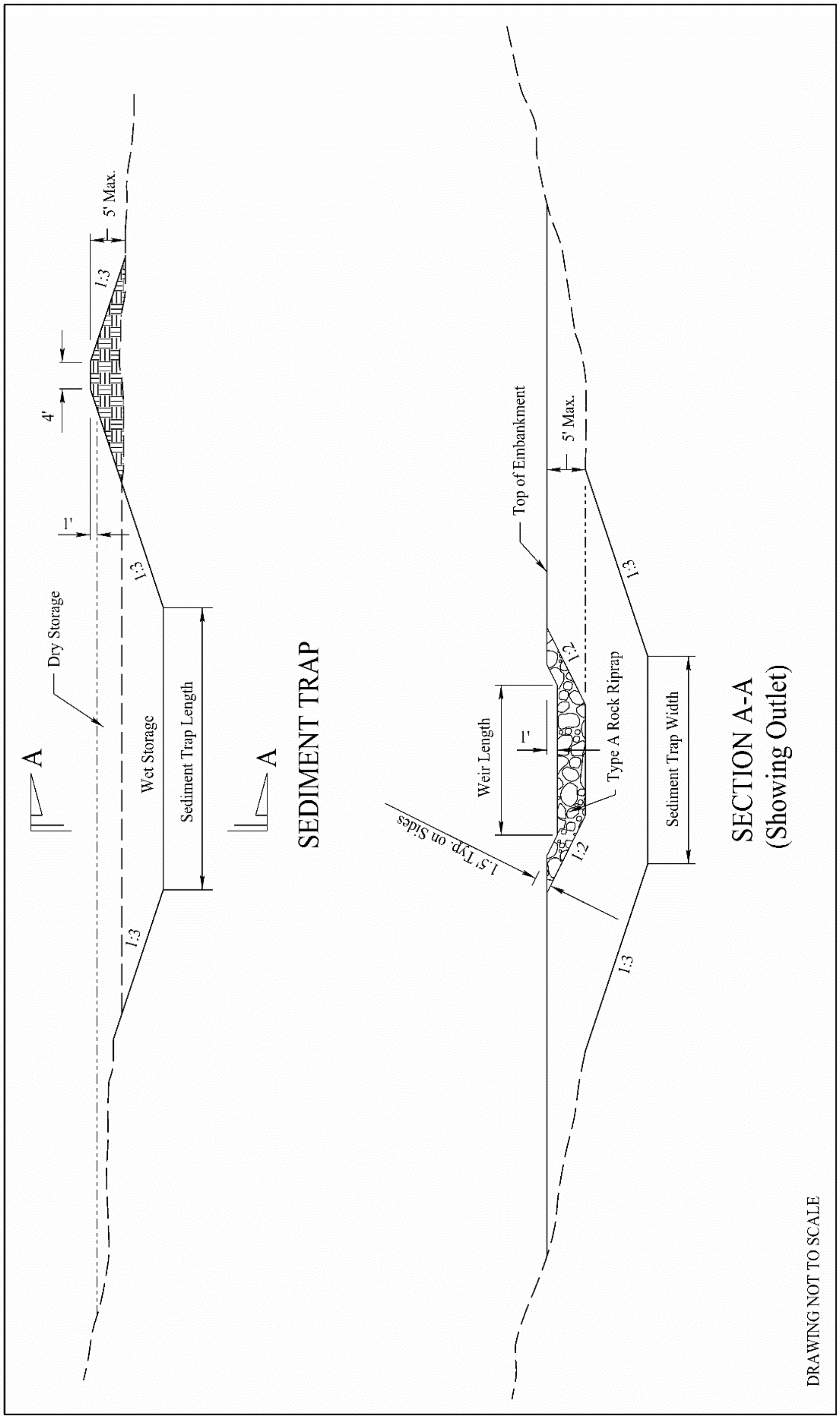



**Exhibit 2.27 Sediment Trap**

### 7.I.2 Sediment Basin

A sediment basin is a structure used to detain sediment-laden runoff from disturbed areas long enough to allow the majority of the sediment to settle out. The structure is created by excavating a basin or by constructing an embankment of compacted soil across a drainage way as a temporary barrier or a permanent dam. Ponded water is released through a controlled stormwater release structure. Sediment basins are generally located downslope from the construction site. The **Roadside Development & Compliance Unit** in the **Project Development Division** recommends sediment basin locations. Sediment basins should be constructed prior to clear running streams and where downstream land use is sensitive to sedimentation.

Sediment basins are used for disturbed areas where the total contributing area is equal to or greater than 5 acres (2 hectares). Sufficient space and appropriate topography must be available for the construction of a temporary sediment basin. These structures should be considered to have a limited useful life of 18 months unless the basins are designed as permanent impoundments.

Large sediment basins require extensive design. There are three general areas of consideration in the design of these sediment basins:

1. Adequate storage volume for expected sediment.
2. Adequate retention of runoff to allow settlement of suspended particles.
3. A dam and spillway to accommodate expected flows.

Storage volume requirements can best be determined from past experience at similar sites. Contact the **Roadway Design Division Hydraulic Engineer** for further information. It is generally not cost effective to provide a volume sufficient to contain the total expected sediment runoff from an area during the entire construction period. Therefore, a reasonable length of time between cleanouts should be established and a volume chosen to accommodate this period.

Required retention time for runoff in a basin is dependent on sediment particle size and the desired percent of sediment removal. It is generally acceptable and practicable to remove 70% to 90% of particles larger than the very fine sands having diameters greater than 0.002 in. (0.051 mm). Silt and clay-sized particles require excessive retention time so it is generally not feasible to design a basin to remove them. Widely used methods of determining suitable size for retention basins are based on particle settling times or a set runoff volume. National Cooperative Highway Research Program (NCHRP), Report 70, Design of Sediment Basins, (Reference 2.13), provides details for sediment basin design and selection.

While retention determinations are based on small inflows in the range of a 10-year return frequency event, the emergency spillway must be designed to accommodate a much larger event. Since failure could result in release of considerable quantities of stored sediment, spillway design should be based on an economic assessment of potential damages.

## 7.J Energy Dissipators

When the outlet velocity from a culvert cannot be reduced to acceptable levels by other means, the flow energy should be dissipated before the discharge is returned to the downstream channel. Prior to designing a scour hole, or other energy dissipator, the designer should try to reduce outlet velocity of the culvert by:

- Choosing gentler slopes if possible.
- Installing a soil saver end section at the inlet and lowering the slope of the culvert.
- Designing a broken back culvert with a flat outlet section (See Chapter One: Drainage, Section 8 and Appendix C, "Pipe Material Policy", for more information on culvert design).

An energy dissipator should be constructed when the outlet velocity of a culvert exceeds the values shown in EXHIBIT 2.28. For further information on the types and design of energy dissipation systems, consult Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, (Reference 2.15), (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf).

| ***REQUIREMENTS FOR ENERGY DISSIPATORS*** | |
|---|---|
| ***Design Flow Outlet Velocity in fps (m/s)*** | ***Is an Energy Dissipator Required?*** |
| *Less than 8 (2.5)* | *No* |
| *8-15 (2.5-4.5)* | *Evaluate on a case-by-case basis* |
| *Greater than 15 (4.5)* | *Yes* |

**Exhibit 2.28 Requirements for Energy Dissipators**

### 7.J.1 Preformed Scour Hole (Riprap Basin)

A preformed scour hole is an excavated hole or depression that is lined with riprap of a stable size and designed to prevent scouring at a culvert outlet, (See EXHIBIT 2.29). The depression provides for both a vertical and lateral expansion of the flow and a temporary stilling pool at the culvert outlet. The turbulence caused by the flow expansion and stilling pool dissipates the excessive energy in the culvert discharge within the protected depression. The creation of a scour hole can result in a significant reduction in the size of the riprap stone required compared to a flat riprap apron.

The design of preformed scour holes is based upon research conducted by Colorado State University and discussed in detail in Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, (Reference 2.15). The depth of the depression for the preformed scour hole is based on the flow velocity and depth at the culvert outlet, and the size of the riprap used to line the depression.

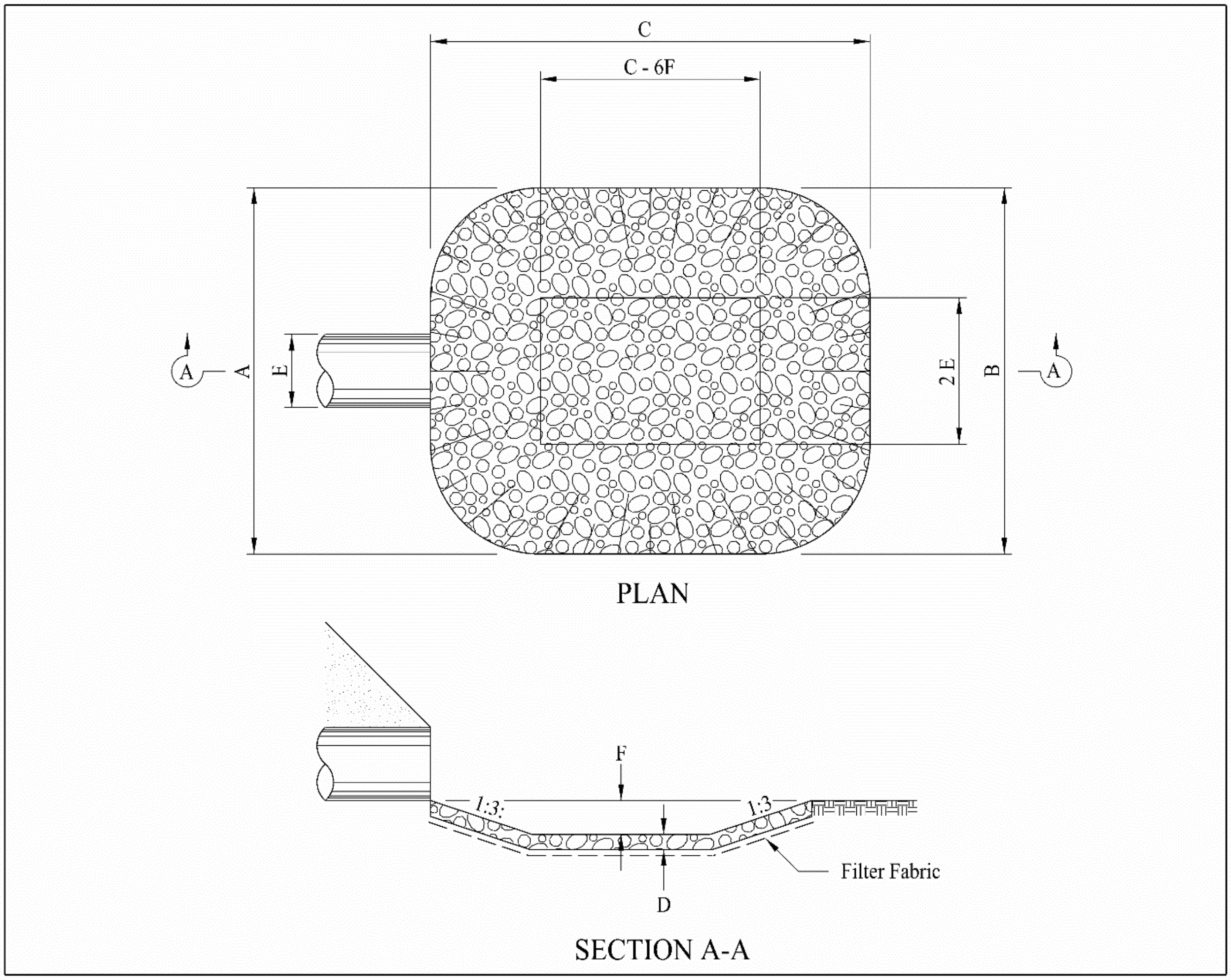



**Exhibit 2.29 Preformed Scour Hole**

Dimensions for a preformed scour hole basin are shown in EXHIBIT 2.29 and can be determined from the following equations:

| | | | |
|---|---|---|---|
| A = | Basin inlet width, ft. (m) | = | 2E + 6F |
| B = | Basin outlet width, ft. (m) | = | 2E + 6F |
| C = | Basin length, ft. (m) | = | Greater of 10F or 3E |
| D = | Thickness of riprap lining, ft. (m) | = | Greater of $2D_{50}$ or $1.5D_{max}$ |
| E = | Culvert diameter or span, ft. (m) | = | E |
| F = | Basin depression, ft. (m) | = | As described in Eq. 2.8 |

Empirical equations developed for the hydraulic design of preformed scour holes are presented on the next page. The equations are applicable to both circular and rectangular culverts flowing full or partly full, and where the ratio of the downstream tailwater depth to the culvert outlet depth is less than 0.75 ($TW/Y_0 < 0.75$). For design considerations where $TW/Y_0 > 0.75$, refer to Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, (Reference 2.15).

Determine the following culvert parameters:

| | | | |
|---|---|---|---|
| TW | = | Tail water depth above culvert invert, ft. (m) | |
| $Y_0$ | = | Depth of flow at culvert outlet, ft. (m) | |
| $Y_e$ | = | Brink depth at culvert outlet, ft. (m) | |
| | = | $Y_0$ for box culverts, or | |
| | = | $(A \div 2)^{0.5}$ for pipe culverts, | Eq. 2.5 |
| $V_0$ | = | Velocity of flow at culvert outlet, ft./s (m/s) | |
| Fr | = | Froude Number = $V_0 \div (g\ Y_e)^{0.5}$ | Eq. 2.6 |

Where: A = Flow Area at outlet, (See EXHIBIT 2.30)
g = Acceleration of Gravity = 32.2 ft./s$^2$ (9.81 m/s$^2$)

Select the desired riprap size:

| | | |
|---|---|---|
| $d_{50}$ | = | Median stone diameter desired for scour hole, ft. (m) |
| | = | 0.77 ft. (230 mm) – Type A Rock Riprap |
| | = | 1.02 ft. (310 mm) – Type B Rock Riprap |
| | = | 1.10 ft. (340 mm) – Broken Concrete Riprap |
| | = | 1.28 ft. (390 mm) – Type C Rock Riprap |

To calculate the Basin Depression, F:

Step 1. Using the $d_{50}/Y_e$ and Fr values determined above, obtain the value $F/Y_e$ either from the chart in EXHIBIT 2.31 or from Equations 2.7a through 2.7f given below, (which were used to derive the chart).

| | | |
|---|---|---|
| $F/Y_e = (3.0864 \times Fr) – 2.0062$, | for $0.10 \leq (d_{50}/Y_e) \leq 0.20$ | Eq. 2.7a |
| $F/Y_e = (1.8519 \times Fr) – 1.5370$, | for $0.21 \leq (d_{50}/Y_e) \leq 0.30$ | Eq. 2.7b |
| $F/Y_e = (1.5432 \times Fr) – 1.4198$, | for $0.31 \leq (d_{50}/Y_e) \leq 0.40$ | Eq. 2.7c |
| $F/Y_e = (1.3514 \times Fr) – 1.4189$, | for $0.41 \leq (d_{50}/Y_e) \leq 0.50$ | Eq. 2.7d |
| $F/Y_e = (1.3053 \times Fr) – 1.5534$, | for $0.51 \leq (d_{50}/Y_e) \leq 0.60$ | Eq. 2.7e |
| $F/Y_e = (1.1719 \times Fr) – 1.5352$, | for $0.61 \leq (d_{50}/Y_e) \leq 0.70$ | Eq. 2.7f |

Step 2. To determine basin depth, ft. (m):

$F = (F/Y_e) \times Y_e$ Eq. 2.8

Step 3. Check to determine if the basin depth to riprap size meets $2 < (F/d_{50}) < 4$; if not, select new riprap size and repeat steps 1 through 3 until riprap size meets the $F/d_{50}$ requirement.

If the necessary riprap size exceeds the $d_{50}$ for Class C Rock Riprap, consider other energy dissipation methods, (See Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, Reference 2.15.

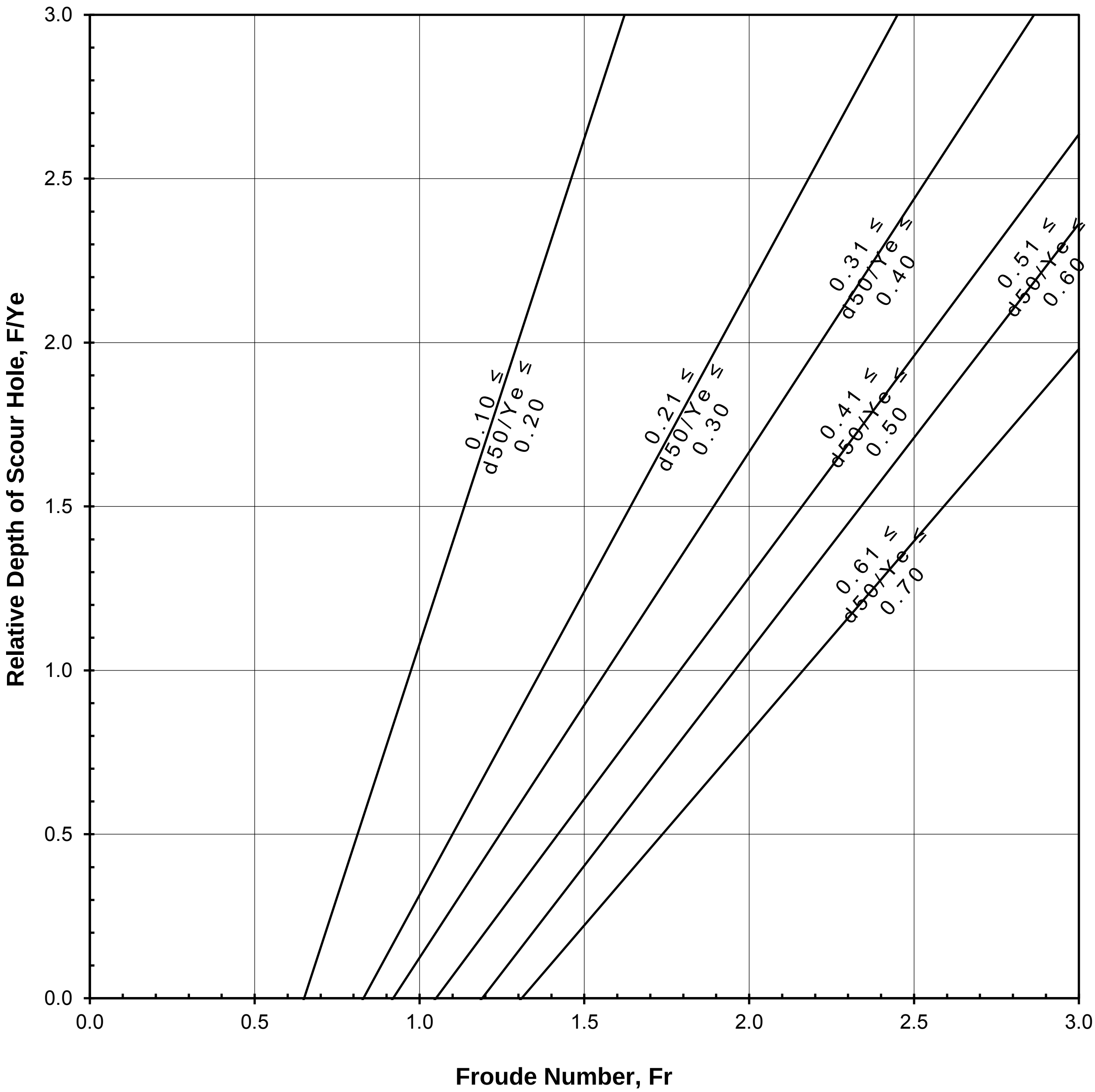



**Exhibit 2.30 Relative Depth of Scour Hole vs Froude Number of Culvert Outlet Flow**
**(Source: Modified from Figure X1-2 of Reference 2.15)**

| d/D | $A/D^2$ | Flow Area (sq.ft.) for Given Pipe Diameter | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15-inch | 18-inch | 24-inch | 30-inch | 36-inch | 42-inch | 48-inch | 54-inch | 60-inch | 66-inch | 72-inch | 78-inch | 84-inch | 90-inch | 96-inch |
| 0.01 | 0.0013 | 0.0020 | 0.003 | 0.005 | 0.008 | 0.012 | 0.016 | 0.021 | 0.026 | 0.033 | 0.039 | 0.047 | 0.055 | 0.064 | 0.073 | 0.083 |
| 0.02 | 0.0037 | 0.006 | 0.008 | 0.015 | 0.023 | 0.033 | 0.045 | 0.059 | 0.075 | 0.093 | 0.112 | 0.133 | 0.156 | 0.181 | 0.208 | 0.237 |
| 0.03 | 0.0069 | 0.011 | 0.016 | 0.028 | 0.043 | 0.062 | 0.085 | 0.110 | 0.140 | 0.173 | 0.209 | 0.248 | 0.292 | 0.338 | 0.388 | 0.442 |
| 0.04 | 0.0105 | 0.016 | 0.024 | 0.042 | 0.066 | 0.095 | 0.129 | 0.168 | 0.213 | 0.263 | 0.318 | 0.378 | 0.444 | 0.515 | 0.591 | 0.672 |
| 0.05 | 0.0147 | 0.023 | 0.033 | 0.059 | 0.092 | 0.132 | 0.180 | 0.235 | 0.298 | 0.368 | 0.445 | 0.529 | 0.621 | 0.720 | 0.827 | 0.941 |
| 0.06 | 0.0192 | 0.030 | 0.043 | 0.077 | 0.120 | 0.173 | 0.235 | 0.307 | 0.389 | 0.480 | 0.581 | 0.691 | 0.811 | 0.941 | 1.080 | 1.229 |
| 0.07 | 0.0242 | 0.038 | 0.054 | 0.097 | 0.151 | 0.218 | 0.296 | 0.387 | 0.490 | 0.605 | 0.732 | 0.871 | 1.022 | 1.186 | 1.361 | 1.549 |
| 0.08 | 0.0294 | 0.046 | 0.066 | 0.118 | 0.184 | 0.265 | 0.360 | 0.470 | 0.595 | 0.735 | 0.889 | 1.058 | 1.242 | 1.441 | 1.654 | 1.882 |
| 0.09 | 0.0350 | 0.055 | 0.079 | 0.140 | 0.219 | 0.315 | 0.429 | 0.560 | 0.709 | 0.875 | 1.059 | 1.260 | 1.479 | 1.715 | 1.969 | 2.240 |
| 0.10 | 0.0409 | 0.064 | 0.092 | 0.164 | 0.256 | 0.368 | 0.501 | 0.654 | 0.828 | 1.023 | 1.237 | 1.472 | 1.728 | 2.004 | 2.301 | 2.618 |
| 0.11 | 0.0470 | 0.073 | 0.106 | 0.188 | 0.294 | 0.423 | 0.576 | 0.752 | 0.952 | 1.175 | 1.422 | 1.692 | 1.986 | 2.303 | 2.644 | 3.008 |
| 0.12 | 0.0534 | 0.083 | 0.120 | 0.214 | 0.334 | 0.481 | 0.654 | 0.854 | 1.081 | 1.335 | 1.615 | 1.922 | 2.256 | 2.617 | 3.004 | 3.418 |
| 0.13 | 0.0600 | 0.094 | 0.135 | 0.240 | 0.375 | 0.540 | 0.735 | 0.960 | 1.215 | 1.500 | 1.815 | 2.160 | 2.535 | 2.940 | 3.375 | 3.840 |
| 0.14 | 0.0668 | 0.104 | 0.150 | 0.267 | 0.418 | 0.601 | 0.818 | 1.069 | 1.353 | 1.670 | 2.021 | 2.405 | 2.822 | 3.273 | 3.758 | 4.275 |
| 0.15 | 0.0739 | 0.115 | 0.166 | 0.296 | 0.462 | 0.665 | 0.905 | 1.182 | 1.496 | 1.848 | 2.235 | 2.660 | 3.122 | 3.621 | 4.157 | 4.730 |
| 0.16 | 0.0811 | 0.127 | 0.182 | 0.324 | 0.507 | 0.730 | 0.993 | 1.298 | 1.642 | 2.028 | 2.453 | 2.920 | 3.426 | 3.974 | 4.562 | 5.190 |
| 0.17 | 0.0885 | 0.138 | 0.199 | 0.354 | 0.553 | 0.797 | 1.084 | 1.416 | 1.792 | 2.213 | 2.677 | 3.186 | 3.739 | 4.337 | 4.978 | 5.664 |
| 0.18 | 0.0961 | 0.150 | 0.216 | 0.384 | 0.601 | 0.865 | 1.177 | 1.538 | 1.946 | 2.403 | 2.907 | 3.460 | 4.060 | 4.709 | 5.406 | 6.150 |
| 0.19 | 0.1039 | 0.162 | 0.234 | 0.416 | 0.649 | 0.935 | 1.273 | 1.662 | 2.104 | 2.598 | 3.143 | 3.740 | 4.390 | 5.091 | 5.844 | 6.650 |
| 0.20 | 0.1118 | 0.175 | 0.252 | 0.447 | 0.699 | 1.006 | 1.370 | 1.789 | 2.264 | 2.795 | 3.382 | 4.025 | 4.724 | 5.478 | 6.289 | 7.155 |
| 0.21 | 0.1199 | 0.187 | 0.270 | 0.480 | 0.749 | 1.079 | 1.469 | 1.918 | 2.428 | 2.998 | 3.627 | 4.316 | 5.066 | 5.875 | 6.744 | 7.674 |
| 0.22 | 0.1281 | 0.200 | 0.288 | 0.512 | 0.801 | 1.153 | 1.569 | 2.050 | 2.594 | 3.203 | 3.875 | 4.612 | 5.412 | 6.277 | 7.206 | 8.198 |
| 0.23 | 0.1365 | 0.213 | 0.307 | 0.546 | 0.853 | 1.229 | 1.672 | 2.184 | 2.764 | 3.413 | 4.129 | 4.914 | 5.767 | 6.689 | 7.678 | 8.736 |
| 0.24 | 0.1449 | 0.226 | 0.326 | 0.580 | 0.906 | 1.304 | 1.775 | 2.318 | 2.934 | 3.623 | 4.383 | 5.216 | 6.122 | 7.100 | 8.151 | 9.274 |
| 0.25 | 0.1535 | 0.240 | 0.345 | 0.614 | 0.959 | 1.382 | 1.880 | 2.456 | 3.108 | 3.838 | 4.643 | 5.526 | 6.485 | 7.522 | 8.634 | 9.824 |
| 0.26 | 0.1623 | 0.254 | 0.365 | 0.649 | 1.014 | 1.461 | 1.988 | 2.597 | 3.287 | 4.058 | 4.910 | 5.843 | 6.857 | 7.953 | 9.129 | 10.387 |
| 0.27 | 0.1711 | 0.267 | 0.385 | 0.684 | 1.069 | 1.540 | 2.096 | 2.738 | 3.465 | 4.278 | 5.176 | 6.160 | 7.229 | 8.384 | 9.624 | 10.950 |
| 0.28 | 0.1800 | 0.281 | 0.405 | 0.720 | 1.125 | 1.620 | 2.205 | 2.880 | 3.645 | 4.500 | 5.445 | 6.480 | 7.605 | 8.820 | 10.125 | 11.520 |
| 0.29 | 0.1890 | 0.295 | 0.425 | 0.756 | 1.181 | 1.701 | 2.315 | 3.024 | 3.827 | 4.725 | 5.717 | 6.804 | 7.985 | 9.261 | 10.631 | 12.096 |
| 0.30 | 0.1982 | 0.310 | 0.446 | 0.793 | 1.239 | 1.784 | 2.428 | 3.171 | 4.014 | 4.955 | 5.996 | 7.135 | 8.374 | 9.712 | 11.149 | 12.685 |
| 0.31 | 0.2074 | 0.324 | 0.467 | 0.830 | 1.296 | 1.867 | 2.541 | 3.318 | 4.200 | 5.185 | 6.274 | 7.466 | 8.763 | 10.163 | 11.666 | 13.274 |
| 0.32 | 0.2167 | 0.339 | 0.488 | 0.867 | 1.354 | 1.950 | 2.655 | 3.467 | 4.388 | 5.418 | 6.555 | 7.801 | 9.156 | 10.618 | 12.189 | 13.869 |
| 0.33 | 0.2260 | 0.353 | 0.509 | 0.904 | 1.413 | 2.034 | 2.769 | 3.616 | 4.577 | 5.650 | 6.837 | 8.136 | 9.549 | 11.074 | 12.713 | 14.464 |
| 0.34 | 0.2355 | 0.368 | 0.530 | 0.942 | 1.472 | 2.120 | 2.885 | 3.768 | 4.769 | 5.888 | 7.124 | 8.478 | 9.950 | 11.540 | 13.247 | 15.072 |
| 0.35 | 0.2450 | 0.383 | 0.551 | 0.980 | 1.531 | 2.205 | 3.001 | 3.920 | 4.961 | 6.125 | 7.411 | 8.820 | 10.351 | 12.005 | 13.781 | 15.680 |
| 0.36 | 0.2546 | 0.398 | 0.573 | 1.018 | 1.591 | 2.291 | 3.119 | 4.074 | 5.156 | 6.365 | 7.702 | 9.166 | 10.757 | 12.475 | 14.321 | 16.294 |
| 0.37 | 0.2642 | 0.413 | 0.594 | 1.057 | 1.651 | 2.378 | 3.236 | 4.227 | 5.350 | 6.605 | 7.992 | 9.511 | 11.162 | 12.946 | 14.861 | 16.909 |
| 0.38 | 0.2739 | 0.428 | 0.616 | 1.096 | 1.712 | 2.465 | 3.355 | 4.382 | 5.546 | 6.848 | 8.285 | 9.860 | 11.572 | 13.421 | 15.407 | 17.530 |
| 0.39 | 0.2836 | 0.443 | 0.638 | 1.134 | 1.773 | 2.552 | 3.474 | 4.538 | 5.743 | 7.090 | 8.579 | 10.210 | 11.982 | 13.896 | 15.953 | 18.150 |
| 0.40 | 0.2934 | 0.458 | 0.660 | 1.174 | 1.834 | 2.641 | 3.594 | 4.694 | 5.941 | 7.335 | 8.875 | 10.562 | 12.396 | 14.377 | 16.504 | 18.778 |
| 0.41 | 0.3032 | 0.474 | 0.682 | 1.213 | 1.895 | 2.729 | 3.714 | 4.851 | 6.140 | 7.580 | 9.172 | 10.915 | 12.810 | 14.857 | 17.055 | 19.405 |
| 0.42 | 0.3130 | 0.489 | 0.704 | 1.252 | 1.956 | 2.817 | 3.834 | 5.008 | 6.338 | 7.825 | 9.468 | 11.268 | 13.224 | 15.337 | 17.606 | 20.032 |
| 0.43 | 0.3229 | 0.505 | 0.727 | 1.292 | 2.018 | 2.906 | 3.956 | 5.166 | 6.539 | 8.073 | 9.768 | 11.624 | 13.643 | 15.822 | 18.163 | 20.666 |
| 0.44 | 0.3328 | 0.520 | 0.749 | 1.331 | 2.080 | 2.995 | 4.077 | 5.325 | 6.739 | 8.320 | 10.067 | 11.981 | 14.061 | 16.307 | 18.720 | 21.299 |
| 0.45 | 0.3428 | 0.536 | 0.771 | 1.371 | 2.143 | 3.085 | 4.199 | 5.485 | 6.942 | 8.570 | 10.370 | 12.341 | 14.483 | 16.797 | 19.283 | 21.939 |
| 0.46 | 0.3527 | 0.551 | 0.794 | 1.411 | 2.204 | 3.174 | 4.321 | 5.643 | 7.142 | 8.818 | 10.669 | 12.697 | 14.902 | 17.282 | 19.839 | 22.573 |
| 0.47 | 0.3627 | 0.567 | 0.816 | 1.451 | 2.267 | 3.264 | 4.443 | 5.803 | 7.345 | 9.068 | 10.972 | 13.057 | 15.324 | 17.772 | 20.402 | 23.213 |
| 0.48 | 0.3727 | 0.582 | 0.839 | 1.491 | 2.329 | 3.354 | 4.566 | 5.963 | 7.547 | 9.318 | 11.274 | 13.417 | 15.747 | 18.262 | 20.964 | 23.853 |
| 0.49 | 0.3827 | 0.598 | 0.861 | 1.531 | 2.392 | 3.444 | 4.688 | 6.123 | 7.750 | 9.568 | 11.577 | 13.777 | 16.169 | 18.752 | 21.527 | 24.493 |
| 0.50 | 0.3927 | 0.614 | 0.884 | 1.571 | 2.454 | 3.534 | 4.811 | 6.283 | 7.952 | 9.818 | 11.879 | 14.137 | 16.592 | 19.242 | 22.089 | 25.133 |

**Exhibit 2.31a Flow Area at Culvert Outlet for Relative Depth of Flow and Pipe Diameter**

| d/D | $A/D^2$ | Flow Area (sq.ft.) for Given Pipe Diameter | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 15-inch | 18-inch | 24-inch | 30-inch | 36-inch | 42-inch | 48-inch | 54-inch | 60-inch | 66-inch | 72-inch | 78-inch | 84-inch | 90-inch | 96-inch |
| 0.51 | 0.4027 | 0.629 | 0.906 | 1.611 | 2.517 | 3.624 | 4.933 | 6.443 | 8.155 | 10.068 | 12.182 | 14.497 | 17.014 | 19.732 | 22.652 | 25.773 |
| 0.52 | 0.4127 | 0.645 | 0.929 | 1.651 | 2.579 | 3.714 | 5.056 | 6.603 | 8.357 | 10.318 | 12.484 | 14.857 | 17.437 | 20.222 | 23.214 | 26.413 |
| 0.53 | 0.4227 | 0.660 | 0.951 | 1.691 | 2.642 | 3.804 | 5.178 | 6.763 | 8.560 | 10.568 | 12.787 | 15.217 | 17.859 | 20.712 | 23.777 | 27.053 |
| 0.54 | 0.4327 | 0.676 | 0.974 | 1.731 | 2.704 | 3.894 | 5.301 | 6.923 | 8.762 | 10.818 | 13.089 | 15.577 | 18.282 | 21.202 | 24.339 | 27.693 |
| 0.55 | 0.4426 | 0.692 | 0.996 | 1.770 | 2.766 | 3.983 | 5.422 | 7.082 | 8.963 | 11.065 | 13.389 | 15.934 | 18.700 | 21.687 | 24.896 | 28.326 |
| 0.56 | 0.4526 | 0.707 | 1.018 | 1.810 | 2.829 | 4.073 | 5.544 | 7.242 | 9.165 | 11.315 | 13.691 | 16.294 | 19.122 | 22.177 | 25.459 | 28.966 |
| 0.57 | 0.4625 | 0.723 | 1.041 | 1.850 | 2.891 | 4.163 | 5.666 | 7.400 | 9.366 | 11.563 | 13.991 | 16.650 | 19.541 | 22.663 | 26.016 | 29.600 |
| 0.58 | 0.4724 | 0.738 | 1.063 | 1.890 | 2.953 | 4.252 | 5.787 | 7.558 | 9.566 | 11.810 | 14.290 | 17.006 | 19.959 | 23.148 | 26.573 | 30.234 |
| 0.59 | 0.4822 | 0.753 | 1.085 | 1.929 | 3.014 | 4.340 | 5.907 | 7.715 | 9.765 | 12.055 | 14.587 | 17.359 | 20.373 | 23.628 | 27.124 | 30.861 |
| 0.60 | 0.4920 | 0.769 | 1.107 | 1.968 | 3.075 | 4.428 | 6.027 | 7.872 | 9.963 | 12.300 | 14.883 | 17.712 | 20.787 | 24.108 | 27.675 | 31.488 |
| 0.61 | 0.5018 | 0.784 | 1.129 | 2.007 | 3.136 | 4.516 | 6.147 | 8.029 | 10.161 | 12.545 | 15.179 | 18.065 | 21.201 | 24.588 | 28.226 | 32.115 |
| 0.62 | 0.5115 | 0.799 | 1.151 | 2.046 | 3.197 | 4.604 | 6.266 | 8.184 | 10.358 | 12.788 | 15.473 | 18.414 | 21.611 | 25.064 | 28.772 | 32.736 |
| 0.63 | 0.5212 | 0.814 | 1.173 | 2.085 | 3.258 | 4.691 | 6.385 | 8.339 | 10.554 | 13.030 | 15.766 | 18.763 | 22.021 | 25.539 | 29.318 | 33.357 |
| 0.64 | 0.5308 | 0.829 | 1.194 | 2.123 | 3.318 | 4.777 | 6.502 | 8.493 | 10.749 | 13.270 | 16.057 | 19.109 | 22.426 | 26.009 | 29.858 | 33.971 |
| 0.65 | 0.5404 | 0.844 | 1.216 | 2.162 | 3.378 | 4.864 | 6.620 | 8.646 | 10.943 | 13.510 | 16.347 | 19.454 | 22.832 | 26.480 | 30.398 | 34.586 |
| 0.66 | 0.5499 | 0.859 | 1.237 | 2.200 | 3.437 | 4.949 | 6.736 | 8.798 | 11.135 | 13.748 | 16.634 | 19.796 | 23.233 | 26.945 | 30.932 | 35.194 |
| 0.67 | 0.5594 | 0.874 | 1.259 | 2.238 | 3.496 | 5.035 | 6.853 | 8.950 | 11.328 | 13.985 | 16.922 | 20.138 | 23.635 | 27.411 | 31.466 | 35.802 |
| 0.68 | 0.5687 | 0.889 | 1.280 | 2.275 | 3.554 | 5.118 | 6.967 | 9.099 | 11.516 | 14.218 | 17.203 | 20.473 | 24.028 | 27.866 | 31.989 | 36.397 |
| 0.69 | 0.5780 | 0.903 | 1.301 | 2.312 | 3.613 | 5.202 | 7.081 | 9.248 | 11.705 | 14.450 | 17.485 | 20.808 | 24.421 | 28.322 | 32.513 | 36.992 |
| 0.70 | 0.5872 | 0.918 | 1.321 | 2.349 | 3.670 | 5.285 | 7.193 | 9.395 | 11.891 | 14.680 | 17.763 | 21.139 | 24.809 | 28.773 | 33.030 | 37.581 |
| 0.71 | 0.5964 | 0.932 | 1.342 | 2.386 | 3.728 | 5.368 | 7.306 | 9.542 | 12.077 | 14.910 | 18.041 | 21.470 | 25.198 | 29.224 | 33.548 | 38.170 |
| 0.72 | 0.6054 | 0.946 | 1.362 | 2.422 | 3.784 | 5.449 | 7.416 | 9.686 | 12.259 | 15.135 | 18.313 | 21.794 | 25.578 | 29.665 | 34.054 | 38.746 |
| 0.73 | 0.6143 | 0.960 | 1.382 | 2.457 | 3.839 | 5.529 | 7.525 | 9.829 | 12.440 | 15.358 | 18.583 | 22.115 | 25.954 | 30.101 | 34.554 | 39.315 |
| 0.74 | 0.6231 | 0.974 | 1.402 | 2.492 | 3.894 | 5.608 | 7.633 | 9.970 | 12.618 | 15.578 | 18.849 | 22.432 | 26.326 | 30.532 | 35.049 | 39.878 |
| 0.75 | 0.6319 | 0.987 | 1.422 | 2.528 | 3.949 | 5.687 | 7.741 | 10.110 | 12.796 | 15.798 | 19.115 | 22.748 | 26.698 | 30.963 | 35.544 | 40.442 |
| 0.76 | 0.6405 | 1.001 | 1.441 | 2.562 | 4.003 | 5.765 | 7.846 | 10.248 | 12.970 | 16.013 | 19.375 | 23.058 | 27.061 | 31.385 | 36.028 | 40.992 |
| 0.77 | 0.6489 | 1.014 | 1.460 | 2.596 | 4.056 | 5.840 | 7.949 | 10.382 | 13.140 | 16.223 | 19.629 | 23.360 | 27.416 | 31.796 | 36.501 | 41.530 |
| 0.78 | 0.6573 | 1.027 | 1.479 | 2.629 | 4.108 | 5.916 | 8.052 | 10.517 | 13.310 | 16.433 | 19.883 | 23.663 | 27.771 | 32.208 | 36.973 | 42.067 |
| 0.79 | 0.6655 | 1.040 | 1.497 | 2.662 | 4.159 | 5.990 | 8.152 | 10.648 | 13.476 | 16.638 | 20.131 | 23.958 | 28.117 | 32.610 | 37.434 | 42.592 |
| 0.80 | 0.6736 | 1.053 | 1.516 | 2.694 | 4.210 | 6.062 | 8.252 | 10.778 | 13.640 | 16.840 | 20.376 | 24.250 | 28.460 | 33.006 | 37.890 | 43.110 |
| 0.81 | 0.6815 | 1.065 | 1.533 | 2.726 | 4.259 | 6.134 | 8.348 | 10.904 | 13.800 | 17.038 | 20.615 | 24.534 | 28.793 | 33.394 | 38.334 | 43.616 |
| 0.82 | 0.6893 | 1.077 | 1.551 | 2.757 | 4.308 | 6.204 | 8.444 | 11.029 | 13.958 | 17.233 | 20.851 | 24.815 | 29.123 | 33.776 | 38.773 | 44.115 |
| 0.83 | 0.6969 | 1.089 | 1.568 | 2.788 | 4.356 | 6.272 | 8.537 | 11.150 | 14.112 | 17.423 | 21.081 | 25.088 | 29.444 | 34.148 | 39.201 | 44.602 |
| 0.84 | 0.7043 | 1.100 | 1.585 | 2.817 | 4.402 | 6.339 | 8.628 | 11.269 | 14.262 | 17.608 | 21.305 | 25.355 | 29.757 | 34.511 | 39.617 | 45.075 |
| 0.85 | 0.7115 | 1.112 | 1.601 | 2.846 | 4.447 | 6.404 | 8.716 | 11.384 | 14.408 | 17.788 | 21.523 | 25.614 | 30.061 | 34.864 | 40.022 | 45.536 |
| 0.86 | 0.7186 | 1.123 | 1.617 | 2.874 | 4.491 | 6.467 | 8.803 | 11.498 | 14.552 | 17.965 | 21.738 | 25.870 | 30.361 | 35.211 | 40.421 | 45.990 |
| 0.87 | 0.7254 | 1.133 | 1.632 | 2.902 | 4.534 | 6.529 | 8.886 | 11.606 | 14.689 | 18.135 | 21.943 | 26.114 | 30.648 | 35.545 | 40.804 | 46.426 |
| 0.88 | 0.7320 | 1.144 | 1.647 | 2.928 | 4.575 | 6.588 | 8.967 | 11.712 | 14.823 | 18.300 | 22.143 | 26.352 | 30.927 | 35.868 | 41.175 | 46.848 |
| 0.89 | 0.7384 | 1.154 | 1.661 | 2.954 | 4.615 | 6.646 | 9.045 | 11.814 | 14.953 | 18.460 | 22.337 | 26.582 | 31.197 | 36.182 | 41.535 | 47.258 |
| 0.90 | 0.7445 | 1.163 | 1.675 | 2.978 | 4.653 | 6.701 | 9.120 | 11.912 | 15.076 | 18.613 | 22.521 | 26.802 | 31.455 | 36.481 | 41.878 | 47.648 |
| 0.91 | 0.7504 | 1.173 | 1.688 | 3.002 | 4.690 | 6.754 | 9.192 | 12.006 | 15.196 | 18.760 | 22.700 | 27.014 | 31.704 | 36.770 | 42.210 | 48.026 |
| 0.92 | 0.7560 | 1.181 | 1.701 | 3.024 | 4.725 | 6.804 | 9.261 | 12.096 | 15.309 | 18.900 | 22.869 | 27.216 | 31.941 | 37.044 | 42.525 | 48.384 |
| 0.93 | 0.7612 | 1.189 | 1.713 | 3.045 | 4.758 | 6.851 | 9.325 | 12.179 | 15.414 | 19.030 | 23.026 | 27.403 | 32.161 | 37.299 | 42.818 | 48.717 |
| 0.94 | 0.7662 | 1.197 | 1.724 | 3.065 | 4.789 | 6.896 | 9.386 | 12.259 | 15.516 | 19.155 | 23.178 | 27.583 | 32.372 | 37.544 | 43.099 | 49.037 |
| 0.95 | 0.7707 | 1.204 | 1.734 | 3.083 | 4.817 | 6.936 | 9.441 | 12.331 | 15.607 | 19.268 | 23.314 | 27.745 | 32.562 | 37.764 | 43.352 | 49.325 |
| 0.96 | 0.7749 | 1.211 | 1.744 | 3.100 | 4.843 | 6.974 | 9.493 | 12.398 | 15.692 | 19.373 | 23.441 | 27.896 | 32.740 | 37.970 | 43.588 | 49.594 |
| 0.97 | 0.7785 | 1.216 | 1.752 | 3.114 | 4.866 | 7.007 | 9.537 | 12.456 | 15.765 | 19.463 | 23.550 | 28.026 | 32.892 | 38.147 | 43.791 | 49.824 |
| 0.98 | 0.7817 | 1.221 | 1.759 | 3.127 | 4.886 | 7.035 | 9.576 | 12.507 | 15.829 | 19.543 | 23.646 | 28.141 | 33.027 | 38.303 | 43.971 | 50.029 |
| 0.99 | 0.7841 | 1.225 | 1.764 | 3.136 | 4.901 | 7.057 | 9.605 | 12.546 | 15.878 | 19.603 | 23.719 | 28.228 | 33.128 | 38.421 | 44.106 | 50.182 |
| 1.00 | 0.7854 | 1.227 | 1.767 | 3.142 | 4.909 | 7.069 | 9.621 | 12.566 | 15.904 | 19.635 | 23.758 | 28.274 | 33.183 | 38.485 | 44.179 | 50.266 |

**Exhibit 2.31b Flow Area at Culvert Outlet for Relative Depth of Flow and Pipe Diameter**

## 8. REFERENCES

2.1 American Association of State Highway and Transportation Officials, Highway Drainage Guidelines, Washington, DC, 1992.

2.2 American Association of State Highway and Transportation Officials, Model Drainage Manual, Washington, DC, 1991.

2.3 American Association of State Highway and Transportation Officials, A Guide For Transportation Landscape and Environmental Design, 1991.

2.4 Manual of Erosion and Sediment Control and Stormwater Management Standards, Lower Platte South Natural Resource District.

2.5 West Virginia Department of Transportation Division of Highways, Erosion and Sediment Control Manual, March 1, 2003. (http://www.transportation.wv.gov/highways/engineering/files/erosion/erosion2003.pdf)

2.6 National Cooperative Highway Research Program, Report 221, Erosion Control During Highway Construction - Manual on Principles and Practices.

2.7 U.S. Department of Transportation, Federal Highway Administration, Design of Roadside Drainage Channels, Hydraulic Design Series No. 4, 1965. (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds4.pdf)

2.8 U.S. Department of Transportation, Federal Highway Administration, Design of Riprap Revetment, Hydraulic Engineering Circular No. 11, 1989. (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hec/hec11sl.pdf).

2.9 U.S. Department of Transportation, Federal Highway Administration, Design Charts for Open-Channel Flow, Hydraulic Design Series No. 3, 1961. (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hds3.pdf)

2.10 Nebraska Department of Transportation, Standard Specifications for Highway Construction, 2017. (http://dot.nebraska.gov/media/10343/2017-specbook.pdf)

2.11 American Association of State Highway and Transportation Officials, A Policy on Geometric Design of Highways and Streets, Washington, DC, 2001.

2.12 Nebraska Department of Transportation, Standard/Special Plan Manual, Current Edition. (http://www.roads.nebraska.gov/business-center/design-consultant/stand-spec-manual/)

2.13 National Cooperative Highway Research Program, Report 70, Design of Sediment Basins, 1980.

2.14 United States Department of the Interior, Bureau of Reclamation, Design of Small Dams, 1977. (https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/SmallDams.pdf)

2.15 U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design of Energy Dissipators for Culverts and Channels, Hydraulic Engineering Circular No. 14, September 1983. (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/06086/hec14.pdf)

2.16 Nebraska Department of Transportation, Roadway Design Manual, Current Edition (http://www.roads.nebraska.gov/business-center/design-consultant/rd-manuals/)

2.17 Nebraska Department of Transportation, Design Process Outline, Current Edition (http://www.roads.nebraska.gov/media/6761/design-process-outline.pdf)

2.18 U.S. Department of Transportation, Federal Highway Administration, Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular No. 15, April 1988. (https://www.fhwa.dot.gov/engineering/hydraulics/pubs/05114/05114.pdf)

2.19 Nebraska Department of Transportation, Approved Products List, Current Edition. (http://www.roads.nebraska.gov/business-center/materials/approved-products/)