4.0 CHANNELS

This section provides guidance for the design of engineered channels within the highway right-of-way. Such channels include road ditches, interceptor ditches, grade-control structures and modified sections of minor streams at highway crossings. The main considerations in channel design are hydraulic capacity, stability, roadside safety, construction cost and maintenance cost. The objective is to provide an economical and stable channel with adequate hydraulic capacity that satisfies roadside safety requirements. The Bridge Design Manual, provides additional guidance for changes to streams at bridges and large culverts.

4.1 SITE APPLICATIONS

4.1.1 Road Ditches

Road ditches intercept and convey storm runoff from the highway right-of-way and small drainage areas adjacent to the right-of-way. Wherever practicable, road ditches should be designed for standard cross-sectional dimensions for the roadway type and are normally be lined with grass, unless greater erosion protection is called for.

4.1.2 Interceptor Ditches

Interceptor ditches redirect hillside runoff away from cut slopes. An interceptor ditch should be located on the natural ground near the top of the cut slope or along the edge of the right-of-way. Typical (minimum) dimensions of the interceptor ditch are 6.0 ft wide by 1.0 ft deep. The ditch should be constructed by forming a small dike near the top of the cut slope rather than by excavation. The dike should have a minimum top width of 6.0 ft. Interceptor ditches are essential in slide-prone areas, and are also commonly used where cut slopes intersect multiple farm terraces. In slide-prone areas with permeable soils, interceptor ditches should be lined with concrete.

4.1.3 Grade Control Structures

A grade control structure is a structure placed across a channel to limit the streambed slope and to control erosion and head cutting. A short, steep run of concrete ditch lining may be used at the end of a section of grass-lined ditch to drop the water into the stream. The designer should evaluate the likelihood that the outfall of the concrete ditch lining will be undercut by scour. An aggregate or concrete ditch lining may be used to carry water down a backslope from an interceptor ditch to a road ditch. An erosion pipe may also be used to carry water down a backslope (see KDOT's standard drawing for erosion pipe). A dike may be needed to direct water from the interceptor ditch into the backslope drain or erosion pipe.

4.1.4 Changes to Streams

Natural streams should be changed as little as is practicable. However, in certain situations, some modification of the natural stream may be appropriate. Such situations include stream crossings where the stream crosses the roadway alignment at an extreme skew and non-crossing locations where a stream could potentially erode the highway embankment. Changes to streams should be designed to minimize erosion and sedimentation. Severe or abrupt changes in the natural alignment should be avoided. The Division of Water Resources (DWR) of the Kansas Department of Agriculture regulates changes to streams in Kansas. A permit for the proposed change may be needed from the DWR. Section 6.2 provides further guidance on channel changes associated with culverts.

4.2 TYPES OF CHANNEL LININGS

Channel linings serve to stabilize the channel and reduce the potential for erosion. Select the most economical type of lining that will provide the required stability and erosion resistance. Road ditches are normally lined with grass unless greater erosion protection is called for. In general, grass linings are preferred over other types of flexible linings, and flexible linings are preferred over rigid linings.

Flexible linings offer several advantages over rigid linings. Flexible linings are generally easier to maintain, more economical and have a more natural appearance than rigid linings. Environmental factors such as freeze-thaw action, high pore-water pressures, and soil swelling can damage rigid linings, but have little effect on flexible linings. The primary advantage of rigid linings is their extremely high resistance to erosion. Rigid linings are appropriate for locations with high flows and steep grades. Permanent flexible lining materials include grass, aggregate, wire-enclosed aggregate (gabions), and geosynthetic blankets. Temporary flexible linings are biodegradable blankets that provide erosion protection in newly constructed channels before the permanent grass lining is established. Temporary erosion-control blankets are manufactured from many different materials, including straw, curled wood, jute, paper, and biodegradable synthetic materials. Rigid lining materials include cast-in-place concrete and grouted stone.

Aggregate channel linings can be effective on moderate slopes. An aggregate lining is constructed by placing crushed aggregate into a prepared channel and grading the aggregate to the desired shape. Aggregate lining materials are categorized by D_{50}, the mean diameter of gradation by weight. Two advantages of aggregate linings are their relatively low costs and their self healing characteristics. Standard aggregate linings are usually not effective on grades steeper than 10%. FHWA's HEC No.15 and HEC No.23 provide guidance for the design of aggregate linings for very steep grades. Aggregate larger than 4 in. (D_{50}) should not be used within the clear zone.

Permanent geosynthetic blankets can be used in conjunction with grass linings. A grass lining reinforced with a permanent geosynthetic blanket can withstand a much larger tractive force than non-reinforced grass lining. A geosynthetic-reinforced grass lining provides a more natural appearance than an aggregate lining.

Concrete channel lining is extremely resistant to erosion. Its disadvantages are a high initial cost, susceptibility to deterioration from environmental factors, and undermining by scour. Concrete channel lining is appropriate in locations with very high tractive forces and in critical locations where erosion would cause extensive damage to the ditch.

A composite channel lining has one lining material on the bottom and lower side slopes and another material on the upper side slopes. The material on the upper side slopes is typically less erosion-resistant than the material on the bottom. In a trapezoidal channel, the shear stresses on the sides are significantly lower than the shear stresses on the bottom. A properly designed composite lining may provide adequate erosion protection at lower cost than a homogenous lining. FHWA’s HEC No.15 provides guidance for the design of composite linings.

4.3 DESIGN CRITERIA FOR ROAD DITCHES

The following design criteria apply only to road ditches. They do not apply to interceptor ditches or modified sections of natural channels at highway crossings.

4.3.1 Allowable Water Surface and Recurrence Interval

The allowable water surface (AWS) for a road ditch is the top of the low bank, or the top of the subgrade at the outside edge of the shoulder in a cut section (Section 2.3). The recurrence interval for overtopping of the low bank is 10 years. In a cut section, overtopping of the road ditch should be reviewed for the effect(s) on the roadway. The recurrence interval for highway overtopping is 50 years for freeways and highways designed to interstate standards, 25 years for primary and secondary routes, and 10 years for local routes (See Table 2.4-1, "Guidelines for Design Recurrence Interval").

If a structure requiring a higher degree of protection could be flooded, determine the AWS and the recurrence interval for that structure according to the criteria in Sections 2.3 and 2.4. The AWS should not be exceeded by a storm with the specified recurrence interval.

4.3.2 Ditch Lining and Stability

Road ditches should be designed to convey the 10-year flow without significant erosion. The stability of flexible channel linings, including grass linings, should be analyzed by the method of maximum shear stress (See Section 4.5, "CHANNEL STABILITY").

Road ditches should be lined with grass wherever practicable. Select soil may need to be provided in some locations to establish and support vegetation. Select soil requirements are typically included with the soils report and also may be requested from the Geotechnical Unit of the Bureau of Structures and Geotechnical Services. The addition of select soil may not be a feasible alternative to establish grass in a ditch that is cut into rock or other material that will not support vegetation. In these situations, the designer should contact the Environmental Services Section to determine an alternative to a grass lining. The Environmental Services Section should be contacted prior to field check or when the soils and geology information is available.

A newly constructed ditch in soil should convey the 1-year flow without significant erosion. If a temporary mulch lining would be unstable at the 1-year flow, temporary erosion-control mat should be provided to protect against erosion until the grass lining is established. The designer should determine the locations requiring temporary erosion protection and provide a list of these locations to the Environmental Services Section.

Aggregate-lined and concrete-lined ditches should be designed to convey the design flow within the lined portion of the ditch. The unlined portion of the banks should be protected from erosion by a good stand of grass.

The height of an aggregate or concrete lining should equal or exceed the sum of the normal depth at the design flow, plus the largest amount of superelevation at upstream bends, plus a freeboard of 0.25 ft. The minimum height of an aggregate or concrete lining should be 0.75 ft.

Aggregate quantities for aggregate-lined ditches may be computed from the dimensions and unit weights shown on KDOT's standard drawing for ditch lining and/or Figure 4.7.3-1 "Aggregate Ditch Lining Rates of Application". If both 4-in. aggregate and 6-in. aggregate are specified, the minimum quantity of each size should be 300 tons. If this minimum quantity is not required, the smaller aggregate may be eliminated and the quantity of the larger aggregate may be increased.

4.3.3 Cross Section

See Road Design Manual, Section 7.2.1, "Roadway Criteria," and Section 7.3.9, "Ditches" for dimensions of standard ditches for various roadways and additional information regarding ditch cross sections.

Ditches within the clear zone should be traversable.

A ditch with a non-standard cross section is termed a special ditch. Special ditches may be used in locations with fill, or limited right-of-way, or may be specified based on other design considerations. The use of special ditches should be kept to a minimum. Deep special ditches may require excessive excavation or call for measures to provide an acceptable roadside geometry, and therefore should be avoided. The ditch elevation may be lowered abruptly in a short, steep run of ditch with proper erosion control. This measure is appropriate if directly adjacent to a culvert or bridge. A concrete-lined ditch may be made narrower or shallower than a standard ditch to reduce concrete quantities. Aside from cross-sectional dimensions, the design criteria for special ditches are the same as for standard ditches.

Aggregate-lined and concrete-lined backslope drains have trapezoidal cross-sections with 4:1 side slopes and a minimum depth of 0.75 ft.

4.3.4 Minimum Grade

The minimum desirable grade of the ditch bottom is 0.3%.

4.3.5 Scour Protection for Highway Embankments

An unlined natural channel in contact with a highway embankment may cause unacceptable scour of the embankment. In locations where scour is likely, a berm should be constructed along the embankment. The minimum top width of the berm should be 20.0 ft. See Volume I, Part B, Section 7.3.11, "Berms." In locations with high-speed flow or erodible soil, studies of the potential for scour and remedies may be necessary.

4.4 CHANNEL CAPACITY

4.4.1 Manning's Equation for Uniform Flow

The capacity of an open channel under conditions of steady and uniform flow is given by Manning's equation:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \qquad (4\text{-}1)$$

where: Q = discharge (cfs)

A = cross-sectional area of flow (ft^2)

R = hydraulic radius (ft)

S = slope of channel (ft/ft)

n = Manning's roughness coefficient

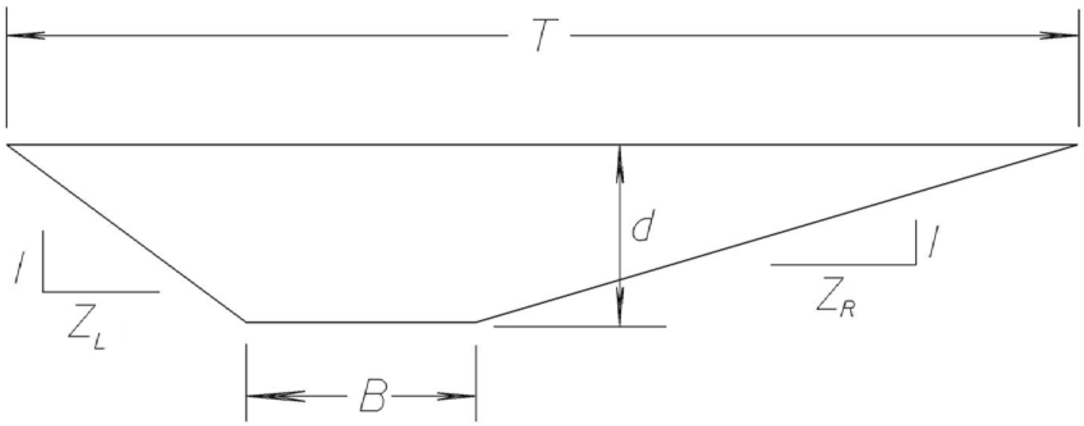
The hydraulic radius, R, equals A/P, where P is the wetted perimeter. The wetted perimeter is the perimeter of the channel cross section below the water surface. This form of Manning's equation applies to channels of various cross-sectional shapes. The depth of uniform flow is termed the normal depth.

The capacity of a channel with a composite lining should be computed by applying Manning's equation separately to the portion of the cross section over each type of lining material.

4.4.2 Geometric Relationships for Trapezoidal Channels

In a channel with a trapezoidal cross section as shown in Figure 4.4.2-1, the cross sectional area, top width and wetted perimeter are given by Eqs. 4-2, 4-3 and 4-4.

Figure 4.4.2-1 Geometric Variables for a Trapezoidal Channel



$$A = Bd + \frac{Z_L + Z_R}{2} d^2 \qquad (4\text{-}2)$$

$$T = B + (Z_L + Z_R)\, d \qquad (4\text{-}3)$$

$$P = B + d\left(\sqrt{Z_L^{\,2} + 1} + \sqrt{Z_R^{\,2} + 1}\right) \qquad (4\text{-}4)$$

where: A = cross-sectional area of flow (ft^2)

T = top width of flow (ft)

P = wetted perimeter (ft)

d = depth of flow (ft)

Z_L = side slope (run/rise) on left side of channel (ft/ft)

Z_R = side slope (run/rise) on right side of channel (ft/ft)

4.4.3 Manning's Roughness Coefficient

The recommended values and equations for Manning's roughness coefficient for channel linings are listed in Table 4.4.3-1. The Manning's n for any aggregate lining can be estimated from the D_{50} particle size (50% finer, by weight) with Equation 4-7.

Table 4.4.3-1 Manning's Roughness Coefficients

Lining Type	Manning's n
Grass, rural areas	Equation 12-5
Grass, urban areas	Equation 12-6
Aggregate	Equation 12-7
Rock cut	0.035
Concrete	0.014
Temporary mulch	0.020
Open-weave textiles*	0.025
Erosion-control blankets*	0.035
Turf reinforcement mats*	0.030

*Typical values before establishment of vegetation.

Reference: FHWA, HEC No.15

The roughness of a grass-lined channel depends on the variety, thickness, and height of the grass. Grass linings are classified into five retardance classes (A through E) according to these factors. KDOT's Environmental Services Section, Landscape Unit, specifies grass types and seeding procedures. These specifications typically result in a grass lining with Class B retardance in rural areas and Class D retardance in urban areas because grass-lined channels are mowed more often in urban areas than in rural areas.

Class B retardance generally includes rural type grasses which vary in height from 11 to 30 inches. Class D retardance generally includes urban type grasses which vary in height from 2 to 10 inches. Class D retardance should be used for medians and other rural locations where the grass is expected to be mowed more often.

Manning's roughness coefficient for a grass lining depends on the retardance class, the hydraulic radius, and the channel slope. Equations 4-5 and 4-6 provide values of Manning's roughness coefficient for grass-lined channels in rural areas and urban areas.

$$n = 0.01704 \cdot (R \cdot S)^{-0.4} \text{ for rural areas (Class B retardance)} \qquad (4\text{-}5)$$

$$n = 0.00599 \cdot (R \cdot S)^{-0.4} \text{ for urban areas (Class D retardance)} \qquad (4\text{-}6)$$

The Manning's n for an aggregate lining depends on the average depth of flow as well as the D_{50} aggregate size (50% finer, by weight), and should be computed with Equation 4-7a or 4-7b, whichever is applicable.

$$n = \frac{0.262 d_a^{1/6}}{2.25 + 5.23 \log_{10}\left[\frac{d_a}{D_{50}}\right]} \text{ for } 1.5 \le \frac{d_a}{D_{50}} \le 185 \qquad (4\text{-}7a)$$

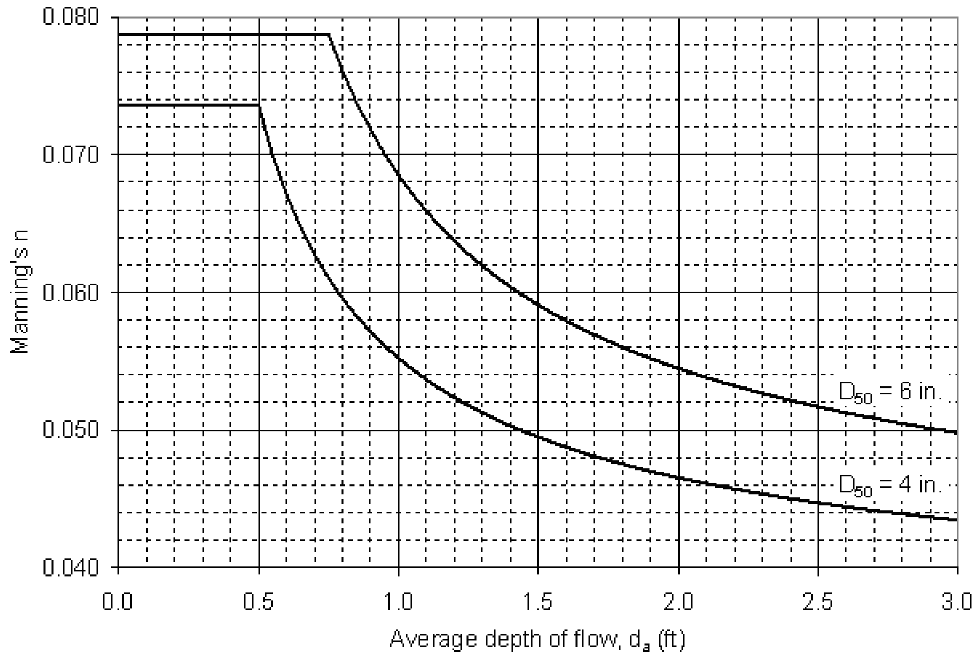
$$n = 0.0884 D_{50}^{1/6} \text{ for } \frac{d_a}{D_{50}} < 1.5 \qquad (4\text{-}7b)$$

where: d_a = A/T = average depth of flow (ft)

D_{50} = median rock size (ft)

Figure 4.4.3-1 provides Manning's n values, computed with Equations 4-7a and 4-7b, for 4-inch and 6-inch aggregate.

Figure 4.4.3-1 Manning's n for Channels lined with 4-inch and 6-inch Aggregate



4.4.4 <u>Uniform Flow in Trapezoidal Channels</u>

The discharge for uniform flow at a specified depth can be computed directly with the Manning equation. Calculation of the normal depth (the depth of uniform flow) for a given discharge requires trial-and-error. The depth is adjusted as needed to obtain the desired discharge. A few trials are usually sufficient.

Examples 4.4.5 and 4.4.6 illustrate the calculation of discharge for a given normal depth and normal depth for a given discharge in a grass-lined road ditch. Examples 4.4.7 and 4.4.8 illustrate the calculation procedures for an aggregate-lined road ditch.

4.4.5 Example: Discharge for Uniform Flow in a Grass-Lined Road Ditch

Problem:

A grass-lined road ditch on a rural highway has a bottom width of 10 ft and a bottom slope of 0.005 ft/ft. The side slopes are 6:1 on the roadway side and 4:1 on the backslope. Find the discharge for uniform flow at a depth of 2.0 ft.

Solution:

Compute the cross-sectional area at a depth of 2.0 ft with Equation 4-2.

$$A = Bd + \frac{Z_L + Z_R}{2} d^2 = 10(2.0) + \frac{6+4}{2}(2.0)^2 = 40.00\ \text{ft}^2$$

Compute the wetted perimeter at a depth of 2.0 ft with Equation 4-4.

$$P = B + d\left(\sqrt{Z_L^2 + 1} + \sqrt{Z_R^2 + 1}\right) = 10 + 2.0\left(\sqrt{6^2 + 1} + \sqrt{4^2 + 1}\right) = 30.41\ \text{ft}$$

Compute the hydraulic radius at a depth of 2.0 ft.

$$R = \frac{A}{P} = \frac{40.00}{30.41} = 1.315\ \text{ft}$$

Compute Manning's n with Equation 4-5 for rural areas.

$$n = 0.01704(R \cdot S)^{-0.4} = 0.01704(1.315 \cdot 0.005)^{-0.4} = 0.1271$$

Compute the discharge for uniform flow with Equation 4-1, Manning's equation.

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} = \frac{1.49}{0.1271}(40.0)(1.315)^{2/3}(0.005)^{1/2} = 40\,\text{cfs}$$

4.4.6 Example: Normal Depth for Given Discharge in a Grass-Lined Road Ditch

Problem:

A grass-lined road ditch on a rural highway has a bottom width of 10 ft and a bottom slope of 0.005 ft/ft. The side slopes are 6:1 on the roadway side and 4:1 on the backslope. Find the normal depth for a discharge of 60 cfs.

Solution:

Compute the discharge for uniform flow at a trial depth by the procedure in Example 4.4.5. Adjust the trial depth and repeat the calculations as needed to obtain the desired discharge. Table 4.4.6-1 shows the results for four trial depths, starting from a depth of 2.0 ft. A normal depth of 2.37 ft yields the desired discharge of 60 cfs.

Table 4.4.6-1: Normal Depth by Trial and Error in Example 4.4.6

d (ft)	A (ft^2)	P (ft)	R (ft)	Manning's n	Q (cfs)
2.0	40.00	30.41	1.315	0.1271	40
2.5	56.25	35.51	1.584	0.1180	68
2.36	51.45	34.09	1.509	0.1203	59
2.37	51.78	34.19	1.515	0.1202	60

Note: A from Equation 4-2; P from Equation 4-4; R = A/P; Manning's n for rural areas from Equation 4-5; Q from Equation 4-1.

4.4.7 Example: Discharge for Uniform Flow in an Aggregate-Lined Road Ditch

Problem:

A road ditch on a rural highway has a bottom width of 10 ft and a bottom slope of 0.010 ft/ft. The side slopes are 6:1 on the roadway side and 4:1 on the backslope. The ditch is lined with 6-in. aggregate. Find the value of Manning's n at a depth of 2.0 ft.

Solution:

Compute the cross-sectional area at a depth of 2.0 ft with Equation 4-2.

$$A = Bd + \frac{Z_L + Z_R}{2}d^2 = 10(2.0) + \frac{6+4}{2}(2.0)^2 = 40.00\ \text{ft}^2$$

Compute the wetted perimeter at a depth of 2.0 ft with Equation 4-4.

$$P = B + d\left(\sqrt{Z_L^2 + 1} + \sqrt{Z_R^2 + 1}\right) = 10 + 2.0\left(\sqrt{6^2 + 1} + \sqrt{4^2 + 1}\right) = 30.41\ \text{ft}$$

Compute the hydraulic radius at a depth of 2.0 ft.

$$R = \frac{A}{P} = \frac{40.00}{30.41} = 1.315\ \text{ft}$$

Compute the top width at a depth of 2.0 ft with Equation 4-3.

$$T = B + (Z_L + Z_R)d = 10 + (6+4)2.0 = 30.00\ \text{ft}$$

Compute the average depth of flow, d_a, and the ratio d_a/D50.

$$d_a = \frac{A}{T} = \frac{40.00}{30.00} = 1.333\ \text{ft}$$

$$\frac{d_a}{D_{50}} = \frac{1.333}{0.50} = 2.666$$

Compute Manning's n with Equation 4-7a or Equation 4-7b, whichever is applicable. In this case, $d_a/D_{50} > 1.5$, so use Equation 4-7a.

$$n = \frac{0.262 d_a^{1/6}}{2.25 + 5.23\log_{10}\left[\frac{d_a}{D_{50}}\right]} = \frac{0.262(1.33)^{1/6}}{2.25 + 5.23\log_{10}\left[\frac{1.333}{0.5}\right]} = 0.0614$$

Alternatively, Manning's n can be read from Figure 4.4.3-1.

Compute the discharge for uniform flow with Equation 4-1, Manning's equation.

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} = \frac{1.49}{0.0614}(40.0)(1.315)^{2/3}(0.01)^{1/2} = 117 \text{ cfs}$$

4.4.8 Example: Normal Depth for Given Discharge in an Aggregate-Lined Road Ditch

Problem:

A road ditch on a rural highway has a bottom width of 10 ft and a bottom slope of 0.010 ft/ft. The side slopes are 6:1 on the roadway side and 4:1 on the backslope. The ditch is lined with 6-in. aggregate. Find the normal depth for a discharge of 150 cfs.

Solution:

Compute the discharge for uniform flow at a trial depth by the procedure in Example 4.4.7. Adjust the trial depth and repeat the calculations as needed to obtain the desired discharge. Table 12.4.8-1 shows the results for four trial depths, starting from an arbitrarily selected depth of 2.0 ft. A normal depth of 2.23 ft yields the desired discharge of 150 cfs.

Table 4.4.8-1 Normal Depth by Trial and Error in Example 4.4.8

d (ft)	A (ft^2)	P (ft)	R (ft)	T (ft)	d_a (ft)	Manning's n	Q (cfs)
2.0	40.00	30.41	1.315	30.00	1.333	0.0614	117
2.3	49.45	33.47	1.477	33.00	1.498	0.0591	162
2.22	46.84	32.66	1.434	32.20	1.455	0.0596	149
2.23	47.16	32.76	1.440	32.30	1.460	0.0596	150

4.4.9 Superelevation in Bends

Flow around a bend results in superelevation of the water surface on the outside of the bend due to centrifugal forces. The amount of superelevation can be estimated with the Equation 4-8 or 4-9.

$$\Delta d = \frac{V^2 T}{2g R_c} \qquad \text{for } Fr < 1 \qquad (4\text{-}8)$$

$$\Delta d = \frac{V^2 T}{g R_c} \qquad \text{for } Fr > 1 \qquad (4\text{-}9)$$

where: Δd = rise at outer bank relative to normal depth in a straight section (ft)

V = velocity (ft/s) (Note: V = Q/A)

T = surface width of the flow (ft)

g = gravitational constant (32.2 ft/s^2)

Rc = radius of bend, measured to centerline of the channel (ft)

The Froude number is obtained from Equation 12-10.

$$Fr = \frac{V}{\sqrt{gA/T}} \qquad (4\text{-}10)$$

where: Fr = Froude number

A = cross-sectional area of flow (ft^2)

4.5 CHANNEL STABILITY

The maximum shear stress in a channel is given by:

$$\tau_d = \gamma \; d \; S \qquad (4\text{-}11)$$

where: τ_d = maximum shear stress (lb/ft^2)

γ = specific weight of water (62.4 lb/ft^3)

d = maximum depth of flow (ft)

S = slope of channel bottom (ft/ft)

The permissible shear stress is the maximum shear stress that the channel lining can sustain without significant erosion. Table 4.5-1 provides permissible shear stresses for grass and aggregate channel linings and temporary mulch. The permissible shear stress for a grass lining depends on the hydraulic resistance of the lining, as measured by Manning's n, and the characteristics of the underlying soil. The permissible shear stress for an aggregate lining is a function of the D_{50} size of the aggregate.

Table 4.5-1 Permissible Shear Stress

Lining Category	**Lining Type**	**Permissible Shear Stress, τ_p (lb/ft^2)**
Grass (good stand)	Non-cohesive soil (PI < 10) Cohesive soil with low plasticity (10 ≤ PI < 20) Silty soils with high plasticity (PI ≥ 20) Clayey soils with high plasticity (PI ≥ 20)	$\tau_p = 313\ n^2$ $\tau_p = 625\ n^2$ $\tau_p = 1250\ n^2$ $\tau_p = 1875\ n^2$
Aggregate	*D_{50} = 4 in. *D_{50} = 6 in. D_{50} = 1 in. D_{50} = 2 in. D_{50} = 3 in. D_{50} = 5 in.	1.6 2.6 0.4 0.8 1.2 2.0

Table 4.5-1 Permissible Shear Stress

#Temporary mulch	Non-cohesive soil (PI<10) Cohesive soil with low plasticity (10 ≤ PI < 20) Silty soils with high plasticity (PI ≥ 20) Clayey soils with high plasticity (PI ≥ 20)	0.06 0.13 0.25 0.38

* Aggregate sizes typically used on KDOT projects.
# Temporary seeding and mulch per KDOT Specifications.

The maximum depth of flow for stability of the channel lining is given by:

$$d_s = \frac{\tau_p}{\gamma\ S} \tag{4-12}$$

where: d_s = maximum depth of flow for stability of channel lining (ft)

τ_p = permissible shear stress (lb/ft^2)

γ = specific weight of water (62.4 lb/ft^3)

S = slope of channel bottom (ft/ft)

For additional information on temporary erosion control materials see Section 2113 of *KDOT Specifications for State Road and Bridge Construction*.

4.6 DESIGN OF ROAD DITCHES WITH GRASS LININGS

4.6.1 Procedure

1. Determine or select a ditch cross-section (bottom width, side slopes and depth) and bottom slope that are compatible with the overall roadway design. Use a standard ditch wherever practicable.

2. Determine the AWS and recurrence interval that govern the ditch capacity (Section 4.3.1).

3. Compute the design flow for ditch capacity by the Rational method (Section 3.2). Also compute Q_{10}, the check flow for lining stability, and Q_1, the check flow for temporary erosion protection.

4. Compute the normal depth for the design flow (Section 4.4.4). If the normal depth is less than the bank-full depth, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or the depth of the ditch and repeat the capacity check.

5. Check the capacity of the ditch as follows. If an improvement requiring a higher degree of protection could be flooded, determine the AWS and recurrence interval for this improvement. Compute the discharge for this recurrence interval by the Rational method. This discharge is the design flow for protection of the improvement. Next, compute the normal depth at this discharge and the corresponding water-surface elevation. If this elevation is less than the AWS level for the improvement, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or the depth of the ditch and repeat this check.

6. Check the stability of the grass lining as follows. Compute the normal depth for Q_{10}, the check flow for lining stability (Section 4.4.4). Compute the maximum shear stress at the normal depth with Equation 4-11. Compute the permissible shear stress for the Q_{10} flow using the appropriate equation from Table 4.5-1 and the Manning's n value at the normal depth. If the maximum shear stress is less than the permissible shear stress, the grass lining is stable. If the maximum shear stress exceeds the permissible shear stress, then either (1) increase the bottom width and repeat the stability check, or (2) select an aggregate lining and follow the design procedure in Section 4.7, "DESIGN OF ROAD DITCHES WITH AGGREGATE LININGS".
7. Check the stability of a temporary mulch lining as follows. Obtain the permissible shear stress for temporary mulch lining from Table 4.5-1. Compute the maximum depth of flow for stability with Equation 4-12. Compute the discharge for uniform flow at this depth with Equation 4-1, using n = 0.020 for temporary mulch (Table 4.4.3-1). This discharge is the

maximum discharge for stability with temporary mulch. If this discharge is less than Q_1, temporary erosion-control mat should be specified.

This design procedure applies to road ditches and interceptor channels on grades of less than 10%. It does not apply to realigned natural channels. FHWA's HEC No.15 provides additional guidance for the design of larger channels and channels on steeper grades.

4.6.2 Example: Design of Road Ditch with Grass Lining

Problem:

Design a road ditch for a cut section on an urban freeway. The side slopes are 6:1 and 4:1, the grade is 0.005 ft/ft, and the horizontal alignment is straight. The AWS for the freeway is the top of the subgrade at the edge of the shoulder (Section 2.3), and the recurrence interval for the freeway is 50 years (Section 2.4). The design flow and check flows are Q_{50} = 46 cfs, Q_{10} = 35 cfs and Q_1 = 22 cfs. The soil is a silty soil with high plasticity (PI≥20). No improvement requiring a higher degree of protection could be flooded.

Solution:

Try a standard ditch with a bottom width of 10 ft and a depth of 3.0 ft.

1. Check the capacity of the ditch at the design flow.

Compute the normal depth for the design flow of 46 cfs by trial and error as in Section 4.4.6. Compute the Manning's n for urban areas (Class D retardance) with Equation 4-6. Table 4.6.2-1 shows the results for four trial depths, starting from an arbitrarily selected depth of 2.0 ft. A normal depth of 1.36 ft yields the desired discharge of 46 cfs. This normal depth is less than the bank-full depth, so the ditch has sufficient capacity.

Table 4.6.2-1 Normal Depth by Trial and Error in Example 4.6.2

d (ft)	A (ft^2)	P (ft)	R (ft)	Manning's n	Q (cfs)
2.0	40.00	30.41	1.315	0.0447	113
1.3	21.45	23.27	0.922	0.0515	42
1.4	23.80	24.29	0.980	0.0503	49
1.36	22.85	23.88	0.957	0.0508	46

Note: A from Equation 4-2; P from Equation 4-4; R=A/P; Manning's n for urban areas Equation 4-6; Q from Equation 4-1.

2. Check the stability of the grass lining for Q_{10}.

Compute the normal depth for the Q_{10} flow of 35 cfs. The trial-and-error calculations yield a normal depth of 1.21 ft and a corresponding Manning's n of 0.0528.

Compute the maximum shear stress at the normal depth with Equation 4-11.

$$\tau_d = \gamma d S = 62.4(1.21)(0.005) = 0.38 \text{ lb/ft}^2$$

Compute the permissible shear stress for the Q_{10} flow with the equation for silty soils with high plasticity from Table 4.5-1.

$$\tau_p = 1250\, n^2 = 1250\,(0.0528)^2 = 3.5 \text{ lb/ft}^2$$

The maximum shear stress is much smaller than the permissible shear stress, so the grass lining is stable.

3. Determine whether temporary erosion protection is needed.

Obtain the permissible shear stress for temporary mulch with silty soils with high plasticity from Table 4.5-1.

$$\tau_p = 0.25 \text{ lb/ft}^2$$

Compute the maximum depth for stability with Equation 4-12.

$$d_s = \frac{\tau_p}{\gamma S} = \frac{0.25}{62.4(0.005)} = 0.801\,\text{ft}$$

Compute the maximum discharge for stability with temporary mulch.

Compute the cross-sectional area with Equation 4-2.

$$A = B\,d + \frac{Z_L + Z_R}{2}\,d^2 = 10\,(0.801) + \frac{6+4}{2}\,(0.801)^2 = 11.22\ \text{ft}^2$$

Compute the wetted perimeter with Equation 4-4.

$$P = B + d\left(\sqrt{Z_L{}^2 + 1} + \sqrt{Z_R{}^2 + 1}\right) = 10 + 0.8\,\left(\sqrt{6^2 + 1} + \sqrt{4^2 + 1}\right) = 18.17\ \text{ft}$$

Compute the hydraulic radius.

$$R = \frac{A}{P} = \frac{11.22}{18.17} = 0.618\ \text{ft}$$

Obtain the Manning's n for temporary mulch from Table 4.4.3-1.

$n = 0.020$

Compute the discharge with Equation 4-1.

$$Q = \frac{1.49}{n}\,A\,R^{2/3}\,S^{1/2} = \frac{1.49}{0.020}\,(11.22)\,(0.618)^{2/3}(0.005)^{1/2} = 43\ \text{cfs}$$

The maximum discharge for stability with temporary mulch exceeds Q_1, so temporary erosion-control mat should not be specified.

4.7 DESIGN OF ROAD DITCHES WITH AGGREGATE LININGS

4.7.1 Procedure

1. Determine or select a ditch cross-section (bottom width, side slopes and depth) and bottom slope that are compatible with the overall roadway design. Use a standard ditch wherever practicable.

2. Determine the AWS (Section 2.3) and recurrence interval (Section 2.4) that govern the ditch capacity.

3. Compute the design flow for ditch capacity by the Rational method (Section 3.2). Also compute Q_{10}, the check flow for lining stability.

4. Select the aggregate size (4 in. or 6 in.) Aggregate larger than 4 in. (D_{50}) should not be used within the clear zone.

5. Check the capacity of the ditch and determine the height of the aggregate lining as follows. Compute the normal depth for the design flow (Section 4.4.4) and amounts of superelevation at bends (Section 4.4.5). Add the normal depth, the largest amount of superelevation and the recommended freeboard of 0.25 ft. If this sum is less than the bank-full depth, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or depth of the ditch and repeat the capacity check. The height of the aggregate lining should equal or exceed the sum of the normal depth, largest amount of superelevation and the freeboard. The lining height should be rounded up to a convenient dimension for constructability. The minimum height of an aggregate lining is 0.75 ft.

6. If an improvement requiring a higher degree of protection could be flooded, determine the AWS and recurrence interval for this improvement. Compute the discharge for this recurrence interval (the design flow for protection of the improvement) by the Rational method. Compute the discharge for uniform flow at the AWS level for the improvement. If the discharge for uniform flow at the AWS level exceeds the design flow for protection of the improvement, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or the depth of the ditch and repeat this check.

7. Check the stability of the aggregate lining as follows. Compute the normal depth for Q_{10} (Section 4.4.4) and maximum shear stress at this depth (Equation 4-11). If the maximum shear stress is less than the permissible shear stress for the aggregate lining (Table 4.5-1), the lining is stable. Otherwise, either (1) select a larger aggregate size (up to 12 in.) and repeat the

stability check, or (2) increase the bottom width and repeat the stability check, or (3) select a concrete lining and follow the design procedure in Section 4.8.

This design procedure applies to road ditches and interceptor channels on grades of less than 10%. It does not apply to realigned natural channels. FHWA's HEC No.23 provides additional guidance for the design of large riprap-lined channels and channels on steeper grades. FHWA's HEC No.23 provides guidance for the design of realigned natural channels for stability.

4.7.2 Example: Design of Road Ditch with Aggregate Lining

Problem:

Design a ditch for a fill section on an urban highway. The side slopes are 6:1 and 4:1 and the grade is 0.020 ft/ft. The ditch will have a bend with a radius of 50 ft at the downstream end. The AWS for the ditch is the low bank (Section 10.3), and the recurrence interval for the ditch is 10 years (Section 2.4). The 10-year design flow (Q_{10}), which is also the check flow for lining stability, is 50 cfs. No improvement requiring a higher degree of protection could be flooded.

Solution:

Try a standard ditch with a bottom width of 10 ft and a depth of 3.0 ft.

Try an aggregate size of 4 in. (D_{50}).

Check the capacity of the ditch and determine the required height for the aggregate lining.

Compute the normal depth at the design flow by trial and error as in Example 4.4.8. Table 4.7.2-1 shows the results for four trial depths, starting from an arbitrarily selected depth of 1.5 ft. The normal depth for the design flow is 1.08 ft. A normal depth of 1.08 ft yields the desired discharge of 50 cfs. This normal depth is less than the bank-full depth, so the ditch has sufficient capacity.

Table 4.7.2-1 Normal Depth by Trial and Error in Example 12.7.2

d (ft)	A (ft^2)	P (ft)	R (ft)	T (ft)	d_a (ft)	Manning's n	Q (cfs)
1.5	26.3	25.3	1.04	25.0	1.05	0.054	104
1.0	15.0	20.2	0.74	20.0	0.75	0.061	42
1.1	17.1	21.2	0.80	21.0	0.81	0.059	52
1.08	16.6	21.0	0.79	20.8	0.80	0.060	50

Note: A from Equation 4-2; P from Equation 4-4; R=A/P; T from Equation 4-3; $d_a = A/T$; Manning's n from Equation 4-7; Q from Equation 4-1.

Compute the amount of superelevation in the bend for the design flow.

Compute the velocity at the normal depth.

$$V = \frac{Q}{A} = \frac{50}{16.6} = 3.01 \quad \text{ft/s}$$

Compute the Froude number at the normal depth with Equation 4-10.

$$Fr = \frac{V}{\sqrt{gA/T}} = \frac{3.01}{\sqrt{32.2(16.6)/20.8}} = 0.59$$

The flow at the normal depth is subcritical (Fr < 1), so use Equation 4-8 to compute the amount of superelevation.

$$\Delta d = \frac{V^2 T}{2g R_c} = \frac{(3.01)^2(20.8)}{2(32.2)(50)} = 0.06 \text{ft}$$

Compute the sum of the normal depth, the amount of superelevation and the recommended freeboard (0.25 ft).

1.08 ft + 0.06 ft + 0.25 ft = 1.39 ft

This sum is less than the depth of the ditch, so the ditch has sufficient capacity. The height of the lining should exceed this sum.

Check the stability of the aggregate lining for Q_{10}.

From the capacity check, the normal depth for the Q_{10} flow is 1.08 ft. Compute the maximum shear stress at this depth with Equation 4-11.

$$\tau_d = \gamma d S = 62.4(1.08)(0.020) = 1.35 \text{ lb/ft}^2$$

Obtain the permissible shear stress for 4-in. aggregate from Table 4.5-1.

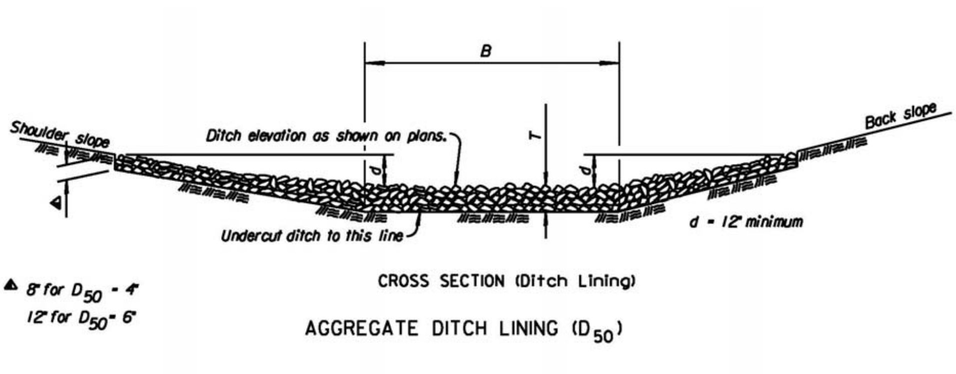
$$\tau_p = 1.6 \text{ lb/ft}^2$$

The maximum shear stress is smaller than the permissible shear stress, so the lining is stable.

4.7.3 Rates of Application

The quantities for aggregate lining may be computed from the dimensions and unit weight for aggregate shown in Figure 4.7.3-1 "Aggregate Ditch Lining Rates of Application". The rates of application per station are listed for various ditch widths and depths using 6:1 and 4:1 sideslopes.

Figure 4.7.3-1 Aggregate Ditch Lining Rates of Application



Example: 10' Ditch with 4:1 & 6:1 Slopes: D50=4"

d = depth = 1'; *T =1'

Total Rate = $R_{side(6:1)}$+R_{bottom}+$R_{side(4:1)}$ =Total Rate=30.0+60.00+20.0=110 Tons/Sta.

Rates of Application – Channel Bed

"B" Width in Ft.	D_{50} =4" Rate Tons Per Sta.	D_{50} =6" Rate Tons Per Sta.
4	24.0	36.0
6	36.0	54.0
8	48.0	72.0
10	60.0	90.0

Rates of Application – 4:1 Side Slopes

D_{50} =4"		D_{50} =6"	
D (ft.)	**Rate Tons Per Sta.**	**D (ft.)**	**Rate Tons Per Sta.**
1.0	20.0	1.0	30.0
1.5	30.0	1.5	45.0
2.0	40.0	2.0	60.0
2.5	50.0	2.5	75.0
3.0	60.0	3.0	90.0
3.5	70.0	3.5	105.0
4.0	80.0	4.0	120.0

Rates of Application – 6:1 Side Slopes

D_{50} =4"		D_{50} =6"	
D (ft.)	**Rate Tons Per Sta.**	**D (ft.)**	**Rate Tons Per Sta.**
1.0	30.0	1.0	45.0
1.5	45.0	1.5	67.5
2.0	60.0	2.0	90.0
2.5	75.0	2.5	112.5
3.0	90.0	3.0	135.0
3.5	105.0	3.5	157.5
4.0	120.0	4.0	180.0

4.8 DESIGN OF ROAD DITCHES WITH CONCRETE LININGS

4.8.1 Procedure

1. Determine or select a ditch cross-section (bottom width, side slopes and depth) and bottom slope that are compatible with the overall roadway design. Use a standard ditch wherever practicable.

2. Determine the AWS (Section 2.3) and recurrence interval (Section 2.4) that govern the ditch capacity.

3. Compute the design flow for ditch capacity by the Rational method (Section 5.2).

4. Check the capacity of the ditch and determine the height of the concrete lining as follows. Compute the normal depth for the design flow (Section 4.4.4) and amounts of superelevation at bends (Section 4.4.5). Add the normal depth, the largest amount of superelevation and the recommended freeboard of 3 in. If this sum is less than the bank-full depth, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or depth of the ditch and repeat the capacity check. The height of the concrete lining should equal or exceed the sum of the normal depth, the largest amount of superelevation and the freeboard. The lining height should be rounded up to a convenient dimension for constructability. The minimum height of a concrete lining is 9 in.

5. If an improvement requiring a higher degree of protection could be flooded, determine the AWS and recurrence interval for this improvement. Compute the discharge for this recurrence interval (the design flow for the improvement) by the Rational method. Compute the discharge for uniform flow at the AWS level for the improvement. If this discharge exceeds the design flow for the improvement, the ditch has sufficient capacity. Otherwise, increase the bottom width and/or the depth of the ditch and repeat this check.

4.8.2 Example: Design of Road Ditch with Concrete Lining

Problem:

Design a concrete lining for a short, steep run of ditch for a fill section on a rural highway. The side slopes are 6:1 and 4:1 and the grade is 0.05 ft/ft, and the horizontal alignment is straight. The AWS for the ditch is the low bank (Section 2.3), and the recurrence interval for the ditch is 10 years (Section 2.4). The 10-year design flow (Q_{10}) is 100 cfs. No structures requiring a higher degree of protection could be flooded.

Solution:

Try a standard ditch with a bottom width of 10 ft and a depth of 3.0 ft.

Check the capacity of the ditch and determine the required height of the lining.

Obtain the Manning's n for the concrete lining from Table 4.4.3-1.

$n = 0.014$

Compute the normal depth at the design flow by trial and error. Table 4.8.2-1 shows the results for four trial depths, starting from an arbitrarily selected depth of 1.0 ft. A normal depth of 0.56 ft yields a discharge approximately equal to the design flow of 100 cfs.

Table 4.8.2-1 Normal Depth by Trial and Error in Example 4.8.2

d (ft)	A (ft^2)	P (ft)	R (ft)	Q (cfs)
1.0	15.00	20.21	0.742	293
0.5	6.25	15.10	0.414	83
0.55	7.01	15.61	0.449	98
0.56	7.17	15.72	0.456	101

Note: A from Equation 4-2; P from Equation 4-4; R=A/P; Q from Equation 4-1.

Compute the sum of the normal depth, the amount of superelevation and the recommended freeboard.

$$0.56 \text{ ft} + 0.00 \text{ ft} + 0.25 \text{ ft} = 0.81 \text{ ft}$$

This sum is less than the depth of the ditch, so the ditch has sufficient capacity. The height of the lining should exceed this sum.

4.9 REFERENCES

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