7.6 Roadside Channel (Type A) Design Procedure

7.6.1 General Design Considerations

The design of Type A channels shall consider flow capacity, economics, traffic safety, aesthetics, erosion control and maintenance. These considerations are usually interrelated to such an extent that optimum conditions cannot be met for one without compromising one or more of the others; the ideal being to achieve a reasonable balance.

The location, linings and cross slope of banks are important factors in safety considerations. Motorists' safety generally improves with increasing distance between the travelway and the channel. This distance may increase the cost of property acquisition which may be offset in part by a reduction in the cost of traffic protection. The channel may be located closer to the roadway if an errant vehicle can negotiate the lining and cross slope and recover.

All channels are to be designed so as to minimize erosion. Erosive velocities can be reduced by flattening channel grades where uniform flow conditions exist, otherwise an appropriate channel lining is to be used. To prevent erosion, all channels, ditches or swales will be lined as soon as they are excavated.

A roadside channel is defined as an open channel usually paralleling the highway embankment and within the limits of the highway right-of-way. It is normally trapezoidal or V-shaped in cross section and lined with grass or a special protective lining.

The primary function of roadside channels is to collect surface runoff from the highway and areas which drain to the right-of-way and convey the accumulated runoff to acceptable outlet points.

A secondary function of a roadside channel is to drain subsurface water from the base of the roadway to prevent saturation and loss of support for the pavement or to provide a positive outlet for subsurface drainage systems such as pipe underdrains.

The alignment, cross section and grade of roadside channels is usually constrained to a large extent by the geometric and safety standards applicable to the project. These channels should accommodate the design runoff in a manner which assures the safety of motorists and minimizes future maintenance, damage to adjacent properties, and adverse environmental or aesthetic effects.

7.6.2 Vertical Alignment

Grade affects both the size of the channel and the flow velocity. The flows should be kept subcritical wherever possible so as to avoid adverse characteristics of supercritical flow.

The approximate grade of a channel is usually determined by the topography of the site. If the terrain is flat then deposition of sediment is unavoidable, the channel should be designed so that the deposition will occur at a location accessible to maintenance.

"Vertical grade drops" or check dams, constructed of concrete walls, stones, gabions, concrete cribbing, metal cribbing or treated timbers, are very useful in maintaining grades which produce acceptable velocities downstream and reduce the costs of lining a channel. These should only be used in channels not accessible to vehicles.

7.6.3 Horizontal Alignment

A straight alignment of a channel permits a simplified hydraulic design. A straight channel does not provide obstacles to the flow and normally will not pick up materials for later deposition at some point downgrade. It is not usually practical to design a straight channel and have it compatible with the terrain or existing streams. Changes in alignment should be as gradual as the right-of-way and terrain permit. Whenever practicable alignment changes should be made in sections with a flat gradient, particularly if flows will become supercritical on a steeper slope. This practice will reduce the force of the water against the banks and allow the use of more effective erosion controls. When horizontal curvature is utilized, the effects of increased water surface on the outsides of curves should be considered.

7.6.4 Swales

Swales are shallow depressed areas used to drain medians, shelves with negative backslopes, and other areas where ditches are not feasible for either safety or aesthetic considerations. Grass-lined swales for the roadways generally have a longitudinal slope which conforms to the roadway grade except on flat grades, where the swale grade may be steeper than the roadway grade.

7.6.5 Interceptor Channels

These channels are used to intercept runoff from adjacent areas, to collect runoff from within the project, and to convey the runoff to suitable outlets, preferably watercourses. Interceptor channels or ditches are divided into three categories: Top-of-slope Channels, Toe-of-Slope Channels and Outlet Channels.

The layout of Interceptor Channels should be made on a topographical map which contains the project, location of storm drainage structures, contours, and drainage area limits.

For the purposes of payment and in accordance with the Department's Standard Specifications, a channel shall be interpreted to mean a natural or artificial watercourse having an average width at the bottom, after excavation, of 1.2m (4 ft) or more. A drainage ditch shall be interpreted to mean an unpaved, artificially constructed open depression having an average width of less than 1.2m (4 ft) at the bottom, after excavation, constructed for the purpose of carrying surface water.

- **Top-of-Slope channels** or ditches are located at the top of cut slopes for the purpose of intercepting runoff from natural slopes inclined towards the project. They serve to reduce erosion of the cut slope face and to prevent debris and sediment from washing onto the project.

The following should be considered before use of a Top-of-Slope Channel:

- The runoff from the contributing area can flow down the cut slope if it will not affect its stability. The Soils and Foundations Section should be consulted to determine this. If the slope will not be stable, then a top-of-slope channel is required.
- If the cost of additional drainage resulting from the absence of a channel exceeds the cost of the channel, then the channel may be warranted. The fact that top-of-slope channels are far removed from the travelway and are difficult to maintain should also be considered.
- These channels are to have a trapezoidal section with 3 horizontal to 1 vertical side slopes for grass linings; and 2 horizontal to 1 vertical side slopes for riprap or rigid linings.
- The channel grade should be such that ponding will not occur thereby causing saturation or overflow at the top of the slope which could result in slope failure. In areas of unstable slopes it may be necessary to intercept, and accelerate the removal of runoff with pipes. Channels crossing highly permeable slopes may require lining with impermeable material.
- To prevent slope failure, the top of the channel nearest the slope should be located no closer than five feet from the outer limit of the rounding created at the top of cut slopes.
- Excessively deep channel cuts to maintain constant grades should be avoided.

• **Toe-of-slope channels** are located near the toe of the embankment when it is necessary to convey water collected by storm drainage systems, swales, or runoff from terrain inclined toward the projects, or to keep flow within the ROW until a suitable outlet is available.

These channels are to have the same cross section geometry as top-of-slope channels if their location will not be hazardous to vehicular traffic. If it is determined that a trapezoidal channel will be hazardous, then the use of guide railing must be considered. The preferred design, for both safety and aesthetics, would be a wide parabolic section with vertical curves to round all angles. The reduction of flow velocities through use of side, shallow channels or swales will minimize erosion and may be possible without an appreciable increase in cost. This type of channel may be found to be more economical after considering the cost of the guide rail, lining and rights of way required for alternatives.

If trapezoidal channels are used they should be located 1.5m (5 feet) from the normal toe rounding of the embankment to prevent the channel from being obstructed by any natural sloughing and erosion of the adjacent embankment. The 5 foot shelf shall be on a slope of 1V:12H between the toe and the top of the channel unless rights of way requirements dictate otherwise.

• **Outlet channels**

Outlet channels are used to convey flow from storm drainage systems and swales to a watercourse or to an area not subject to erosion.

They are usually designed with side slopes of 1V:2H. For vehicular safety, it may be necessary to use flatter side slopes and wider trapezoidal channels, especially where outletting swales from roadway cut sections to the toes of adjoining embankments.

Outlet channels should be located beyond the area required for vehicular recovery. They should be accessible for maintenance since they may trap sediment and debris.

7.6.6 Type A Channel Design Concepts

HEC-15 provides a detailed presentation of stable channel design concepts related to the design of roadside and median channels which convey a design discharge less than **1.42 m^3/s or 50 cfs**. This section provides a brief summary of significant concepts.

Stable channel design concepts provide a means of evaluating and defining channel configurations that will perform within acceptable limits of stability. For most highway drainage channels, bank instability and lateral migration can not be tolerated. Stability is achieved when the material forming the channel boundary effectively resists the erosive forces of the flow. Principles of rigid boundary hydraulics can be applied to evaluate this type of system.

Both velocity and tractive force methods have been applied to the determination of channel stability. Permissible velocity procedures are empirical in nature, and have been used to design numerous channels in the United States and throughout the world. However, tractive force methods consider actual physical processes occurring at the channel boundary and represent a more realistic model of the detachment and erosion processes.

The hydrodynamic force created by water flowing in a channel causes a shear stress on the channel bottom. The bed material, in turn, resists this shear stress by developing a tractive force. Tractive force theory states that the flow-induced shear stress should not produce a force greater than the tractive resisting force of the bed material. This tractive resisting force of the bed material creates the permissible or critical shear stress of the bed material. In a uniform flow, the shear stress is equal to the effective component of the gravitational force acting on the body of water parallel to the channel bottom. The average shear stress is equal to:

$$\tau = \gamma \, R \, S \tag{7.11}$$

where: τ = average shear stress, Pa (lb/ft^2)
γ = unit weight of water, 9810 N/m^3 (62.4 lb/ft^3) (at 15.6 °C (60 °F))
R = hydraulic radius, m (ft)
S = average bed slope or energy slope, m/m (ft/ft)

The maximum shear stress for a straight channel occurs on the channel bed and is less than or equal to the shear stress at maximum depth. The maximum shear stress is computed as follows:

$$\tau_d = \gamma \, d \, S \tag{7.12}$$

where: τ_d = maximum shear stress, Pa (lb/ft^2)
d = maximum depth of flow, m (ft)

Shear stress in channels is not uniformly distributed along the wetted perimeter of a channel. A typical distribution of shear stress in a trapezoidal channel tends toward zero at the corners with a maximum on the bed of the channel at its centerline, and the maximum for the side slopes occurs around the lower third of the slope as illustrated in Figure 7-7.

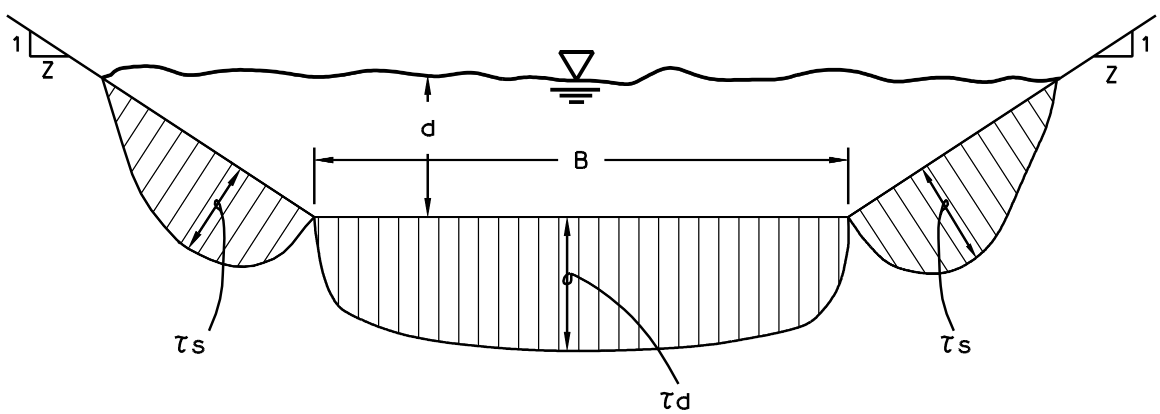


Figure 7-7 Distribution of shear stress

For trapezoidal channels lined with gravel or riprap having side slopes steeper than 3 horizontal to 1 vertical, side slope stability must also be considered. This analysis is performed by comparing the tractive force ratio between side slopes and channel bottom with the ratio of shear stresses exerted on the channel sides and bottom. The ratio of shear stresses on the sides and bottom of a trapezoidal channel, K_1, is given in Figure 7-9 and the tractive force ratio, K_2, is given in Figure 7-10. The angle of repose, θ, for different rock shapes and sizes is provided in Figure 7-11. The required rock size for the side slopes is found using the following equation:

$$(D_{50})_{sides} = \frac{K_1}{K_2}(D_{50})_{bottom} \tag{7.13}$$

where: D_{50} = the mean riprap size, m (ft)
K_1 = ratio of shear stresses on the sides and bottom of a trapezoidal channel (see Figure 7-9).
K_2 = ratio of tractive force on the sides and bottom of a trapezoidal channel (see Figure 7-10).

Flow around a bend in an open channel induces centrifugal forces because of the change in flow direction. This results in a superelevation of the water surface at the outside of bends and can cause the flow to splash over the side of the channel if adequate freeboard is not provided. This superelevation can be estimated by the following equation.

$$\Delta d = \frac{V^2 T}{g R_c} \tag{7.14}$$

where: Δd = difference in water surface elevation between the inner and outer banks of the channel in the bend, m (ft)
V = average velocity, m/s (ft/s)
T = surface width of the channel, m (ft)
g = gravitational acceleration, 9.8 m/s^2 (32.2 ft/s^2)
R_c = radius to the centerline of the channel, m (ft)

Equation 7.14 is valid for subcritical flow conditions. The elevation of the water surface at the outer channel bank will be $\Delta d/2$ higher than the centerline water surface elevation (the average water surface elevation immediately before the bend) and the elevation of the water surface at the inner channel bank will be $\Delta d/2$ lower than the centerline water surface elevation.

Flow around bends also creates secondary currents which impose higher shear stresses on the channel sides and bottom compared to straight reaches. Areas of high shear stress in bends are illustrated in Figure 7-8. The maximum shear stress in a bend is a function of the ratio of channel curvature to bottom width. This ratio increases as the bend becomes sharper and the maximum shear stress in the bend increases. The bend shear stress can be computed using the following relationship:

$$\tau_b = K_b \tau_d \tag{7.15}$$

where: τ_b = bend shear stress, Pa (lb/ft^2)
K_b = function of R_c/B (see Figure 7-12)
R_c = radius to the centerline of the channel, m (ft)
B = bottom width of channel, m (ft)
τ_d = maximum channel shear stress, Pa (lb/ft^2)

The increased shear stress produced by the bend persists downstream of the bend a distance L_p, as shown in Figure 7-8. This distance can be computed using the following relationship:

$$L_p = \frac{0.736\,R^{7/6}}{n_b} \qquad \left(L_p = \frac{0.603 R^{7/6}}{n_b} \right) \qquad \textbf{(7.16)}$$

where: L_p = length of protection (length of increased shear stress due to the bend) downstream of the point of tangency, m (ft)
n_b = Manning's roughness in the channel bend
R = hydraulic radius, m (ft)

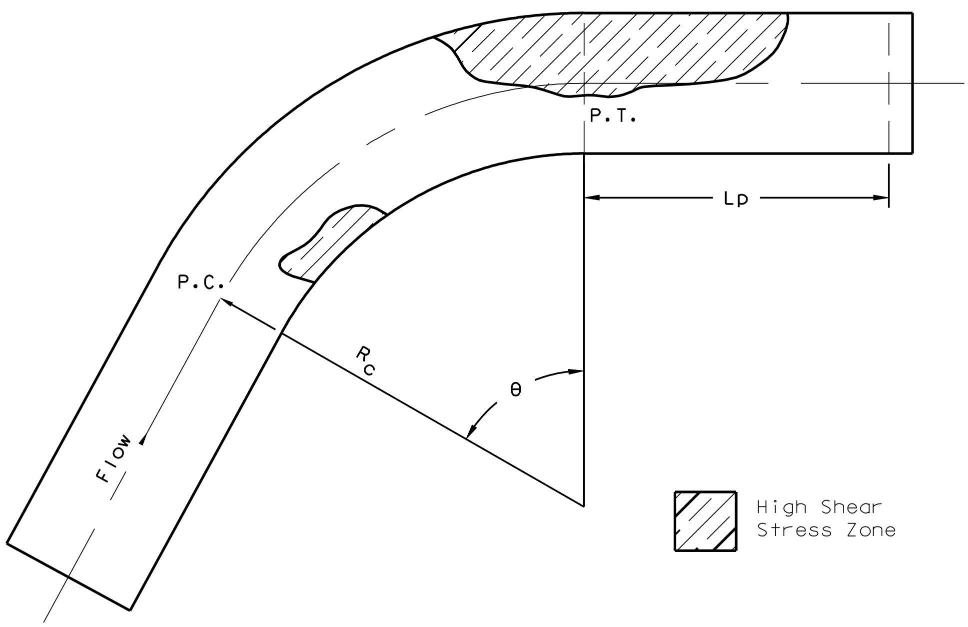


Figure 7-8 Shear stress distribution in channel bends

7.6.7 Design Parameters

Parameters required for the design of roadside and median channels include discharge frequency, channel geometry, channel slope, vegetation type, freeboard, and shear stress. This section provides criteria relative to the selection or computation of these design elements.

- **Discharge Frequency**

Roadside and median drainage channels are designed to carry the 10 year design flow. A 2-year return period is used for the design of temporary linings.

Channels will be designed to convey the discharge of any connecting facility, with consideration for possible additional flow from adjacent areas which may increase the discharge and require adjustments in the design. The preliminary layout of the channel should be made on a topographic map which contains the location of the project and has adequate contours to determine the contributing drainage areas. From this map, the discharge can be estimated at appropriate points along the channel. For watercourses, it is usually not necessary to compute more than one discharge unless there are extenuating circumstances. Additional information on design discharge can be found in other sections of this chapter.

- **Channel Geometry**

Channel side slopes for triangular or trapezoidal channels cannot exceed the angle of repose of the soil and/or lining material, and should generally be 3 horizontal to 1 vertical or flatter. In areas where traffic safety may be of concern, channel side slopes should be 4 horizontal to 1 vertical or flatter.

Design of roadside and median channels should be integrated with the highway geometric and pavement design to insure proper consideration of safety and pavement drainage needs.

- **Channel Slope**

Channel bottom slopes are generally dictated by the road profile or other constraints. However, if channel stability conditions warrant, it may be feasible to adjust the channel gradient slightly to achieve a more stable condition. Channel gradients greater than two percent may require the use of flexible linings to maintain stability. Most flexible lining materials are suitable for protecting channel gradients of up to 10 percent, with the exception of some grasses. Linings, such as riprap and wire-enclosed riprap are more suitable for protecting very steep channels with gradients in excess of 10 percent. Rigid linings, such as concrete paving, are highly susceptible to failure from structural instability due to such occurrences as overtopping, freeze thaw cycles, swelling, and excessive soil pore water pressure.

- **Roughness Coefficient (Manning's n values)**

The selection of an appropriate Manning's n value for design purposes is often based on observation and experience. Manning's n values are also known to vary with flow depth. Table 7-2 provides a tabulation of Manning's n values for various channel lining materials. Manning's roughness coefficient for vegetative and other linings vary significantly depending on the amount of submergence. The classification of vegetal covers by degree of retardance is provided in

HEC-15. Table 7-3 provides a list of Manning's n relationships for five classes of vegetation defined by their degree of retardance.

• **Freeboard**

The freeboard of a channel is the vertical distance from the water surface to the top of the channel banks. The importance of this factor depends on the consequence of overflow of the channel bank. At a minimum the freeboard should be sufficient to prevent waves, superelevation changes, or fluctuations in water surface from overflowing the sides. In a permanent roadside or median channel, 0.3m (1 ft) of freeboard is generally considered adequate. For temporary channels no freeboard is necessary. However, a steep gradient channel should have a freeboard height equal to the flow depth to compensate for the large variations in flow caused by waves, splashing, and surging.

• **Shear Stress**

The permissible or critical shear stress in a channel defines the force required to initiate movement of the channel bed or lining material. Table 7-4 presents permissible shear stress values for manufactured, vegetative, and riprap channel lining. The permissible shear stress for non-cohesive soils is a function of mean diameter of the channel material as shown in Figure 7-13. For larger stone sizes not shown in Figure 7-13 and rock riprap, the permissible shear stress is given by the following equation:

$$\tau_p = K_p D_{50} \qquad \textbf{(7.17)}$$

where: τ_p = permissible shear stress, Pa (lb/ft^2)
D_{50} = mean riprap size, m (ft)
K_p = 628 (4.0)

For cohesive materials the plasticity index provides a good guide for determining the permissible shear stress as illustrated in Figure 7-14.

Table 7-2. Manning's roughness coefficients for Roadside and Median Channels. *

Lining Category	ConnDOT Designations	Lining Type	n - Value for Given Depth Ranges 0-0.15 m (0-0.5 ft)	0.15-0.60 m (0.5-2.0 ft)	>0.60 m (>2.0 ft)
Rigid		Concrete	0.015	0.013	0.013
		Grouted Riprap	0.040	0.030	0.028
		Stone Masonry	0.042	0.032	0.030
		Soil Cement	0.025	0.022	0.020
		Asphalt	0.018	0.016	0.016
Unlined		Bare Soil	0.023	0.020	0.020
		Rock Cut	0.045	0.035	0.025
Erosion Control Matting** (Temporary or Permanent)	Type E	Woven Paper Net	0.016	0.015	0.015
		Jute Net	0.028	0.022	0.019
	Type F	Fiberglass Roving	0.028	0.021	0.019
	Type G	Straw with Net	0.065	0.033	0.025
		Curled Wood Mat	0.066	0.035	0.028
	Type H	Synthetic Mat	0.036	0.025	0.021
Gravel Riprap		25 mm (1 in) D_{50}	0.044	0.033	0.030
	Special	50 mm (2 in) D_{50}	0.066	0.041	0.034
Rock Riprap	Modified	125 mm (5 in) D_{50}	0.095	0.062	0.035
		150 mm (6 in) D_{50}	0.104	0.069	0.035
	Intermediate	200 mm (8 in) D_{50}	--	0.072	0.037
		300 mm (12 in) D_{50}	--	0.078	0.040
	Standard	380 mm (15 in) D_{50}	--	--	0.042

NOTE: Values listed are representative values for the respective depth ranges. Manning's roughness coefficients, n, vary with the flow depth.

* Table reproduced from HEC-15

** See Section 7.6.8

Table 7-3. Manning's n relationships for vegetal degree of retardance.

Retardance Class***	Manning's n Equation*	
A	$1.22\ R^{1/6} / [30.2 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ (R^{1/6} / [15.8 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ )$	**(7-18)**
B	$1.22\ R^{1/6} / [37.4 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ (R^{1/6} / [23.0 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ )$	**(7-19)**
C**	$1.22\ R^{1/6} / [44.6 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ (R^{1/6} / [30.2 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ )$	**(7-20)**
D	$1.22\ R^{1/6} / [49.0 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ (R^{1/6} / [34.6 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ )$	**(7-21)**
E	$1.22\ R^{1/6} / [52.1 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ (R^{1/6} / [37.7 + 19.97 \log (R^{1.4}\ S_o^{0.4})]\ )$	**(7-22)**

* Equations are valid for flows less than 1.42 m^3/s (50 ft^3/s).
Nomograph solutions for these equations are contained in HEC-15.

** Use on ConnDOT projects when calling for turf establishment

*** See HEC-15 for definition of retardance classes

Table 7-4 Permissible Shear Stresses for Lining Materials*

Lining Category	ConnDOT Designations	Lining Type	Permissible Unit Shear Stress Pa	lb/ft^2
Erosion Control Matting**	Type E	Woven Paper Net	7.2	0.15
		Jute Net	21.5	0.45
	Type F	Fiberglass Roving:		
		Single	28.7	0.60
		Double	40.7	0.85
	Type G	Straw with Net	69.4	1.45
		Curled Wood Mat	74.2	1.55
	Type H	Synthetic Mat	95.8	2.00
Vegetative		Class A	177.2	3.70
		Class B	100.6	2.10
Turf Establishment		Class C-Use for DOT projects	47.9	1.00
		Class D	28.7	0.60
		Class E	16.8	0.35
Gravel Riprap		25 mm (1 in)	15.8	0.33
	Special	50 mm (2 in)	31.6	0.67
Rock Riprap	Modified	125 mm (5 in)	79.8	1.68
		150 mm (6 in)	95.8	2.00
	Intermediate	200 mm (8 in)	127.7	2.68
		300 mm (12 in)	191.5	4.00
	Standard	380 mm (15 in)	239.3	5.00
Bare Soil		Non-cohesive	Figure 7-13	
		Cohesive	Figure 7-14	

* Reproduced from HEC-15
** See Section 7.6.8

7.6.8 Erosion Control Matting

Erosion control matting is evaluated by the Department for use in eight Types (A-H), grouped into two Classes. Types A through D are included in Class 1 and are designated as Slope Protection. This classification is based upon steepness of the slope and soil type. The purpose of Class 1 matting is to protect the seedbed from loss of soil, and promote the establishment of a warm-season, perennial vegetative cover.

Types E through H are included in Class 2 and are designated as Flexible Channel Liner Protection. This classification is based upon the permissible shear stress of the material. The purpose of Class 2 matting is to protect the geometry of a channel from loss of soil, and to promote the establishment of a warm-season, perennial vegetative cover. Class 2 Types are designated according to the shear stress limits shown in Table 7-5. The shear stress ranges are based on values published in HEC-15.

Table 7-5 Erosion Control Matting (Class 2) Shear Stress Ranges

Matting Type	Permissible Shear Stress – Pa (lb/ft^2)
E	< 25 (<0.5)
F	25 to < 50 (0.5 to <1.0)
G	50 to < 100 (1.0 to <2.0)
H	$\geq$ 100 ($\geq$2.0)

Products approved by the Department for use as erosion control matting on State projects are placed on an Approved Products List. This list is updated annually and distributed by the Department's Office of Research and Materials. Products listed by brand or trade name on the Approved Products List have demonstrated their ability to meet or exceed the Department's minimum performance standards by independent testing conducted at facilities such as the Texas Department of Transportation/Texas Transportation Institute Hydraulics and Erosion Control Laboratory.

The drainage designer is primarily concerned with Class 2 matting materials for use in the construction of roadside channels. Erosion control matting in channel lining applications can be temporary (bio- or photodegradable) or permanent (non-bio- or non-photodegradable). Types E, F and G matting are generally temporary and include but are not limited to the following materials: (E) Woven Paper Net, Jute Net and (F) Single or Double Fiberglass Roving and (G) Straw with Net, Curled Wood Mat. Type H matting is generally composed of synthetic material, is permanent and is commonly used for turf reinforcement. **If the channel design requires the use of a permanent matting, the matting should be noted as permanent on the project plans.**

The designer should be aware that it is the contractor's option as to which product he or she actually uses on a project, provided that the product used is on the Approved Products List for that application. Appropriate judgement should be reflected in the engineering calculations when selecting the Type of Matting (E, F, G or H) to be specified on the project plans.

See Appendix B for additional guidance regarding the use of erosion control matting in vegetative (grass) lined swales.

7.6.9 Design Procedure for Roadside Ditches, Swales, and Channels (Type A)

This section presents a generalized procedure for the design of roadside and median channels. Although each project will be unique, the design steps outlined below will normally be applicable.

Step 1. Establish a Preliminary Drainage Plan

For proposed median or roadside channels, the following preliminary action should be taken:

A. Prepare existing and proposed plan and profile of the proposed channels. Include any constraints on design such as highway and road locations, culverts, utilities, etc.

B. Determine and plot on the plan the locations of natural basin divides and channel outlet points.

C. Collect any available site data such as soil types and topographic information.

Step 2. Obtain or Establish Cross Section Data

Establish preliminary cross section geometric parameters and controlling physical features considering the following guides:

A. Adequate channel depth should be provided to drain the pavement subbase and minimize freeze-thaw.

B. Channel side slopes based on geometric design criteria including safety, economics, soil, aesthetics, and access should be chosen.

Step 3. Determine Initial Channel Grades

Plot initial grades on the plan and profile. Note that slopes on roadside channels in cuts are usually controlled by highway grades. Use the following guides when establishing initial grades:

A. Provide a channel slope with a minimum 0.5% grade to minimize ponding and sediment accumulation.

B. Where possible, avoid features which may influence or restrict grade, such as utility structures.

Step 4. Check flow Capacities and Adjust Sections as Necessary

A. Compute the design discharge at the downstream end of channel segments.

B. Set preliminary values for channel size, roughness, and slope, based on long term conditions and considering maintenance.

C. Determine the maximum allowable depth of channel including freeboard.

D. Check the flow capacity using Manning's equation

E. If the capacity is not adequate, possible considerations for increasing the capacity are provided below.

- increase bottom width
- make channel side slopes flatter
- make channel slope steeper
- provide smoother channel lining
- install drop inlets and a parallel storm drain pipe beneath the channel to supplement channel capacity

Step 5. Determine Channel Protection Needed

A. Select a lining and determine the permissible shear stress from Table 7-4. For detailed information related to lining performance, see HEC-15.

B. Estimate the flow depth and choose an initial Manning's n value from Table 7-2 or Table 7-3.

C. Calculate the normal flow depth at design discharge using Manning's equation and compare with the estimated depth. If the flow depth is acceptable, continue with the design procedure. If the depth is not acceptable, repeat steps 5B and 5C.

D. Compute the maximum shear stress at normal depth using equation 7.12.

E. If the maximum shear stress (step 5D) is less than the permissible shear stress (step 5A), then the lining is acceptable. Otherwise consider the following options:

- choose a more resistant lining
- use concrete, gabions, or other more rigid lining either as full lining or composite (keeping in consideration the possible deficiencies of rigid linings)
- decrease channel slope
- decrease slope in combination with drop structures
- increase channel width and/or flatten side slopes

If the maximum shear stress is excessively less than the permissible shear stress, the lining material may be redesigned to provide a more comparable lining material.

F. For trapezoidal channels lined with gravel or riprap having side slopes steeper than 3 horizontal to 1 vertical, use equation 7-13 and Figures 7-9 and 7-10 to evaluate side slope stability.

G. For flow around bends, use equation 7.15 and Figure 7-12 to evaluate lining stability.

H. When channel gradients approach 10 percent, compare results obtained above with steep slope procedures in HEC-15.

I. For composite linings use procedures in HEC-15.

J. If a grass lining is designated without a permanent erosion control matting, then a temporary protective lining will be designed using a 2 year frequency storm repeating the above steps. See Appendix B for additional guidance regarding the use of erosion control matting in vegetative (grass) lined swales.

Step 6. Check Channel Transitions and End of Reach Conditions

Channel transition include locations where there are changes in cross section, slope, discharge, and/or roughness. At these locations, the gradually varying flow assumption may be violated, and a more detailed hydraulic evaluation may be required.

A. Identify transition locations.

B. Review hydraulic conditions upstream and downstream of the transition (flow area, depth, and velocity). If significant changes in these parameters are observed, perform additional hydraulic evaluations to determine flow conditions in the vicinity of the transition. See HEC-15.

C. Provide for gradual channel transitions to minimize the possibility for sudden changes in hydraulic conditions at channel transitions.

Step 7. Analyze Outlet Points and Downstream Effects

A. Identify any adverse impacts to downstream properties which may result from one of the following at the channel outlets:

- increase or decrease in peak discharge
- increase in flow velocity
- confinement of sheet flow
- change in outlet water quality
- diversion of flow from another watershed

B. Mitigate any adverse impacts identified in 7A. Possibilities in order relative to above impacts include:

- enlarge outlet channel and/or install control structures to provide detention of increased runoff in channel
- install velocity control or energy dissipation structure
- increase capacity and/or improve lining of downstream channel
- install sophisticated weirs or other outlet devices to redistribute concentrated channel flow
- eliminate diversions which result in downstream damage and which cannot be mitigated in a less expensive fashion

To obtain the optimum roadside channel system design, it may be necessary to make several trials of the above procedure before a final design is achieved.

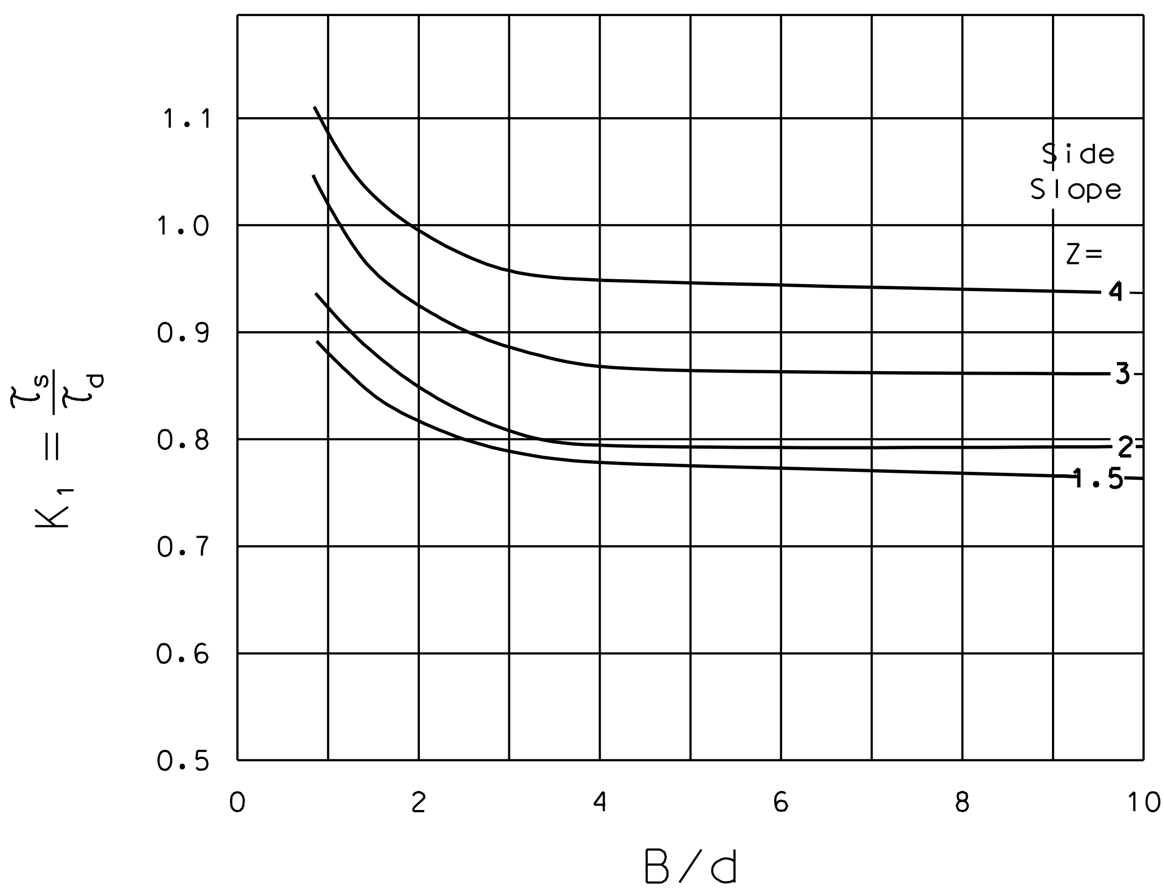


Figure 7-9 Channel Side Shear Stress to Bottom Shear Stress Ratio, K_1.

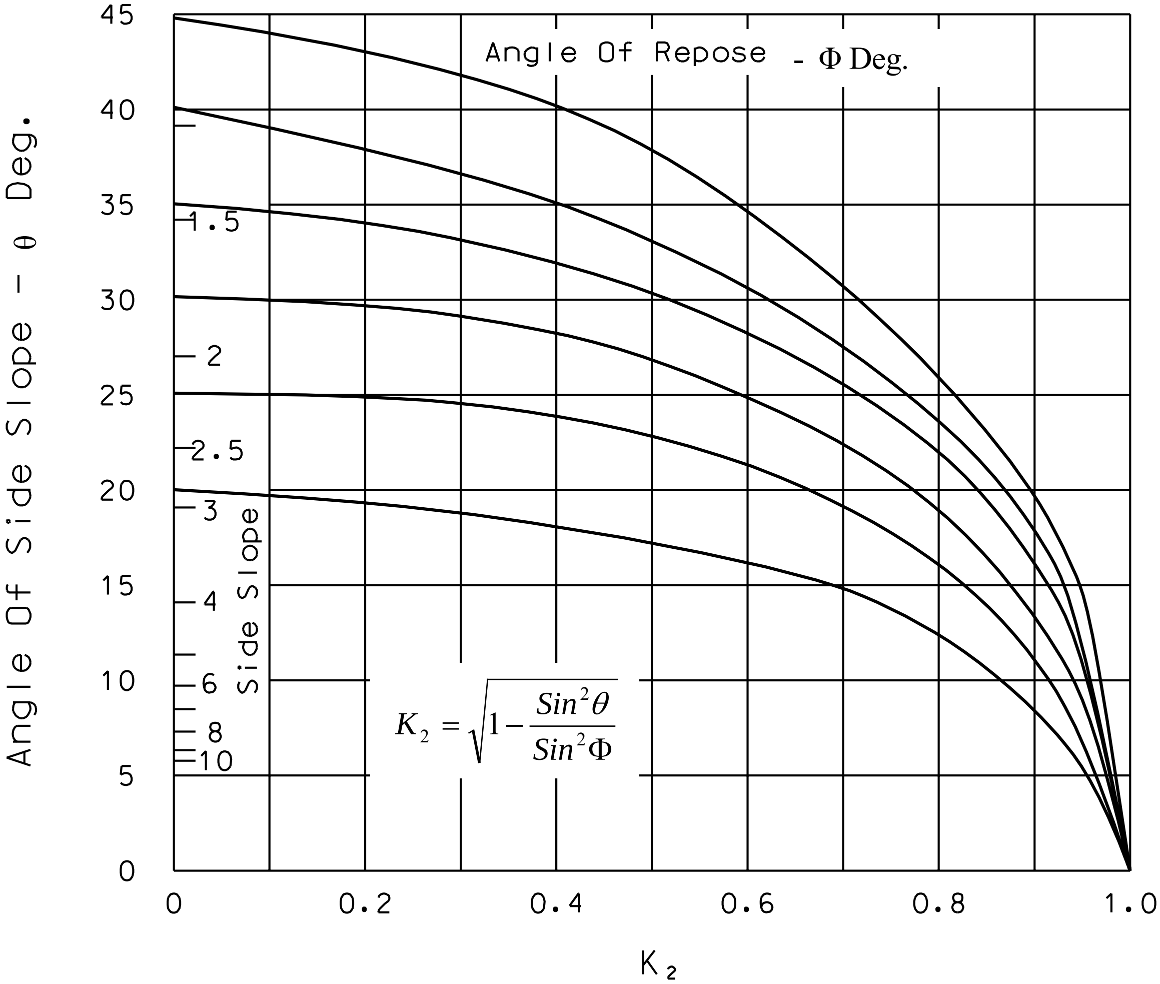


Figure 7-10 Tractive Force Ratio, K_2

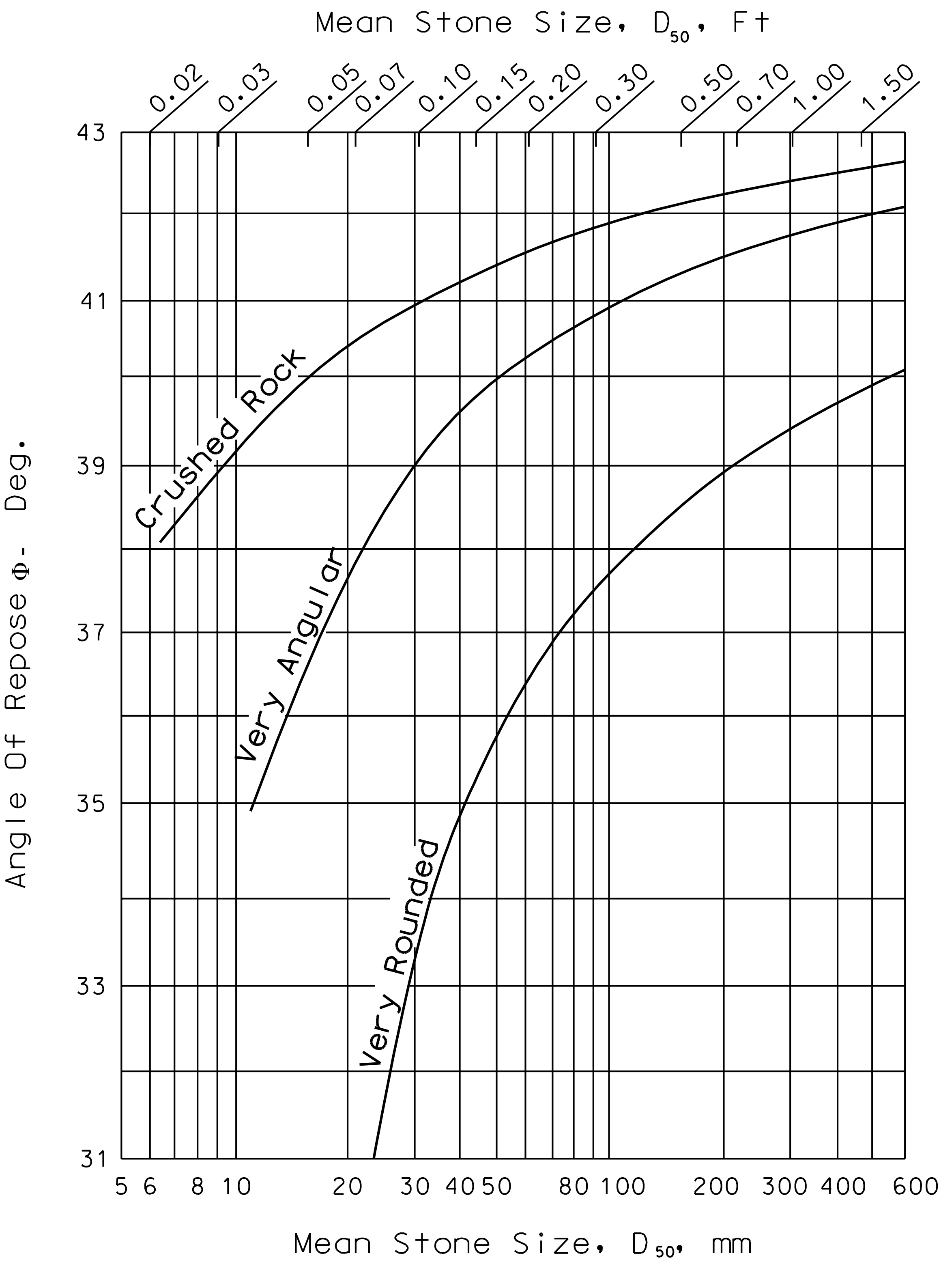


Figure 7-11 Angle of Repose of Riprap in Terms of Mean Size and Shape of Stone

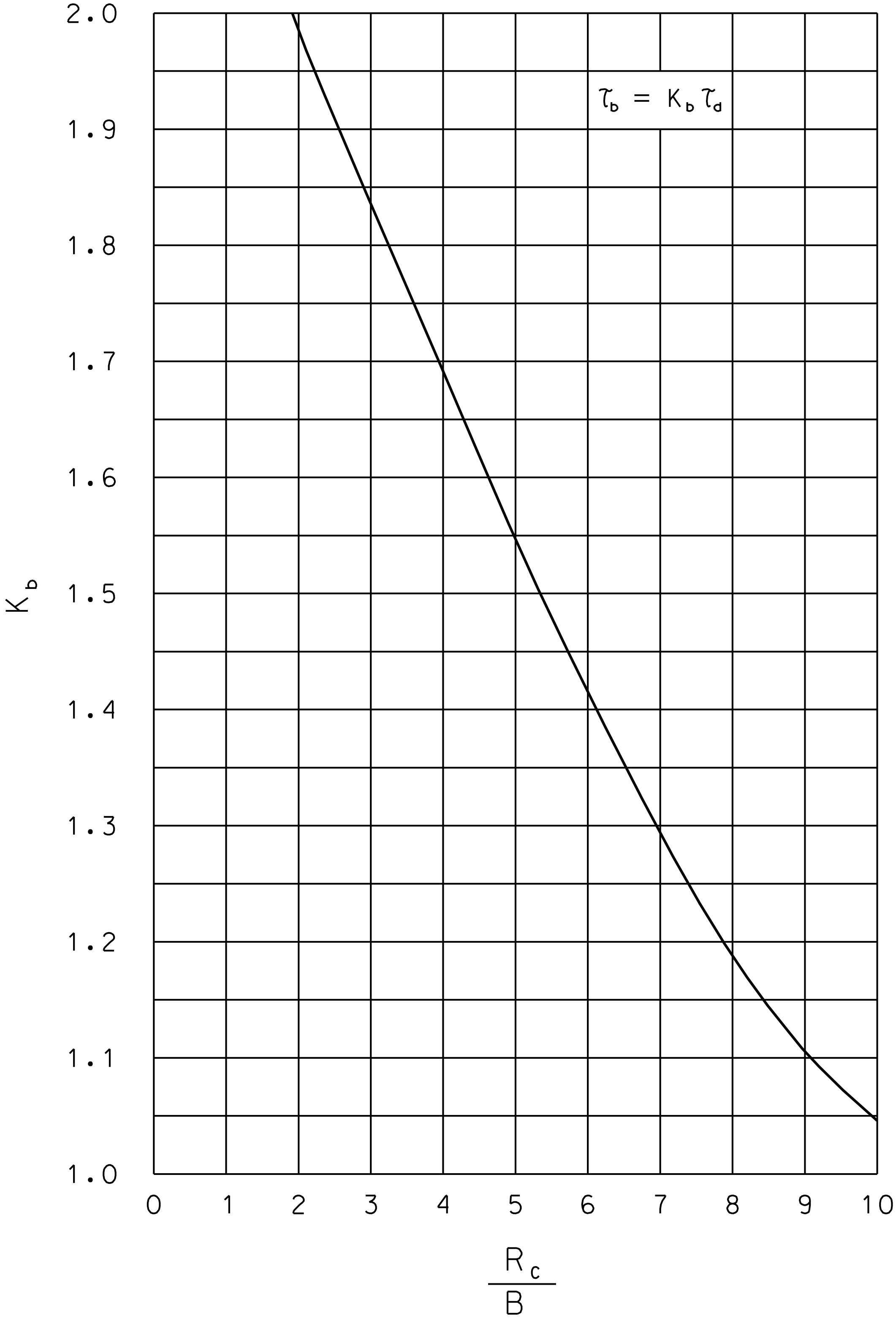
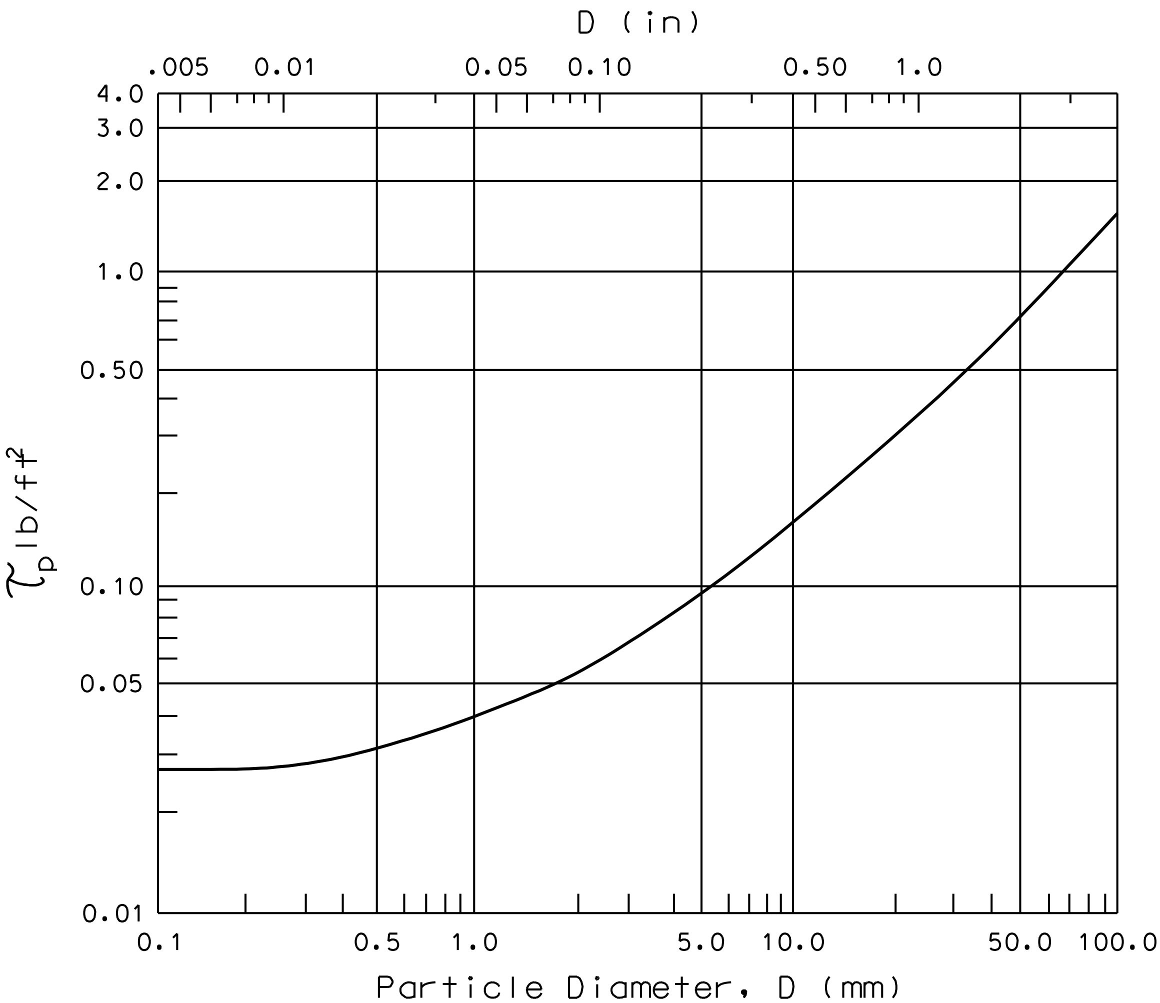
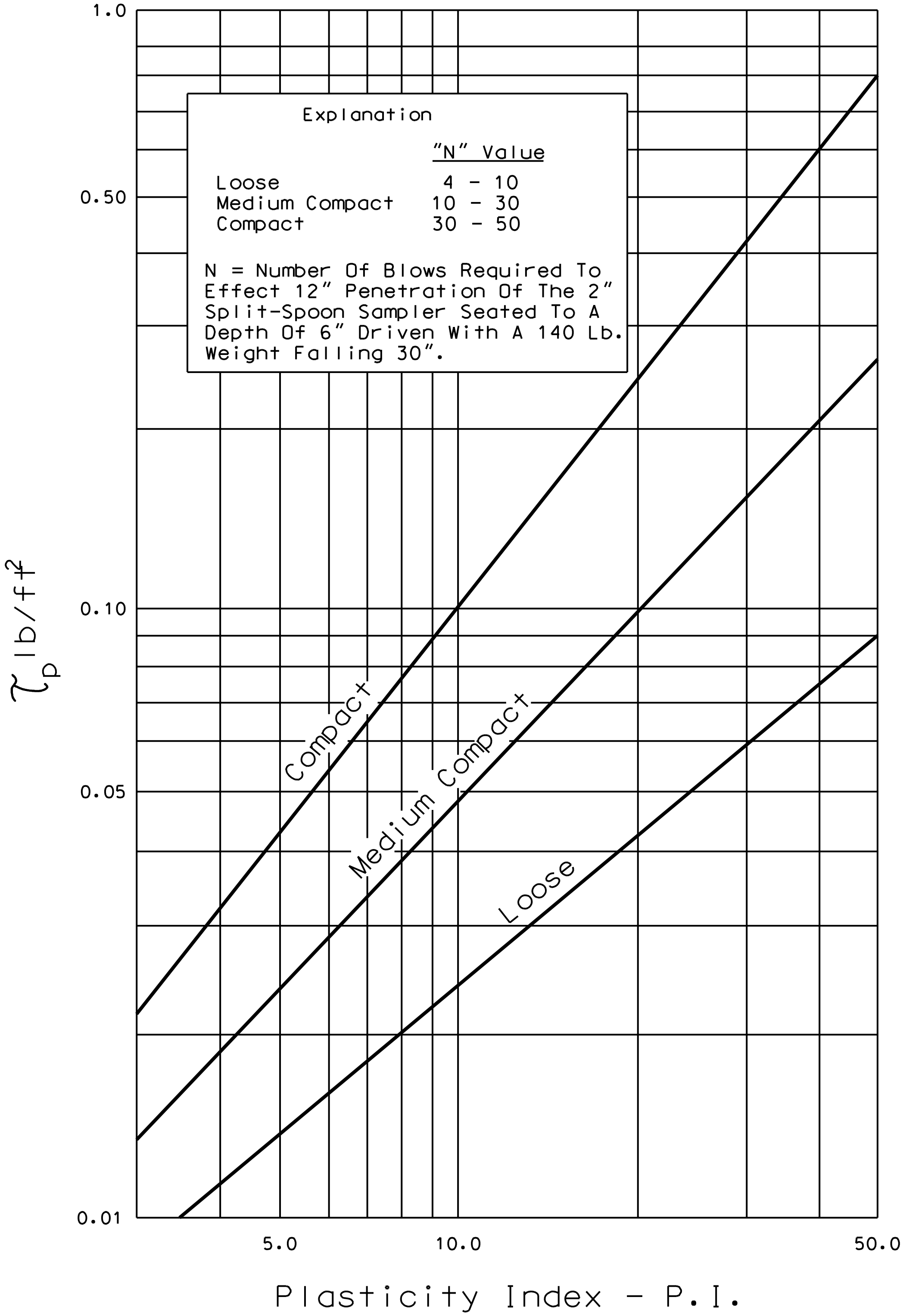


Figure 7-12 K_b Factor for Maximum Shear Stress on Channel Bends.



1 lb/ft^2 = 47.88 N/m^2 (Pascal)

Figure 7-13 Permissible Shear Stress for Non-cohesive Soils



1 lb/ft^2 = 47.88 N/m^2 (Pascal)

Figure 7-14 Permissible Shear Stress for Cohesive Soils

7.6.10 Documentation (Type A, Channel)

The following items shall be included in the documentation file (see Chapter 1, Section 1.6). The intent is not to limit data to only those items listed, but rather establish a minimum requirement consistent with the channel design procedures as outlined in this chapter. If circumstances are such that the design is prepared other than the normal procedures or is governed by factors other than hydrologic/hydraulic factors, then a narrative summary detailing the design basis shall appear with the other data:

The following items shall be included in the documentation file:

- Computations based on Section 7.6.9
- Channel configuration
- Complete watershed map
- Prepare report and file with background information