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16. Abstract

This manual provides hydraulic design methods for various types of flexible channel linings. The permanent linings include vegetation and dumped rock riprap. The temporary linings are fiber glass roving, jutemesh, excelsior mat, and erosionet. Properly designed flexible linings have a number of advantages which are also discussed in the manual.

Design charts and tables; computation sheets and examples; and sample specifications are provided in the manual.

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PREFACE

Erosion in highway drainage channels has been a problem for as long as highways have been built, at times causing damage to the highway, downstream sediment damage, and water pollution. A common solution is to pave channels with rigid linings such as portland cement concrete; however, many problems are inherent in the use of rigid linings.

This circular was developed to assist the designer in utilizing various types of flexible channel linings, including vegetation and dumped rock riprap. When properly designed, flexible materials have a number of advantages, including a natural appearance and self-healing qualities.

ACKNOWLEDGEMENTS

Many individuals have assisted in the development of the design material contained herein. Included are the researchers, Professors J. C. McWhorter of Mississippi State University, Alvin G. Anderson of the University of Minnesota and Allen L. Cox, Consulting Engineer, Baton Rouge, Louisiana (formerly with the Louisiana Department of Highways), who generously supplied information and advice. Appreciation is also due Herbert G. Bossy and others in the Federal Highway Administration (FHWA), Office of Research, who provided encouragement and ideas during the development of the design method. The channel lining design procedures developed by the Kansas, Vermont, and New York State Highway Departments also aided in the development of this circular.

The circular could not have been completed without the thoughts, assistance, and review provided by Frank L. Johnson, Dennis L. Richards, and Albert H. Lowe of the Hydraulics Branch, Office of Engineering, FHWA, and the support provided by the Demonstration Projects Division of Region 15, FHWA. Also appreciated are the valuable comments and recommendations of all the FHWA field offices and State highway departments who reviewed the draft publication.

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LIST OF SYMBOLS

A = Area of flow prism, sq.ft.

B = Bottom width of trapezoidal channel, ft.

D = Width of semicircular channel in bottom of trapezoidal channel, ft.

D_{50}, D_{85} = Particle size of gradation, of which 50 percent, 85 percent, etc., of the mixture is finer by weight, ft.

d = Depth of flow in channel, ft.

d_{adj} = Adjusted depth of flow, ft.

d_{max} = Maximum permissible depth of flow for a particular lining, channel slope, and soil erodibility, ft. If d_{max} is exceeded, it is likely that damage to the channel will occur.

K_1 = Ratio of maximum shear on sides of trapezoidal channel to maximum shear on bottom of trapezoidal channel.

K_2 = Ratio of critical shear on sides to critical shear on bottom of trapezoidal channel for noncohesive material.

K_3 = Ratio of maximum shear stress in bend to maximum bottom shear stress in straight channel.

K_3' = K_3 value for short bends.

n = Manning flow resistance coefficient.

P = Wetted perimeter of flow prism, ft.

Q = Flow rate, cfs.

R = Hydraulic radius, A/P, ft.

R_d = Radius of bend measured at mid-point of outer bank.

$$R_d = R_o + \left(\frac{T + B}{4}\right)$$

R_o = Mean radius of channel center line, ft.

S_o = Longitudinal channel slope, ft./ft.

T = Top width of flow prism, ft.

CT = Curve to tangent intersection for horizontal bend.

V = Mean channel velocity, ft./sec.

Z = Side slope; cotangent of angle measured from horizontal. $Z = \cot \phi$.

Δ = Internal angle of channel bend, degrees.

Δ_c = Internal angle of channel bend which differentiates between a short and a long bend, degrees.

ΔX = Incremental width of central portion of channel, ft.

Δy = Superelevation of the water surface in a bend, ft.

γ = Unit weight of water, lb./cu. ft.

θ = Angle of repose of rock riprap, degrees.

τ_b = Shear stress on bottom of channel, lb/sq. ft.

τ_c = Critical shear stress on channel boundaries, lb./sq. ft.

τ_{cb} = Critical shear stress on channel bottom, lb./sq. ft.

τ_{cs} = Critical shear stress on channel sides, lb./sq. ft.

τ_o = Average shear stress, lb./sq. ft.

τ_s = Shear stress on sides of channel, lb./sq. ft.

ϕ = Angle of side slope measured from horizontal, degrees.

Conversion Factors for British to Metric Units

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
feet/second	0.3048	meters/second
cubic feet/second	0.028317	cubic meters/second
pounds	0.453592	kilograms

LIST OF DESIGN CHARTS

U.S. DEPARTMENT OF TRANSPORTATION

Federal Highway Administration

DESIGN OF STABLE CHANNELS WITH FLEXIBLE LININGS

By

Jerome M. Normann

I. Introduction

One means of reducing erosion on the right-of-way during highway construction and operation is through the use of properly designed linings in drainage channels. Linings may be rigid, such as portland cement or asphaltic concrete, or flexible, such as vegetation or rock riprap.

Flexible linings of erosion resistant vegetation and rock riprap should be used whenever feasible. When vegetation is chosen as the permanent channel lining, it may be established by seeding or sodding. Installation by seeding usually requires protection by one of a variety of temporary lining materials until the vegetation becomes established.

While vegetation and rock riprap linings have been used for many years, in most cases the success or failure of the lining has been a matter of chance, and design information has been limited or difficult to apply. This circular presents design methods developed from recent research results for temporary linings, vegetative linings and rock riprap linings.

Flexible linings are generally less expensive to install than rigid linings, provide a safer roadside, and have self-healing qualities which reduce maintenance costs. They also permit infiltration and exfiltration, have a natural appearance, especially after vegetation is established, and provide a filtering media for runoff contaminants. Vegetative and rock riprap liners provide less improvement in conveyance over natural conditions and the resultant acceleration of flow volume and peak is less than with rigid liners.

Flexible linings do have the disadvantage of being limited in the depth of flow which they can accommodate without erosion occurring. As a result, the channel may provide a low capacity for a given cross-sectional area when compared to a rigid lining. Also limited right-of-way, unavailability of rock, or the inability to establish vegetation may preclude the use of flexible linings. In these instances, rigid linings may be the only alternative.

Rigid linings are generally quite smooth, so that they have a high capacity for a given cross sectional area due to low hydraulic resistance, and thus produce a high flow velocity. When properly designed and constructed, rigid linings will prevent erosion in steep or difficult channels where other linings cannot be used. They may also be used in areas where the channel width is restricted, since steep sidewall slopes may be constructed. So long as the rigid lining is intact, the underlying soil is completely protected upon construction of the lining.

However, rigid linings also have a number of inherent disadvantages. They are expensive to construct and maintain, have an unnatural appearance, prevent or reduce natural infiltration, and contribute to high velocities and scour at the downstream end of the lining unless roughness elements are added to slow the flow. Many rigid linings are destroyed due to flow undercutting the lining, channel headcutting, or hydrostatic pressure behind the channel walls or floor.

Rigid linings will be discussed briefly as related to the flexible lining materials. However, the hydraulic design of rigid linings is covered in detail in Hydraulic Design Series No. 3, "Design Charts for Open Channel Flow." (1)[1/]

The continued use of Hydraulic Engineering Circular (HEC) No. 11, "Use of Riprap for Bank Protection" (2), for the design of dumped stone riprap channel linings should be discouraged since the methods of this circular were based on more recent information. This recommendation is based on a detailed evaluation and comparison of the two methods. However, HEC No. 11 contains information and details on other rigid linings such as hand-placed riprap, sacked concrete and grouted riprap. Hand-placed riprap is considered to be a rigid lining since it cannot accommodate even minor movement of the surface it protects (2).

[1/] Numbers in parenthesis refer to references in Appendix A.

II. Background

Considerable research and development has been completed within the past few years on temporary lining materials and rock riprap. Combining that information with the applicable past research on vegetative linings results in methods which cover most types of flexible linings being used at present. An exception is that wire enclosed rock gabions are not covered herein because no appropriate design criteria is known to exist at present, possibly because they are a proprietary product. If such information becomes available, it can easily be inserted into this design circular.

A more detailed discussion of the development of the curves and design methods of this circular is presented in Appendix C.

Temporary Linings

Temporary linings are flexible coverings used to protect a channel until permanent vegetation can be established using seeding. For the most part, the materials used are biodegradable.

Research was completed at Mississippi State University (MSU) in 1968 (3) on bare soil and a variety of temporary lining materials for the Mississippi State Highway Department, under the Highway Planning and Research (HP&R) Program. Both the erosion prevention capability and hydraulic resistance of various linings were determined from the tests. The materials for which design information was produced were:

1. Bare soil - ten soils ranging from cohesive clays to non-cohesive sands and gravels.

2. Erosionet 315 - a paper yarn with openings approximately 7/8-inch by 1/2-inch. Normally used to hold other materials such as straw. Secured with steel pins.

3. Jute mesh - a woven mat of coarse jute yarn with openings about 3/8-inch by 3/4-inch. Held in place with steel pins.

4. Stranded fiber glass roving with Erosion 315 - fine glass fibers blown onto the channel bed using compressed air and a special nozzle, and held in place with steel pins and Erosionet (See No. 2 above).

5. 3/8-inch fiber glass mat - a fine glass fiber mat similar to furnace air filter material held in place with steel pins.

6. 1/2-inch fiber glass mat - same as No. 5 above, except thicker and more dense. May retard seed germination and vegetation growth.

7. Excelsior mat - dried shredded wood held together with a fine paper net and secured with steel pins.

8. Straw with erosionet - chopped straw held in place with Erosionet and steel pins.

A more complete description of each temporary lining material is presented along with the design charts. It should be ascertained that the lining material being considered for use is nearly the same as the material which was tested. Otherwise, the design charts are not applicable.

Note that the stranded fiber glass roving was held in place with Erosionet 315 in No. 4 above. This was due to the configuration of the test channels used by MSU, which were rectangular with smooth sidewalls. Additional research on fiber glass roving as a channel lining material was performed by the Louisiana Department of Highways as an HP&R study (4). The results on erosion prevention were based on actual field installations, while the hydraulic resistance results were from laboratory flume experiments. It was concluded that the fiber glass roving and asphalt should be applied at least 2 feet, measured along the slope, beyond the anticipated high water level to prevent the tractive force of the flow from pulling the liner from the side slopes of the channel. Naturally, this recommended type of installation was not possible during the MSU tests in rectangular channels with smooth sidewalls.

The Louisiana results include some limited field observations of jute mesh channel linings which compare well with the MSU results on the same material, and tend to confirm the design charts of this circular.

The basic design method used in this circular, maximum permissible depth of flow, was developed as a part of the MSU research, and will be discussed in detail in the next section of this circular.

Vegetative Linings

The classic tests on vegetative linings were performed by Palmer, Law, and Ree of the Soil Conservation Service (SCS) and are summarized in the publication, Handbook of Channel Design for Soil and Water Conservation (5). For compatibility with the methods of this circular, those results, in terms of maximum permissible velocity, have been converted to maximum permissible depth curves for selected grasses. The hydraulic resistance curves for vegetation from the SCS report have been incorporated into this circular without revision.

Bermuda grass sod, with a grass length of 2-1/2 inches was tested by MSU in their vertical sidewall channels (3). The sod seemed to work as well as established grass when compared with the SCS test results (5). Thus, sodding provides the immediate protection of an established vegetative lining, provided the installation is properly performed and gaps do not exist between sod strips.

Rock Riprap Linings

A design procedure for rock riprap channel linings was developed by Anderson at the University of Minnesota as a part of a National Cooperative Highway Research Program (NCHRP) study under the sponsorship of the American Association of State Highway and Transportation Officials (AASHTO) (6). Empirical erosion prevention and hydraulic resistance information was developed based on a survey of results in the literature and that information was incorporated into a new design procedure for triangular and trapezoidal channels. Verification of the method was performed in rectangular laboratory channels and through field observations of four installations discussed in the field evaluation report on the above NCHRP study (7). All of the test installations were performing adequately as of June 1973. The design techniques of NCHRP Report 108 were modified slightly herein to conform with the concept of maximum permissible depth of flow, as used in this circular. Methods similar to those of NCHRP Report 108 for design of riprap on side slopes and a procedure for designing the granular filter blanket for riprap linings are contained in this circular. Criteria for plastic filter cloth design and a new procedure for design of channel protection in bends are also included.

Colorado State University (CSU) has under development a riprap design method which applies not only to channel linings but also to riprap design at bridge abutments and other channel discontinuities (8). However, from preliminary evaluation it does not appear that results from the CSU method will differ appreciably from the methods of this circular, assuming uniform, developed channel flow. When the flow is rapidly varied, as when discontinuities such as bridge abutments disrupt the flow, the methods of this circular should not be used.

III. Design Concepts

The basic design method presented in this circular is based on the concept of maximum permissible depth of flow, coupled with the hydraulic resistance of the particular lining material. In all cases, the lining material defines the hydraulic resistance of the channel while providing its own peculiar degree of erosion protection.

Erosion Prevention

The d_{max} charts are used to define the maximum permissible depth of flow for a particular lining, based on channel slope, S_o, and the erodibility of the underlying soil. The maximum permissible depth concept is based on the tractive force theory of channel lining design. Tractive force, basically, is the shear stress exerted by the flow on the channel perimeter. For wide channels of any shape, and for a given channel slope, depth, and lining, the vertical velocity distribution in the central and deepest section, where wall effects are negligible, should be identical. Also, the first scour occurs at the deepest portion of the channel, since the wall or bottom shear stress is greatest in that portion.

If the depth of flow, channel slope, lining, and soil are the same in all channels shown in Figure 1, then the flow rate and the mean channel velocity for the three channels will be different, but in the central section of the channels, represented by ΔX, the vertical velocity distribution and bottom shear stress will be nearly identical. Therefore, in these channels, there exists a limiting depth of flow above which scour will occur, and this depth, d_{max}, is the same for all wide channels of the same longitudinal slope, lining, and underlying soil. Of course, any depth of flow less than d_{max} is noneroding.

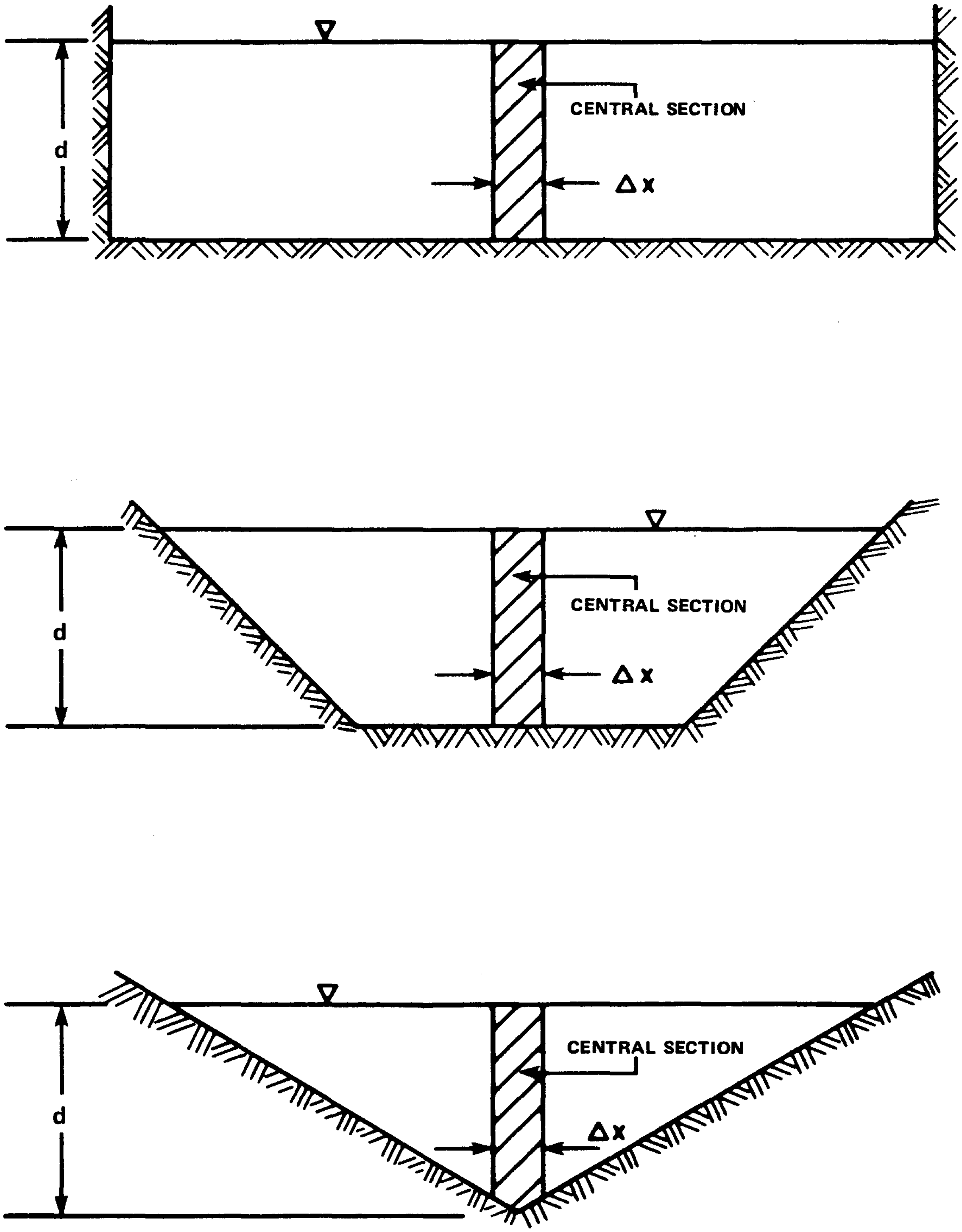


Figure 1. SCHEMATIC DIAGRAM OF CHANNELS OF DIFFERENT SHAPES

This concept is verified by the MSU tests (3), the Louisiana Department of Highway tests (4), and the empirical equations from NCHRP Report 108 (6). For most lining materials, the erodibility of the underlying soil is a design parameter. For rock riprap channel linings, the underlying soil is not a consideration because a properly designed filter blanket should be used, as necessary, to prevent leaching of the underlying soil through the riprap. Design of the filter blanket will be discussed in a latter section of this circular. The SCS results on maximum permissible velocity for vegetative linings can be transformed into permissible depth curves by the method explained in Appendix C.

The erodibility of cohesive soils has thus far eluded quantitative definition. It is suggested that the erodibility of specific soils be based on the designer's experience rather than any quantitative analysis based, for example, on the plasticity index. The difficulties involved in defining the erodibility of cohesive soils is well described by Partheniades (9). Based on the MSU work, which covered ten soils of different characteristics, soils with a gravel, sand and clay mixture are erosion resistant; fine-grained sands or silts are erodible; and plastic and semi-plastic soils are in the intermediate range. The soil erodibility index (K) for the Universal Soil-Loss Equation, developed by the Agricultural Research Service, could also be used as a guide to soil erodibility. For example, in Maryland, all soils have been assigned K values of from 0.17 to 0.49 (10). A soil with a K value of 0.17 would be considered erosion resistant, while a soil with a K value of 0.49 would tend toward the erodible classification. These K determinations by the Soil Conservation Service are subjective for the most part, but they give the designer some basis for his appraisal of a particular soil.

Another source of information on the erodibility of the soils in a particular area are the county soil reports published in many areas of the country by the Soil Conservation Service. These reports often describe the erodibility of the various soils in a particular location with enough detail to make an estimate for the site under consideration.

If the designer has no knowledge of the erodibility of the soil at a particular channel site, a reasonable estimate of d_{max} may be obtained by interpolating half-way between the "erosion resistant" and "erodible" lines of the maximum permissible depth charts (except Chart 27 for rock riprap, where no range is given because the underlying soil has no influence on the erosion resistance of the riprap lining).

Hydraulic Resistance

The flow velocity charts were developed to define the relationship between the hydraulic radius of the channel, R, longitudinal slope of the channel, S_o, and mean channel velocity, V, for a given channel lining. For some linings, such as rock riprap of a given size and fiber glass roving tacked with asphalt, the Manning equation may be used since the n value is essentially constant. For rock riprap, the Manning n value varies with mean stone size, as follows (6):

$$n = 0.0395 \, D_{50}^{1/6}$$

Thus, the following n values apply for common stone sizes:

D_{50} (ft.)	n
0.25	0.0314
0.50	0.0352
0.75	0.0377
1.00	0.0395
1.50	0.0423

For fiber glass roving tacked with asphalt, Cox (4) found that the Manning n value was approximately a constant:

	Smooth Rolled Channels	Channels with Clods and Tracks
Single layer	0.030	0.035
Double layer	0.020	0.025

The higher values of n were used in the development of Charts 5 and 6, assuming that most highway channels will be rather rough after seeding and mulching.

For the other channel linings, Manning n values were found to vary with slope and hydraulic radius, therefore, empirical curves were developed to represent the data. Equations are shown on the respective charts for the unlined channel and the temporary channel linings. For the vegetative linings of various retardances, curves were taken directly from the SCS Handbook (5). Retardance is the hydraulic resistance relationship for a certain group of grasses of given lengths as defined by the SCS (See Appendix C). Retardance A refers to grasses of high hydraulic resistance, such as 30-inch Weeping lovegrass, while Retardance E refers to grasses of very low hydraulic resistance, such as 1.5-inch Bermuda grass.

Channel Geometry

After the maximum permissible depth of flow has been defined, it is necessary to relate that depth to the area and hydraulic radius of the flow prism for a specific channel geometry. There are a variety of methods of defining those relationships, ranging from direct computation to channel geometry plots, such as Chart 1 of this circular. Chart 1 was developed for trapezoidal channels, but similar graphs could be developed for other geometries, such as parabolic channels. Tables of geometry and the appropriate equations for a variety of channel shapes are given in the MSU report (3). Equations from the MSU report for channels of various shapes are included in Appendix B.

Rigid Channel Linings

For rigid channel linings, such as concrete or soil cement, there is no maximum permissible depth for the flow velocities normally encountered in highway drainage work, since no erosion can occur. Thus, the maximum flow depth is based only on the freeboard requirement for the channel. The Manning equation may be solved by trial and error for designing these channels or charts similar to those in HDS No. 3 (1) can be used. One such chart is shown as Chart 35, developed for a trapezoidal concrete channel with a bottom width of 4 feet, 4:1 side slopes, and a Manning n of 0.013.

Design Flow Rate

The design flow rate for roadside and median drainage channel linings is usually one having a 5- or 10-year recurrence interval. If a vegetative lining is feasible, and a temporary lining is to be used during the establishment period, a lower recurrence interval flow might be considered for the design of the temporary lining than for the vegetative lining.

This is because the risk of damage to the temporary lining during this relatively short time is quite low, and if the lining is damaged, repairs are usually inexpensive.

Selection of the design flow rates should be based on analysis of the cost of the lining and the damages incurred should the channel lining fail. If available channel linings are found to be inadequate for the selected design flow rate and inlet spacing, it may be feasible to decrease the inlet spacing to intercept more flow and reduce the flow rate to a manageable level.

Channel Bends

Flow around a bend in an open channel creates secondary currents which impose higher shear stresses on the channel sides and bottom than are found in straight channel reaches. According to Anderson (6), the location of the maximum shear varies to such an extent that it is not possible to define the exact points where additional erosion protection is required.

In order to protect the bend against scour, it may be necessary to use another lining material or, if rock riprap is used, adjust the rock size. To determine the modifications necessary, a correction factor varying linearly from 1 to 4 as a function of V^2/R_d (Chart 33) is applied to the design depth of flow in the straight channel reach to obtain an adjusted depth of flow, d_{adj}. V is the mean upstream channel velocity and R_d is the average radius of the outside bank of the bend as shown in Figure 2.

$$R_d = R_o + \left(\frac{T + B}{4}\right)$$

where: R_o = mean radius of the center line of the channel, ft.

T = top width of the channel, ft.

B = bottom width of the channel, ft.

For channels with no defined bottom width, such as triangular or parabolic channels, set B equal to zero.

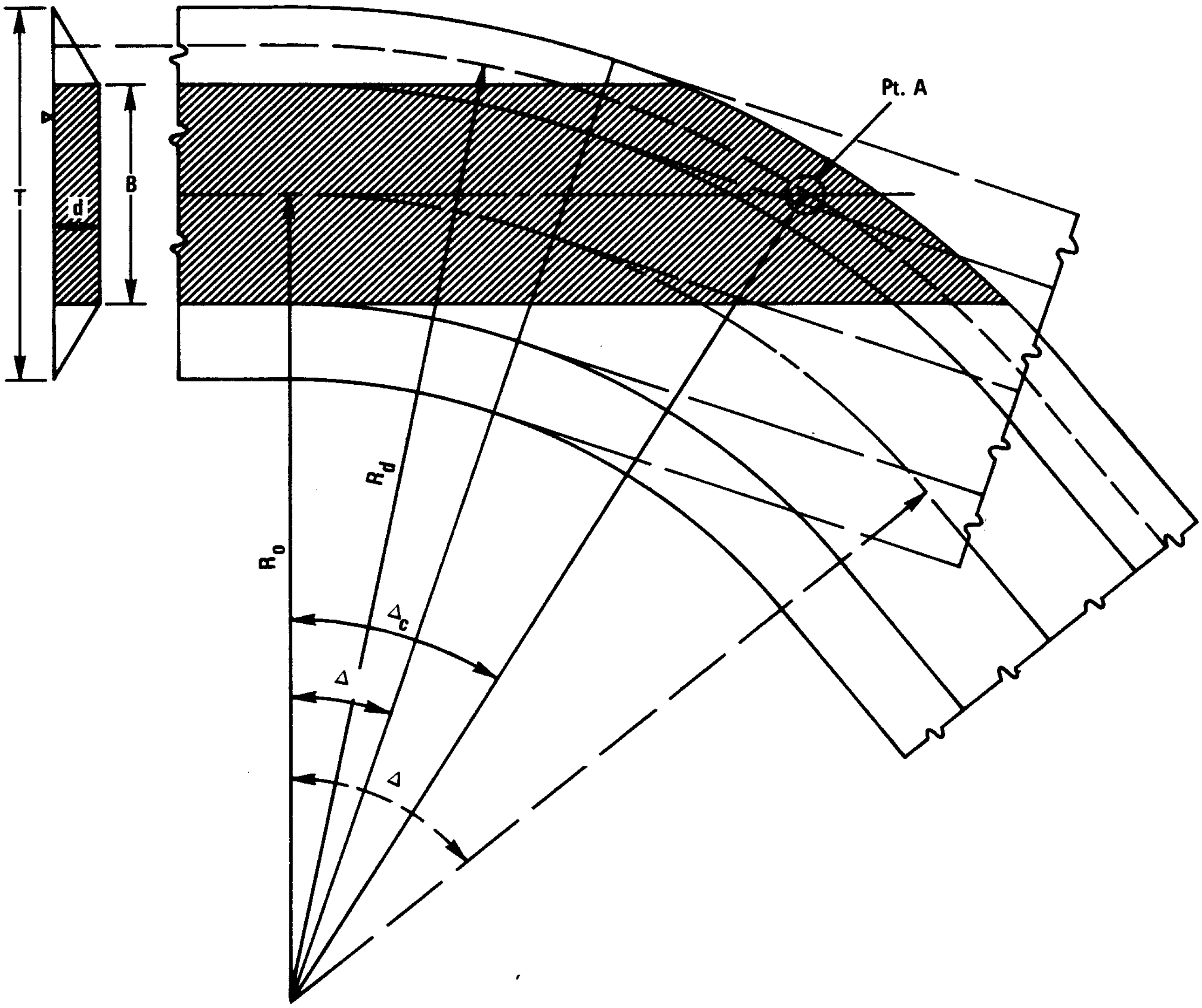


Figure 2. **DEFINITION SKETCH FOR FLOW IN BENDS**

Channel Side Slopes

For purposes of safety, construction, maintenance, and erosion resistance, it is suggested that channel side slopes be kept as flat as possible. Ideally, side slopes should be 3:1 or flatter for erosion resistance. Still flatter slopes may be necessary for safety or other reasons.

Analysis of the NCHRP Report No. 108 riprap design method demonstrates that if a riprap lined channel has 3:1 or flatter side slopes, there is no need to check the sides for scour. With steeper side slopes, the combination of velocity against the stone and gravitational effects may dislodge the stone on the sides before the channel bottom is disturbed.

The SCS (5) recommends maximum 3:1 to 4:1 side slopes on vegetative lined channels for ease of construction, mowing, and crossing the channel with equipment. In the Louisiana research (4), eroded field test channels were reconstructed with side slopes no steeper than 3:1. Therefore, all design charts are for channels with side slopes of 3:1 or flatter. For rock riprap, a method of designing steeper side slopes is presented in the Design Procedures Section.

Channel Freeboard

Channel freeboard should be evaluated based on the consequences of overflow of the channel banks. In a usual situation, about one foot of freeboard, measured vertically should be adequate for small drainage channels, although in some cases more should be used and in some cases no freeboard is necessary. When freeboard is provided, the depth of flow may exceed d_{max} and then scour of the channel will occur.

Most lining materials should extend to the top of the bank or at least two feet above the design water level, measured along the slope.

In large channels, wave height may define freeboard requirements. Wave height determinations are beyond the scope of this circular.

In bends, superelevation of the flow surface may occur on the outside bank, which may be estimated by the equation:

$$\Delta y = \frac{V^2 T}{g R_o}$$

where:
Δy = superelevation of the water surface, ft.
V = mean velocity, fps
T = surface width of the channel, ft.
g = gravitational acceleration, 32.2 ft/sec^2
R_o = mean radius of the bend, ft.

Δy must be considered in selecting channel freeboard for the outside bank.

IV. Design Procedures

This section outlines the design procedure for flexible channel linings and the design procedures for providing protection for channel bends and for channels with steep side slopes.

Flexible Lining Design

The design consists of the following steps:

1. Perform hydrologic computations.
2. Select design flows for permanent lining material and for temporary linings.
3. Estimate soil erodibility.
4. Define channel shape, slope, and maximum top width.
5. Select least costly permanent lining material available.
6. Determine d_{max} for the selected lining, slope, and soil erodibility from the Maximum Permissible Depth Charts.
7. Determine hydraulic radius, R, and area, A, for the selected channel geometry and d_{max}. (Chart 1 or calculations).

8. Determine velocity from R and slope, S_o, from the Flow Velocity vs. Hydraulic Radius Charts.

9. Allowable Q = AV.

10. If the allowable Q is much greater than the design Q, the channel is overdesigned. If Q is less than the design Q, the lining is inadequate. In either case, select another channel size and return to step 5 or select another lining material and return to step 6. Also, consider the feasibility of additional inlets to reduce the flow in the channel.

11. If a grass lining is the choice from the above computations, and it is desired to use a temporary lining material for channel protection during the period of grass establishment, perform steps 6, 7, 8 and 9 using the channel bottom width and side slopes for the grass lined channel with the selected temporary lining material and flow rate. The most stable temporary lining material is a double layer of fiber glass tacked with asphalt; however, this lining may retard vegetation germination and growth.

A computation sheet, shown in Figure 3, has been developed to facilitate the above design procedure using the charts of this circular.

Steep Side Slope Protection

When channel side slopes are steeper than 3:1, and rock riprap is chosen as the channel lining, the channel sides may become unstable. To design riprap for the channel sides, use the following procedure based on charts from NCHRP Report 108 (6):

1. Determine the size of rock required for the channel bottom from the procedure outlined previously.

2. From Chart 30, determine the angle of repose for the bottom rock size and shape.

3. From Chart 31, determine K_1, the ratio of maximum side shear to maximum bottom shear for a trapezoidal channel, based on B/d and side slope, Z.

4. From Chart 32, determine K_2, the ratio of critical shear on the side to critical shear on the channel bottom, based on side slope and the stone angle of repose.

5. The required D_{50} for the side slopes is K_1/K_2 times D_{50} for the bottom.

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

Bend Protection

There are two design situations: long bends, $\Delta \geq \Delta_c$, and short bends, $\Delta < \Delta_c$, where Δ is the internal angle of the channel bend and Δ_c is the internal angle which differentiates between a short and a long bend. Determine which condition exists by computing Δ_c and comparing this value with Δ.

$$\Delta_c = \text{arc cos } \frac{R_o}{R_d}$$

If $\Delta \geq \Delta_c$, use the long bend procedure.

If $\Delta < \Delta_c$, use the short bend procedure.

Long Bend Procedure

1. Determine the design depth of flow, d, in the straight channel reach.

2. From Chart 33, obtain K_3 based on the ratio V^2/R_d.

3. The adjusted depth of flow, d_{adj}, for which the lining must be designed is K_3 times the design depth for the straight reach.

$$d_{adj} = K_3 (d)_{straight}$$

4. Determine lining and/or rock size for d_{adj}, slope, and soil erodibility from the Maximum Permissible Depth Charts.

Short Bend Procedure

1. Determine the design depth of flow, d, in the straight channel reach.
2. From Chart 33, obtain K_3 based on the ratio V^2/R_d.
3. From Chart 34, obtain K_3' based on the ratio Δ/Δ_c or obtain K_3' from the equation

$$K_3' = 1 + [(K_3 - 1) \frac{\Delta}{\Delta_c}]$$

4. The adjusted depth of flow, d_{adj}, for which the lining must be designed is K_3' times the design depth of flow for the straight reach.

$$d_{adj} = K_3' (d)_{straight}$$

5. Determine lining and/or rock size for d_{adj}, slope, and soil erodibility from the Maximum Permissible Depth Charts.

For the condition where both the sides and the bottom of the channel are to be protected and the channel is narrow (width to depth ratio less than 10), additional protection should be provided for all surfaces. For the condition of wide rivers (width to depth ratio greater than 10) where only the banks are to be protected, generally only the outside bank of the bend should have additional protection. This increased protection should extend both upstream and downstream from the points of curvature to a point where near uniform flow conditions occur in the channel. For very sinuous, high velocity channels where waves can be diverted across the channel to the inside bank or where return of overbank flow can create scour problems, both banks (inside and outside) should have additional protection.

Figure 3

DRAINAGE CHANNEL LINING DESIGN

DATE: ____________

PROJECT: ____________________________________ DESIGNER: ____________

STATION ____________ TO STATION ____________

DRAINAGE AREA = ________________ ACRES

HYDROLOGIC COMPUTATIONS:

DESIGN FLOW: Q ____ = ________ cfs

DESIGN FLOW FOR TEMPORARY LINING: Q ____ = ________ cfs

SOIL ERODIBILITY: ________________________

CHANNEL DESCRIPTION: MAX. TOP WIDTH = ____________ ft.

S_o = ________________

AVAILABLE LININGS:

LINING	d_{max}	B	$\frac{d_{max}}{B}$	$\frac{A}{Bd}$	A	$\frac{R}{d}$	R	V	Q=AV	T	REMARKS

V. Composite Channel Lining Design

The methods of this circular may be used for the design of channels lined with more than one material. The most common composite channel is a grass lined channel with a concrete lining in the channel bottom. The smooth concrete liner greatly increases the capacity of the channel, while the grass lined channel sides provide freeboard.

The junction of two materials with different resistance to flow is critical due to the development of secondary currents at the shear zone. Such junctions should be carefully installed, and d_{max} for the weaker material should be chosen conservatively.

VI. Design Charts

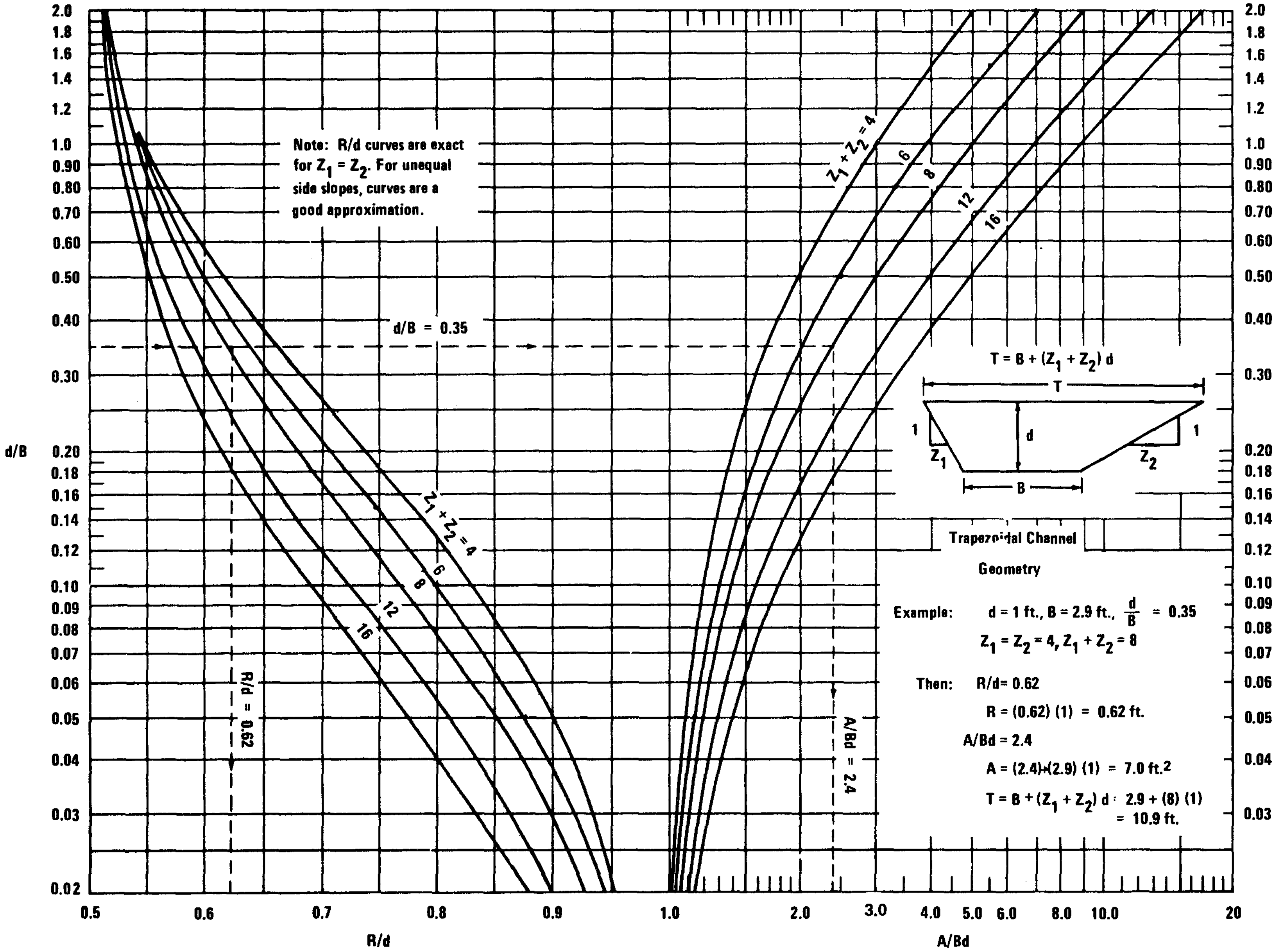
The following design charts comprise the figures to determine the maximum permissible depth of flow (d_{max}- S_o Charts) and the hydraulic resistance (V - R Charts) for the various lining materials. In addition, there are design charts for rock riprap lined channels with side slopes steeper than 3:1 and with bends, and one example capacity chart for a concrete lined trapezoidal channel.

Preceding the design charts is a brief description of each lining material. The descriptions are not meant to be complete specifications; however, they should be adequate for the designer to determine whether the lining material for which the design curves have been prepared is the same as the material available to him. If the material is significantly different, the design charts of this manual should not be used.

Channel Geometry

Chart 1 is an illustrative example of a geometric design aid for trapezoidal channels, either symmetrical or unsymmetrical. Similar charts may be developed for other channel geometries such as parabolic channels. Geometric tables and the equations for a variety of channel shapes are given in the MSU report (3) and Appendix B.

Chart 1



Note: R/d curves are exact for $Z_1 = Z_2$. For unequal side slopes, curves are a good approximation.

Example: d = 1 ft., B = 2.9 ft., $\frac{d}{B}$ = 0.35

$Z_1 = Z_2 = 4, Z_1 + Z_2 = 8$

Then: R/d= 0.62

R = (0.62) (1) = 0.62 ft.

A/Bd = 2.4

A = (2.4)·(2.9) (1) = 7.0 ft.^{2}

T = B + $(Z_1 + Z_2)$ d = 2.9 + (8) (1) = 10.9 ft.

TRAPEZOIDAL CHANNEL GEOMETRY

Unlined Channels

The design charts for unlined channels (bare soils) are based on MSU tests on ten different classes of soils ranging from cohesive clays to noncohesive sands and gravels. The d_{max} - S_o curves are drawn to encompass the majority of the data points. Generally, sandy, noncohesive soils tend to be very erodible, the large grained gravel-clay-silt mixtures are erosion resistant, and the mixtures of sand, clay, and colloids are moderately erodible. More detail on the soils tested may be found in the MSU report (3).

Fiber Glass Roving

Fiber glass roving is delivered as a lightly bound ribbon of continuous glass fibers. The material is applied to the channel bed using a special venturi nozzle driven by an air compressor, which separates the fibers and results in a web-like mat of glass fibers. The glass fibers are tacked with asphalt for adhesion to each other and to the soil.

The single layer of fiber glass roving consists of one layer of blown fiber glass fibers applied at a minimum rate of 0.25 pound per square yard tacked with asphalt emulsion or asphalt cement at a minimum rate of 0.25 gallon per square yard.

The double layer application consists of two alternating layers of fiber glass and asphalt, each layer consisting of fiber glass roving at 0.25 pound per square yard and asphalt of 0.25 gallon per square yard.

Jute Mesh

Jute mesh is a mat lining woven of jute yarn which varies from 1/8- to 1/4-inch in diameter. The mat weighs approximately 0.80 pound per square yard, with openings about 3/8-inch by 3/4-inch.

Steel pins or staples are used to hold the jute mesh in place. A typical stapling configuration is shown in Figure 4. The pins or staples should be spaced not more than 3 feet apart in 3 rows for each strip, with one row along each edge and one row alternately spaced in the center. At the overlapping edges of parallel strips, staples should be spaced at 2 feet or less. At all anchor slots, junction slots, and check slots, spacing should be 6 inches or less.

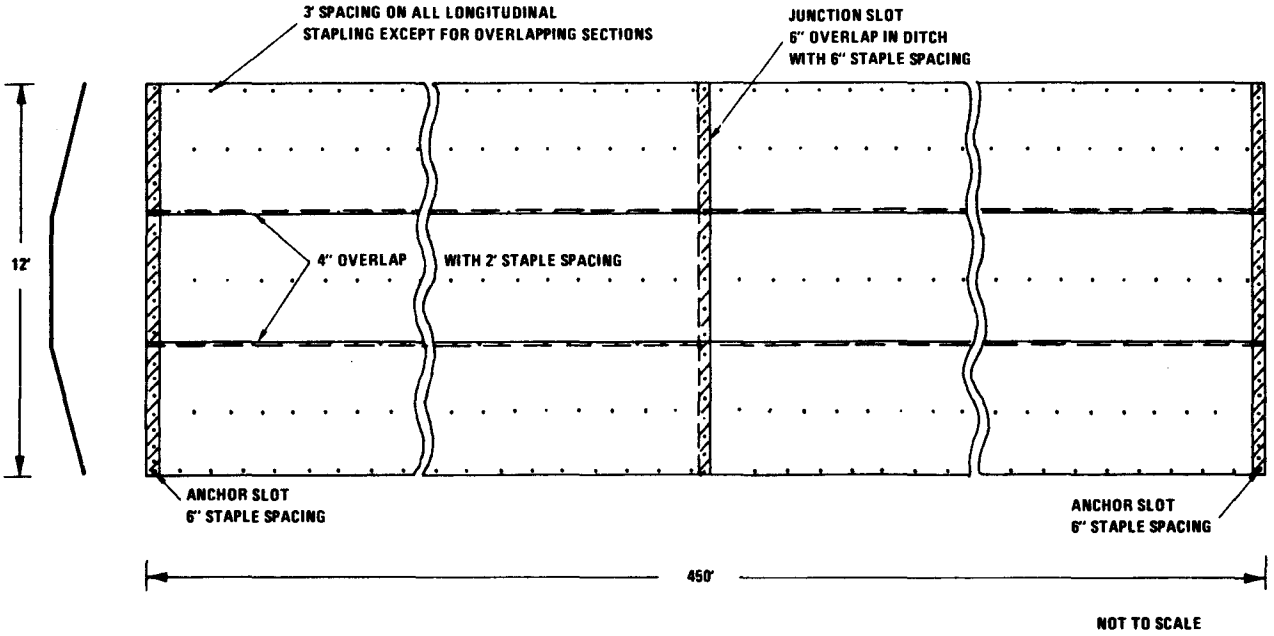


Figure 4. **STAPLING CONFIGURATION FOR JUTE MESH**

Excelsior Mat

Excelsior mat is composed of 0.8 pound per square yard of excelsior (dried, shredded wood) covered with a fine paper net covering. The paper net, reinforced along the edges, has an opening size of approximately 1/2-inch by 2 inches. The mat is held in place by steel pins or staples at the rate of 5 staples per 6 linear feet of mat, with two staples along each side and one in the middle. At the start of each roll, 4 or 5 staples are spaced approximately one foot apart. Where more than one mat is required, the mats are butt-joined and securely stapled.

Straw and Erosionet

This lining consists of straw applied at a rate of 3 tons per acre (1.25 pounds per square yard). The straw is covered with Erosionet 315 (See description following).

This lining is pinned in the same manner as jute mesh, as shown in Figure 4.

3/8-inch Fiber Glass Mat

This lining is a fine, loosely woven glass fiber mat similar to furnace air filter material. It has a weight of 0.11 pound per square yard. This material is not to be confused with more dense fiber glass mats used to eliminate plant growth.

Steel pins or staples are placed at the rate of 5 staples per 6 linear feet of mat, with two staples along each side and one in the middle. At the start of each roll 4 or 5 staples are spaced approximately one foot apart. Where more than one mat is required, the mats are butt-joined and securely stapled.

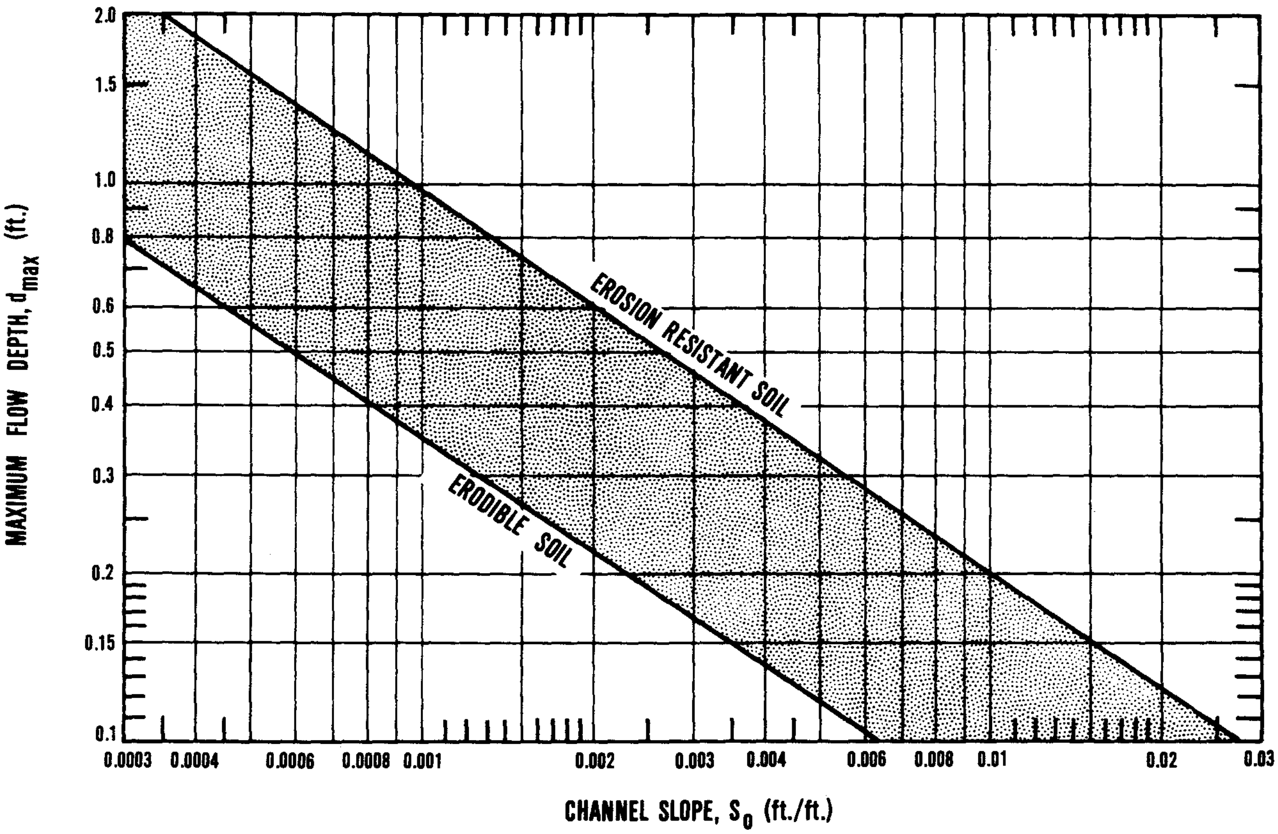
1/2-inch Fiber Glass Mat

This lining is a fine, loosely woven glass fiber mat, similar to but denser than the 3/8-inch fiber glass mat, as it weighs 0.35 pound per square yard. The stapling procedure is the same as for the 3/8-inch fiber glass mat.

Erosionet 315

Erosionet is a paper yarn approximately 0.05 inch in diameter, woven into a net with openings approximately 7/8-inch by 1/2-inch. The material has little erosion prevention capability in itself, and is generally used to hold other lining material in place.

Erosionet weighs about 0.20 pound per square yard, and is pinned in the same manner as jute mesh, shown in Figure 4.



MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR UNLINED CHANNELS (BARE SOIL)

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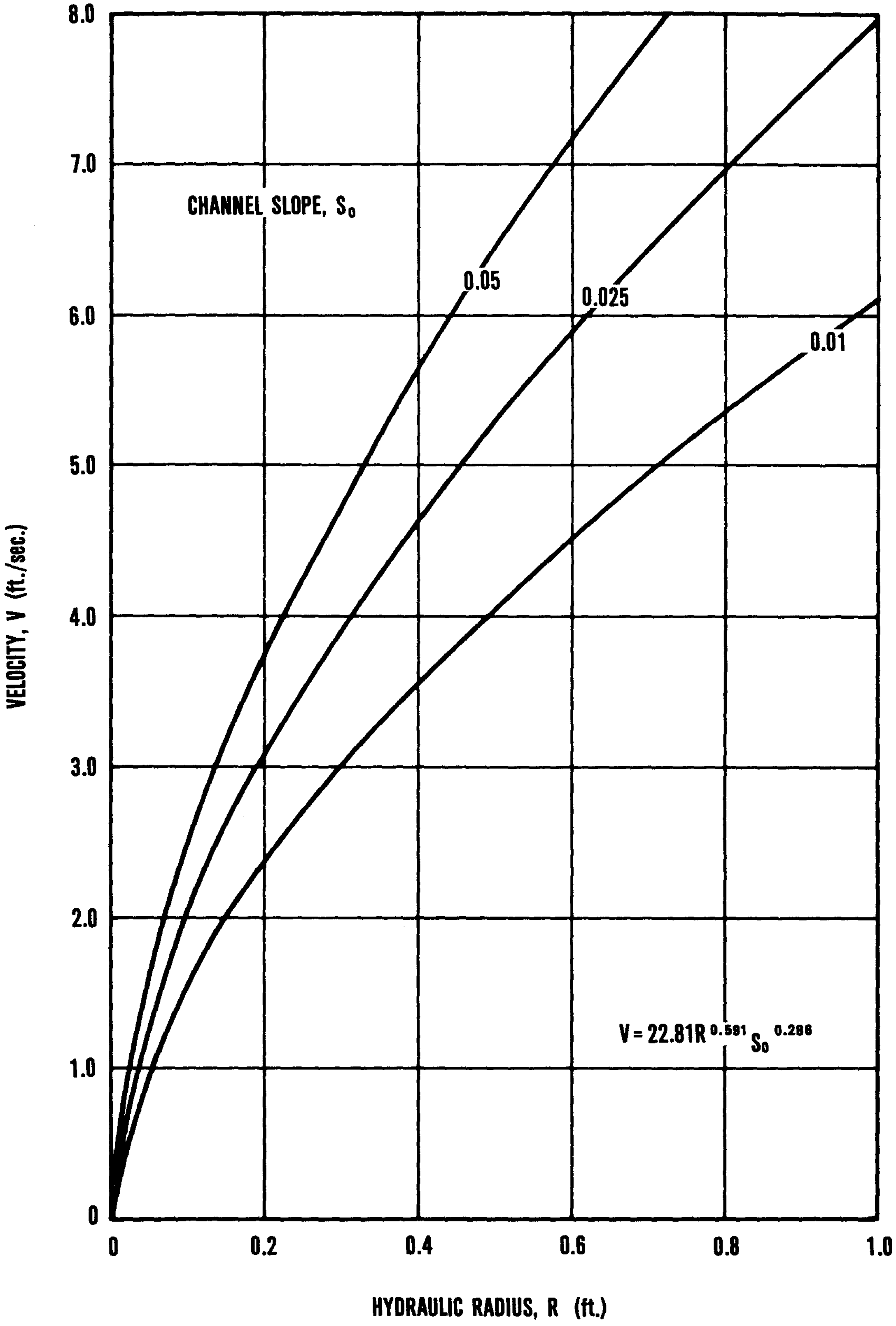
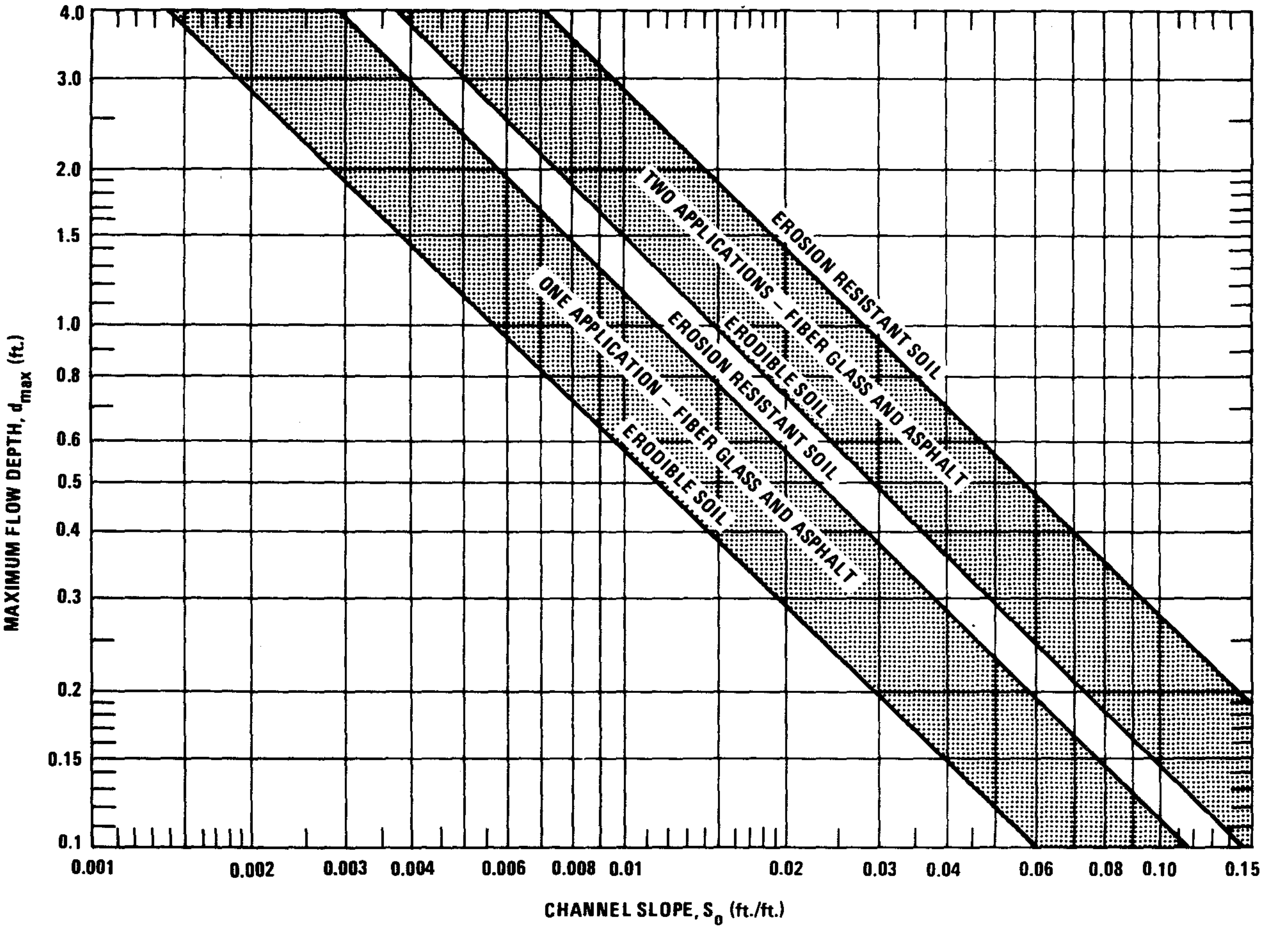
Chart 3

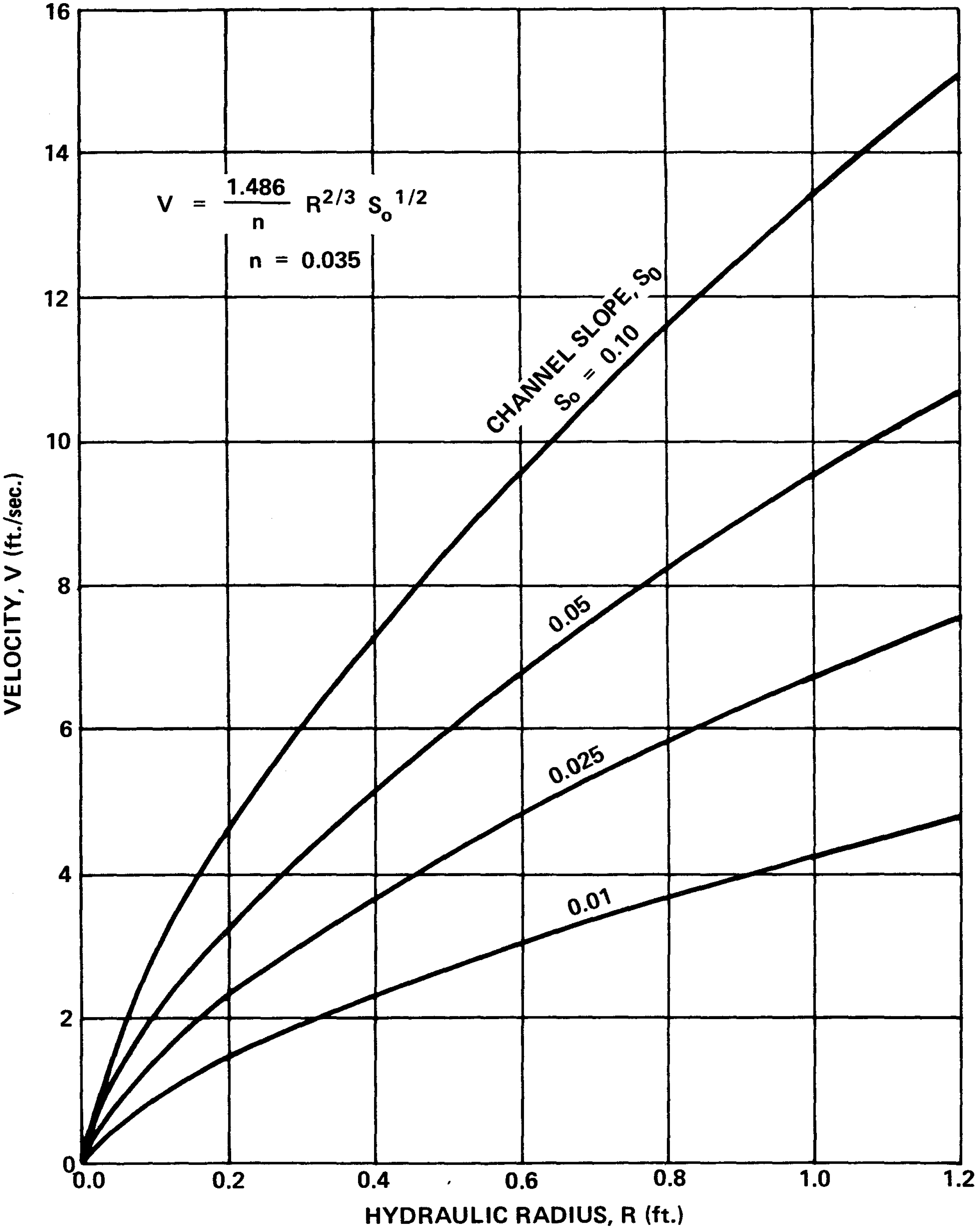


FLOW VELOCITY FOR UNLINED CHANNELS (BARE SOIL)

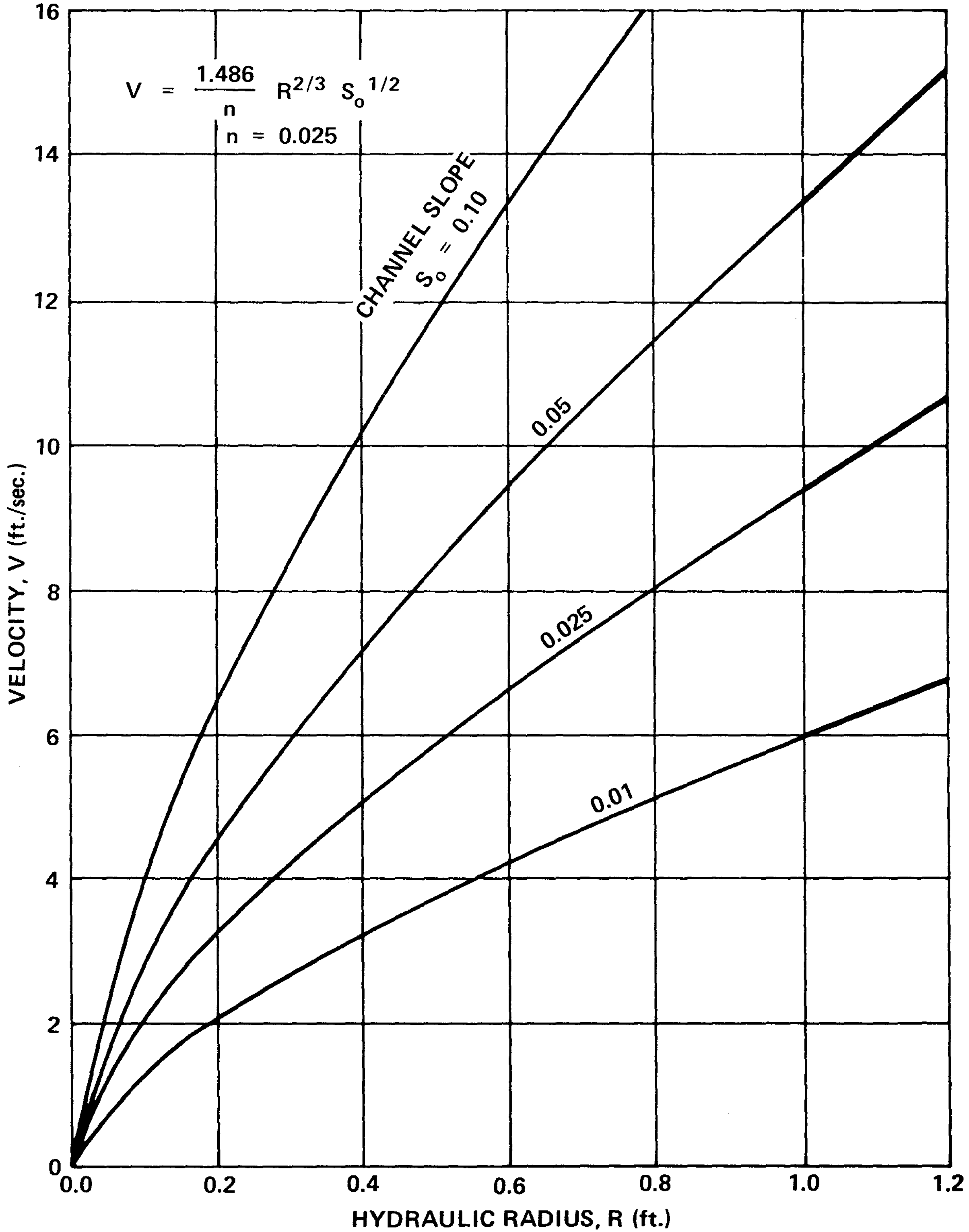


MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH FIBER GLASS ROVING (SINGLE AND DOUBLE LAYER)

Chart 5

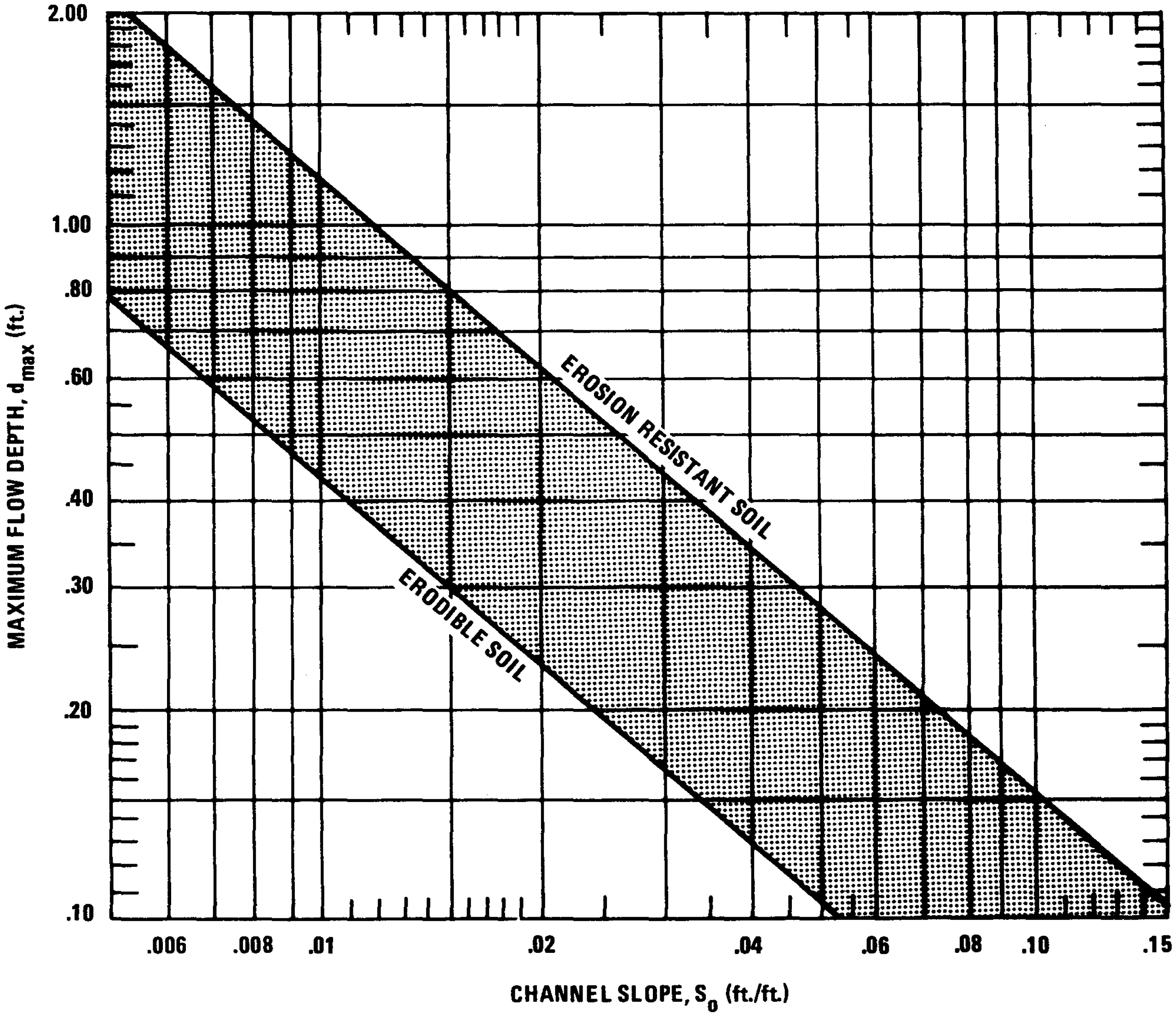


FLOW VELOCITY FOR CHANNELS LINED WITH FIBER GLASS ROVING TACKED WITH ASPHALT,SINGLE LAYER



FLOW VELOCITY FOR CHANNELS LINED WITH FIBER GLASS ROVING TACKED WITH ASPHALT, DOUBLE LAYER

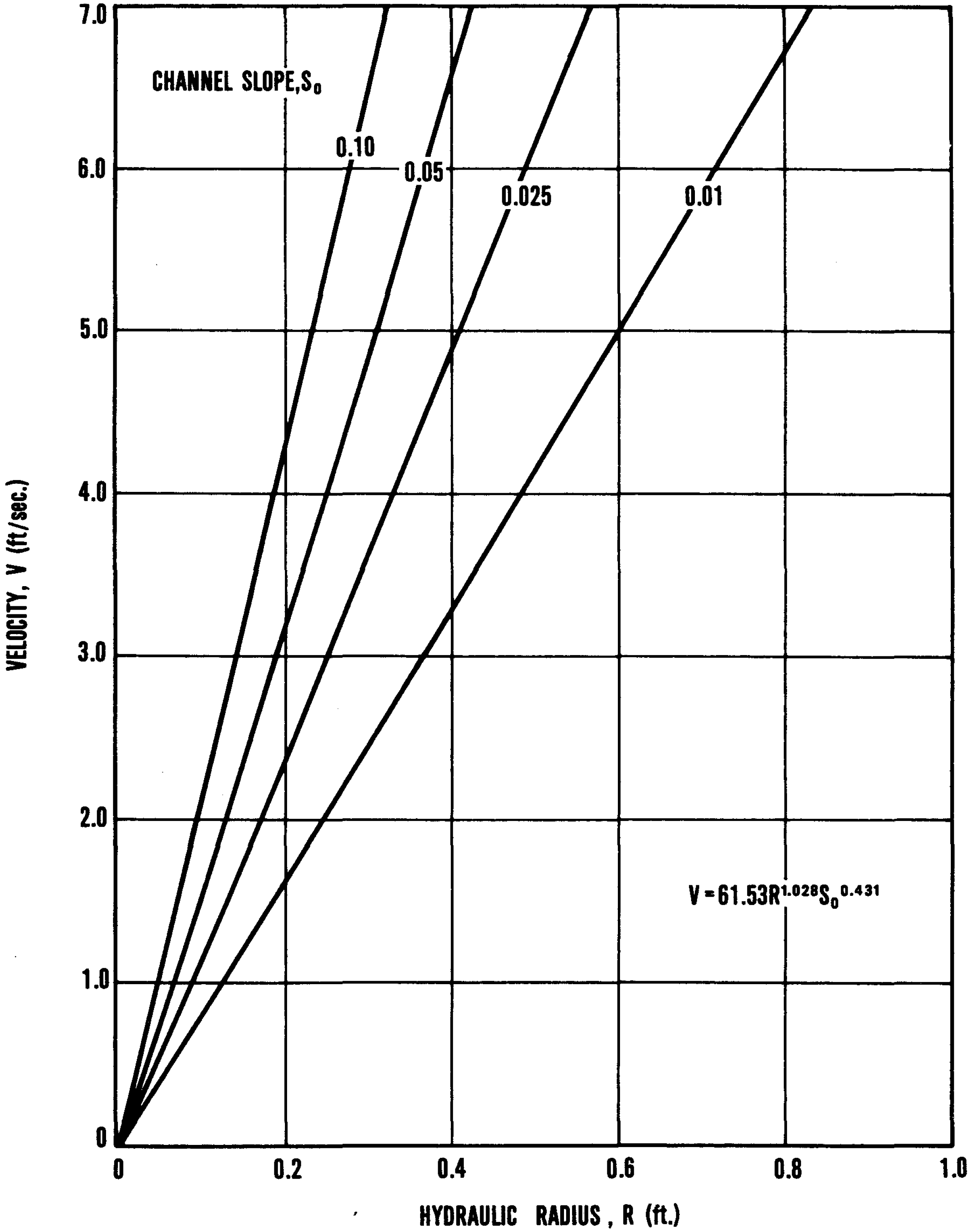
Chart 7



From Mississippi State University Report

"Erosion Control Criteria for Drainage Channels"

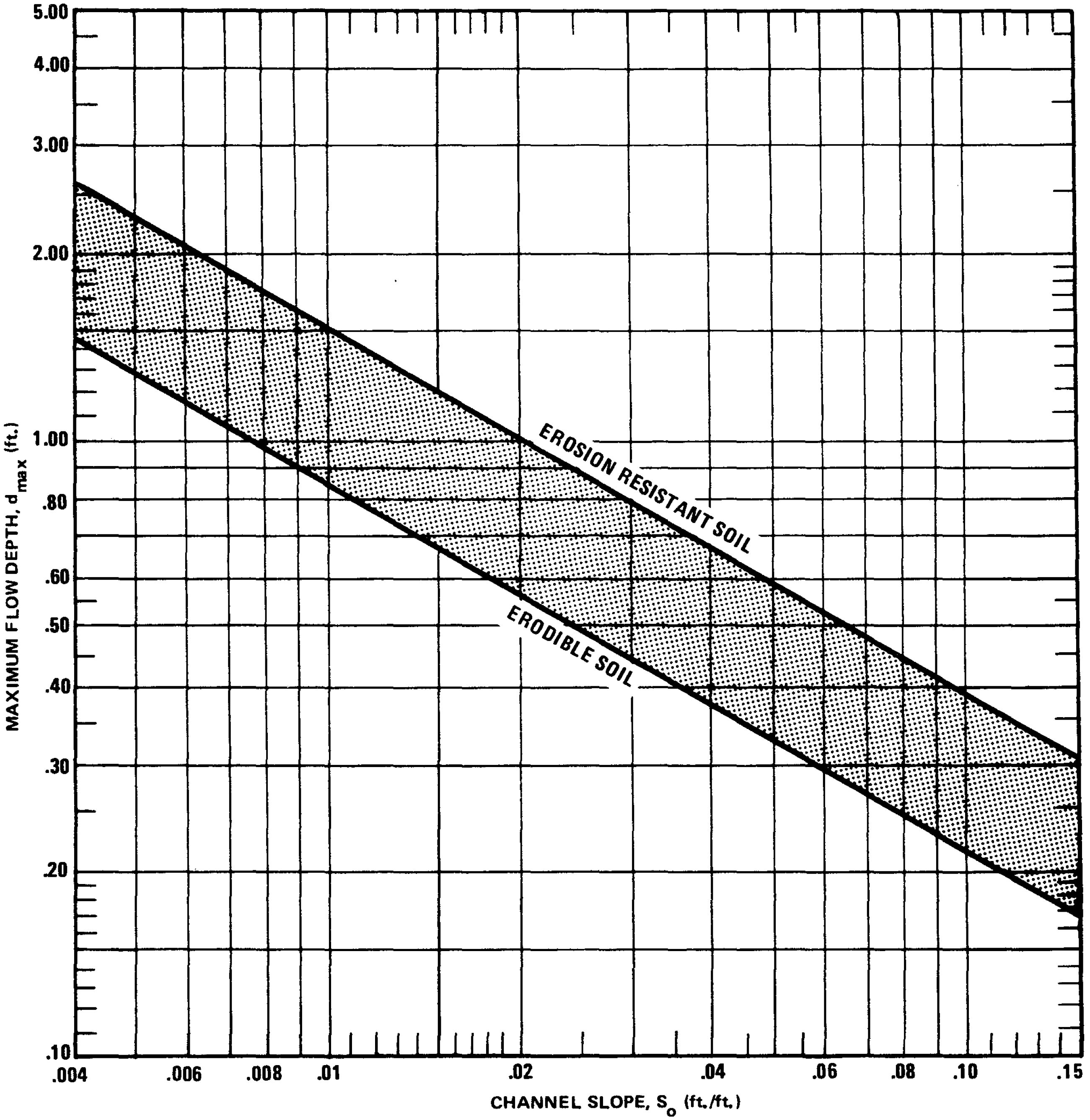
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH JUTE MESH



FROM MISSISSIPPI STATE UNIVERSITY REPORT,
"EROSION CONTROL CRITERIA FOR DRAINAGE CHANNELS"

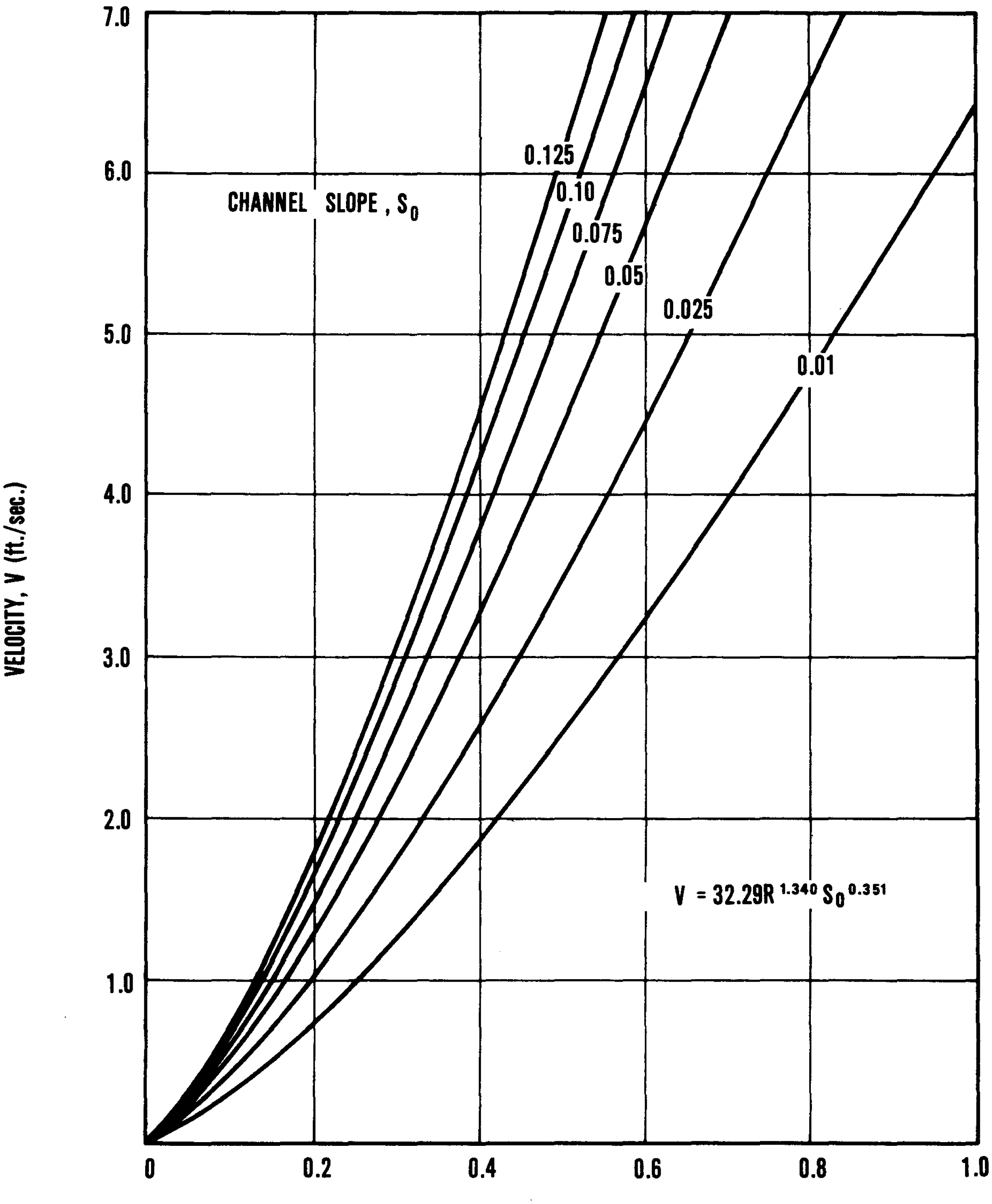
FLOW VELOCITY FOR CHANNELS LINED WITH JUTE MESH

Chart 9



From Mississippi State University Report
"Erosion Control Criteria for Drainage Channels"

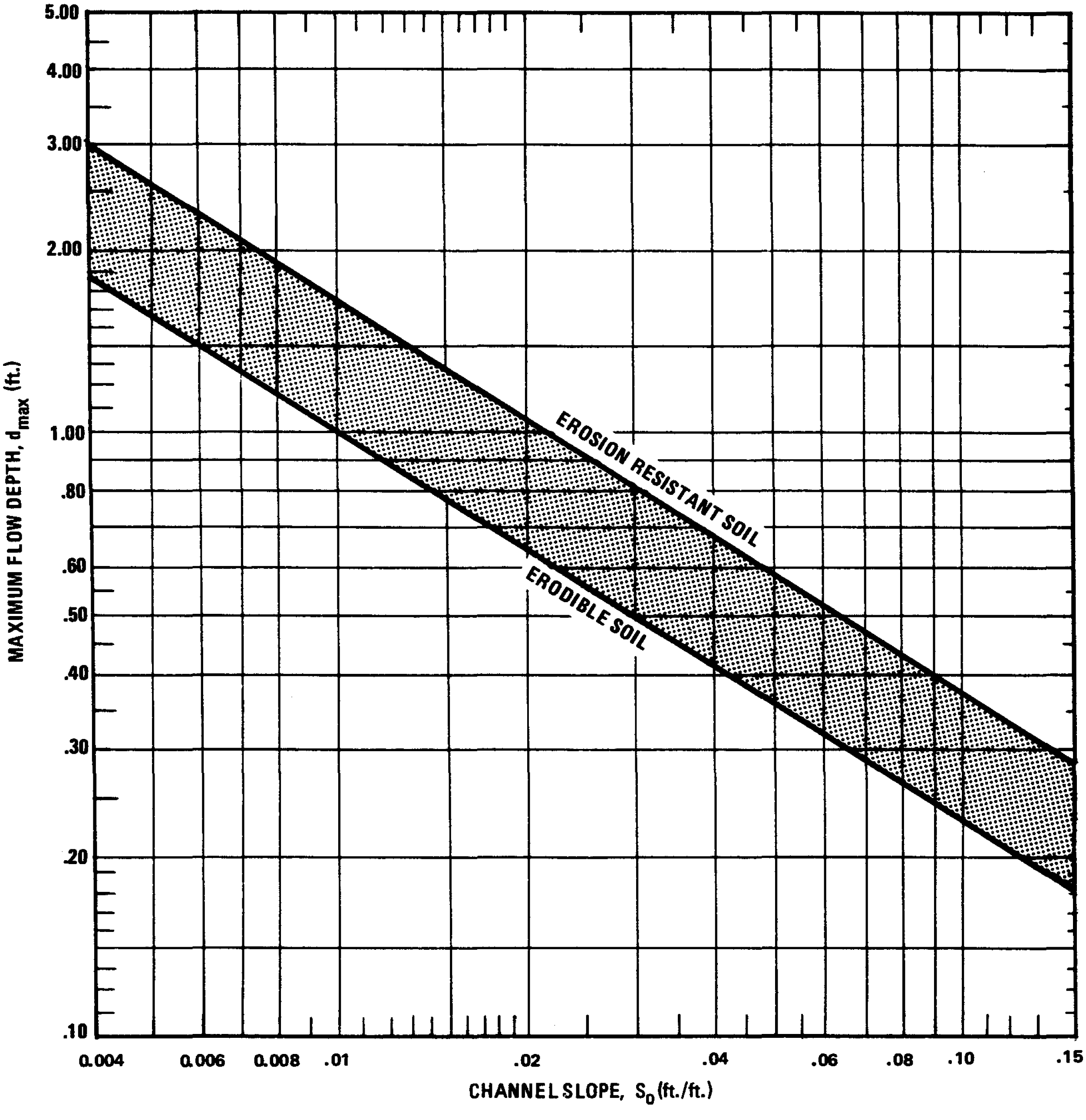
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH EXCELSIOR MAT



FROM MISSISSIPPI STATE UNIVERSITY REPORT,
"EROSION CONTROL CRITERIA FOR DRAINAGE CHANNELS"

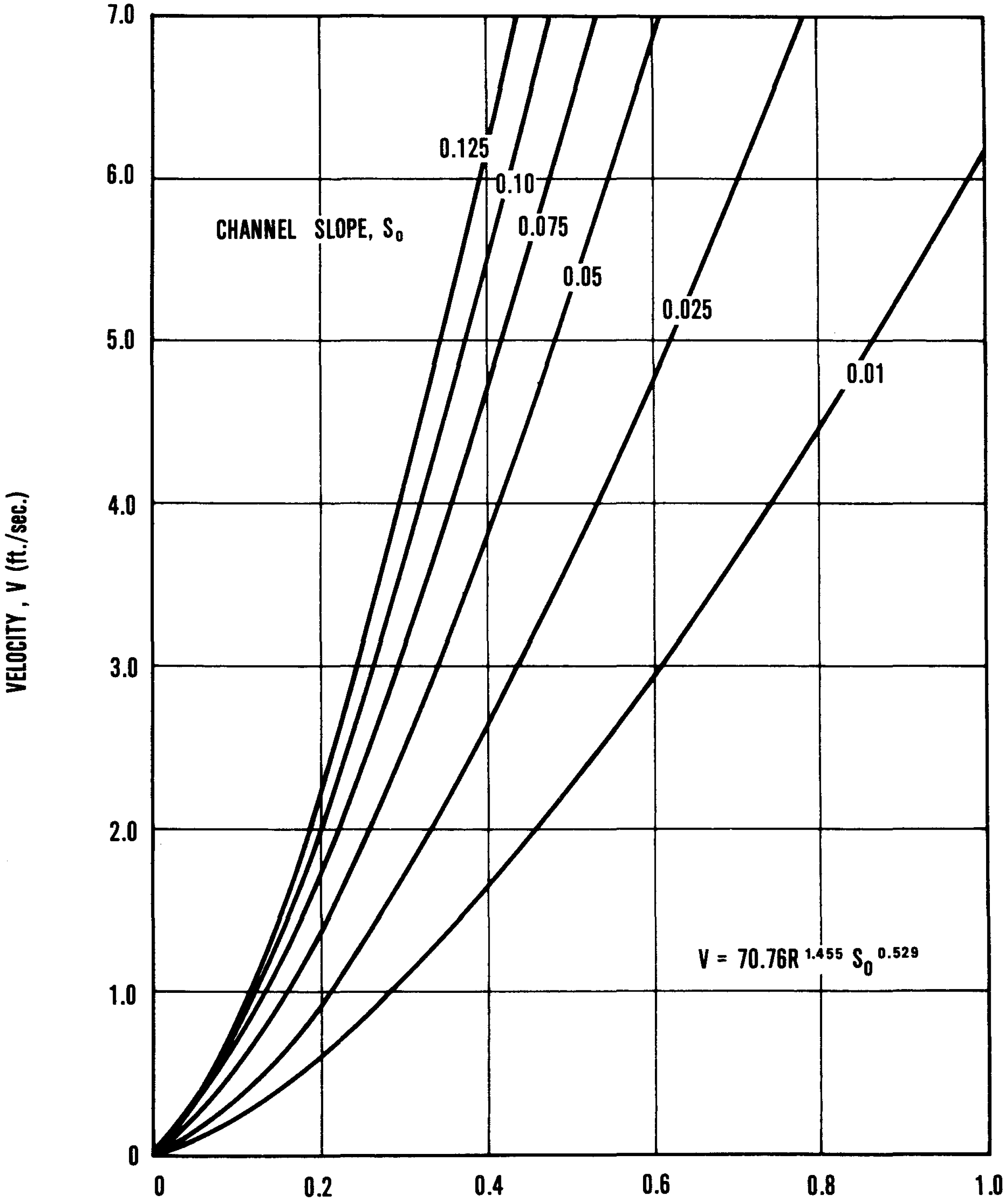
FLOW VELOCITY FOR CHANNELS LINED WITH EXCELSIOR MAT

Chart 11



From Mississippi State University Report
"Erosion Control Criteria for Drainage Channels"

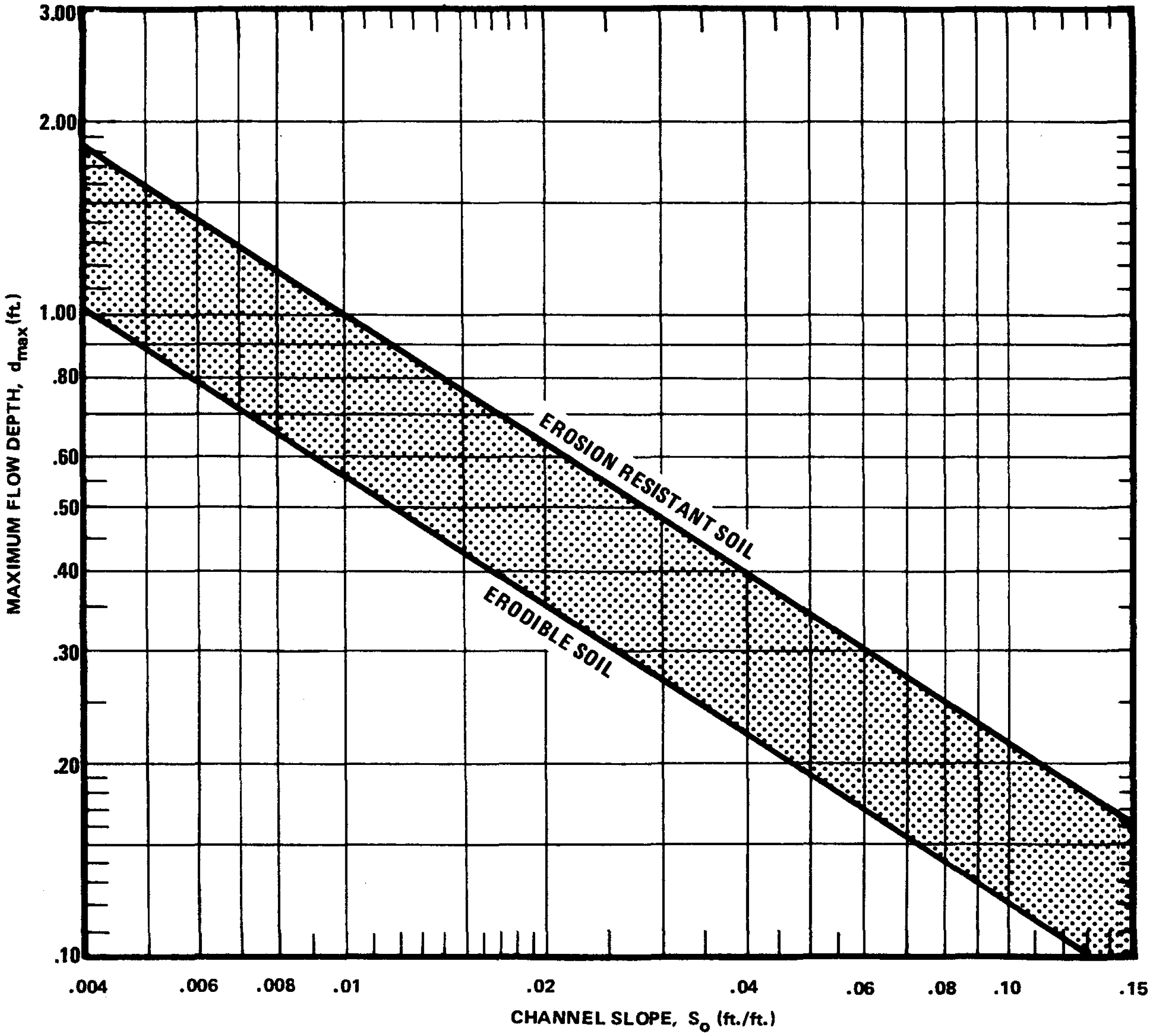
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH STRAW AND EROSIONET



FROM MISSISSIPPI STATE UNIVERSITY REPORT,
"EROSION CONTROL CRITERIA FOR DRAINAGE CHANNELS"

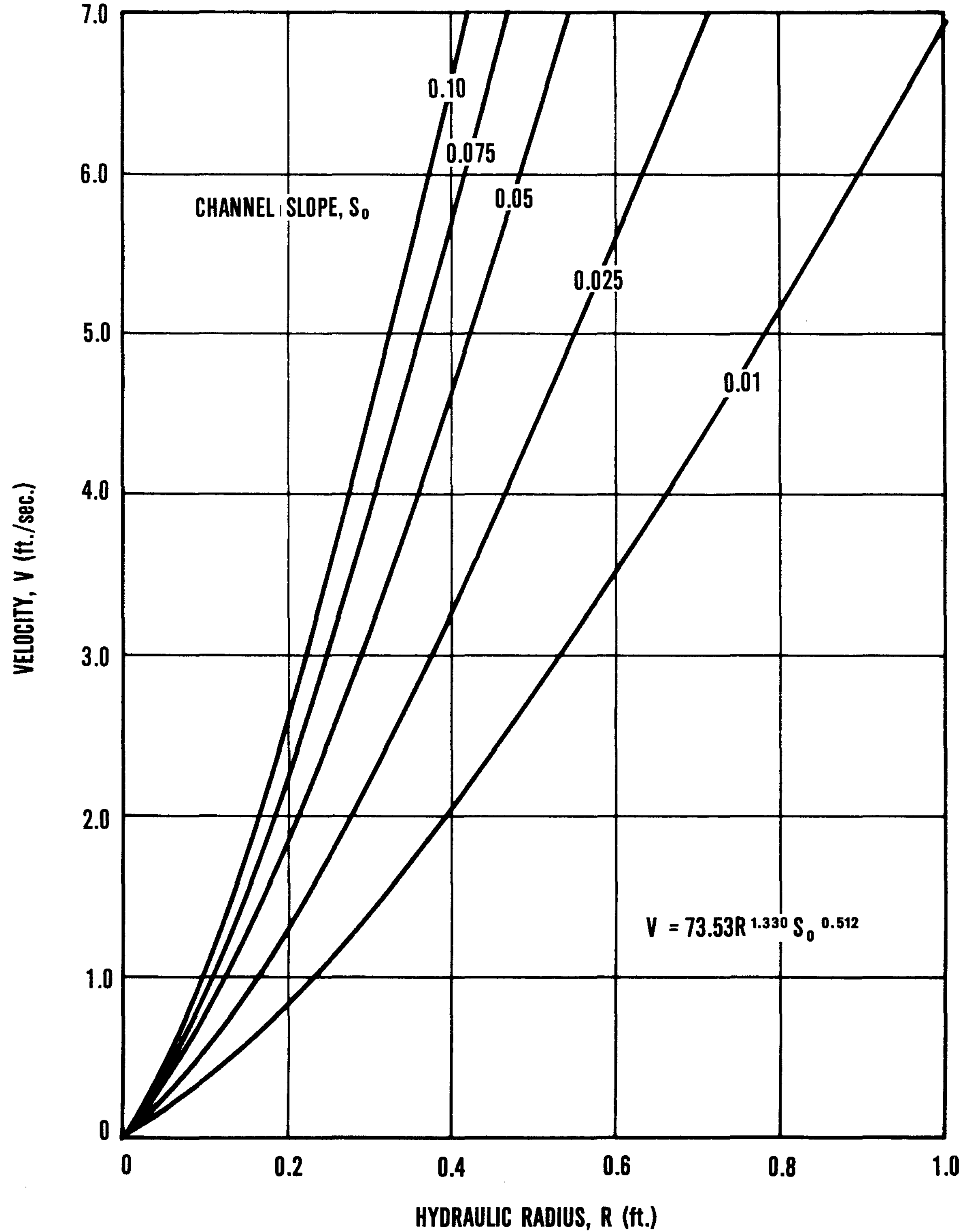
FLOW VELOCITY FOR CHANNELS LINED WITH STRAW AND EROSIONET

Chart 13



From Mississippi State University Report,
" Erosion Control Criteria for Drainage Channels"

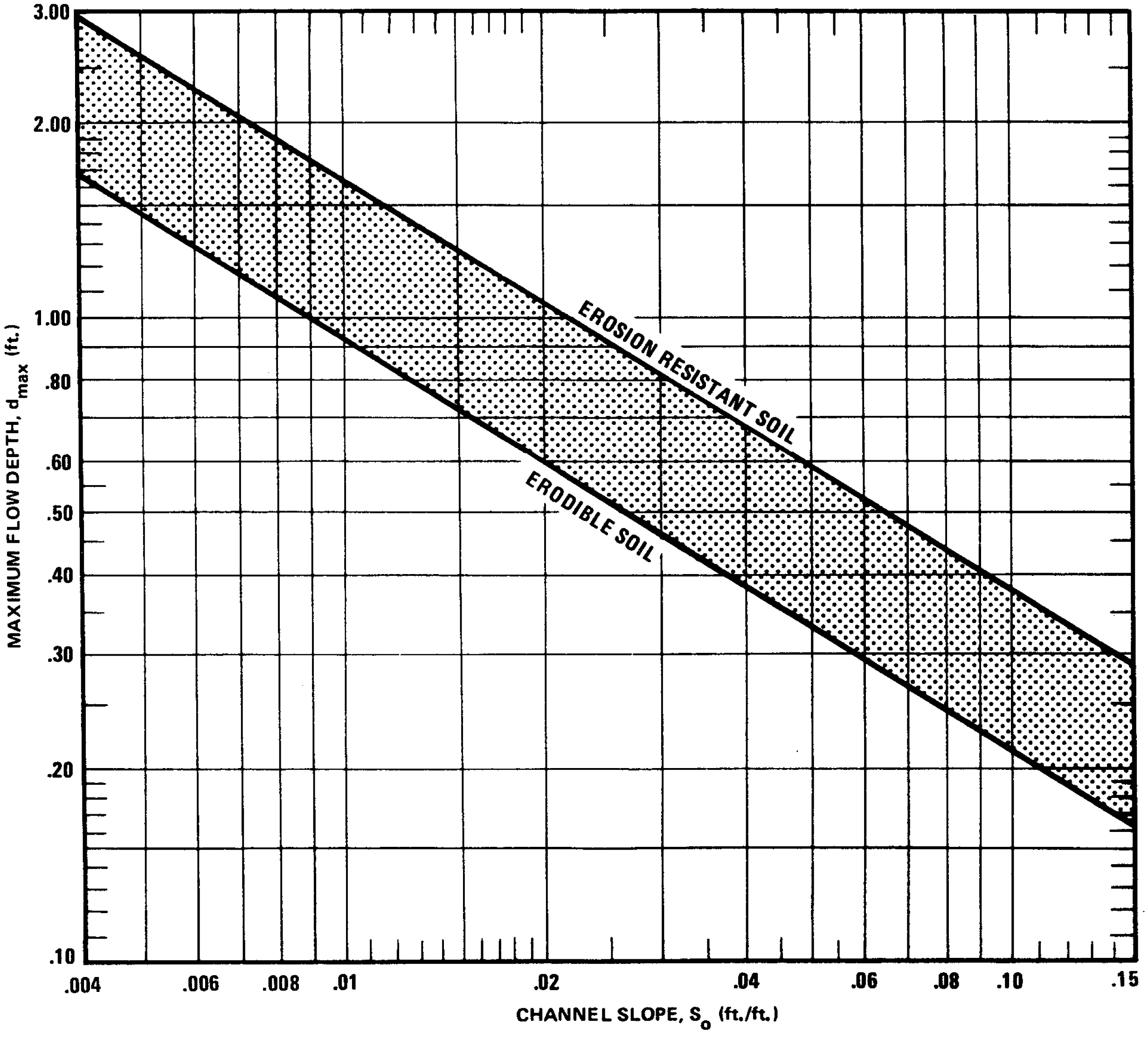
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH 3/8-INCH FIBER GLASS MAT



From Mississippi State University Report
"Erosion Control Criteria for Drainage Channels"

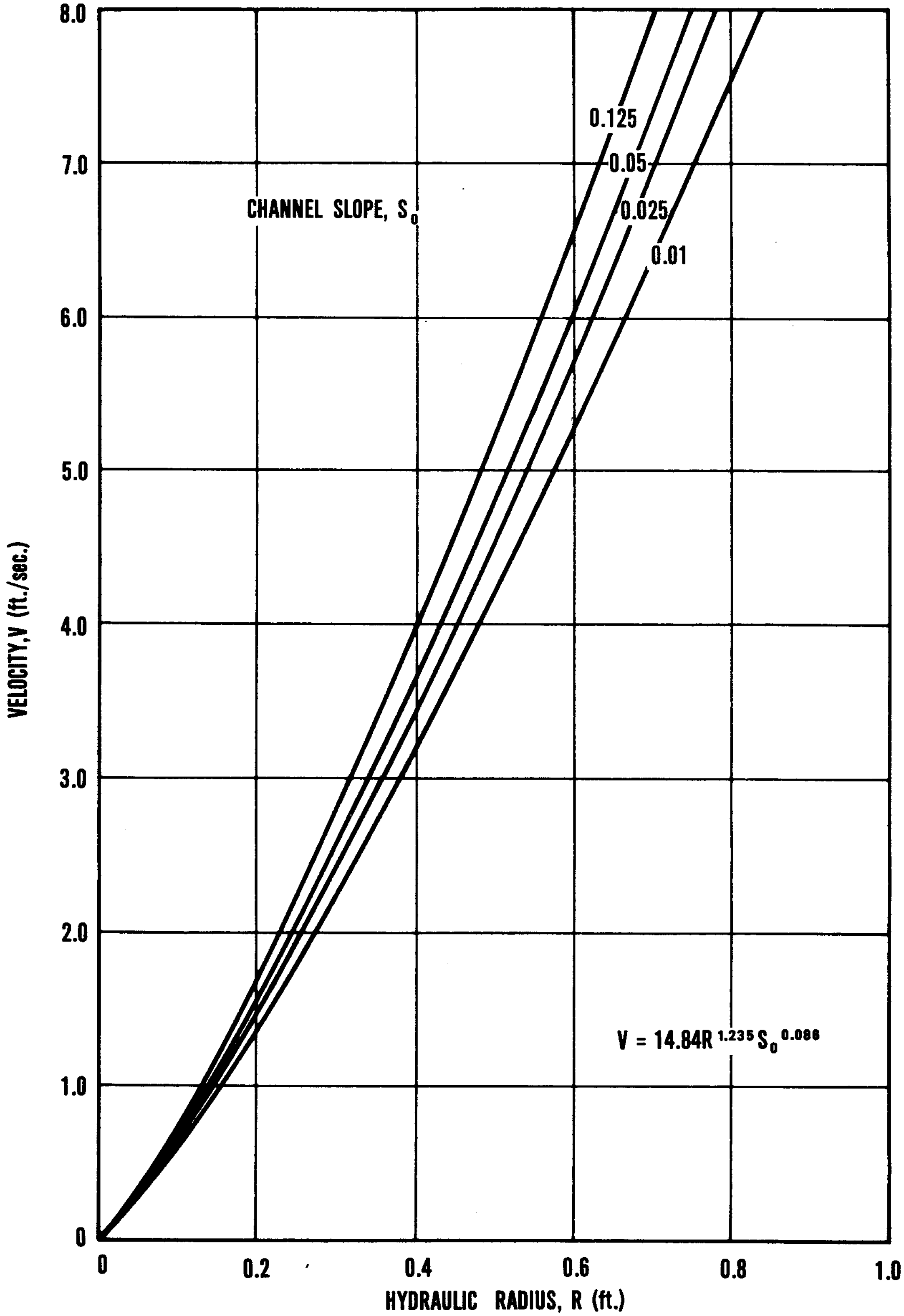
FLOW VELOCITY FOR CHANNELS LINED WITH
3/8-INCH FIBER GLASS MAT

Chart 15



From Mississippi State University Report
"Erosion Control Criteria for Drainage Channels"

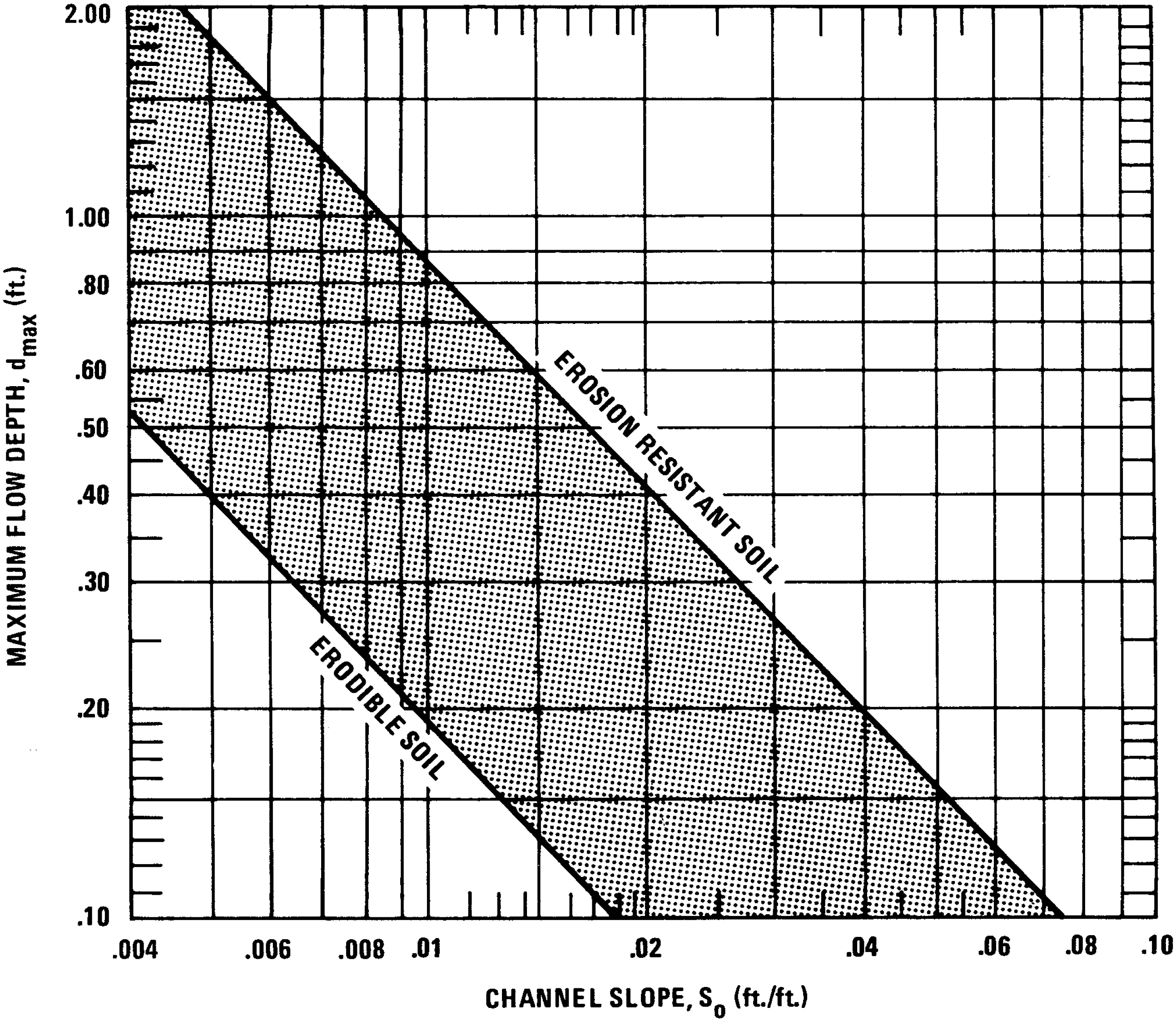
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH 1/2-INCH FIBER GLASS MAT



FROM MISSISSIPPI STATE UNIVERSITY REPORT,
"EROSION CONTROL CRITERIA FOR DRAINAGE CHANNELS"

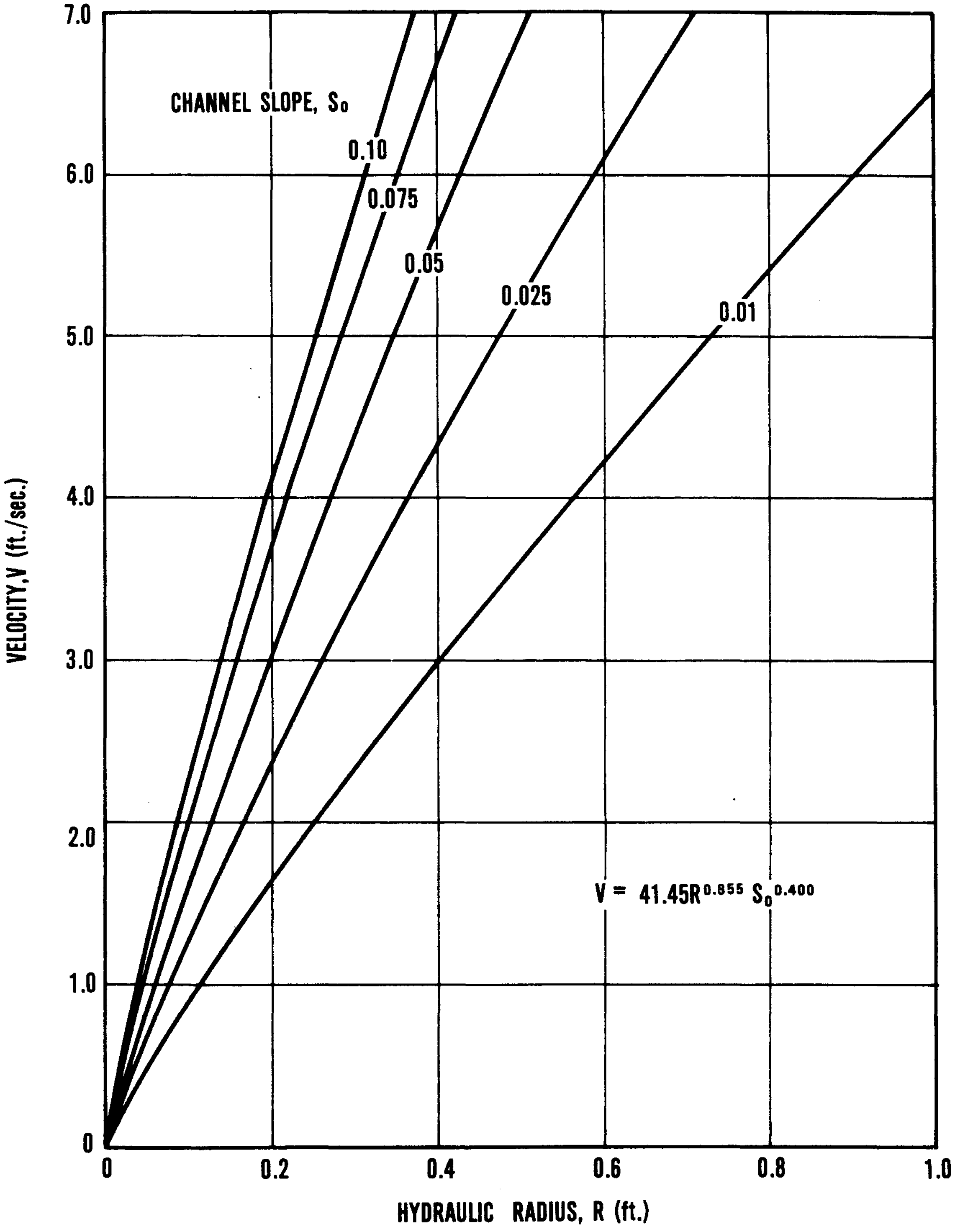
FLOW VELOCITY FOR CHANNELS LINED WITH
1/2-INCH FIBER GLASS MAT

Chart 17



From Mississippi State University Report
"Erosion Control Criteria for Drainage Channels"

MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH EROSIONET



FROM MISSISSIPPI STATE UNIVERSITY REPORT,
"EROSION CONTROL CRITERIA FOR DRAINAGE CHANNELS"

FLOW VELOCITY FOR CHANNELS LINED WITH EROSIONET

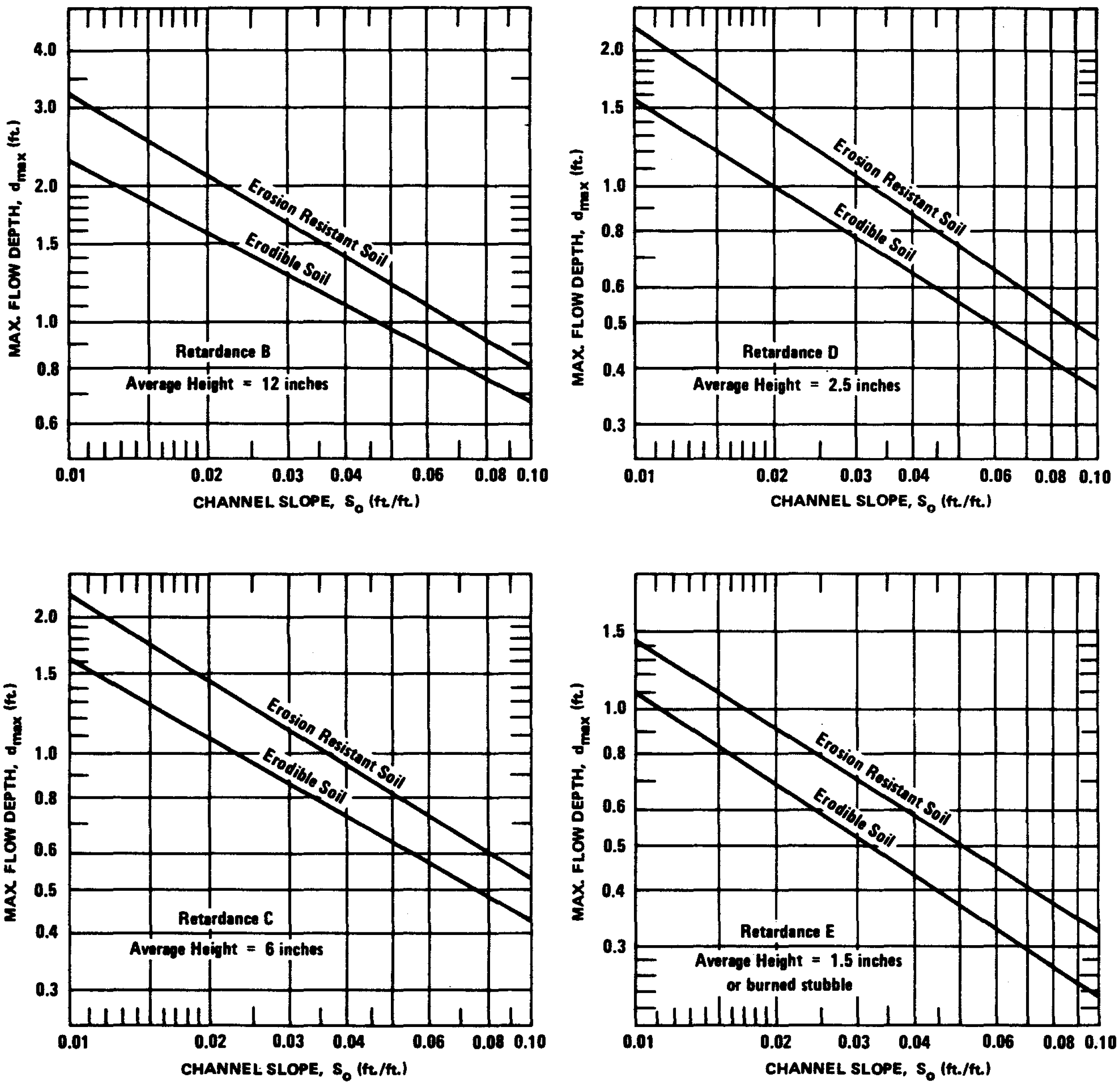
Vegetative Linings

Maximum permissible depth charts have been developed for three different types of vegetation using the data from the SCS "Handbook of Channel Design for Soil and Water Conservation" (5) and the methods described in Appendix C. The vegetation types covered are: Bermuda grass of various lengths, uncut grass mixtures, and common Lespedeza. These vegetations illustrate the range of possible erosion protection since the Bermuda grass offers a high protective capability, the grass mixture a moderate protective capability, and the common Lespedeza a low degree of protection against scour.

The Bermuda grass charts may be used to check the erosion resistance of a channel when the grass is cut short and the channel capacity when the grass is long and uncut.

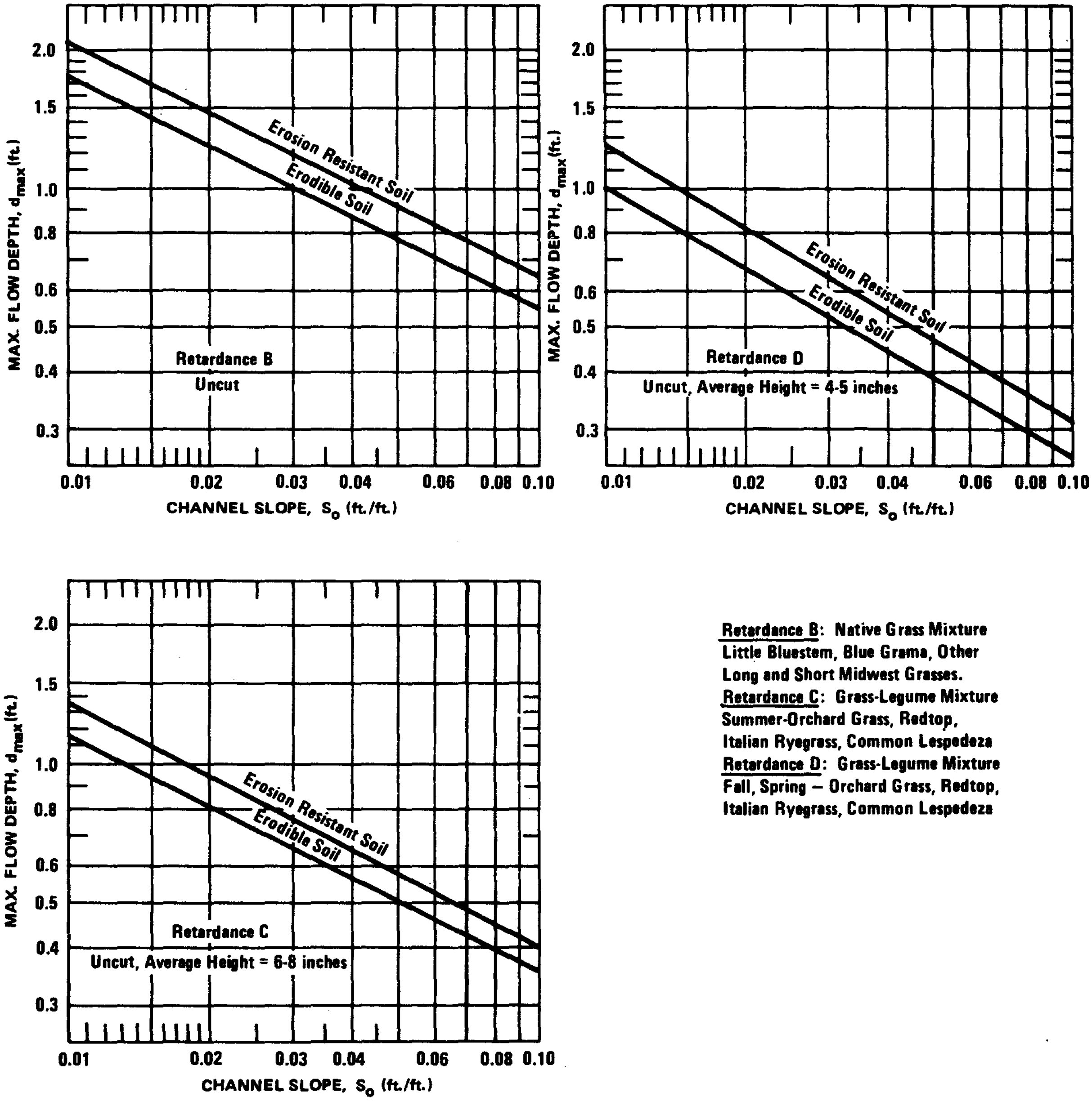
The velocity charts are from the SCS report with no revision. The appropriate retardance (A, B, C, D or E) is indicated on the d_{max} charts for each type of vegetation.

Chart 19



MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH BERMUDA GRASS. GOOD STAND, CUT TO VARIOUS LENGTHS

Note: Use on slopes steeper than 10 percent is not recommended

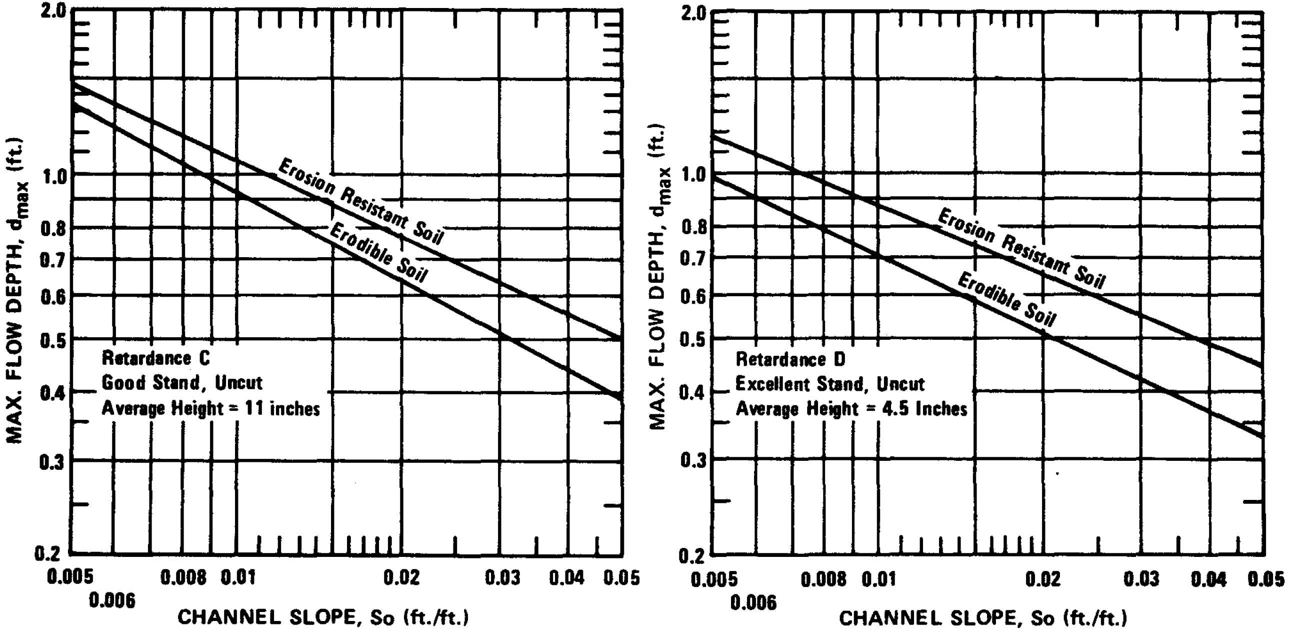


Retardance B: Native Grass Mixture Little Bluestem, Blue Grama, Other Long and Short Midwest Grasses.
Retardance C: Grass-Legume Mixture Summer-Orchard Grass, Redtop, Italian Ryegrass, Common Lespedeza
Retardance D: Grass-Legume Mixture Fall, Spring – Orchard Grass, Redtop, Italian Ryegrass, Common Lespedeza

MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH GRASS MIXTURES. GOOD STAND,UNCUT

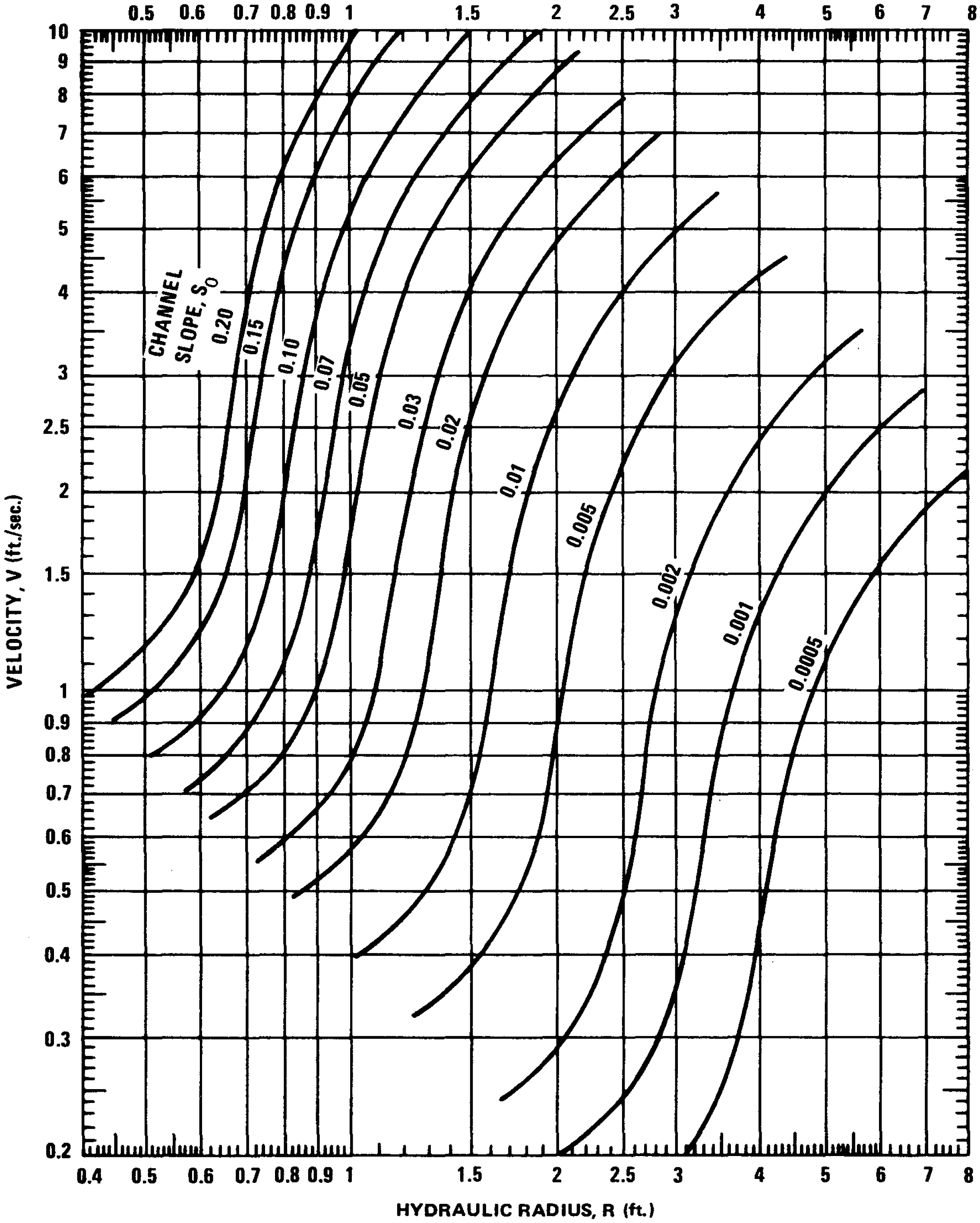
NOTE: USE ON SLOPES STEEPER THAN 10 PERCENT IS NOT RECOMMENDED

Chart 21



MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max}) FOR CHANNELS LINED WITH COMMON LESPEDEZA OF VARIOUS LENGTHS

Chart 22



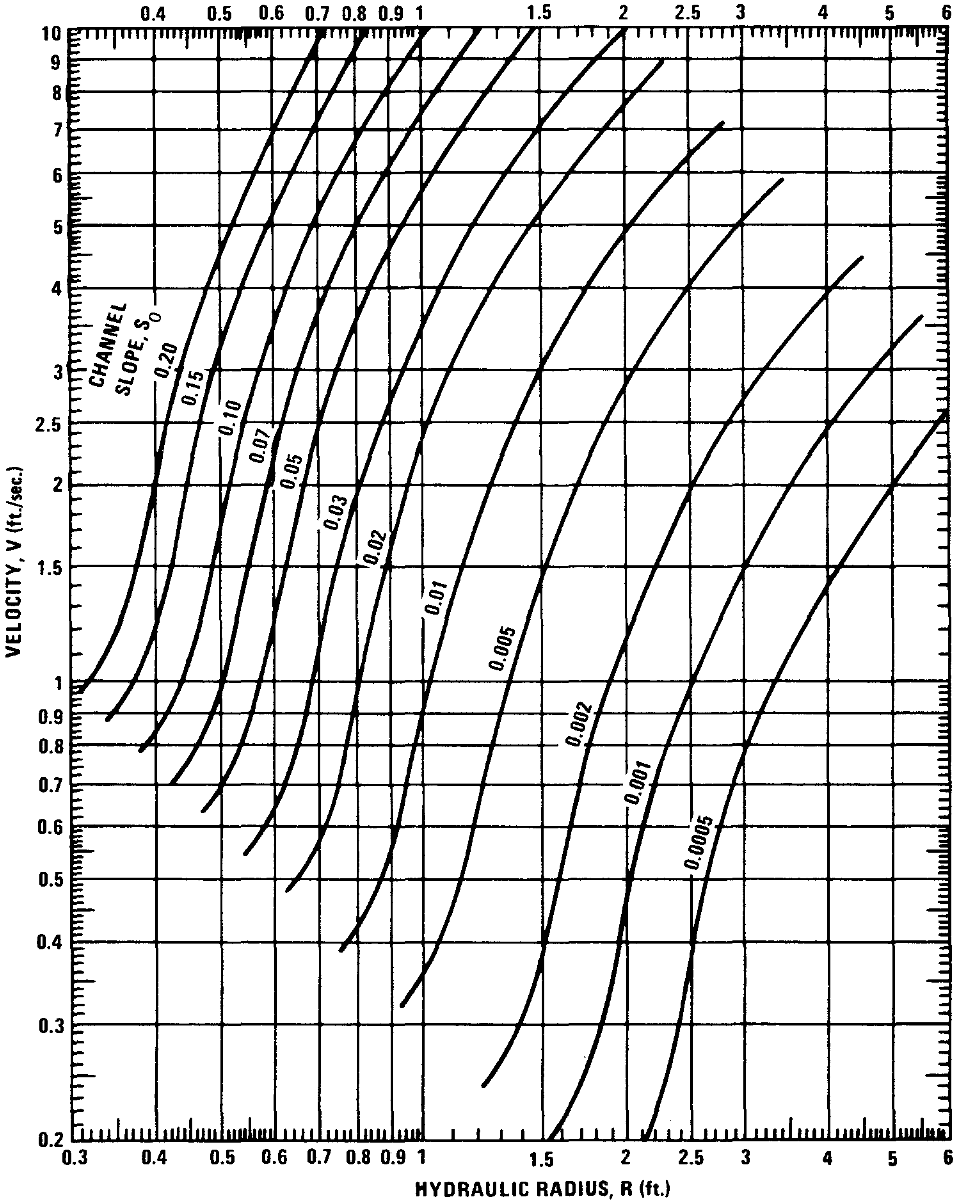
FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE A

Retardance A Includes:

Weeping lovegrass.	Excellent stand, tall, (average 30")
Yellow bluestem Ischaemum . . .	Excellent stand, tall, (average 36")

From "Handbook of Channel Design for Soil and Water Conservation," SCS-TP-61, Revised 1954.

Chart 23

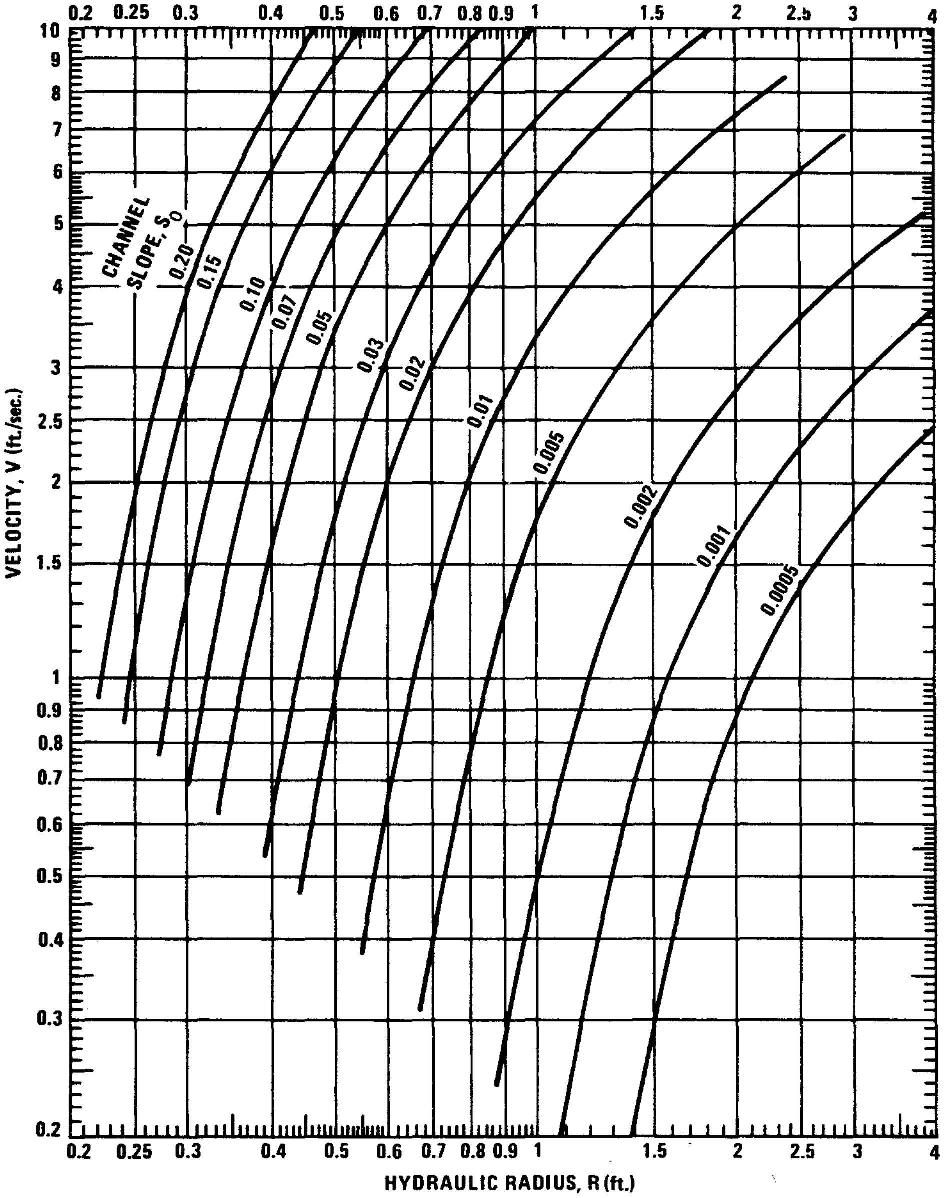


FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE B

Retardance B Includes:

Kudzu	Very dense growth, uncut
Bermudagrass	Good stand, tall (average 12")
Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
Weeping lovegrass	Good stand, tall, (average 24")
Lespedeza sericea	Good stand, not woody, tall (average 19")
Alfalfa	Good stand, uncut, (average 11")
Weeping lovegrass	Good stand, mowed, (average 13")
Kudzu	Dense growth, uncut
Blue grama	Good stand, uncut, (average 13")

From "Handbook of Channel Design for
Soil and Water Conservation," SCS-TP-61,
Revised 1954.



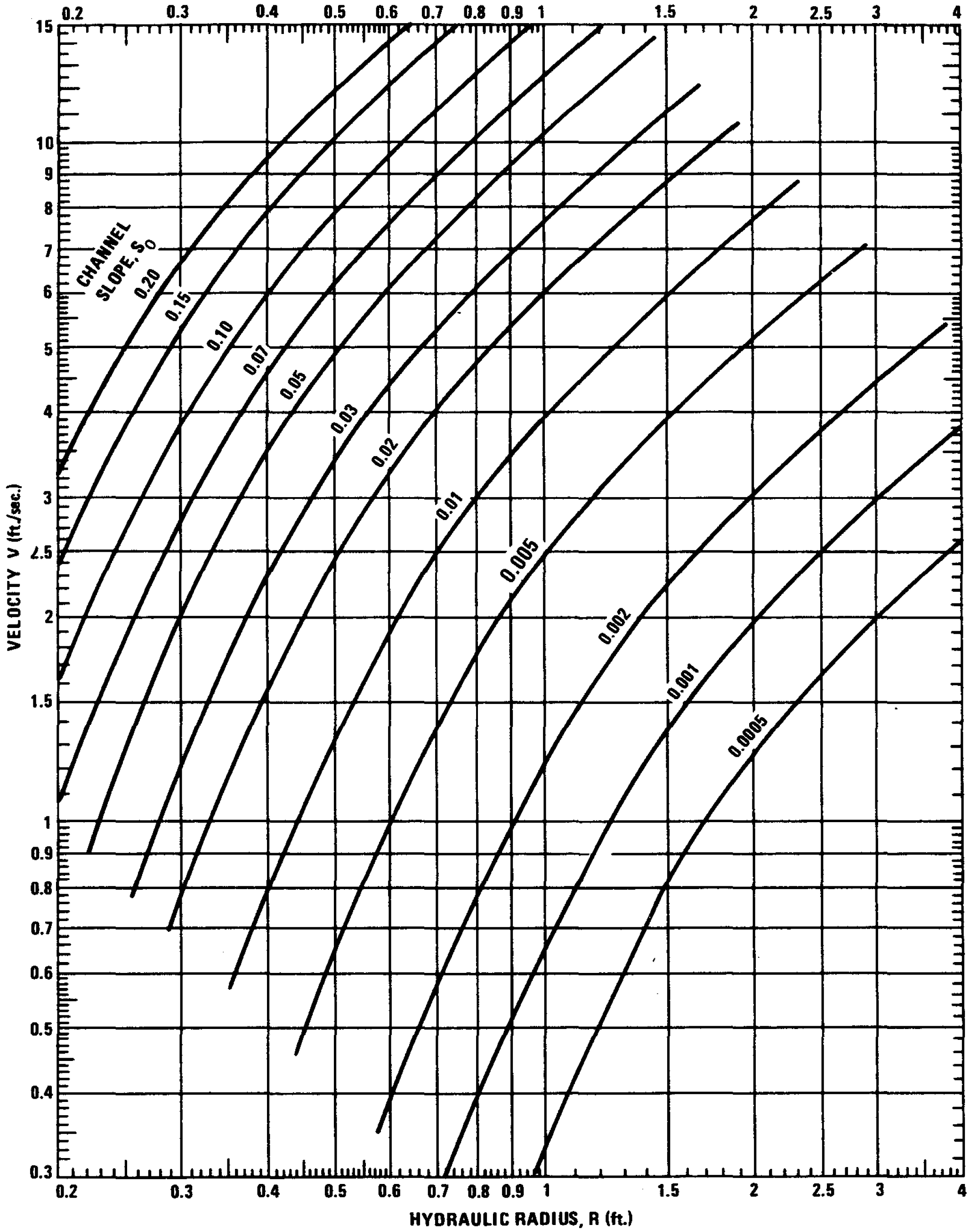
FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE C

Retardance C Includes:

Crabgrass	**Fair stand, uncut (10 to 48")**
Bermudagrass	**Good stand, mowed (average 6")**
Common lespedeza	**Good stand, uncut (average 11")**
Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)	**Good stand, uncut (6 to 8 inches)**
Centipedegrass	**Very dense cover (average 6 inches)**
Kentucky bluegrass	**Good stand, headed (6 to 12 inches)**

From "Handbook of Channel Design for Soil and Water Conservation," SCS-TP-61, Revised 1954.

Chart 25

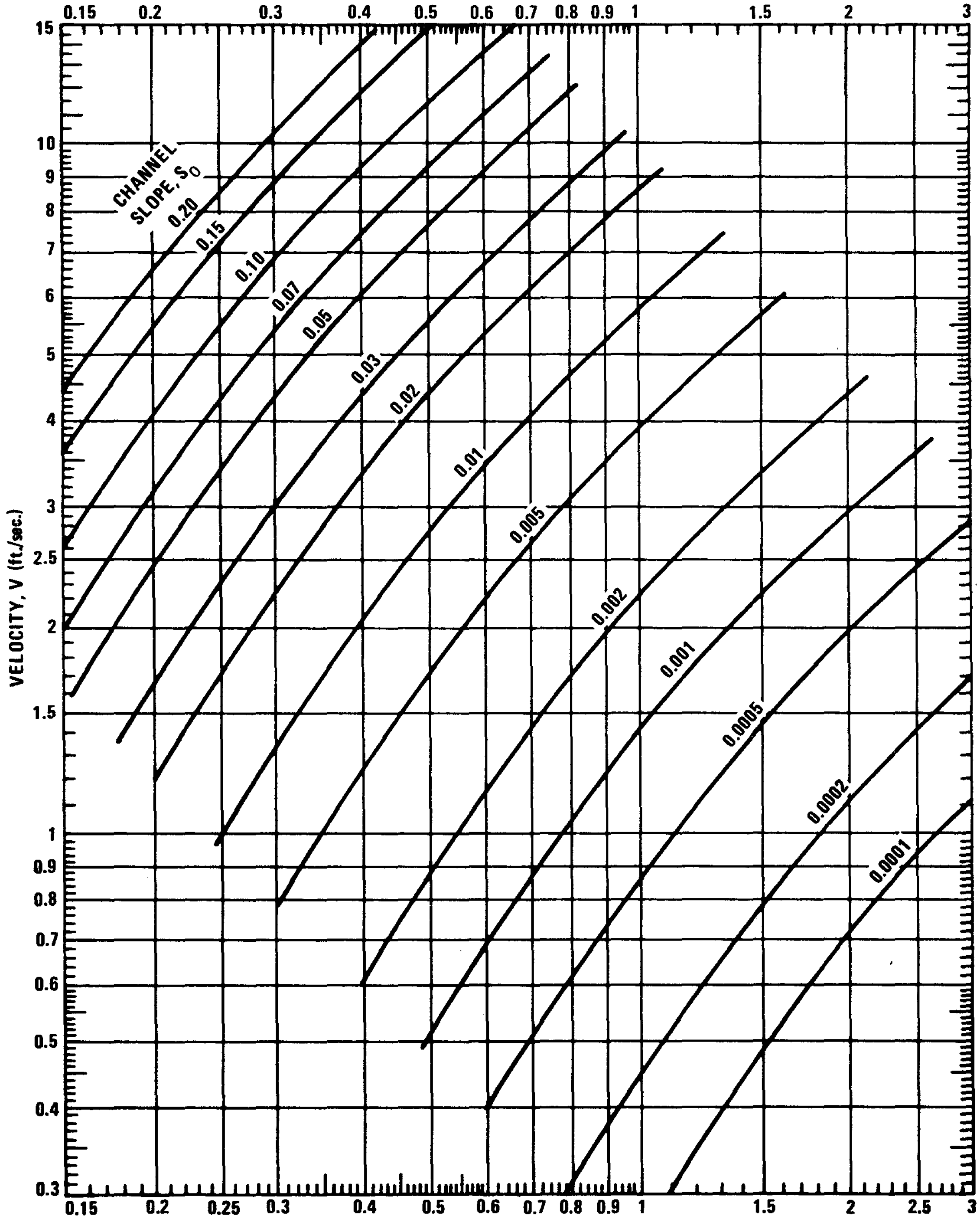


FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE D

Retardance D Includes:

Bermudagrass	**Good stand, cut to 2.5-inch height**
Common lespedeza	**Excellent stand, uncut (average 4.5")**
Buffalograss	**Good stand, uncut (3 to 6 inches)**
Grass-legume mixture — fall, spring (Orchardgrass, redtop, Italian ryegrass, and common lespedeza)	**Good stand, uncut (r to 5 inches)**
Lespedeza sericea	**After cutting to 2-inch height. Very good stand before cutting.**

From "Handbook of Channel Design for
Soil and Water Conservation," SCS-TP-61,
Revised 1954.



FLOW VELOCITY FOR CHANNELS LINED WITH VEGETATION OF RETARDANCE E

Retardance E Includes:

Bermudagrass	**Good stand, cut to 1.5 inches height**
Bermudagrass	**Burned stubble.**

From "Handbook of Channel Design for Soil and Water Conservation," SCS-TP-61, Revised 1954.

Dumped Rock Riprap

The maximum permissible depth of flow curves for dumped rock riprap channel linings were developed by modifying the results of NCHRP Report Number 108 (6) as discussed in Appendix C.

Charts 28 and 29 were developed from the Manning equation and the relationship for n from NCHRP Report Number 108.

When rock riprap is used, the need for an underlying filter material must be evaluated. The filter material may be either a granular filter blanket or plastic filter cloth.

Design of Granular Filter Blanket

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

$$\frac{D_{15\ \text{filter}}}{D_{85\ \text{base}}} < 5 < \frac{D_{15\ \text{filter}}}{D_{15\ \text{base}}} < 40$$

and

$$\frac{D_{50\ \text{filter}}}{D_{50\ \text{base}}} < 40$$

In the above relationships, filter refers to the overlying material and base refers to the underlying material. The relationships must hold between the filter blanket and base material and the riprap and filter blanket. Filters designed by the above criteria have been evaluated by Posey (11) and found to perform very well.

Design of Plastic Filter Cloth

Plastic filter cloths have been evaluated by the Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi. The following text was prepared by Colorado State University (12):

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> "Plastic filter cloths are being used beneath riprap and other revetment materials such as articulated concrete blocks with considerable success. The cloths are generally in 100 ft. long rolls, 12 to 18 ft. wide. The edges of the plastic sheets are hand sewn in the field with nylon twine. Overlap of 8 to 12 inches is provided with pins at 2 to 3 ft. intervals along the seam to prevent separation in case of settlement of the base material. Some amount of care must be exercised in placing riprap over the plastic cloth filters to prevent damage. Experiments and results with various cloth filters were reported by Calhoun, Compton and Strohm (1971) in which specific manufacturers and brand names are listed. Stones weighing as much as 3,000 lbs. have been placed on plastic filter cloths with no apparent damage. Filters can be placed subaqueously by using steel rods as weights fastened along the edges. Additional intermediate weights would assist in sinking the cloth in place. Durability of filter cloths has not yet been established because they have been in use only since about 1967. However, inspections at various installations seem to indicate little or no deterioration had occurred in the few (1 to 4) years that have elapsed for test installations."

For filter cloths adjacent to granular materials containing 50 percent or less by weight fines (minus No. 200 material):

(1) $$\frac{\text{85 percent size of material (mm)}}{\text{EOS (mm)}} > 1$$

(2) Open area not to exceed 36 percent.

For filter cloths adjacent to all other soils:

(1) EOS no larger than the opening in the U.S. Standard Sieve No. 70.

(2) Open area not to exceed 10 percent.

NOTE: No cloth specified should have an open area less than 4 percent or an EOS with openings smaller than the opening in a U.S. Standard Sieve Size No. 100. When possible, it is preferable to specify a cloth with openings as large as allowable by the criteria. It may not be possible to obtain a suitable cloth with the maximum allowable openings which also meets the strength requirements, however, due to the limited number of cloths available.

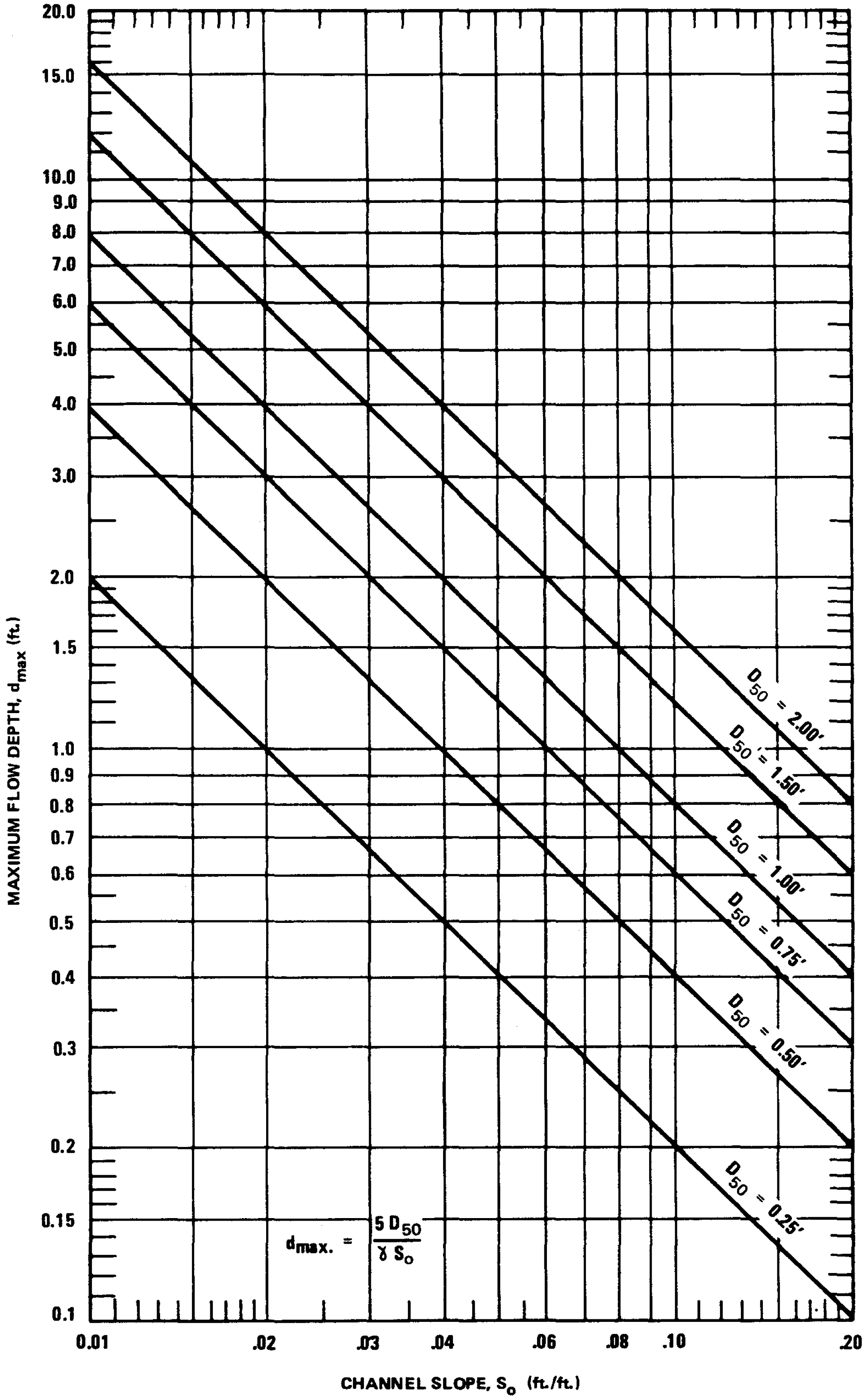
EOS is the Equivalent Opening Size, as defined in Appendix E.

Rock Riprap Specifications

Most riprap specifications for durability, hardness, angularity, resistance to weathering, etc., such as shown in Appendix D, are based on the requirements of shore protection, dams, or for river banks where the stone is constantly wet or exposed to freezing, thawing, and wave action.

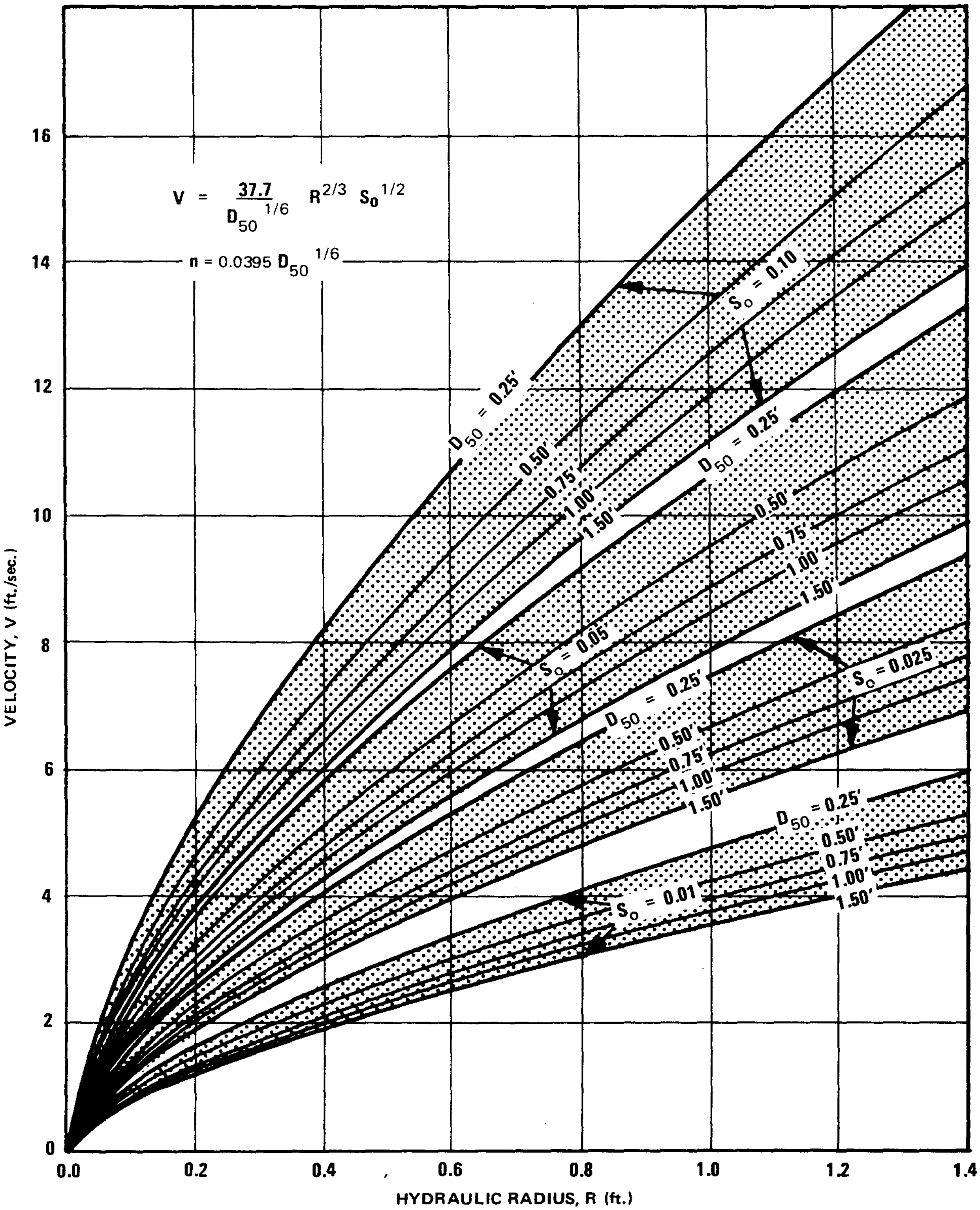
For highway drainage channels with intermittent flow, or where freezing is not a problem, it may be feasible to relax the more rigid specifications if it will make rock riprap more available. However, the durability of available rock should be evaluated before such a decision is made, considering the flow conditions expected in the channel.

Chart 27



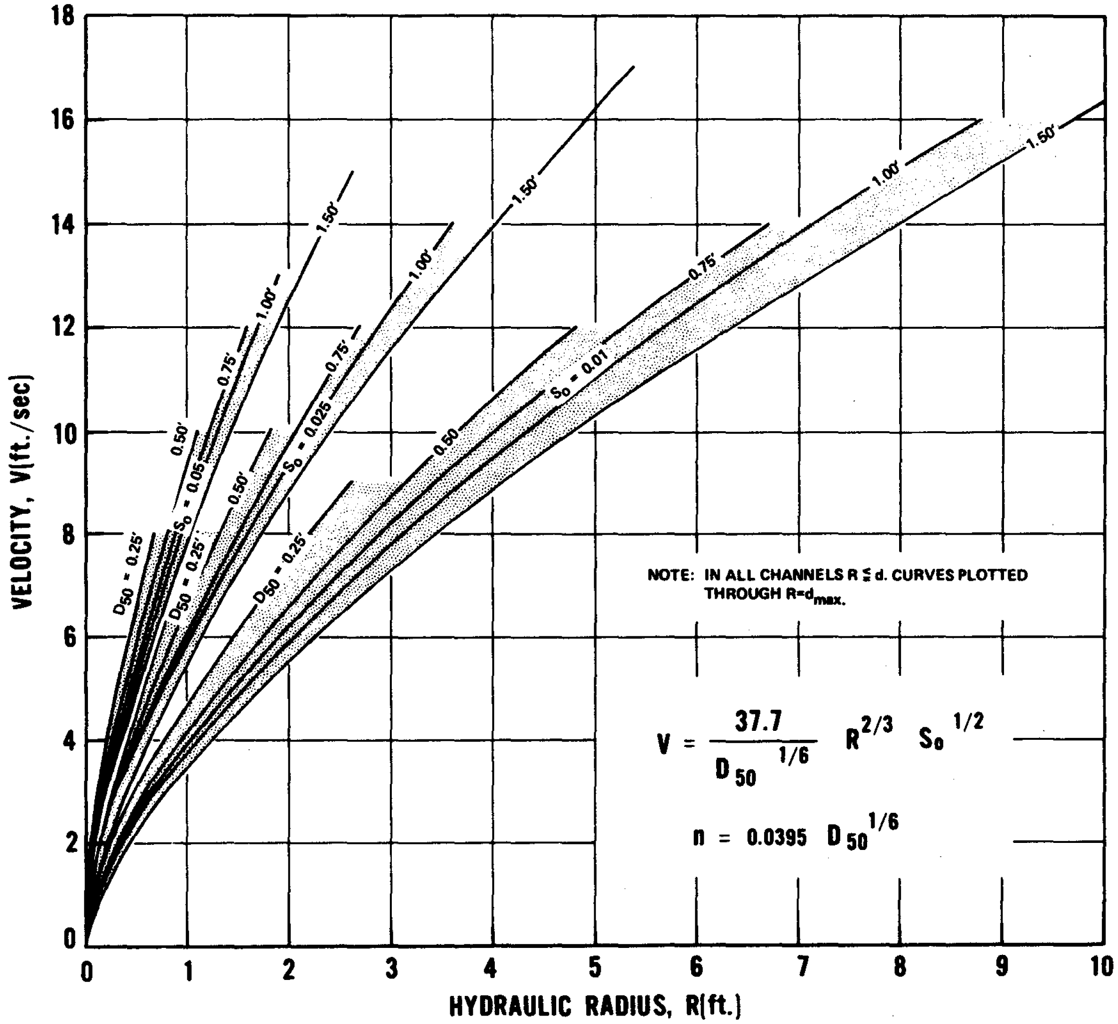
MAXIMUM PERMISSIBLE DEPTH OF FLOW (d_{max})
FOR CHANNELS LINED WITH ROCK RIPRAP

Chart 28

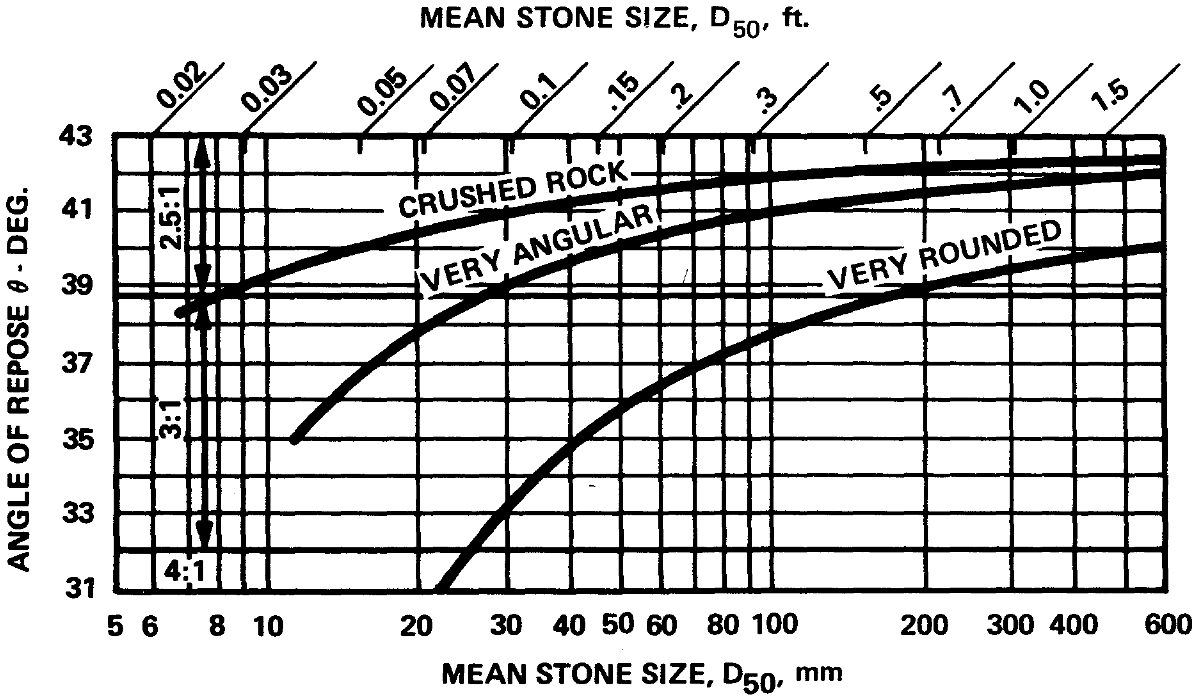


FLOW VELOCITY FOR CHANNELS LINED WITH ROCK RIPRAP
SLOPES=0.01 TO 0.10, D_{50} = 0.25' TO 1.50'

Chart 29

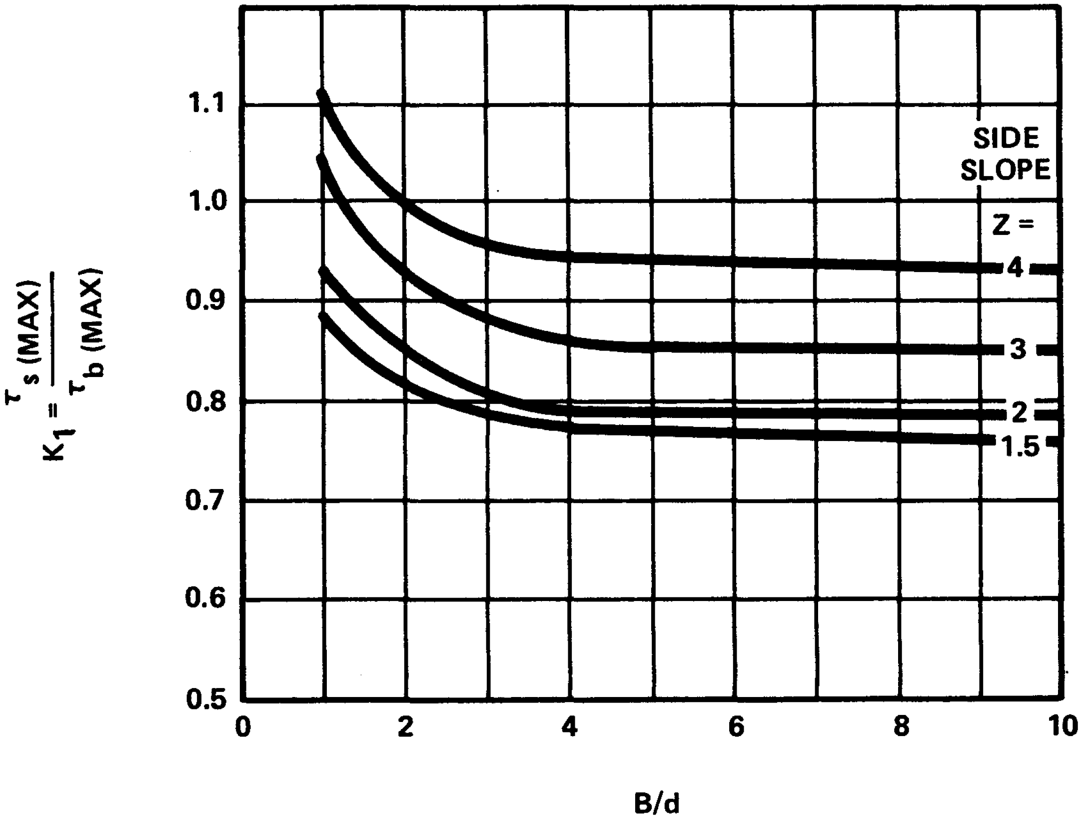


FLOW VELOCITY FOR CHANNELS LINED WITH ROCK RIPRAP
SLOPES = 0.01 TO 0.05, D_{50} = 0.25' TO 1.50'

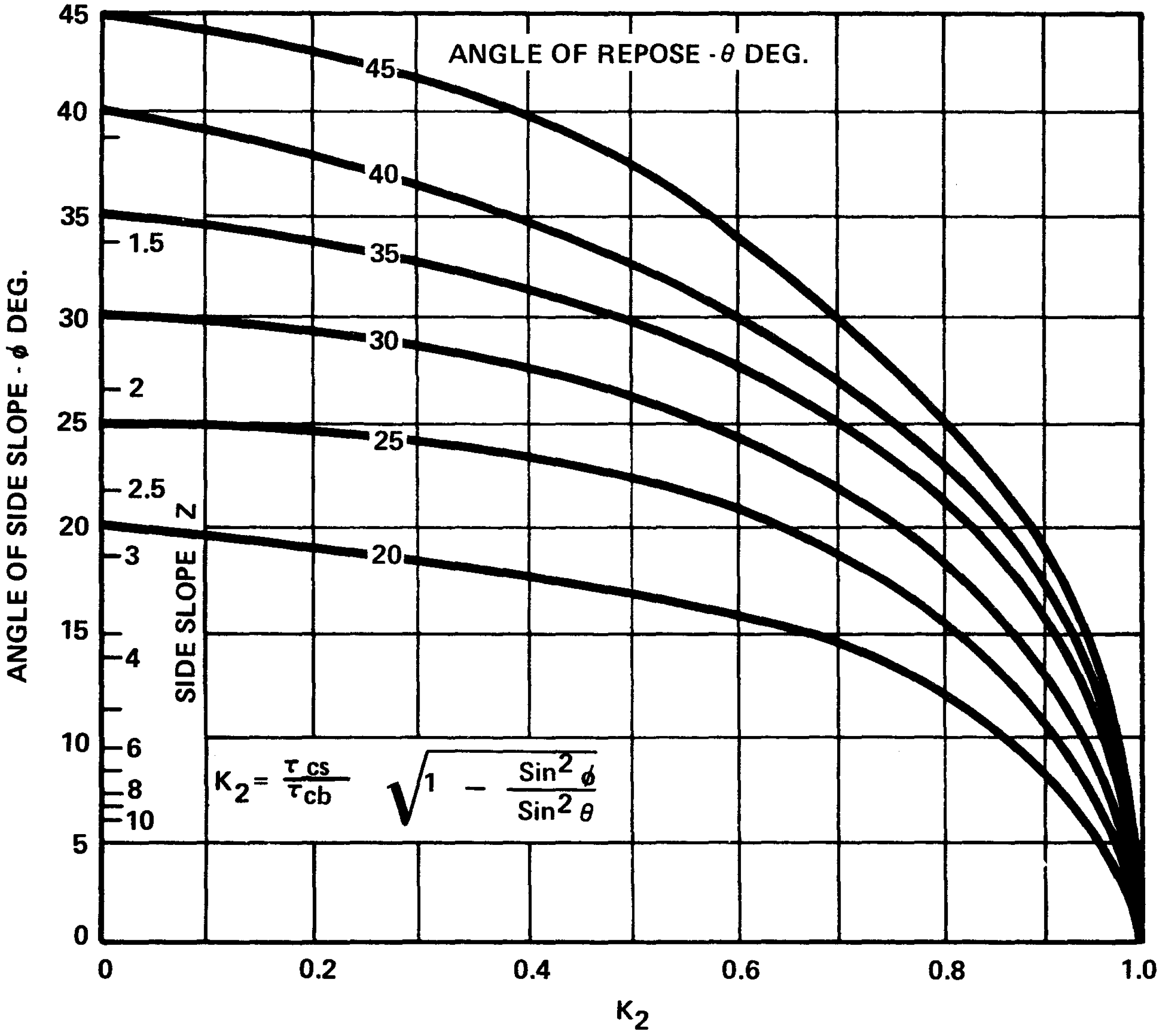


ANGLE OF REPOSE OF RIPRAP IN TERMS OF MEAN SIZE AND SHAPE OF STONE

Chart 31

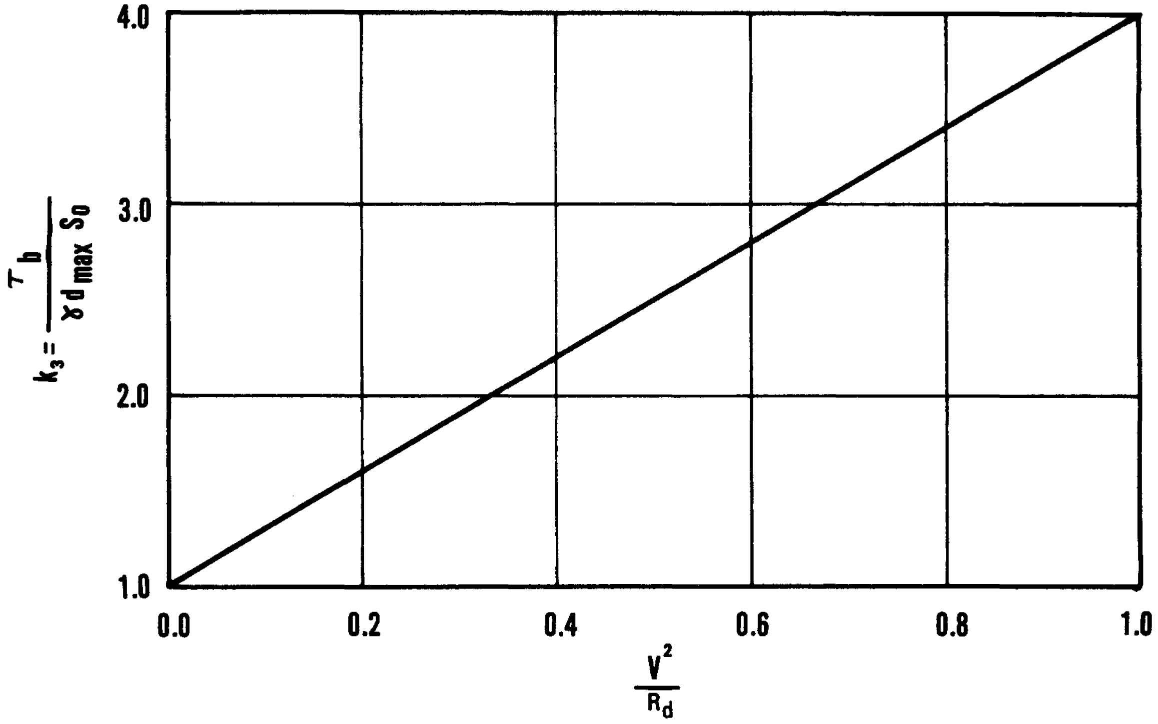


DISTRIBUTION OF BOUNDARY SHEAR AROUND WETTED PERIMETER OF TRAPEZOIDAL CHANNELS

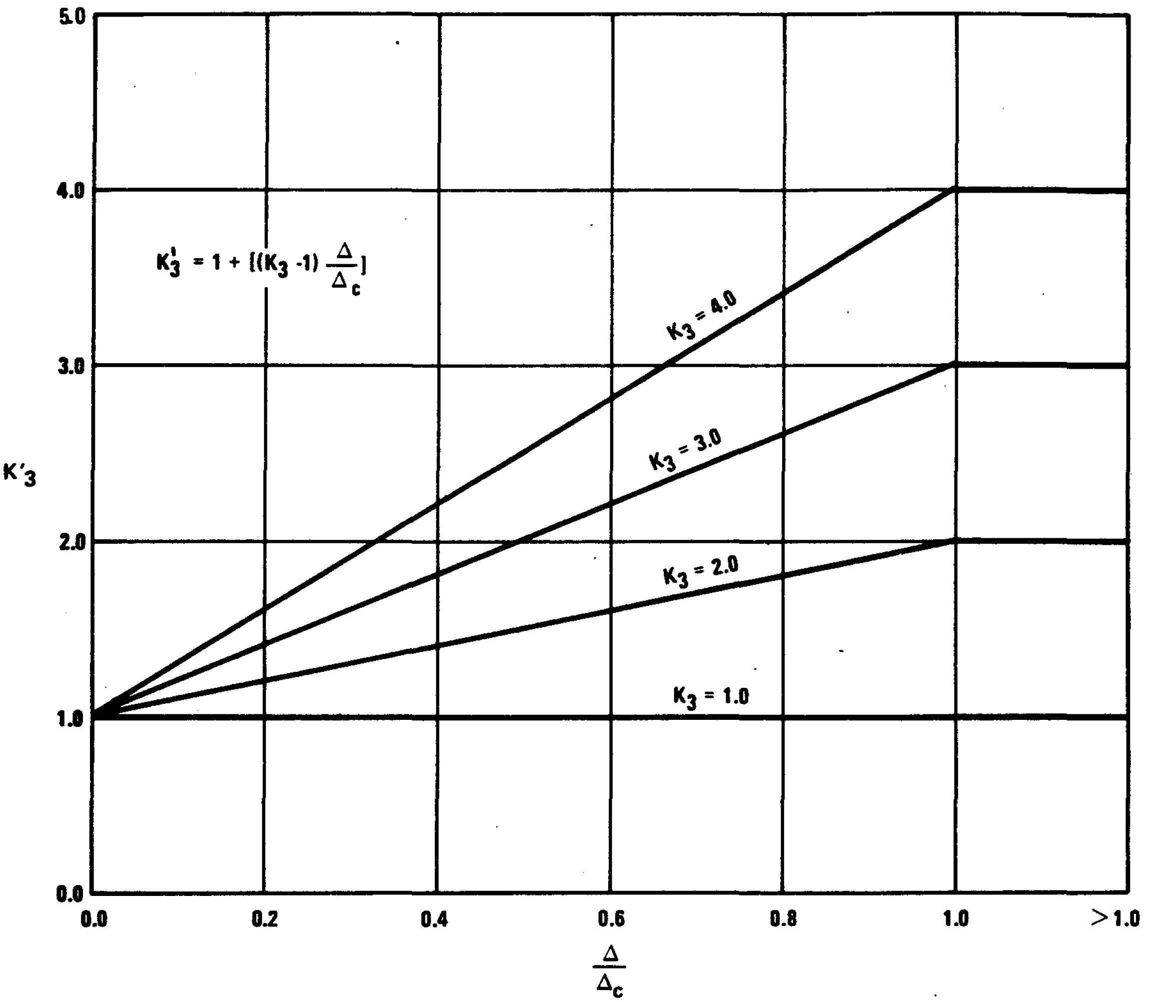


RATIO OF CRITICAL SHEAR ON SIDES TO CRITICAL SHEAR ON BOTTOM FOR NONCOHESIVE SEDIMENT

Chart 33



RATIO OF MAXIMUM BOUNDARY SHEAR IN BENDS
TO MAXIMUM BOTTOM SHEAR IN STRAIGHT REACH



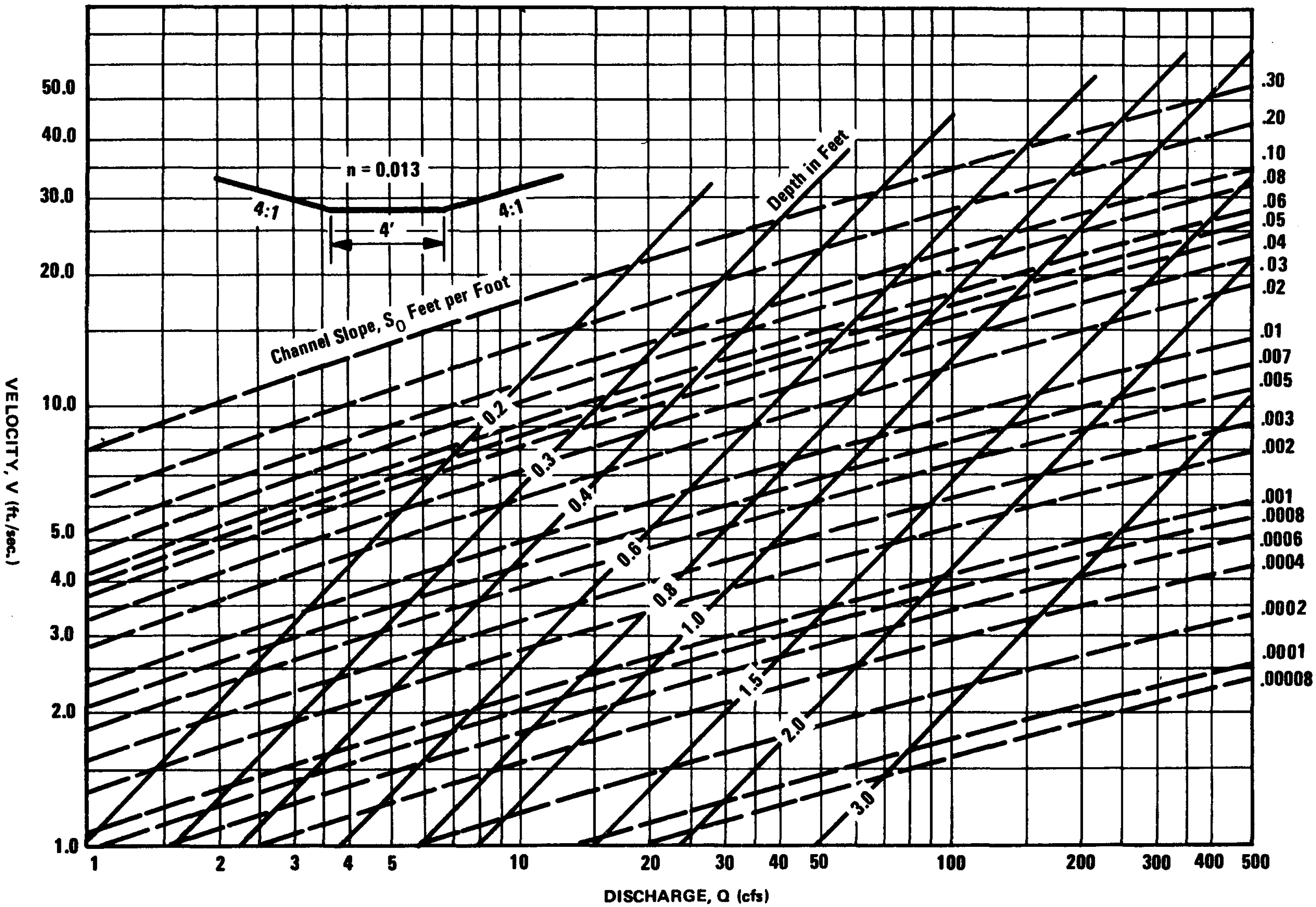
RATIO OF MAXIMUM BOUNDARY SHEAR IN SHORT BENDS TO MAXIMUM BOTTOM SHEAR IN STRAIGHT REACH

Concrete Lined Channels

Chart 35 is a capacity chart for a trapezoidal concrete channel with 4:1 side slopes and a 4 ft. bottom width. The Manning n is 0.013. This chart is similar to those in Hydraulic Design Series No. 3, "Design Charts for Open Channel Flow" (1), and is presented as an example of a capacity chart for a channel with a rigid lining. Similar charts should be developed for each channel cross section normally used by the design organization.

Since no scour occurs in rigid linings for the velocities normally encountered in drainage design, no d_{max} curves are necessary. A capacity chart relates velocity and discharge to the channel geometry, slope, and resistance.

Chart 35



From "Design of Stable Roadside Channels,"
by the State Highway Commission of Kansas, 1972.

CHANNEL CAPACITY CHART FOR TRAPEZOIDAL CONCRETE CHANNEL

VII. Example Problems

Example Problem No. 1

This first example problem is presented to illustrate the basic use of the design charts and the concepts involved.

The objective is to design a channel lining for a trapezoidal channel with a 4 foot bottom width and 4:1 side slopes. Based on an analysis of the risks of channel failure, it is decided to design the permanent lining for a 10-year recurrence interval runoff and the temporary lining for the mean annual flood flow, with a recurrence interval of 2.33 years.

To determine the runoff rate, the Rational Equation is used for the 4.3 acre drainage area. The soil is judged to have an average erodibility. Due to right-of-way constraints, the channel top width must be restricted to 12 feet. Channel slope is 5 percent. Several permanent and temporary channel lining materials are available.

Detailed calculations are shown in Figure 5. Note that the bare soil would convey very little flow on this 5-percent slope without severe erosion. Bermuda grass or rock riprap are adequate. Since 6-inch Bermuda grass is the lining chosen, temporary linings are evaluated and either a double layer of fiber glass roving and asphalt or excelsior mat are adequate to convey the mean annual flow rate of 5.0 cfs.

Should the grass be permitted to grow to a 12-inch length, the retardance of the channel would be increased. Then, the channel may not convey the 10-year runoff without overtopping its banks. A check of the 12-inch Bermuda grass reveals that d_{max} is greater than 1.0 ft., so that the top width of the flow exceeds 12 feet. Therefore, a 1.0 ft. depth of flow is used to check the channel capacity, which is found to be 15.2 cfs.

The concrete lining has no d_{max}. From Chart 35, it is found that a 1.0 ft. depth of flow in the concrete lining at a 5-percent slope would convey 154 cfs at a velocity of 19 fps. This is the hydraulic advantage and disadvantage of a concrete lining in a nutshell: high capacity coupled with a high, erosive outlet velocity.

Figure 5

DRAINAGE CHANNEL LINING DESIGN

DATE: 11/9/72

PROJECT: FAI - I (87)

DESIGNER: JMN

STATION 105 + 40 TO STATION 112 + 80

DRAINAGE AREA = 4.3 ACRES

HYDROLOGIC COMPUTATIONS:

10 year flow

$Q = CiA = (0.7)(5.0)(4.3) = 15$ cfs

Mean Annual flow

$Q = CiA = (0.7)(1.6)(4.3) = 4.8$ cfs

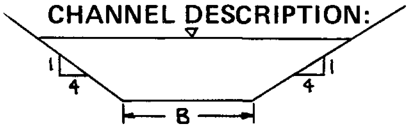
Use 5 cfs

DESIGN FLOW: Q_{10} = 15 cfs

DESIGN FLOW FOR TEMPORARY LINING: $Q_{2.33}$ = 5 cfs

SOIL ERODIBILITY: Average

CHANNEL DESCRIPTION:



MAX. TOP WIDTH = 12 ft. $T = B + (Z_1 + Z_2)d$

$= 4 + 8d$

S_o = 0.05

AVAILABLE LININGS: Permanent

1. Bare Soil
2. Bermuda Grass (6")
3. Riprap (3", 6", 12")

Temporary

1. Fiber Glass Roving
2. Excelsior Mat

LINING	d_{max}	B	$\frac{d_{max}}{B}$	$\frac{A}{Bd}$	A	$\frac{R}{d}$	R	V	Q=AV	T	REMARKS
				Chart 1		Chart 1					
Bare Soil	0.04	4	0.01	—	0.17	—	0.038	1.40	0.24	4.3	No Good
6" Bermuda	0.71	4	0.18	1.7	4.83	0.69	0.49	3.3	15.9	9.7	OK
Grass (retard. C)											
3" Riprap	0.40	4	0.10	1.4	2.24	0.78	0.31	4.9	11.0	7.2	No Good
6" Riprap	0.80	4	0.20	1.8	5.76	0.68	0.54	6.3	36.3	10.4	Ok over designed
Therefore,		use	6" Bermuda		Grass						
Temporary	Linings										
Fiber Glass											
1 Layer	0.16	4	0.04	1.16	0.74	0.87	0.14	2.5	1.85	5.3	No Good
2 Layers	0.40	4	0.10	1.35	2.16	0.77	0.31	6.0	13.0	7.2	OK
Excelsior Mat	0.45	4	0.11	1.4	2.52	0.76	0.34	2.7	6.8	7.6	OK
Check	Capacity	of	12"	Bermuda	Grass						
12" Berm. Grass	1.1	4	0.275	2.1	9.2	0.64	0.70	2.5	23.0	12.8	T>12', Use d=1
	1.0	4	0.25	2.0	8.0	0.66	0.66	1.9	15.2	12.0	
Concrete	1.0 *							19	154		High Velocity
* No dmax											Rigid Channel

Example Problem No. 2

Problem 2 illustrates the design of a rock riprap lining for channel side slopes steeper than 3:1.

Assume a trapezoidal channel with bottom width of 4 feet, permissible depth of flow of 4 feet, and side slopes of 1.5:1. Slope = 0.01.

1. From design method $(D_{50})_{bottom} = 0.5$ feet. The available stone is classified as crushed rock.

2. Determine the angle of repose. From Chart 30, the angle of repose, $\theta = 42^{o}$.

3. Determine the ratio of maximum side shear to maximum bottom shear. From Chart 31, with $B/d = 1.0$ and $Z = 1.5$, $K_1 = 0.88$.

4. Determine the ratio of critical side shear to critical bottom shear. From Chart 32, with $Z = 1.5$, and $\theta = 42^{o}$, $K_2 = 0.53$.

5. Determine the adjusted rock size for the channel sides.

$$(D_{50})_{sides} = \frac{0.88}{0.53} (D_{50})_{bottom}$$

$$= \frac{0.88}{0.53} (0.5) = 0.83 \text{ ft.}$$

Caution: If the angle of the channel side slope exceeds the rock angle of repose, the channel sides are unstable at any flow rate.

Example Problem No. 3

Design of a granular filter blanket

The following example was adapted from NCHRP Report 108, Example 3 (6). A channel will be constructed on a base material of the following characteristics:

D_{50} = 0.5 mm = 0.0016 ft.

D_{85} = 1.5 mm = 0.0049 ft.

D_{15} = 0.167 mm = 0.00055 ft.

The riprap has the following properties:

D_{50} = 200 mm = 0.66 ft.

D_{85} = 400 mm = 1.31 ft.

D_{15} = 100 mm = 0.33 ft.

Application of the preceding filter criteria results in:

$$\frac{D_{15\ \text{riprap}}}{D_{85\ \text{base}}} = \frac{0.33}{0.0049} = 67.4 \nless 5$$

$$\frac{D_{15\ \text{riprap}}}{D_{15\ \text{base}}} = \frac{0.33}{0.00055} = 600 \nless 40$$

$$\frac{D_{50\ \text{riprap}}}{D_{50\ \text{base}}} = \frac{0.66}{0.0016} = 412 \nless 40$$

Since the relationships between riprap and base do not meet the recommended dimensional criteria, a filter blanket is required.

First determine the required dimensions of the filter with respect to the base material:

$$\frac{D_{50\text{ filter}}}{D_{50\text{ base}}} < 40, \text{ so } D_{50\text{ filter}} < 40 \times 0.0016' = 0.064' \text{ (20mm)}$$

$$\frac{D_{15\text{ filter}}}{D_{15\text{ base}}} < 40, \text{ so } D_{15\text{ filter}} < 40 \times 0.00055' = 0.022' \text{ (6.7mm)}$$

$$\frac{D_{15\text{ filter}}}{D_{85\text{ base}}} < 5, \text{ so } D_{15\text{ filter}} < 5 \times 0.0049' = 0.024' \text{ (7.3mm)}$$

$$\frac{D_{15\text{ filter}}}{D_{15\text{ base}}} > 5, \text{ so } D_{15\text{ filter}} > 5 \times 0.00055' = 0.0028' \text{(0.83mm)}$$

Therefore, with respect to the base material, the filter must satisfy $D_{50\text{ filter}} < 0.064'$ and $0.0028' < D_{15\text{ filter}} < 0.022'$.

Second, determine the required filter dimensions with respect to the riprap:

$$\frac{D_{50\text{ riprap}}}{D_{50\text{ filter}}} < 40, \text{ so } D_{50\text{ filter}} > \frac{0.66'}{40} = 0.016' \text{ (4.9mm)}$$

$$\frac{D_{15\text{ riprap}}}{D_{15\text{ filter}}} < 40, \text{ so } D_{15\text{ filter}} > \frac{0.33'}{40} = 0.0082' \text{ (2.5mm)}$$

$$\frac{D_{15\text{ riprap}}}{D_{85\text{ filter}}} < 5, \text{ so } D_{85\text{ filter}} > \frac{0.33'}{5} = 0.066' \text{ (20mm)}$$

$$\frac{D_{15\text{ riprap}}}{D_{15\text{ filter}}} > 5, \text{ so } D_{15\text{ filter}} < \frac{0.33'}{5} = 0.066' \text{ (20mm)}$$

With respect to the riprap, $D_{50\ \text{filter}} > 0.016'$, $0.0082' < D_{15\ \text{filter}} < 0.066'$, and $D_{85\ \text{filter}} > 0.066'$.

Combining: $0.0082' < D_{15\ \text{filter}} < 0.022'$

$0.016' < D_{50\ \text{filter}} < 0.064'$

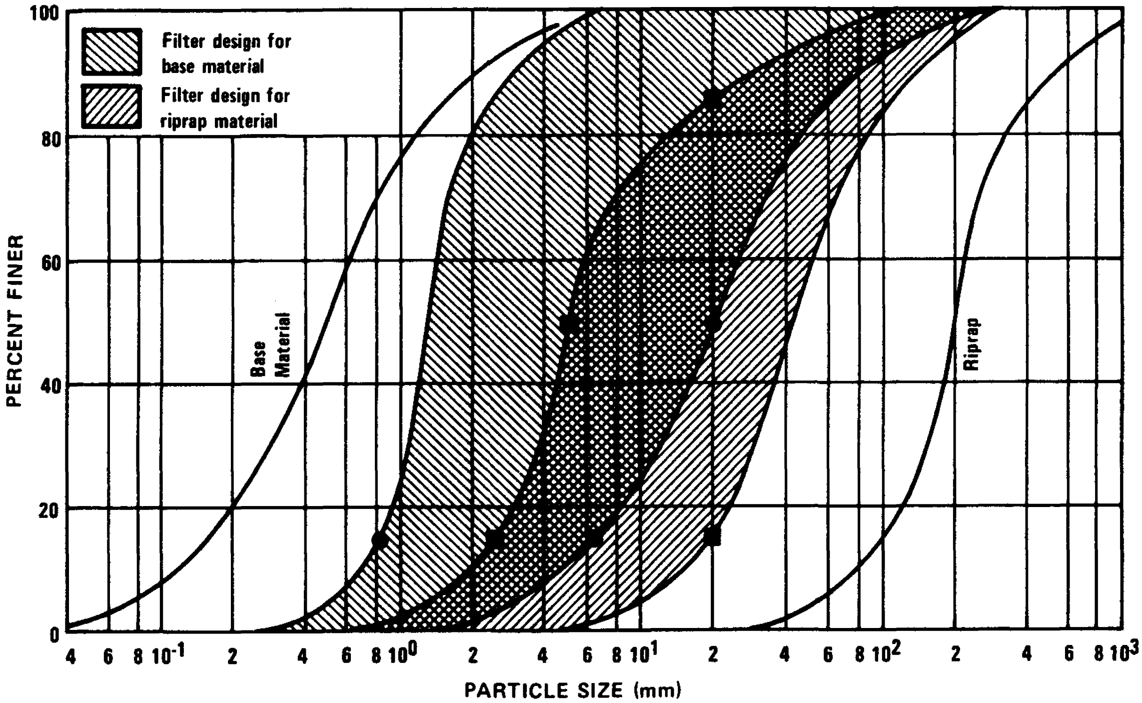
$D_{85\ \text{filter}} > 0.066'$

or, in metric units:

$2.5\text{mm} < D_{15\ \text{filter}} < 6.7\text{mm}$

$4.9\text{mm} < D_{50\ \text{filter}} < 19.5\text{mm}$

$D_{85\ \text{filter}} > 20\text{mm}$

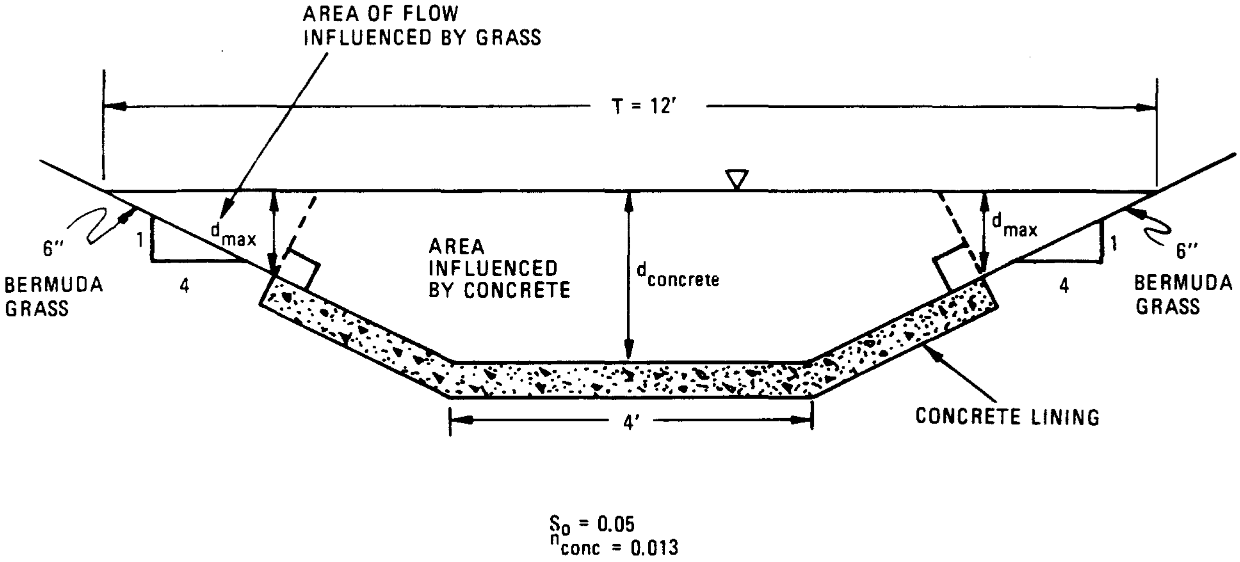


GRADATIONS OF GRANULAR FILTER BLANKET FOR EXAMPLE PROBLEM NO. 3

Example Problem No. 4

Design of a channel with a composite lining.

Compute the capacity of the channel in Example Problem No. 1, if the top width is limited to 12 feet, and the channel bottom and part of the sides are concrete lined. $S_o = 0.05$, $B = 4$ ft., $Z_1 = Z_2 = 4$. Bermuda grass is to be mowed to a 6-inch length, on the average.



Not to Scale

d_{max} (Bermuda Grass) = 0.63 ft., (Chart 19). Use lower (erodible) value to compensate for secondary currents.

For $T_{max} = 12$ ft., d (concrete) = 1.0 ft.

$$A_{total} = (4.0)(1.0) + 4\,(1.0)^2 = 8.0 \text{ ft.}^2$$

$$P_{total} = 4.0 + 2\,(\sqrt{17})(1.0) = 12.25 \text{ ft.}$$

For shear boundary, take normal to side slopes at edge of concrete lining.

$$A_{\text{Bermuda Grass}} = (4\,d_{max} + 0.25\,d_{max})_{\text{Grass}} \cdot d_{max}\text{ Grass} =$$

$$(4.25)(0.63)^2 = 1.69 \text{ ft.}^2$$

$P_{\text{Bermuda Grass}} = 2(\sqrt{17})d_{\max} = 2(\sqrt{17})(.63) = 5.20$ ft.

$R_{\text{Bermuda Grass}} = \frac{1.69}{5.20} = 0.324$ ft.

$V_{\text{Bermuda Grass}} = 0.55$ ft./sec. (Chart 25)

$Q_{\text{Bermuda Grass}} = AV = (1.69)(0.55) = 0.93$ cfs.

$A_{\text{concrete}} = A_{\text{Total}} - A_{\text{Grass}} = 8.0 - 1.69 = 6.31 \text{ ft.}^2$

$P_{\text{concrete}} = P_{\text{Total}} - P_{\text{Grass}} = 12.25 - 5.20 = 7.05$ ft.

$R_{\text{concrete}} = \frac{6.31}{7.05} = 0.895$ ft.

$$Q_{\text{concrete}} = \frac{1.486}{n} AR^{2/3} S_o^{1/2}$$

$$= \frac{(1.486)}{0.013}(6.31)(0.895)^{2/3}(.05)^{1/2} = 150 \text{ cfs}$$

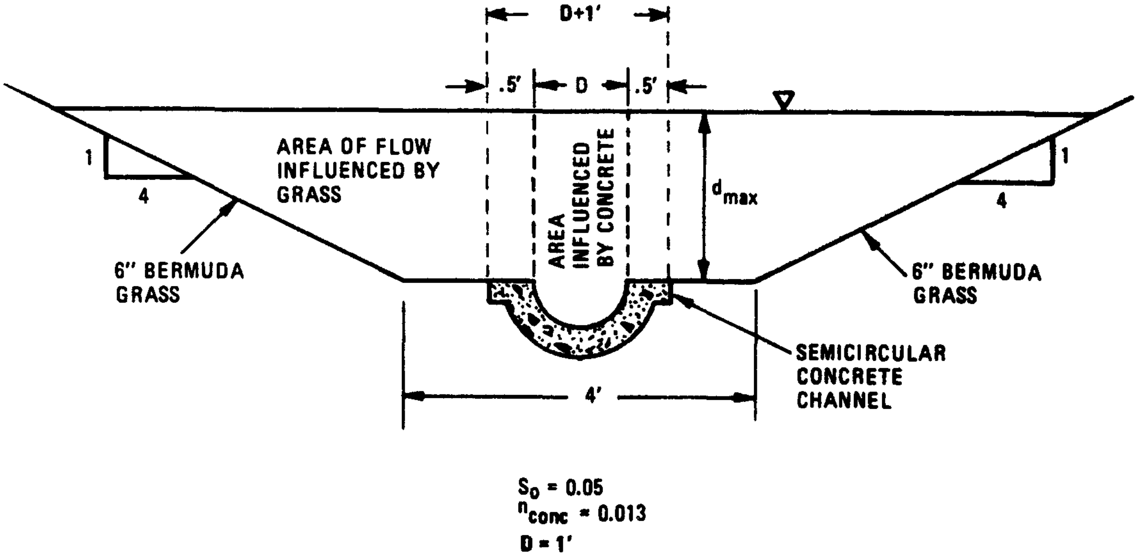
$Q_{\text{Total}} = 150 + 1 = 151$ cfs, or about the same as the totally lined channel.

Outlet velocity $= \frac{Q_{\text{Total}}}{A_{\text{Total}}} = \frac{151}{8.0} = 18.9$ ft./sec.

Example Problem No. 5

Design of a channel with a composite lining, using a semicircular low flow channel within a grass lined channel.

Assume a Bermuda Grass lined trapezoidal channel with B = 4 ft., $Z_1 = Z_2 = 4$. Assume that a 1 ft. wide semicircular channel is installed in the bed to convey perennial flow, as shown in the figure. $S_o = 0.05$. Bermuda grass is to be mowed to a 6-inch length, on the average.



Not to Scale

d_{max} (Bermuda Grass) = 0.63 ft. (Chart 19). This is a conservative value to compensate for scour potential.

$$A_{Total} = (d_{max})\,(B) + (Z)\,(d_{max})^2 + \frac{\pi D^2}{8}$$

$$= (0.63)(4) + (4)(.63)^2 + \frac{\pi(1)}{8}$$

$$= 2.52 + 1.59 + 0.39 = 4.50 \text{ ft.}^2$$

$$P_{Total} = B - D + 2\,(d_{max})\,\sqrt{Z^2 + 1} + \frac{\pi D}{2}$$

$$= 4 - 1 + 2\,(.63)\,\sqrt{17} + \frac{\pi(1)}{2}$$

$$= 4 - 1 + 5.2 + 1.57 = 9.77 \text{ ft.}$$

$$A_{concrete} = (D + 1)\ (d_{max}) + \frac{(\pi)(D^2)}{8}$$

$$= 2\ (.63) + \frac{\pi(1)}{8} = 1.65\ \text{ft.}^2$$

$$P_{concrete} = \frac{\pi D}{2} + 1\ \text{ft.} = 2.57\ \text{ft.}$$

$$R_{concrete} = \frac{A}{P} = \frac{1.65}{2.57} = 0.64\ \text{ft.}$$

$$Q_{concrete} = \frac{1.486}{n} AR^{2/3} S_o^{\ 1/2}$$

$$= \frac{(1.486)}{0.013}\ (1.65)(.64)^{2/3}(.05)^{1/2} = 31.3\ \text{cfs}$$

$$A_{Grass} = A_{Total} - A_{concrete} = 4.50 - 1.65 = 2.85\ \text{ft.}^2$$

$$P_{Grass} = P_{Total} - P_{concrete} = 9.77 - 2.57 = 7.20\ \text{ft.}$$

$$R_{Grass} = \frac{A}{P} = \frac{2.85}{7.20} = 0.395\ \text{ft.}$$

V_{Grass} = 1.55 ft./sec. (Chart 25)

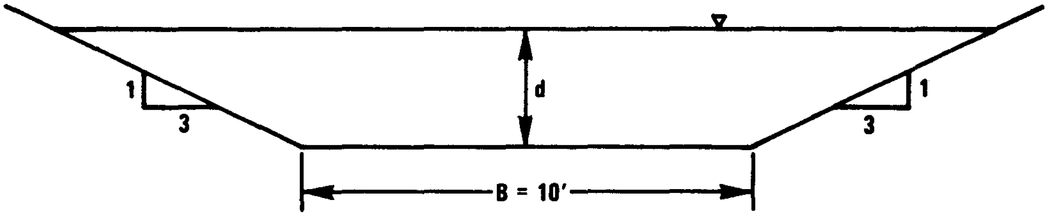
$$Q_{Grass} = AV = (2.85)(1.55) = 4.42\ \text{cfs}$$

$$Q_{Total} = Q_{concrete} + Q_{Grass} = 31.3 + 4.4 = 35.7\ \text{cfs}$$

Example Problem No. 6

Design of a bend in a channel lined with rock riprap.

Assume a trapezoidal channel with a 10 ft. bottom and 3:1 side slopes. $S_o = 0.02$. Design discharge = 150 cfs. Mean rock size in the straight reach = 0.5 ft.



$$Q = VA = \frac{1.49}{n} R^{2/3} S^{1/2} A$$

$$Q = \frac{1.49}{0.0395\, D_{50}^{1/6}} \left[\frac{Bd + Zd^2}{B + 2d\sqrt{Z^2 + 1}}\right]^{2/3} (S^{1/2})\ [Bd + Zd^2]$$

$$150 = \frac{1.49}{0.0395(0.5)^{1/6}} \left[\frac{(10 + 3d)d}{10 + 6.32\ d}\right]^{2/3} (0.02)^{1/2}\ [(10 + 3d)d]$$

$$24.91 = \frac{[(10 + 3d)d]^{5/3}}{(10 + 6.32\ d)^{2/3}}$$

By trial and error, d = 1.55 ft.

Define Bend (See Figure 2): $R_o = 100$ ft.

$$T = B + 2Zd = 10 + 2(3)(1.55) = 19.3$$

$$R_d = R_o + \left(\frac{T + B}{4}\right) = 100 + \left(\frac{19.3 + 10}{4}\right)$$

$$= 107.3 \text{ ft.}$$

$$\Delta_c = \text{arc cos } \frac{R_o}{R_d} = \text{arc cos } 0.9319 = 21^\circ$$

(a) $\Delta = 30^{o}$, so that $\Delta > \Delta_c$, and the bend is a long bend.

$$\frac{d}{B} = \frac{1.55}{10} = 0.155$$

From Chart 1, $R/d = 0.74$

$$R = 1.15$$

From Chart 29, $V = 6.6$ fps

$$\frac{V^2}{R_d} = \frac{(6.6)^2}{107.3} = 0.41$$

From Chart 33, $K_3 = 2.2$

Then, $d_{adj} = K_3(d)_{straight}$
$= 2.2(1.55) = 3.41$ ft.

Then, find a liner which will withstand a d_{max} of 3.41 ft. with $S_o = 0.02$.

From Chart 27, a rock with $D_{50} = 0.85$ ft. must be used in the bend area. Since it is not possible to predict the exact location of the maximum shear, the entire channel cross section should be protected with the same size rock.

(b) Suppose $\Delta = 15^{o}$, so that $\Delta < \Delta_c$, and the bend is a short bend. Then, use both Charts 33 and 34, as follows:

From Chart 33, $K_3' = 1.9$

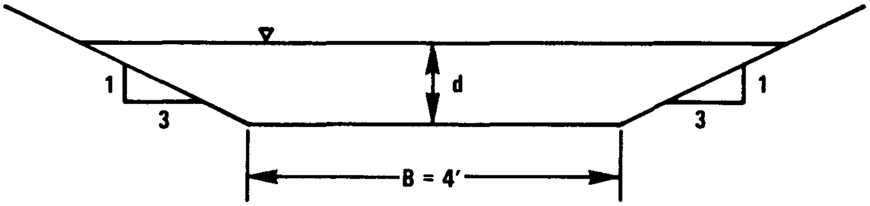
Then, $d_{adj} = K_3'(d)_{straight}$
$= 1.9(1.55) = 2.95$ ft.

From Chart 27, a rock with $D_{50} \geq 0.75$ ft. must be used in the bend area.

Example Problem No. 7

Design of a bend in a channel lined with fiber glass roving.

Assume a trapezoidal channel with a 4 ft. bottom width and 3:1 side slopes. $S_o = 0.01$. Single layer of fiber glass and asphalt. Design discharge = 12 cfs. Soil has an average erodibility.



$$Q = VA = \frac{1.49}{n} R^{2/3} S^{1/2} A$$

$$Q = \frac{1.49}{0.035} \left[\frac{Bd + Zd^2}{B + 2d\sqrt{Z^2 + 1}}\right]^{2/3} (S^{1/2})\ (Bd + Zd^2)$$

$$12 = \frac{1.49}{0.035} \left[\frac{(4 + 3d)\ d}{4 + 6.32\ d}\right]^{2/3} (0.01)^{1/2} [(4 + 3d)\ d]$$

$$2.82 = \frac{[(4 + 3d)\ d]^{5/3}}{(4 + 6.32\ d)^{2/3}}$$

By trial and error, d = 0.71 ft.

Define Bend (See Figure 2): $R_o = 15$ ft.

$$T = B + 2Zd = 4 + 2(3)(0.71) = 8.26 \text{ ft.}$$

$$R_d = R_o + \frac{T + B}{4} = 15 + \frac{8.26 + 4}{4} = 18.1 \text{ ft.}$$

$$\Delta_c = \text{arc cos} \frac{R_o}{R_d} = \text{arc cos } 0.829 = 34^\circ$$

Assume $\Delta = 40^\circ$

Since $\Delta > \Delta_c$, the bend is a long bend. Use Chart 33 only.

$$\frac{d}{B} = \frac{0.71}{4} = 0.18$$

From Chart 1, $R/d = 0.72$
$R = 0.51$

From Chart 5, $V = 2.7$ fps

$$\frac{V^2}{R_d} = \frac{(2.7)^2}{18.1} = 0.40$$

From Chart 33, $K_3 = 2.2$

Then, $d_{adj} = K_3(d)_{straight}$

$= 2.2(0.71) = 1.56$ ft.

Then, find a liner which will withstand a d_{max} of 1.56 ft. with $S_o = 0.01$.

Check two layers of fiber glass roving and asphalt.

From Chart 4, it appears that a double layer of fiber glass roving and asphalt will resist the scouring velocity in the bend.

It will not always be possible to find such a temporary lining. For example, suppose d_{adj} had been 3.2 ft. The only linings which would resist this depth of flow in a channel on a 0.01 slope are dumped rock riprap with $D_{50} > 0.4$ ft. or concrete. Thus, the bend area must be protected with one of these permanent lining materials.

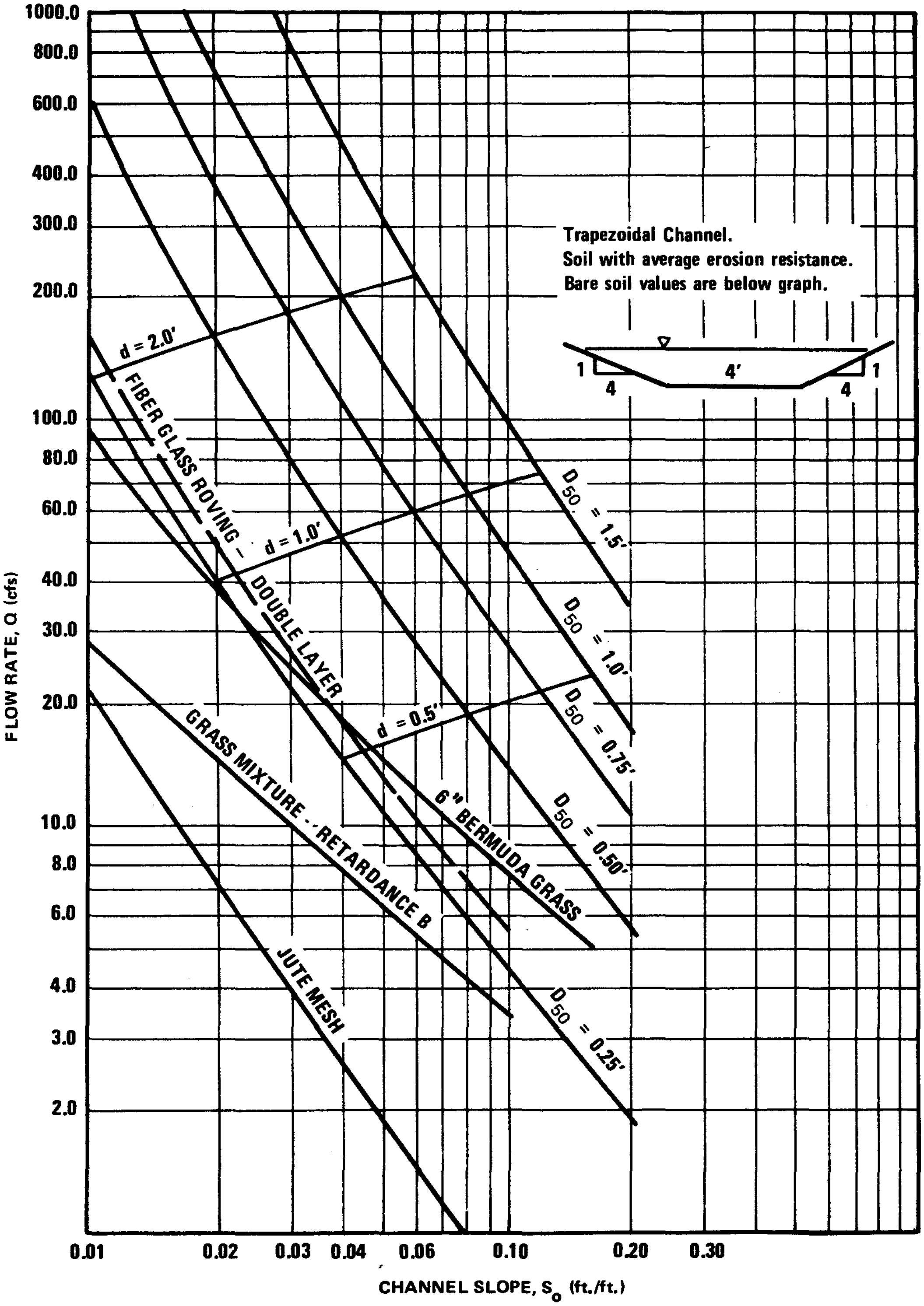
VIII. Development of Flow Rate versus Slope Curves for a Selected Channel Geometry

Design curves such as Figure 6 may be developed for a given channel geometry and a series of lining materials by the following procedure:

1. Select channel geometry.
2. Select erodibility of soil (Erosion Resistant, Very Erodible, etc.).
3. Select lining material.
4. For a series of slopes (S_o), determine d_{max} values (maximum permissible depth charts).
5. From d_{max} values, determine area (A) and hydraulic radius (R) for the selected channel geometry. (Chart 1)
6. Determine velocity from R and S_o. (Flow velocity charts)
7. $Q = AV$
8. Plot Q versus S_o for the selected lining.
9. Repeat for other lining materials.

Such curves are especially useful if certain channel geometries are frequently used. It would be helpful to show d_{max} on the curves for various liners by use of a series of labeled points. From Figure 6, the possible solutions to Example Problem No. 1 may easily be determined.

Figure 6



MAX. FLOW RATE VERSUS SLOPE FOR VARIOUS LININGS

IX. Method of Programing Channel Design Procedure

To program the channel design procedure, the same sequence should be followed as for the design method followed previously.

Charts for maximum permissible depth for various linings may be represented by power equations of the form:

$$d_{max} = a(S_o)^m$$

where a is a coefficient
and m is an exponent.

Equations for these curves may be derived graphically.

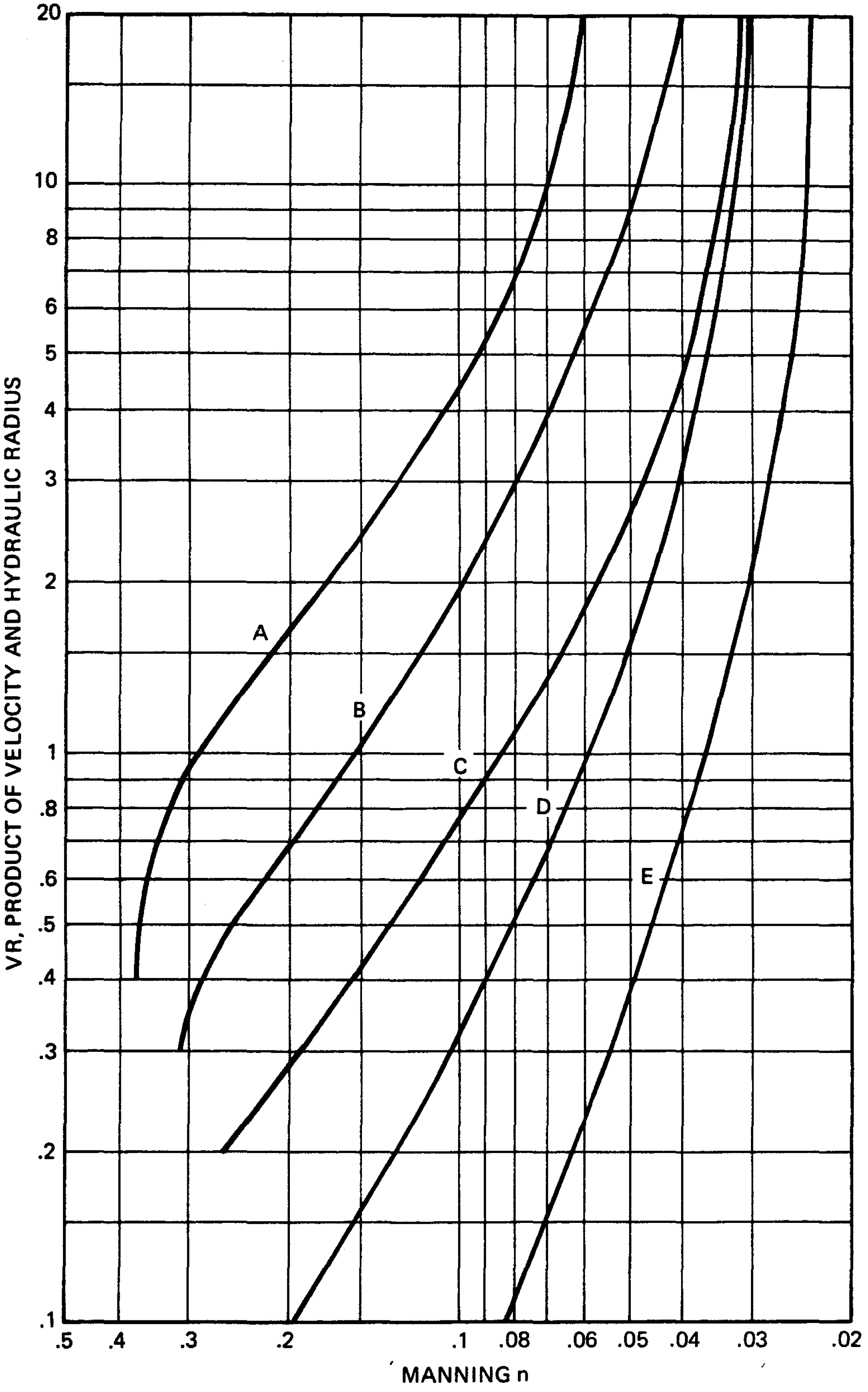
The channel geometry, area, and hydraulic radius may be easily derived through direct computation. The equations for several channel shapes are given in Appendix B.

To derive the velocity (V) versus hydraulic radius(R) curves for various liners, as shown in the flow velocity - hydraulic radius charts, proceed as follows:

For flow velocity charts for other than vegetative linings, use the empirically derived equations shown on the charts. For the vegetative linings represented in Charts 22-26, derive best fit polynomials for the curves shown in Figure 7. To utilize these curves, the polynomial should use VR as the dependent variable and Manning n as the independent variable. From d_{max} and channel geometry, define R. Then, by an iterative process, assume an n value, solve for VR, then for V. Check V using the Manning equation. If V does not check, revise n and recompute until an equality occurs.

The remainder of the design procedure is the same as presented previously. Input codes should be developed for the various available permanent and temporary channel linings and for the available channel geometries.

Figure 7



DEGREES OF VEGETAL RETARDANCE FOR WHICH GRAPHICAL SOLUTIONS OF THE MANNING FORMULA HAVE BEEN PREPARED

FROM SCS "HANDBOOK OF CHANNEL DESIGN FOR SOIL AND WATER CONSERVATION"

APPENDIX A

REFERENCES

APPENDIX A - REFERENCES

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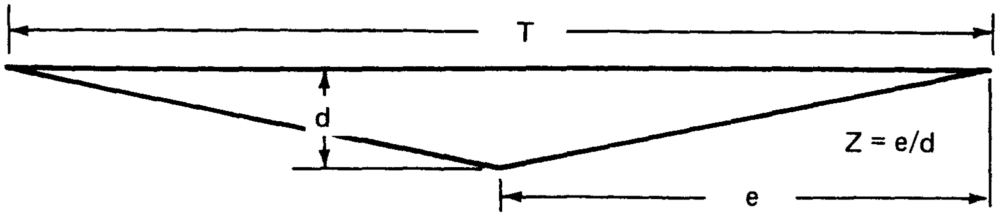
APPENDIX B

EQUATIONS FOR VARIOUS CHANNEL GEOMETRIES

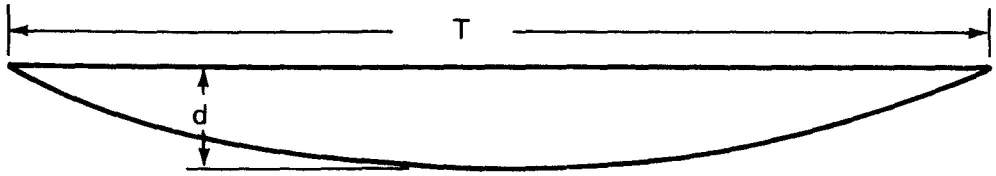


$A = Zd^2$

$P = 2d\sqrt{Z^2 + 1}$

$T = 2dZ$

V-SHAPE

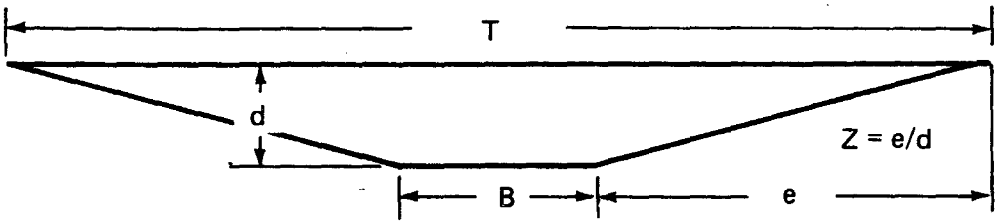


$A = \frac{2}{3} Td$

$P = \frac{1}{2}\sqrt{16d^2 + T^2} + \left(\frac{T^2}{8d}\right) \ln_e \left(\frac{4d + \sqrt{16d^2 + T^2}}{T}\right)$

$T = 1.5 \frac{A}{d}$

PARABOLIC



$A = Bd + Zd^2$

$P = B + 2d\sqrt{Z^2 + 1}$

$T = B + 2dZ$

TRAPEZOIDAL

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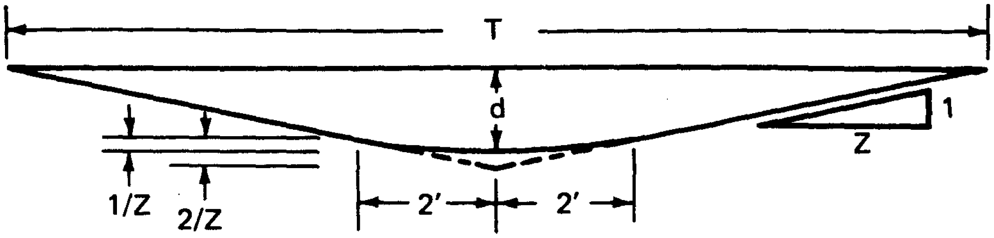


2 CASES

NO. 1

IF d ≤1/Z, THEN:

$$A = \frac{8}{3} d \sqrt{dZ}$$

$$P = 2Z \ln_e \left(\sqrt{\frac{d}{Z}} + \sqrt{1 + \frac{d}{Z}} \right) 2 \sqrt{d^2 + dZ}$$

$$T = 4 \sqrt{dZ}$$

NO. 2

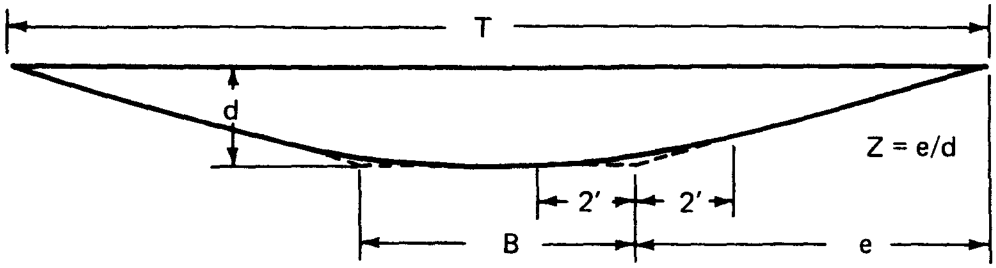
IF d >1/Z, THEN:

$$A = \frac{8}{3} Z + 4 \left(d - \frac{1}{Z} \right) + Z \left(1 - \frac{1}{Z} \right)^2$$

$$P = 2 Z \ln_e \left(\frac{1}{Z} + \sqrt{\frac{Z^2 + 1}{Z}} \right) + 2 \sqrt{\frac{1 + Z^2}{Z}} + 2 \left(d - \frac{1}{Z} \right) \sqrt{1 + Z^2}$$

$$T = 2Z \left(d + \frac{1}{Z} \right)$$

V-SHAPE WITH ROUNDED BOTTOM



2 CASES

NO. 1

IF d ≤2/Z, THEN:

$$A = d(B-4) + 8d\sqrt{\frac{2dZ}{3}}$$

$$P = 2\sqrt{2dZ}\sqrt{1+\frac{d}{2Z}} + 4Z\ln_e\left(\frac{\sqrt{2dZ}}{2Z} + \sqrt{1+\frac{d}{2Z}}\right) + B - 4$$

$$T = B + 2dZ$$

NO. 2

IF d >2/Z, THEN:

$$A = 2\frac{(B-4)}{Z} + \frac{32}{3Z} + (B+4)\left(d-\frac{2}{Z}\right) + Z\left(d-\frac{2}{Z}\right)^2$$

$$P = (B-4) + 4\sqrt{1+\frac{1}{Z^2}} + 4Z\ln_e\left(\sqrt{1+\frac{1}{Z^2}} + \frac{1}{Z}\right) + 2\left(d-\frac{2}{Z}\right)\sqrt{1+Z^2}$$

$$T = B + 2dZ$$

TRAPEZOIDAL WITH ROUNDED CORNERS

APPENDIX C

DEVELOPMENT OF DESIGN CHARTS AND PROCEDURES

DEVELOPMENT OF DESIGN CHARTS AND PROCEDURES

The design charts and procedures of this circular were obtained and developed principally from References 3 and 4 for temporary channel linings, Reference 5 for vegetative linings, and Reference 6 for rock riprap linings. The purpose of this Appendix is to describe modifications to the techniques in those reports.

Chart 1 - developed from the equations for the geometry of a trapezoidal channel. R/d curves are approximate for non-symmetrical channels. Similar charts for other channel geometries may be developed from the equations in Appendix B.

Charts 2 and 3 - d_{max} curve and V-R curve for unprotected soil are from Reference 3.

Chart 4 - d_{max} curves for single and double layers of fiber glass roving from Reference 4. Cox defined a single curve for one- and two-layer applications. The estimated range of d_{max} from erodible soil to erosion resistant soil is based on results from Reference 3 on fiber glass roving with Erosionet 315.

Charts 5 and 6 - V-R curves for a single and double layer of fiber glass roving and asphalt are developed from the Manning equation using n values presented in Reference 4.

Charts 7 and 8 - d_{max} curve and V-R curve for jute mesh are from Reference 3.

Charts 9 and 10 - d_{max} curve and V-R curve for excelsior mat are from Reference 3.

Charts 11 and 12 - d_{max} curve and V-R curve for straw held with Erosionet 315 are from Reference 3.

Charts 13 and 14 - d_{max} curve and V-R curve for 3/8-inch fiber glass mat are from Reference 3.

Charts 15 and 16 - d_{max} curve and V-R curve for 1/2-inch fiber glass mat are from Reference 3.

Charts 17 and 18 - d_{max} curve and V-R curve for Erosionet 315 are from Reference 3.

Chart 19 - d_{max} curves for Bermuda grass of various lengths. Developed from References 3 and 5. MSU tests were run on channel slopes of 7.5, 10.0, and 12.5 percent; thus, slope effects were not well defined since the range of slopes tested was very narrow. Curves in Reference 3 were adjusted based on maximum permissible velocities from Reference 5 as shown in Table C-1, and Retardance definitions as shown in Table C-2.

TABLE C-1.--Permissible velocities for channels lined with vegetation
The values apply to average, uniform stands of each type of cover.

Cover	Slope range[2]	Permissible velocity[1]	
		Erosion resistant soils	Easily eroded soils
	Percent	Ft. per sec.	Ft. per sec.
Bermudagrass	0-5	8	6
	5-10	7	5
	over 10	6	4
Buffalograss Kentucky bluegrass Smooth brome Blue grama	0-5	7	5
	5-10	6	4
	over 10	5	3
Grass mixture	0-5	5	4
	5-10	4	3
Lespedeza sericea Weeping lovegrass Yellow bluestem Kudzu Alfalfa Crabgrass	[3]0-5	3.5	2.5
Common lespedeza[4] Sudangrass[4]	[5]0-5	3.5	2.5

From SCS "Handbook of Channel Design for Soil and Water Conservation"(5)

[1] Use velocities exceeding 5 feet per second only where good covers and proper maintenance can be obtained.

[2] Do not use on slopes steeper than 10 percent except for side slopes in a combination channel.

[3] Do not use on slopes steeper than 5 percent except for side slopes in a combination channel.

[4] Annuals--used on mild slopes or as temporary protection until permanent covers are established.

[5] Use on slopes steeper than 5 percent is not recommended.

TABLE C-2.--Classification of vegetal covers as to degree of retardance

Note: Covers classified have been tested in experimental channels. Covers were green and generally uniform.

Retardance	Cover	Condition
A	Weeping lovegrass	Excellent stand, tall, (average 30")
	Yellow bluestem Ischaemum ..	Excellent stand, tall, (average 36")
B	Kudzu	Very dense growth, uncut
	Bermudagrass	Good stand, tall (average 12")
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses)	Good stand, unmowed
	Weeping lovegrass	Good stand, tall, (average 24")
	Lespedeza sericea	Good stand, not woody, tall (average 19")
	Alfalfa	Good stand, uncut, (average 11")
	Weeping lovegrass	Good stand, mowed, (average 13")
	Kudzu	Dense growth, uncut
	Blue grama	Good stand, uncut,(average 13")
C	Crabgrass	Fair stand, uncut (10 to 48")
	Bermudagrass	Good stand, mowed (average 6")
	Common lespedeza	Good stand, uncut (average 11")
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (6 to 8 inches)
	Centipedegrass	Very dense cover (average 6 inches)
	Kentucky bluegrass	Good stand, headed (6 to 12 inches)
D	Bermudagrass	Good stand, cut to 2.5-inch height
	Common lespedeza	Excellent stand, uncut (average 4.5")
	Buffalograss	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture--fall, spring (Orchardgrass, redtop, Italian ryegrass, and common lespedeza)	Good stand, uncut (4 to 5 inches)
	Lespedeza sericea	After cutting to 2-inch height. Very good stand before cutting.
E	Bermudagrass	Good stand, cut to 1.5 inches height
	Bermudagrass	Burned stubble.

From SCS "Handbook of Channel Design for Soil and Water Conservation"(5)

To derive d_{max} curves for a given vegetation and length, the following procedure was used:

1. For a series of slopes, determine the permissible velocities for erosion resistant and easily eroded soils.

2. Assume that the permissible velocity is the mean central velocity. This is verified in Reference 5.

3. Determine the Retardance for the selected vegetation and length from Table C-2.

4. Enter Charts 22-26, for the Retardance, and read R for the given V_{max} and slope, S_o.

5. For the mean central velocity, R = d. Therefore, the R derived in step 4 is equivalent to d_{max}.

6. Plot derived d_{max} values and draw a best fit line for Erodible and Erosion Resistant Soils.

For example, for 6-inch Bermuda Grass on a 7 percent slope:

V_{max} = 5 to 7 ft./sec. (Table C-1)

Retardance = C (Table C-2)

R = 0.51 to 0.64 ft. (Chart 24)

Therefore, d_{max} = 0.51' for Erodible Soil

d_{max} = 0.64' for Erosion Resistant Soil

The same procedure may be followed to develop d_{max} curves for any grass listed in Table C-1.

Chart 20	- d_{max} curves for Grass Mixtures. Developed from Tables C-1 and C-2 as described for Chart 19.
Chart 21	- d_{max} curves for Common Lespedeza of various lengths were developed from Tables C-1 and C-2 as described for Chart 19.
Charts 22 through 26	- V-R curves for vegetations of Retardances A-E are from Reference 5. Classifications of vegetations into retardance categories are given in Table C-2.
Chart 27	- d_{max} curves for rock riprap. Developed from modifications of the methods of Reference 6. From Figure C-1, it appears that $\tau_c = 5\ D_{50}$ fits the data well. Anderson suggests the conservative use of $\tau_c = 4\ D_{50}$. However, this may be overly conservative since:

1. Rock riprap is generally oversized because of available gradations. The required size is determined and the next larger available size is chosen.

2. The design flow, Q, often occurs only at the lower ends of the riprap lined drainage channel. The remainder of the channel is understressed.

3. Riprap lined channels are self-healing and, should some damage occur, repairs are generally simple and economical. Therefore, $\tau_c = 5\ D_{50}$ is considered to be sufficiently conservative.

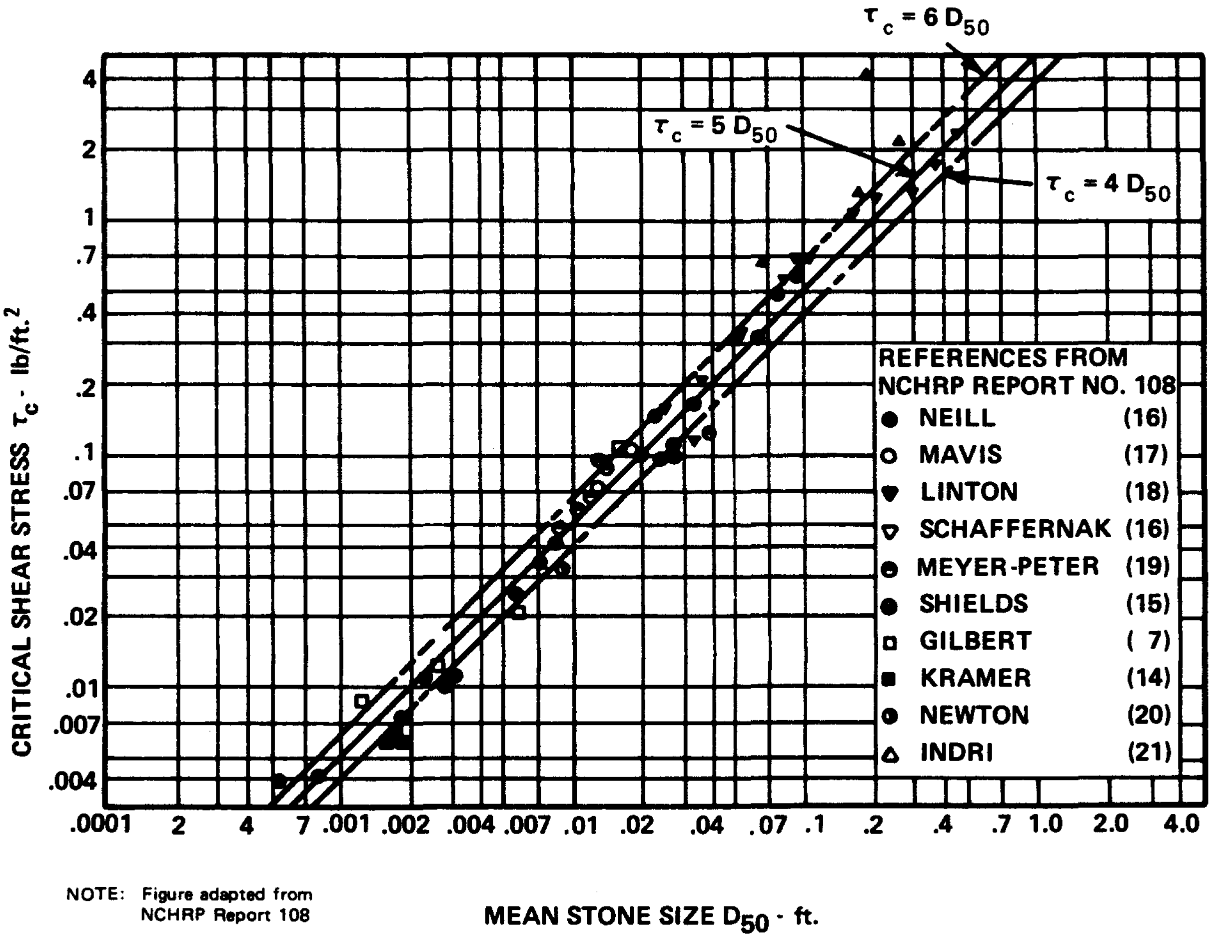
Rather than using 1.5 $\gamma R S_o$, for $(\tau_o)_{max}$ as suggested by Anderson, $\gamma d S_o$ is used, which better represents the maximum shear stress at the bottom in the center of a wide channel, such as those used in highway drainage. This is illustrated in Figures C-2 and C-3.

Setting $(\tau_o)_{max} = \tau_c$

$$\gamma d S_o = 5\ D_{50}$$

$$d_{max} = \frac{5\ D_{50}}{\gamma\ S_o}$$

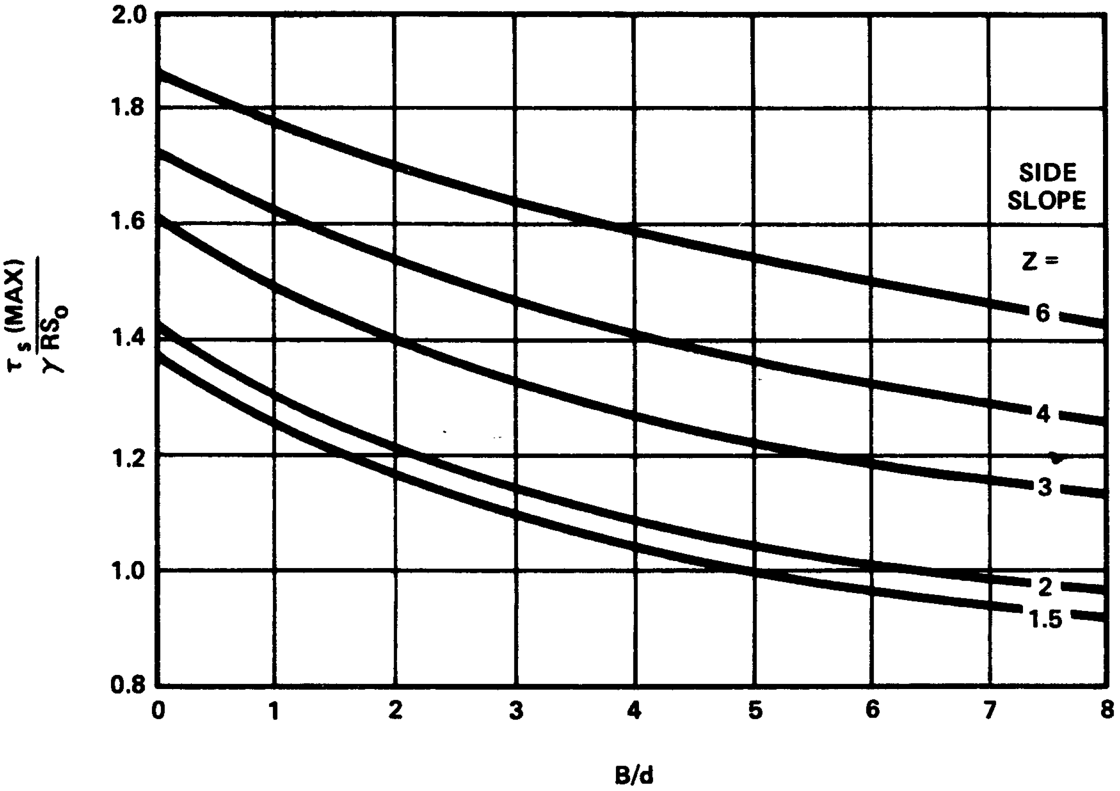
Figure C-1



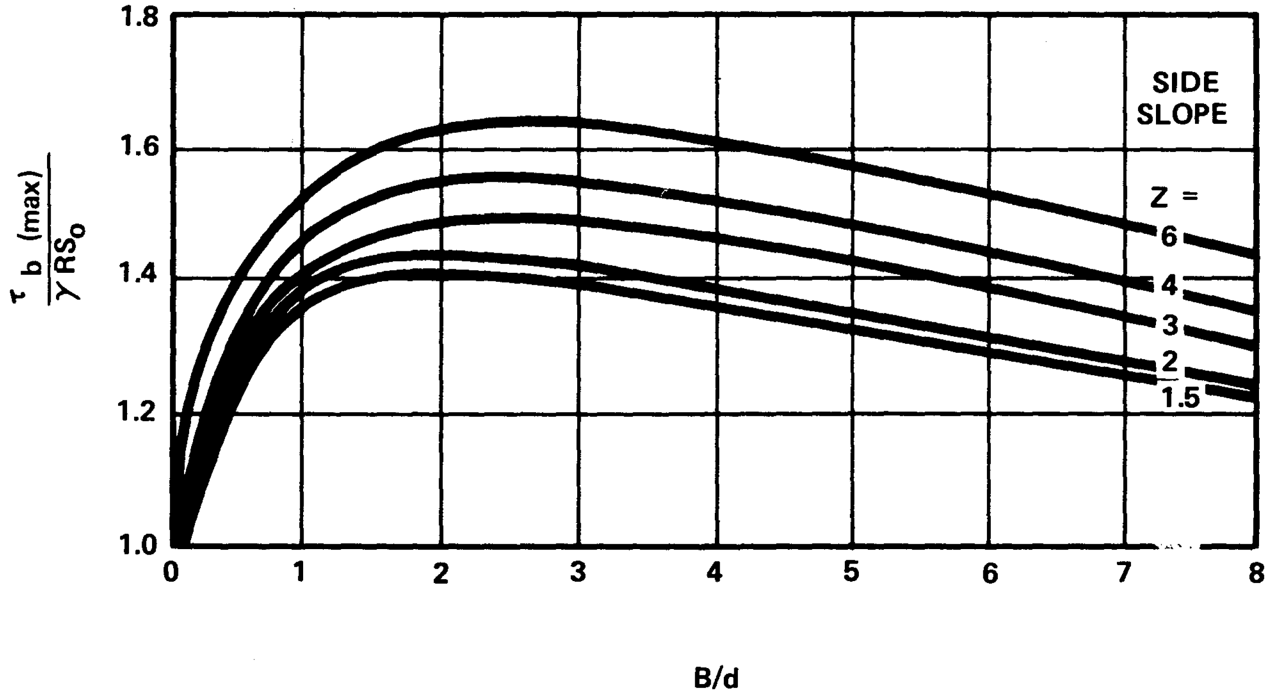
NOTE: Figure adapted from NCHRP Report 108

CRITICAL BOUNDARY SHEAR AT INCIPIENT MOVEMENT IN TERMS OF STONE SIZE

Figure C-2



MAXIMUM BOUNDARY SHEAR STRESS
ON SIDES OF TRAPEZOIDAL CHANNELS



MAXIMUM BOUNDARY SHEAR STRESS

ON BOTTOM OF TRAPEZOIDAL CHANNELS

Note that the largest stone size tested in developing the curves of Figure C-1 had a D_{50} of about 0.5 feet. Thus, for large stones or d_{max} values, the relationship above may be somewhat conservative. However, until more definitive data becomes available, no reduction in stone size is recommended in large channels.

Charts 28 and 29 - V-R curves for rock riprap. Developed using the Manning equation and the relationship for n from NCHRP Report No. 108 (6):

$$n = 0.0395\ D_{50}{}^{1/6}$$

Figure C-4 illustrates the data used to develop the relationship.

Chart 30 - Angle of Repose of Rock Riprap is from Reference 6.

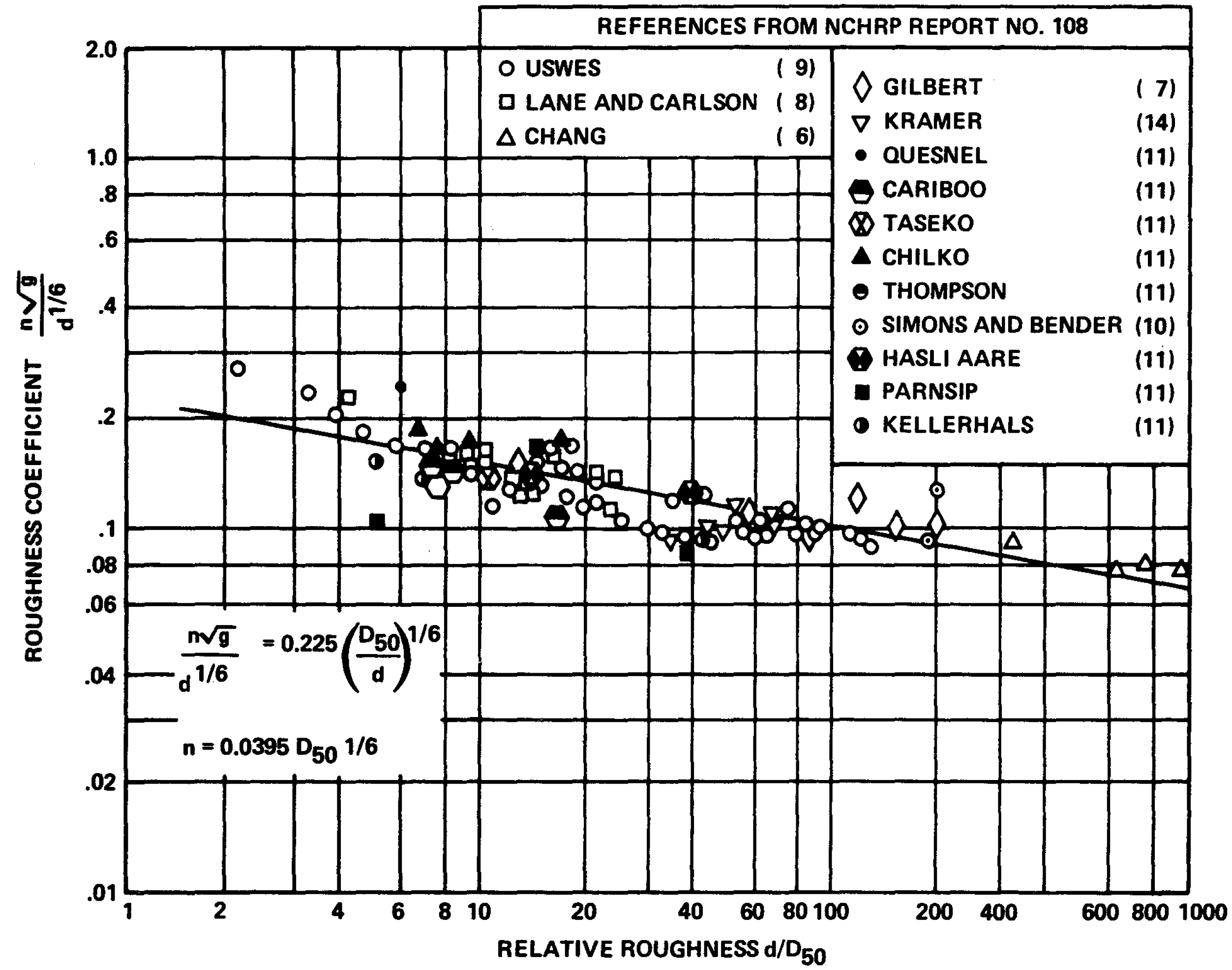
Chart 31 - Distribution of Boundary Shear Around Wetted Perimeter of Trapezoidal Channels is from Reference 6.

Chart 32 - Ratio of Critical Shear on Sides to Critical Shear on Bottom for Noncohesive Sediment is from Reference 6.

Chart 33 - The Ratio of Maximum Boundary Shear in Bends to the Maximum Bottom Shear in a Straight Reach was developed by F. J. Watts while employed by the Federal Highway Administration in 1975. The relationship is based on the assumption that, in a bend, direct impingement of the flow velocity on the rock is the main factor causing rock movement. (Refer to Figure 4, main text).

Further, it is assumed that the significant bend radius is the mean radius of the outside bank, R_d. With all other variables constant, a decrease in R_d will cause an increase in the deflection of the incoming flow with resultant run-up and flow-back of surging flow on the bank surface. Therefore, the shear correction factor will vary inversely with R_d ($K_3 \propto \frac{1}{R_d}$).

Figure C-4



VARIATION OF MANNING n WITH RELATIVE ROUGHNESS OF CHANNEL BED

Also, the height of runup and the drag force exerted by the flow on the bank surface is directly proportional to V^2 ($K_3 \propto V^2$).

Combining the above, $K_3 \propto \frac{V^2}{R_d}$.

From "Bank and Shore Protection in California Highway Practice," State of California, Department of Public Works, Division of Highways, 1960, page 110, the impinging velocity on the outside of bends is 4/3 V, while on straight reaches the impinging velocity is 2/3 V. Thus, the bend impinging velocity is twice the impinging velocity in a straight reach. Since the rock D_{50} is proportional to V^2, shear in a bend should vary from 1 to 4 times that in a straight reach. ($K_3 = 1$ to 4).

It was assumed for a value of $\frac{V^2}{R_d} = 0.01$, $K_3 = 1$ and for a value of $\frac{V^2}{R_d} = 1.0$, $K_3 = 4$.

It was also assumed that K_3 varies linearly from 1 to 4. Thus, Chart 33 was formulated, which produces higher values of K_3 than Figure 17 in Reference 6.

Some empirical substantiation of Chart 33 was found in "Hydraulic Design of Flood Control Channels," Corps of Engineers EM 1110-2-1601, Plate 33, page III-35, and in "Flow Dynamics in Trapezoidal Open Channel Bends," by Khalid S. Al-Shaikh Ali, CER 64KSA19, Colorado State University, Fort Collins, Colorado, May 1964.

Source	$\frac{V^2}{R_d}$	K_3	Type Channel
EM 1110-2-1601	0.28	1.63	Smooth
EM 1110-2-1601	0.21	2.0	Rough
CER 64KSA19	0.18	1.07	Smooth
CER 64KSA19	0.53	2.5	Smooth
CER 64KSA19	0.34	1.43	Smooth

These may be compared with Chart 33. However, very few actual data points are available for flow in bends.

Chart 34 - The Ratio of Maximum Boundary Shear in Short Bends to Maximum Bottom Shear in a Straight Reach is based on a straight line interpolation between a bend long enough to develop the maximum shear value and a straight channel. It has been assumed that the maximum shear can be developed if the bend has an internal angle $\geq \Delta_c$, as defined by Point A in Figure 4, main text. For lesser values of Δ, the value of K_3 is reduced proportionally. If $\Delta = 0$, $K_3 = 1$.

Chart 35 - Capacity Chart for a Trapezoidal Concrete Channel was obtained from "Design of Stable Roadside Channels," State Highway Commission of Kansas.

APPENDIX D

SAMPLE SPECIFICATIONS

SAMPLE SPECIFICATIONS

The sample specifications in this Appendix are presented for the information of the designer, and may be modified as desired.

The rock riprap specifications are from Reference 2, and the specifications for jute matting (mesh), fiber glass roving, asphalt mulch, and bituminous materials are from Reference 4.

For convenience, the specifications from HEC No. 11 (2) have been included for the following rigid rock riprap channel lining materials:

Wire Enclosed Riprap
Grouted Riprap
Concrete Riprap in Bags
Concrete Slab Riprap

SECTION 612 - RIPRAP

612.01 Description. This work consists of furnishing all plant, labor, equipment, and materials and performing all work necessary to place a protective covering of erosion-resistant material on the slopes of embankments, dikes, or streambanks, at culvert inlets and outlets, on bottoms and side slopes of channels, at abutment wings, at structure foundations, at other locations shown on the plans, or as directed by the engineer. The work shall be done in accordance with these specifications and applicable special provisions and in conformity with the lines and grades shown on the plans or established by the engineer.

The types of riprap included in this specification are:

(a) Dumped Riprap. Dumped riprap consists of stone or broken concrete dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids.

(b) Wire-Enclosed Riprap. Wire-enclosed riprap consists of mats or baskets fabricated from wire mesh, filled with stone, connected together and anchored to the slope. Details of construction may differ depending upon the degree of exposure and the service, whether used for revetment or used as a toe protection for the other types of riprap.

(c) Grouted Riprap. Grouted riprap consists of riprap with all or part of the interstices filled with portland cement mortar.

(d) Concrete Riprap in Bags. Concrete riprap in bags consists of concrete in cement sacks or suitable burlap bags.

(e) Concrete-Slab Riprap. Concrete-slab riprap consists of concrete, plain or reinforced, poured in place or precast concrete blocks.

(f) Filter Blanket. A filter blanket consists of one or more layers of graded material placed on the bank before placing the riprap in order to prevent the bank material from passing through the riprap protection. The thickness and gradation of filter blanket will be shown on the plans.

MATERIALS

612.02 Materials. All materials shall meet the following requirements:

(a) Dumped Riprap. Stone used for dumped riprap shall be hard, durable, angular in shape; resistant to weathering and to water action; free from overburden, spoil, shale and organic material; and shall meet the gradation requirements for the class specified. Neither breadth nor thickness of a single stone should be less than one-third its length. Rounded stone or boulders will not be accepted unless authorized by special provisions. Broken concrete may be substituted for stone when authorized by special provisions. Shale and stone with shale seams are not acceptable. The minimum weight of the stone shall be 155 pounds per cubic foot as computed by multiplying the specific gravity (bulk-saturated-surface-dry basis, AASHO Test T 85) times 62.3 pounds per cubic foot.

The sources from which the stone will be obtained shall be selected well in advance of the time when the stone will be required in the work. The acceptability of the stone will be determined by service records and/or by suitable tests. If testing is required, suitable samples of stone shall be taken in the presence of the engineer at least 25 days in advance of the time when the placing of riprap is expected to begin. The approval of some rock fragments from a particular quarry site shall not be construed as constituting the approval of all rock fragments taken from that quarry.

In the absence of service records, resistance to disintegration from the type of exposure to which the stone will be subjected will be determined by any or all of the following tests as stated in the special provisions:

1. When the riprap must withstand abrasive action from material transported by the stream, the abrasion test in the Los Angeles machine shall also be used. When the abrasion test in the Los Angeles machine (AASHO Test T 96) is used, the stone shall have a percentage loss of not more than 40 after 500 revolutions.

2. In locations subject to freezing or where the stone is exposed to salt water, the sulfate soundness test (AASHO Test T 104 for ledge rock

using sodium sulfate) shall be used. Stones shall have a loss not exceeding 10 percent with the sulfate test after five cycles.

3. When the freezing and thawing test (AASHO Test 103 for ledge rock procedure A) is used as a guide to resistance to weathering, the stone should have a loss not exceeding 10 percent after 12 cycles of freezing and thawing.

Stone shall be free from overburden, spoil, shale, and organic material and shall meet the following gradation requirements for the class specified:

Size of stone		Percent of total weight smaller than the given size
Class I		
100 lb.		100
60 lb.		80
25 lb.		50
2 lb.	not to exceed	10
Class II		
700 lb.		100
500 lb.		80
200 lb.		50
20 lb.	not to exceed	10
Class III		
2,000 lb.		100
1,400 lb.		80
700 lb.		50
40 lb.	not to exceed	10

Each load of riprap shall be reasonably well graded from the smallest to the maximum size specified. Stones smaller than the specified 10 percent size and spalls will not be permitted in an amount exceeding 10 percent by weight of each load.

Control of gradation will be by visual inspection. The contractor shall provide two samples of rock of at least 5 tons each, meeting the gradation for the class specified. The sample at the construction site may be a part of the finished riprap covering. The other sample shall be provided at the quarry. These samples shall be used as a frequent reference for judging the gradation of the riprap supplied. Any difference of opinion between the engineer and the contractor shall be resolved by dumping and checking the gradation of two random truck loads of stone. Mechanical equipment, a sorting site, and labor needed to assist in checking gradation shall be provided by the contractor at no additional cost to the State.

(b) Wire-Enclosed Riprap. Stone used for wire-enclosed riprap shall meet the requirements of section 612.02(a) except for size and gradation of stone. Stone used shall be well graded within the sizes available and 70 percent, by weight, shall exceed in least dimension the wire mesh opening. The maximum size of stone, measured normal to the slope, shall not exceed the mat thickness.

Wire mesh shall be galvanized woven fencing conforming to the specifications for Fence Fabric, section _____, and shall be of the gage and dimensions shown on the plans. Ties and lacing wire shall be No. 9 gage galvanized unless otherwise specified.

(c) Grouted Riprap. Grout for grouted riprap shall consist of one part portland cement and three parts sand, thoroughly mixed with water to produce grout having a thick creamy consistency. The minimum amount of water should be used to prevent excess shrinkage of the grout after placement. The cement, sand, and mixing shall conform to the specifications for Concrete Masonry, section _____.

The stones for grouted riprap shall meet the requirements of section 612.02(a) except for size and gradation. Size and gradation will be specified for each particular project. Stone shall be free of fines which prevent penetration of grout and care shall be taken in placing the stone to keep earth or sand from filling the spaces between the stones.

(d) Concrete Riprap in Bags. Concrete riprap in bags shall consist of class C concrete in cement sacks or suitable burlap bags. Each bag shall contain about 2/3 cubic foot of concrete, securely tied if in cement sacks or folded if in burlap bags, and shall immediately be placed in the work.

(e) Concrete-Slab Riprap. Concrete for concrete-slab riprap shall be class B unless the riprap is exposed to salt water, in which case it shall be class A. The slabs shall be of two types, plain concrete or reinforced. If reinforcement is specified, it shall be furnished as shown on the plans. Except as modified herein, materials and construction shall conform to specifications for Concrete Masonry, section _____.

(f) Filter Blanket. The filter blanket shall consist of one or more layers of gravel, crushed rock, or sand of the thickness shown on the plans. The gradation of material in each layer of the filter blanket shall meet the requirements of the special provisions. All material comprising the filter blanket shall be composed of tough, durable particles, reasonably free from thin, flat, and elongated pieces, and shall contain no organic matter or soft, friable particles in quantities in excess of those approved by the engineer.

CONSTRUCTION REQUIREMENTS

612.03 General. Slopes to be protected by riprap shall be free of brush, trees, stumps, and other objectionable material and be dressed to a smooth surface. All soft or spongy material shall be removed to the depth shown on the plans or as directed by the engineer and replaced with approved material. Filled areas will be compacted as specified for Embankments, section _____. A toe trench as shown on the plans shall be dug and maintained until the riprap is placed.

Protection for structure foundations shall be provided as early as the foundation construction permits. The area to be protected shall be cleaned of waste materials and the surfaces to be protected prepared as shown on the plans. The type of riprap specified will be placed in accordance with these specifications as modified by the special provisions.

When shown on the plans, a filter blanket shall be placed on the prepared slope or area to be provided with foundation protection as specified in section 612.09 before the stone is placed.

612.04 Dumped Riprap. Stone for riprap shall be placed on the prepared slope or area in a manner which will produce a reasonably well-graded mass of stone with the minimum practicable percentage of voids. The entire mass of stone shall be placed so as to be in conformance with the lines, grades, and thicknesses shown on the plans. Riprap shall be placed to its full course thickness at one operation and in such a manner as to avoid displacing the underlying material. Placing of riprap in layers, or by dumping into chutes, or by similar methods likely to cause segregation, will not be permitted.

The larger stones shall be well distributed and the entire mass of stone shall conform to the gradation specified in section 612.02. All material going into riprap protection shall be so placed and distributed that there will be no large accumulations of either the larger or smaller sizes of stone.

It is the intent of these specifications to produce a fairly compact riprap protection in which all sizes of material are placed in their proper proportions. Hand placing or rearranging of individual stones by mechanical equipment may be required to the extent necessary to secure the results specified.

Unless otherwise authorized by the engineer, the riprap protection shall be placed in conjunction with the construction of the embankment with only sufficient lag in construction of the riprap protection as may be necessary to allow for proper construction of the portion of the embankment protected and to prevent mixture of embankment and riprap. The contractor shall maintain the riprap protection until accepted, and any material displaced by any cause shall be replaced to the lines and grades shown on the plans at no additional cost to the State.

When riprap and filter material are dumped under water, thickness of the layers shall be increased as shown on the plans; and methods shall be used that will minimize segregation.

612.05 Wire-Enclosed Riprap. The plans and supplemental specifications will show details of wire-enclosed riprap and specify the construction procedure to be used.

612.06 Grouted Riprap. The stones shall be placed on the prepared slope substantially to the dimensions shown on the plans. The stones shall be thoroughly moistened and any excess of fines shall be sluiced to the underside of the stone blanket before grouting.

The grout may be delivered to the place of final deposit by any means that will insure uniformity and prevent segregation of the grout. If penetration of grout is obtained by gravity flow into the interstices, the grout will be spaded or rodded into the interstices to completely fill the voids in the stone blanket. Pressure grouting shall not unseat the stones; and after placing by this method, the grout shall be spaded or rodded into the voids. Penetration of the grout shall be to the depth specified on the plans. When a rough surface is specified, stone shall be brushed until from one-fourth to one-half of the depth of surface stone is exposed. For a smooth surface, grout shall fill the interstices to within a 1/2 inch of the surface.

Weep holes shall be provided through the blanket as shown on the plans or as directed by the engineer. Where the depth specified for grouting is in excess of 12 inches, such as cutoff walls, the riprap shall be placed in lifts of 12 inches or less and each lift shall be grouted prior to placing the next lift. The succeeding lifts shall be constructed and grouted before the grout in the previous lift has hardened.

Grout shall be placed only when the temperature is above 35°F. and rising. It shall be protected from freezing and cured as specified in section _____.

612.07 Concrete Riprap in Bags. Cloth cement sacks about two-thirds filled and securely tied, or burlap grain sacks containing about 2/3 cubic feet of concrete and folded at the top, are immediately placed in position after filling. The fold on burlap bags shall be placed underneath the bag for headers and against the previously placed sack for stretchers. When the protected slope is 1-1/2:1 or steeper, a bed consisting of two rows of sacks placed as stretchers shall be followed by a row of sacks placed as headers. Succeeding rows of sacks shall be placed as stretchers with joints between sacks staggered. Each sack shall be hand placed and pushed into firm contact with adjacent sacks. On slopes flatter than 1-1/2:1 all rows after the bed row shall be placed as headers.

Cutoffs and weep holes shall be placed as shown on the plans or as directed by the engineer. The finished work shall present a neat appearance with parallel rows of sacks, and no sacks shall protrude more than 3 inches from the finished surface.

The riprap shall be placed only when the temperature is above 35°F. and rising. It will be protected from freezing and cured as specified in section _____.

Whenever placement of concrete riprap in bags is delayed sufficiently to affect the bond between succeeding courses, a small trench about half the depth of a sack shall be excavated back of the last row of sacks in place and the trench filled with fresh concrete before the next layer of sacks is laid. At the start of each day's work, or when a delay of over 2 hours occurs during the placing of successive layers of sacks, the previously placed sacks shall be moistened and dusted with cement to develop bond.

612.08 Concrete-Slab Riprap. Slabs of the dimensions and type, plain or reinforced, shown on the plans shall be poured in place with class B concrete unless otherwise specified. Alternate slabs shall be poured and the remaining panels shall be poured later.

Unless otherwise specified, the slabs shall be laid in horizontal courses and successive courses shall break joints with the preceding ones. Horizontal joints shall be normal to the slope and shall be cold joints without filler. The joints extending up the slope shall be formed with 3/4-inch lumber, which shall be removed and the joint left open. The slabs shall be finished with a wood float.

The pouring and curing shall be carried out as specified for class B concrete in section _____.

612.09 Filter Blanket. When required, a filter blanket shall be placed on the prepared slope or area to the full specified thickness of each layer in one operation, using methods which will not cause segregation of particle sizes within the bedding. The surface of the finished layer should be reasonably even and free from mounds or windrows. Additional layers of filter material, when required, shall be placed in the same manner, using methods which will not cause mixture of the material in the different layers.

METHOD OF MEASUREMENT

612.10 Measurement. The quantity of riprap to be paid for, of specified thickness and extent, in place and accepted, shall be measured by one of the following methods as specified for the type of riprap placed. Riprap placed outside the specified limits will not be measured or paid for, and the contractor may be required to remove and dispose of the excess riprap without cost to the State.

(a) Per cubic yard. The quantity for dumped riprap, grouted riprap, concrete riprap in bags, and filter blanket shall be the number of cubic yards as computed from surface measurements parallel to the riprap surface and thickness measured normal to the riprap surface.

(b) Per square yard. The quantity for wire-enclosed riprap and concrete-slab riprap shall be the number of square yards obtained by measurements parallel to the riprap surface.

BASIS OF PAYMENT

612.11 Payment. The quantities determined, as provided in section 612.10, shall be paid for at the contract unit price per unit of measurement for each particular item listed in the following schedule and shown in the bid schedule, which price shall be full compensation for furnishing all material, tools, and labor; the preparation of the subgrade; the placing of the filter blanket when required; the placing of the stone; the grouting when required; furnishing steel for reinforced concrete-slab riprap; and all other work incidental to finished construction in accordance with these specifications.

Item No.	Pay Item	Unit of Measurement
612 (1)	Dumped riprap	per cubic yard
612 (2)	Wire-enclosed riprap	per square yard
612 (3)	Grouted riprap	per cubic yard
612 (4)	Concrete riprap in bags	per cubic yard
612 (5)	Concrete-slab riprap	per square yard
612 (6)	Filter blanket	per cubic yard
612 (7)	Broken concrete riprap	per cubic yard

SECTION 622 - JUTE MESH (MATTING)

622.01 Description. This work shall consist of furnishing and installing jute matting for stabilization of soils on slopes and ditches where shown on the plans.

MATERIALS

622.02 Materials. Materials shall meet the requirements of the following subsections of Part VII, Materials.

Jute Matting	705.01
Staples	705.02

CONSTRUCTION REQUIREMENTS

622.03 General. The jute matting shall be placed immediately after seeding and mulch sodding operations have been completed except for final rolling.

Beginning at the upgrade end, the matting shall be laid out flat, parallel to, and in the direction of the flow of water. When more than one strip is required to cover the area, they shall overlap on the sides at least 4 inches and the ends shall overlap at least 12 inches, with the upslope sections on top.

The matting shall be spread evenly and smoothly and shall be in contact with the soil or mulch sod at all points.

The upgrade end of each strip shall be buried to a depth of not less than 6 inches in a slot perpendicular to the ground, with the soil tamped firmly against it.

In ditches and on slopes, check slots or junction slots shall occur at 50 foot intervals as shown on the plans or as otherwise directed. Edges of jute matting shall be buried around the edges of catch basins and other structures by placing a tight fold of the matting at least 6 inches vertically into the soil.

622.04 Stapling. Matting shall be tightly held to the ground by vertically driven staples. Furnishing and installing staples shall be included in price bid on jute matting. Staples shall be spaced not more than 3 feet apart in 3 rows for each strip, with 1 row along each edge and 1 row alternately spaced in the center. On the overlapping edges of parallel strips, staples shall be spaced not more than 2 feet apart. At all anchor slots, junction slots, and check slots, staples shall be spaced not more than 6 inches apart.

622.05 Rolling. After installation is complete, the jute matting shall be firmly embedded in the soil or mulch sod durface by tamping or rolling with an approved roller. Rolling shall be accomplished without damage to the matting and the established grades. Matting shall be pressed firmly into the soil or mulch sod and be nearly flush with the ground surface over the entire area.

622.06 Maintenance and Repairs. Jute matting shall be repaired immediately if damaged. Soil in any damaged area shall be restored to original grade and shall be re-fertilized or re-sodded or re-seeded as originally specified. No payment shall be made for such areas repaired.

622.07 Equipment. Equipment shall include the following

(a) Approved smooth wheel hand sod roller.

(b) Necessary hammers, rakes and other hand tools.

METHOD OF MEASUREMENT

622.08 Measurement. The quantity of jute matting shall be measured by the square yard complete in place.

BASIS OF PAYMENT

622.09 Payment. Jute matting placed and accepted shall be paid for at the contract unit price.

Payment will be made under:

Item No.	Pay Item	Pay Unit
622 (1)	Jute Matting	Square Yard

SECTION 623 - FIBER GLASS ROVING

623.01 Description. This work shall consist of furnishing and installing fiber glass roving and asphalt for stabilization of soils on slopes and in ditches where shown on the plans or as directed by the engineer.

MATERIALS

623.02 Materials. All materials shall meet the requirements of the following specifications:

(a) Fiber Glass Roving: This material shall meet the following requirements:

1. General Requirements: The material shall be formed from continuous fibers drawn from molten glass, coated with a chrome-complex sizing compound, collected into strands and lightly bound together into roving without the use of clay, starch or like deleterious substances. The roving shall be wound into a cylindrical package approximately 1 foot high in such a manner that the roving can be continuously fed from the center of the package through an ejector driven by compressed air and expanded into a mat of glass fibers on the soil surface. The material shall contain no petroleum solvents or other agents known to be toxic to plant or animal life.

2. Detailed Requirements: The fiber glass roving shall conform to these detailed requirements:

Property	Limits	Test Method
Strands/Rove	56-64	End Count
Fibers/Strand	184-234	
Fiber Diameter, in. (Trade Designation-G)	0.00035-0.0004	ASTM D 578
Yards/lb. of Strand	13,000-14,000	ASTM D 578
Yards/lb. of Rove	210-230	ASTM D 578
Organic Content, percent max.	0.75	ASTM D 578
Package Weight, lbs.	30-35	ASTM D 578

(b) Asphalt Material: The asphalt furnished shall be either asphalt cement grade AC-8 or an approved emulsified asphalt, all meeting the following requirements:

1. General Requirements: The asphalt shall be prepared by the refining of petroleum. It shall be uniform in character and shall not foam when heated to 350°F.

All storage tanks, piping, retorts, booster tanks, distributors and other equipment used in delivering, storing or handling bituminous materials shall be kept clean and in good operating condition at all times and shall be operated in such manner as to avoid any possible contamination of the contents with foreign materials.

All final test results for the bituminous materials shall be applied to the proper schedule for conformance to the specifications. Any deviation from the specifications will result in an adjustment in unit price, and any adjustment in unit price shall be made as specified.

Schedules No. 1, 2, 3, 4, 5, 6, 7 and 8 shall be used for the purpose of adjusting the appropriate unit prices of bituminous materials. The adjustment in pay for bituminous materials shall be applied only to samples taken at the point of delivery. All samples taken at the refinery shall be in accordance with the specification requirements. Should the sample fail to meet these requirements, the material will be rejected.

The intent of adjustments in pay for point of delivery samples is to allow partial payment for bituminous materials which, in the judgment of the engineer, are satisfactory for use in the work and will serve the purpose intended, but which do not conform to the specifications in every detail.

In the event the engineer finds the bituminous materials not conforming to the requirements listed under 100 percent pay have resulted in an inferior or unsatisfactory product, the materials shall be removed and replaced or otherwise corrected by and at the expense of the contractor.

If the test results are such that a penalty would result from more than one of the test values, only the price adjustment for the greatest reduction shall apply.

2. Asphalt Cement. Whenever samples of AC-3 and AC-5 taken at the point of delivery or from the hot mix plant storage tanks do not meet the specification requirements as shown in Schedule No. 1, then an

adjustment in unit price shall be made according to Schedule No. 1 provided the material is performing satisfactorily.

Whenever samples of AC-8 taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 2, then an adjustment in unit price shall be made according to Schedule No. 2 provided the material is performing satisfactorily. All testing of asphalt cement, unless otherwise directed, shall be in accordance with the test methods given in Schedules No. 1 and 2.

3. Emulsified Asphalt. Whenever samples of anionic emulsified asphalts RS-1 and RS-2 taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 3, then an adjustment in unit price shall be made according to Schedule No. 3 provided the material is performing satisfactorily.

Whenever samples of SS-1 and SS-1h anionic emulsified asphalts taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 4, then an adjustment in unit price shall be made according to Schedule No. 4 provided the material is performing satisfactorily.

Whenever samples of MS-2 (EA-4) anionic emulsified asphalts taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 5, then an adjustment in unit price shall be made according to Schedule No. 5 provided the material is performing satisfactorily.

Whenever samples of cationic asphalt RS-3K and quick-set emulsion for Slurry Seals taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 6, then an adjustment in unit price shall be made according to Schedule No. 6 provided the material is performing satisfactorily.

All testing of emulsified asphalts, unless otherwise specified, shall be in accordance with the test methods given in Schedules No. 3, 4, 5 and 6.

4. Cutback Asphalt. Whenever samples of cutback asphalts taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 7 for medium curing or Schedule No. 8 for rapid curing, then an adjustment in unit price shall be made according to Schedules No. 7 or 8 for medium curing or rapid curing cutback asphalts respectively provided the material is performing satisfactorily.

   All testing of cutback asphalts, unless otherwise specified, shall be in accordance with the test methods given in Schedules No. 7 and 8.

5. Undersealing Asphalt. Whenever samples of the undersealing asphalt taken at the point of delivery do not meet the specification requirements as shown in Schedule No. 9, then an adjustment in unit price shall be made according to Schedule No. 9 provided the material is performing satisfactorily.

   All testing of undersealing asphalt shall be in accordance with the test methods given in Schedule No. 9.

CONSTRUCTION REQUIREMENTS.

623.03 General. The fiber glass roving shall be applied over the designated area within 24 hours after the normal seeding operations have been completed.

The fiber glass roving shall be spread uniformly over the designated area to form a random mat of continuous glass fibers at the rate of from 0.25 to 0.35 pounds per square yard. This rate may be varied as directed by the engineer.

The fiber glass roving shall be anchored to the ground with the asphaltic material applied uniformly over the glass fibers at the rate of from 0.25 to 0.35 gallons per square yard. This rate may be varied as directed by the engineer.

The upgrade end of the lining shall be buried to a depth of one foot to prevent undermining. The above instructions for slope and ditch protection may be varied by the engineer to fit the field conditions encountered.

623.04 Maintenance and Repairs. The lining shall be repaired immediately, if damaged due to the contractor's operations. Soil in any damaged areas shall be restored to original grade, refertilized and reseeded if originally specified, all at no additional cost to the State.

623.05 Equipment. Equipment shall include the following:

(a) Pneumatic ejector capable of applying fiber glass roving at a rate of 2 pounds per minute (approximately 8 square yards per minute).

(b) Air compressor capable of supplying 40 cfm at 80 to 100 psi. Acceptable air hoses necessary for supplying air to areas not accessible to the compressor.

(c) Approved asphaltic material distributor with necessary hoses and hand spray bar for working on slopes and other areas not accessible to the distributor.

METHOD OF MEASUREMENT

623.06 Measurement. Fiber glass roving will be measured by the pound, and the quantity to be measured will be that actually used on the project.

The asphalt cement (AC-8) or emulsified asphalt will be measured by the gallon at the temperature of 60° F. in accordance with temperature volume correction, Tables II and III given in subsection 505.11. The quantity of asphalt to be measured will be that actually used on the project.

BASIS OF PAYMENT

623.07 Payment. The accepted quantities of fiber glass roving and asphalt material will be paid for at the respective contract unit prices.

If the asphalt material does not conform to the specifications, the final test results for the material taken at the point of delivery will be applied to the appropriate acceptance schedule for price adjustment, and any adjustment in unit price will be made as specified.

Payment will be made under:

Item No.	Pay Item	Pay Unit
623 (1)	Fiber Glass Roving	Pound
623 (2)	Asphaltic Material	Gallon

SECTION 624 - ASPHALT MULCH

624.01 Description. This work shall consist of furnishing and placing asphalt on areas that have been seeded or mulch sodded as shown on plans or directed by engineer.

MATERIALS

624.02 Materials. The asphalt mulch used shall be an approved emulsified asphalt meeting the requirements of section 623.02(b).

CONSTRUCTION REQUIREMENTS

624.03 General. Asphalt mulching shall follow seeding or mulch sodding operations as soon as possible in order to protect such areas from erosion. If the areas to receive asphalt mulch have not been sufficiently moistened by rainfall, these areas should be watered to the satisfaction of the engineer. Asphalt shall be spread with a mechanical spreader equipped with approved boon or hand spray nozzles.

624.04 Spreading Rates. Asphalt shall be spread over the surface of the newly seeded or mulch sodded areas at the rate of 0.2 to 0.3 gallons per square yard. When required, the asphalt shall be diluted with water in such proportions as designated by the engineer; however, payment will be made only for the asphalt used.

METHOD OF MEASUREMENT

624.05 Measurement. The asphalt mulch will be measured by the gallon at a temperature of 60°F. in accordance with Temperature Volume Correction, Table III, given in subsection 505.11. The quantity of emulsified asphalt to be measured will be that actually used on the project. No measurement or payment will be made for water used in the emulsion.

BASIS OF PAYMENT

624.06 Payment. The asphalt mulch placed and accepted will be paid for at the contract unit price.

If the emulsified asphalt material does not conform to the specifications, the final test results for the material taken at the point of delivery will be applied to the appropriate acceptance schedule for price adjustment, and any adjustment in unit price will be made as specified.

Payment will be made under:

Item No.	Pay Item	Pay Unit
624 (1)	Asphalt Mulch	Gallon

APPENDIX E

PLASTIC FILTER CLOTH*

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* For more detailed information and specifications see, "Plastic Filter Cloth," CE-1310, Guide Specifications, Civil Works Construction, Office of the Chief of Engineers, Corps of Engineers, Department of the Army, May 1973.

RECOMMENDED PROCEDURES FOR DETERMINING EQUIVALENT OPENING SIZE AND PERCENT OPEN AREA OF PLASTIC FILTER CLOTH

Determination of Equivalent Opening Size (EOS)

Five unaged samples shall be tested. Obtain about 150 gm of each of the following fractions of a sand composed of sound rounded particles:

U.S. Standard Sieve Number

Passing	Retained On	Passing	Retained On	Passing	Retained On
10	20	30	40	50	70
20	30	40	50	70	100
				100	120

The cloth shall be affixed to a standard sieve having openings larger than the coarsest sand used in such a manner that no sand can pass between the cloth and the sieve wall. The sand shall be oven dried. Shaking shall be accomplished as described in paragraph 2d(1)(g), Appendix V, EM 1110-2-1906, except shaking shall be continued for 20 minutes. Determine by sieving (using successively coarser fractions) that fraction of sand of which 5 percent or less by weight passes the cloth; the equivalent opening size of the cloth sample is the "retained on" U.S. Standard Sieve number of this fraction. The EOS shall be no finer than the U.S. Standard Sieve No. ____ and no coarser than the U.S. Standard Sieve No. ____.

Determination of Open Area

Each of five samples, unaged, shall be placed separately in a 2-inch by 2-inch glass slide holder and the image projected with a slide projector on a screen. A block of 25 openings near the center of the image shall be selected and the length and width of each of the 25 openings and the widths of the fibers adjacent to the openings shall be measured to the nearest 0.001 inch. The percent open area is determined by dividing the sum of the open areas of the 25 openings by the sum of the total area of the 25 openings and their adjacent fibers. The open area shall be not less than *(4) ( ) percent and not more than *(36) ( ) percent.

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* Inapplicable provisions are to be deleted.

Additional References on Plastic Filter Cloths

1. Barrett, Robert J., USE OF PLASTIC FILTERS IN COASTAL STRUCTURES, Proceedings, Tenth International Conference on Coastal Engineering, Tokyo, Japan, 1966.

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3. Calhoun C. C. Jr., DEVELOPMENT OF DESIGN CRITERIA AND ACCEPTANCE SPECIFICATIONS FOR PLASTIC FILTER CLOTHS, U.S. Army Engineer Waterways Experiment Station Technical Report 5-72-7, Vicksburg, Miss., June 1972.

4. Calhoun C. C., Jr., INVESTIGATION OF PLASTIC FILTER CLOTHS, Master's Thesis, Oklahoma State University, Stillwater, Oklahoma, June 1972.

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6. Fairley, J. G., et al., USE OF PLASTIC FILTER CLOTHS IN REVETMENT BANK PAVING, Potamology Investigation Report 21-4, U.S. Army Engineer District, Memphis, Tennessee, June 1970.

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