National Cooperative Highway Research Program

RESEARCH RESULTS DIGEST

DIGEST 1 - DECEMBER, 1968

Superseded by NCHRP Rept. 108

Tentative Design Procedures for Riprap-Lined Channels

A digest of the essential findings from the final report on NCHRP Project 15-2, "Design to Control Erosion in Roadside Drainage Channels," prepared by Alvin G. Anderson, Professor of Civil Engineering, and Amreek S. Paintal and John T. Davenport, Research Assistants, St. Anthony Falls Hydraulic Laboratory, University of Minnesota.

THE PROBLEM AND ITS SOLUTION

Hydraulic design engineers will find that this research has succeeded in achieving the objective of developing criteria and extending the procedures for the design of roadside drainage channels for conditions intermediate between those for which easily established grass cover will suffice and those for which paved channels or pipe flumes are more economical. The product--design techniques that require little or no modification of standards and specifications and provide a simplified approach for selecting riprap channel protection as the lining for roadside ditches having a design discharge of less than 1,000 cfs--is particularly noteworthy because it stands alone in its contribution to the practicing engineer and does not have to be combined with the results from other research to make it useful. Furthermore, it is defined explicitly enough to permit direct application to practice, and does not have to be translated into the working tools of the practicing engineer. An additional concern of the practicing engineer, that of whether or not the research findings have been evaluated sufficiently to assure success in use, will be answered in the near future inasmuch as the research is being continued to provide for field evaluation of the design procedures. In the meantime, some degree of assurance has been provided in that the design procedures, by extrapolation, have been applied by the Connecticut State Highway Department in the relocation of a stream and its tributaries having a design flood of 3,300 cfs. The procedures have been found to be easily applied by someone at the technician level. Comparisons were made with the Bureau of Public Roads' Hydraulic Engineering Circular No. 11, "Use of Riprap for Bank Protection" (June, 1967), and the Army Engineer Draft Report 20 (April, 1966), "Criteria for Graded Stone Riprap Channel Protection." All were found to result in nearly identical requirements for channel protection.

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FINDINGS

Taking into account the information and practices that have been reported in the literature; plus limited laboratory experimentation and model verification; and the interrelationships between discharge, longitudinal slope, size and shape of the channel, and the size distribution and other characteristics of the riprap material--a layer of discrete fragments of rock sufficient in size to resist the erosion forces of flow--tentative procedures have been arrived at for the design of riprap linings for roadside channels to provide a protective, erosion-resistant lining for climates where vegetative cover is difficult to establish or for situations where a protective lining intermediate in performance and cost between turf and paving is desired. The procedures are represented in design chart form that permits rapid and simple establishment of channel shape and size, as well as the properties of the riprap lining. Regular trapezoidal channels with a maximum discharge of 1,000 cfs and median, or side, ditches with a maximum discharge of 100 cfs are the two primary types--both with a maximum slope of 0.10 ft/ft--that were chosen for the preparation of simplified design charts. The latter are relatively wide and often approach a triangular cross section because of the flat side slopes. Other conditions assumed are:

List of Symbols

A - Channel area, ft^2
B - Channel bottom width, ft
d_{50} - Mean particle size diameter at which 50 percent is finer by weight, mm, ft
n - Manning's coefficient of roughness
P - Wetted perimeter, ft
Q - Discharge, cfs
R - Hydraulic radius, ft
S_b - Bed slope, ft per ft
V - Velocity, fs
Y - Channel depth, ft
z - Side slope, ft hor to 1 ft vert
γ_s - Unit weight of riprap, pcf
θ - Angle of repose, degrees
ϕ - Side slope, degrees
ϕ_R - Side slope ratio
τ_c - Critical shear stress, pounds per ft^2

1. The drainage channel will be essentially straight.

2. The flow will be essentially uniform and can be described by the Manning formula:

$$V = \frac{1.49}{n} R^{2/3} S_b^{1/2}$$

3. The roughness coefficient will depend on the effective size of the riprap and can be expressed as $n = 0.0395 \, d_{50}^{1/6}$

4. The critical boundary shear is directly proportional to the effective size and can be expressed as $\tau_c = 4 \, d_{50}$

5. The ratio of the maximum boundary shear stress is taken to be 1.5 times the mean for regular trapezoidal channels and 2 times the mean for wide triangular channels.

For the purpose of preparing simplified design charts for riprap linings, highway drainage channels have been divided into two standard types. The first comprises regular trapezoidal channels with a maximum discharge of 1,000 cfs. The second type consists of median or side ditches for the drainage of roadways with a maximum discharge of 100 cfs. These latter are relatively wide and often approach a triangular cross section because of the flat side slopes. A maximum channel slope of 0.10 has been selected for the development of the design charts.

Regular Trapezoidal Channels

Using these assumptions, an equation is developed relating the discharge, longitudinal slope, size of the riprap, and shape of the channel in the following form:

$$Q = \frac{1}{118} \frac{d_{50}^{5/2}}{S_b^{13/6}} \frac{P}{R}$$

This equation shows that for a given discharge and slope the size of riprap needed to protect the channel depends only on the channel shape. For given values of P/R and regular trapezoidal channels, the equation can be plotted with the discharge, Q, as a function of the slope, S_b, with d_{50} as a parameter. Charts 1 and 2 were prepared representing the equation for P/R = 13.3 and P/R = 30, respectively. For these values of P/R the charts give the size of riprap required to line a channel having a given discharge and slope so that the riprap is stable. Once the size of riprap is chosen, the velocity and the hydraulic radius can be determined from Charts 3 and 4. Having the mean velocity from Chart 3, the required cross-sectional area is obtained from Chart 5. The required side slopes are obtained from Charts 6 and 7. Given the size of riprap, d_{50}, and its angularity, the angle of repose is taken from Chart 6. Using this angle of repose the side slope is determined from Chart 7. Having chosen the side slope and having determined the cross-sectional area and the hydraulic radius, the channel geometry is obtained directly from one of the Charts 8a through 8e. In these design charts the side slope is established so that the riprap on the side is as stable as that on the bottom and the size of the riprap is a minimum consistent with the discharge and channel slope.

Wide Triangular Channels

Safety considerations require that side slopes of roadside ditches be relatively flat and wide enough so that vehicles leaving the roadway can be controlled without serious danger to the occupants. These requirements plus construction considerations suggest that shallow triangular or trapezoidal channels be used. By assuming a triangular cross section for the wide channels with a discharge of up to 100 cfs, the channel shape is eliminated as a design factor and erosion control will depend primarily on the discharge, longitudinal slope, and size of riprap.

The riprap size characteristic is normally determined as the mean diameter, d_{50}, without regard to size distribution. To simplify the design and construction of linings for small channels, standard sizes of coarse aggregates such as those listed in AASHO Designation M43-54, "Standard Sizes of Coarse Aggregate for Highway Construction," were chosen. The gradations of eight of these standard sizes having a reasonable, systematic change in mean diameter are given in Table 1. It is anticipated that a mean diameter for local aggregates having approximately the same gradations could be computed or estimated.

As for trapezoidal channels, the basic equation relating discharge to channel properties is the Manning equation, combined with the equation of continuity. However, for a triangular channel the ratio P/R depends only on the side slope of the channel. The equation that has been developed for relating to triangular channel characteristics is written as:

$$Q = \frac{1}{64.4} \frac{d_{50}^{5/2}}{S^{13/6}} \frac{z^2+1}{z}$$

From Charts 9 through 16, the size of riprap, in the form of an AASHO standard gradation, and the depth of flow can be determined for a given discharge, longitudinal slope, and side slope. The chart corresponding to the given side slope is entered with the discharge and longitudinal slope; the riprap classification is read off at

TABLE 1

SIZES AND MEAN DIAMETERS OF COARSE AGGREGATES

Sieve Size	Percent by Weight Passing AASHO Size[a]							
	No. 1	No. 2	No. 24	No. 4	No. 357	No. 467	No. 57	No. 68
4 In.	100							
3 1/2 In.	90-100							
3 In.		100	100					
2 1/2 In.	25-60	90-100	90-100		100			
2 In.		35-70		100	95-100	100		
1 1/2 In.	0-15	0-15	25-60	90-100		95-100	100	
1 In.				20-55	35-70		95-100	100
3/4 In.		0-5	0-10	0-15		35-70		90-100
1/2 In.			0-5		10-30		25-60	
3/8 In.				0-5		10-30		30-65
No. 4					0-5	0-5	0-10	5-25
No. 8							0-5	0-10
No. 16								0-5
d_{50} [b]	*0.185*	*0.149*	*0.109*	*0.080*	*0.059*	*0.044*	*0.034*	*0.024*

(a) Adapted from AASHO Standard Specification M43-54.

(b) Mean particle size diameter (in feet) at which 50 percent is finer by weight.

their intersection. If the intersection does not fall on a standard size, the next larger size of aggregate should be chosen. The depth of flow may be interpolated at the point of intersection. The minimum thickness of an aggregate lining for roadside ditches should be equivalent of 3 times the mean diameter, d_{50}, or the minimum thickness for effective placement, whichever is greater. It is suggested that it be not less than 4 inches compacted. Normal compaction procedures will result in greater resistance to erosion and damage by encroaching vehicles.

APPLICATIONS

The procedures developed during this study for determining riprap lining characteristics adequate for erosion protection of roadside ditches and small streams are considered to be tentative and will be subjected to further laboratory and field evaluation. However, due to the fact that they are based on generally accepted theoretical considerations, extensive field experience, and significant model verification, they are suitable in their present form for application. Experimental studies on linings designed in accordance with the proposed procedures failed at a discharge of approximately twice the design discharge for uniform riprap material and at 1.5 times the design discharge for graded riprap material. The graded material was found to be more effective than the uniform material in the prevention of leaching. A layer whose thickness is equivalent to 3 mean diameters appears adequate to prevent leaching of sand through the lining.

The design charts included herein provide a simplified means for determining the suitability of a locally available aggregate for erosion protection of drainage channels with discharges under 1,000 cfs. From an economic standpoint, the use of such an aggregate lining would be particularly appropriate if it utilized a material being produced for paving mixes, base course, or some other portion of the project. In addition to providing an erosion-resistant lining intermediate between turf and paving, the aggregate lining should be applicable where, due to climatic, soil, or other conditions, it is difficult to establish and maintain vegetative protection.

Application of the tentative design procedures on a trial and comparison basis would appear to be desirable in order to obtain field experience with respect to performance, economics, and maintenance considerations. The more arid portions of the country are likely to find this particularly appropriate due to problems of establishing turf cover and preserving the aesthetics of the roadside.

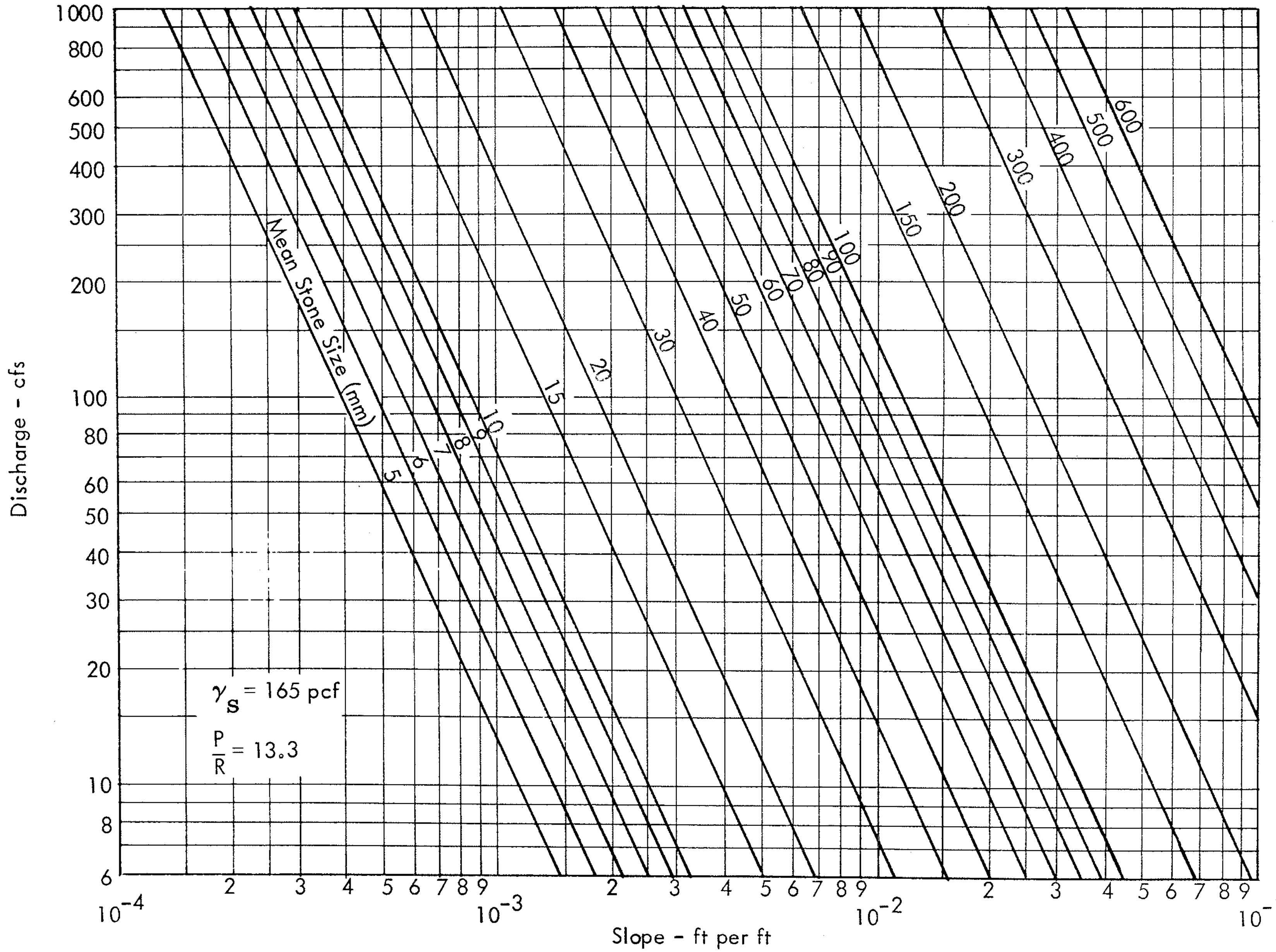


Chart 1 - Minimum Size (mean) of Stone Riprap that will be Stable in Trapezoidal Channels with P/R = 13.3 for Various Combinations of Discharge and Slope

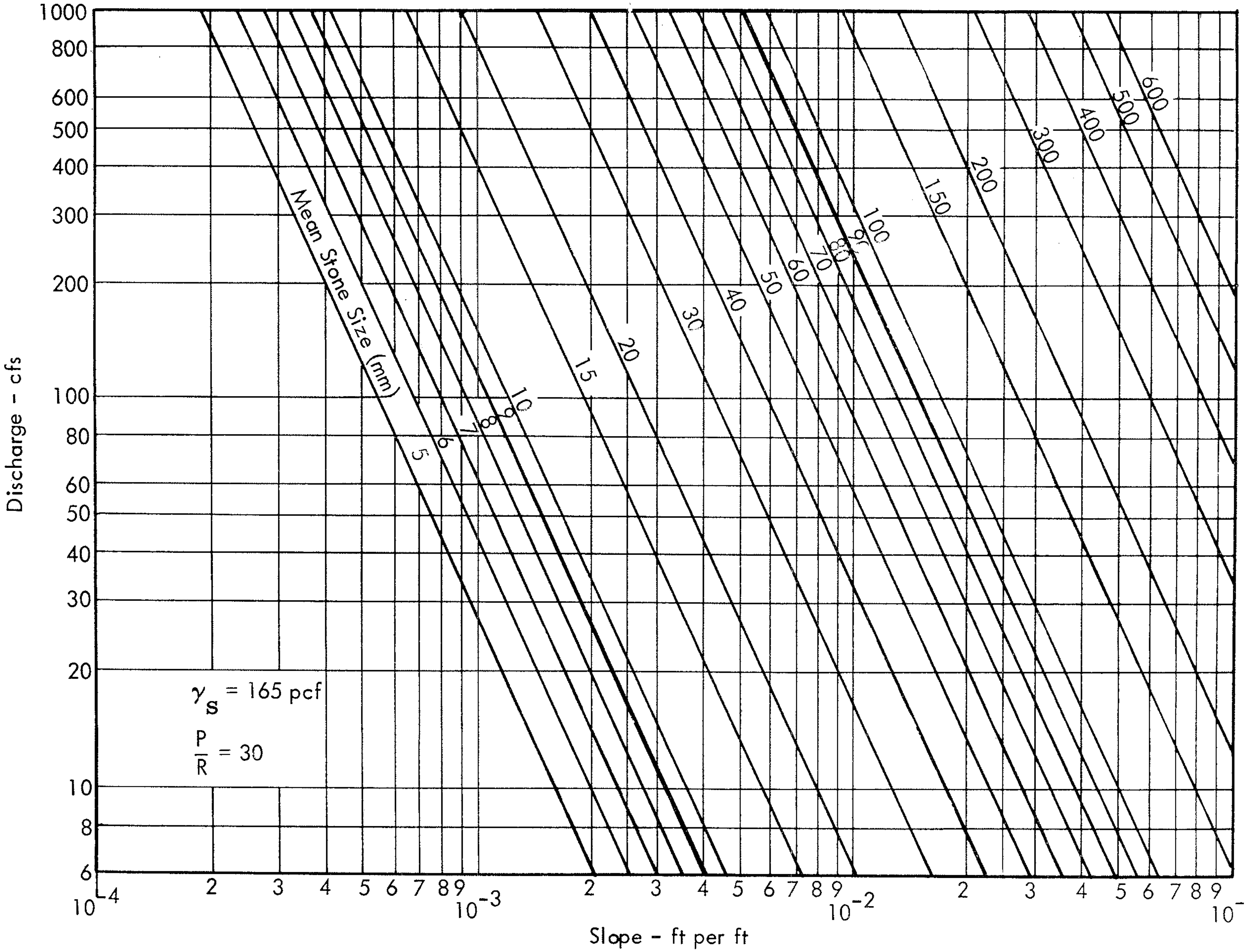


Chart 2 - Minimum Size (mean) of Stone Riprap that will be Stable in Trapezoidal Channels with P/R = 30 for Various Combinations of Discharge and Slope

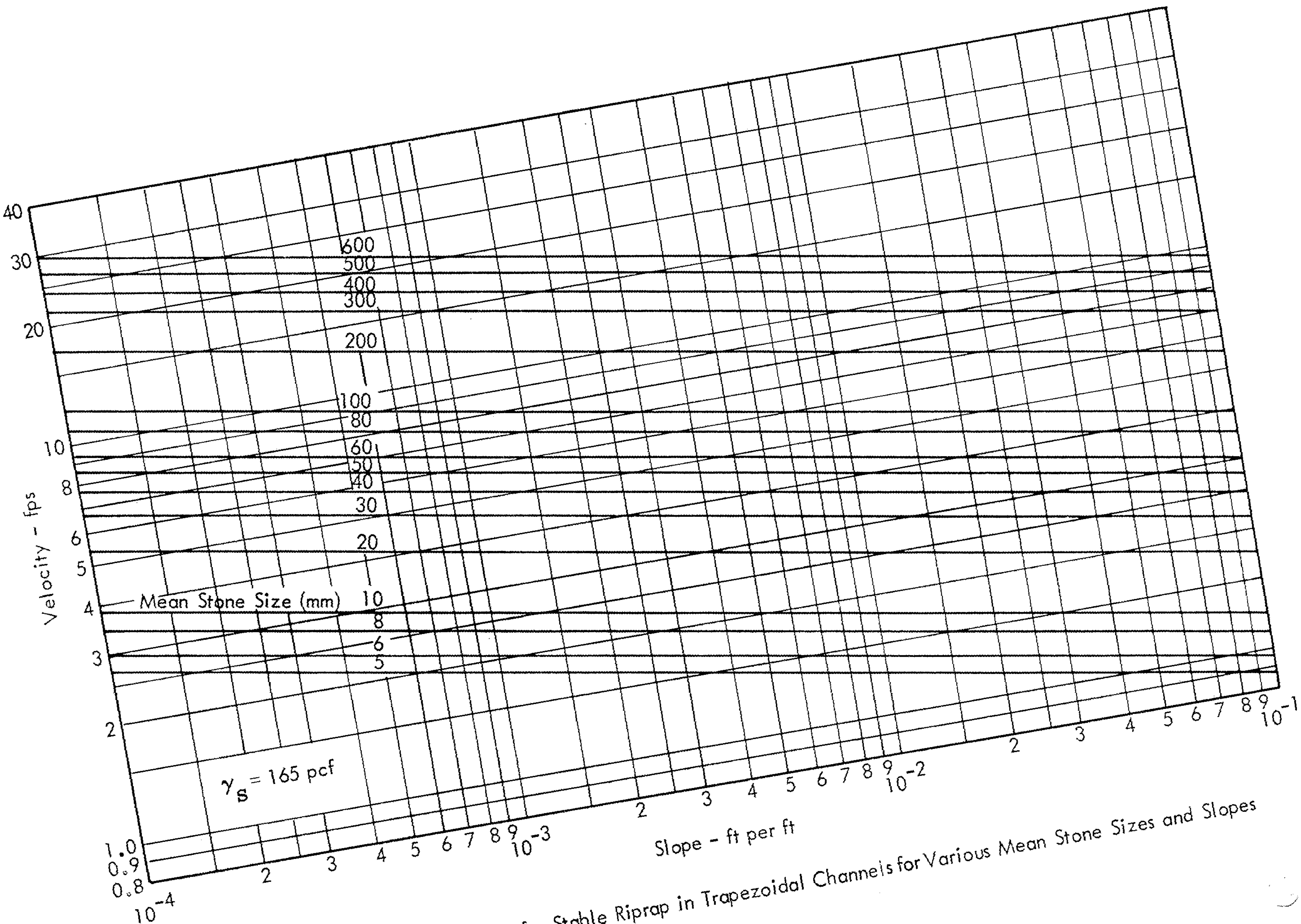


Chart 3 - Maximum Mean Velocity for Stable Riprap in Trapezoidal Channels for Various Mean Stone Sizes and Slopes

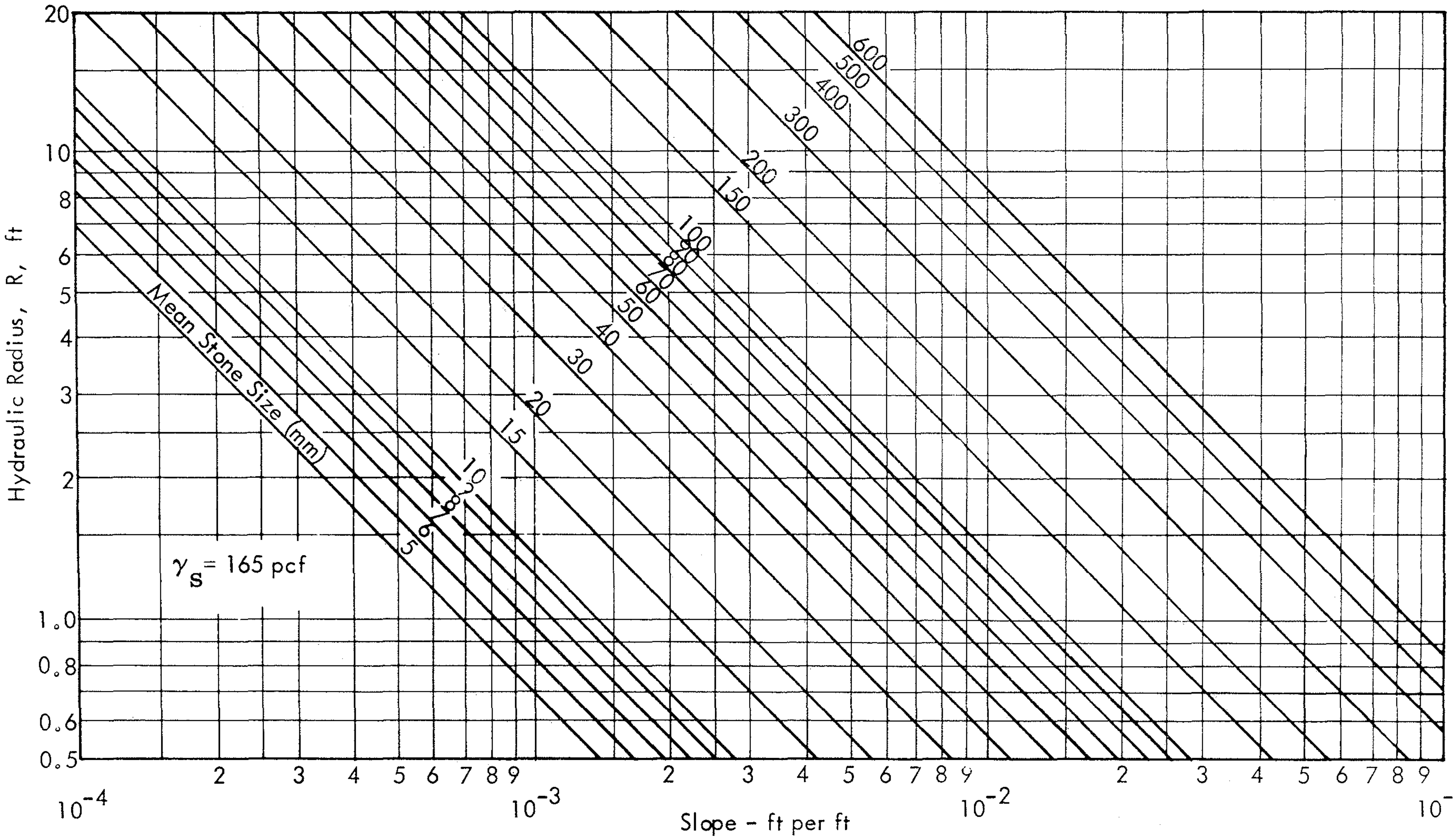


Chart 4 - Hydraulic Radius for Trapezoidal Channels in Terms of Mean Stone Size and Slope

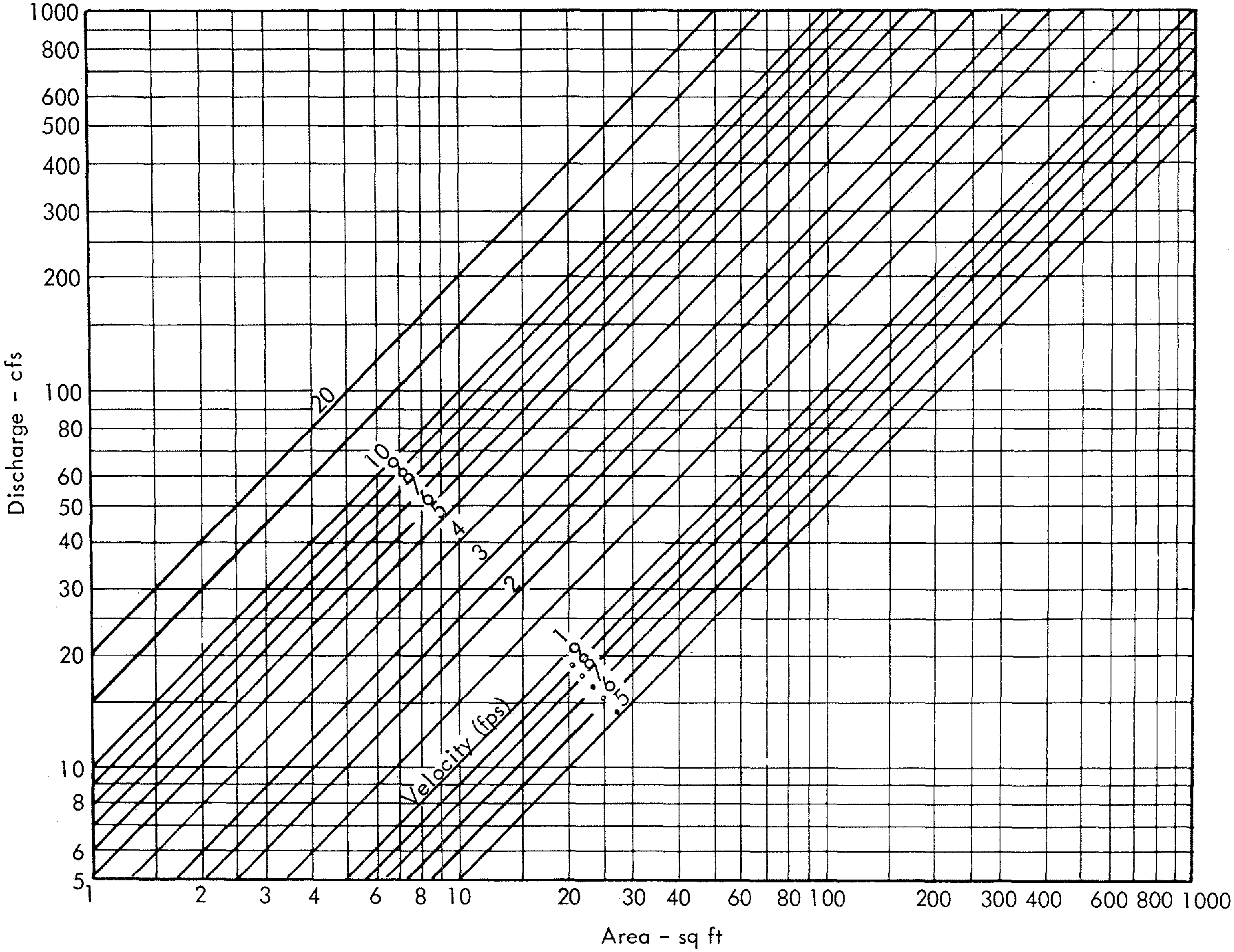


Chart 5 - Area of a Trapezoidal Channel in Terms of Discharge and Maximum Mean Velocity

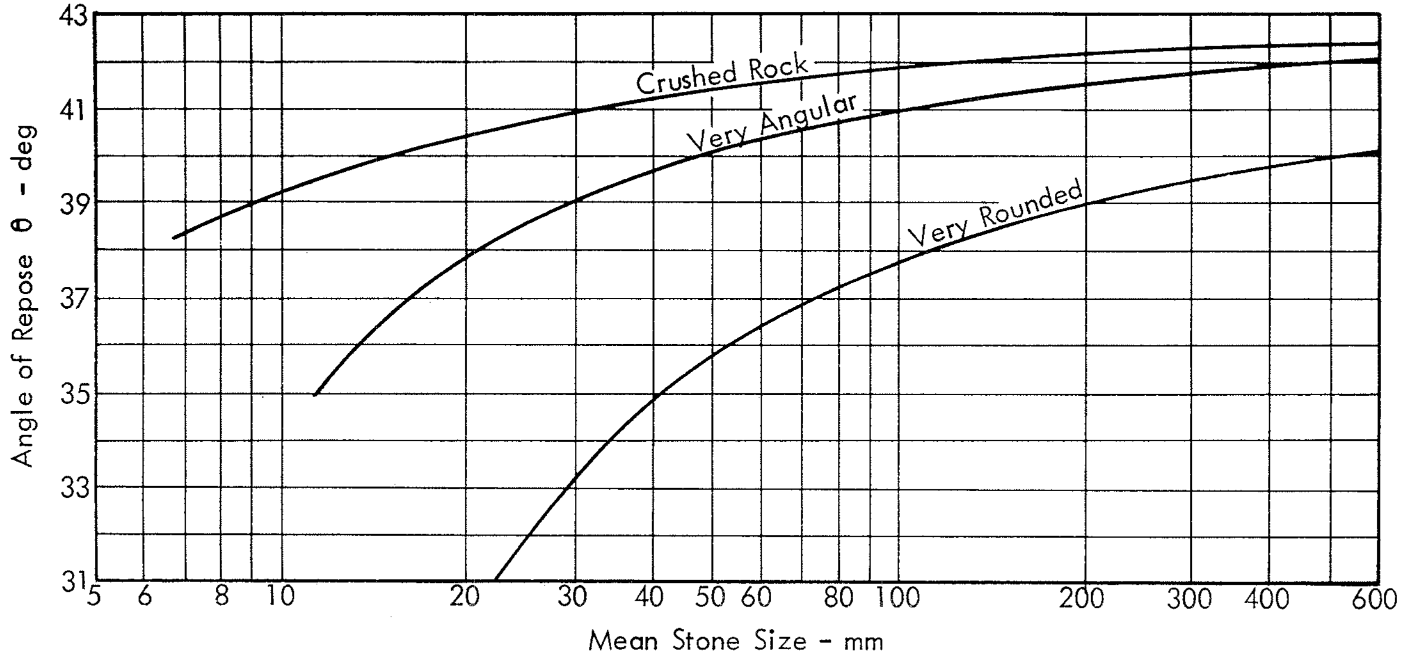


Chart 6 - Angle of Repose of Riprap in Terms of Mean Size and Shape of Stone

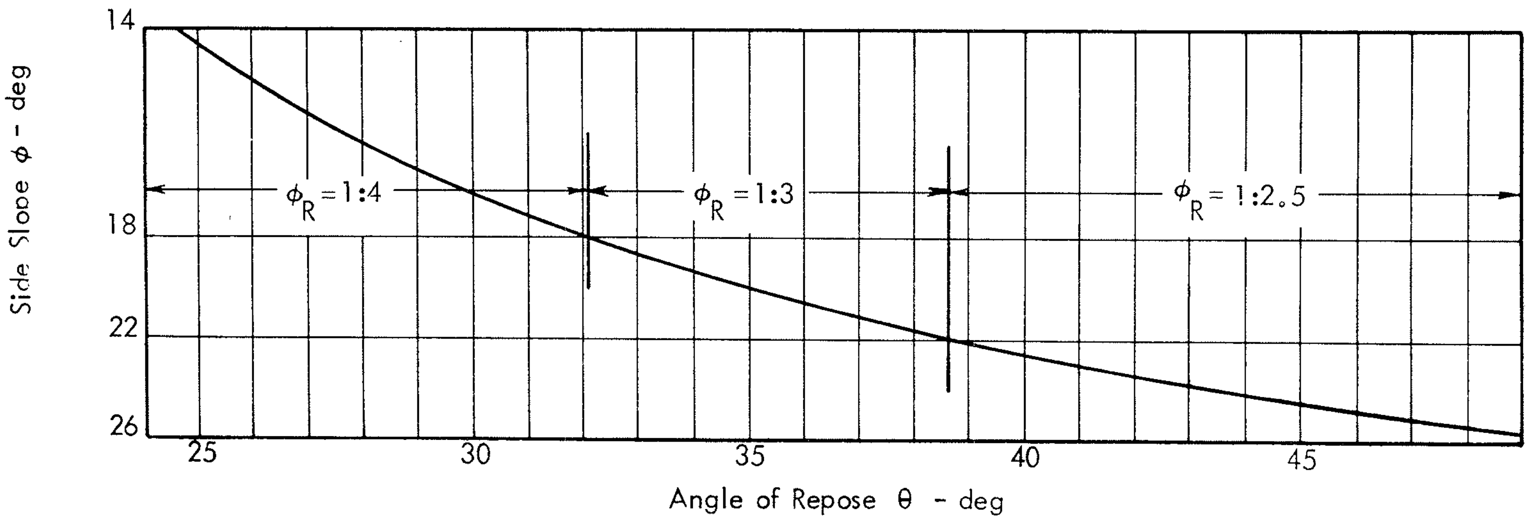


Chart 7 - Recommended Side Slopes of Trapezoidal Channels in Terms of Riprap Angle of Repose

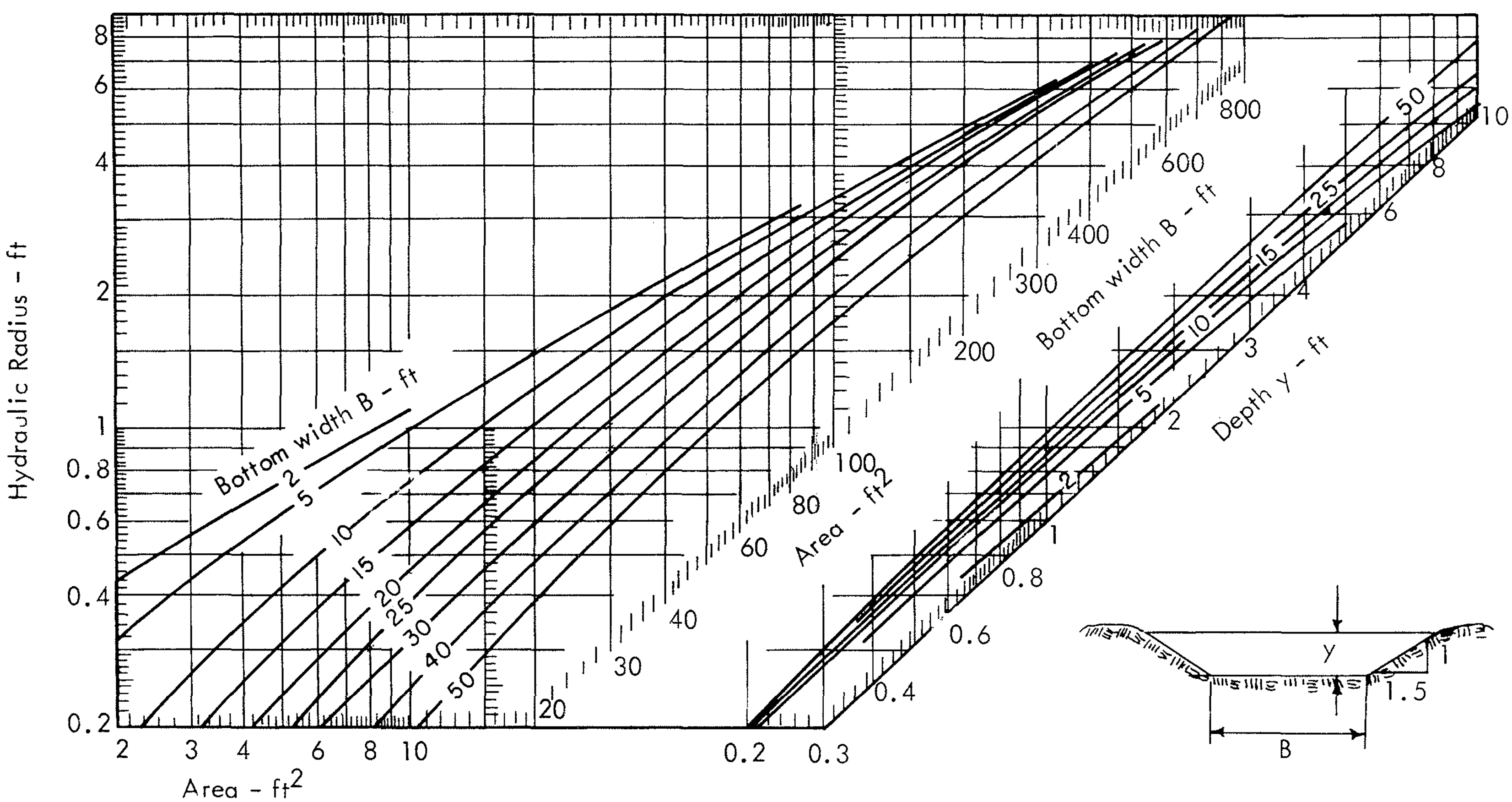


Chart 8(a) - Geometry of Trapezoidal Channels with 1.5:1 Side Slopes [3]

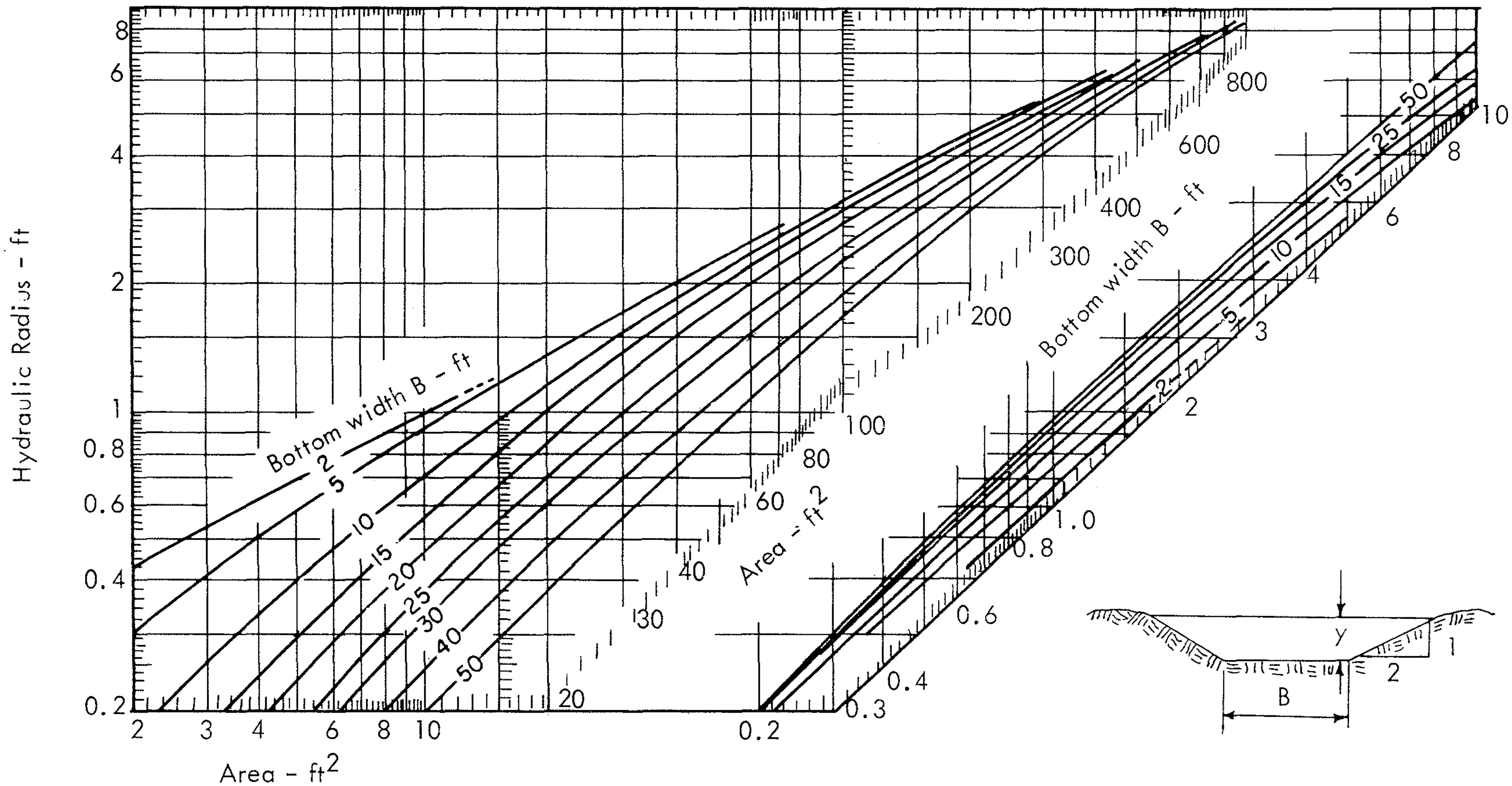


Chart 8(b) - Geometry of Trapezoidal Channels with 2:1 Side Slopes [3]

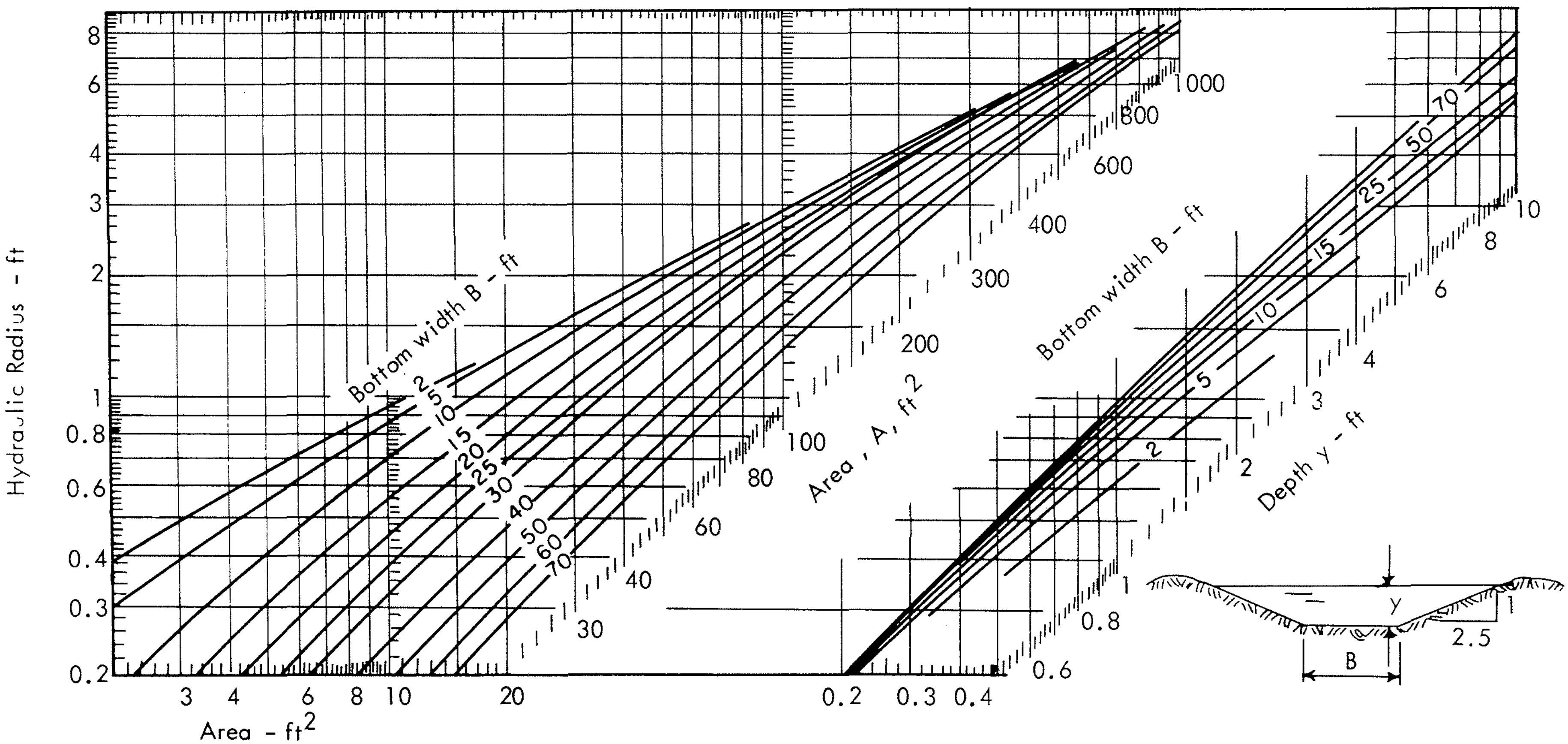


Chart 8(c) - Geometry of Trapezoidal Channels with 2.5:1 Side Slopes [3]

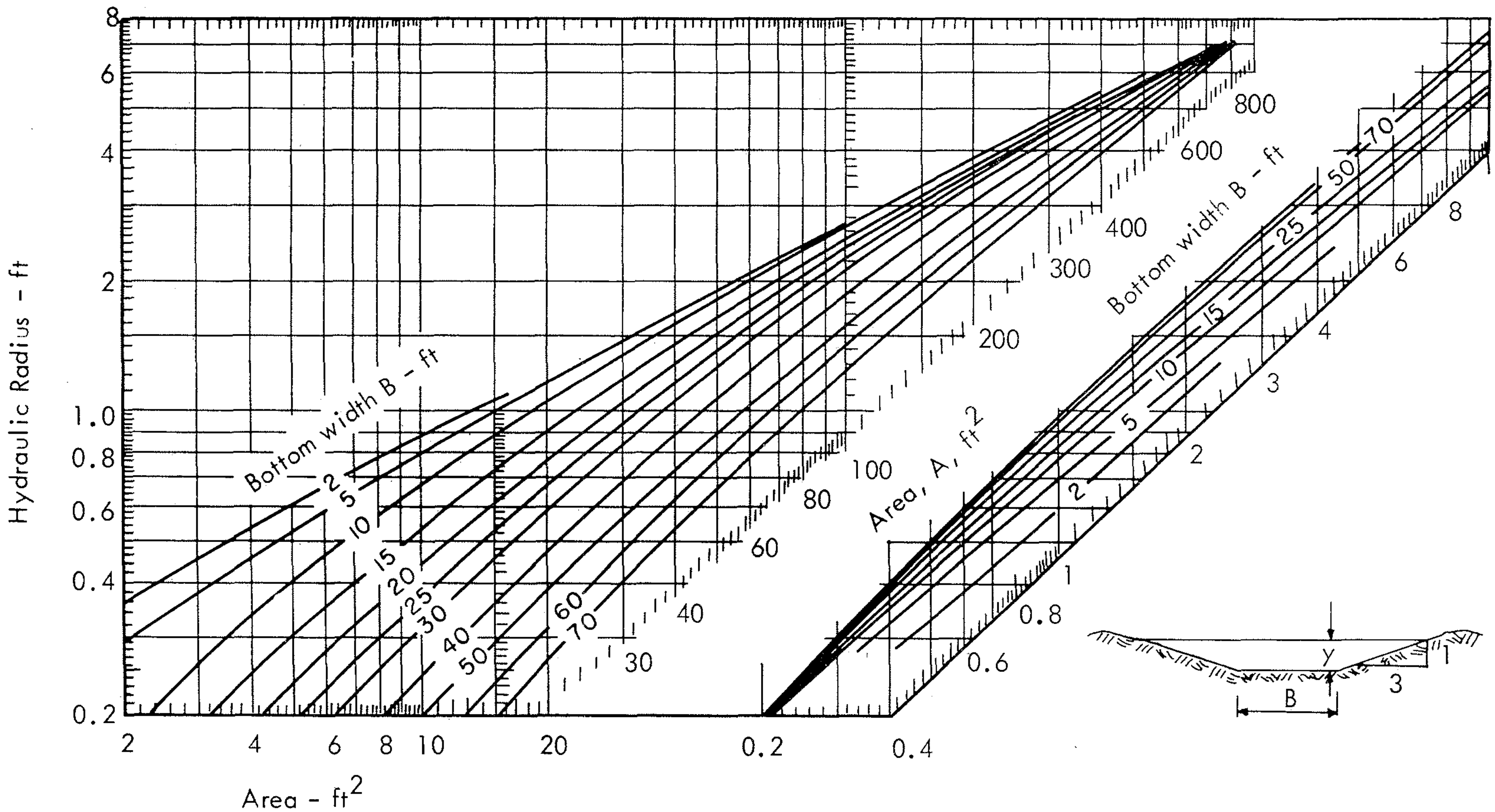


Chart 8(d) - Geometry of Trapezoidal Channels with 3:1 Side Slopes [3]

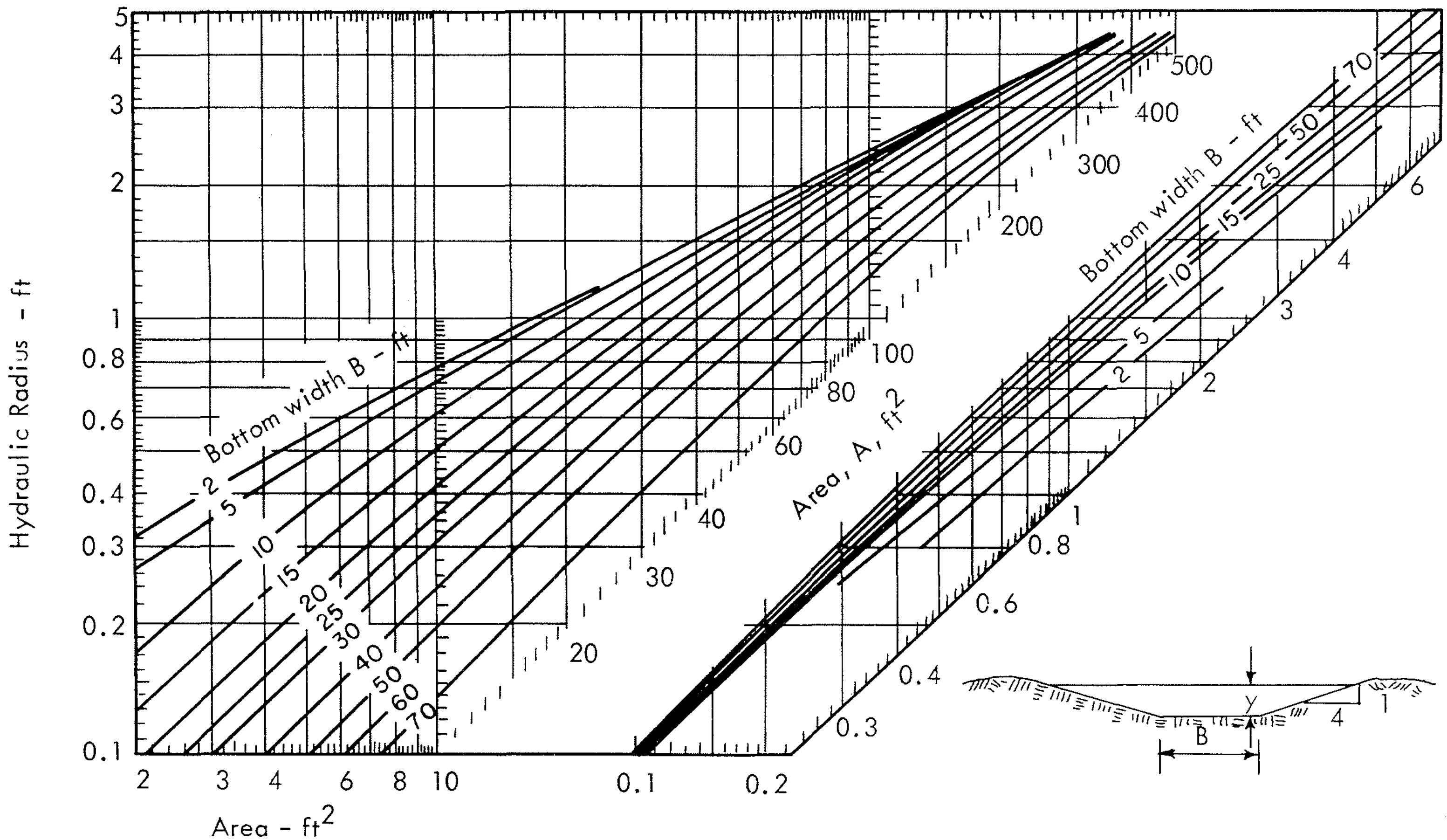


Chart 8(e) - Geometry of Trapezoidal Channels with 4:1 Side Slopes [3]

Chart 9 - Depth of Flow and Size of Standard Aggregate for Channel Stability

Side Slope 3:1

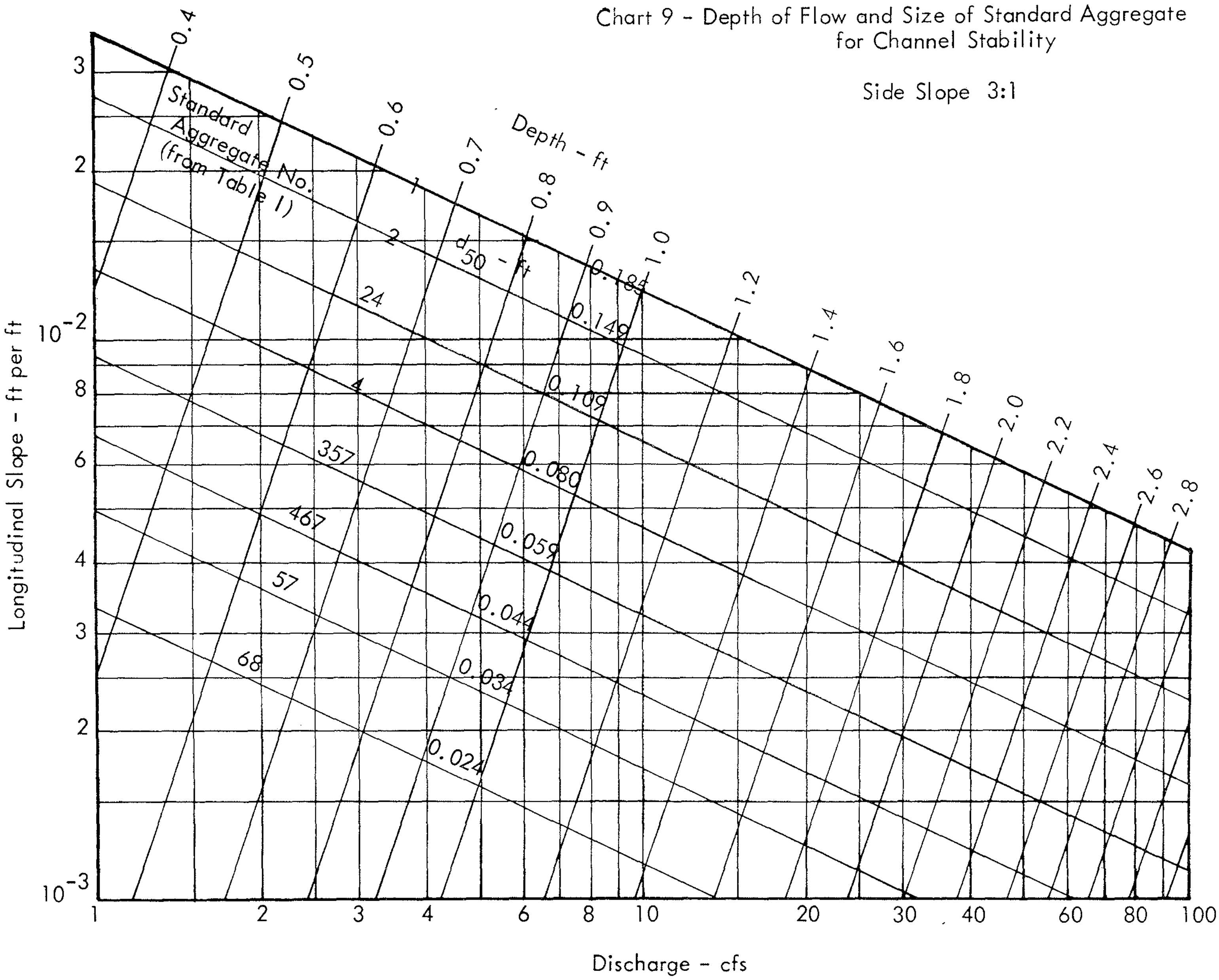
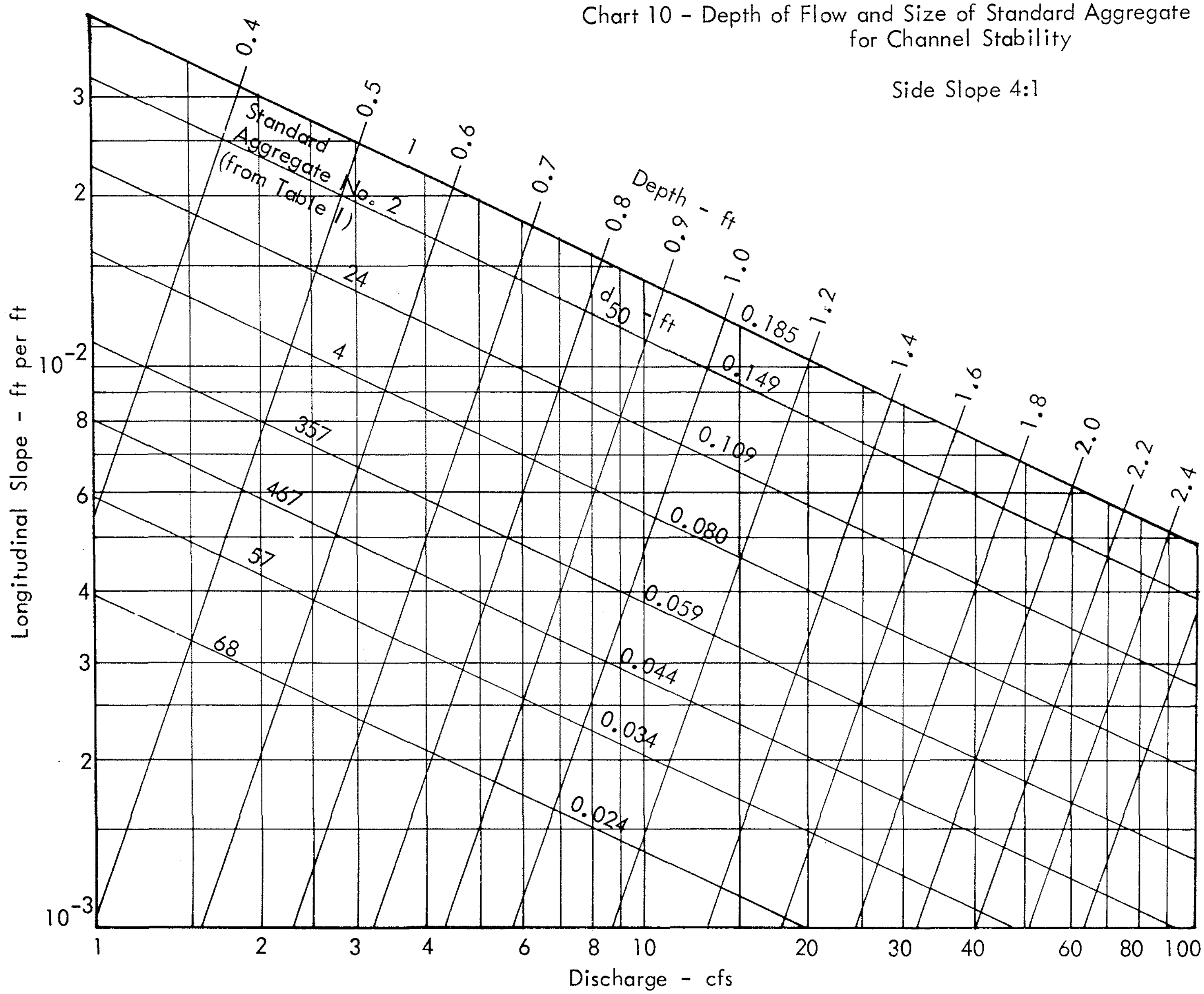


Chart 10 - Depth of Flow and Size of Standard Aggregate for Channel Stability

Side Slope 4:1



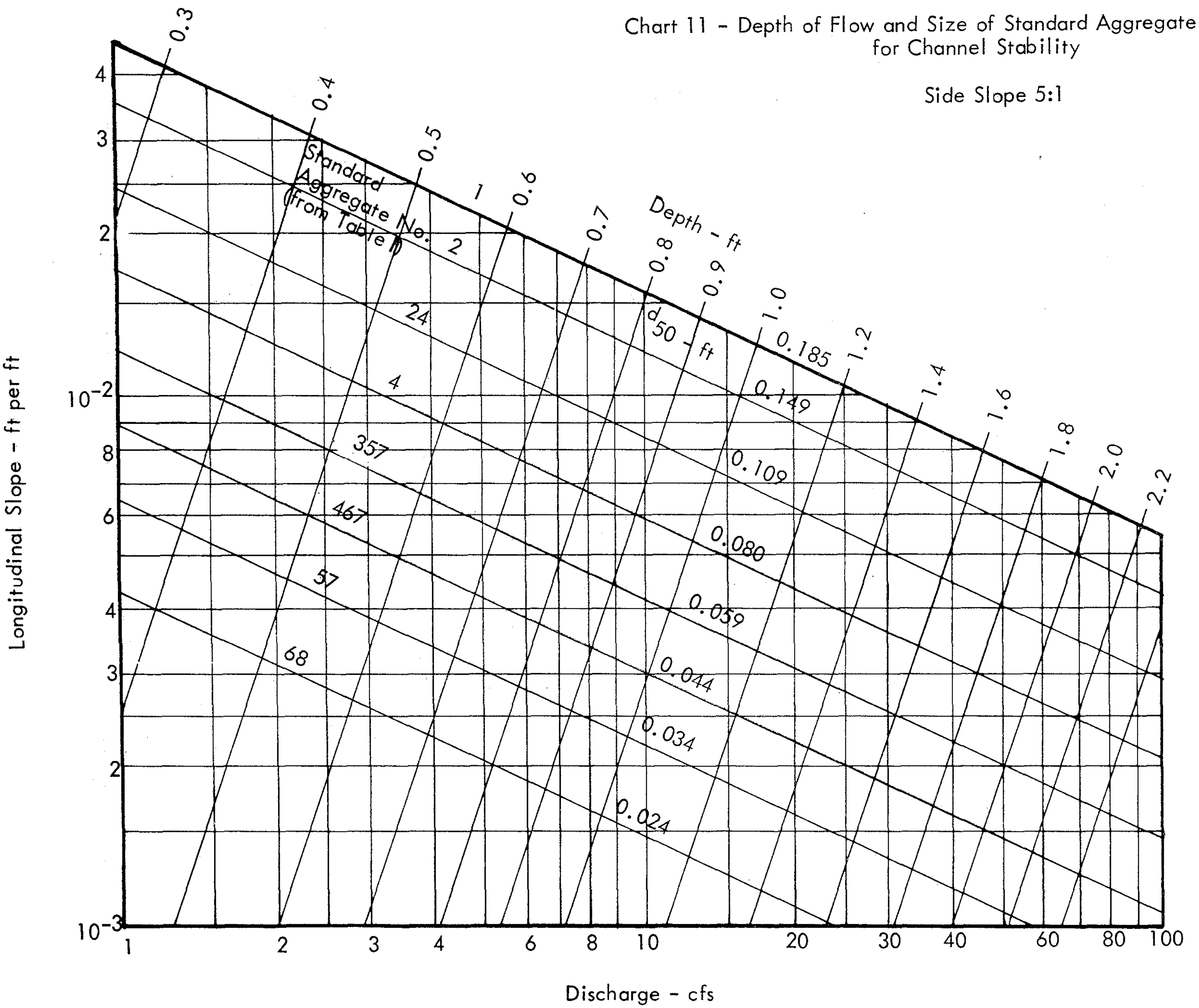


Chart 11 - Depth of Flow and Size of Standard Aggregate for Channel Stability
Side Slope 5:1
Standard Aggregate No. (from Table I)
1
2
24
4
357
467
57
68
Depth - ft
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
2.0
2.2
d50 - ft
0.185
0.149
0.109
0.080
0.059
0.044
0.034
0.024
Longitudinal Slope - ft per ft
Discharge - cfs

Chart 12 - Depth of Flow and Size of Standard Aggregate for Channel Stability

Side Slope 6:1

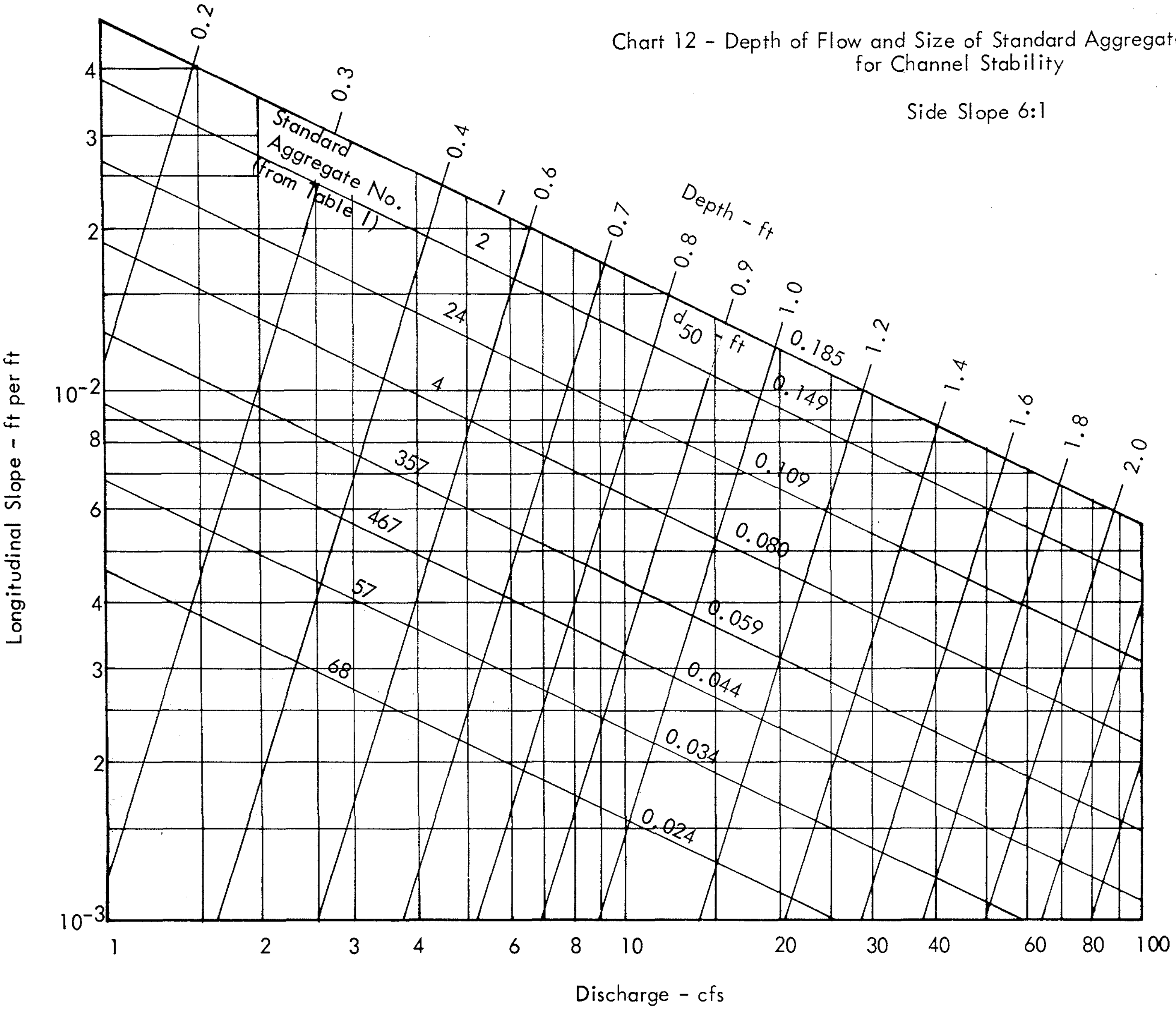
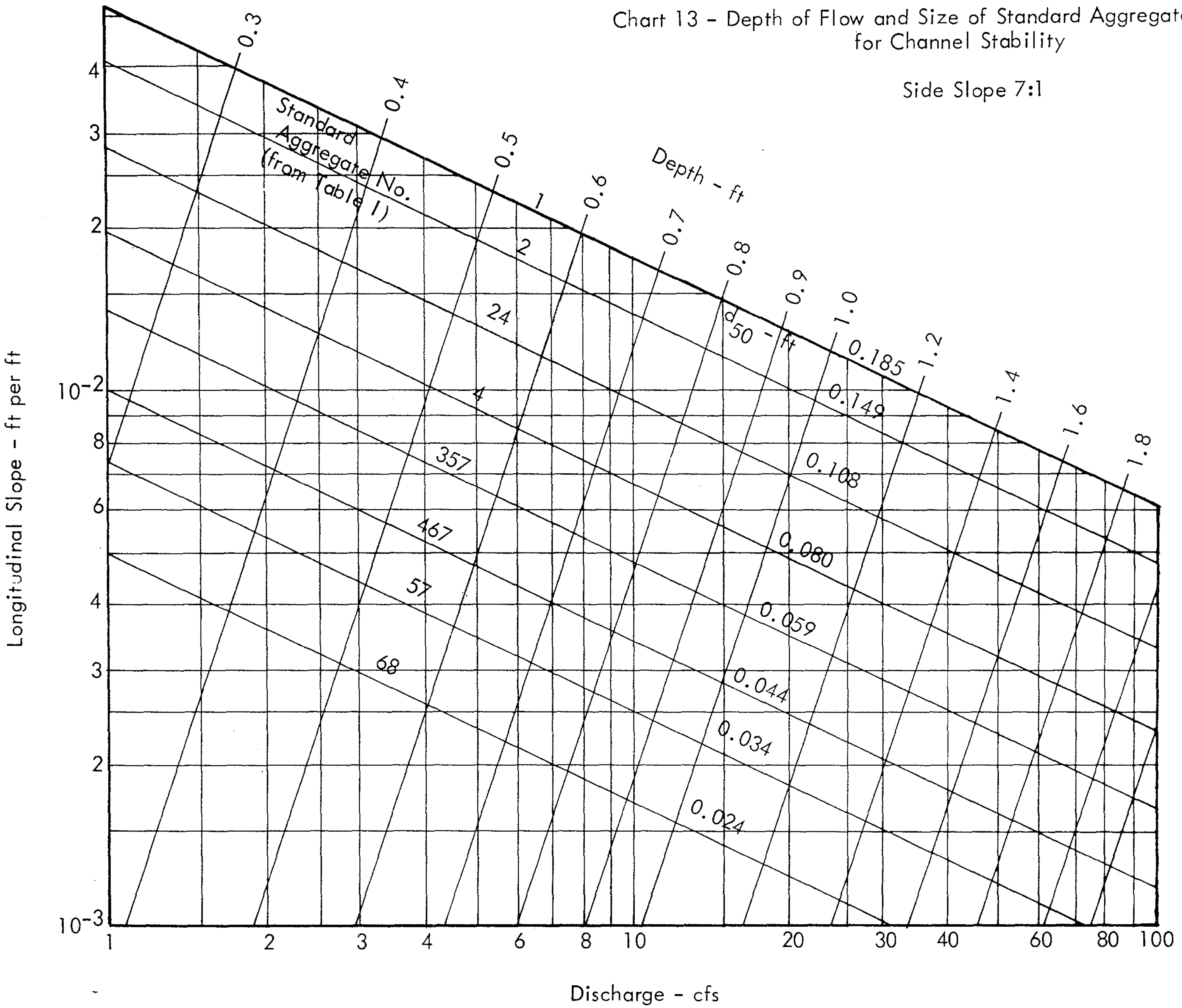


Chart 13 - Depth of Flow and Size of Standard Aggregate for Channel Stability

Side Slope 7:1



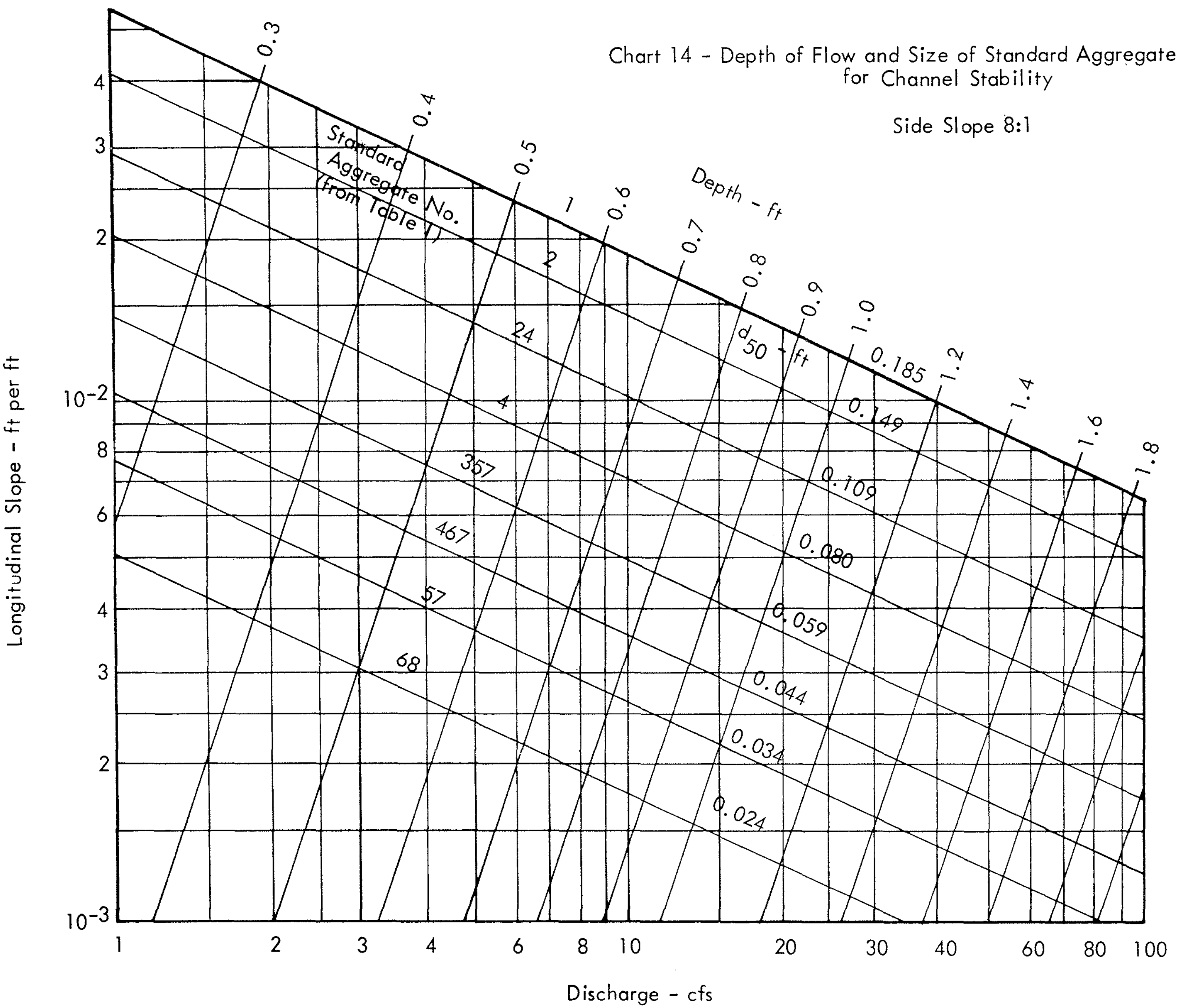


Chart 14 - Depth of Flow and Size of Standard Aggregate for Channel Stability
Side Slope 8:1
Standard Aggregate No. (from Table I)
Depth - ft
d_{50} - ft
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1.8
1
2
24
4
357
467
57
68
0.185
0.149
0.109
0.080
0.059
0.044
0.034
0.024
Longitudinal Slope - ft per ft
10^{-2}
10^{-3}
4
3
2
8
6
1
10
20
30
40
60
80
100
Discharge - cfs

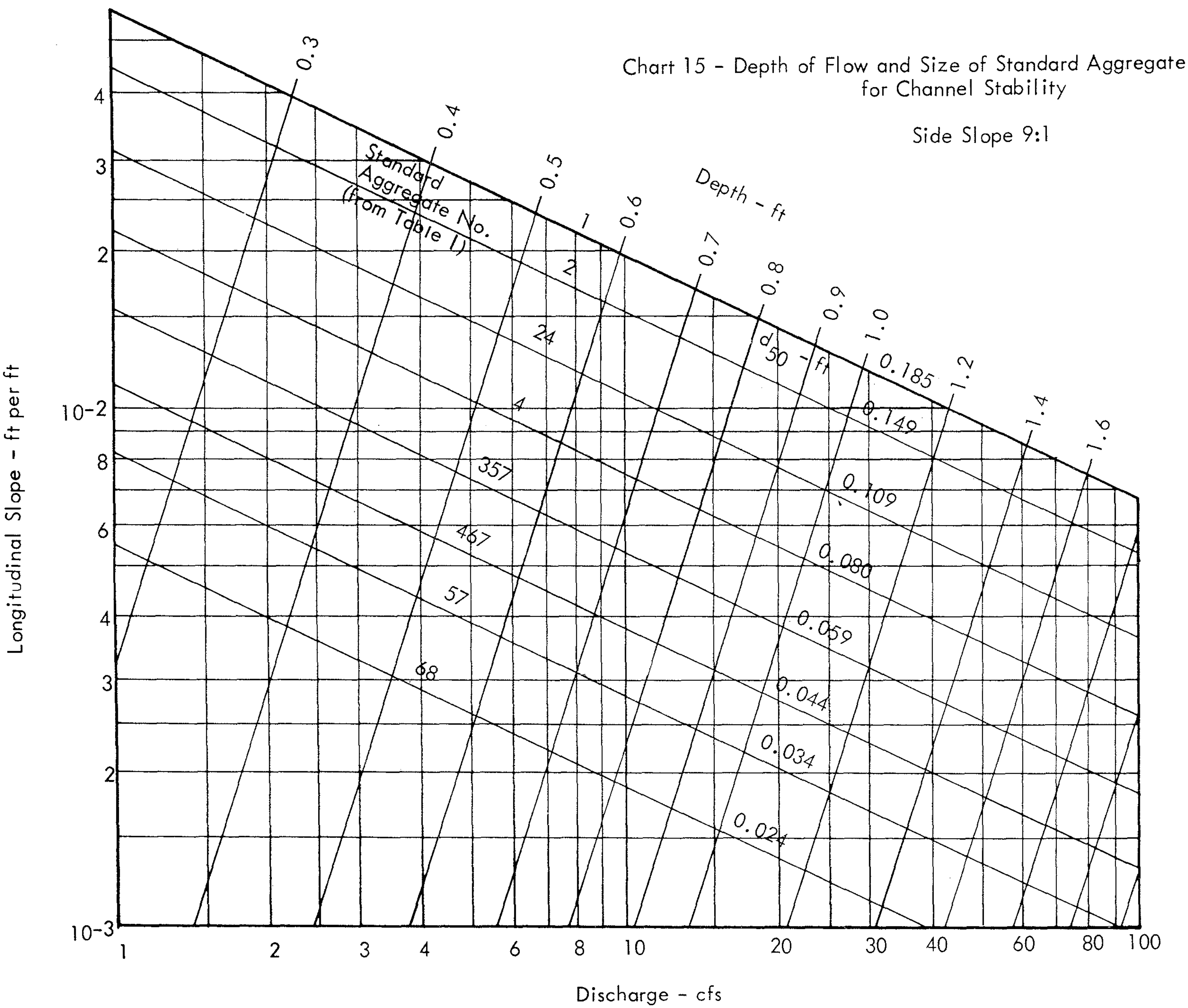


Chart 15 - Depth of Flow and Size of Standard Aggregate for Channel Stability
Side Slope 9:1
Standard Aggregate No. (from Table I)
Depth - ft
d_{50} - ft
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.2
1.4
1.6
1
2
24
4
357
467
57
68
0.185
0.149
0.109
0.080
0.059
0.044
0.034
0.024
Longitudinal Slope - ft per ft
10^{-2}
10^{-3}
Discharge - cfs
1
2
3
4
6
8
10
20
30
40
60
80
100

Chart 16 - Depth of Flow and Size of Standard Aggregate for Channel Stability

Side Slope 10:1