DESIGN GUIDE MD #6

RIPRAP DESIGN METHODS

A COLLECTION OF DESIGN EXAMPLES
AND RELATED INFORMATION

NRCS Natural Resources Conservation Service

Maryland

January 2004

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SECTION I

GENERAL

This design guide is a technical resource prepared by the Maryland NRCS Engineering staff and is intended for use by the NRCS in Maryland and its partners. The intent is not to reinvent existing procedures but to gather and put in one place commonly used design examples, charts and other pertinent information related to riprap design that has been used and distributed over the years.

Section II contains the construction specifications to be used as part of the site-specific design. Add site specific construction specifications as needed.

Section III contains typical values for riprap areas, volumes and dimension for common slopes of riprap used for bank stabilization. These tables can be used to quickly determine the dimensions of the riprap used for bank stabilization and for estimating the volume of riprap needed.

Section IV contains an example of a preformed scour hole design commonly used below a culvert pipe or pond barrel pipe outlet.

Section V contains a design example of an outlet protection used below of a pond barrel pipe.

Section VI contains an example procedure for design of a riprap outlet commonly used for waterway or diversion outlets or for designing riprap channels.

GRADATIONS

Gradation is the size distribution of a particular riprap or aggregate. Material that is well graded has a uniform distribution of sizes, within a given minimum and maximum range. Void spaces between the larger rock are filled with the smaller material. Void space is reduced which results in a denser placement of riprap or aggregate that is less likely to settle or move when under loads. Rock that is poorly graded or gap graded does not have a uniform distribution of sizes within the minimum and maximum range. Material of particular size(s) are missing. Void space is increased which results in increased settlement and movement of the material when under loads.

When choosing riprap or aggregate for a project it is important to choose a material with the proper range of sizes, and a material that is well graded. The State Highway Administration (SHA) in Maryland has gradations of rock for riprap and aggregate. These gradations are generally known by most quarries and contractors. These gradations are published in the SHA, Standard Specifications for Construction Materials, Section 901.02.01 Stone for Riprap and is shown on the following pages. In addition, other gradations of aggregate are contained in American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Construction Materials and are shown on the following pages.

Maryland Department of Transportation, State Highway Administration
Standard Specifications for Construction Materials
901.02.01 Stone for Riprap

Class of Riprap	Size in Weight	Approximate Diameter	Percent of Total by Weight
0	Heavier than 33 lb	7 Inches	0
	Heavier than 10 lb	4 Inches	50
	Less than 1 lb	2 Inches	10 max
I	Heavier than 150 lb	12 Inches	0
	Heavier than 40 lb	8 Inches	50
	Less than 2 lb	3 Inches	10 max
II	Heavier than 700 lb	20 Inches	0
	Heavier than 200 lb	14 Inches	50
	Less than 20 lb	6 Inches	10 max
III	Heavier than 2000 lb	28 Inches	0
	Heavier than 600 lb	20 Inches	50
	Less than 40 lb	8 Inches	10 max

Note: Optimum gradation is 50 percent of the stone being above and 50 percent below the midsize. Reasonable visual tolerances will apply.

STATE HIGHWAY ADMINISTRATION
AGGREGATE GRADING REQUIREMENTS TEST METHOD T-27
TABLE 901A

MATERIALS		SIEVE SIZE															
		2 ½"	2"	1-1/2"	1"	¾"	½"	3/8"	No. 4	No. 8	No. 10	No. 16	No. 30	No. 40	No. 50	No. 100	No. 200
Crusher Run Aggregate CR-6 (f)(g)		-	100	90-100	-	60-90	-	-	30-60	-	-	-	-	-	-	-	0-15
Bank Run Gravel - Subbase		100	-	-	90-100	-	60-100	-	-	-	35-90	-	-	20-55	-	-	5-25
Graded Aggregate – Base Design Range (a)		-	100	95-100	-	70-92	-	50-70	35-55	-	-	-	12-25	-	-	-	0-8
Tolerance (b)		-	-2	±5	-	±8	-	±8	±8	-	-	-	±5	-	-	-	±3(c)
Bank Run Gravel - Base		100	-	-	85-100	-	60-100	-	-	-	35-75	-	-	20-50	-	-	3-20
Course Aggregate Portland Cement Concrete	57 and Underdrain (h)	-	-	100	95-100	-	25-60	-	0-10	0-5	-	-	-	-	-	-	-
	67	-	-	-	100	90-100	-	20-55	0-10	0-5	-	-	-	-	-	-	-
	7	-	-	-	-	100	90-100	40-70	0-15	0-5	-	-	-	-	-	-	-
Fine Aggregate – Portland Cement Concrete, Undrain and Pneumatic Mortar (d)		-	-	-	-	-	-	100	95-100	-	-	45-85	-	-	10-30	0-10	-
Course Aggregate – Lightweight Portland Cement Concrete		-	-	-	100	90-100	-	10-50	0-15	-	-	-	-	-	-	-	-
Fine Aggregate – Lightweight Portland Cement Concrete (d)		-	-	-	-	-	-	100	85-100	-	-	40-80	-	-	10-35	5-25	-
Fine Aggregate/Sand Mortar and Epoxies (d)		-	-	-	-	-	-	-	100	95-100	-	-	-	-	-	0-25	0-10
Mineral Filler		-	-	-	-	-	-	-	-	-	-	-	100	-	95-100	-	70-100
Crushed Glass (e)		-	-	-	-	100	-	-	0-55	-	-	45-85	-	-	-	0-10	-

(a) To establish target values for design.
(b) Production Tolerance.
(c) ±2 for field grading (omitting T11).
(d) Fine Aggregate includes natural or manufactured sand.
(e) Crushed glass shall not contain more than one percent contaminants by weight.
(f) Not to be used in the structural part of any Administration project.
(g) Recycled asphalt pavement physical property requirements in TABLE 901B.
(h) When this material is used for drainage applications, recycled concrete shall not be used.

STATE HIGHWAY ADMINISTRATION
AGGREGATE PHYSICAL PROPERTY REQUIREMENTS
TABLE 901 B

MATERIAL TYPE I	TEST METHOD										
	SPECIFICATION	T90	T104	T112	T113	T112 &T113	T11	T113	D 4791 (a)	T96	T21
		PI max	SODIIUM SULFATE SOUNDESS % max	CLAY LUMPS & FRIABLE PARTICLES % max	CHERT; LESS THAN 2.40 Sp Gr % max	SUM OF CLAY LUMPS, FIRABLE PARTICLE S & CHERT % max	MATERIAL FINER THAN No. 200 SIEVE % max	COAL & IGNITE % max	Flat & ELONGATED % max	LOS ANGELES ABRASION % max	ORGANIC IMPURITIES max
Crusher run Aggregate CR-6	D 2940 (h)	6	12	-	-	-	-	-	15	50	-
Bank Run Gravel – Subbase	D 2940	9	12	-	-	-	-	-	-	50	-
Graded Aggregate – Base	D 2940	6	12	-	-	-	-	-	15	50	-
Bank Run Gravel – Base	D 2940	9	12	-	-	-	-	-	-	50	-
Course Aggregate – PCC (b)	M 80 Class A	-	12	2.0	3.0	3.0	1.0(c)	0.5	12	50	-
Fine Aggregate – PCC (b)(d)	M 80 Class B	-	10	3.0	-	-	4.0(e)	1.0	-	-	3.0
Course Aggregate Lightweight PCC	M 195	-	-	2.0	-	-	-	-	12	-	-
Fine Aggregate Lightweight PCC (f)	M 195	-	-	2.0	-	-	-	-	-	-	3.0
Fine Aggregate/Sand Mortar & epoxies	M 45	-	10	1.0	-	-	-	0.5	-	-	3.-
Mineral Filler	M17	NP	-	-	-	-	-	-	-	-	-
Crushed Class	M80	-	12	-	-	-	-	-	-	45	-

(a) Dimensional ratio of calipers shall be 5:1
(b) Course and fine aggregate for PCC shall be tested for alkali silica reactivity (ASR) as specified in MSMT 212.
(c) 1.5 if material passing No. 200 sieve is dust of fracture, free of clay or shale.
(d) In areas exposed to traffic manufactured sand shall have a minimum ultimate polish value of 8, based on the parent rock.
(e) 5.0 for concrete not subject to surface abrasion.
(f) Fine aggregate conforming to M 6 may be used if the lightweight concrete does not exceed the maximum unit weight specified in the contract Documents.
(g) Fly ash shall have a maximum of 12 percent loss on ignition.
(h) Other approved inert materials of similar characteristics may be used provided they conform to these provisions. When crushed reclaimed concrete is used, the soundness loss by five cycles of the magnesium sulfate test shall not exceed 18 percent when tested as specified in T 104.

AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)
TABLE 1 Standard Sizes of Course Aggregate
M43 SPECIFICATIONS FOR MATERIALS

Size	Nominal Size. Square Openings	Amounts Finer than Each Laboratory Sieve (Square Openings) weight percent														
		4-in. (100-mm)	3½ -in. (90-mm)	3-in. (75-mm)	2½-in. (63-mm)	2-in. (50-mm)	1½ in 37.5-mm).	1-in. (25-mm)	¾-in. (19.0-mm)	½-in. (12.5-mm)	3/8-in. (9.5-mm)	No. 4 (4.75-mm)	No. 8 (2.36-mm)	No. 16 (1.18-mm)	No. 50 (300-µm)	No. 100 (150--µm)
1	3½ to 1½ in. (90 to 37.7 mm)	100	90 to 100	-	25 to 60	-	0 to 15	-	0 to 5	-	-	-	-	-	-	-
2	2½ to 1½ in. (63 to 37.7 mm)	-	-	100	90 to 100	35 to 75	0 to 15	-	0 to 5	-	-	-	-	-	-	-
24	2 ½ to ¾ in. (63 to 37.7 mm)	-	-	100	90 to 100	0	25 to 60	-	0 to 10	0 to 5	-	-	-	-	-	-
3	2 to 1 in. (50 to 7.75 mm)	-	-	-	100	90 to 100	35 to 70	0 to 15	-	0 to 5	-	-	-	-	-	-
357	2 in. to No. 4 (50 to 4.75 mm)	-	-	-	100	90 to 100	35 to 75	0 to 15	-	0 to 5	-	-	-	-	-	-
4	1½ to ¾ in. (37.5 to 19 mm)	-	-	-	-	100	90 to 100	20 to 55	0 to 15	-	0 to 5	-	-	-	-	-
467	1½ in to No. 4 (37.5 to 4.75 mm)	-	-	-	-	100	95 to 100	-	35 t0 70	-	10 to 30	0 to 5	-	-	-	-
5	1 to ½ in. (25 to 12.5 mm)	-	-	-	-	-	100	90 to 100	20 to 55	0 to 10	0 to 5	-	-	-	-	-
56	1 to ? in. (25 to 9.5 mm)	-	-	-	-	-	100	90 to 100	40 to 85	10 to 40	0 to 15	0 to 5	-	-	-	-
57	1 in. to No. 4 (25 to 4.75 mm)	-	-	-	-	-	100	95 to 100	-	25 to 60	-	0 to 10	0 to 5	-	-	-
6	¾ to ? in. (19 to 9.5 mm)	-	-	-	-	-	-	100	90 to 100	20 to 55	0 to 15	0 to 5	-	-	-	-
67	¾ in to No. 4 (19 to 4.75 mm)	-	-	-	-	-	-	100	90 to 100	-	20 to 55	0 to 10	0 to 5	-	-	-
68	¾ in to No. 8 (9.5 to 2.36 mm)	-	-	-	-	-	-	100	90 to 100	-	30 to 65	5 to 25	0 to 10	0 to 5	-	-
7	½ in to No. 4 (12.5 to 4.75 mm)	-	-	-	-	-	-	-	100	90 to 100	40 to 70	0 to 15	0 to 5	-	-	-
78	½ in to No. 8 (12.5 to 2.36 mm)	-	-	-	-	-	-	-	100	90 to 100	40 to 75	5 to 25	0 to 10	0 to 5	-	-
8	? in to No. 8 (9.5 to 2.36 mm)	-	-	-	-	-	-	-	-	100	85 to 100	10 to 30	0 to 10	0 to 5	-	-
89	? in to No. 16 (9.5 to 1.18 mm)	-	-	-	-	-	-	-	-	100	90 to 100	20 to 55	5 to 30	0 to 10	0 to 5	-
9	No. 4 to No. 16 (4.75 to 1.18 mm)	-	-	-	-	-	-	-	-	-	100	85 to 100	10 to 40	0 to 10	0 to 5	-
10	No. 4 to 0[A] (4.75 mm)	-	-	-	-	-	-	-	-	-	100	85 to 100	-	-	-	10 to 30

[A] Screenings.

GEOTEXTILE

The geotextile prevents migration of the fine soil particles through voids in the structure, distributes the weight of the armor units to provide more uniform settlement, and permits relief of hydrostatic pressures with the soils.

The proper design of fabric filters is critical to the stability of riprap installations on channel banks. If openings in the filter are too large, excessive piping through the filter can cause erosion and failure of the bank material below the filter. On the other hand, if the openings in the filter are too small, the build-up of hydrostatic pressures behind the filter can cause a slip plane to form along the filter resulting in massive translational slide failure. For many installations with riprap, non-woven geotextiles are preferred over woven geotextiles. This is especially true for slopes steeper than 3:1. Non-woven geotextiles have more friction to resist sliding. Also, the non-woven fabrics have more stretch and can conform to irregular surfaces and settlement better than woven geotextiles. Geotextiles should be selected carefully. Manufacturers frequently offer a selection, with each intended for a different purpose.

The State Highway Administration (SHA) in Maryland has classifications for geotextile. These classifications are generally known by most suppliers and contractors. These classifications are published in the SHA, Standard Specifications for Construction Materials, Section 921.09 Geotextiles and are shown below. For most conservation practices geotextile Application Class SE nonwoven or woven will be used.

STATE HIGHWAY ADMINISTRATION GEOTEXTILE REQUIREMENTS						
Maryland Application Class	Type of Geotextile	Grab Strength Lb D 4632	Puncture Strength Lb D 4833	Permittivity Sec-1	Apparent Opening Size. Max Mm D 4751	Trapezoid Tear Strength Lb D4533
SD TYPE I	NONWOVEN	160	56	0.50	0.43	55
	WOVEN, MONOFILAMENT	250	90	0.50	0.43	90
SD TYPE II	NONWOVEN	160	56	0.20	0.25	55
	WOVEN, MONOFILAMENT	250	90	0.20	0.25	90
PE TYPE I	NONWOVEN	200	80	0.70	0.43	80
	WOVEN, MONOFILAMENT	250	90	0.70	0.43	90
PE TYPE I	NONWOVEN	200	80	0.20	0.25	80
	WOVEN, MONOFILAMENT	250	90	0.20	0.25	90
PE TYPE III	NONWOVEN	200	80	0.10	0.22	80
	WOVEN	250	90	0.10	0.22	90
SE	NONWOVEN	200	80	0.20	0.30	80
	WOVEN	250	90	0.20	0.30	90
ST	WOVEN	300*	110	0.05	0.15**	110
F	WOVEN	100	-	0.05	0.60	-
E	NONWOVEN	90	30	0.05	0.30	30

Note: 1 All property values are based on minimum average roll values in the weakest principle direction, except for apparent opening size.
Note: 2 The ultraviolet stability shall be 50 percent after 500 hours of exposure for all classed, except Class F, which shall be 70 percent (D 4355)
* Minimum 15 percent elongation.
** This is a minimum apparent opening size, not a maximum.

SECTION II

CONSTRUCTION SPECIFICATIONS

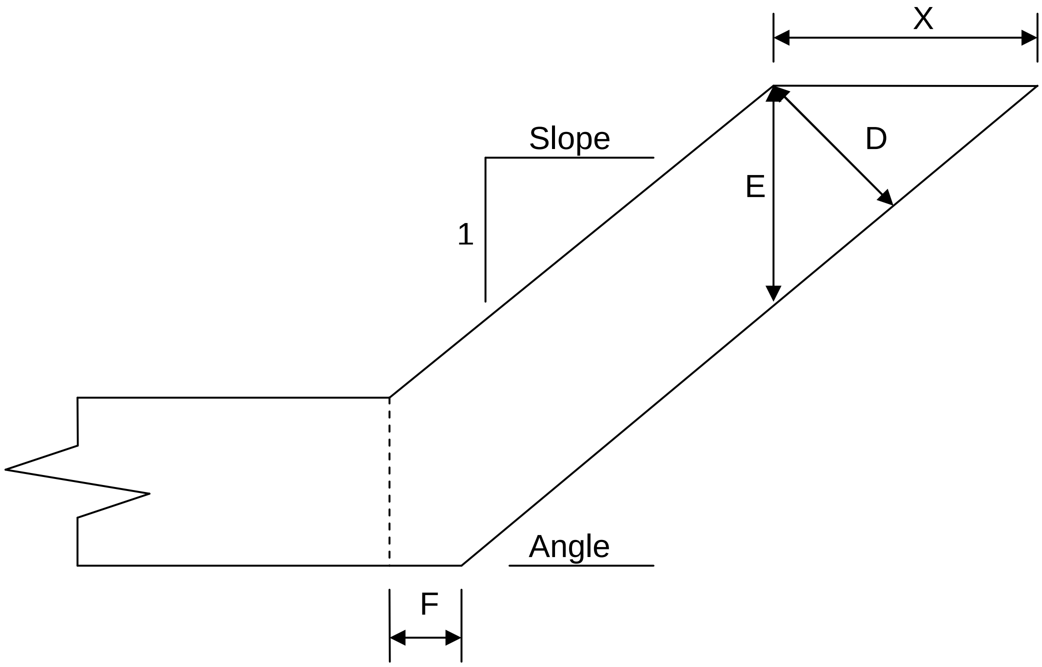
1. All materials and construction shall be in accordance with applicable NRCS standards and construction specifications.
2. Any changes in the plans or specifications must be approved by the engineer prior to being made. Changes are to be reviewed by the landowner for concurrence.
3. Rock Riprap shall conform to the requirements as shown on the plans. It shall be free from dirt, clay, sand, rock fines, and other material not meeting the required gradation limits.
4. The subgrade surface on which the rock riprap, filter, bedding, or geotextile is to be placed shall be cut or filled and graded to the lines and grades shown on the drawings. When fill to subgrade lines is required, it shall consist of approved material and shall conform to the requirements as shown on the plans. Rock riprap, filter, bedding, or geotextile shall not be placed until the foundation preparation is completed and the subgrade surface has been inspected and approved.
5. The rock riprap shall be placed by equipment on the surface and to the depth specified. It shall be installed to the full course thickness in one operation and in such a manner as to avoid serious displacement of the underlying material. The rock for riprap shall be delivered and placed in a manner that ensures the riprap in place is reasonably homogeneous with the larger rocks uniformly distributed and firmly in contact one to another with the smaller rocks and spalls filling the voids between the larger rocks. Some hand placing may be required to provide a neat and uniform surface.
6. The Soil Conservation District makes no representation as to the existence or nonexistence of any utilities at the construction site. Shown on these construction drawings are those utilities, which have been identified. It is the responsibility of the landowners or operators and contractors to assure themselves that no hazard exists or damage will occur to utilities. Miss Utility should be contacted at
   1 800-257-7777.

SECTION III

Typical Values for Riprap Areas, Volumes and Dimensions

COMMON DIMENSIONS

Sheet 1 of 1



X = D/Sin of Angle X = D × A

E = D/Cos of Angle E = D × B

F = D x Cot ((180º - angle)/2) F = D × C

SLOPE	ANGLE	A	B	C
1:1	45.00º	1.41	1.41	0.41
1.5:1	33.69º	1.80	1.20	0.30
2:1	26.57º	2.24	1.12	0.24
2.5:1	21.80º	2.69	1.08	0.19
3:1	18.43º	3.16	1.05	0.16
4:1	14.04º	4.12	1.03	0.12
5:1	11.31º	5.10	1.02	0.10

ROCK RIPRAP VALUES

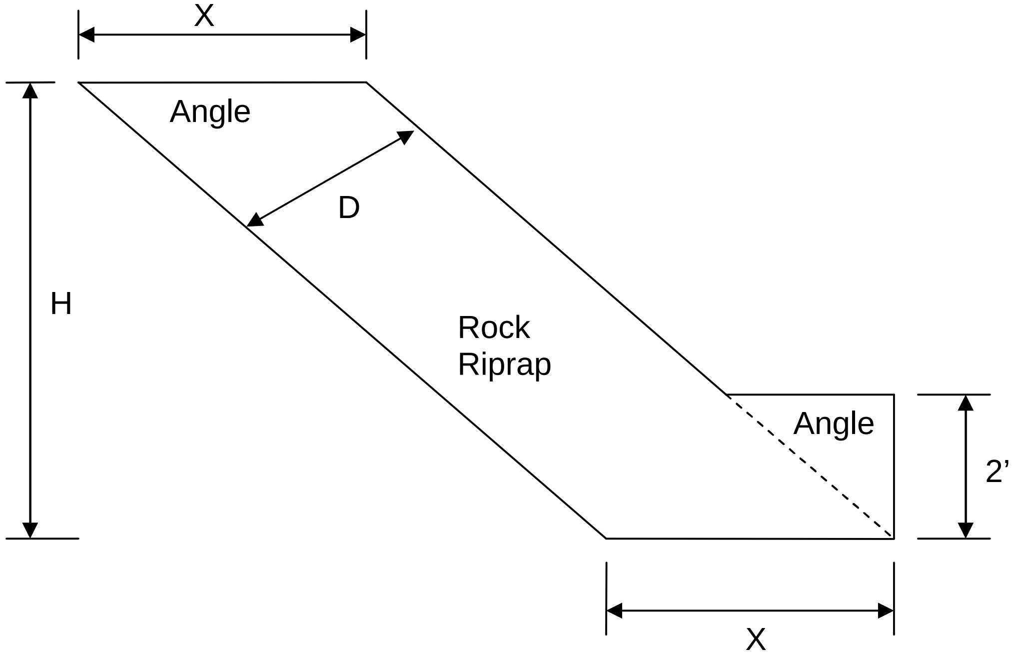


Table of X Values				
(D) Rock Thickness	Side Slopes			
	1.5:1	2:1	2.5:1	3:1
12"	1.8'	2.2'	2.7'	3.2'
18"	2.7'	3.4'	4.0'	4.7'
24"	3.6'	4.5'	5.4'	6.3'
30"	4.5'	5.6'	6.7'	7.9'
36"	5.4'	6.7'	8.1'	9.5'
42"	6.3'	7.8'	9.4'	11.1'
48"	7.2'	8.9'	10.8'	12.7'
Angle	33.69º	26.57º	21.80º	18.43º

AREA OF 1.5:1 SIDE SLOPES (FT^2)							
"H" Ft.	Placement Thickness "D" (ft.)						
	1'	1.5'	2.0'	2.5'	3.0'	3.5'	4.0'
3	8.41	11.11	13.82	16.51	19.23	21.93	24.63
4	10.21	13.82	17.42	21.03	24.63	28.24	31.84
5	12.01	16.52	21.03	25.53	30.04	34.55	39.06
6	13.82	19.23	24.63	30.04	35.45	40.86	46.27
7	15.62	21.93	28.24	34.55	40.86	47.17	53.48
8	17.42	24.63	31.84	39.06	46.27	53.48	60.69
9	19.23	27.34	35.45	43.56	51.68	59.79	67.90
10	21.03	30.04	39.06	48.07	57.08	66.10	67.90
"H"	1.8'	2.7'	3.6'	4.5'	5.4'	6.3'	7.2'
(Ft.)	Value for "X" (Ft)						

AREA OF 2:1 SIDE SLOPES (FT^2)							
"H" Ft.	Placement Thickness "D" (ft.)						
	1'	1.5'	2.0'	2.5'	3.0'	3.5'	4.0'
3	10.71	14.06	17.41	20.77	24.12	27.47	30.85
4	12.94	17.41	21.89	26.36	30.83	35.30	39.77
5	15.18	20.77	26.36	31.95	37.54	43.12	48.71
6	17.41	24.12	30.83	37.54	44.24	50.95	57.66
7	19.65	27.47	35.30	43.12	50.95	58.77	66.60
8	21.89	30.83	39.77	48.71	57.66	66.60	75.54
9	24.12	34.18	44.24	54.30	64.36	74.42	84.48
10	26.36	37.54	48.71	59.89	71.07	82.25	93.43
"H"	2.2'	3.4'	4.5'	5.6'	6.7'	7.8'	8.9'
(Ft.)	Value for "X" (Ft)						

AREA OF 2.5:1 SIDE SLOPES (FT^2)							
"H" Ft.	Placement Thickness "y" (ft.)						
	1'	1.5'	2.0'	2.5'	3.0'	3.5'	4.0'
3	9.04	11.06	13.08	15.10	17.12	19.14	21.16
4	15.77	21.16	25.24	31.93	37.31	42.70	48.08
5	18.46	25.20	31.30	38.66	45.39	52.12	58.85
6	21.16	29.23	37.31	45.39	53.47	61.55	69.63
7	23.85	33.27	42.70	52.12	61.55	70.97	80.40
8	26.54	37.31	48.08	58.85	69.63	80.40	91.17
9	29.23	41.35	53.47	65.59	77.70	89.82	101.94
10	31.93	45.39	58.85	72.32	85.78	99.25	112.71
"H" (Ft.)	2.7'	4.0'	5.4'	6.7'	8.1'	9.4'	10.8'
	Value for "X" (Ft)						

AREA OF 3:1 SIDE SLOPES (FT^2)							
"H" Ft.	Placement Thickness "D" (ft.)						
	1'	1.5'	2.0'	2.5'	3.0'	3.5'	4.0'
3	15.49	20.23	24.98	29.72	34.47	39.21	43.96
4	18.65	24.98	31.30	37.63	43.96	50.28	56.61
5	21.82	29.72	37.63	45.54	53.45	61.35	69.26
6	24.98	34.47	43.96	53.45	62.94	72.43	81.91
7	28.14	39.21	50.28	61.35	72.43	83.50	94.57
8	31.30	43.96	56.61	69.26	81.91	94.57	107.22
9	34.47	48.70	62.94	77.17	91.40	105.64	119.87
10	37.63	53.45	69.26	85.08	100.89	116.71	132.52
"H" (Ft.)	3.2'	4.7'	6.3'	7.9'	9.5'	11.1'	12.7'
	Value for "X" (Ft)						

SECTION IV

Preformed Scour Hole

Sheet 1 of 3

RIPRAP LINED PLUNGE POOL OR STILLING BASIN

Preformed stilling basins are normally recommended where materials eroded from plunge pools can cause downstream damage to the channel or the environment. Riprap lining is recommended for basins in erodible soils or where seepage occurs in the basin. Basins are normally required for cantilevered outlets on dams, grade stabilization structures, etc.

Limited to a Maximum Diameter of 30 inches.

In order to develop additional design and cost effective measures for pond outfalls the following methodology will be used to design outfall for several selected pond sites.

Methodology in detail is explained in Miscellaneous paper H-72-5 “Practical Guidance for Estimating and Controlling Erosion at Culvert Outlet.” U.S. Army Engrs. Waterways Experiment Station Vicksburg, Mississippi, May 1972.

Step 1 Determine Trail Depth (d_0) Preformed Scour Hole

Try $d_0 = 0.5 \times$ Diameter of pipe $= 0.5 \times D_0$

Step 2 Determine pipe capacity, Q and Tailwater, TW for site

Q
TW

Step 3 Select C value dependent on scour depth d_0

If $d_0 = 0.5D_0$ use $C = 0.0125$
If $d_0 = 1.0D_0$ use $C = 0.0082$

Step 4 Compute the following equation: to determine riprap size:

$d_{50} = C(D_0^2/TW)(Q/D_0^{5/2})^{4/3}$

Step 5 Determine dimensions of preformed scour hole based on attached section and plan view.

Step 6 Compute volume of riprap.

Volume = (depth of riprap)$(L + 2(3d_0^2 + d_0^2))^{1/2}(w + 2(3d_0^2 + d_0^2))^{1/2}$

<u>Example:</u>

Given $Q = 65$ cfs
$D_0 = 30$ inch CMP

Step 1 $d_0 = 0.5(30in)(1ft/12in) = 1.25$ feet

Step 2 $Q = 65$ cfs

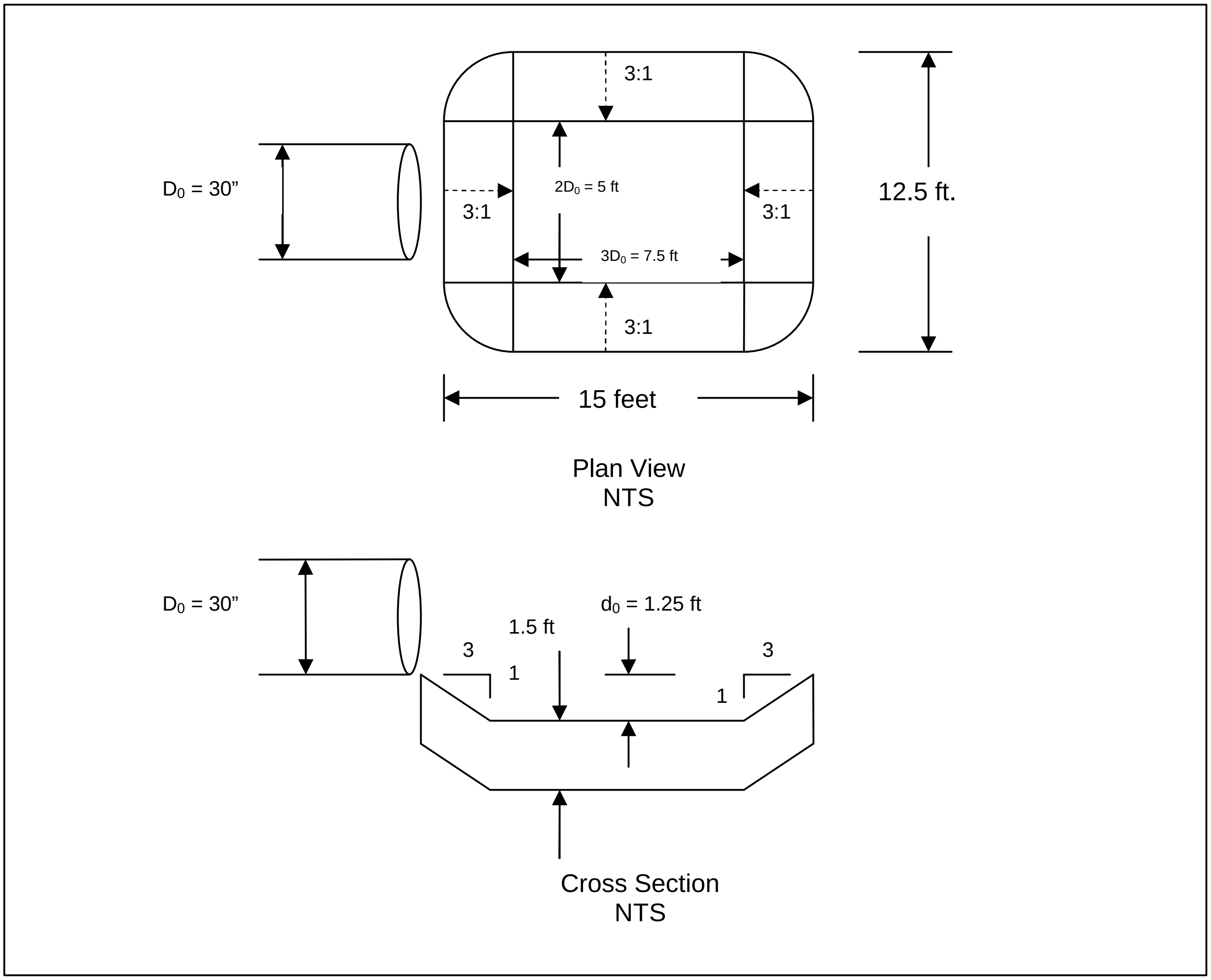
$TW = (30in/2)(1ft/12in) = 1.25$ feet
Minimum TW selected is $\frac{1}{2}D_0$ (Wide floodplain downstream).

Step 3 $C = 0.0125$ for $d_0 = 0.5D_0$

Step 4 $d_{50} = C(D_0^2/TW)(Q/D_0^{5/2})^{4/3}$

$d_{50} = 0.0125(2.5^2/1.25)(65/2.5^{5/2})^{4/3}$
$d_{50} = 0.0125(5.0)(12.32) = 0.77$ feet
$d_{50} = 0.77$ feet use 9" to 10" stone

Step 5



Step 6

$$\text{Surface Area} = (L + 2(3d_0^2 + d_0^2))^{1/2}(w + 2(3d_0^2 + d_0^2))^{1/2}$$
$$\text{Surface Area} = (7.5 + 2(3.75^2 + 1.25^2))^{1/2}(5 + 2(3.75^2 + 1.25^2))^{1/2}$$
$$\text{Surface Area} = (15.4)(12.9)$$
$$\text{Surface Area} = 198.7\text{ft}^2$$

$$\text{Volume} = ((1.5')(198.7\text{ft}^2))/27\text{ft}^3/\text{yd}^3 = 11.04\text{ yd}^3 \quad \text{Use } 11\text{ yd}^3$$

Convert to Weight
$(11\text{ yd}^3)(1.5\text{ ton/yd}^3) = 16.5\text{ ton}$

SECTION V

Example Procedure for Design of Outlet Protection

DESIGN OF OUTLET PROTECTION

Outlet protection as presented here is a level apron of sufficient length and flare such that the expanding flow (from pipe or conduit to channel) loses sufficient velocity and energy that it will not erode the next downstream channel reach. The design curves are based on circular conduits flowing full. The curves provide the apron size and if riprap is to be used, the minimum d_{50} size for the riprap. There are two curves, one for a low or minimum tailwater condition and the other a high or maximum tailwater condition. The minimum condition applies to a tailwater surface elevation less than the center of the pipe whereas the maximum condition applies to a tailwater surface elevation equal to or higher than the center of the pipe.

The first requirement in using this procedure is to determine the tailwater condition as required in the standard and specifications. Then, for circular conduits, enter the appropriate chart with the discharge and the pipe diameter to find the riprap size and apron length. Then calculate the apron width.

Example 1:

A circular conduit is flowing full.
Q = 280 cfs, diameter = 66 inches and tailwater (surface) is 2 feet above the pipe invert.
This is a minimum tailwater condition.
Read d_{50} = 1.2’, and apron length = 38 feet.
Apron width = diameter + L_a = 38’ + 5.5’ = 43.5 feet.
Maximum stone size in the riprap mixture = 1.5 × d_{50} = 1.5 × 1.2’ = 1.8 feet.

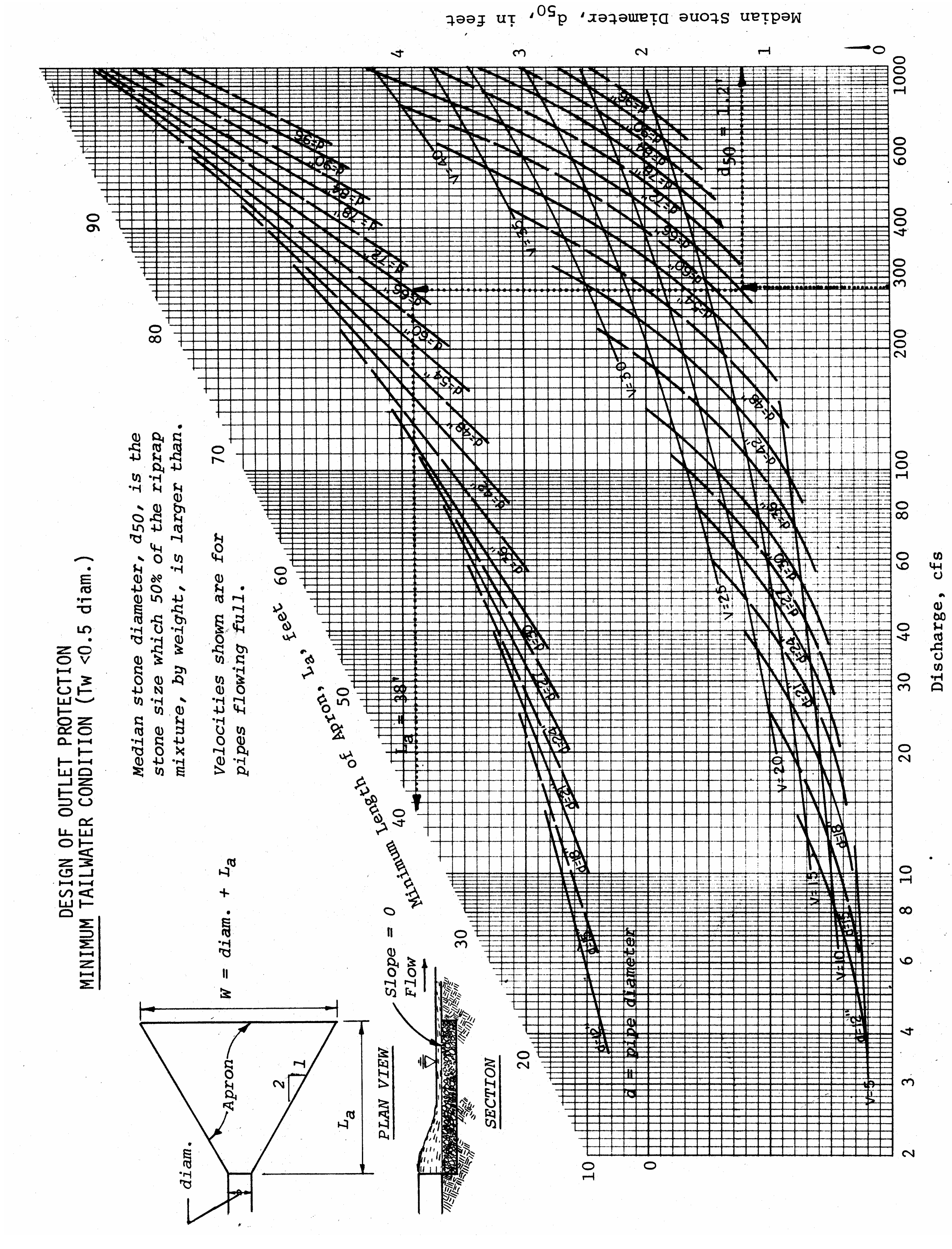
The curves may also be used for the design of outlet protection for rectangular conduits but the procedure is slightly different. Depth of flow and velocity are the two flow parameters to be used. Enter the lower set of curves with velocity and depth (using the diameter curves for depth), then read to the right to find d50 and up and left for the length of apron. To find the apron width subsitute conduit width for diameter in the apron width equations.

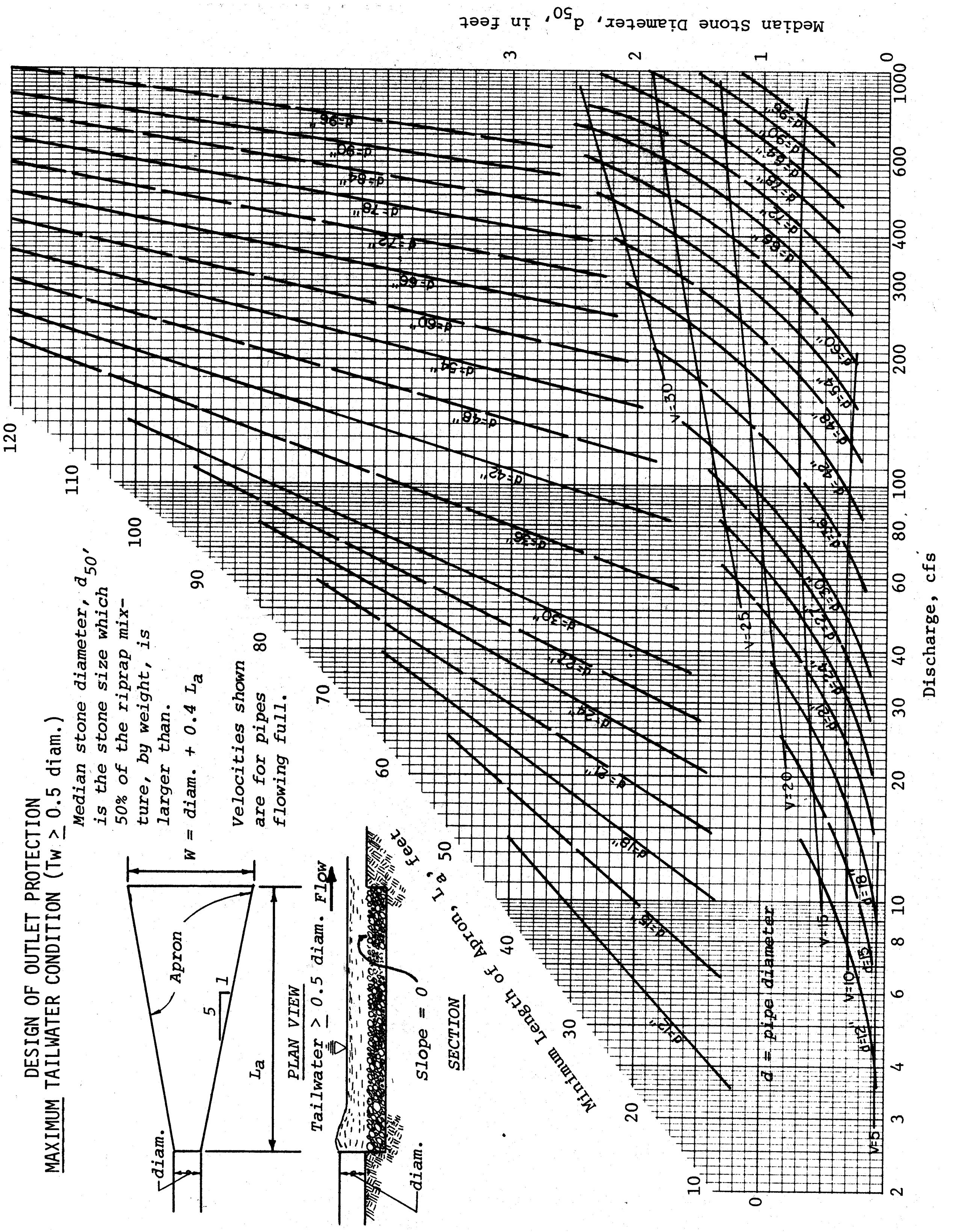
Example 2:

A concrete box 5.5’ x 10’ is flowing 5.0’ deep, Q = 600 cfs and tailwater surface 5’ above invert (Max. tailwater condition).

V = Q/A = 600/(5.0’ x 10’) = 12 feet/second

At the intersection of the curve d = 60” and V = 12 fps, read d_{50} = 0.4 feet.
Then reading up to the d = 60” curve, read apron length = 40 feet.
Apron width, W = conduit width + 0.4 L_a = 10 + (0.4)(40) = 26 feet.
Largest stone size = 0.4 x 1.5 = 0.6 feet or 7inches.


DESIGN OF OUTLET PROTECTION
MINIMUM TAILWATER CONDITION (Tw <0.5 diam.)
Median stone diameter, d50, is the stone size which 50% of the riprap mixture, by weight, is larger than.
Velocities shown are for pipes flowing full.
W = diam. + La
Minimum Length of Apron, La, feet
La = 38'
d50 = 1.2'
Median Stone Diameter, d50, in feet
Discharge, cfs
d = pipe diameter
diam.
Apron
La
PLAN VIEW
Slope = 0
Flow
SECTION


DESIGN OF OUTLET PROTECTION
MAXIMUM TAILWATER CONDITION (Tw ≥ 0.5 diam.)
Median stone diameter, d_{50}, is the stone size which 50% of the riprap mixture, by weight, is larger than.
W = diam. + 0.4 L_a
Velocities shown are for pipes flowing full.
Apron
diam.
L_a
PLAN VIEW
Tailwater ≥ 0.5 diam.
Flow
Slope = 0
diam.
SECTION
Median Stone Diameter, d_{50}, in feet
Discharge, cfs
Minimum Length of Apron, L_a, feet
d = pipe diameter

SECTION VI

Example Procedure for Designing a Riprap Outlet
By: Jeff Teets 3/98

DESIGNING

RIPRAP

OUTLETS

PROCEDURE FOR DESIGNING A RIPRAP OUTLET

1. Survey profile and cross section at outlet location.
2. Plot survey and determine grade.
3. Determine peak flow for design storm. Q_{10} for this example.
4. Select a readily available riprap size (example – MSHA Class I) or determine size of existing riprap.
5. From the Manning's chart, Chapter IV – Technical Guide for Lined Waterway or Outlet 468-3, choose a flow depth for the D_{50} rock size you selected.
6. From the National Engineering Handbook, Chapter 16, Appendix 16A, isbash curve, determine the maximum velocity for the D_{50} rock size selected.
7. Using Manning's equation, determine the size of the riprap channel needed for the appropriate discharge in cfs.
8. Determine the riprap thickness needed (1.5 times D_{max}).
9. Calculate the riprap quantities.

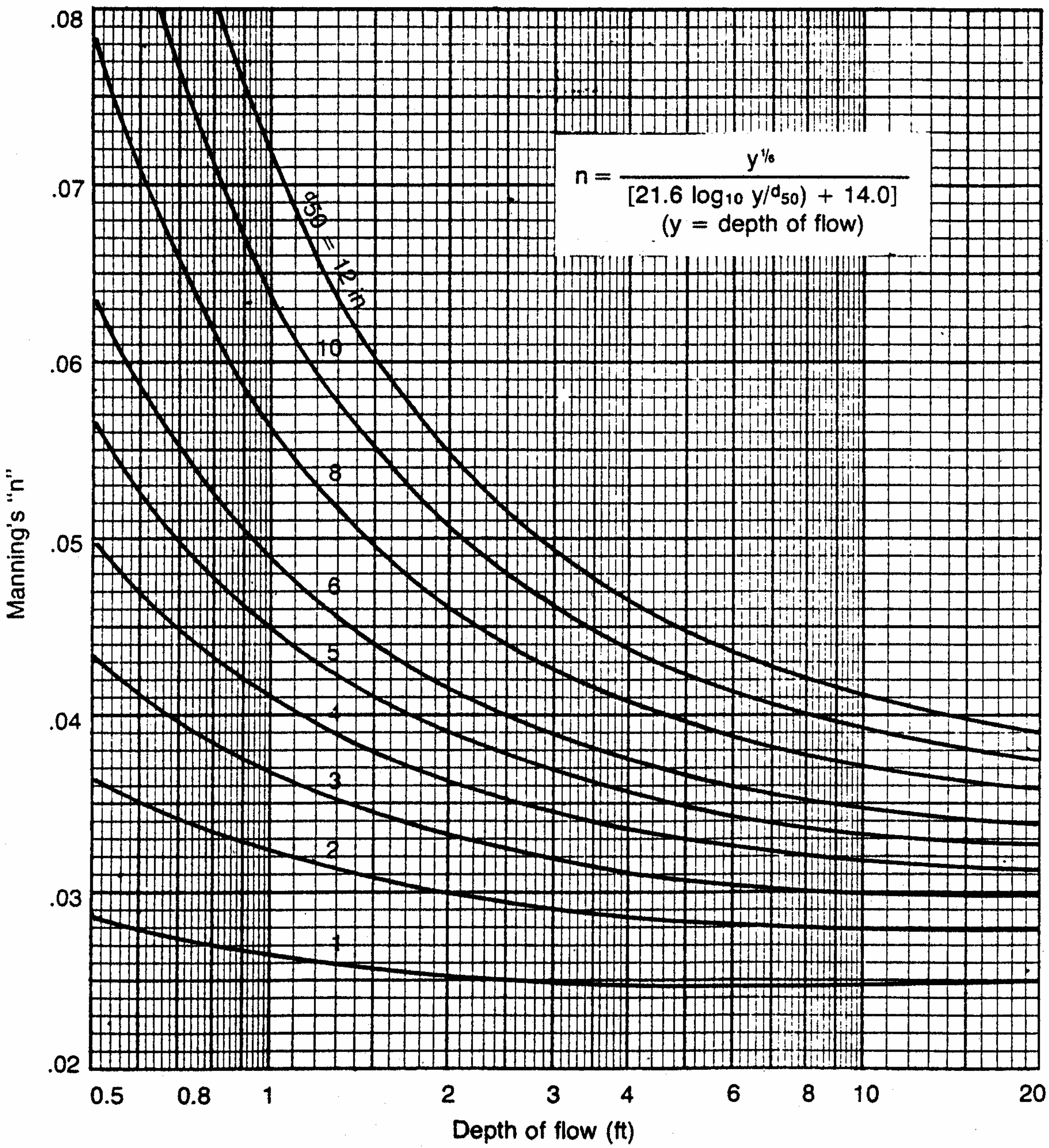
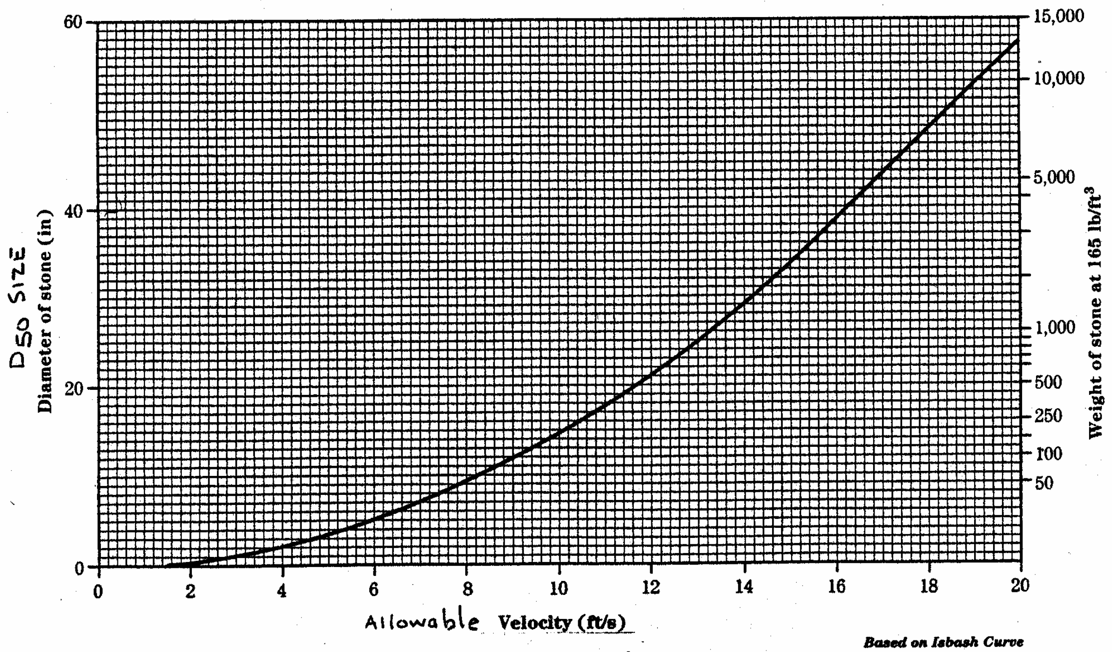


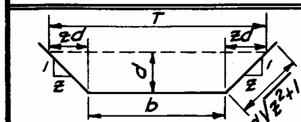
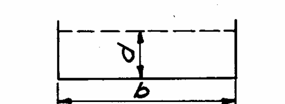
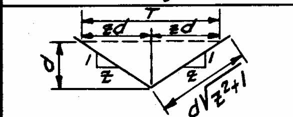
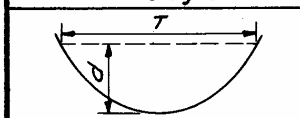
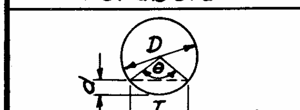
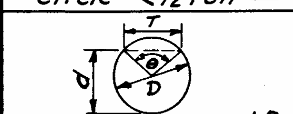
Figure 1.—Values of *n* for riprap-lined channels, d_{50} size vs depth of flow.



Procedure

1. Determine the design velocity.
2. Use velocity and fig. 16A-1 (Isbash Curve) to determine basic rock size.
3. Basic rock size is the D_{50} size.

HYDRAULICS: ELEMENTS OF CHANNEL SECTIONS

Section	Area a	Wetted Perimeter p	Hydraulic Radius r	Top Width T
 Trapezoid	$bd+zd^2$	$b+2d\sqrt{z^2+1}$	$\frac{bd+zd^2}{b+2d\sqrt{z^2+1}}$	$b+2zd$
 Rectangle	bd	$b+2d$	$\frac{bd}{b+2d}$	b
 Triangle	zd^2	$2d\sqrt{z^2+1}$	$\frac{zd}{2\sqrt{z^2+1}}$	$2zd$
 Parabola	$\frac{2}{3}dT$	$T+\frac{8d^2}{3T}$ [1]	$\frac{2dT^2}{3T^2+8d^2}$ [1]	$\frac{3a}{2d}$
 Circle - < ½ full [2]	$\frac{D^2}{8}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$\frac{\pi D\theta}{360}$	$\frac{45D}{\pi\theta}\left(\frac{\pi\theta}{180}-\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$
 Circle - > ½ full [3]	$\frac{D^2}{8}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$\frac{\pi D(360-\theta)}{360}$	$\frac{45D}{\pi(360-\theta)}\left(2\pi-\frac{\pi\theta}{180}+\sin\theta\right)$	$D\sin\frac{\theta}{2}$ or $2\sqrt{d(D-d)}$

[1] Satisfactory approximation for the interval $0<\frac{d}{T}\leqq 0.25$
When $d/T>0.25$, use $p=\frac{1}{2}\sqrt{16d^2+T^2}+\frac{T^2}{8d}\sinh^{-1}\frac{4d}{T}$

[2] $\theta=4\sin^{-1}\sqrt{d/D}$
[3] $\theta=4\cos^{-1}\sqrt{d/D}$
Insert θ in degrees in above equations

REFERENCE

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. Bennett, Chief

ENGINEERING STANDARDS UNIT

STANDARD DWG. NO. ES-33
SHEET 1 OF 1
DATE 6-6-50

Riprap Channel Sizing

Data:

8’	Bottom Width	(b)
2:1	Side Slopes	(Z)
1.0’	Flow Depth	(d)
0.06	Manning’s	(n)
0.010 ft/ft	Slope	(s)
65 cfs	Discharge	(Q)

Where:

A = Area
WP = Wetted Perimeter
R = Hydraulic Radius
V = Velocity

1. $A = (b + Zd)(d)$

   $A = (8' + 2\times1')(1')$

   $A = 10ft^2$

2. $WP = b + zd(Z^2 + 1)^{1/2}$

   $WP = 8' + 2\times1'(2'^2 + 1)^{1/2}$

   $WP = 8' + 2'(5ft^2)^{1/2}$

   $WP = 8' + 4.47'$

   $WP = 12.47'$

3. $r = A/WP$

   $r = 10ft^2/12.47ft$

   $r = 0.80'$

4. $V = 1.486/n \times r^{2/3} \times S^{1/2}$

   $V = 1.486/0.06 \times 0.080^{2/3} \times 0.10^{1/2}$

   $V = 24.77 \times 0.862 \times 0.316$

   $V = 6.75$ ft./sec.

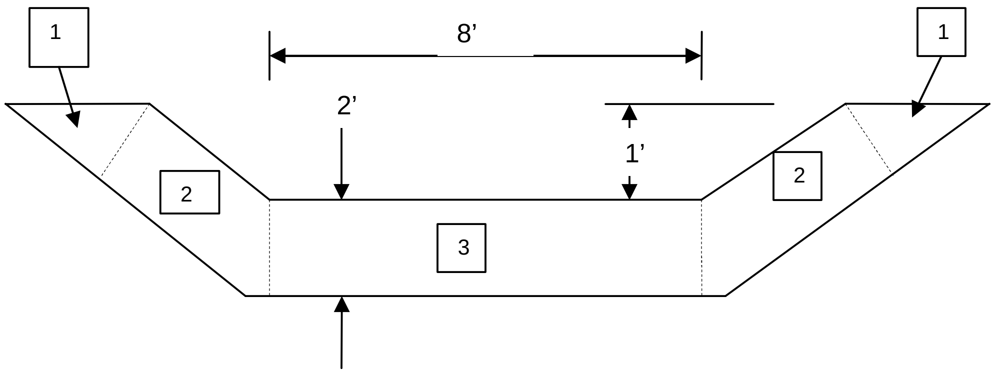
5. $Q = AV$

   $Q = (10ft^2 \times 6.75ft./sec.)$

   $Q = 67.5$ cfs

Use class I riprap D_{50} - 8 inches, D_{max} – 12 inches
Thickness = 1.5 D_{max} = 18 - inches (use 24 inches)

Class of Riprap	Size in Weight	Approximate Diameter	Percent of Total by Weight
0	Heavier than 33 lb Heavier than 10 lb Less than 1 lb	7 Inches 4 Inches 2 Inches	0 50 10 max
I	Heavier than 150 lb Heavier than 40 lb Less than 2 lb	12 Inches 8 Inches 3 Inches	0 50 10 max
II	Heavier than 700 lb Heavier than 200 lb Less than 20 lb	20 Inches 14 Inches 6 Inches	0 50 10 max
III	Heavier than 2000 lb Heavier than 600 lb Less than 40 lb	28 Inches 20 Inches 8 Inches	0 50 10 max



Area 1 = $(((Z^2 + d^2) \times \text{Thickness})/2) \times 2$ each

Area 1 = $((2'^2 + 1'^2)(2'))/2 \times 2$ each

Area 1 = $2.23 ft^2 \times 2$ each

Area 1 = $4.46\ ft^2$

Area 2 = $(2'^2 + 1'^2)^{1/2} \times 2' \times 2$ each

Area 2 = $(5\ ft^2)^{1/2} \times 2' \times 2$ each

Area 2 = $8.94\ ft^2$

Area 3 = 2' x 3'

Area 3 = $16\ ft^2$

Volume_{123} = (Area 1 + Area 2 + Area 3)(Length)

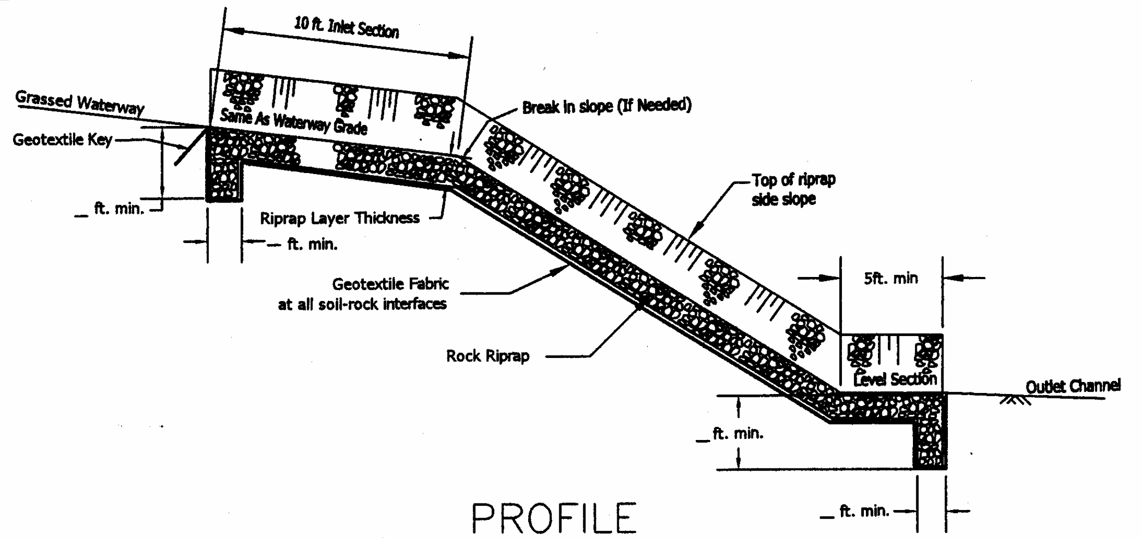
$\text{Volume}_{123} = (4.46\ ft^2 + 8.94\ ft^2 + 16\ ft^2)(30\ \text{feet})$

$\text{Volume}_{123} = 882\ ft^3$

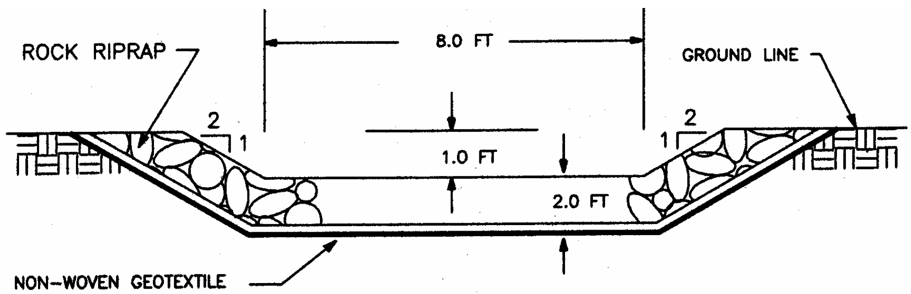
Cutoff Volume = (16' long) x (2' thick) x (2' wide) x (2 each) = $128\ ft^3$

Total Volume = $882 ft^3 + 128\ ft^3 = 1010\ ft^3$

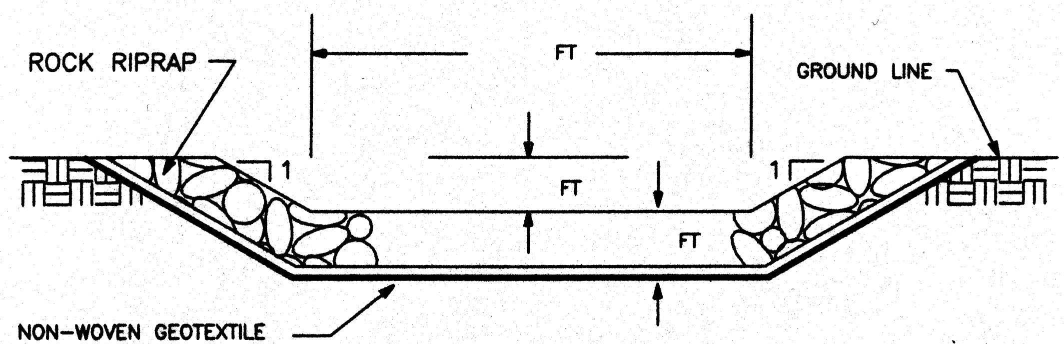
Convert to Tons $(1010\ ft^3) \times (1\ yd^3 / 27\ ft^3) \times 1.8\ ton/yd^3 = 67$ ton



PROFILE
(NOT TO SCALE)



DESIGN EXAMPLE
TYPICAL SECTION
(NOT TO SCALE)



TYPICAL SECTION

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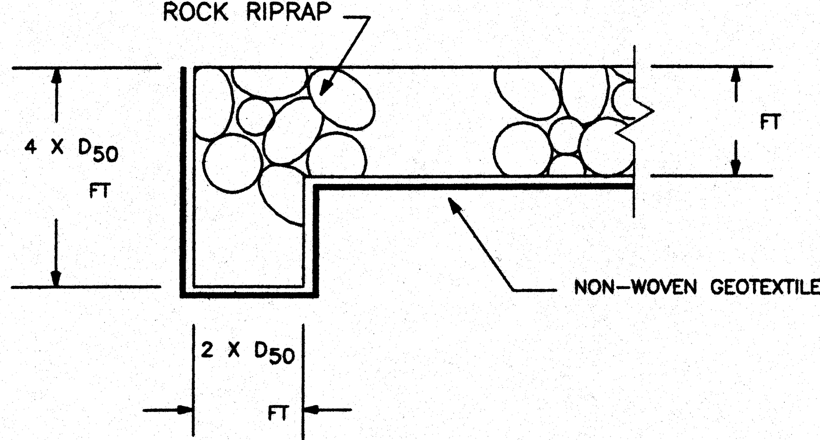

CHUTE ANCHOR DETAIL

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