STANDARD FOR RIPRAP

Definition

A layer of loose rock, aggregate, bagged concrete, gabions, or concrete revetment blocks placed over an erodible soil surface.

Purpose

The purpose of riprap is to protect the soil surface from the erosive forces of water.

Conditions Where Practice Applies

This practice applies to soil-water interfaces where the soil conditions, water turbulence and velocity, expected vegetative cover, and groundwater conditions are such that the soil may erode under the design flow conditions. Riprap may be used, as appropriate, at such places as channel banks and/or bottoms, roadside ditches, drop structures and shorelines of open freshwater bodies. Riprap may also be used in conjunction with Soil Bioengineering Techniques which are found in that standard (pg. 26-1). This Standard applies to slopes less than ten percent.

Water Quality Enhancement

Both stream channel and shoreline environments will benefit from the protection against erosion caused by flowing water and wave action. Protection of banks and shores not only prevents soil loss directly into surface waters, but also protects vegetation in these areas which contribute other water quality and wildlife benefits. .

Design Criteria - Open Channel Flow Conditions

Design Storm

The riprap shall be designed to be stable when the channel is flowing at the design discharge or the 25-year frequency storm discharge, whichever is greater.

Capacity shall be determined by the following methods:

1. Rational Method - for peak discharge of uniform drainage areas as outlined in Technical Manual for Land Use Regulation Program, Bureau of Inland and Coastal Regulations Stream Encroachment Permits, Trenton, N.J. September 1997 or subsequent editions

2. USDA-NRCS hydrologic procedures such as WinTR55 or WinTR20.

3. U.S. Army Corps of Engineers HEC HMS

4. Other methods which produce similar results to the models listed above.

Riprap Design

Storm water conveyance or flood control channels

Riprap shall be sized using the design procedures in this Standard or the "National Cooperative Highway Research

Program Report No. 108, Tentative Design Procedure for Riprap-Lined Channels." These procedures are for determining a design stone size, such that the stone is stable under the design flow conditions. The design stone size is the d_{50} stone diameter.

Erosive forces of flowing water are greater in bends than in straight channels. If the riprap size (d_{50}) computed for bends is less than 10% greater than the riprap size (d_{50}) for straight channels, then the riprap size for straight channels shall be considered adequate for bends. Otherwise, the larger riprap size shall be used in the bend. The riprap size to be used in a bend shall extend upstream from the point of curvature and downstream from the point of tangency a distance equal to five times the channel bottom width, and shall extend across the bottom and up both sides of the channel.

Riprap for banks shall extend up the banks to the level of the design storm or the top of bank, whichever is lower.

In channels where no riprap or paving is required in the bottom, but is required on the banks, the toe of the bank riprap shall extend below the channel bottom a distance at least 8 times the maximum stone size, but in no case more than 3 feet unless analysis of scour potential demonstrates the need for deeper installation. The only exemption to this would be if there is a non-erodible hard, rock bottom.

Stream stabilization- Soil Bioengineering

For determining $d_{50,}$ riprap may be sized using the procedures in this Standard or procedures contained in Chapter 16 of the NRCS Engineering Field Handbook including the Isbash Curve or Lane's Method. For stream stabilization, the use of riprap is generally limited to critically erosive locations such as the base of the channel side slopes up to the elevation of the one year flow event. Riprap is designed to be used in combination with vegetation as a part of a bioengineering solution (see Standard for Soil Bioengineering). Riprap may be placed on slopes steeper than 2 horizontal to 1 vertical following the procedures in this Standard (Curve 22-6). Large, over-sized stone having a minimum d_{50} of 18 inches, or two times the required d_{50}, whichever is greater, may be stacked to a slope no steeper than 0.5 horizontal to 1 vertical where site conditions are acceptable. Stability of the stream bank and bed material along with the flow conditions in the stream shall be evaluated in determining site acceptability.

Riprap Gradation

The riprap shall be composed of a well-graded mixture such that 50% of the mixture by weight shall be larger than the d_{50} size as determined from the design procedure. A well-graded mixture as used herein is defined as a mixture composed primarily of the larger stone sizes, but with a sufficient mixture of other sizes to fill the progressively-smaller voids between the stones. The diameter of the largest stone size in such a mixture shall be 1.5 times the d_{50} size. The d_{75} should be 1.25 times the d_{50} and the d_{15} should be 0.5 times the d_{50} size.

The designer, after determining the riprap size that will be stable under the flow condition, shall consider that size to be a minimum size and then, based on riprap gradations actually available in the area, select the size or sizes that equal or exceed the minimum size. The possibility of vandalism shall be considered by the designer in selecting a riprap size.

Thickness of Riprap Lining

Construction techniques, discharge, size of channel, sizes and graduation of riprap, etc., should be taken into consideration when determining the thickness of riprap lining. The thickness of riprap lining shall meet at least one of the following two criteria:

1. A thickness of at least three times the d_{50} size if a filter layer is not used.

2. A thickness of at least two times the d_{50} size if a filter layer is used.

The minimum thickness shall be 6 inches.

Filter

Leaching is the process by which the finer base materials beneath the riprap are picked up and carried away by the turbulence that penetrates the interstices of the riprap. Leaching is reduced to a negligible rate by using a properly designed filter under the riprap, or by making the riprap layer thick enough and with fine enough interstices to keep erosion currents away from underlying soil.

A filter is required unless the riprap lining has a thickness of at least 3 times the d_{50} size of the riprap. On steep slopes, highly erodible soils, loose sand, or with high water velocities, a filter should be used or riprap thickness increased beyond the minimums.

A filter can be of two general forms. One is a geotextile manufactured for that express purpose. Another is a properly graded layer of sand, gravel, or stone.

A sand, gravel, or stone filter shall meet the following criteria:

$$\frac{d_{15}\text{ Riprap}}{d_{85}\text{ Filter}} < 5 < \frac{d_{15}\text{ Riprap}}{d_{15}\text{ Filter}} < 40$$

$$\frac{d_{50}\text{ Riprap}}{d_{50}\text{ Filter}} < 40$$

Where d_{15}, d_{50}, and d_{85} are the diameters of riprap and filter material of which 15, 50, and 85% are finer by weight. The base material may be used as the filter if it meets the above criteria. The minimum sand gravel or stone filter thickness shall be 6 inches or 3 times the d_{50} size of the filter, whichever is greater.

Geotextile fabric[1] shall meet the following criteria:

A. For filter fabric adjacent to granular materials containing 50% or less by weight of fines (Minus No. 200 material):

For Woven Fabric:

1. $\frac{\text{85\% size of material (mm)}}{\text{AOS}^2\text{ (mm)}} \geq 1$

and AOS no smaller than the opening in the U.S. Standard Sieve No. 100

[1] Geotextile fabric shall meet the U.S. Army Corps of Engineers Guide Specifications, CW02215-86, for strength. Riprap that is 12" and larger shall not be dumped directly onto synthetic filter cloth unless the manufacturer recommends such use for the cloth. Otherwise, a 4-inch minimum thickness blanket of gravel shall be placed over the filter cloth. Where seepage forces exist or where hydrostatic pressures may be developed in the base soil, the permeability of the geotextile shall be 10 times the permeability of the base soil.

[2] Apparent Opening Size is defined as the number of the U.S. Standard sieve having openings closest in size to the geotextile openings.

2. For non-woven fabric: AOS no larger than the opening in the U.S. Standard Sieve No. 40.

B. For geotextile fabric adjacent to all other soils:

For woven fabric:

1. AOS no larger than the opening in the U.S. Standard Sieve No. 70, and AOS no smaller than the opening in the U.S. Standard Sieve No. 100.

2. For non-woven fabric: AOS no larger than the opening in the U.S. Standard Sieve No. 40.

Quality

Stone for riprap shall consist of field stone or quarry stone of approximately rectangular shape. The stone shall be hard and angular and of such quality that it will not disintegrate on exposure to water or weathering. The specific gravity of the individual stones shall be at least 2.5.

Rubble concrete may be used provided it has a density of at least 150 pounds per cubic foot, and otherwise meets the requirements of this Standard.

Bagged Concrete

Bagged concrete is made up of bags filled with concrete and placed next to each other. The consistency of the concrete shall be as stiff as satisfactory discharge from the mixer and the process of bagging will permit. The bags shall be filled three-quarters full with concrete and shall be laid in close contact, with staggered joints and tied ends turned in.

Bagged concrete may be used when all the following conditions are met:

1. The design storm, riprap size and location, and filter criteria for riprap are met.

2. The weight of the filled bags is at least equal to the weight of the maximum stone size required for rock riprap.

3. Settlement or lateral movement of foundation soils is not anticipated.

4. Ice conditions are not severe.

5. A filter is used.

6. Slopes somewhat steeper than 2 to 1 may be permitted under special circumstances.

Wire-mesh stone filled structures

Baskets formed of plastic-coated wire mesh and filled with cobbles or coarse gravel (a thinner version of gabions is known as a "mattress") may be used when all the following conditions are met:

1. The design storm shall be the same as that required for riprap. Riprap size and location, filter, and quality criteria shall be as outlined below.

2. The design water velocity does not exceed that given in table 22-1:

Table 22-1 Gabion Dimensions

GABION THICKNESS (ft.)	MAXIMUM VELOCITY (ft./sec.)
1/2	6
3/4	11
1	14

3. The Manning's "n" value used for gabions shall be 0.025.

4. The wire mesh structures are not exposed to abrasion from sand or gravel transported by moving water.

5. Plastic coated wire shall be used.

6. All wire mesh structures placed against the bottom of a channel shall be underlain by geotextile or a gravel filter designed according to the limits outlined in Table 22-1.

7. The rock used to fill basket structures shall be 4" to 7" angular, block-shaped rock. For wire mesh “mattress” structures, 3" to 4" stone may be used provided the mesh opening is small enough to contain the stone. Smaller stone will provide more stone “layers” in the mattress where larger stone would not sufficiently fill the structure’s void space

Table 22-2 Maximum Gabion Slope by Soil Texture

Soil Texture	Erosive Velocity, VE (fps)	Maximum Allowable Bottom Slope (ft./ft.) using geotextile Fabrics*
Sandy Loam	2.5	0.029
Silt Loam	3.0	0.041
Sandy Clay Loam	3.5	0.056
Clay Loam	4.0	0.074
Clay, fine gravel, graded loam to gravel	5.0	0.115
Cobbles	5.5	0.139

*For bottom slopes steeper than those shown, a properly designed gravel filter shall be placed under the gabions.

Sand, gravel, or stone filters placed under wire mesh basket structures shall meet the filter requirements shown on page 22-3.

Concrete Revetment Blocks

Concrete revetment blocks are precast interlocking or cabled concrete grids designed for soil stabilization.

Concrete revetment blocks may be used when all the following conditions are met:

1. The design storm shall be the same as that required for riprap.
2. The water velocity does not exceed 9 feet per second.
3. The Manning's "n" value used for concrete revetment blocks shall be 0.026, unless otherwise recommended by manufacturer's literature.
4. A filter is used in accordance with manufacturer's recommendations.
5. Cabled-concrete shall use non-degrading, non-corroding cable.

Recommended Design Procedure for Riprap-Lined Channels

This design of riprap-lined channels is from the "National Cooperative Highway Research Program Report No. 108, Tentative Design Procedure for Riprap-Lined Channels." It is based on the tractive stress method, and covers the design of riprap in two basic channel shapes: trapezoidal and triangular.

NOTE: This procedure is for uniform flow at normal depth in channels and is not to be used for design of riprap energy dissipation devices immediately downstream from such high velocity devices as pipes and culverts. See the Standard for Conduit Outlet Protection, p. 12-1.

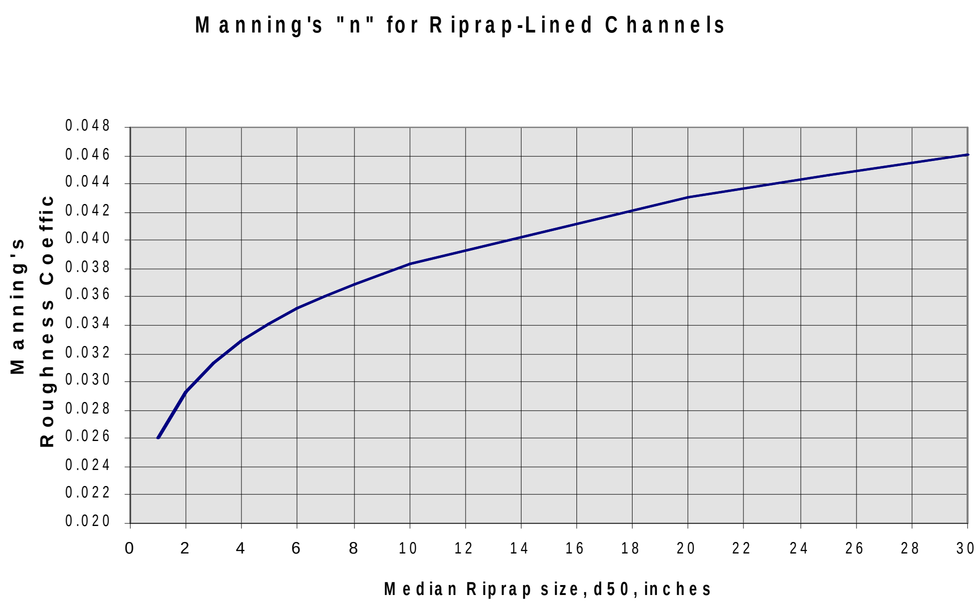
The method in Report No. 108 (design procedure beginning on p. 18) gives a simple and direct solution to the design of trapezoidal channels, including channel carrying capacity, channel geometry, and the riprap lining.

This procedure is based on the assumption that the channel is already designed and the remaining problem is to determine the riprap size that would be stable in the channel. The designer would first determine the channel dimensions by the use of Manning's equation. The "n" value for use in Manning's equation is obtained by estimating a riprap size and then determining the corresponding "n" value for the rip rapped channel from:

$$n = 0.0395(d_{50})^{0.167}$$

where d_{50} is in feet, or by using Curve 22-1 where d_{50} is in inches.

Curve 22-1



When
the channel dimensions are known, the riprap can be designed (or an already completed design may be checked) as follows:

Trapezoidal Channels

1. Calculate the b/d ratio and enter Curve 22-2 to find the P/R ratio.

2. Enter Curve 22-3A with S_b, Q, and P/R to find median riprap diameter, d_{50}, for straight channels.

3. Enter Curve 22-1 to find the actual "n" value corresponding to the d_{50} from step 2. If the estimated and actual "n" values do not reasonably agree, another trail must be made.

4. For channels with bends, calculate the ratio Bs/Ro, where Bs is the channel surface width and Ro is the radius of the bend. Enter Curve 22-4 and find the bend factor, F_B. Multiply the d_{50} for straight channels by the bend factor to determine riprap size to be used in bends. If the d_{50} for the bend is less than 1.1 times the d_{50} for the straight channel, then the size for straight channel may be used in the bend; otherwise, the larger stone size calculated for the bend shall be used. The riprap shall extend across the full channel section and shall extend upstream and downstream from the ends of the curve a distance equal to five times the bottom width.

5. Enter Curve 22-5 to determine maximum stable side slope of riprap surface. In Curve 22-5, the side slope is established so that the riprap on the side slope is as stable as that on the bottom. If for any reason it is desirable to make the side slopes steeper than what is given by Curve 22-5, the size of the riprap can be increased and the side slopes made steeper by using the following procedures:

   a. Compute d_{50} and maximum stable side slope as above.

   b. Enter Curve 22-6 with the computed side slope to determine K for that side slope.

   c. Enter Curve 22-6 with the desired side slope to determine K'.

   d. Compute riprap size for desired slope by the formula:

$$d50' = d50\ K/K'$$

6. Maximum side slopes, 2:1.

<u>Triangular Channels</u>

1. Enter Curve 22-3B with S_b, Q, and Z and find the median riprap diameter, d_{50}, for straight channels.

2. Enter Curve 22-1 to find the actual "n" value. If the estimated and actual "n" values are not in reasonable agreement, another trial must be made.

3. For channels with bends, see step 4 under Trapezoidal channels.

Example:

Given:

Trapezoidal channel

Q = 100 cfs.
S = 0.01 ft./ft.

Side slopes = 2.5:1.
Mean bend radius, Ro = 25'.

n = 0.033 (estimated, and used to design the channel to find that b = 6' and d = 1.8').
Type of rock available is crushed stone.

Solution:

Straight channel reach

b/d = 6/1.8 = 3.33.
from Curve 22-2, P/R = 13.0.
from Curve 22-3A, d_{50} = 3.4"

from Curve 22-1, n (actual) = 0.032, which is reasonably close to the estimated n of 0.033

Use 5" as maximum riprap size and 8" as riprap layer thickness with a filter.

Channel bend

Bs = b + 2zd = 6 + (2)(2.5)(1.8) = 15'

Bs/Ro = 15/25 - 0.60.

from Curve 22-4, F_B = 1.33

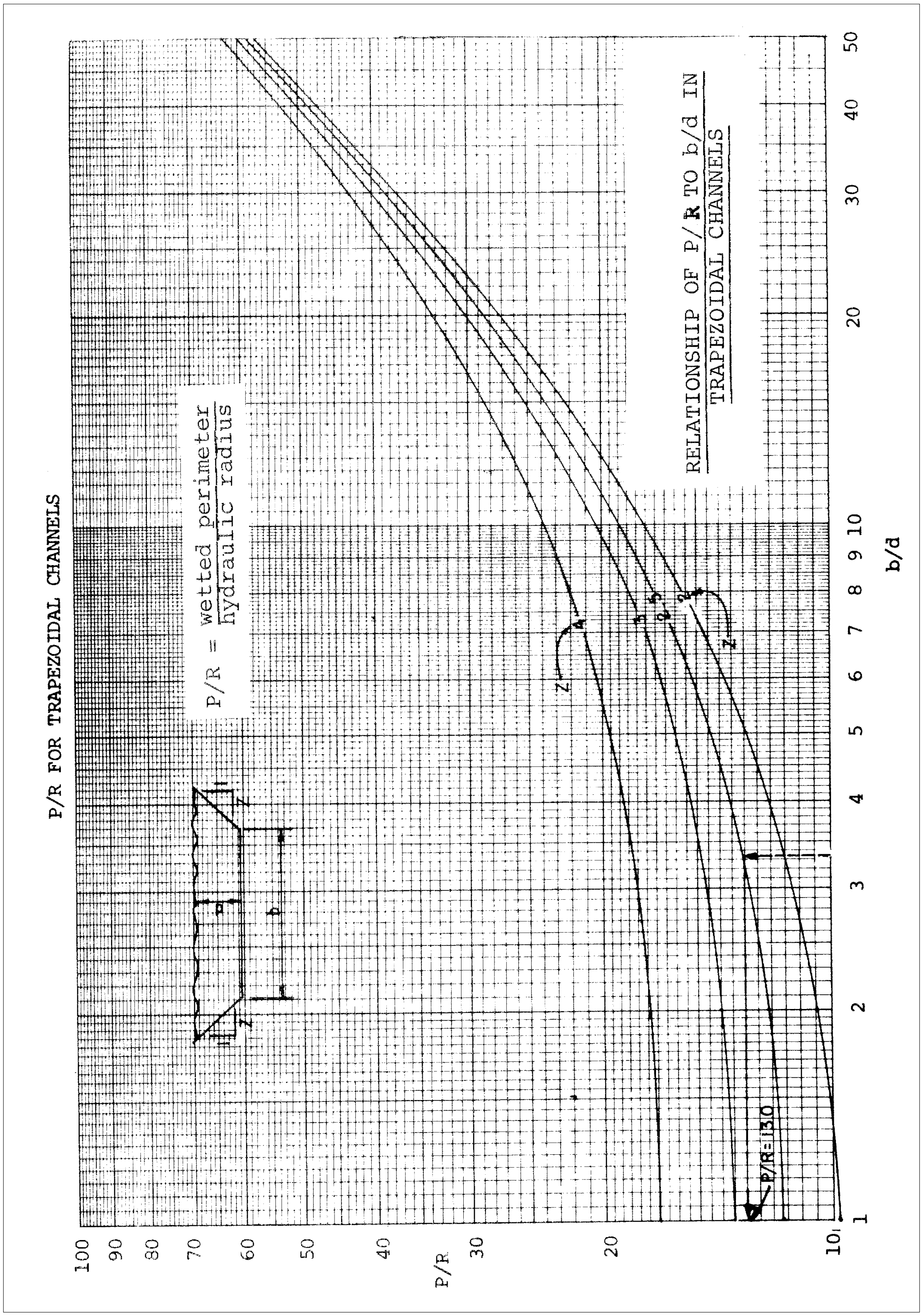
F_B = 1.33 > 1.1, therefore, the bend factor must be used.

Riprap size in bend, d_{50} = 3.4 x 1.33 = 4.52"

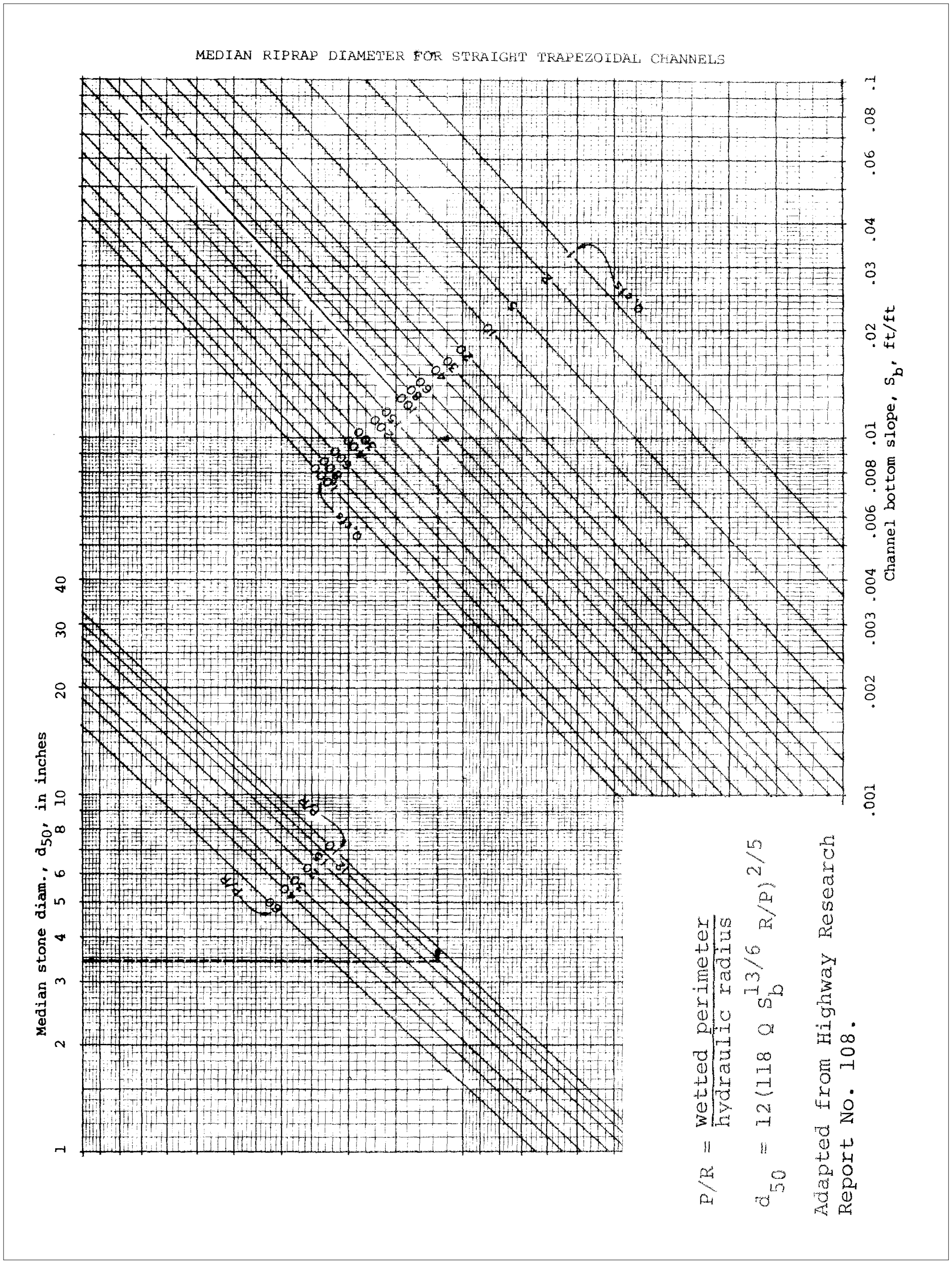
The heavier riprap for the bend shall extend upstream and downstream from the ends of the bend a distance of (5)(6) = 30 feet.

From Curve 22-5, it can be found that the riprap for d50 = 3.4" and 4.52" will both be stable on a 2.5:1 side slope.

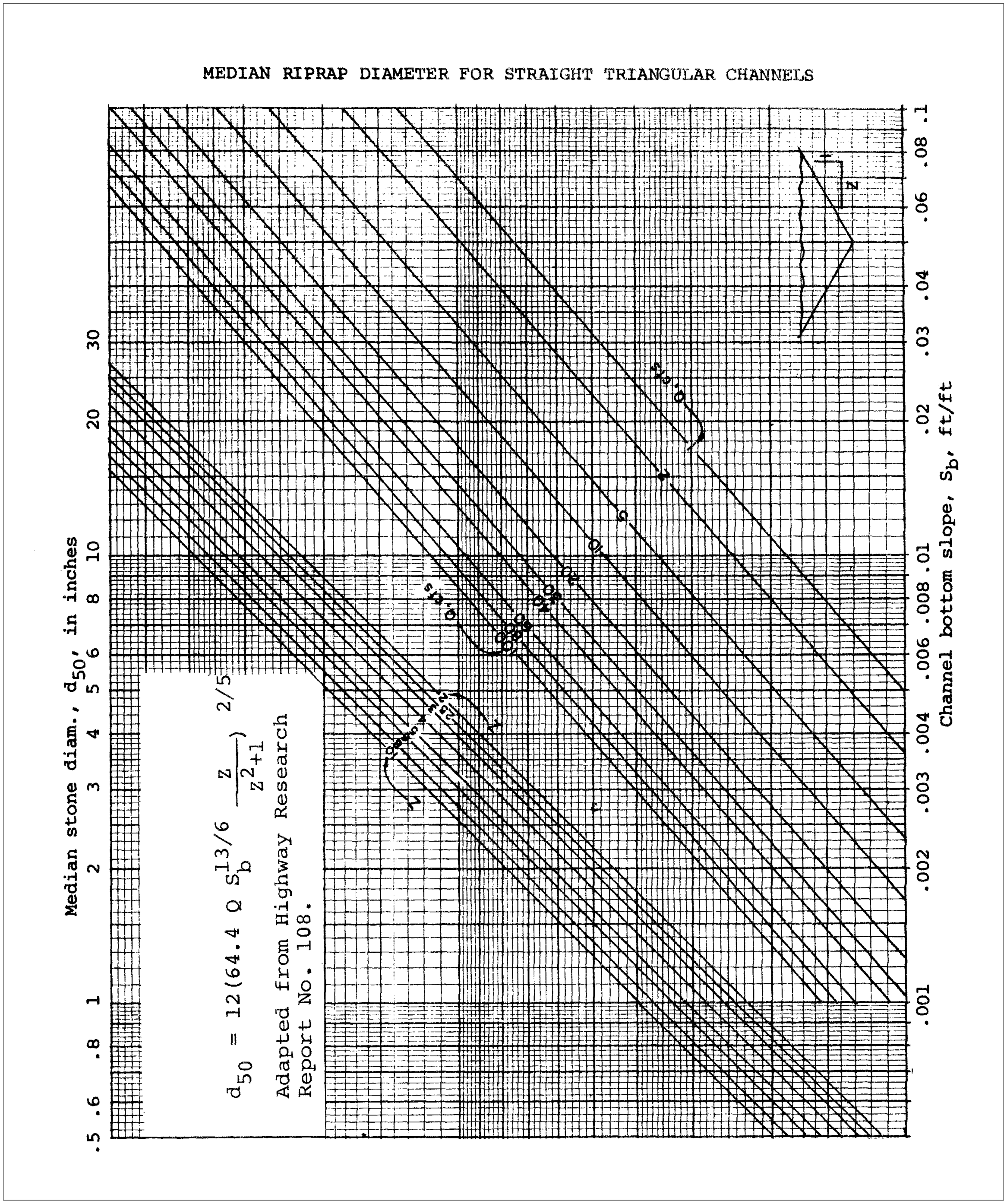
Curve 22-2


P/R FOR TRAPEZOIDAL CHANNELS
P/R = wetted perimeter / hydraulic radius
RELATIONSHIP OF P/R TO b/d IN TRAPEZOIDAL CHANNELS
b/d
P/R
P/R=13.0
Z
4
3
2.5
2

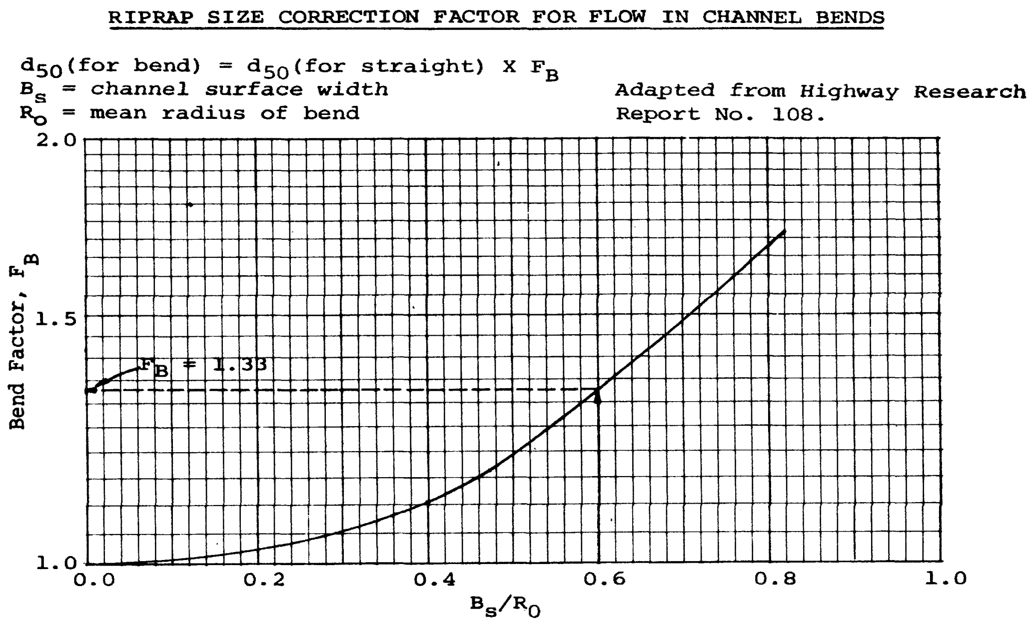
Curve 22-3A


MEDIAN RIPRAP DIAMETER FOR STRAIGHT TRAPEZOIDAL CHANNELS
Median stone diam., d50, in inches
1 2 3 4 5 6 8 10 20 30 40
Channel bottom slope, Sb, ft/ft
.001 .002 .003 .004 .006 .008 .01 .02 .03 .04 .06 .08 .1
Q, cfs
P/R
P/R = wetted perimeter / hydraulic radius
d50 = 12(118 Q Sb^13/6 R/P)^2/5
Adapted from Highway Research Report No. 108.

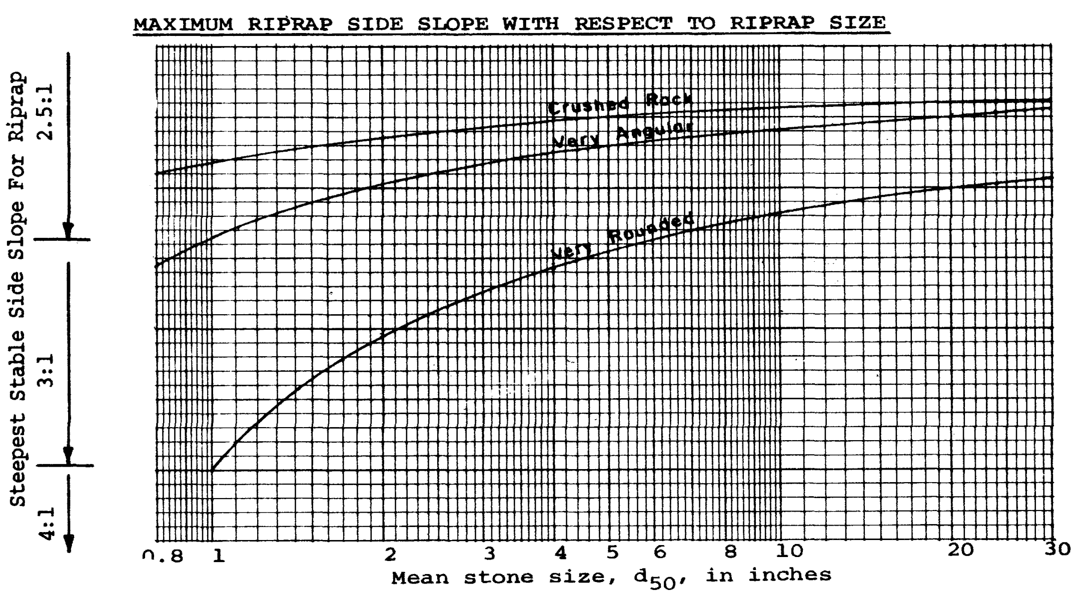
Curve 22-3B


MEDIAN RIPRAP DIAMETER FOR STRAIGHT TRIANGULAR CHANNELS
Median stone diam., d_{50}, in inches
.5 .6 .8 1 2 3 4 5 6 8 10 20 30
Channel bottom slope, S_b, ft/ft
.001 .002 .003 .004 .006 .008 .01 .02 .03 .04 .06 .08 .1
$d_{50} = 12(64.4\ Q\ S_b^{13/6}\ \frac{Z}{Z^2+1})^{2/5}$
Adapted from Highway Research Report No. 108.

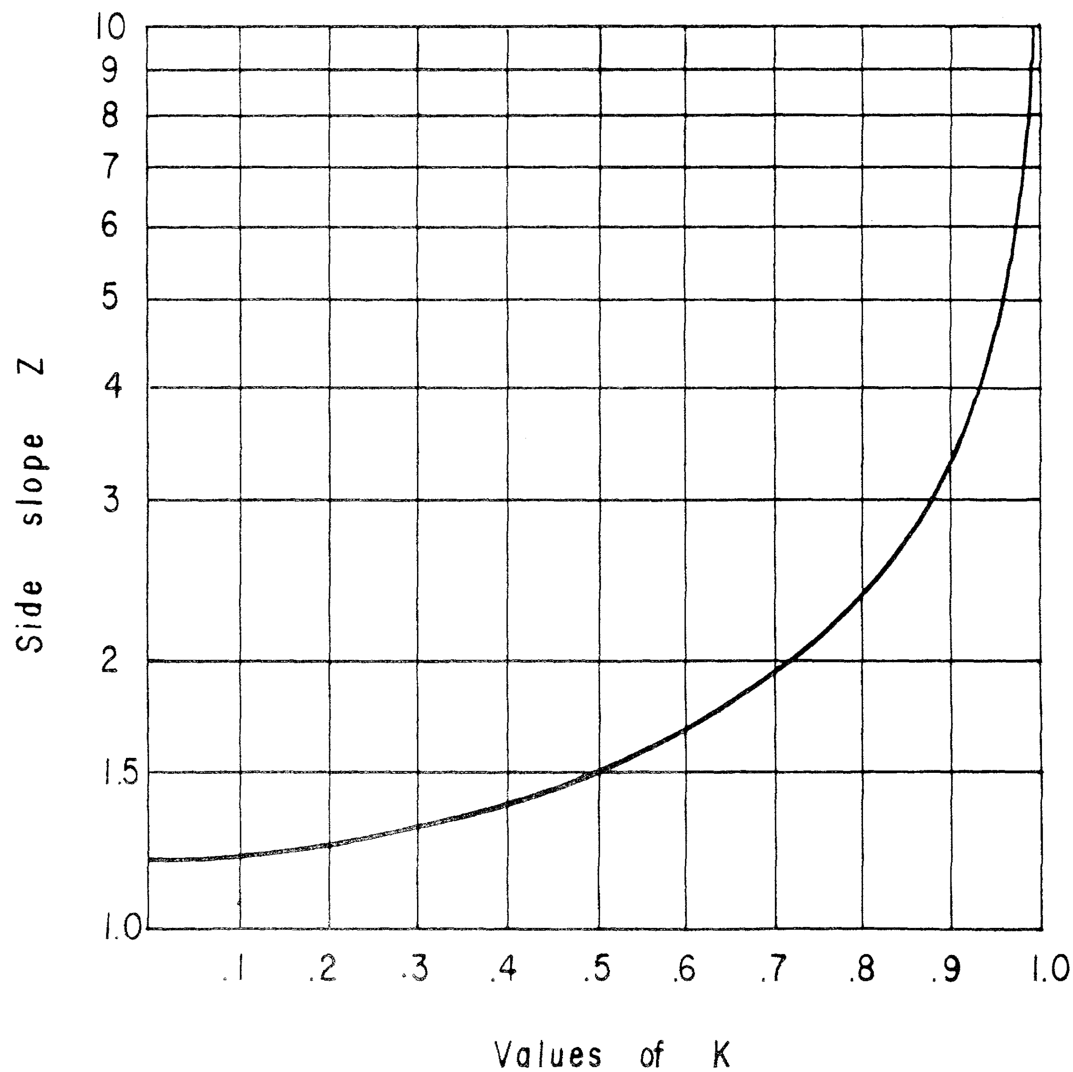
Curve 22-4



Curve 22-5



Curve 22-6



Riprap Shoreline Protection

Conditions where practice applies

This design procedure applies to riprap protection of shorelines surrounding open bodies of water, such as lakes, bays, estuaries etc. against the erosive action of surface waves. It is not intended as a design procedure for the protection of embankments of open channels. Refer to the beginning of this standard for open channel riprap design.

Design Procedure

1. Find wind speed from Figures 22-1 or 22-2 (figures are based on the 10 or 25 year return period). In general, use a 25 year return period unless a higher risk of failure is acceptable.

2. Find wave height from Table 22-3, 22-4, 22-5 or 22-6. Fetch length is the distance across open water in the prevailing wind direction.

3. Find rock weight (in lbs) from Tables 22-7, 22-8 and 22-9.

4. Find rock size (d_{50}) from Curve 22-7 Note: curve is calibrated for rock with a specific gravity of 2.6, or a unit weight of 165 lbs/ ft^3. Table 22-9, Correction for unit weight, will correct for rock with a different unit weight.

Riprap is to be installed according to limits established for depth, filter material and slope as outlined earlier in this standard.

Example:

Given:

25 year storm event, fetch length of 1 mile, depth of 5 feet, installation slope of 1:3, and stone unit weight = 160 lbs/ft^3, find:

1. From figure 22-2, wind speed for Central New Jersey for the 25 year design storm is 75 mph.

2. From Table 22-3, wave height is 2.0 feet for a fetch length of 1.0 mile and average depth of 5.0 feet.

3. From Table 22-7, the estimated required weight of stone based on wave height is 50 lbs. (per piece).

4. From Table 22-8, the correction factor for a slope of 1:3 is 0.7.

5. From Table 22-9, the correction factor for stone unit weight of 160 lbs/ft^3 is 1.1.

6. The required stone weight is: 50 x 0.7 x 1.1 = 38.5 lbs. (per piece).

7. From Curve 22-7, the d_{50} stone size for 38.5 lbs is 9.3 inches, say 9 inches.

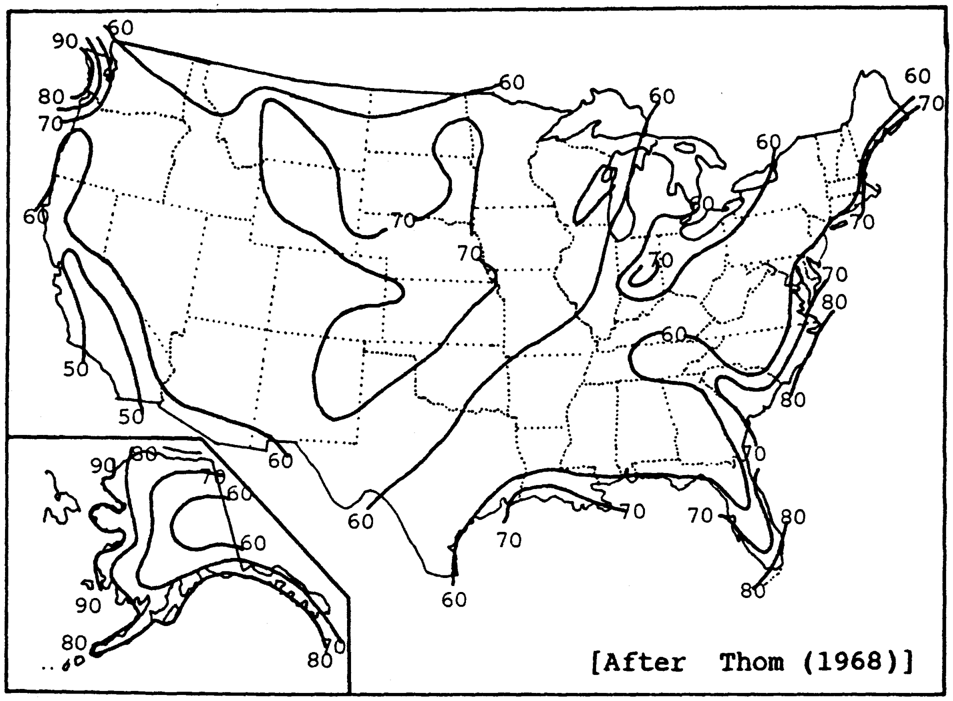


Figure 22-1 Fastest-Mile Wind Speeds: 10-year Return Period

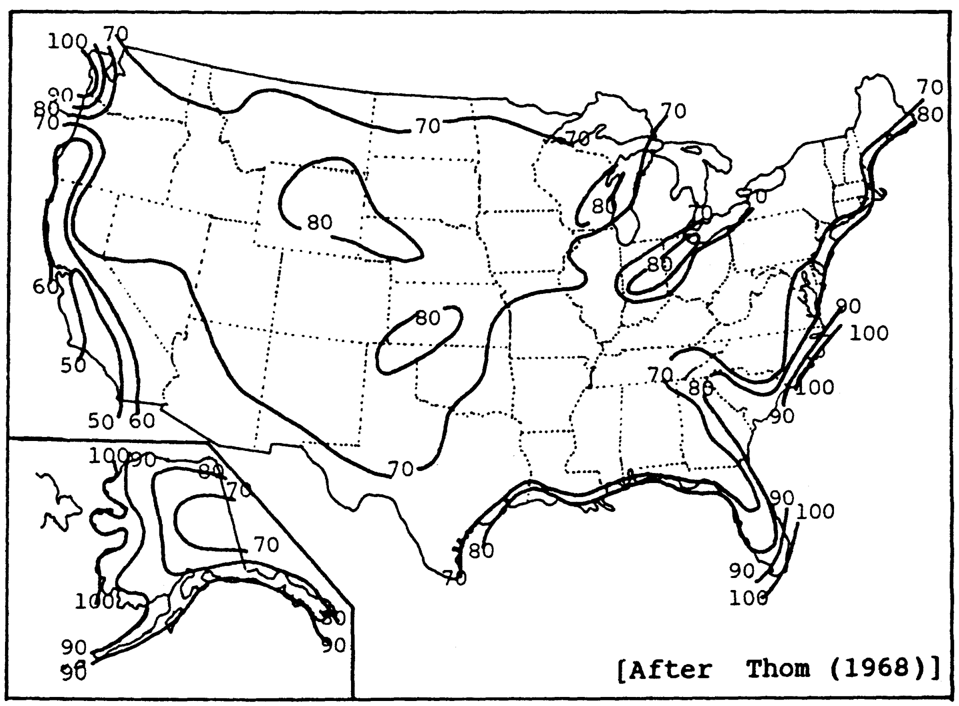


Figure 22-2 Fastest-Mile Wind Speeds: 25-year Return Period

Table 22-3

WIND-GENERATED WAVE HEIGHTS AND (PERIODS)
FETCH LENGTHS WITH AVERAGE DEPTHS = 5 FEET

Wind Speed (mph)	Fetch Length (miles) 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0
10	0.5 (1.0)	0.5 (1.0)	0.5 (1.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)
20	0.5 (1.0)	0.5 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)
30	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.5 (2.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)
40	1.0 (2.0	1.5 (2.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)
50	1.5 (2.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)
55	1.5 (2.0)	1.5 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)
60	1.5 (2.0	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)
65	1.5 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)
70	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)
75	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)	2.0 (4.0)
80	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)

Table 22-4

WIND-GENERATED WAVE HEIGHTS AND (PERIODS)
FETCH LENGTHS WITH AVERAGE DEPTHS = 10 FEET

Wind Speed (mph)	Fetch Length (miles) 0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	6.0	7.0	8.0	9.0	10.0
10	0.5 (1.0)	0.5 (1.0)	0.5 (1.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	0.5 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)
20	0.5 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.0 (2.0)	1.5 (2.0)	1.5 (2.0)	1.5 (2.0)	1.5 (2.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)
30	1.0 (2.0)	1.5 (2.0)	1.5 (2.0)	1.5 (3.0)	1.5 (3.0)	1.5 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)
40	1.5 (2.0)	1.5 (2.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.0 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (4.0)	2.5 (4.0)	2.5 (4.0)
50	1.5 (2.0)	2.0 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)
55	2.0 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	2.5 (3.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)
60	2.0 (3.0)	2.5 (3.0)	2.5 (3.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)
65	2.0 (3.0)	2.5 (3.0)	3.0 (3.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.0 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)
70	2.5 (3.0)	3.0 (3.0)	3.0 (3.0)	3.0 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)
75	2.5 (3.0)	3.0 (3.0)	3.0 (3.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)
80	2.5 (3.0)	3.0 (3.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (4.0)	3.5 (5.0)	4.0 (5.0)	4.0 (5.0)	4.0 (5.0)	4.0 (5.0)	4.0 (5.0)	4.0 (5.0)

TABLE 22-7
ESTIMATED WEIGHT OF ARMOR STONE

WAVE HEIGHT H (ft)	ESTIMATED WEIGHT W (lb)
0.5	1
1.0	10
1.5	20
2.0	50
2.5	100
3.0	160
3.5	260
4.0	390
4.5	550
5.0	750
5.5	1000
6.0	1300
6.5	1650
7.0	2100

TABLE 22-8
CORRECTION FOR SLOPE

SLOPE (ft/ft)	CORRECTION FACTOR K_1
1:2	1.0
1:2½	0.8
1:3	0.7
1:3½	0.6
1:4	0.5
1:4½	0.4
1:5	0.4
1:5½	0.4
1:6	0.3

TABLE 22-9
CORRECTION FOR UNIT WEIGHT

UNIT WEIGHT w_r (lb/ft^3)	CORRECTION FACTOR K_2
120	4.3
130	2.8
135	2.4
140	2.0
145	1.7
150	1.5
155	1.3
160	1.1
165	1.0
170	0.9
175	0.8
180	0.7
185	0.6
190	0.6

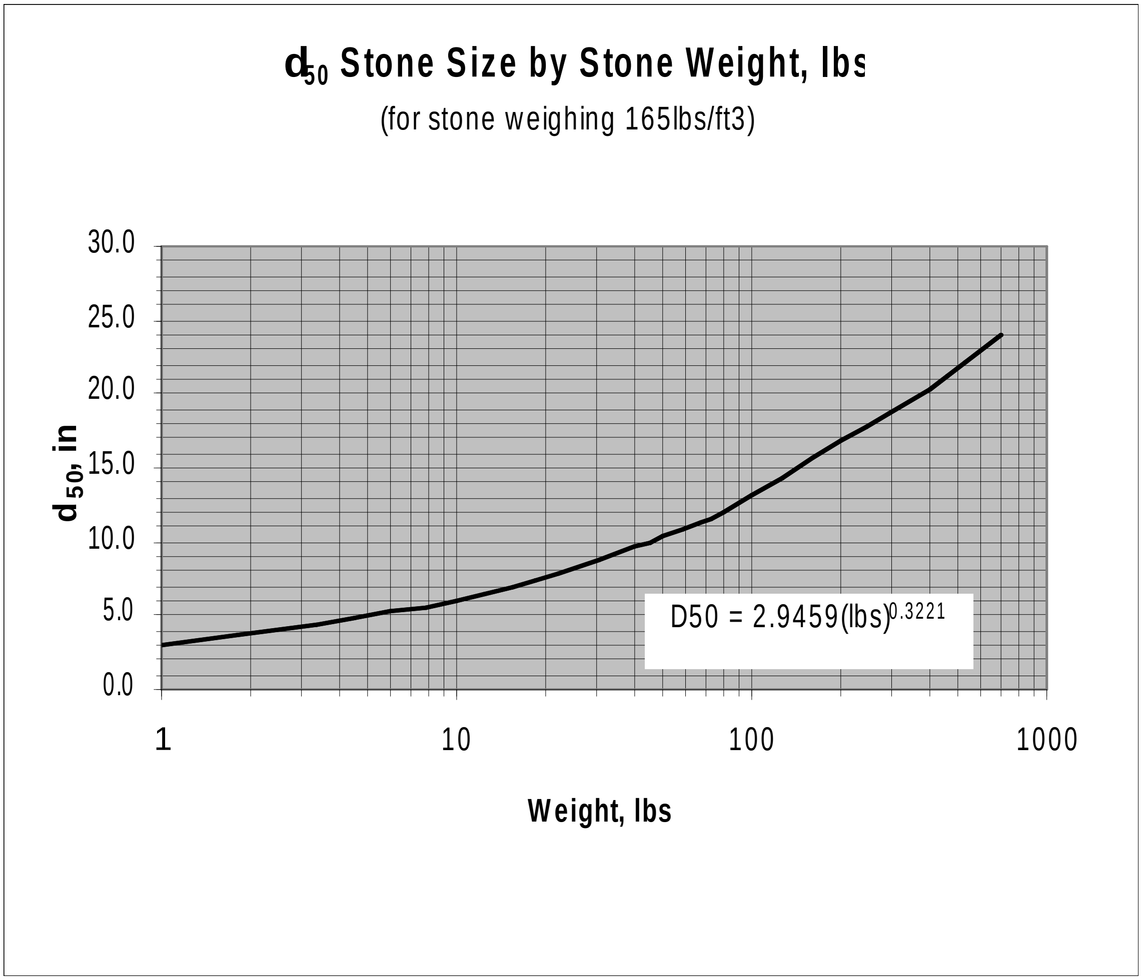
EXAMPLE

GIVEN: The wave height (H) is 3.0 feet and the structure slope is 1 on 3 (1 Vertical on 3 Horizontal) and one cubic foot of rock weighs 155 lbs (w_r)

FIND: The required weight of armor stone (W) from the tables (Dashed Line)

$$W = 160 \text{ lbs} \times 0.7 \times 1.3 = 145 \text{ lbs}$$

Curve 22-7


d50 Stone Size by Stone Weight, lbs
(for stone weighing 165lbs/ft3)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
d50, in
D50 = 2.9459(lbs)0.3221
1
10
100
1000
Weight, lbs