ARMORFLEX

EROSION CONTROL SYSTEM

BANK AND CHANNEL PROTECTION

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TECHNICAL BULLETIN BC - 1

ARMORFLEX
EROSION CONTROL SYSTEM
BANK AND CHANNEL PROTECTION

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF CHARTS

1.0 INTRODUCTION

Designers of waterways, highways and general construction projects are constantly faced with designing channels and protective channel linings. Channels range from small roadside drainage ditches to major rivers. These channels will generally experience erosion of banks and scour of the bottom, therefore, they require the construction of a protective liner. The ARMORFLEX system has several advantages, especially in areas requiring protection from the destructive energy of high water velocity. ARMORFLEX provides a flexible protective liner that is a functional and economical alternative to dumped stone rip-rap, gabions and poured concrete.

1.1 Forces Acting on ARMORFLEX in a Flowing Channel

ARMORFLEX is an assemblage of interlocking precast concrete grids, of uniform size, shape and weight, that when placed in a channel bed, forms an erosion resistant boundary.

When ARMORFLEX is exposed to flowing water, certain forces are generated on the system. Figure 1-1. illustrates these forces as they might be applied to ARMORFLEX grids, along with a characteristic velocity profile at the boundary surface. Because of ARMORFLEX's no-slip condition, the velocity decreases as it approaches the boundary. Also shown in Figure 1-1. are the turbulent eddies in the zone of separation, or wake region. As the flow passes over the ARMORFLEX, the streamlines are slightly deflected. However, due to ARMORFLEX's relatively uniform boundary surface, the streamline deflections are less than those that might be expected with rip-rap.

As a result of the velocities over the ARMORFLEX, forces are generated on the grids which may be separated into drag forces in the direction of the velocity, and lift forces perpendicular to the velocity. The drag force is composed of skin friction drag and a form drag. Since ARMORFLEX has a uniform surface, the form drag is reduced, leaving only the skin friction component to act along the top of the grids.

The lift force is the resultant of the pressure difference between the top and bottom sides of the ARMORFLEX grids. The top side pressure is reduced below the static pressure by the curve of the streamlines and resulting increase in velocity. On the bottom side where flow is small, the pressure approaches the static pressure.

The forces resisting motion of the ARMORFLEX grids are their submerged weight, the downward force components of friction caused by contact with other grids, and the systems interlocking features. The submerged weight depends on the class of ARMORFLEX grids. The friction force is a result of small gravel and soil particles that are lodged between adjacent grids. In addition, the degree of exposure to the forces of flowing water depends on the relative position of the grids, which in the case of ARMORFLEX, can be considered to be level with the channel bed. Consequently, the movement of the individual ARMORFLEX grids will depend on the relative magnitudes of the forces acting on their upper surfaces. If the moment of the resultant of the lift and drag about the top of a grid is greater than the moment of the

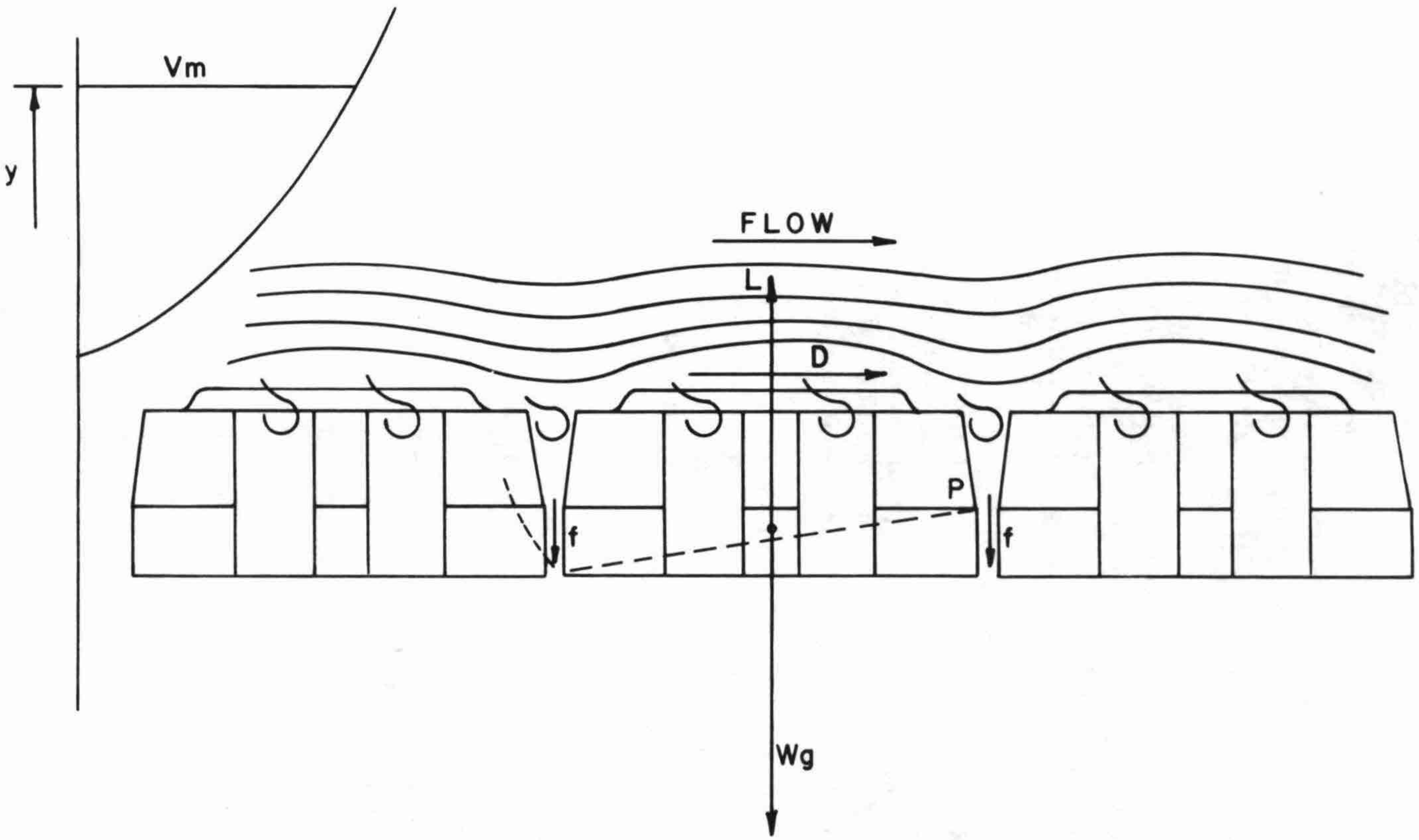


FIG. 1-1. DIAGRAMMATIC DESCRIPTION OF FORCES ON ARMORFLEX IN A FLOWING CHANNEL

submerged weight about the same point, the grid will be rolled from its initial position to some point downstream. If the lift force becomes greater than the submerged weight, the grid will be lifted bodily from the channel bed and carried upward. The drag force acting on the grid at this point will also tend to move the grid downstream.

1.2 ARMORFLEX Grids

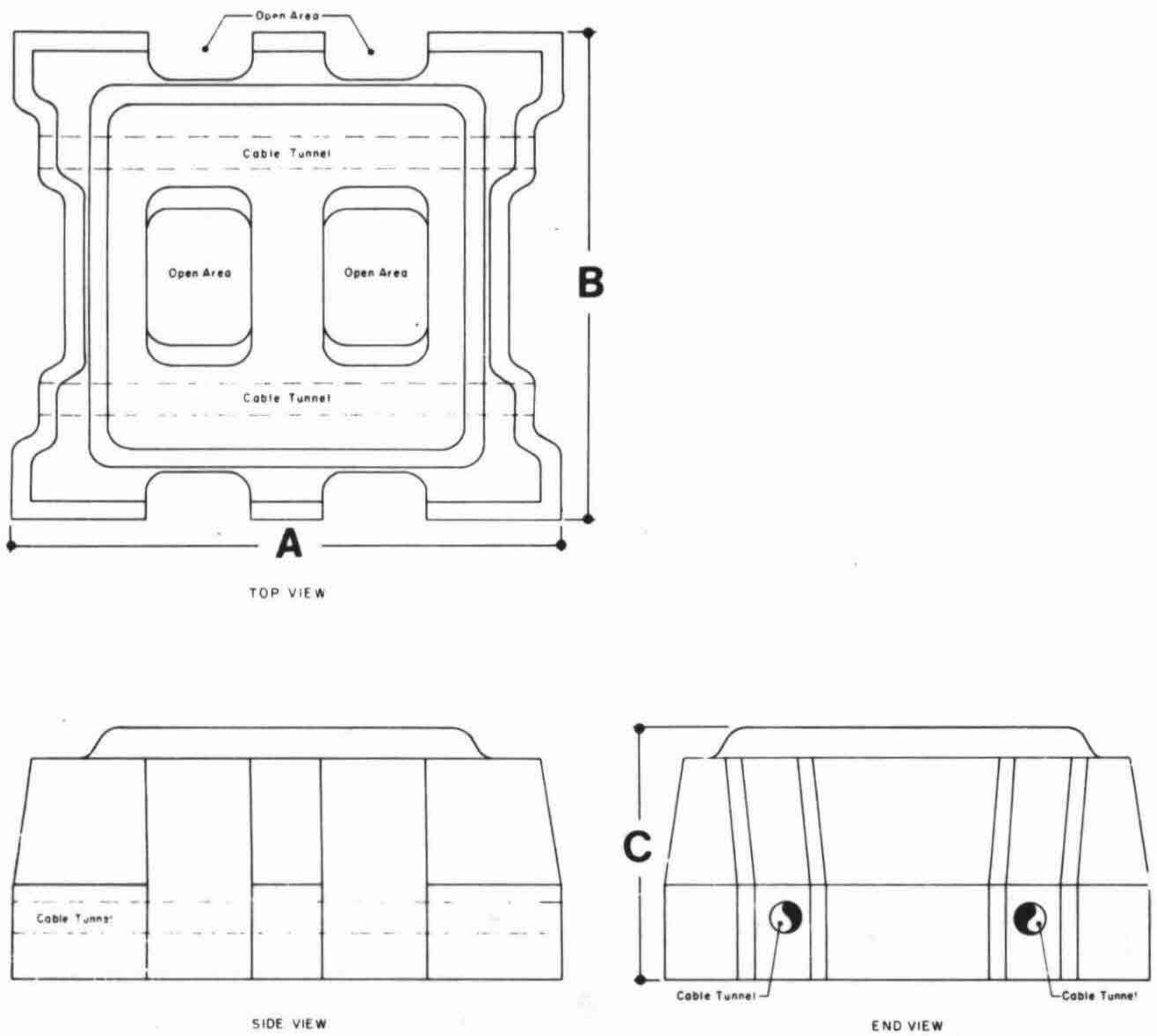
ARMORFLEX is available in six (6) classes to provide a selection of unit weight, surface roughness, and open area; Figures 1-2.. This enables the designer to specify the ARMORFLEX class capable of resisting displacement by a wide range of drag and lift forces that might act upon the system. The weight of the ARMORFLEX grid resists these forces by exerting a greater moment about the same point of rotation than that exerted by the lift and drag forces, and also by counteracting the lift forces that act perpendicular to the velocity, Figure 1-1.

The unique shape factors of ARMORFLEX contribute to the stability of the grids by assuring that they perform as an integral system as opposed to a group of separate elements. Interlocking channels and projections key adjacent ARMORFLEX grids together to form a continuous chain of stable grids. This interlocking chain assures that each row of grids works in conjunction with subsequent rows, thus assuring that progressive rows of grids cannot be laterally displaced.

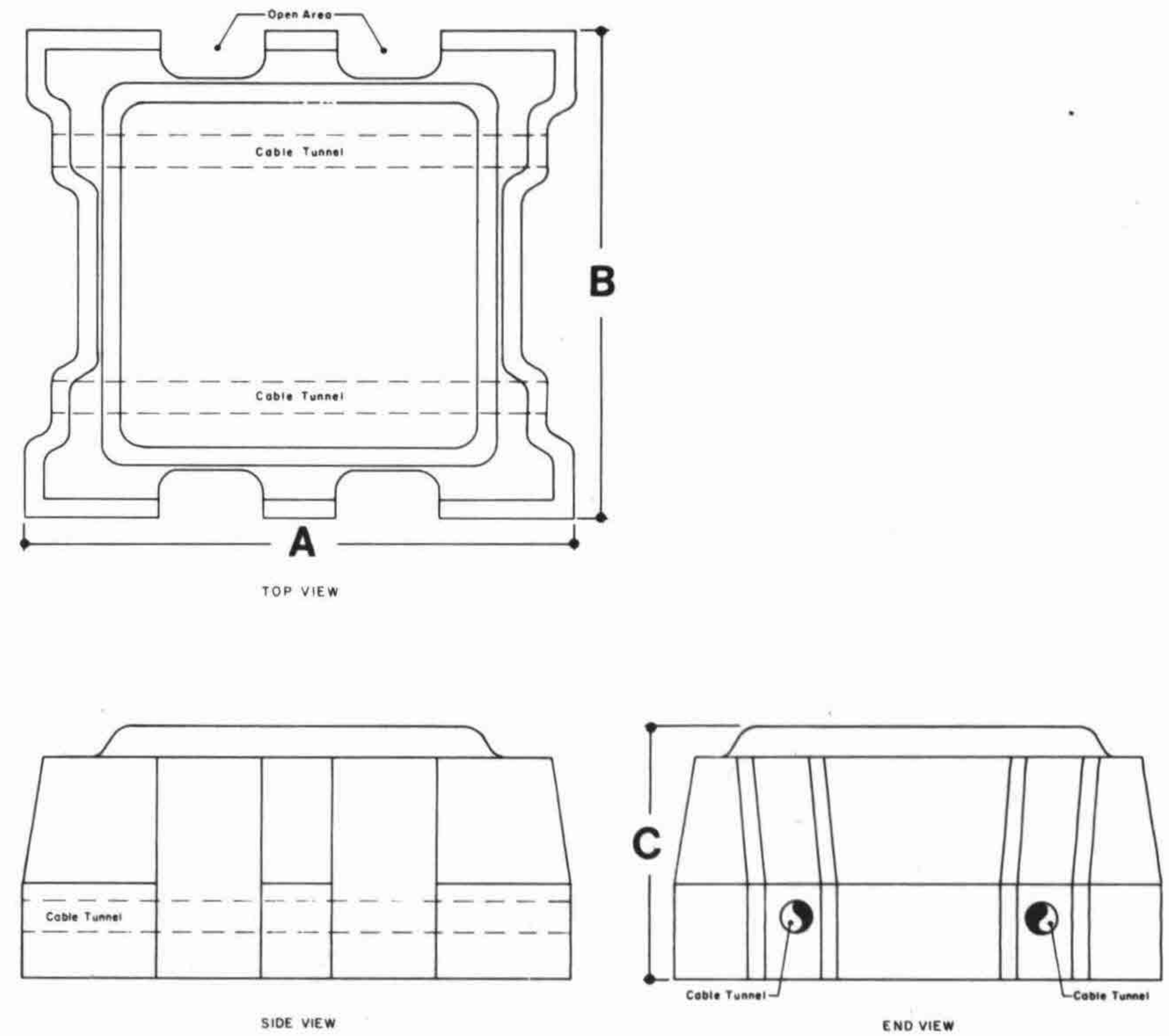
Its upper side walls are sloped inwardly, allowing for the flexibility of adjacent grids in the system. This flexibility is necessary in order that the system is free to articulate and adjust itself to the surface contours of the channel without damage from subgrade deformation. After the ARMORFLEX has settled into the channels contour, the lower vertical side walls of the grids add to the stability of the system by encouraging the buildup of binding soil and other particles between abutting grids. In addition, the lower vertical grid surface inhibits dislocation of grids since the grids within the system cannot be rolled out of position. The point of rotation on an ARMORFLEX grid is at the intersection of the verticle and sloped side walls; thus, in order for the grid to rotate out of position, the bottom edge of the grid would have to arc through the vertical planes of the adjacent grids, Figure 1-1.

The ARMORFLEX system, with vertical open cells, provides for hydraulic relief, velocity dissipation, soil retention and vegetative growth. Water is free to pass through the ARMORFLEX system, thereby relieving the damaging hydrostatic pressures that can form behind the structure. As flowing water passes over the open cells, the water will form eddy currents within the cells. These currents are energy dissipators and will reduce the erosive velocity of the water.

When non-cohesive material is placed in the open cells and subjected to flowing water, the material will be removed to depth A, Figure 1-5.. The forces at this depth will be inadequate to remove more material from the cells. The maximum scour depth, A, is approximately equal to the open cell width, L. Since ARMORFLEX with open cells filled with gravel or soil is assured of retaining all or most of the material in place, it provides the perfect environment for the establishment of vegetation. Vegetation unitizes the fill material by the formation of a root system. The root and fill material



OPEN CELL GRID

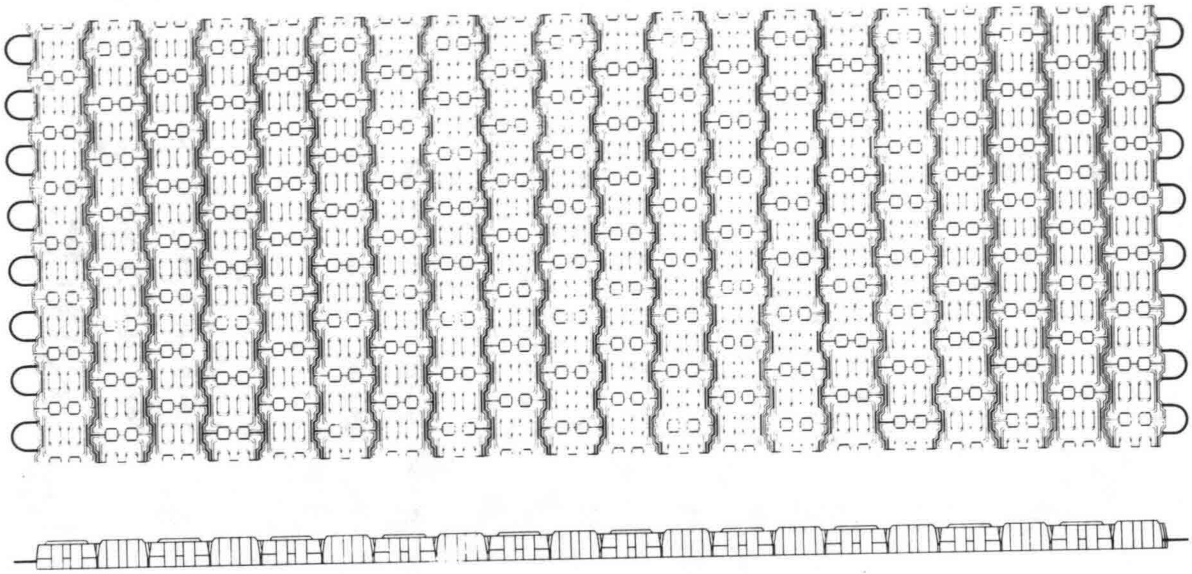


CLOSED CELL GRID

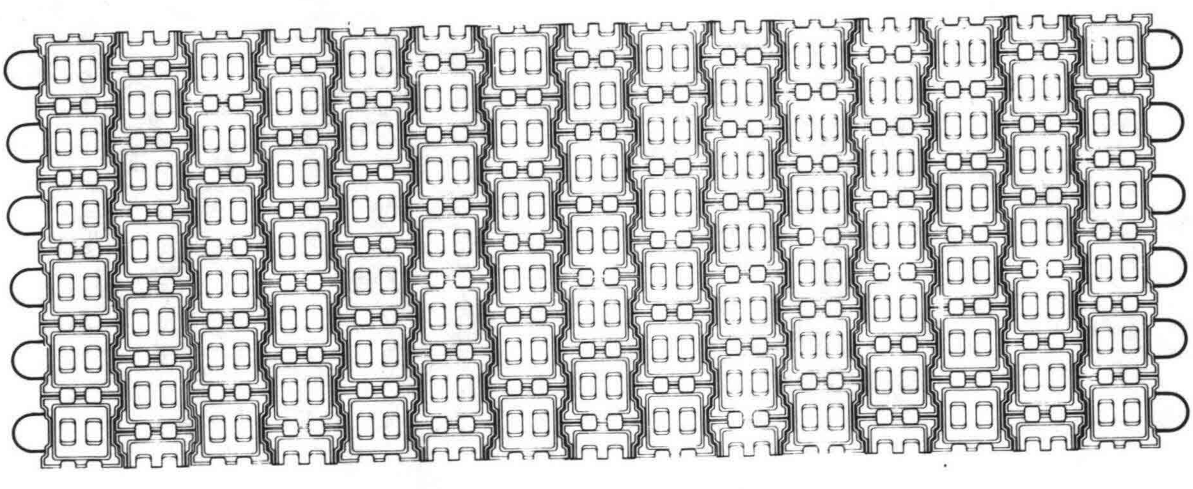
ARMORFLEX GRID SPECIFICATIONS

		TECHNICAL DATA			DIMENSIONS & WEIGHTS						
	CLASS	SPECIFIC WEIGHT LBS./CU.FT.	COMPRESSIVE STRENGTH LBS./SQ.IN.	% MAXIMUM ABSORPTION	NOMINAL DIMENSIONS IN. A	B	C	GROSS AREA/ GRID SQ.FT.	WEIGHT/ GRID LBS.	WEIGHT/ AREA LBS./SQ.FT.	OPEN AREA %
OPEN CELL	30	130-150	4000-5000	5	13.0	11.6	4.75	0.98	31-36	32-37	25
	50	130-150	4000-5000	5	13.0	11.6	6.0	0.98	45-52	46-53	20
	70	130-150	4000-5000	5	17.4	15.5	9.0	1.77	120-138	68-78	20
CLOSED CELL	45	130-150	4000-5000	5	13.0	11.6	4.75	0.98	39-45	40-46	10
	55	130-150	4000-5000	5	13.0	11.6	6.0	0.98	53-61	54-62	10
	85	130-150	4000-5000	5	17.4	15.5	9.0	1.77	145-167	82-95	10

FIG. 1-2. ARMORFLEX GRIDS

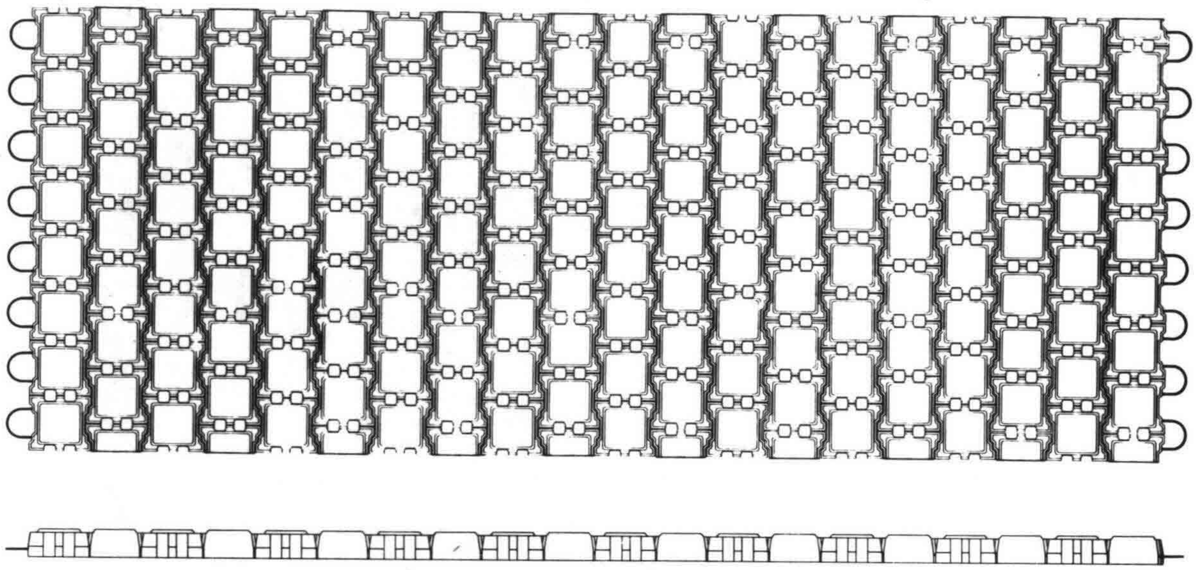


CLASS 30 OR 50 MAT

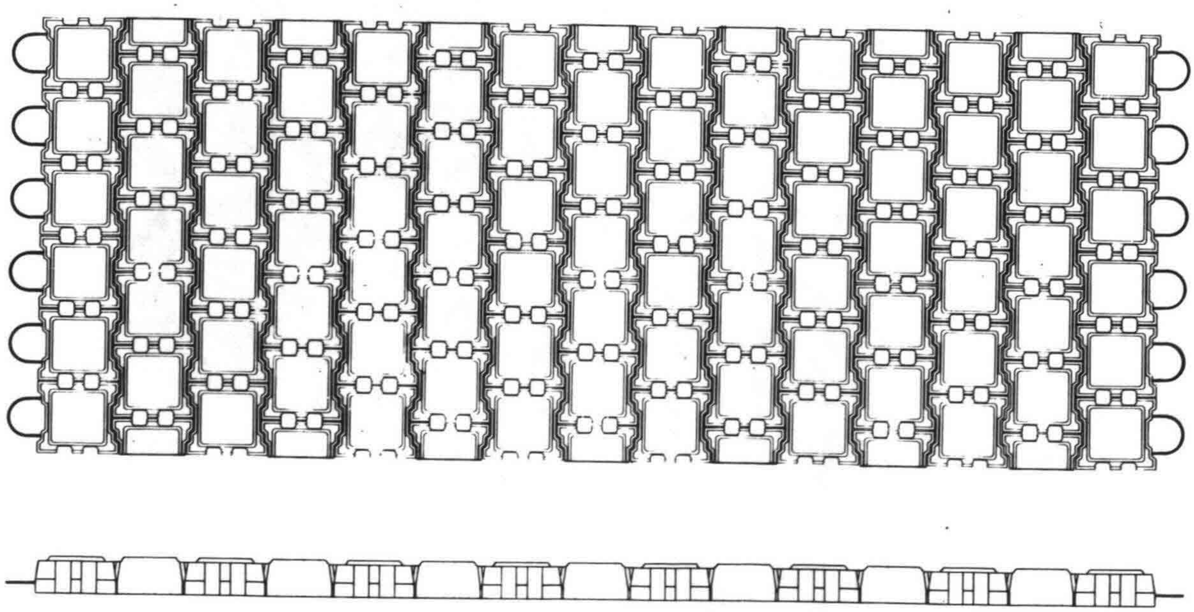


CLASS 70 MAT

FIG. I-3. TYPICAL ARMORFLEX MATS WITH OPEN CELLS



CLASS 45 OR 55 MAT



CLASS 85 MAT

FIG. I-4. TYPICAL ARMORFLEX MATS WITH CLOSED CELLS

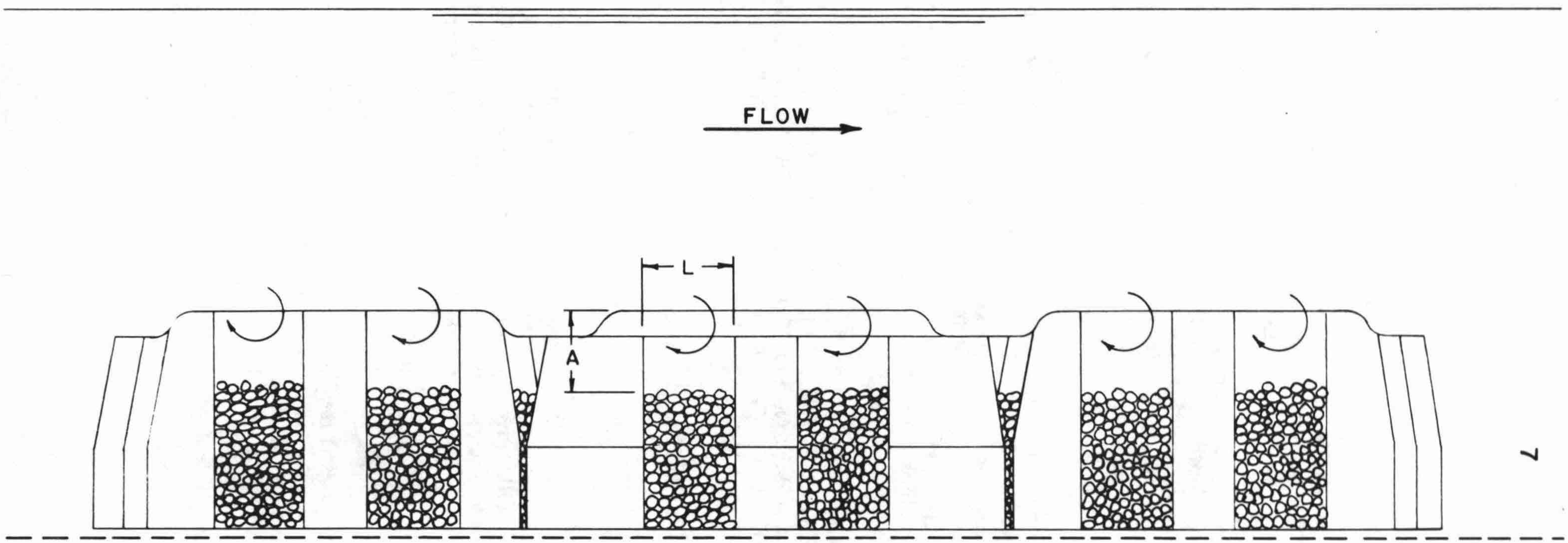


FIG. 1-5. ACTION OF OPEN CELLS IN BANK STABILIZATION

system forms a plug effect, opposing the uplifting of the ARMORFLEX grids. Vegetation will eventually establish between grids and within the open cells, and extend over the top of the grids to provide a complete cover to the system. Such vegetation contributes to the stability as well as to the ecological and aesthetic value of the areas lined by ARMORFLEX. However, it is important to note that the effect of vegetation is not taken into account when determining the stability of ARMORFLEX.

The ARMORFLEX system, with closed cells, provides for higher velocities, at the same channel slope and depth, due to its lower roughness coeffients, heavier weight and the elimination of vegetative growth. Water is still free to pass between the grids of the ARMORFLEX system, thereby relieving damaging hydraulic pressures behind the structure.

The ARMORFLEX system also incorporates the use of cables passing through parallel, horizontal cable tunnels in each grid to effectively interconnect grids into an integral mat, Figures 1-3. and 1-4. An articulated mat is thus constructed that provides for ease of placement, even under water, of the ARMORFLEX system, and contributes an additional order of stability to the already stable features of the system. Once again, it is important to note that the contribution of the cables is not taken into account when determining the stability of ARMORFLEX.

THE FOLLOWING INFORMATION IS PROVIDED AS A GUIDELINE TO PLANNERS AND DESIGNERS IN THE SELECTION OF THE CLASS OF ARMORFLEX GRIDS AND MATS REQUIED TO PREVENT EROSION DAMAGE TO BANKS AND BOTTOMS OF CHANNELS. SOUND ENGINEERING PRACTICE SHOULD BE USED AT ALL TIMES.

2.0 CONDITIONS LEADING TO CHANNEL EROSION

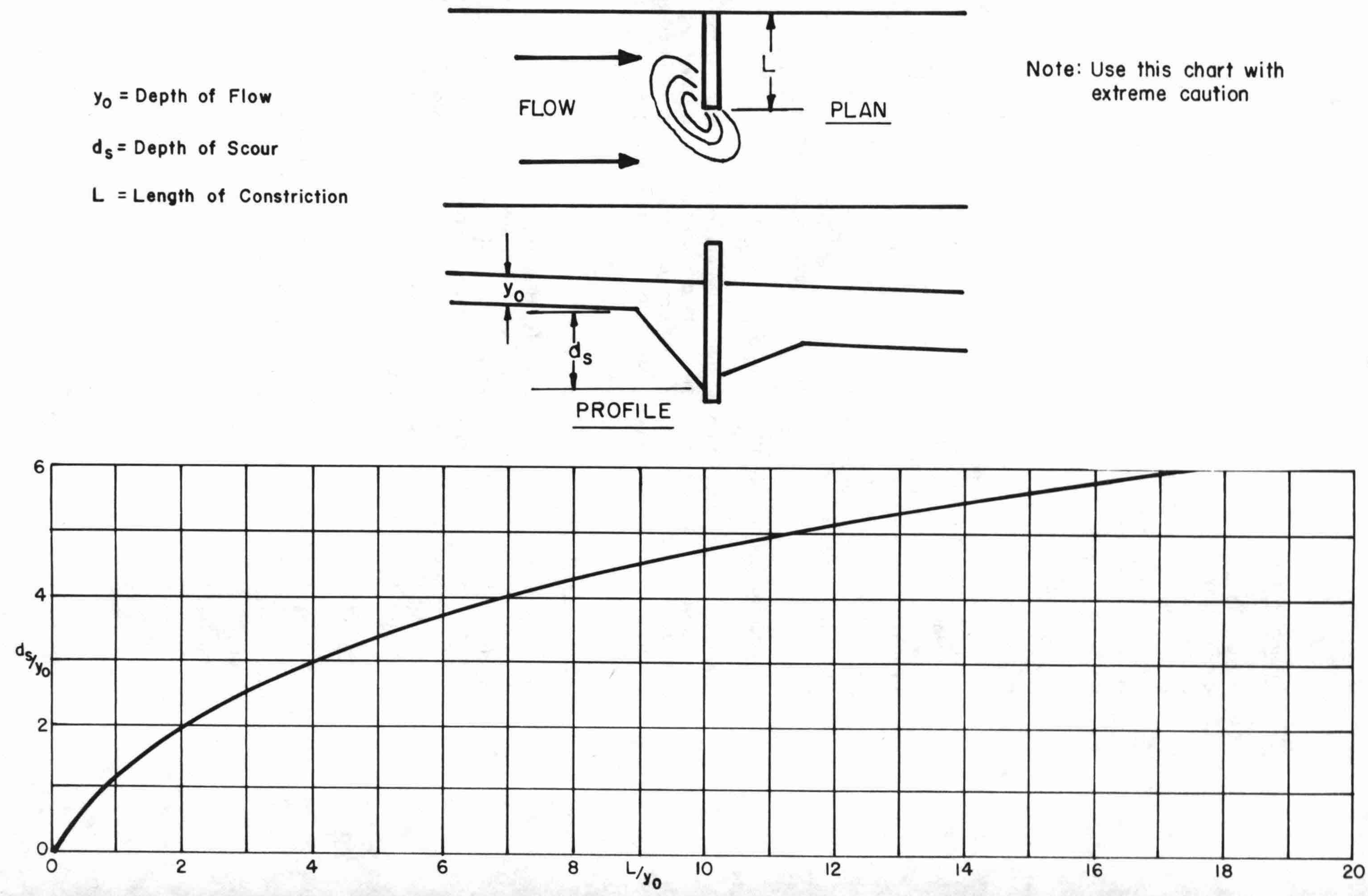
2.1 General

When water flows in a channel, forces are developed that act both in the direction of flow and perpendicular to the mean velocity. These forces are simply the drag force and lift force. When these forces are large enough, the particles in the channel bed will move and erosion takes place. In channels with steep grades or steep side slopes, the tendency of soil and rock particles to move down the slope reduces the magnitude of water forces necessary to cause movement.

2.2 Constrictions

A constriction in a channel constitutes a reach of sudden reduction in the channel cross section. The flow velocity is increased, resulting in erosion of the banks and scour of the bottom above and below the constriction unless protection is provided. In the case of a bridge having a pier in the channel of a narrow stream, the resultant scour may endanger the approach embankment and even cause movement of the abutment toward the stream, Figure 2-1. If this type of situation cannot be avoided by pier relocation, scour should be anticipated and the approach embankment protected by a properly designed lining.

FIG. 2-1. DEPTH OF SCOUR AT SHORT CHANNEL CONSTRICTIONS



2.3 Impinging Flow

Erosion and scour occurs, unless adequate protection is provided, on the outside bank of bends and at junctions where water flow impinges on a bank. In narrow man-made channels with high velocity flow, the water flowing around the outside of a bend may be deflected against the inside bank and cause erosion there also, Figure 2-2. In order to limit erosion, sharp bends should be avoided when relocating streams, rivers, or designing drainage channels.

2.4 Changes in Bottom Slope

When streams are relocated and bends are straightened, the result is an increased bottom slope gradient and, therefore, higher velocities in the straightened channel. As a result, scour is likely to occur within the channel upstream of the relocation, and erosion of the banks is likely to occur immediately downstream of the relocation. To control this erosion and the amount of protective material used, check dams, or drop structures, are constructed across the streams at intervals. The slopes between adjacent check dams are kept equal to the natural slope of the stream, with the additional gradient resulting from the straightening of the stream compensated for by a verticle drop at each check dam, Figure 2-3.

2.5 Changes in Channel Width

When a gradual transition is not provided at changes in channel width, separation eddies are created that may erode unprotected banks and scour the channel bottom. In order to prevent erosion damage, changes in channel width should be made gradual or an adequate protective lining should be provided, Figure 2-4.

2.6 Junctions of Channels

When there is a junction of channels, flow from one channel may impinge on the opposite bank of the other, causing erosion. When the velocity of the receiving channel is much less than that of the tributary channel which is carrying the silt load, there is a tendency to drop the load at the junction of the channels causing the formation of a constriction, Figure 2-5. Additional protection should be provided at such locations and continued well above and below the point of the junction.

2.7 Increased Flow

Increased flow may result from intensified runoff, diversion of adjacent watercourses or new contruction, thereby resulting in an increased velocity of water in a channel. Consequently, a previously stable channel may start to erode.

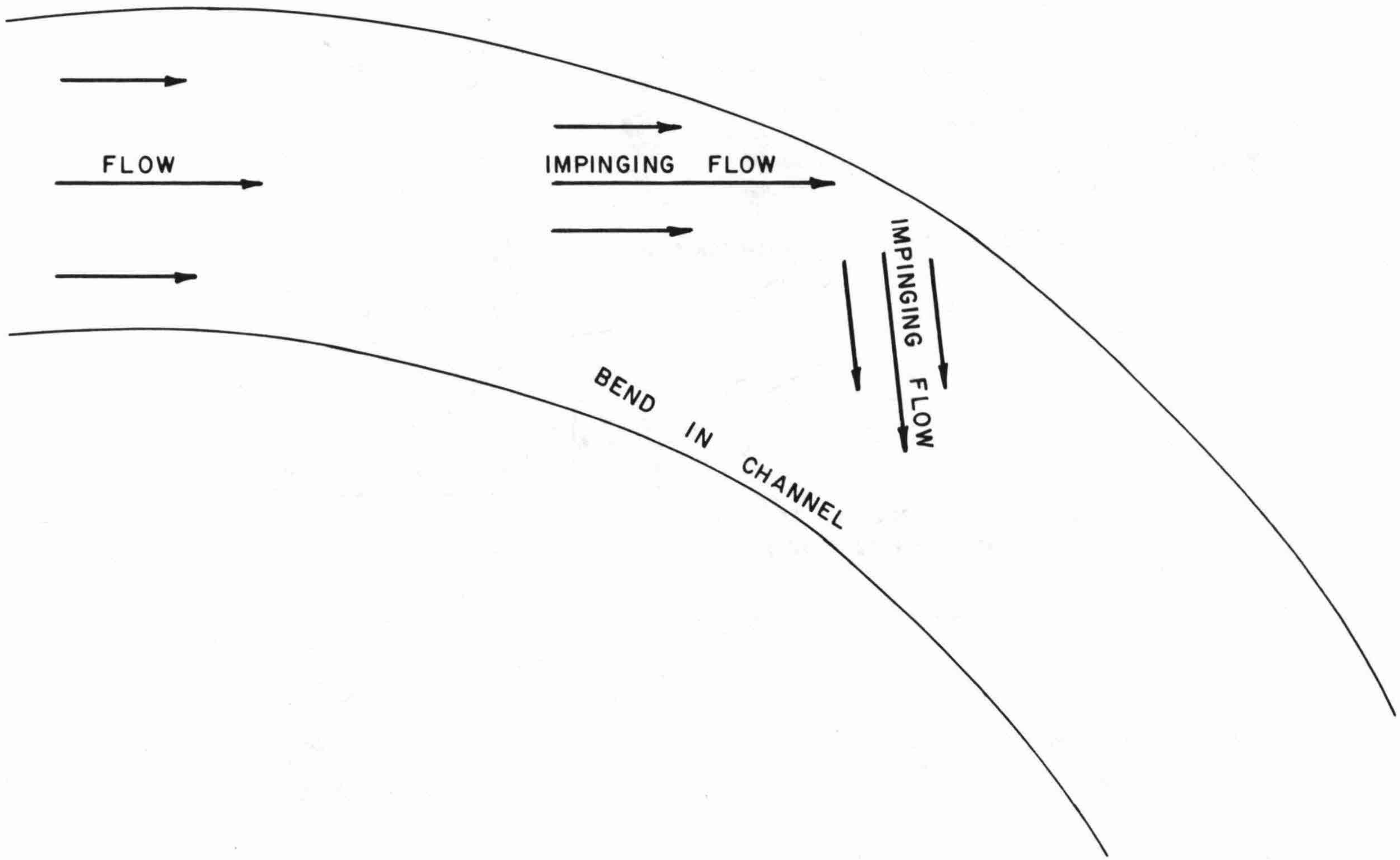


FIG. 2-2. IMPINGING FLOW AT BENDS IN CHANNELS

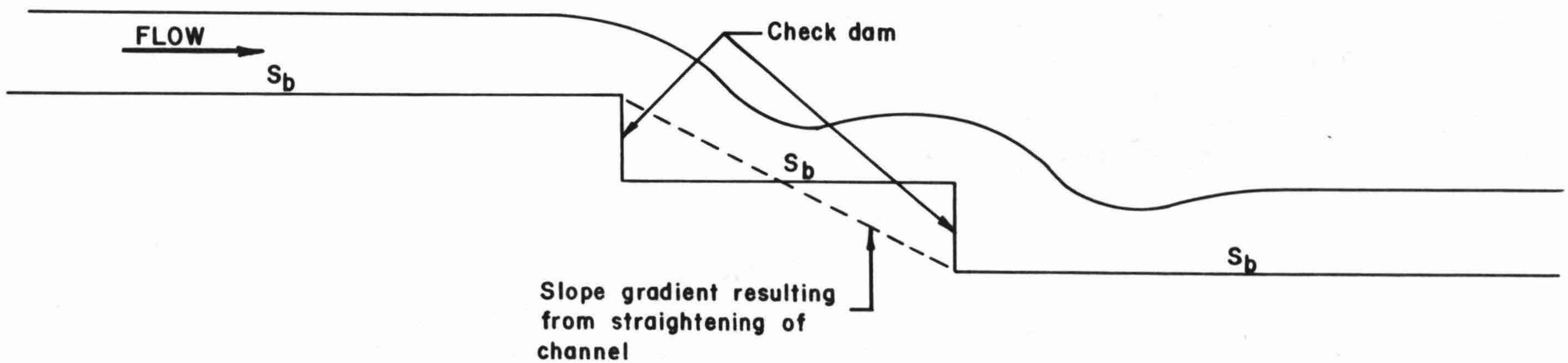
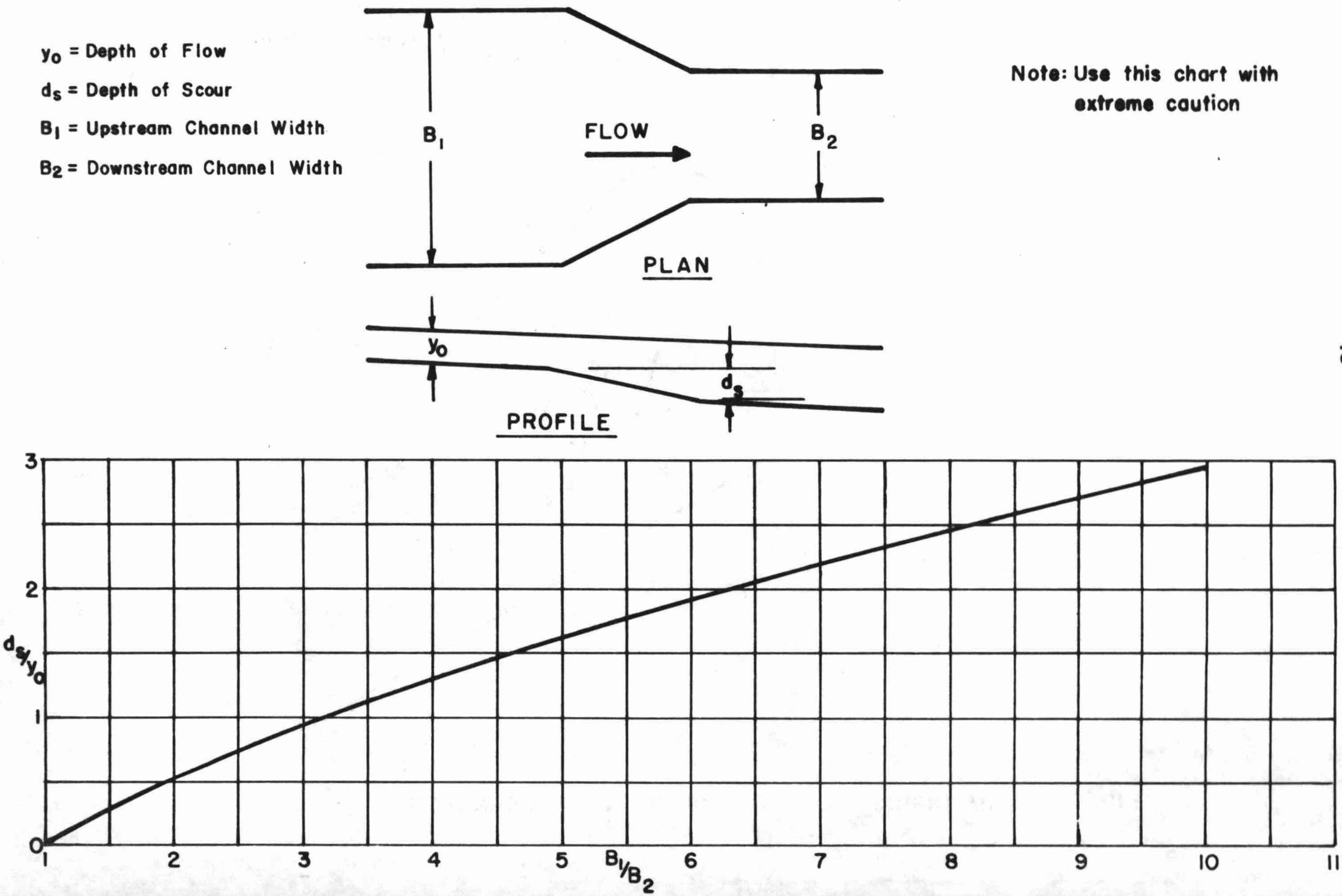


FIG. 2-3. CHECK DAMS TO COMPENSATE FOR CHANGES IN BOTTOM SLOPE

FIG. 2-4. DEPTH OF SCOUR IN LONG CHANNEL CONSTRICTIONS



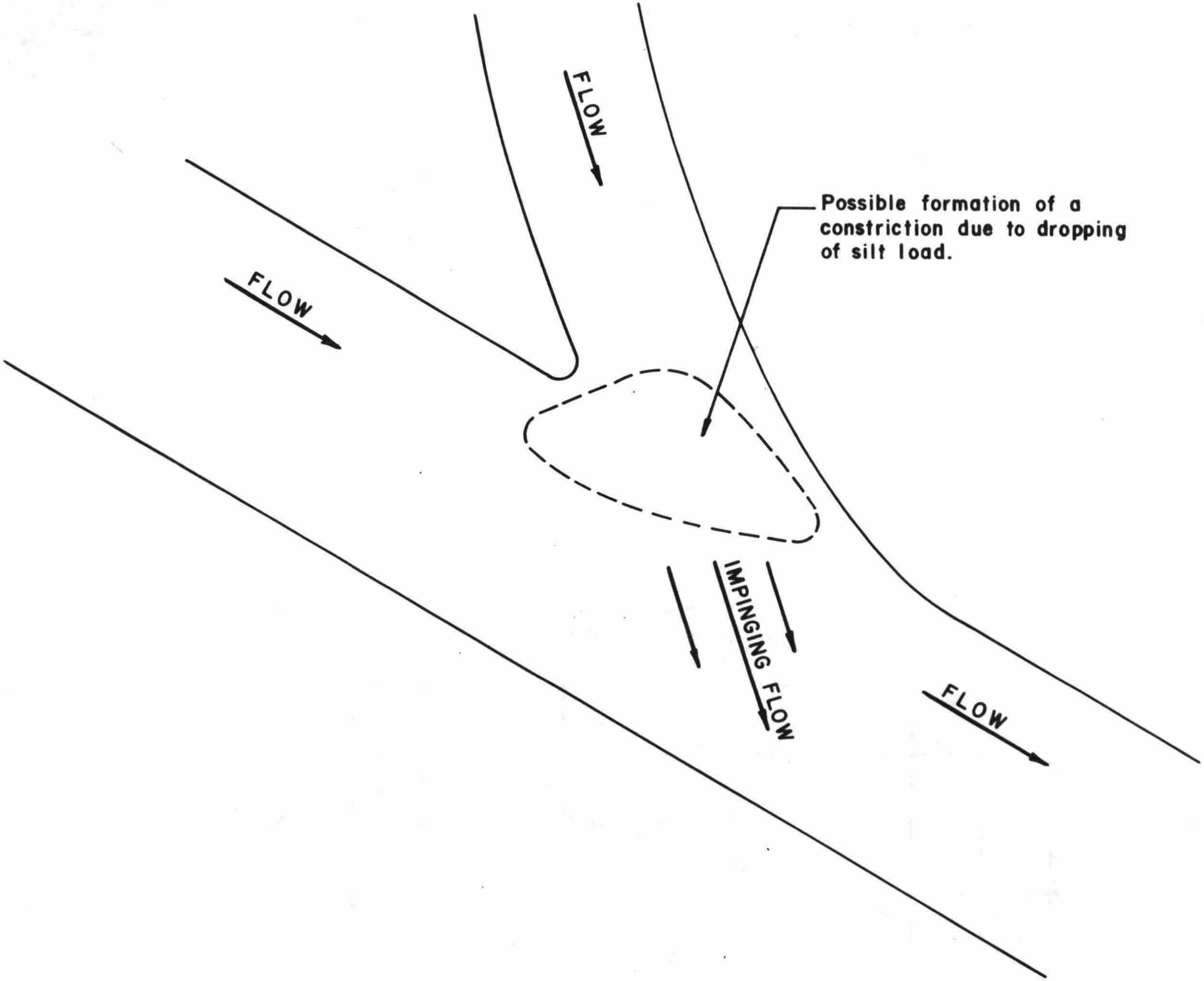


FIG. 2-5. IMPINGING FLOW AT JUNCTION OF CHANNELS

3.0 FACTORS INFLUENCING DESIGN

3.1 Natural or Artificial Channels

The behavior of flow in a channel is influenced by many physical factors and field conditions. Classified according to its origin, a channel may be either natural or artificical.

Natural channels include watercourses that exist naturally, varying in size from creeks, through streams, rivers and tidal estuaries. The hydraulic properties of natural channels are generally very irregular. Flow in natural channels is almost always turbulent flow with water particles moving in an irregular pattern.

Artificial channels are those constructed by man; navigation channels, power canals, irrigation canals, flumes, drainage channels, spillways, floodways, roadside ditches, etc. The hydraulic properties of such channels can be either controlled to the extent desired or designed to meet given requirements.

3.2 Erodible or Non-erodible Chanels

The stability of a channel is dependent mainly on the properties of the material forming the channel boundary. Unlined channels are generally erodible, except those excavated in firm foundations, such as bedrock. Only after a stable section is obtained, can the designer be assured that the channel will not be subject to erosion. Most lined channels can withstand erosion satisfactorily and are therefore considered nonerodible.

3.3 Maximum Permissible Velocity

The maximum permissible velocity, or the nonerodible velocity, is the greatest mean velocity that will not cause erosion of the channel boundary. In general, old and well-seasoned channels will resist much higher velocities than new ones, because the old channel bed is usually better stabilized, particularly with the deposition of colloidal matter.

When other conditions are the same, a deeper channel will convey water at a higher mean velocity without erosion than a shallower one. This is probably because the scouring is caused primarily by the bottom velocity and for the same mean velocity, the bottom velocities are greater in the shallower channel.

3.4 Nonerodible Lining

The purpose of lining a channel is to prevent erosion. In lined channels, the maximum permissible velocity, i.e., the maximum that will not cause erosion, can be ignored, provided that the water does not carry sand, gravel, or stone. If there are to be very high velocities over a lining, however, it should be remembered that there is a tendency for the rapidly moving water to pick up the lining material and push it out of position. Accordingly, the lining should be designed against such possibilities.

3.5 Minimum Permissible Velocity

The minimum permissible velocity, or the nonsilting velocity, is the lowest velocity that will not start sedimentation and induce the growth of aquatic plants and moss. Generally, a mean velocity of 2 to 3 fps may be used safely when the percentage of silt present in the channel is small; a mean velocity of not less than 2.5 fps will prevent a growth of vegetation.

3.6 Mean Velocity

The mean or average velocity is the flow quantity, Q, in a channel divided by the cross-sectional area, A, of the flow.

3.7 Velocity Distribution in a Channel Section

Due to the presence of a free surface and the roughness along the channelbanks and bottom, the velocities in a channel are not uniformly distributed in the channel section. The maximum velocity in ordinary channels usually appears to occur below the free surface at a distance of 0.05 to 0.25 of the depth. The closer to the banks, the deeper is the maximum. Figure 3-1. illustrates the general pattern for velocity distribution in a trapezoidal channel section.

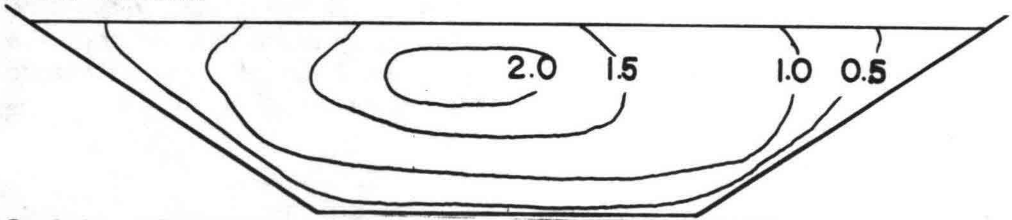


FIG. 3-1. VELOCITY DISTRIBUTION IN A TRAPEZOIDAL CHANNEL

The velocity distribution in a channel section depends also on other factors, such as the geometry of the section and the presence of bends. At a bend, the velocity increases greatly at the impinged side, owing to the centrifugal action of flow.

3.8 Channel Slopes

The longitudinal bottom slope of a channel is generally governed by the topography and the energy head required for the flow of water. In many cases, the slope may depend also on the purpose of the channel. The side slopes of a channel depend mainly on the kind of material comprising the channel banks. Under no circumstances should the side slope be greater than the angle of repose of the soil forming the channelbank under the dynamic conditions of attack expected. Other factors to be considered in determining slopes are method of construction, climatic changes, channel size, etc. Generally, side slopes should be made as steep as practicable and should be designed for high hydraulic efficiency and stability. For lined channels of ARMORFLEX, slopes of 3:1 to 1.5:1 are suggested where practicable.

3.9 Depth of Flow

The depth of flow is the vertical distance from the free surface to the lowest point of a channel section. This term is often used interchangeably with the depth of flow section. The depth of flow section is the depth of flow normal to the direction of flow, or the height of the channel section containing the water. For a channel with a longitudinal slope angle α it can be seen that the depth of a flow is equal to the depth of flow section divided by cos α . In the case of steep channels, the two terms should be used discriminately.

3.10 Roughness Coefficient

The value of Manning Roughness Coefficient, **n**, for various design conditions, is highly variable and depends on a number of factors.
The most important factor is the surface roughness which is represented by the size and shape of the material forming the protective lining and producing a retarding effect on the flow.

Table 3-1. is a comparison of Manning Roughness Coefficients for channels of various covers.

3.11 Freeboard

The freeboard of a channel is the vertical distance from the top of the channel to the water surface at the design condition. This distance should be sufficient to prevent waves or fluctuations in water surface from overflowing the sides. For lined channels, the height of lining above the water surface will depend on a number of factors; size of channel, velocity of water, curvature of alignment, condition of storm and drain water inflow, fluctuations in water level due to operation of flow regulating structures, and wind action. In a similar manner, the height of bank above the water surface will vary with size and location of channel, type of soil, amount of intercepted storm or drain water, etc. As a guide for lined channel design, the U.S. Bureau of Reclamation has prepared curves for average freeboard and bank heights in relation to discharge, Figure 3-2.

3.12 Best Hydraulic Section

The conveyance of a channel section increases with increase in the hydraulic radius or with decrease in the wetted perimeter. From a hydraulic viewpoint, the channel section having the least wetted perimeter for a given area, has the maximum conveyance. In general, a channel section should be designed for the best hydraulic efficiency, but should be modified for practicability.

It should be noted that the best hydraulic section, Table 3-2. is the section that gives the minimum area for a given discharge, but not necessarily the minimum excavation. The section of minimum excavation occurs only if the water surface is at the level of the bank tops.
Where the water surface is below the bank tops, channels narrower than those of the best hydraulic section will give minimum excavation. If the water surface overtops the banks and they are even with the ground level, wider channels will provide minimum excavation.

.075 .07 .065 .06 .055 .05 .045 .04 .035 .03 .025 .02 .015

ARMORFLEX

CLASS	CLEAN	GRASS
30	0.031	0.041
50	0.032	0.042
70	0.034	0.044
45	0.026	-
55	0.027	-
85	0.028	-

- Transported bed load 0.075
- Channels not maintained, weeds & brush uncut 0.060 - 0.075
- Natural Streams
  Sluggish reaches, weedy, deep pools
  0.060 - 0.075
- Natural Streams
  - Straight
    - Clean 0.030 - 0.035
    - Stones, weeds 0.035 - 0.040
  - Winding
    - Clean 0.040 - 0.045
    - Weeds, stones 0.045 - 0.050
- Mountain Streams
  - Bottom : gravels, cobbles and few boulders 0.030 - 0.050
  - Bottom : cobbles, large boulders 0.040 - 0.060
- Dumped Stone
- Excavated
  - Earth, straight & uniform
    - Clean 0.020 Gravel 0.025
    - Short grass 0.030
  - Earth, winding & sluggish - Cl. 0.025 Grs, weeds 0.030
- Dressed Ashler 0.015 - 0.020
- Asphalt 0.015 - 0.020
- Smooth Concrete 0.015

TABLE 3-1. COMPARISON OF MANNING ROUGHNESS COEFFICIENTS FOR CHANNELS OF VARIOUS COVER

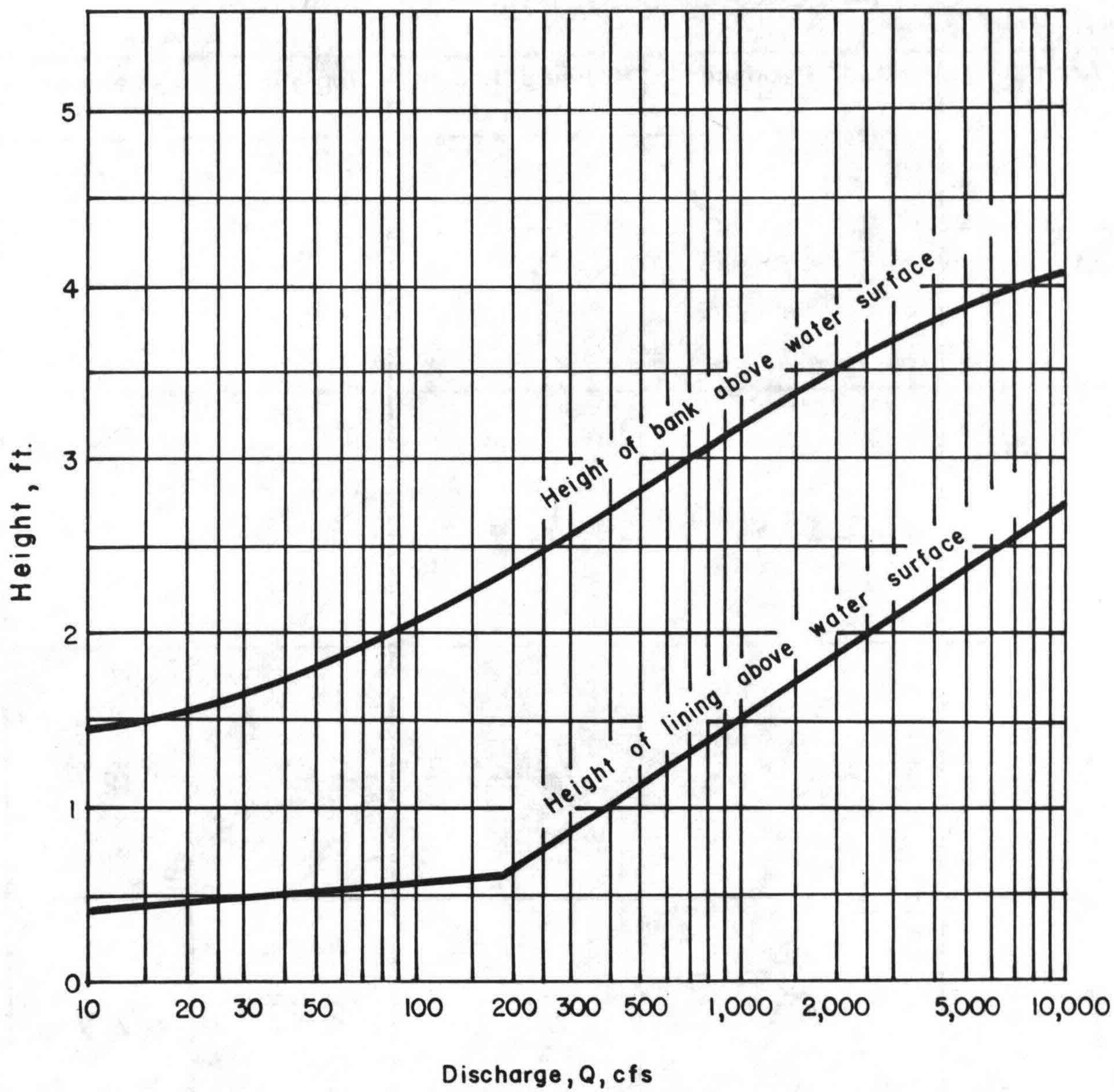
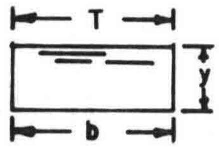
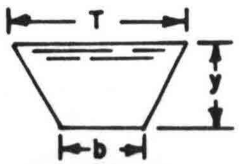
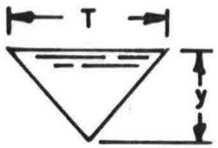
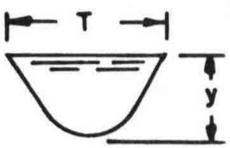


FIG. 3-2. RECOMMENDED FREEBOARD AND HEIGHT OF BANK OF LINED CHANNELS

TABLE 3-2. BEST HYDRAULIC SECTIONS

Cross Section	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width T	Hydraulic Depth D	Section Factor Z
 Rectangle	$2y^2$	$4y$	$\frac{1}{2}y$	$2y$	y	$2y^{2.5}$
 Trapezoid	$\sqrt{3}\,y^2$	$2\sqrt{3}\,y$	$\frac{1}{2}y$	$\frac{4}{3}\sqrt{3}\,y$	$\frac{3}{4}y$	$\frac{3}{2}y^{2.5}$
 Triangle	y^2	$2\sqrt{2}y$	$\frac{1}{4}\sqrt{2}\,y$	$2y$	$\frac{1}{2}y$	$\frac{\sqrt{2}}{2}y^{2.5}$
 Parabola	$\frac{4}{3}\sqrt{2}\,y^2$	$\frac{8}{3}\sqrt{2}y$	$\frac{1}{2}y$	$2\sqrt{2}\,y$	$\frac{2}{3}y$	$\frac{8}{9}\sqrt{3}\,y^{2.5}$

4.0 REQUIRED INFORMATION FOR DESIGN OF CHANNELS

4.1 Velocity or Flow Quantity

Protective linings should be designed to meet the flow quantity or velocity conditions of not less than a 20-year design storm or flood.

For data on the discharge and velocity characteristics of many waterways, contact the U.S. Geologic Survey, Water Resources Division.

Flow in smaller channels is computed by hydrologic methods.

The mean velocity, V_m , of water flowing in a channel is determined by the use of Chart 4-1., derived from the Manning equation:

$$V_m = \frac{1.49}{n} R^{2/3} S^{1/2}$$ Equa. 4-1.

Where:

R = hydraulic radius, ft.

S = longitudinal slope gradient of channel, ft./ft.
n = Manning's Roughness Coefficient

Flow Quantity is Computed by:

$$Q = V_m A$$ Equa. 4-2.

Where:

Q = discharge flow, cu. ft./sec.

V_m = mean velocity of water, ft./sec.
A = cross sectional area of channel, sq.ft.

Therefore:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2}$$ Equa. 4-3.

4.2 Channel Geometry

For existing channels, the designer can determine the geometry; depth, slope gradient, side slopes, bends, junctions, and constrictions from field survey data. For new channels, the designer selects the geometry of the channel to meet design requirements and field conditions. Table 4-1. lists four common shapes. The expression $Q/g^{1/2}$ is called the section factor, Z , for uniform flow computation; it is an important element in the computation of uniform flow. This factor can be expressed as:

$$Z = \frac{Q}{\sqrt{g}} = \left[\frac{A^3}{T}\right]^{1/2}$$ Equa. 4-4.

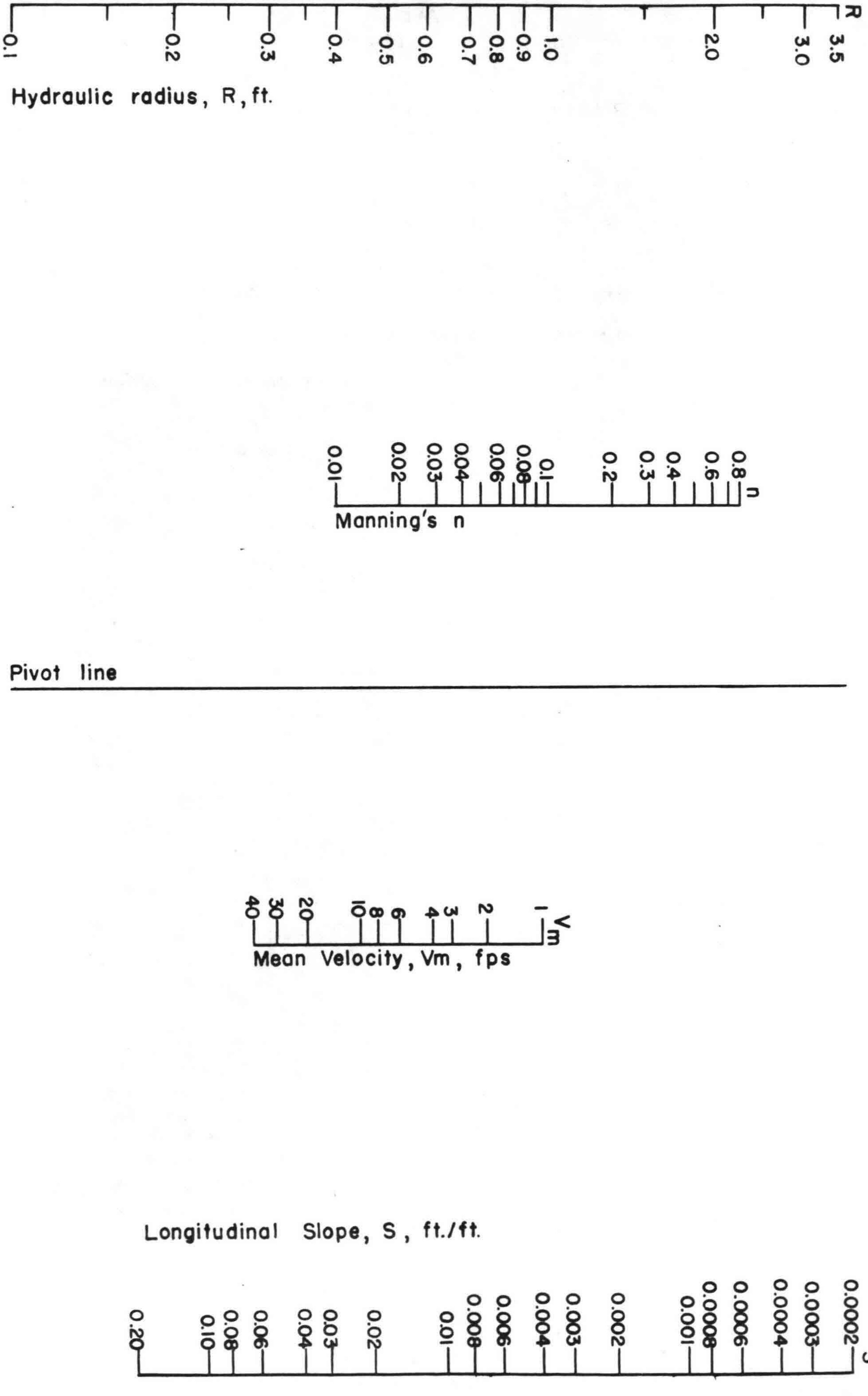
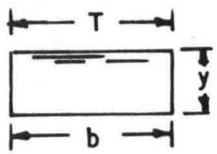
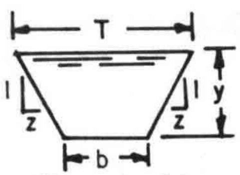
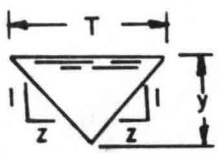
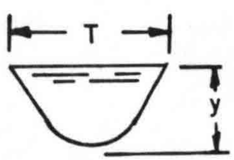


CHART 4-1. NOMOGRAPH SOLUTION OF THE MANNING FORMULA

TABLE 4-1. GEOMETRIC ELEMENTS OF CHANNEL SECTIONS

Cross Section	Area A	Wetted Perimeter P	Hydraulic Radius R	Top Width T	Hydraulic Depth D	Section Factor Z
 Rectangle	by	$b+2y$	$\frac{by}{b+2y}$	b	y	$by^{1.5}$
 Trapezoid	$(b+zy)y$	$b+2y\sqrt{1+z^2}$	$\frac{(b+zy)y}{b+2y\sqrt{1+z^2}}$	$b+2zy$	$\frac{(b+zy)y}{b+2zy}$	$\frac{[(b+zy)y]^{1.5}}{\sqrt{b+2zy}}$
 Triangle	zy^2	$2y\sqrt{1+z^2}$	$\frac{zy}{2\sqrt{1+z^2}}$	$2zy$	$1/2\,y$	$\frac{\sqrt{2}}{2}zy^{2.5}$
 Parabola	$2/3\,Ty$	$T+8/3\,y^2/T$	$\frac{2T^2y}{3T^2+8y^2}$	$\frac{3}{2}\frac{A}{y}$	$2/3\,y$	$2/9\sqrt{6}\,Ty^{1.5}$

To determine the depth substitute in Equa. 4-4., the expressions for **A** , and **T** , obtained from Table 4-1., and solve for the depth. If there are other unknowns, such as **b** and **z** of a trapezoidal section, then assume the values for these unknowns and solve Equa. 4-4. for the depth. By assuming several values of the unknowns, a number of combinations of section dimensions can be obtained. The final dimensions are decided on the basis of hydraulic efficiency and practicability.

4.3 Channel Body Soils

The susceptibility of soils to erosion varies within wide limits; very high and very low erosion resistance can occur within a short distance on the same project. The design engineer should utilize information from subsurface exploration, apply his knowledge of the properties and extent of different depositional soils units, and evaluate past erosion problems with the particular soil types. Based on the above data, the engineer will be able to point out areas of specific soil types on a project and indicate their relative susceptibility to erosion.

4.4 Non-Uniform Settlement

Non-uniform settlement, due to soft channel body soils, can lead to cracking of paved or rigid linings and to undesirable movement of the individual particles of rip-rap. With ARMORFLEX, the liner is flexible and interconnected; therefore, it is able to withstand a normal amount of settlement. However, in areas where settlement is expected to be severe, due to extremely unstable foundation soil, the designer should take steps to remove these soils and replace them with select material having proper stability.

4.5 Wave Action

In wide rivers, all or most of the erosion by water results from wave action. For inland bodies of water, wave heights can be estimated from information given in the ARMORFLEX Shoreline Protection Manual, if the wind velocity and fetch are known. Wind velocities and direction can be determined from observations made at the nearest weather station. The fetch can be scaled from a plan of the project.

4.6 Ice Action

The severity of ice action at a given site may be obtained from the known climatic conditions of the area. In general, the more uniform the channel boundary, the more resistant the channel lining is to displacement by ice action.

4.7 Watercourse Traffic

Data regarding watercourse traffic and wake effects on erosion of banks can be provided by the Army Corps of Engineers, or by local and State Waterway Maintenance Engineers.

5.0 DESIGN PROCEDURE FOR ARMORFLEX LINED CHANNELS

The function of protective linings is to prevent the erosion of underlying soils when conditions leading to erosion cannot be eliminated. In order to perform this function, the lining has to be designed and constructed so as to:

1) be able to resist the forces exerted by flowing water on the lining.

2) have an adequate extent along the watercourse so that erosion adjacent to the lining will not cause its failure by undermining.

3) prevent the leaching of underlying materials through openings in the lining.

5.1 ARMORFLEX Lining

ARMORFLEX's uniformity of weight, size, shape and composition assure the construction of an efficient lining, Figures 1-2.. Unlike rip-rap linings, ARMORFLEX has no material smaller than the design weight that can be dislodged by the forces of flowing water, subsequently, undermining the larger material. Each ARMORFLEX grid in an installation has exactly the same stability potential as the adjacent grids, thus forming an effective lining with the most conservative use of material weight. Even more important is the interconnection of the ARMORFLEX grids, allowing the entire system to work homogeneously and thus preventing one or more grids from being removed independently from the system.

5.2 Basic Design Assumptions

The class of ARMORFLEX and channel geometry required to carry a discharge, **Q** , on a slope, **S** , without erosion, is determined by the use of Figures 5-1. through 5-18.

The charts were developed by applying the theory of open channel flow as outlined in Tentative Design Procedure for Rip-Rap-Lined Channels to the design of ARMORFLEX lined channels. The theory is used in conjunction with the characteristics of flow to describe the characteristics of the ARMORFLEX lining and the channel dimensions necessary to convey a given discharge on a given slope. Based on these relationships, it is assumed that, for purposes of design, the following conditions are applicable:

5.2.1 The channel is essentially straight and of trapezoidal cross section. The effect of bends in the alignment of the channel on the ARMORFLEX selection is treated as a corrective factor that will be applied to the design, Section 5.3.2.

5.2.2 The flow will be essentially uniform and can be described by Manning's formula:

$$V_m = \frac{1.49}{n} R^{2/3} S^{1/2} \qquad \text{Equa. 4-1.}$$

in which the symbols are as previously defined and listed in Section 4.1. It is recognized that certain precautions must be taken at the entrance and outlet of the channel, and considerations must be given to these regions of possible non-uniform flow. The design of appropriate stilling basins and drop structures is considered to be a special problem that is not within the scope of this manual.

5.2.3 The Manning Roughness Coefficient, **n** , will depend on the effective size of the ARMORFLEX grids that line the channel, and whether the grids are open cell or closed cell, and can be expressed as:

$$n = 0.0341(W_g/\gamma_g)^{1/18} \quad \text{Open Cell} \qquad \text{Equa. 5-1.a.}$$

$$n = 0.0278(W_g/\gamma_g)^{1/18} \quad \text{Closed Cell} \qquad \text{Equa. 5-1.b.}$$

Where:

W_g = weight of the ARMORFLEX grid, lbs.
γ_g = specific weight of the ARMORFLEX grid, lbs/cu.ft.

5.2.4 The critical boundary shear, τ_c , which represents the maximum shear for which the ARMORFLEX will be stable, is in direct proportion to the effective size of the grids or:

$$\tau_c = 0.04(\gamma_g - \gamma)\left(\frac{6\,W_g}{\pi\gamma_g}\right)^{1/3} \qquad \text{Equa. 5-2.}$$

Where:

W_g = weight of the ARMORFLEX grid, lbs.

γ_g = specific weight of the ARMORFLEX grid, lbs/cu.ft.

γ = specific weight of water, lbs/cu.ft.

5.2.5 The boundary shear stress is not uniformly distributed around the wetted perimeter of the channel. The magnitude and location of the maximum shear on the boundary depends on the shape of the channel cross section. For wide trapezoidal channels, the maximum shear occurs at the center of the channel bottom. For narrow channels, the maximum shear occurs on the side slopes. The excess of the maximum boundary shear over the mean shear varies somewhat with the width-depth ratio. To simplify the computation and charts, the ratio of the maximum boundary shear stress is taken to be 1.5 times the mean shear for all trapezoidal channels.

$$\tau_{o_{max}} = 1.5\gamma RS \qquad \text{Equa. 5-3.}$$

Where:

R = hydraulic radius, ft.
S = longitudinal slope gradient of channel, ft./ft.
γ = specific weight of water, lbs./cu.ft.

5.2.6 Because of the component of the force of gravity acting on the ARMORFLEX in the direction of the side slope, the critical boundary shear stress for the ARMORFLEX on the sloping side is less than that for ARMORFLEX on the channel bottom. The ratio of the critical boundary shear on the sloping side, τc_s, to the critical boundary shear acting on a similar particle on the channel bottom, τc_b, is:

$$K = \frac{\tau c_s}{\tau c_b} = \sqrt{1 - \frac{\sin^2 \phi}{\sin^2 \theta}}$$ Equa. 5-4.

Where:

ϕ = side slope angle, deg.

θ = angle of repose of ARMORFLEX, deg.

5.2.7 The discharge, **Q**, to be conveyed in the channel and the longitudinal slope, **S**, are prescribed by external conditions; that is, they are independent variables. Under certain circumstances, the class of ARMORFLEX that may be available may be considered an independent variable and the channels may be designed to take this into account.

5.2.8 The ratio of width to depth for trapezoidal channels must be limited to practical values. This may be done arbitrarily within certain limits using the ratio P/R (in which P is the wetted perimeter and R is the hydraulic radius). For channels with side slopes of 1:1, P/R (min) equal 8.0; 1-1/2:1 P/R (min) equals 8.7; 2:1, P/R (min) equals 10.0, for 3:1 P/R (min) equals 13.3; and for side slopes of 4:1, P/R (min) equals 17. Because trapezoidal channels with side slopes of 1:1 and 4:1 are relatively rare, the minimum P/R ratio is taken as 8.7. The upper limit of P/R is set at 30 because wider channels become uneconomical. In practice, the ultimate design probably will be between these limits.

5.3 Use of Design Charts

To facilitate the design of channels and the selection of the proper class of ARMORFLEX, a series of design charts has been developed from which the channel properties and class of ARMORFLEX can be determined. The development of design charts for trapezoidal channels is founded on the basic equations described in Section 5.2.1 through 5.2.8. The combination of these equations with the equation of continuity for the flow results in a relationship between the principal variables of discharge, slope, shape of channel, and class of ARMORFLEX.

Where vegetation of side slope is desired, ARMORFLEX with open cells should be selected for use above the lower water level.

Where vegetation is not desired, or where the discharge and longitudinal slope result in the requirement for a class of ARMORFLEX with a lower roughness coefficient and a heavier weight, ARMORFLEX with closed cells should be selected.

5.3.1 Parallel Flow

A. ARMORFLEX with Open Cells

The selection of the appropriate class of ARMORFLEX with open cells and channel geometry for known and/or assumed flow conditions is determined by using the following steps:

1) Determine the discharge, **Q** , and slope, **S** , from known data and or field surveys.

2) With the given discharge, **Q** , and slope, **S** , enter Figures 5-1. and 5-2. and determine the class of ARMORFLEX from each chart. This provides two limits within which the actual class of ARMORFLEX must fall.

3) Select the class of ARMORFLEX from Figure 5-2. in Step 2.

4) With the selected class of ARMORFLEX and known value of slope, **S** , enter Figure 5-5. and determine the mean velocity, V_m .

5) With the selected class of ARMORFLEX and known value of slope, **S** , enter Figure 5-6. and determine the hydraulic radius, **R** .

6) With the mean velocity, V_m , and discharge, **Q** , enter Figure 5-9., and determine the required cross-sectional area, **A** , of the channel.

7) Since the angle of repose, θ_g , of ARMORFLEX is generally greater than the soils on which it is placed, the required side slopes, ϕ , of the channel are determined by entering Figure 5-10., for non-cohesive soils, to obtain the angle of repose, θ , of the soil and then using the angle of repose enter Figure 5-11. to determine the required side slope ϕ. For cohesive soils, utilize information from exploration, and apply knowledge of the properties of the soil types to determine their angle of reposes, θ , and then using the angle of repose, enter Figure 5-11. to determine the required side slope.

   The curve in Figure 5-11. represents the actual variation between angle of repose, θ , and side slope, ϕ , but for practical purposes, the range of side slopes are divided into four groups and each assigned a value.

8) With the chosen side slope, ϕ, and previously determined cross- sectional area, **A** , and hydraulic radius, **R** , enter the appropriate Figures 5-12. through 5-17. and determine the channel geometry. In those charts, the side slope is established so that the class of ARMORFLEX on the side is as stable as that on the bottom of the channel.

9) If the channel geometry determined in Step 8 results in a channel width that is too wide, return to Step 2 and select the class of ARMORFLEX from Figure 5-1. then proceed to Step 4 and repeat the remaining procedures to determine a new channel geometry.

The foregoing procedures suggest that for each channel geometry, there is a certain effective class of ARMORFLEX that must be used. In fact, however, the class of ARMORFLEX as determined from the charts represents minimum size. After the channel dimensions have been determined, any heavier class of ARMORFLEX can be used in its construction. The effect of the heavier class of ARMORFLEX will be to decrease the mean velocity and consequently increase the cross-sectional area. This means that the heavier class of ARMORFLEX will be somewhat more stable than necessary. Under these circumstances, the charts cannot be used directly to determine if changes in geometry are needed, because they are designed to provide a channel geometry at the lower limit of stability and to define the minimum class of ARMORFLEX to be used. Equation 5-1a. indicates that the roughness coefficient will be increased slightly with an increase in the weight of the ARMORFLEX. If one specifies that the hydraulic radius of the channel and the longitudinal slope are to remain constant, then Equation 4-1. applied to both the basic design and the new design with heavier class of ARMORFLEX, can be used to determine the velocity to be expected in the new channel; that is:

$$V' = V\,[W_g/W_g']^{1/18} \qquad \text{Equa. 5-5.}$$

Where:

V' = velocity in the channel having the heavier class of ARMORFLEX.
W_g' = weight of the heavier class of ARMORFLEX.

Having the new velocity, V', the required cross-sectional area, A' is:

$$A' = Q/V' \qquad \text{Equa. 5-6.}$$

Then, with the area and the hydraulic radius, which is unchanged, enter the appropriate Figures 5-12. through 5-17. to determine the new bottom width and the new depth.

B. ARMORFLEX with Closed Cells

The selection of the appropriate class of ARMORFLEX with closed cells and channel geometry for known and/or assumed flow conditions is determined by using the following steps:

1) Determine the discharge, Q, and slope, S, from known data and or field surveys.

2) With the given discharge, Q, and slope, S, enter Figures 5-3. and 5-4. and determine the class of ARMORFLEX from each chart. This provides two limits within which the actual class of ARMORFLEX must fall.

3) Select the class of ARMORFLEX from Figure 5-4. in Step 2.

4) With the selected class of ARMORFLEX and known value of slope, S, enter Figure 5-7. and determine the mean velocity, V_m.

5) With the selected class of ARMORFLEX and known value of slope, S, enter Figure 5-8. and determine the hydraulic radius R.

6) With the mean velocity, V_m, and discharge, Q, enter Figure 5-9., and determine the required cross-sectional area, A, of the channel.

7) Since the angle of repose, θ_g, of ARMORFLEX is generally greater than the soils on which it is placed, the required side slopes, ϕ, of the channel are determined by entering Figure 5-10., for non-cohesive soils, to obtain the angle of repose, θ, of the soil and then using the angle of repose enter Figure 5-11. to determine the required side slope ϕ. For cohesive soils, utilize information from exploration, and apply knowledge of the properties of the soil types to determine their angle of reposes, θ, and then using the angle of repose, enter Figure 5-11. to determine the required side slope.

   The curve in Figure 5-11. represents the actual variation between angle of repose, θ, and side slope, ϕ, but for practical purposes, the range of side slopes are divided into four groups and each assigned a value.

8) With the chosen side slope, ϕ, and previously determined cross- sectional area, **A**, and hydraulic radius, **R**, enter the appropriate Figures 5-12. through 5-17. and determine the channel geometry. In those charts, the side slope is established so that the class of ARMORFLEX on the side is as stable as that on the bottom of the channel.

9) If the channel geometry determined in Step 8 results in a channel width that is too wide, return to Step 2 and select the class of ARMORFLEX from Figure 5-3. then proceed to Step 4 and repeat the remaining procedures to determine a new channel geometry.

The foregoing procedures suggest that for each channel geometry, there is a certain effective class of ARMORFLEX that must be used. In fact, however, the class of ARMORFLEX as determined from the charts represents minimum size. After the channel dimensions have been determined, any heavier class of ARMORFLEX can be used in its construction. The effect of the heavier class of ARMORFLEX will be to decrease the mean velocity and consequently increase the cross-sectional area. This means that the heavier class of ARMORFLEX will be somewhat more stable than necessary. Under these circumstances, the charts cannot be used directly to determine if changes in geometry are needed, because they are designed to provide a channel geometry at the lower limit of stability and to define the minimum class of ARMORFLEX to be used. Equation 5-1b. indicates that the roughness coefficient will be increased slightly with an increase in the weight of the ARMORFLEX. If one specifies that the hydraulic radius of the channel and the longitudinal slope are to remain constant, then Equation 4-1. applied to both the basic design and the new design with heavier class of ARMORFLEX, can be used to determine the velocity to be expected in the new channel; that is:

$$V' = V[W_g/W'_g]^{1/18} \qquad \text{Equa. 5-5.}$$

Where:

V' = velocity in the channel having the heavier class of ARMORFLEX.
W'_g = weight of the heavier class of ARMORFLEX.

Having the new velocity, V', the required cross-sectional area, A' is:

$$A' = Q/V' \qquad \text{Equa. 5-6.}$$

Then, with the area and the hydraulic radius, which is unchanged, enter the appropriate Figures 5-12. through 5-17. to determine the new bottom width and the new depth.

5.3.2 Impinging Flow

The class of ARMORFLEX required to resist displacement from direct impingment, as might occur with a bend in the alignment of the channel, may be greater than that for the parallel reaches of channel. Figure 5-18. shows that the shear stress may be increased locally due to the secondary currents that are generated at bends and that the amount increases with the ratio of the channel surface width B_S to the mean radius of the bend R_O. It may therefore be necessary to use a heavier class of ARMORFLEX in this section of the channel to counteract the local increase in boundary shear, Equations 5-2. and 5-3. relate the critical boundary shear to the class of ARMORFLEX and the channel geometry, so that for stability in a straight channel:

$$1.5\gamma RS = 0.04(\gamma_g - \gamma)\left(\frac{6W_g}{\pi\gamma_g}\right)^{1/3} \qquad \text{Equa. 5-7.}$$

Figure 5-18. gives the relative increase in shear due to the channel curvature, so that, again for stability,

$$(\tau_o/\bar{\tau}_o)_{max}\,\gamma RS = 0.04(\gamma_g - \gamma)\left(\frac{6W_g'}{\pi\gamma_g}\right)^{1/3} \qquad \text{Equa. 5-8.}$$

Where:

τ_o = maximum local boundry shear in the bend.

$\bar{\tau}_o$ = mean shear in a corresponding straight channel

W_g' = weight of the heavier class of ARMORFLEX needed at the bend.

If one specifies that the hydraulic radius of the channel and the longitudinal slope are to remain constant, then,

$$W_g' = W_g\left(\frac{(\tau_o/\bar{\tau}_o)_{max}}{1.5}\right)^3 \qquad \text{Equa. 5-9.}$$

The weight of the ARMORFLEX grid determined from Equation 5-9. should be compared to the available classes of ARMORFLEX to determine the appropriate class of ARMORFLEX.

Because of the heavier class of ARMORFLEX, the velocity will be reduced as described in Equation 5-5. and the area will be increased as shown by Equation 5-6. With these data, the appropriate Figures 5-12. - 5-17. can be used to determine the channel geometry.

For bends where the radius is more than four times the channel width, no provision for added protection is needed.

The class of ARMORFLEX that is prescribed for the bend should be applied throughout the bend and a portion of the straight channel upstream of the bend so that a good transition will be made.

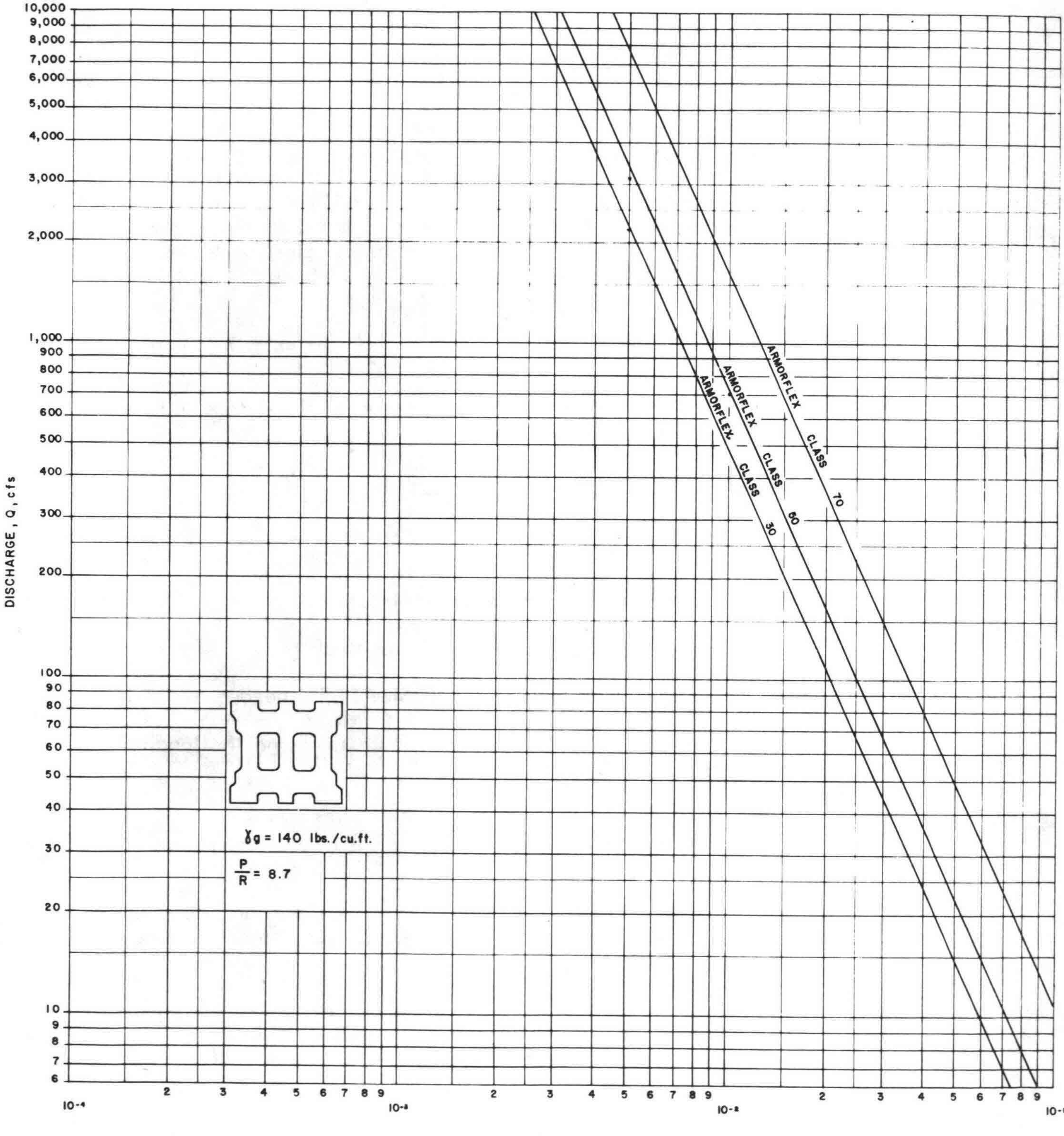


FIG. 5-1. CLASS OF ARMORFLEX WITH OPEN CELLS THAT WILL BE STABLE IN TRAPEZOIDAL CHANNELS WITH P/R = 8.7 FOR VARIOUS COMBINATIONS OF DISCHARGE AND SLOPE

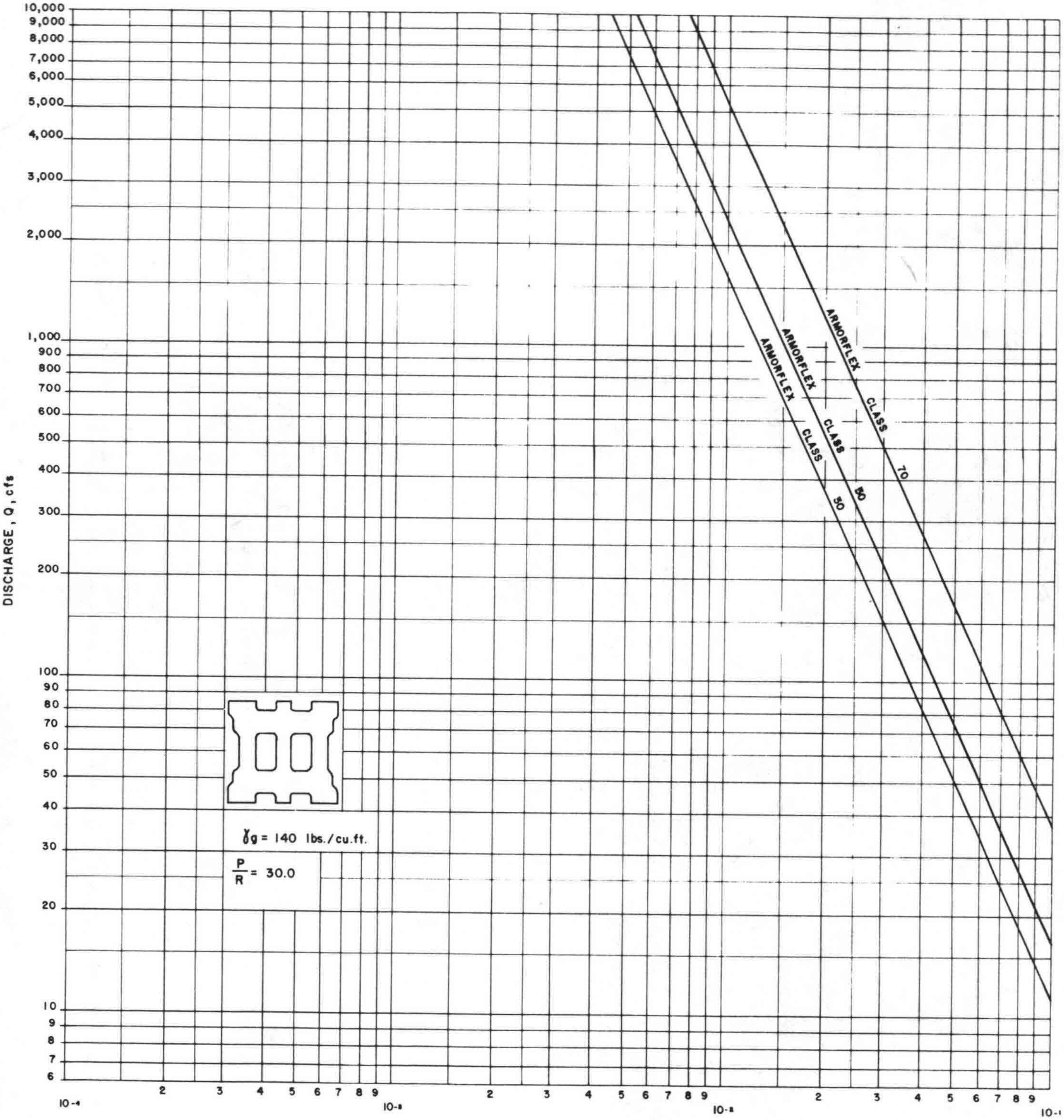


FIG. 5-2. CLASS OF ARMORFLEX WITH OPEN CELLS THAT WILL BE STABLE IN TRAPEZOIDAL CHANNELS WITH P/R = 30.0 FOR VARIOUS COMBINATIONS OF DISCHARGE AND SLOPE

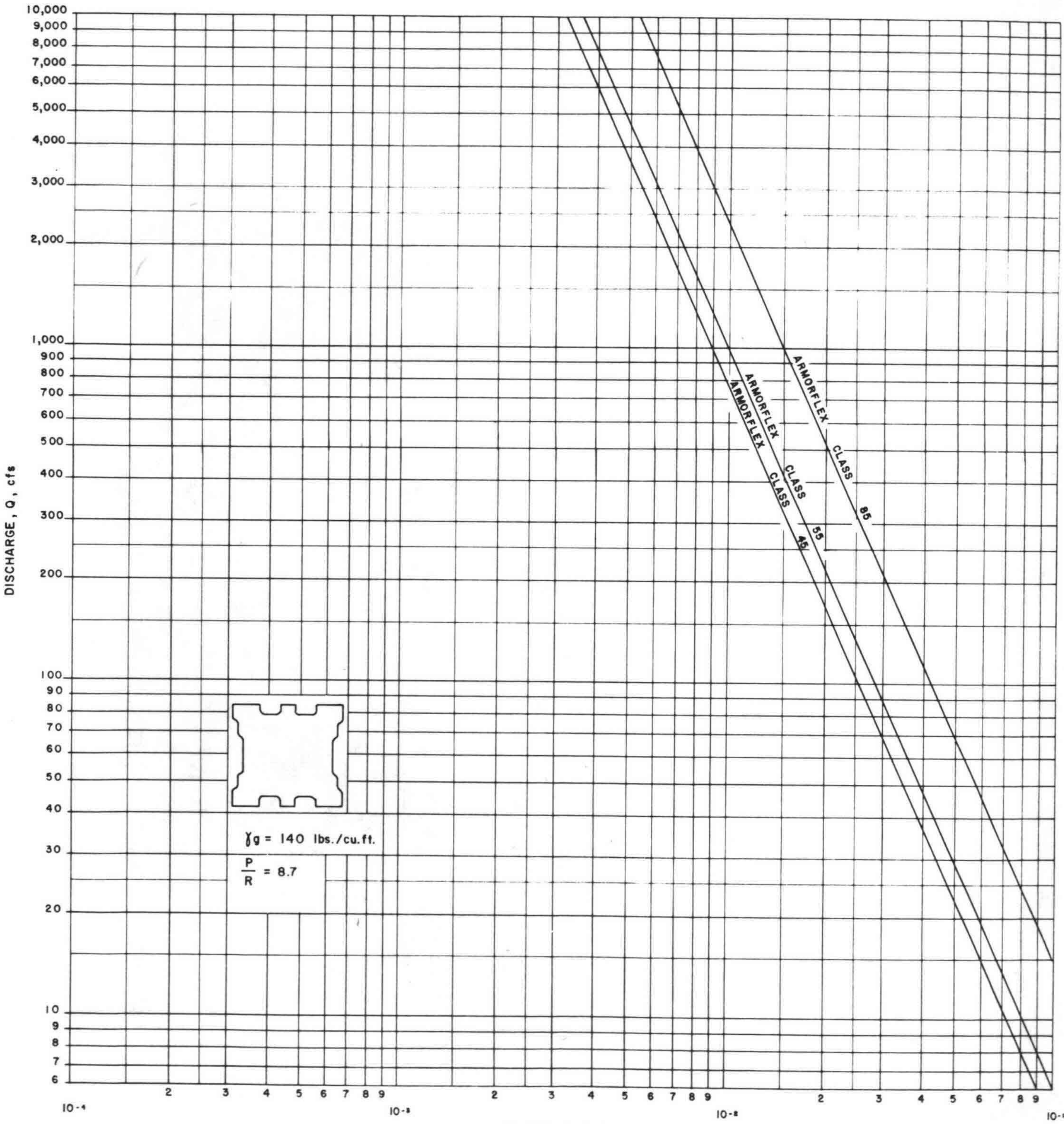


FIG. 5-3. CLASS OF ARMORFLEX WITH CLOSED CELLS THAT WILL BE STABLE IN TRAPEZOIDAL CHANNELS WITH P/R = 8.7 FOR VARIOUS COMBINATIONS OF DISCHARGE AND SLOPE

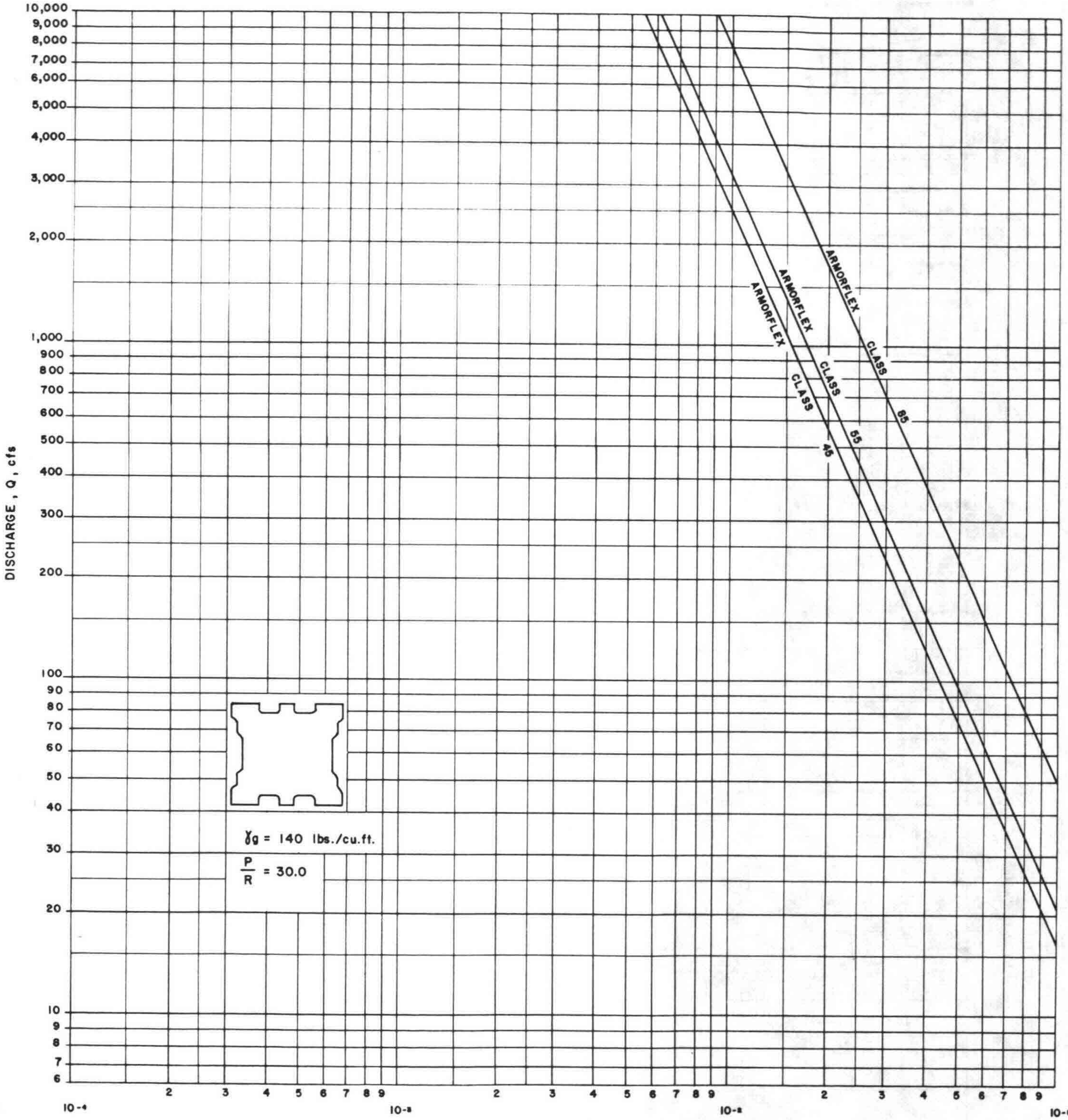


FIG. 5-4. CLASS OF ARMORFLEX WITH CLOSED CELLS THAT WILL BE STABLE IN TRAPEZOIDAL CHANNELS WITH P/R = 30.0 FOR VARIOUS COMBINATIONS OF DISCHARGE AND SLOPE

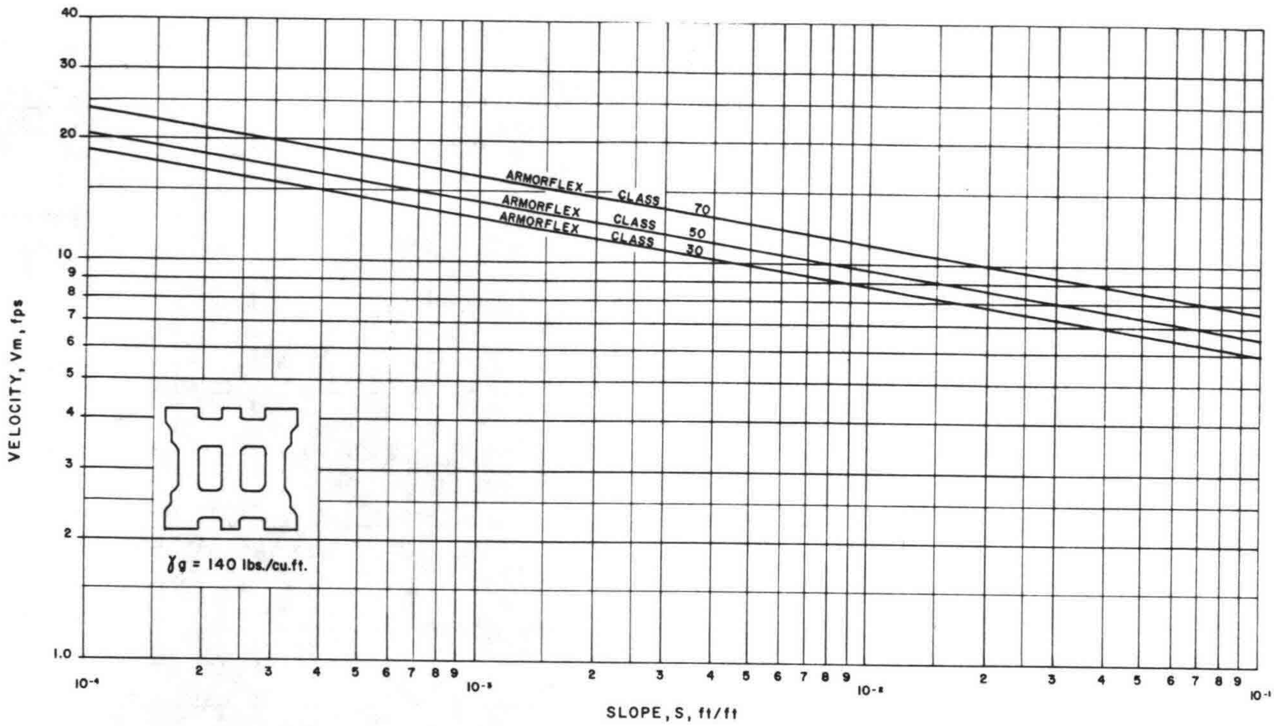


FIG. 5-5. MAXIMUM MEAN VELOCITY FOR CLASSES OF ARMORFLEX WITH OPEN CELLS IN TRAPEZOIDAL CHANNELS WITH VARIOUS SLOPES

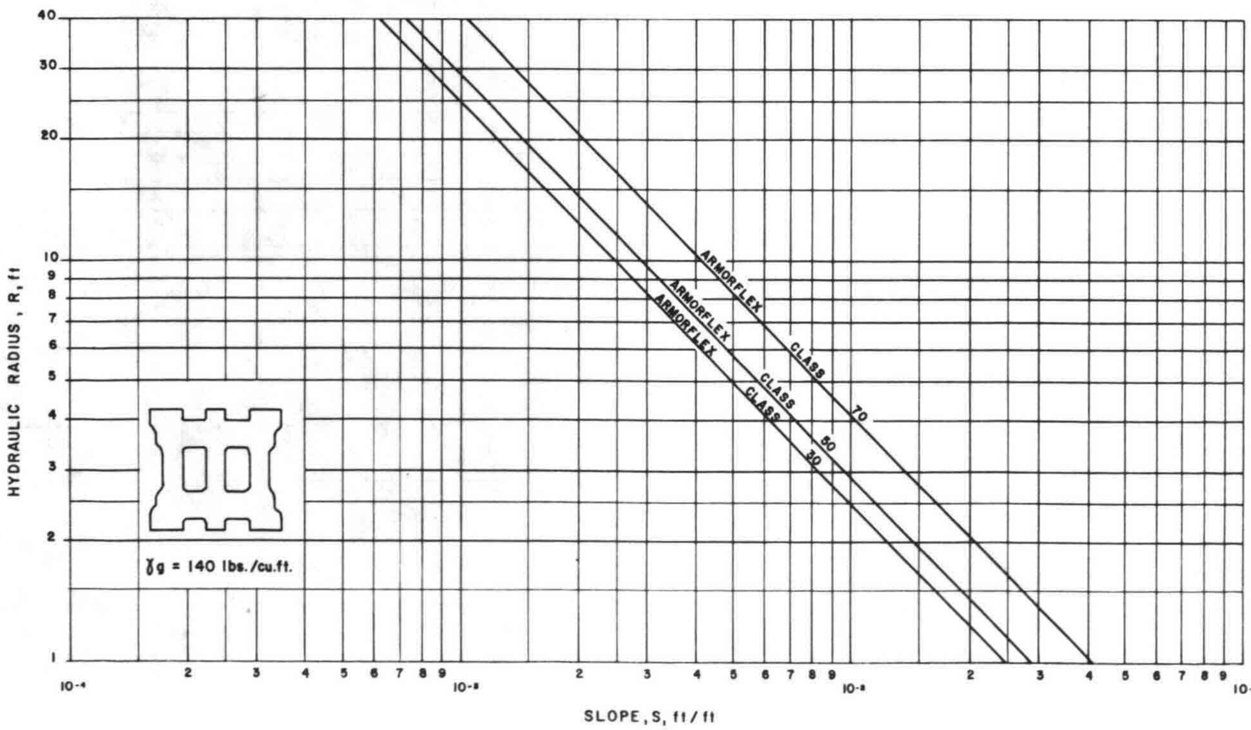


FIG. 5-6. HYDRAULIC RADIUS FOR TRAPEZOIDAL CHANNELS IN TERMS OF CLASS OF ARMORFLEX WITH OPEN CELLS AND SLOPE

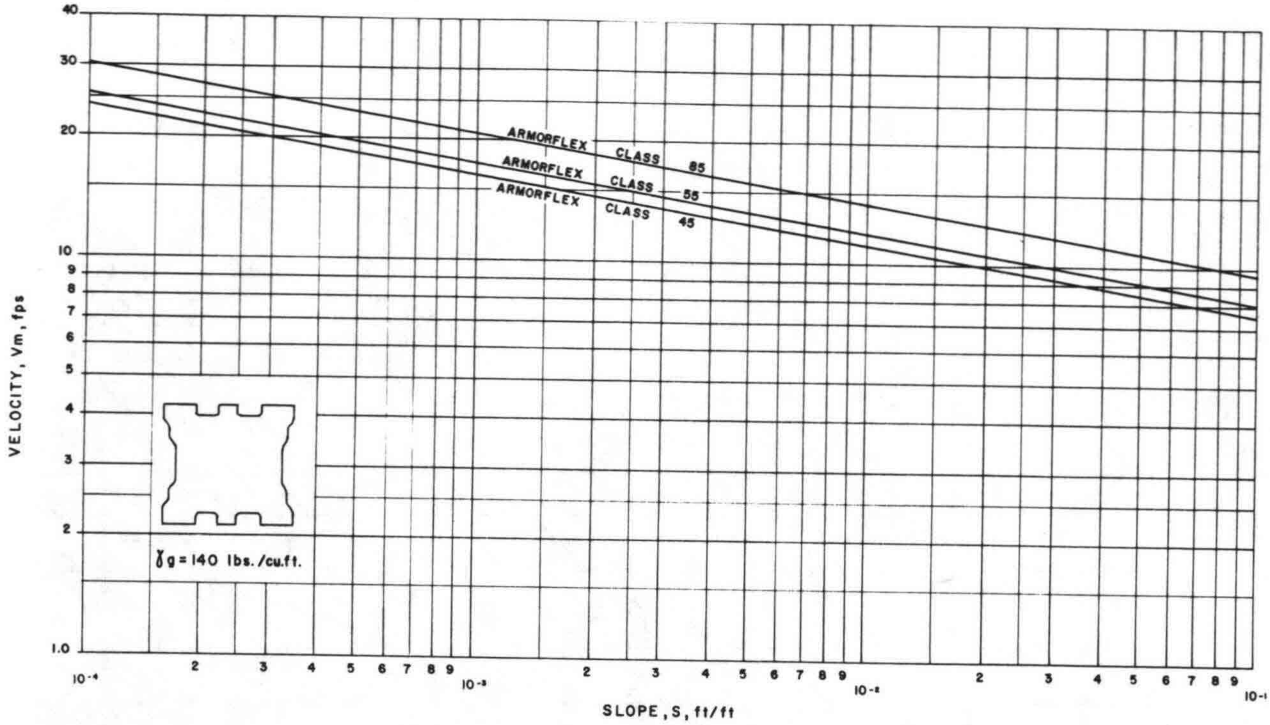


FIG. 5-7. MAXIMUM MEAN VELOCITY FOR CLASSES OF ARMORFLEX WITH CLOSED CELLS IN TRAPEZOIDAL CHANNELS WITH VARIOUS SLOPES

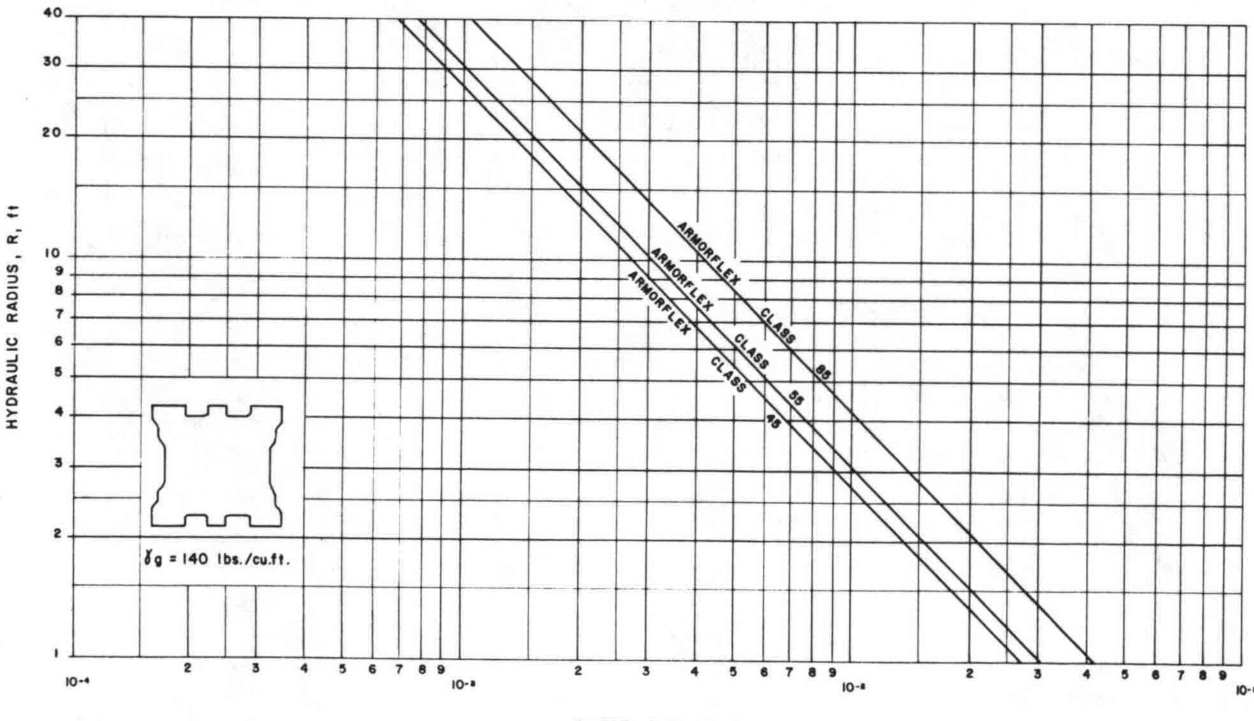


FIG. 5-8. HYDRAULIC RADIUS FOR TRAPEZOIDAL CHANNELS IN TERMS OF CLASS OF ARMORFLEX WITH CLOSED CELLS AND SLOPE

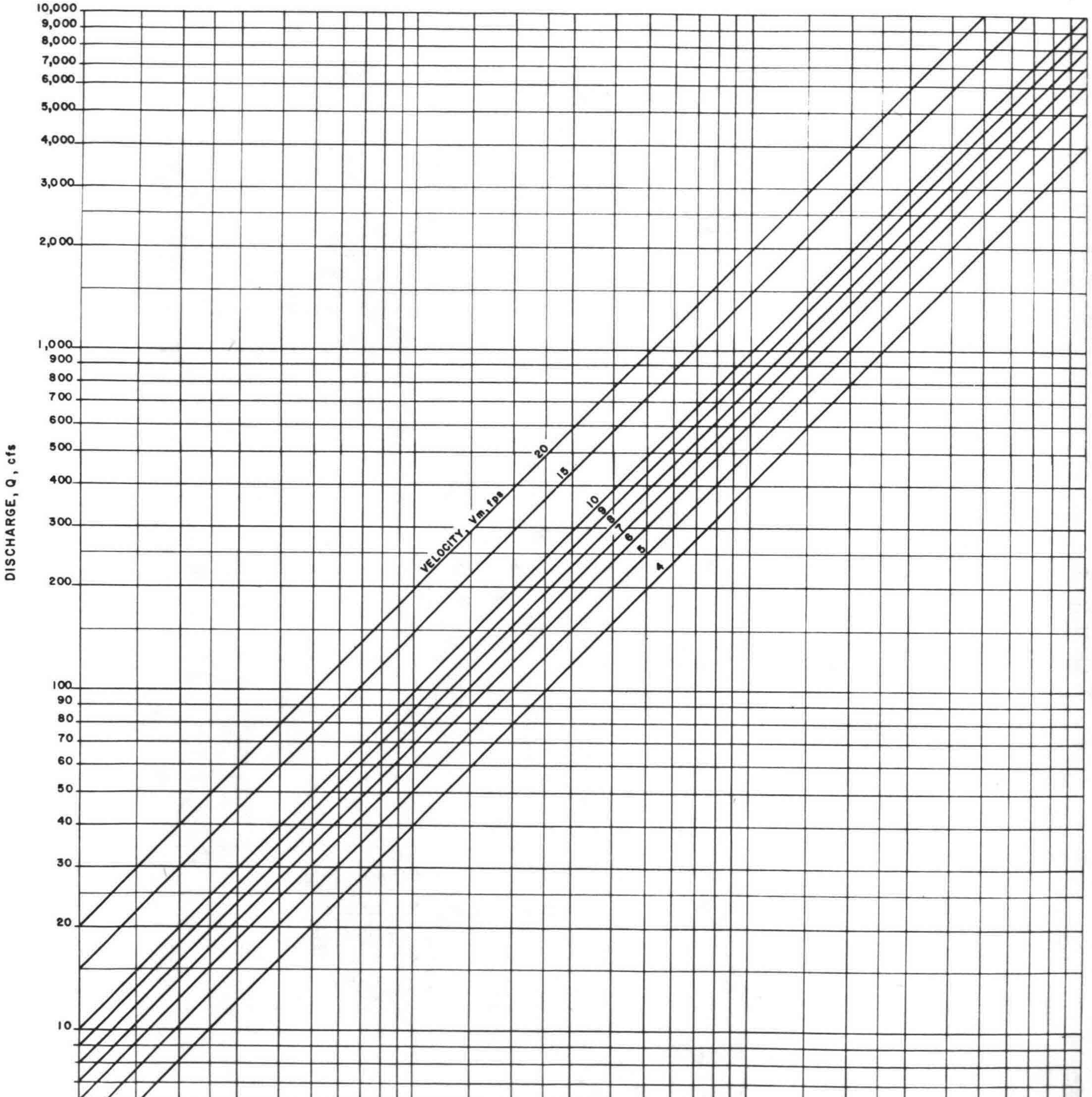


FIG. 5-9. AREA OF A TRAPEZOIDAL CHANNEL IN TERMS OF DISCHARGE AND MAXIMUM MEAN VELOCITY

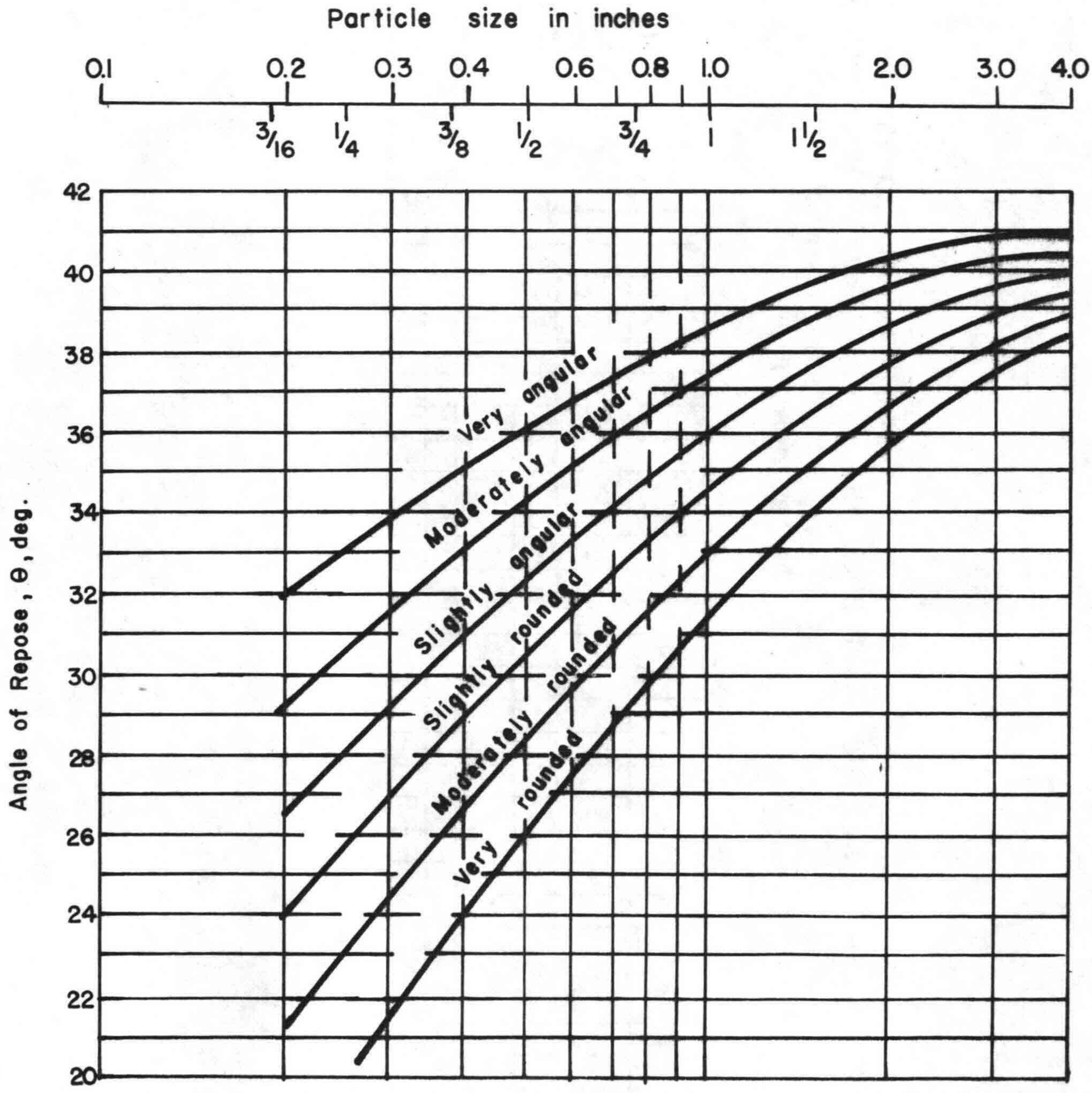


FIG. 5-10. ANGLES OF REPOSE OF CHANNEL BANK IN TERMS OF MEAN SIZE AND SHAPE OF MATERIAL

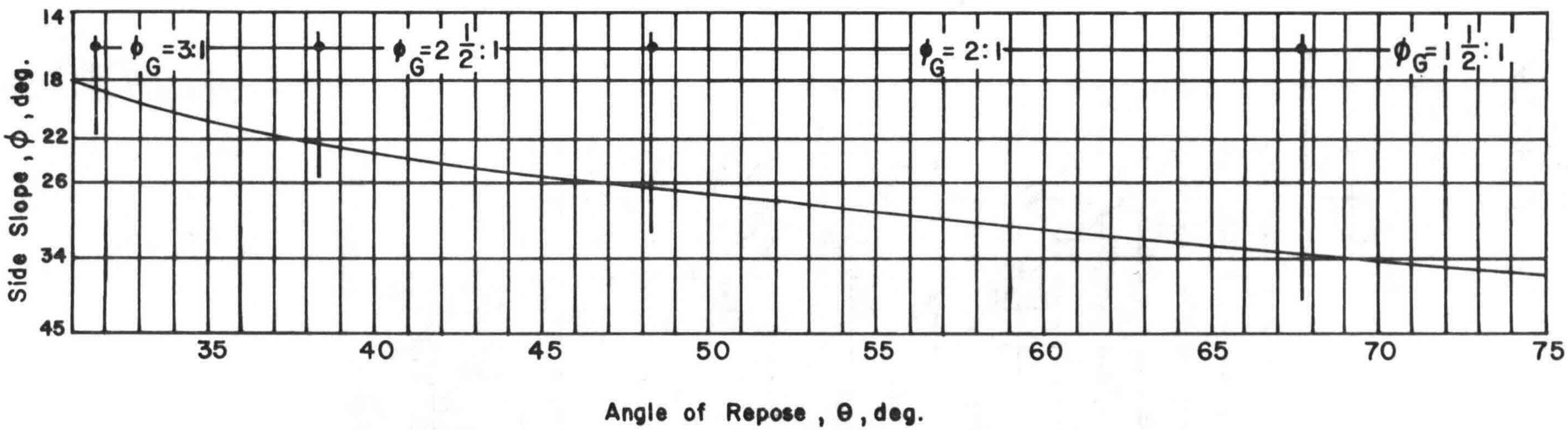


FIG. 5-11. RECOMMENDED SIDE SLOPES OF TRAPEZOIDAL CHANNELS IN TERMS OF ANGLE OF REPOSE OF CHANNEL BANK

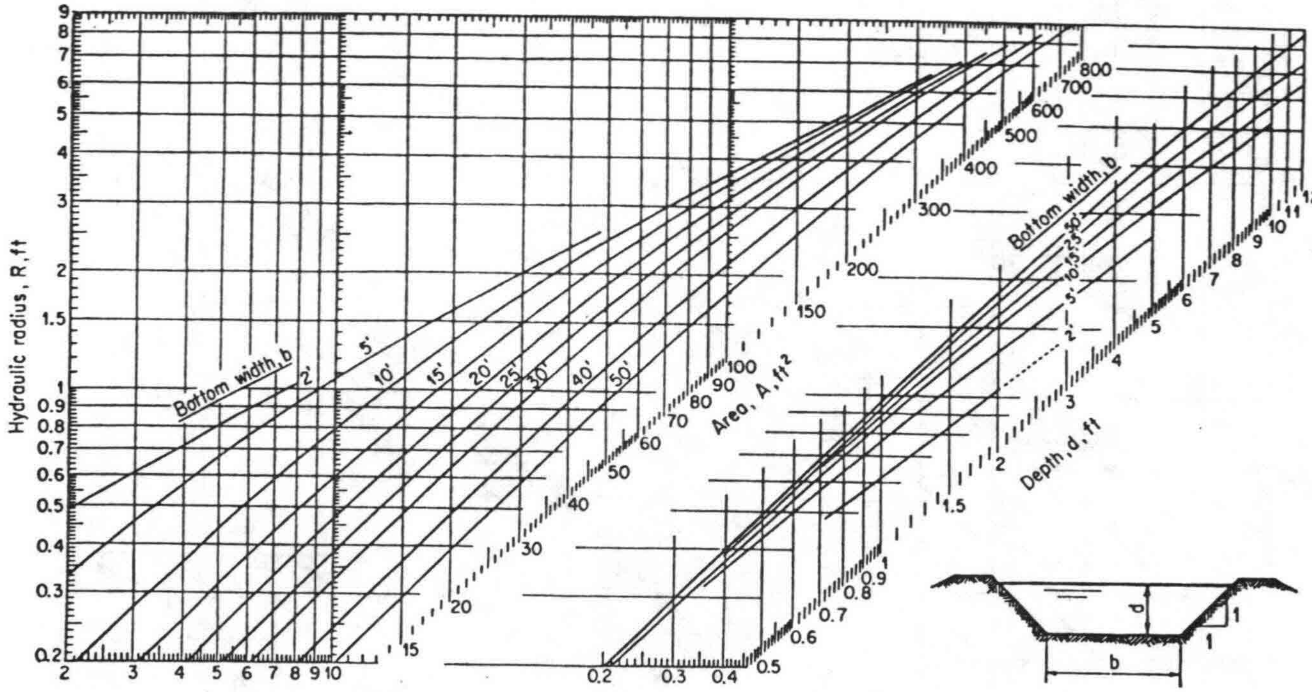


FIG. 5-12. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH 1:1 SIDE SLOPES

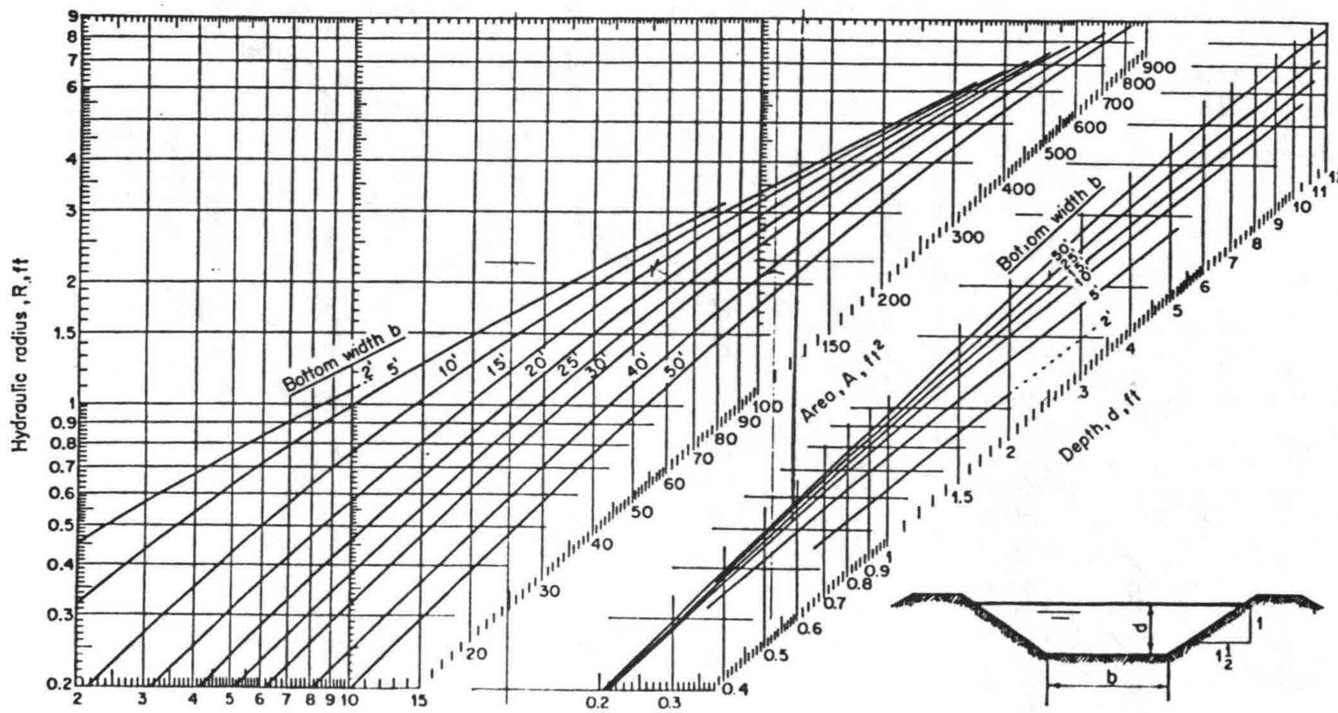


FIG. 5-13. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH 1½:1 SIDE SLOPES

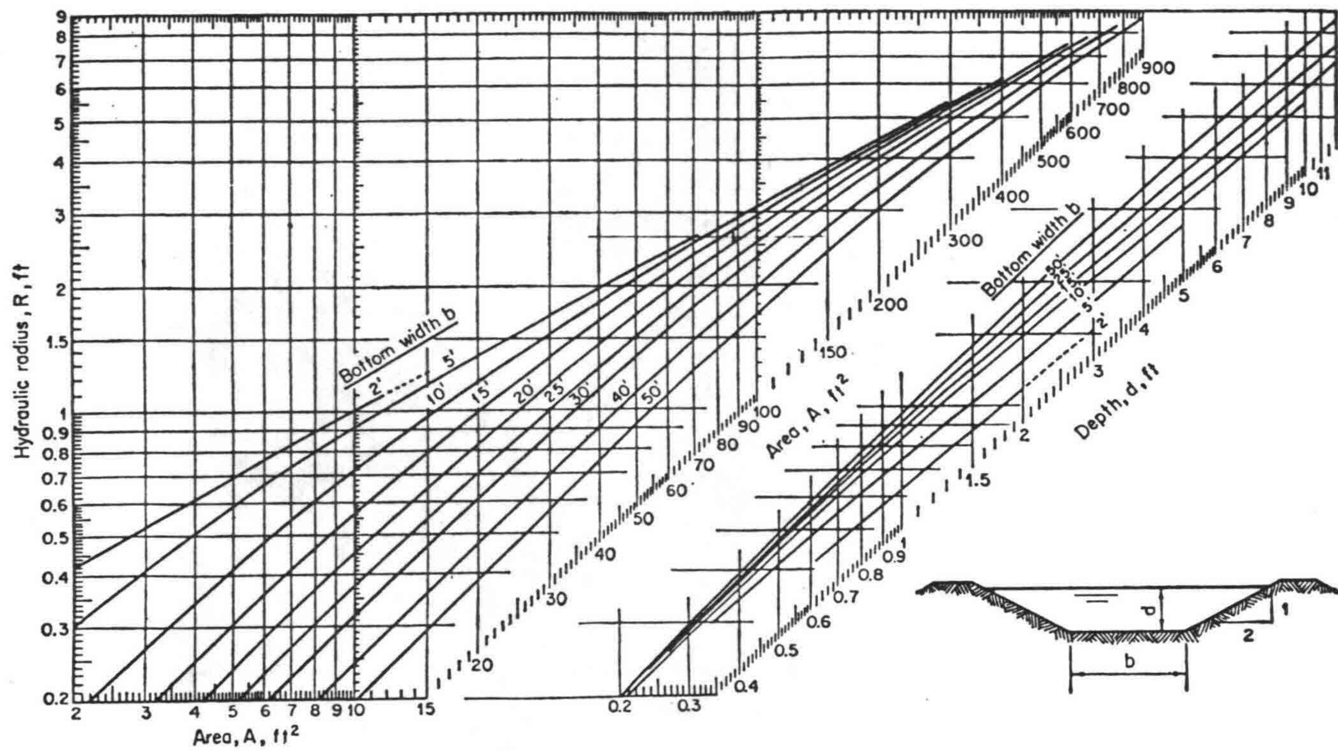


FIG. 5-14. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH 2:1 SIDE SLOPES

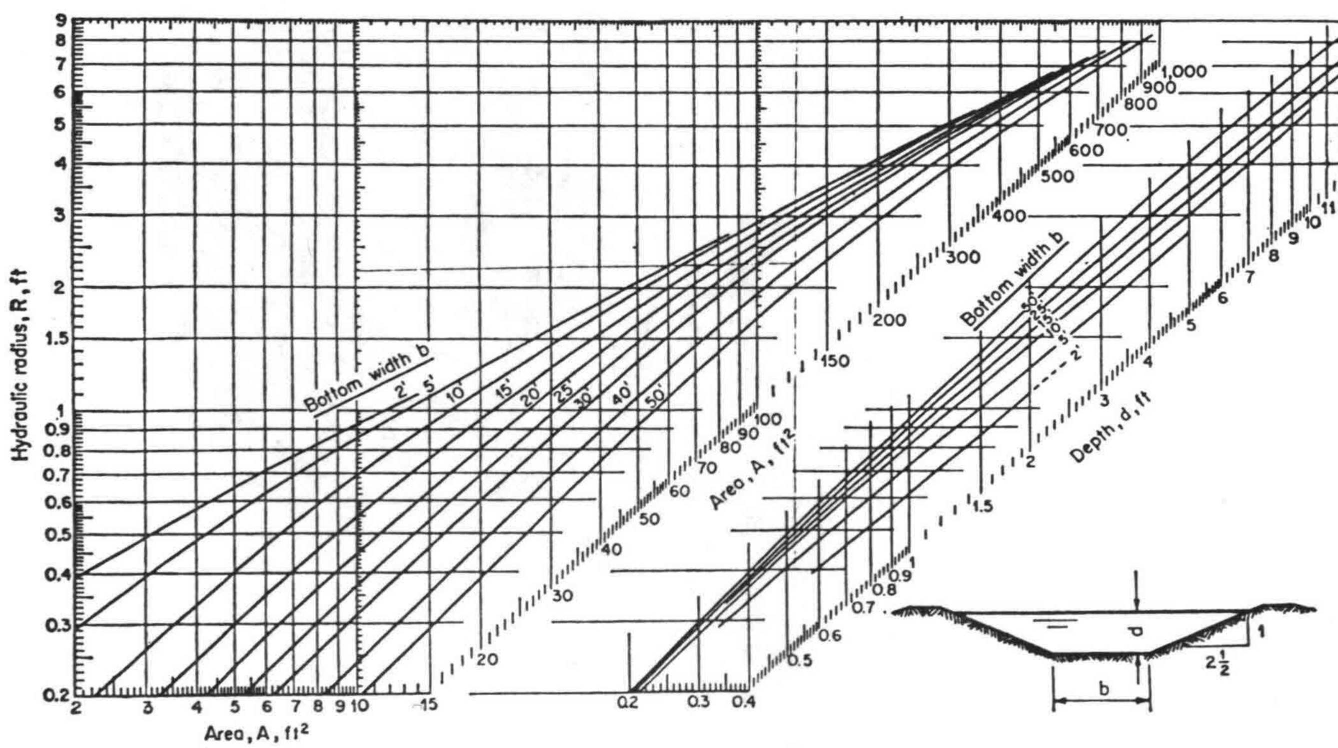


FIG. 5-15. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH $2\frac{1}{2}$:1 SIDE SLOPES

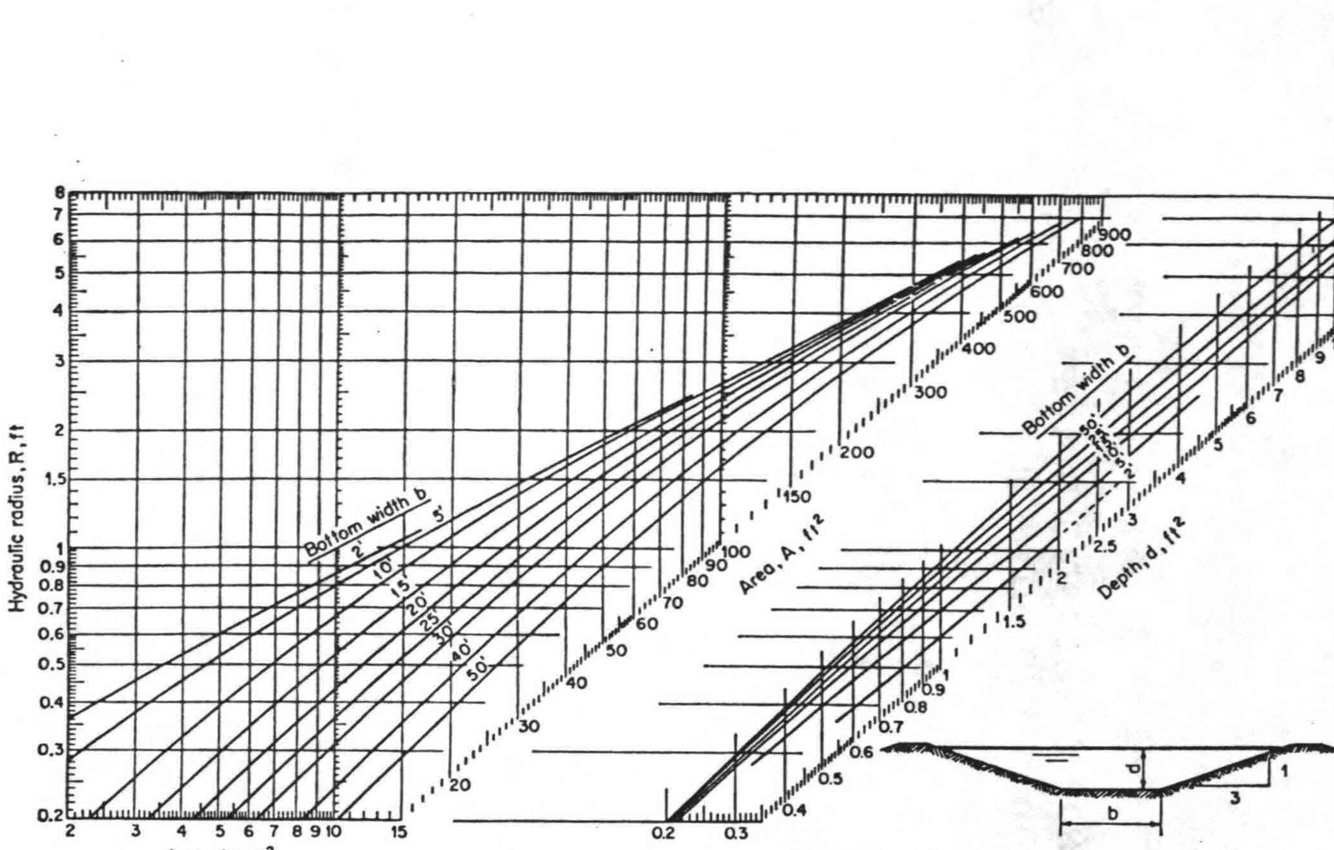


FIG. 5-16. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH 3:1 SIDE SLOPES

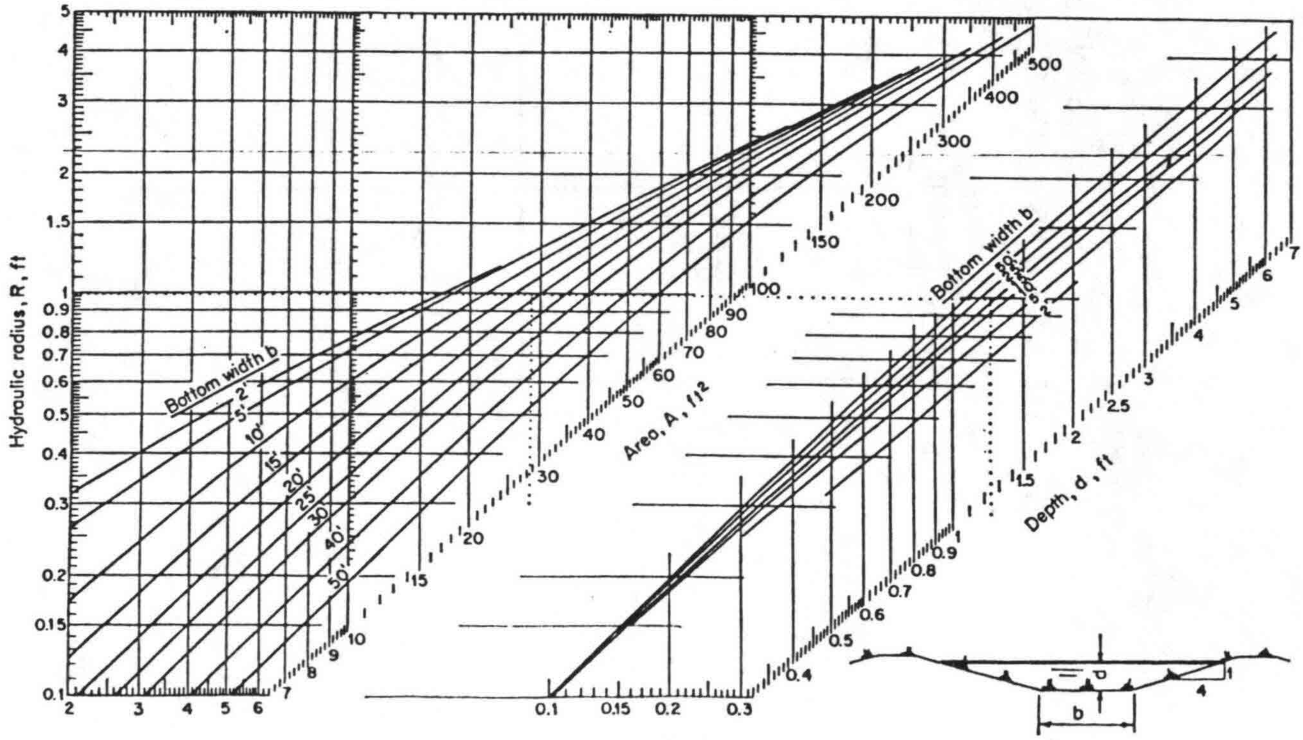


FIG. 5-17. GEOMETRY OF TRAPEZOIDAL CHANNELS WITH 4:1 SIDE SLOPES

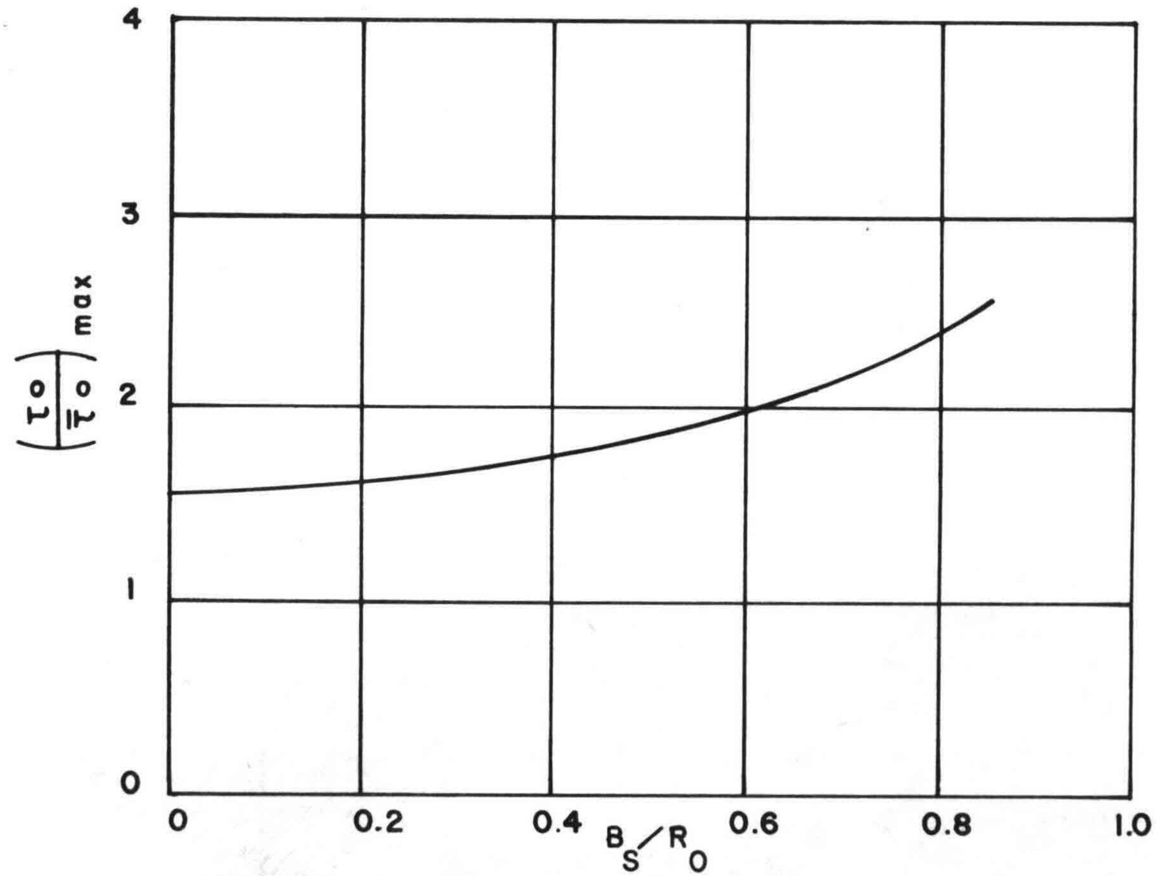


FIG. 5-18. RATIO OF MAXIMUM BOUNDARY SHEAR STRESS TO THE MEAN SHEAR STRESS FOR FLOW IN BENDS.

6.0 EXTENT OF PROTECTIVE LINING

The majority of protective lining failures can be attributed to inadequate extent of the lining and subsequent undermining.

6.1 Upper Bank Protection

The lining should be extended above design water height. The allowance for freeboard depends upon the velocities near the lining and at some locations, upon the height of waves that might be generated on the water surface, Figure 3-2. Vegetative cover established above the lining will provide considerable protection from floods, which overtop the lining.

The lining should be extended both upstream and downstream from the points of reverse curvature on the outside of a curved channel. Bank protection should begin and end at a stable feature in the channel, if practicable. Such features might be outcroppings of bedrock, natural slopes deriving erosion resistance from well established vegetation or headwalls, etc. If this is not feasible, cutoffs should be provided at the upstream and downstream terminals of the lining, Figure 6-1. If the protective lining is long, intermediate cutoffs might be required to reduce the hazard of lining failure, Figure 6-2.

6.2 Toe Trenches and Aprons

Protection against erosion at the toe of a bank is obtained by continuing the lining into a toe trench extending to bedrock or other erosion resistant stratum. However, it is seldom feasible to do so. Therefore, where the channel is composed of sand or silt, bank protection should extend a minimum vertical distance of 5 feet below the channel bottom on a continuous slope with the bank, Figure 6-3. On the outside of curves or sharp bends, where scour is particularly severe, the toe of the bank should be placed deeper than in straight reaches.

At locations where it is not practicable to excavate a toe trench and continue the protection below the channel bottom, a flexible apron should be constructed, Figure 6-4.

A flexible ARMORFLEX apron is designed to settle without fracture and to adhere to the ground as scour occurs. The length of the apron in front of the structure is generally 1-1/2 to 2 times the estimated scour depth, Figure 6-4. This depth may be estimated relying on past experience, or by the method indicated in the book "Regime Behaviour of Canals and Rivers", by Dr. T. Blench. As with excavated toes, on the outsides of curves or sharp bends, the toe of the lining should be protected by a wider apron.

When constructing an apron the bed is levelled or sloped taking care to fill large cavities with material from the channel bottom itself so that erosion will occur as uniformly as possible. If the water is relatively deep, the bed may be built up by dumping granular material until it reaches a level where the apron can be placed conveniently. In water of considerable depth, an efficient method of large scale placement is accomplished by divers.

Where the channel bottom is nonerodible, the lining should be extended to the channel bottom or preferably to a vertical distance of 1 to 2 feet below the channel bottom on a continuous slope with the bank, Figure 6-5..

For relatively narrow channels with erodible channel bottoms, the entire width of the channel should be lined, Figure 6-6..

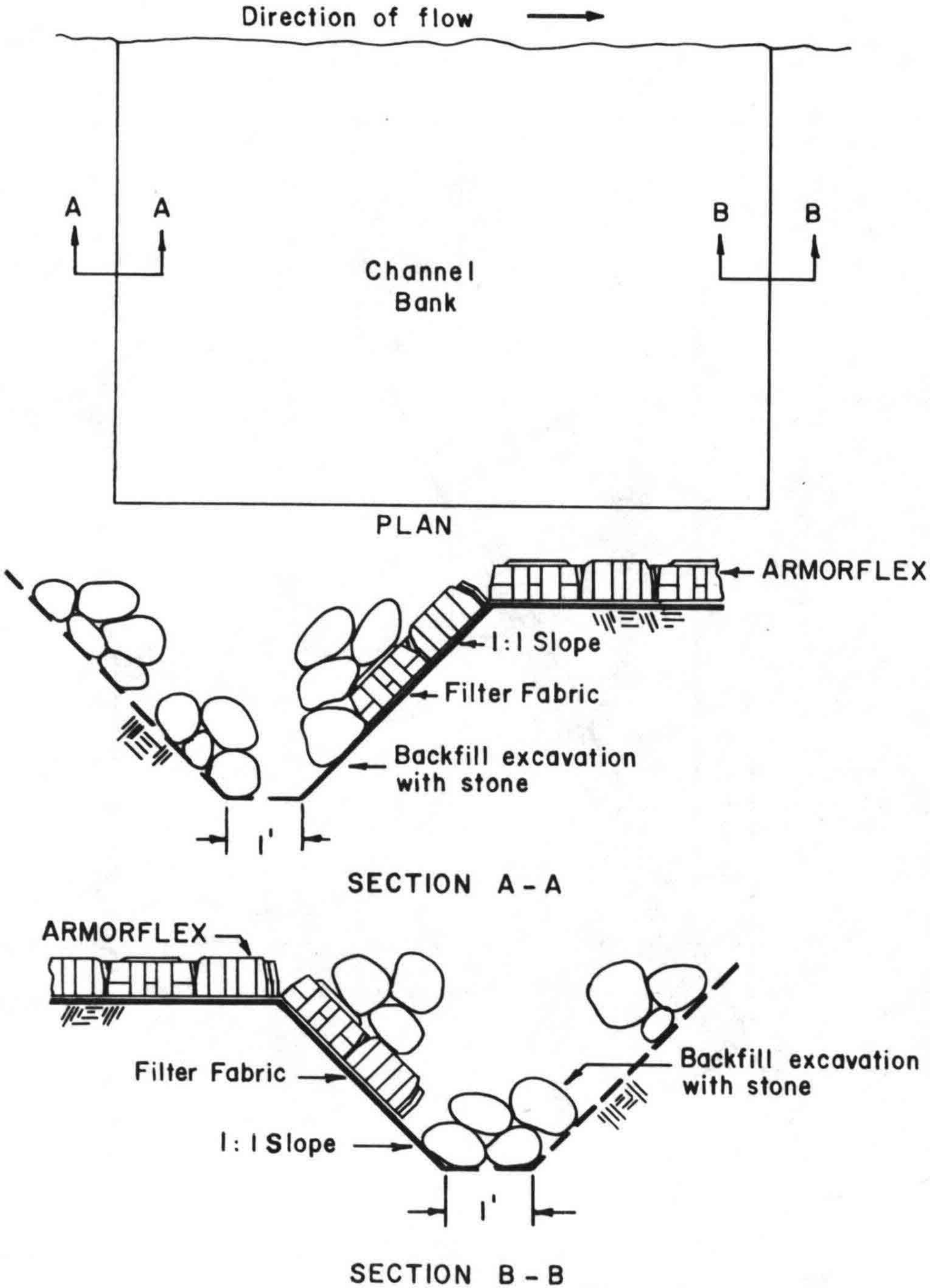


FIG. 6-1. CUTOFF AT TERMINALS OF ARMORFLEX PROTECTIVE LININGS

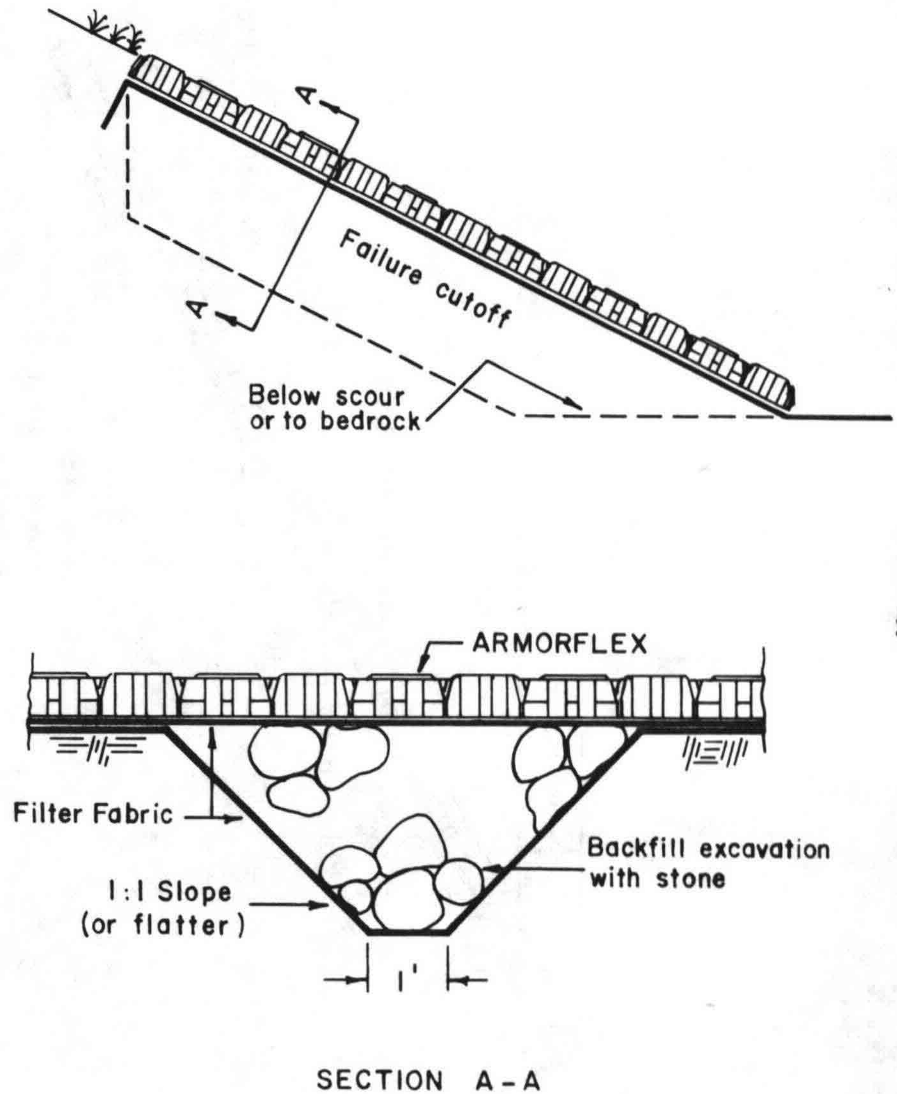


FIG. 6-2. FAILURE CUTOFF FOR ARMORFLEX PROTECTIVE LINING

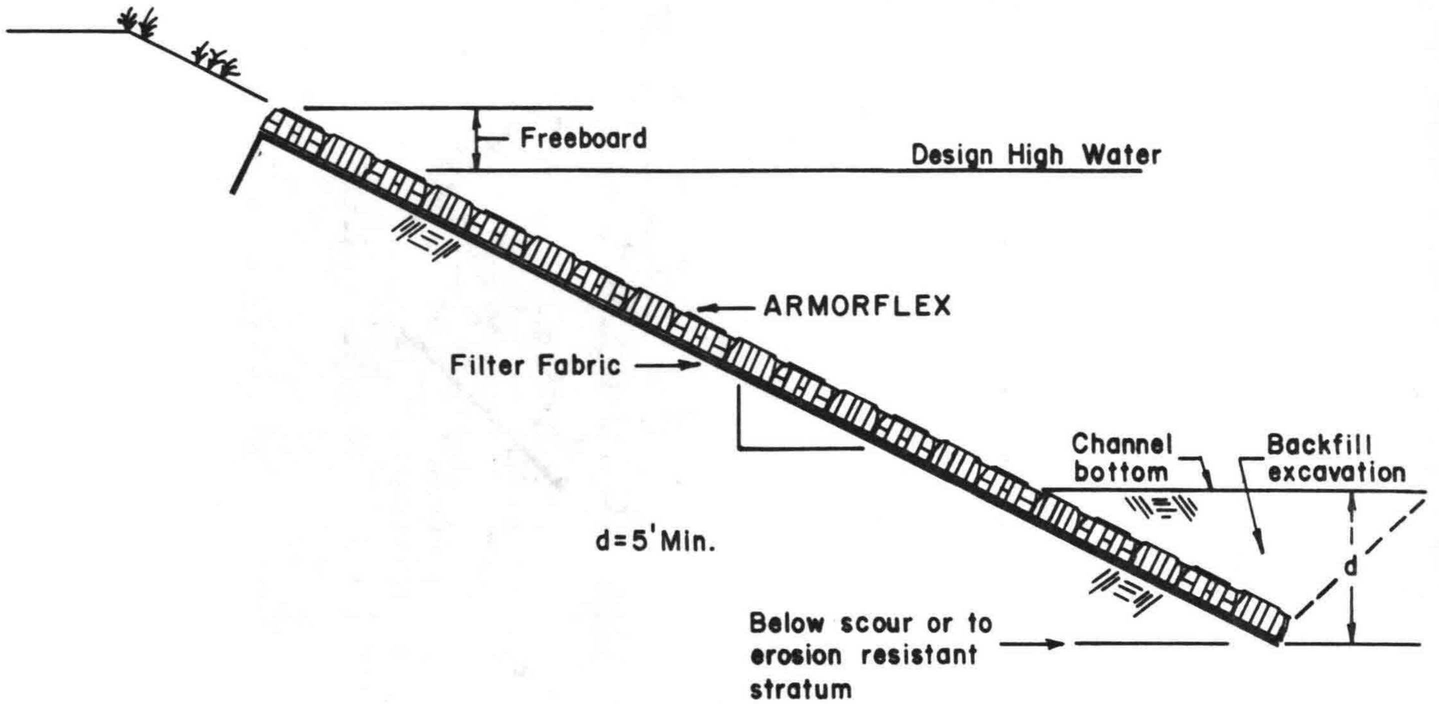


FIG. 6-3. ARMORFLEX PROTECTIVE LINING AND TOE TRENCH DETAIL

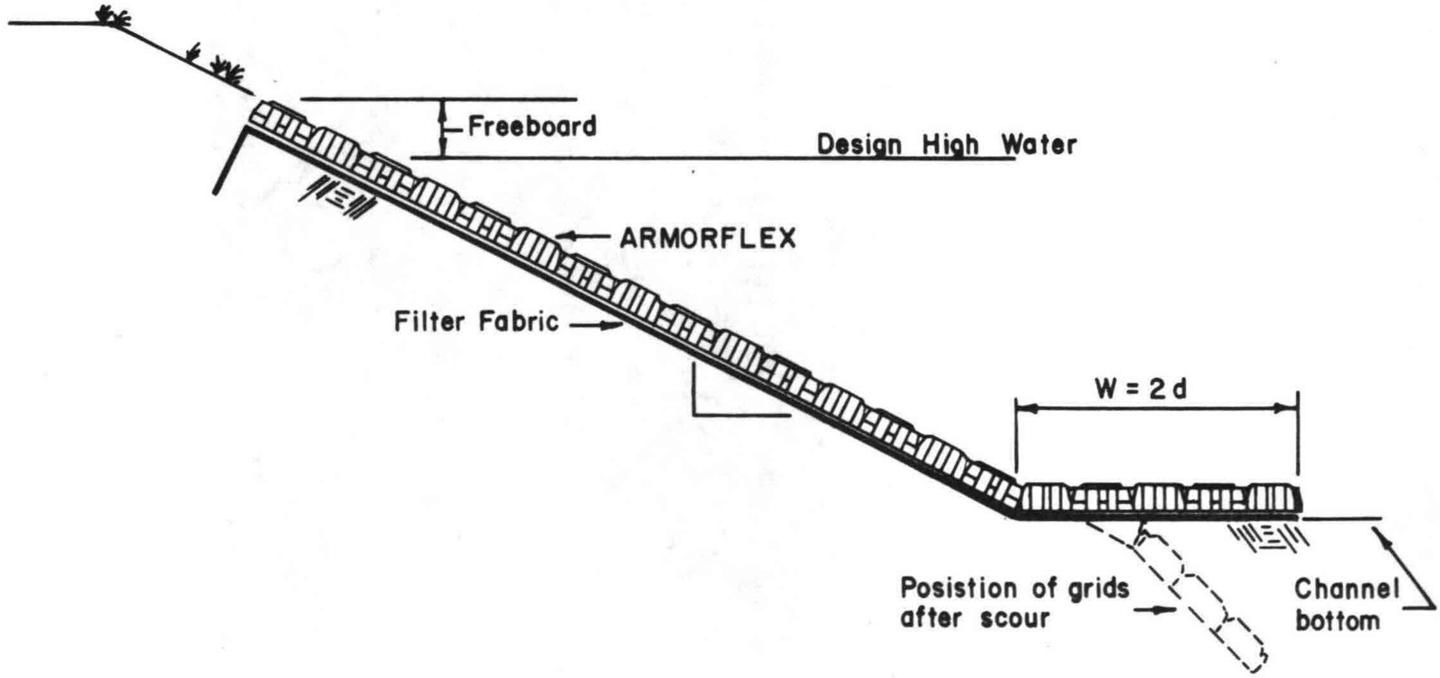


FIG. 6-4. ARMORFLEX PROTECTION LINING AND APRON DETAIL

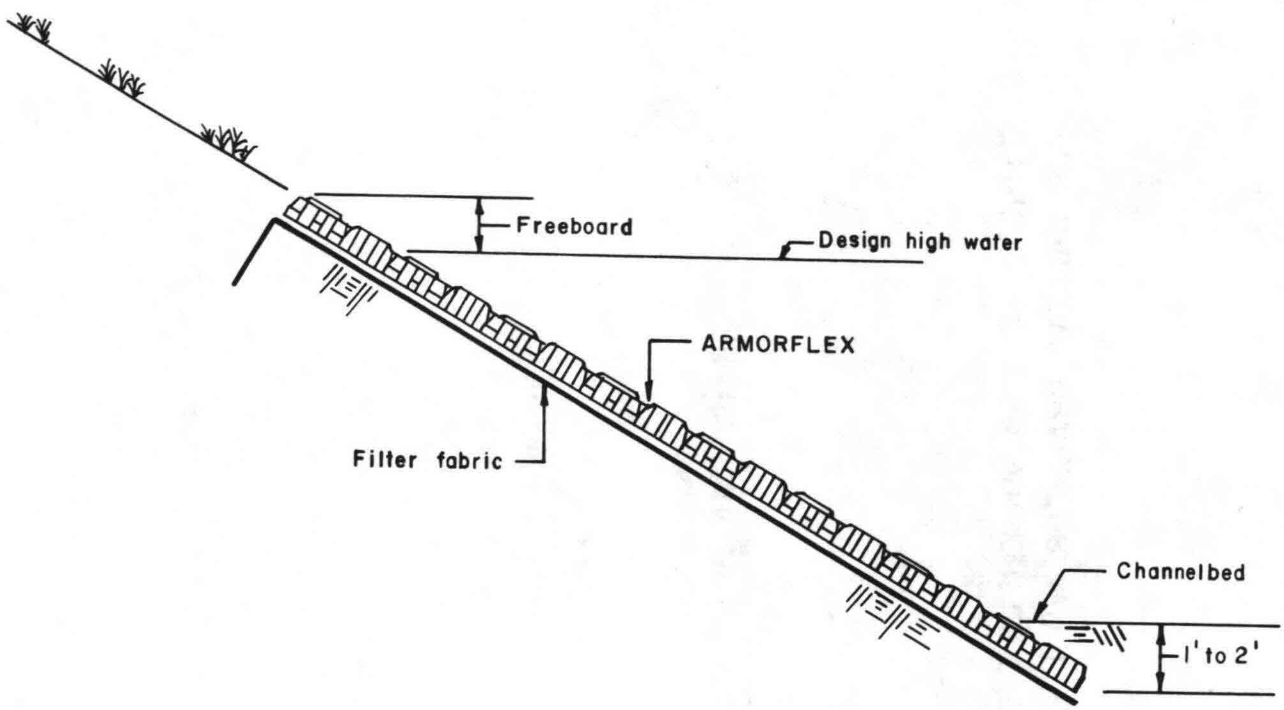


FIG. 6-5. TYPICAL SECTION, ARMORFLEX SLOPE PROTECTION FOR TANGENT REACHES WITH NONERODIBLE BEDS

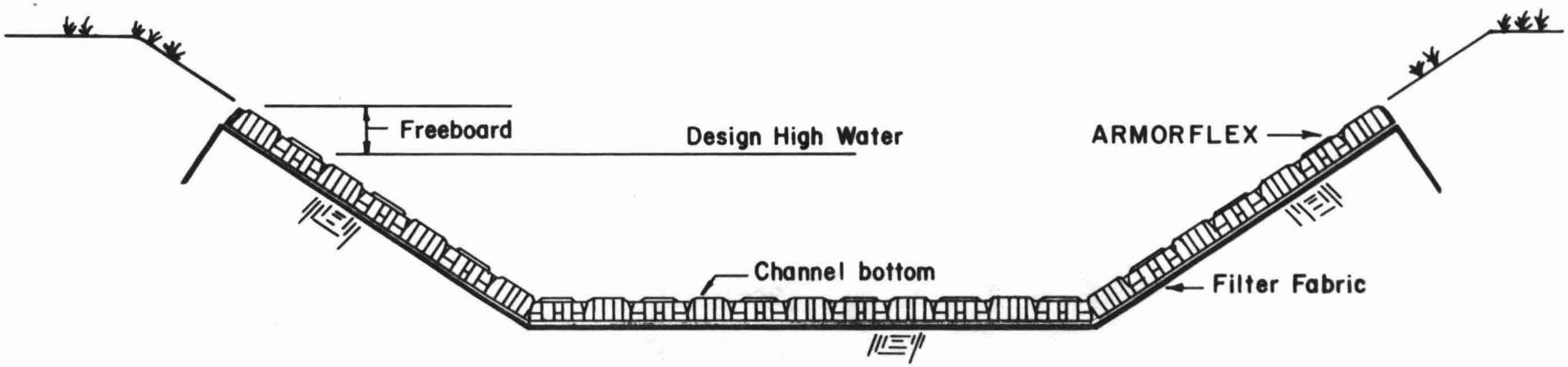


FIG. 6-6. TYPICAL SECTION, ARMORFLEX SLOPE PROTECTION FOR NARROW CHANNELS WITH EROSIVE BEDS.

7.0 SELECTION OF FILTER FABRIC

The proper filter fabric to be used in conjunction with ARMORFLEX is determined after the sieve analyses are taken of the channel body materials. After the analyses, a filter fabric is selected that will retain the soils being protected while having openings large enough to permit drainage and prevent clogging.

The selection of "Equivalent Opening Size" (EOS) and "Percent Open Area" is based on the following criteria:

a) Filter fabric adjacent to granular materials containing 50% or less by weight fines, minus 200 micron or 0.200mm material.

1. $\frac{D_{15} \text{ size of soil}}{\text{Opening size of EOS sieve}} \geq 1$

2. Percent Open Area not to exceed 35%

b) Filter fabric adjacent to all other type soils:

1) EOS no larger than the openings in the U.S. Standard Sieve No. 70 (0.210mm)

2) Percent Open Area not to exceed 25%

To reduce the chances of clogging, no fabric should be selected with a percent open area less than four (4) percent or an EOS with openings smaller than the openings of a U.S. Standard Sieve Size No. 100 (0.149mm). When possible, it is preferable to select a fabric with openings as large as allowable by the criteria.

In soils where there is a high proportion of fines, $D_{15} < 0.149$mm, or a substantially uniform small particle size, some form of supplementary filter will be necessary. This may either be a blend of medium and coarse sand, to be placed under the selected filter fabric in order to promote the development of a natural graded filter, or a non-woven filter fabric to be applied under the selected filter fabric.

Careful analyses should be conducted before using filter fabrics with soils having (1) liquid limit values greater than 40% and (2) plasticity index values greater than 15%.

8.0 BACKFILL AND VEGETATION

ARMORFLEX has an aesthetic advantage over other protective linings. ARMORFLEX with open cells enhances the appearance of the protection through its ability to encourage the re-establishment of natural vegetation. ARMORFLEX's open cells should be backfilled with gravel or crushed stone, $d_{50} < .75$ in., in areas below the water line and with soil in areas above the water line. Do not overfill the cells with soil; the best results are obtained when the soil level is kept 3/8" - 3/4" below the top of the grids.

The vegetation will provide additional stability to ARMORFLEX and to the bank area above the protective lining by consolidating the soil. Eventually the vegetative growth will completely cover the ARMORFLEX. However, vegetation will not take a permanent hold below a point on the side slope of the channel where water flows for an extended period of time, or where the flow velocity exceeds the permissible velocity for the vegetation.

8.1 Retardance Coefficient

The retardance coefficient of the vegetation varies with the mean velocity, Vm, and the hydraulic radius, R, of the channel.

There are five different degrees of retardance: very high, high, moderate, low, and very low. The classification of degree of retardance is based on the kind of vegetation and the condition of growth, as described in Table 8-1. The term "stand" used in the table, refers to the density of vegetation, or the count of vegetation, which is the number of stems per square foot.

Table 8-2. is a guide in the selection of the vegetal retardance of different conditions of stand and average length of the vegetation.

8.2 Permissible Velocity

Permissible velocity for different vegetal covers, channel slopes, and soil conditions recommended on the basis of investigation by the Soil Conservation Service are shown in Table 8-3.

8.3 Selection of Vegetation

The selection of the vegetation depends upon the climate and soil in which the vegetation will grow and survive under the given conditions. From a hydraulic viewpoint, stability and other factors should be considered. In general, a higher discharge requires a stronger vegetation.

On steep slopes, bunch grasses, such as alfalfa, lespedeza, and kudzu, will develop channeling of the flow and, hence, are unsatisfactory. It is recommended that fine and uniformly distributed sod-forming grasses, such as Bermuda, Kentucky Bluegrass, and smooth broom be used. For fast establishment of vegetation, Bermuda grass and Weeping Love grass are recommended. Sometimes, annuals are used temporarily until permanent covers by native grasses are established.

TABLE 8-I. CLASSIFICATION OF DEGREE OF RETARDANCE FOR VARIOUS KINDS OF GRASS

Retardance	Cover	Condition
A Very high	Weeping love grass	Excellent, stand, tall (av. 30 in.)
B High	Kudzu Bermuda grass Weeping love grass Lespedeza Alfalfa Weeping love grass Kudzu	Very dense growth, uncut Good stand, tall (av. 12 in.) Good stand, tall (av. 24 in.) Good stand, tall (av. 19 in.) Good stand, uncut (av. 11 in.) Good stand, mowed (av. 13 in.) Dense growth, uncut
C Moderate	Crab grass Bermuda grass Common lespedeza Kentucky bluegrass	Fair stand, uncut (10 to 48 in.) Good stand, mowed (av. 6 in.) Good stand, (av. 11 in.) Good stand, (6 to 12 in.)
D Low	Bermuda grass Common lespedeza Lespedeza sericea	Good stand, cut to 2.5 in. height Excellent stand, uncut (4-5") Very good stand before cutting
E Very low	Bermuda grass Bermuda grass	Good stand, cut to 1.5 in. Burned stubble

TABLE 8-2. GUIDE IN SELECTION OF VEGETAL RETARDANCE

Stand	Average length of grass, in.	Degree of retardance
Good	>30 11-24 6-10 2-6 <2	A Very high B High C Moderate D Low E Very low
Fair	>30 11-24 6-10 2-6 <2	B High C Moderate D Low E Very low

TABLE 8-3. PERMISSIBLE VELOCITIES FOR CHANNELS LINED WITH GRASS

Cover	Slope Range %	Permissible velocity fps	
		Erosion-resistant soils	Easily eroded soils
Bermuda grass	0-5 5-10 >10	8 7 6	6 5 4
Buffalo grass, Kentucky bluegrass, smooth brome, blue grama	0-5 5-10 >10	7 6 5	5 4 3
Grass mixture	0-5 5-10 >10	5 4	4 3
Lespedeza sericea, weeping love grass, ischaemum (yellow bluestem), kudzu, alfalfa, crabgrass	0-5 5-10 >10	3.5	2.5
Annuals-used on mild slopes or as temporary protection until permanent covers are established, common lespedeza, Sudan grass	0-5 5-10 >10	3.5	2.5

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