# EROSION CONTROL

## SYNOPSIS

The control of erosion as related to highways was discussed in a series of papers at a session of the Departments of Design and Maintenance with the Joint Committee on Roadside Development

Some new hydraulic data relating to flow of water in channels lined with vegetation were presented by Howard L Cook Values of n in the formulas of Manning and Kutter, called the coefficient of retardance in the paper, were determined for Bermuda grass linings, and a formula was derived for calculating the capacity of small channels lined with this grass Tests were also made to determine the characteristics of the rank vegetations often used in "meadow strips" Mr Cook points out that since retardance coefficients for vegetal linings cannot be constants, values will need to be determined experimentally under a wide range of conditions for a large number of linings He also presented data relating to the capacities of notches used in drop structures in ditches

In their paper on erosion control on highway slopes, John E Snyder and Charles R Hursh called attention to the fact that deterrents to the protection of banks by natural growth are instability of exposed soil due to freezing and thawing and in many cases to insufficient soil moisture The use of mulches is recommended to be of great value in low cost erosion control

Professor J S Crandell in describing highway erosion control methods in Illinois, stressed particularly the necessity for cooperation by land owners in securing proper methods of planting to conserve moisture and prevent erosion He also called attention to the fact that design of many engineering features such as culverts, bank slopes and grade lines is important in erosion control and should be fully considered by highway engineers

In summarizing the discussion Arnold Davis stated that correlation of slope design with highway needs is a first step toward economic and permanent erosion control, also that correlation of farm land water disposal systems with those of the highways is important He noted that classification of soils on the basis of erodibility for the use of engineers is being made

## SOME NEW HYDRAULIC DATA

By Howard L Cook

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Hydraulic investigations form an important part of the comprehensive research program of the Soil Conservation Service One series of the hydraulic studies underway was instituted for the express purpose of solving the numerous practical problems confronting the field engineers of the Service Since much of the data obtained in these studies are directly applicable to the design of highway drainage systems it is proposed to briefly summarize the more pertinent results in this paper

The studies sufficiently far advanced to justify discussion here are

(1) Study of the effect of vegetal linings on channel capacities

(2) Determination of allowable velocities for vegetal channel linings

(3) Determination of the capacities of rectangular notches in thick walls

Most of the data presented herein were obtained at an outdoor hydraulic laboratory located near Spartanburg, S C[1] The work at this project was formerly supervised by Mr F B Campbell Mr W O Ree has been Project Supervisor for the laboratory since Mr Campbell's resignation on November 1, 1938. All of the research reviewed here was carried

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[1] This laboratory is described in Civil Engineering, Vol 8, No 10, October, 1938

out under the general direction of Mr. C. E Ramser, Head, Section of Watershed and Hydrologic Studies The hydraulic research of this Section is under the immediate direction of the writer All research of the Soil Conservation Service is administered by Dr M L Nichols, Acting Chief, Division of Research

### THE EFFECT OF VEGETAL LININGS ON CHANNEL CAPACITIES

To be acceptable to farmers of ordinary means, soil and water conservation practices must be simple and cheap Inasmuch as the cost of handling storm run-off constitutes a major item of expense in conservation programs, much effort has been directed toward reducing the cost of farm hydraulic works This has led to considerable experimentation with vegetal channel linings The studies made under controlled conditions at the Spartanburg laboratory have yielded especially valuable results Preparatory to the discussion of these results, a few remarks on flow formula and retardance coefficients are in order

#### *Flow Formulae and Retardance Coefficients*

In the United States the two formulas most widely used in the design of open channels are

The Kutter formula

$$V = \frac{41\ 65 + \dfrac{0\ 00281}{S} + \dfrac{1\ 811}{n_k}}{1 + \dfrac{n_k}{\sqrt{R}}\left(41\ 65 + \dfrac{0\ 00281}{S}\right)}\sqrt{RS},$$

and the Manning formula.

$$V = \frac{1\ 486}{n_m} R^{2/3} S^{1/2}$$

In these formulae

$V$ = Mean velocity in feet per second

$R$ = Hydraulic radius in feet.

$S$ = Slope of channel where flow is uniform (slope of energy grade line where flow is non-uniform).

$n_k$ = Kutter's $n$

$n_m$ = Manning's $n$

The flow impeding characteristics of the channel linings are supposed to be represented in the above formulae by the coefficients $n_k$ and $n_m$ These are usually called "roughness" coefficients, but this term is not sufficiently descriptive of their true nature, for they must account for:

(a) The reduction in the effective area of channel cross-section due to the presence of the lining;

(b) The turbulence producing power, or "hydraulic roughness," of the lining, and

(c) The departure of the formula from the true law of flow for the given channel

It is obvious that when used in connection with vegetal linings the term "roughness coefficient" becomes inadequate For lack of a better name $n_k$ and $n_m$ will here be called "retardance coefficients"

When water flows at slight depths in a channel lined with rank vegetation a large proportion of the cross-section is taken up by the plants Moreover, the numerous stems and leaves extending into the flowing water produce excessive turbulence in the flowing mass These two actions serve to produce a high retardance coefficient in either the Kutter or Manning formula

As the depth of flow increases the following occurs

(1) The percentage of the cross-section taken up by the vegetation decreases and the retardance coefficient is thus reduced This reduction would take place even though no change occurred in the lining itself—in other words, even if the plants were replaced with rigid replicas

(2) Because of the increases in velocity and depth the bending moments exerted on the plants are in-

creased. When these become large enough, the plants are bent over and flattened against the bed of the channel. The consequent sudden reduction in the percentage of cross-section occupied by vegetation is accompanied by a sharp decrease in the turbulence producing power of the lining and the two effects together bring about a striking decrease in the retardance coefficients.

It is apparent from the foregoing that the retardance coefficients for vegetal linings must necessarily change with depth of flow. Taking a slightly different viewpoint, the retardance coefficient for a given vegetal lining may be said to depend upon the flow condition to which it is subjected as well as upon the character of the vegetation. In other words, a lining of erect vegetation subjected to a flow which flattens the plants becomes, hydraulically, an altogether different lining.

Since retardance coefficients for vegetal linings cannot be constants, research must be directed toward determining the values of the coefficients under a wide range of conditions and for a large number of vegetations.

The bending moment exerted upon a plant by flowing water depends upon the shape and size of the plant, the velocity of flow and its variation with distance from the bed, and the depth of flow when the height of the plant exceeds the depth of water—or the height of plant when this is greater than the water depth. It can be shown that for a given type of vegetation and a specified channel slope the bending moments exerted by shallow flows will depend primarily upon the hydraulic radius. In a given channel, therefore, the degree of bending of the vegetation will be a function of the hydraulic radius and there should exist some relation between the retardance coefficients and this quantity. Proceeding on this assumption the retardance coefficients for the test channels were plotted against the hydraulic radius for presentation in this paper.

*Bermuda Grass Linings*

Because of the high degree of protection against scour afforded by Bermuda grass, especially complete studies of this vegetation are being made at the Spartanburg laboratory. The results of tests on five channels are now available. The principal characteristics of these channels and the number and length of test reaches are given in Table 1.

TABLE 1

| Channel Designation | Bed Slope | Bottom Width | Test Reaches | |
|---|---|---|---|---|
| | | | Number | Length of Each |
| | *percent* | *feet* | | *feet* |
| B1–2 | 20 | 1.5 | 3 | 10 |
| B1–3 | 10 | 1.5 | 3 | 10 |
| B2–7 | 3 | 4.0 | 4 | 10 |
| B2–8 | 3 | 1.5 | 4 | 10 |
| Supply canal | 0.1 | 4.0 | 1 | 100 |

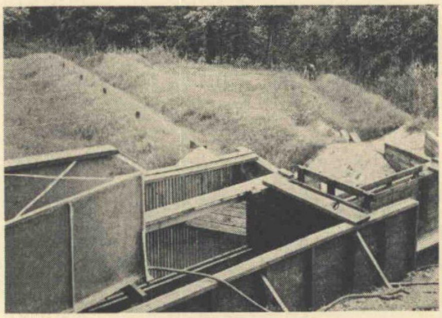

**Figure 1. View of Three of the Test Channels Used in the Experiments on Bermuda Grass Channel Linings. Forebays and measuring flume in the foreground.**

All of these channels had side slopes of 1 on $1\frac{1}{2}$ and were constructed in Cecil clay loam soil. The first four channels were built especially for experimental work and will be referred to as test channels. Figure 1 is a photograph of a set of these test channels. The channel designated "supply canal" was constructed primarily to conduct the water to the test channels and the determinations of retardance coefficients for this channel were carried out incidentally.

All of the channels were lined by sodding the entire area to be in contact with flowing water. The vegetal linings of all of the channels were practically identical at the time of the tests. The grass was not cut before the tests and was in a condition of maximum rankness.

Each of the channels was subjected to a series of steady test flows. The tests were separated by intervals of time varying from several hours to several days. The duration of a single test was usually about thirty minutes. The first test in each series was made with a flow of about 5 cu. ft. per sec. and succeeding tests were made at discharges progressively increasing in increments of about 5 up to 30 cu. ft. per sec. or more. Each channel was usually subjected to seven or eight individual tests.

During each test transverse profiles of the water surface were made at the ends of each test reach. Transverse profiles of the bottom of the channel were made before and after each test at the same sections. The test reaches occupied a continuous length of channel, that is, they had common end sections.

For each test the mean retardance coefficient for all of the test reaches used was calculated. These coefficients have been plotted on Figure 2 against the corresponding mean values of $R$.

From the data shown on Figure 2 there was derived the following approximate expression for Manning's $n$ for long Bermuda grass linings:

$$n_m = \frac{0.007}{R^{1.1} S^{0.43}}$$

The curves appearing on Figure 2 were derived from this formula.

The flow in the channels was not strictly uniform and the slope of the energy grade line was not the same as the slope of the bed. In the relatively flat supply canal the differences between the effective slope and the bed slope were particularly large and erratic. This partially accounts for the scatter of the values of $n$ for this channel.

Retardance coefficients taken from the curves of Figure 2 should be considered rough approximations only and should not be used outside the range of the experiments.

Given the above expression for $n_m$ it is, of course, possible to derive an approximate velocity formula for the test channels. Substitution of the equation for $n_m$ in the Manning formula yields:

$$V = 212\, R^{1.77} S^{0.93}$$

This formula may be used directly for calculating the capacity of small channels lined with long Bermuda grass. However, care should be taken not to use it outside the range of the data on which it is based. More specifically it is suggested that the following restrictions be placed upon its use.

1. Do not use when the equivalent $n_m$ would be less than 0.04, that is, when the product $R^{1.1} S^{0.43}$ *exceeds* a value of 0.175.
2. Do not use when the quantity $R^{1.1} S^{0.43} (1 + 3R)$ is *less* than 0.175.
3. Do not use when $R$ exceeds 1.5.
4. Do not use when excessive internal impact losses are likely to occur, that is, for steep channels in which the depth will be sufficient to produce excessively "rough" or "white water" flow.

Until further information becomes available, it is recommended that in the design of channels for which the calculated value of $n_m$ is less than 0.04, ($R^{1.1} S^{0.43}$ exceeds 0.175), the Manning formula be used with a retardance coefficient of 0.04. For this value of $n_m$ the Manning formula becomes

$$V = 37.2\, R^{\frac{2}{3}} S^{\frac{1}{2}}$$

The reason for the limitation number four is illustrated by the dotted curves of Figure 2 It will be noted that for the 10 percent channel the retardance coefficient appears to reach a minimum value at a hydraulic radius of about 0.6 foot. The retardance coefficient for the 20 percent channel begins to increase when the hydraulic radius exceeds a value slightly over 0 4 foot These departures from the general trend of the remainder of the data are thought to be caused principally

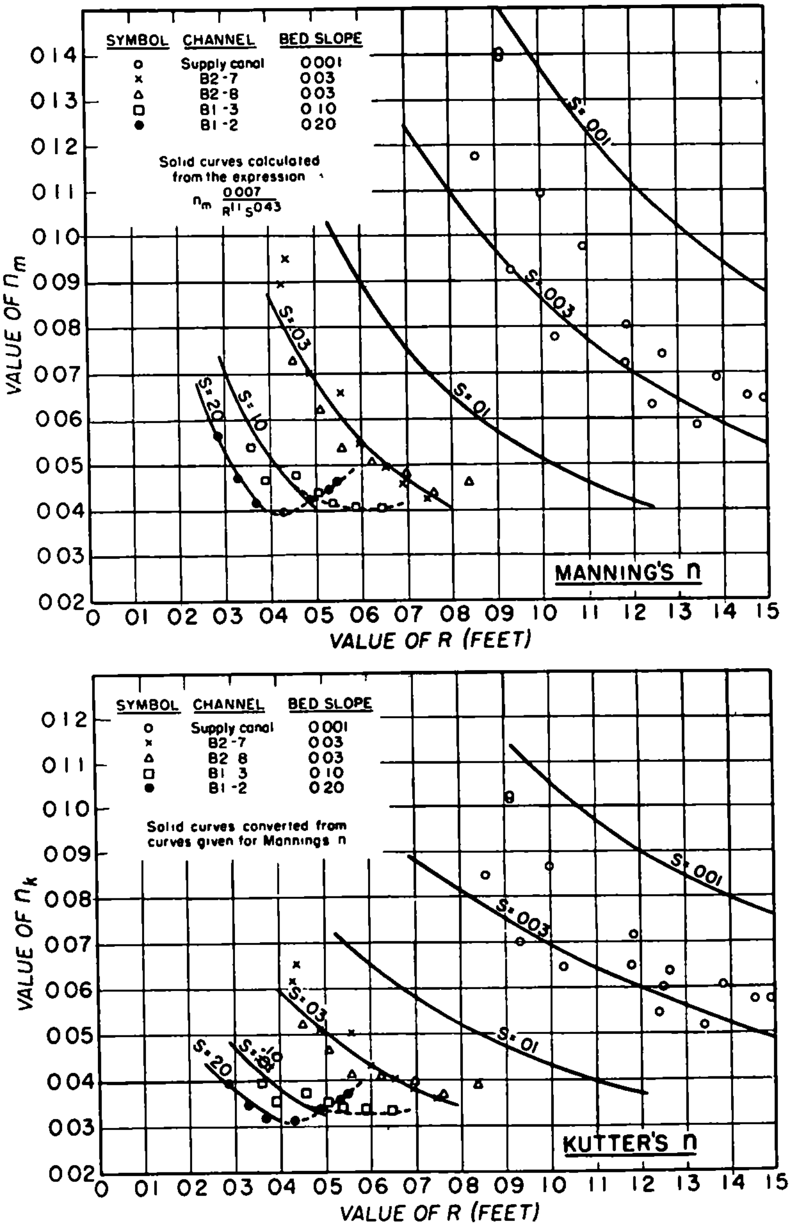

**Figure 2. Retardance Coefficients for Channel Linings of Long Bermuda Grass**

by the excessive dissipation of energy by impact in the deeper flows on these steep slopes.

The values of the retardance coefficients for exceptionally steep channels are also influenced by the "bulking" of the flow with entrainment of air. In the tests reported the percentages of air entrained were probably not large enough to affect materially the retardance coefficients.

In order to evaluate the effect of clipping on the retardance coefficients for Bermuda grass, the lining of the supply canal was cut to a height of about four inches. Subsequent tests indicated that Manning's *n* had been reduced to about two-thirds of its former value. Further tests on short grass are now underway.

### *Meadow Strip Vegetations*

A series of tests were made to determine the characteristics of the rank vegetations often used in "meadow strips." These are extremely broad, shallow channels, used both as drainageways for storm flows and for hay production. The characteristics of the test channels are given as follows:

Shape: Trapezoidal
Bottom width: 2 feet
Side slopes: 1 vertical to 3 horizontal
Length: 60 feet
Slope: 6%
Soil: Cecil sandy loam topsoil
Linings:
  Channel No. B2–1; Lespedeza sericea
  Channel No. B2–2; Common lespedeza
  Channel No. B2–3; Sudan grass

Figure 3 is a photograph of these channels taken during a test of the Sudan grass lining.

The tests of these channels were carried out in practically the same way as those of the Bermuda grass channels. Three 10-ft. test reaches were used in each channel. The test flows varied from less than 5 to roundly 15 cu. ft. per sec. for most of the channels. Each channel was subjected to a series of at least four separate tests.

The results of the tests of meadow strip vegetations are graphically depicted by the curves of Figure 4.

The Sudan grass "flattened" or "shingled" at quite low flows. The common lespedeza plants began to bend at the higher test flows but failed to form as smooth a mat as the Sudan grass. The lespedeza sericea failed to bend under the test flows available and for this reason the retardance coefficients do not change materially with depth. If the tests had been repeated on steeper slopes, or if higher test flows could have been used, the bending moments exerted on the vegetation would have been increased and it is quite probable that the retardance coefficients for the lespedeza sericea would have been substantially decreased. It is also probable that when these linings are used in channels of very mild slope the retardance coefficients for both Sudan grass and common lespedeza will be considerably higher for the same hydraulic radii, since at lower velocities the bending moments produced may be too low to flatten the plants.

**Figure 3. View of Channels Used for Tests of Meadow Strip Vegetations. Sudan Grass Lining Undergoing Test. Common Lespedeza Adjacent to Sudan Grass and Lespedeza Sericea at far right.**

### *Relation Between Manning's n and Kutter's n*

It will be observed that for the channels tested the values of Kutter's *n* are always less than the corresponding values of Manning's $n$. It is often carelessly stated in textbooks on hydraulics that the two retardance coefficients are practically identical, but the two can be exactly equal only for a stream having a hydraulic radius of 3.28 ft (1 meter).

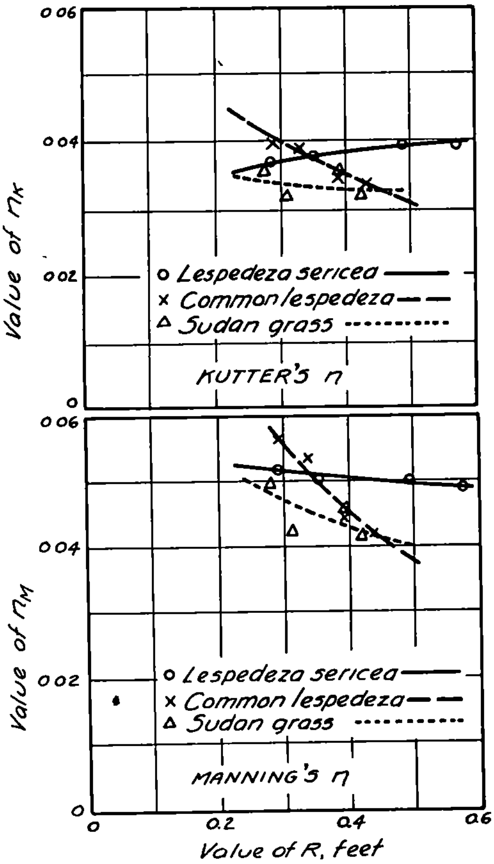

**Figure 4. Variation of Retardance Coefficients with Hydraulic Radius**

For other values of the hydraulic radius the two coefficients differ. The differences are relatively small for "smooth" channels, whether small or large, and for nearly all large streams However, in small rough channels $n_m$ often greatly exceeds $n_k$ The relation between the two is well shown by Figure 5 This diagram can be used in converting from Kutter's to Manning's coefficient, or vice versa In preparing it the slope term in Kutter's expression for Chezy's $C$ was neglected For this reason it should not be used for channels of slight slope

## ALLOWABLE VELOCITIES FOR VEGETAL LININGS

Channels are usually lined to prevent the erosion of the bed by rapidly flowing water Vegetal linings reduce the scour of channels because

(1) They reduce the velocity of flow.

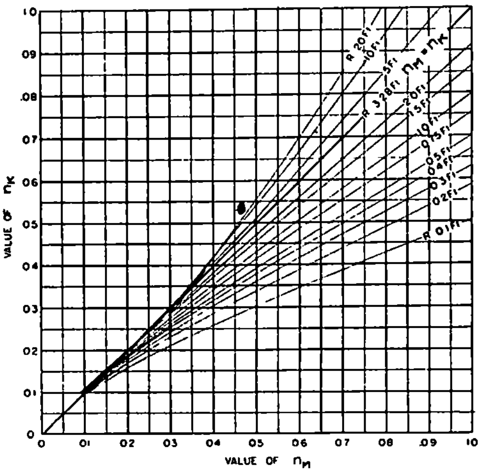

**Figure 5 Relation between Kutter's n and Manning's n**

(2) The plant-soil complex is more resistant to erosion than the soil alone.

The reduction in velocity is brought about by the greater flow-retarding action of vegetal linings The increased resistance to erosion is due to the formation of a protective mat of vegetation between the flowing water and the soil surface and, the "binding" action of the plant roots.

Tests at the Spartanburg laboratory have indicated that plants having limber stems are especially valuable for channel protection Pliant vegetation readily "shingles" the bed of the channel with a highly protective mat of stems and leaves. The increased resistance to erosion brought about by this mat is usually more than sufficient to compensate for the greater potential scouring power of the more rapid flow permitted by the flattening of the vegetation.

The previously discussed tests of vegetal linings were made to determine the protective, as well as the hydraulic, characteristics of the vegetations tested. The scour in each test channel was determined by measuring cross-sections at ten foot intervals before and after each test. A study of the scour data thus obtained, and close observations of the channels during and after each test, led to the tentative adoption of the following allowable velocities.

| Vegetation | Allowable Velocity* *ft per sec* |
|---|---|
| Bermuda grass | 8 |
| Sudan grass | 4 |
| Common lespedeza | 4 |
| Lespedeza sericea | 3 |

Most of the test channels were constructed in soil for which the safe velocity was about one foot per second. All of the linings tested consisted of good stands of vegetation.

It should be understood that the foregoing allowable velocities are recommended only for channels lined over their entire inner surface with a good stand of vegetation. Moreover, it is presupposed that only storm flows will pass through the channels and that these, as is normally the case, will last for only short periods of time, with recovery periods intervening between storms. Since the vegetal linings were practically dormant when tested, the recommended velocities may be considered conservative if the other conditions specified above are met.

## NOTCH CAPACITIES

When it is economical to localize the dissipation of energy by the construction of drop structures another troublesome design problem is met in calculating the dimensions of the aperture, or notch, through which the run-off is discharged.

A series of experiments was made at the Spartanburg laboratory to determine the capacity of a type of rectangular notch frequently employed. The notches tested were essentially simple rectangular apertures in thick walls. Since notches constructed in the field are either built flush with the bed of the approach channel, or the channel soon silts up to the level of the notch, all of the tests were made with the bed of the channel level and flush with the bottom of the notch. The approach channel was trapezoidal in shape and had 1 on 1 side slopes. In all of the tests the ratio of the notch length to the width of the bed of the approach channel was 0.8. The flow through the notches was "free," that is, the water surface elevation in the channel below the notch was always less than the elevation of the bottom of the notch.

It was found that discharge coefficients for the notches were dependent upon the thickness of the wall in which the aperture was cut, the length of the notch opening, and the head on the notch.

In order to extend the range of the experiments, supplementary tests were made on model notches at the hydraulic laboratory of the National Bureau of Standards. These tests demonstrated that such notches follow simple laws of hydraulic similitude. This makes it possible to use the more precise and more easily obtained model data in determining the discharge coefficients for field scale notches.

An analysis of all of the data resulted in Figure 6. From this diagram it is possible to obtain the value of the discharge coefficient $N$ for any notch geometrically similar to those used in the tests.

The formula used in preparing Figure 6 involves a velocity head term. This

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* Mean velocity, the rate of flow divided by the cross-sectional area of the channel.

formula was chosen so that the coefficients could be used for notches not exactly similar to those tested Preliminary tests have indicated that when this diagram is used for a notch only four-tenths as wide as the approach channel (*L*/*W* = 0 4) the estimated capacity will be about 10 percent too high It is probable that even larger errors will be encountered if the diagram is used for notches having *L*/*W* ratios *greater* than 0 8

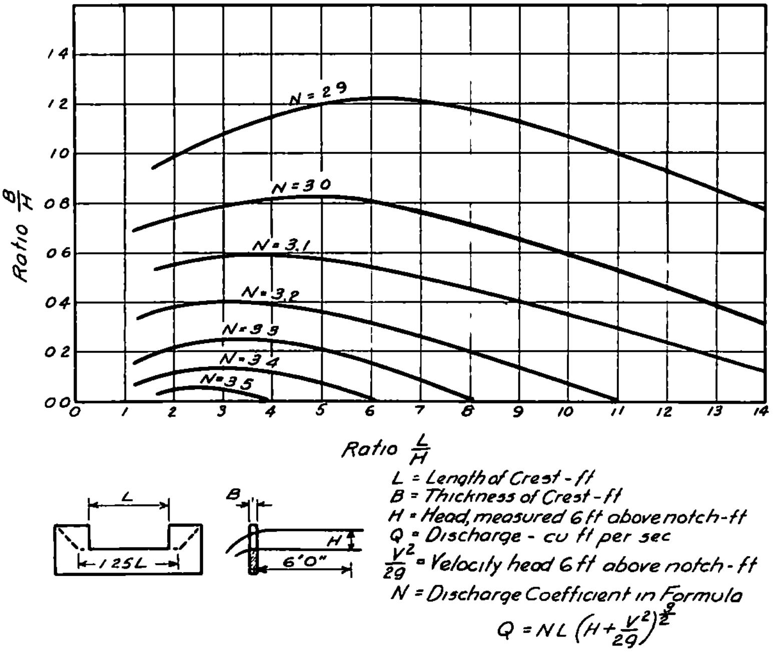

**Figure 6. Discharge Coefficients for Rectangular Notches Flush With Approach Channel, Plotted Against the Ratios $\frac{L}{H}$ and $\frac{B}{H}$.**