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HYDRAULICS OF RIVER FLOW UNDER ARCH BRIDGES

REPORT NO. 5

DISCUSSION —

"ROUGHNESS SPACING IN RIGID OPEN CHANNELS"

JUNE 1961

NO. 21

by

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Joint Highway Research Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Technical Paper

HYDRAULICS OF RIVER FLOW UNDER ARCH BRIDGES

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TO:	K. B. Woods, Director Joint Highway Research Project	June 21, 1961
FROM:	H. L. Michael, Assistant Director Joint Highway Research Project	File No: 9-8-2 Project No: C-36-62B

Attached is a technical paper which is a discussion on a recent ASCE paper titled "Roughness Spacing in Rigid Open Channels". This discussion is by Messrs. P. F. Biery and J. W. Delleur of our staff and reports some results obtained from the research project on hydraulics of river flow under arch bridges.

The paper is submitted to the Board for the record and for release as a discussion for publication by the American Society of Civil Engineers. It will, upon approval by the Board, be submitted to the State Highway Commission of Indiana and the Bureau of Public Roads for review and release.

Respectfully submitted,

Harold L. Michael

Harold L. Michael, Secretary

HLM:kmc

Attachment

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HYDRAULICS OF RIVER FLOW UNDER ARCH BRIDGES

REPORT NO. 5

Discussion on

"Roughness Spacing in Rigid Open Channels"

by

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Bureau of Public Roads

Joint Highway Research Project
Project No. C-36-62B
File No. 9-8-2

Purdue University
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June, 1961

ROUGHNESS SPACING IN RIGID OPEN CHANNELS[a]

Discussion by P. F. Biery and J. W. Delleur

P. F. BIERY[27], AM. ASCE and J. W. DELLEUR[28], M. ASCE

The authors are to be congratulated for a very lucid presentation on the effect of longitudinal and transverse spacing of roughness on the flow in rigid open channels. The discussers wish to extend the paper by showing the result of applying Sayre and Albertson's analysis to a different type of roughness element consisting of round bars, and to consider a possible extension to field conditions.

The tests were performed in a steel tilting flume 5 feet wide, 2 feet deep and 64 feet long. Uniform flow tests were run with two different boundary roughness patterns. The first roughness pattern, which will be referred to as smooth boundary, consisted of the steel flume walls finished with an epoxy resin paint. The second roughness pattern, which will be referred to as rough boundary, consisted of ½-inch aluminum rods as follows: a) along the bottom a layer of longitudinal bars placed 12 inches on center and a top layer of transverse bars 6 inches on center, b) along the side walls one layer of vertical bars 6 inches on center placed ½ inch from the wall. The bottom layer of bars were tied together with wire. The vertical bars were tied at the bottom to the transverse bars and clamped to the walls above the free surface. Figure 13 shows the artificial roughness in place.

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[a] May, 1961, by William W. Sayre and Maurice L. Albertson, (Proc. Paper 2823)

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Uniform flow tests were run for smooth and rough boundaries. The Darcy-Weisbach friction factor, f, was calculated from the equation

$$f = 8gR_nS/V_n^2 \tag{32}$$

where V_n is the average velocity, R_n is the hydraulic radius, and S is the slope. In figure 14 the friction factor, f, is plotted versus the Reynolds Number $R_e = \frac{V_nR_n}{\nu}$ where ν is the kinematic viscosity of the fluid.

The roughness elements used here are different from those used by Sayre and Albertson. In particular, there is a definite amount of flow under the roughness elements. Figure 15 shows a qualitative sketch of the flow around the transverse bars. Centerline velocity profiles measured very close to a transverse bar and at a point midway between transverse bars are shown in fig. 16.

Six tests were run to determine the roughness parameter, χ . In order to have fully rough turbulent flow, the flume was set to its maximum slope of 0.0125. The test data are given in table II.

A plot of $C/\sqrt{g}$ against log y_n/a similar to fig. 5 was prepared. Taking the roughness height, a, equal to ½ inch, (that is, the total height of the two layers of bars along the bottom), it was found that the points plotted along a straight line with a slope of 6.06 confirming the empirical constant in equ. (17). The extrapolated value of C_2 was 3.15. With these values of C_2 and a, χ was determined to be 0.0126 feet.

Centerline velocity profiles were taken at a slope of 0.0125 and a discharge of 3.714 cfs. The profile is shown in dimensionless form in figure 17, where it is compared to the velocity profile presented in fig. 9 and equ. (20). The equation obtained for round bar roughness was

$$\frac{v}{\sqrt{\frac{\tau_o}{\rho}}} = 6.06 \log \frac{y}{.0126} + 4.6 \tag{33}$$

It is interesting to note that with the change of roughness pattern the first of the empirical constants, 6.06, checked; but the second constant changed from 2.6 to 4.6. The difference is attributed to that fact that the roughness baffles used by Sayre and Albertson were placed in such a way that there was no flow beneath the roughness elements, whereas there was a certain amount of flow underneath the transverse bars used in experiments reported in this discussion.

If equ. (20) is accepted for the bar roughness, it would be possible to find the value of an equivalent roughness height, a, for the round bar roughness. Equating equs. (20) and (33), the equivalent roughness parameter, χ, for the round bars is found to be .0059 ft. Replacing this value of χ in equ. (19) with $C_2 = 3.15$, and solving for a, one obtains a = .0195 ft. = .234 in., which is close to the diameter of the bar of 0.25 in. It may then be concluded that equ. (20) for the velocity distribution may also be used for round bar roughness with a reasonable degree of accuracy by considering the roughness height equal to the diameter of the transverse bars.

Fig. 18 shows a portion of the general resistance diagram of Fig. 10, with test data for the bar roughness added, where the values of y/χ indicated correspond to a value of χ of 0.0126 ft. There is a generally good agreement.

It is probable that the roughness parameter, χ, may also be used in natural streams, where it could be determined from velocity measurements at $0.2\,y_n$ and $0.8\,y_n$ which are commonly used in field measurements. Equations (20) or (33) can be rewritten as

$$v = 6.06\, V_f \log \frac{y}{\varepsilon\chi} = 6.06\, V_f \log \frac{y/y_n}{\varepsilon\chi/y_n} \qquad (34)$$

where $6.06 \log 1/\varepsilon$ is equal to the second empirical constant in equ. (20) or (33), and V_f is the friction velocity $\sqrt{\tau_o/\rho} = \sqrt{gy_nS}$. Taking the velocities at 0.2 and 0.8 time the depth

$$v_{0.2} = 6.06\, V_f \log \frac{0.2}{\varepsilon \chi / y_n} \qquad (35)$$

$$v_{0.8} = 6.06\, V_f \log \frac{0.8}{\varepsilon \chi / y_n} \qquad (36)$$

Taking the ratio of equ. (35) and (36), letting $W = V_{0.2}/V_{0.8}$ and solving for χ,

$$\chi = \frac{y_n\, 0.8^{\frac{W}{W-1}}}{\varepsilon\, 0.2^{\frac{1}{W-1}}} \qquad (37)$$

Equ. (37) gives the roughness parameter, χ, in terms of the ratio of the velocity measured at two tenths and eight tenths of the depth. The determination of χ must necessarily depend on the value of ε which is used. For the experiments of this discussion, using equ. (33), $4.6 = 6.06 \log 1/\varepsilon$ and $\varepsilon = 0.174$. With this value of ε, equ. (37) gives(with w = .' for the velocity profile of fig. 16 a value of χ of 0.0123 ft. which compares favorably with the value of 0.0126 obtained previously. If instead equ. (20) is used, $\varepsilon = .372$ and χ is found to be .0058 ft. which is close to .0059 ft. calculated previously.

The kinetic energy coefficient, α, may also be given in terms of roughness coefficient χ, the parameter ε, and the ratio of the velocities at 0.2 y_n and 0.8 y_n. Using equ. (34) in

$$\alpha = \frac{v^3 dy}{V^3 y} \qquad (38)$$

it follows that

$$\alpha = \frac{G(U)}{(\log U \varepsilon)^3} \qquad (39)$$

where $U = y_n/\epsilon\chi$ and

$$G(U) = (\log U)^3 - 3(\log U)^2 - 6 \log U - 6 \tag{40}$$

Based on the velocity profile of fig. 13, the value of α computed by equ. (39) was found to be 1.01.

The authors have shown that equ. (17) is more accurate than Manning's formula over the range of conditions tested. The discussers have shown that equ. (17) is also applicable to a different type of roughness, and that the χ parameter may be used for field conditions where it can be obtained from velocity measurements at two and eight tenths of the depth. The discussers hope that sufficient information on the roughness parameter, χ, may be collected in the near future so that designing engineers can use it reliably for field channels and natural streams, perhaps even including channels in alluvial terrains.

TABLE II - TESTS FOR THE ROUGHNESS PARAMETER χ

A) Normal Depth Tests

Run No.	y_n cm.	Q cfs	S	$C/\sqrt{g}$	y_n/a	y_n/χ
1	8.66	3.714	0.0125	8.169	6.829	22.548
2	8.44	3.574	"	8.162	6.650	21.976
3	8.05	3.273	"	8.005	6.348	20.960
4	7.72	3.066	"	7.982	6.086	20.095
5	7.07	2.586	"	7.646	5.574	18.405
6	6.06	1.969	"	7.283	4.779	15.778

B) Velocity Profile Data (y measured from the bottom)

Q = 3.714 cfs ; y_n = 0.275 ft. ; S = 0.0125 :

y ft.	y/χ	v fps	$v/\sqrt{\tau_o/\rho}$
0.010	0.794	1.89	5.985
0.015	1.190	1.94	6.143
0.020	1.587	2.00	6.333
0.025	1.984	2.17	6.872
0.030	2.381	2.25	7.125
0.035	2.778	2.31	7.315
0.040	3.175	2.42	7.663
0.045	3.571	2.59	8.201
0.050	3.968	2.69	8.518
0.055	4.365	2.74	8.676
0.060	4.762	2.83	8.961
0.065	5.159	2.94	9.310
0.070	5.556	2.99	9.468
0.080	6.349	3.10	9.816
0.090	7.143	3.27	10.355
0.100	7.937	3.38	10.703
0.110	8.730	3.48	11.020
0.120	9.524	3.57	11.305
0.130	10.317	3.65	11.558
0.140	11.111	3.68	11.653
0.160	12.698	3.75	11.875
0.180	14.286	3.86	12.223
0.200	15.873	3.94	12.476
0.220	17.460	4.00	12.666
0.240	19.048	4.06	12.856

Acknowledgment

The study of roughness effect described in this discussion was made in connection with the model testing of arch bridge constrictions sponsored by the State Highway Department of Indiana in cooperation with the U. S. Department of Commerce, Bureau of Public Roads.

FIGURE 13. TESTING FLUME WITH ARTIFICIAL ROUGHNESS.

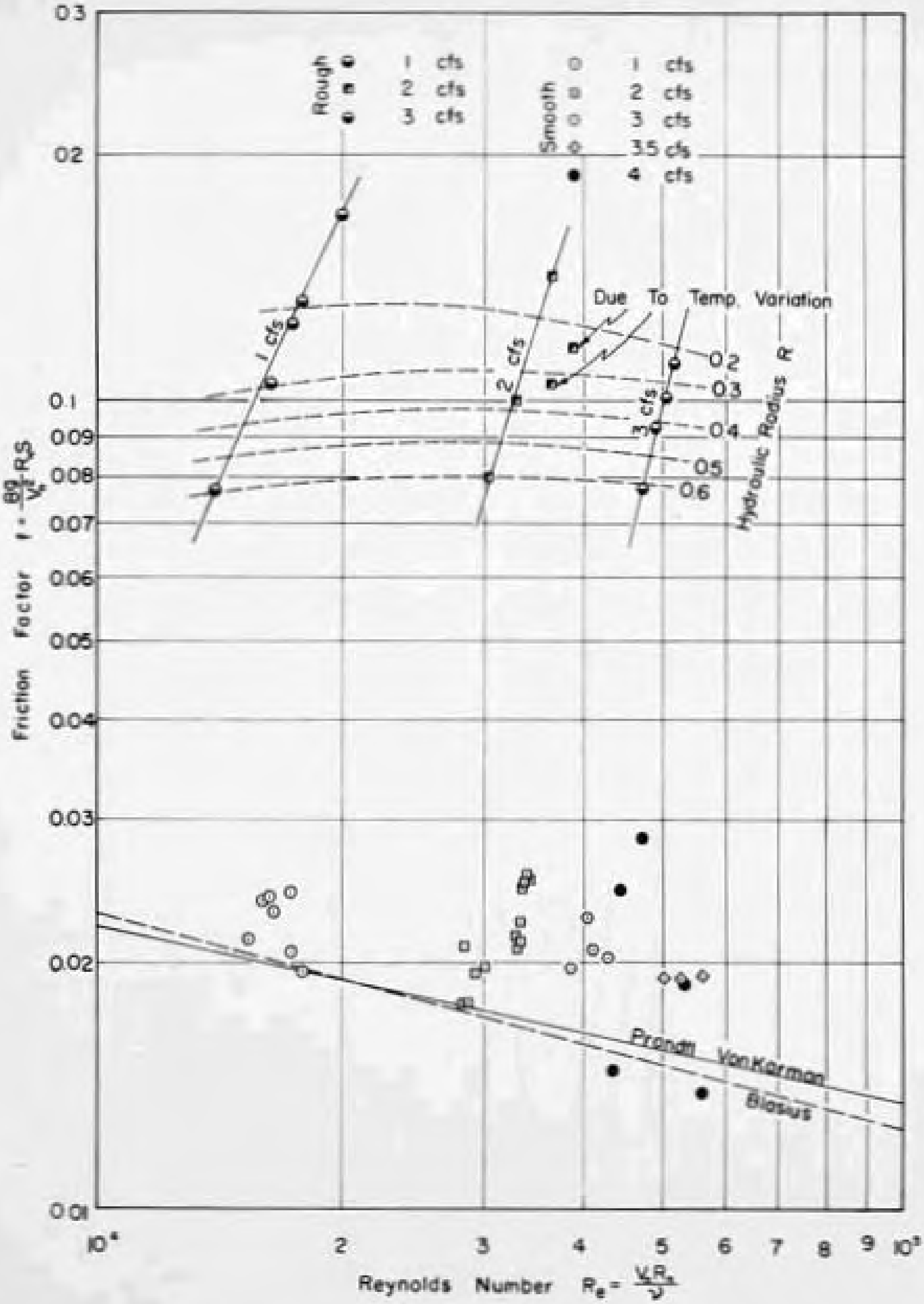

FIGURE 14 – f – Re RELATION FOR NORMAL DEPTH TESTS

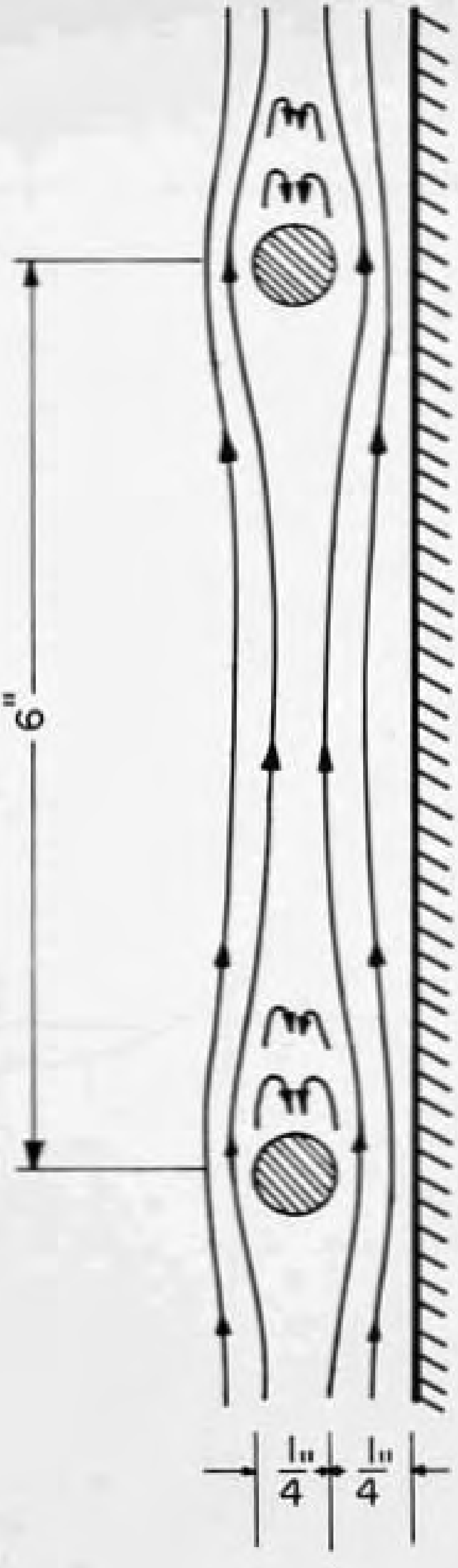

FIGURE 15 - QUALITATIVE SKETCH OF FLOW AROUND ROUGHNESS ELEMENTS.

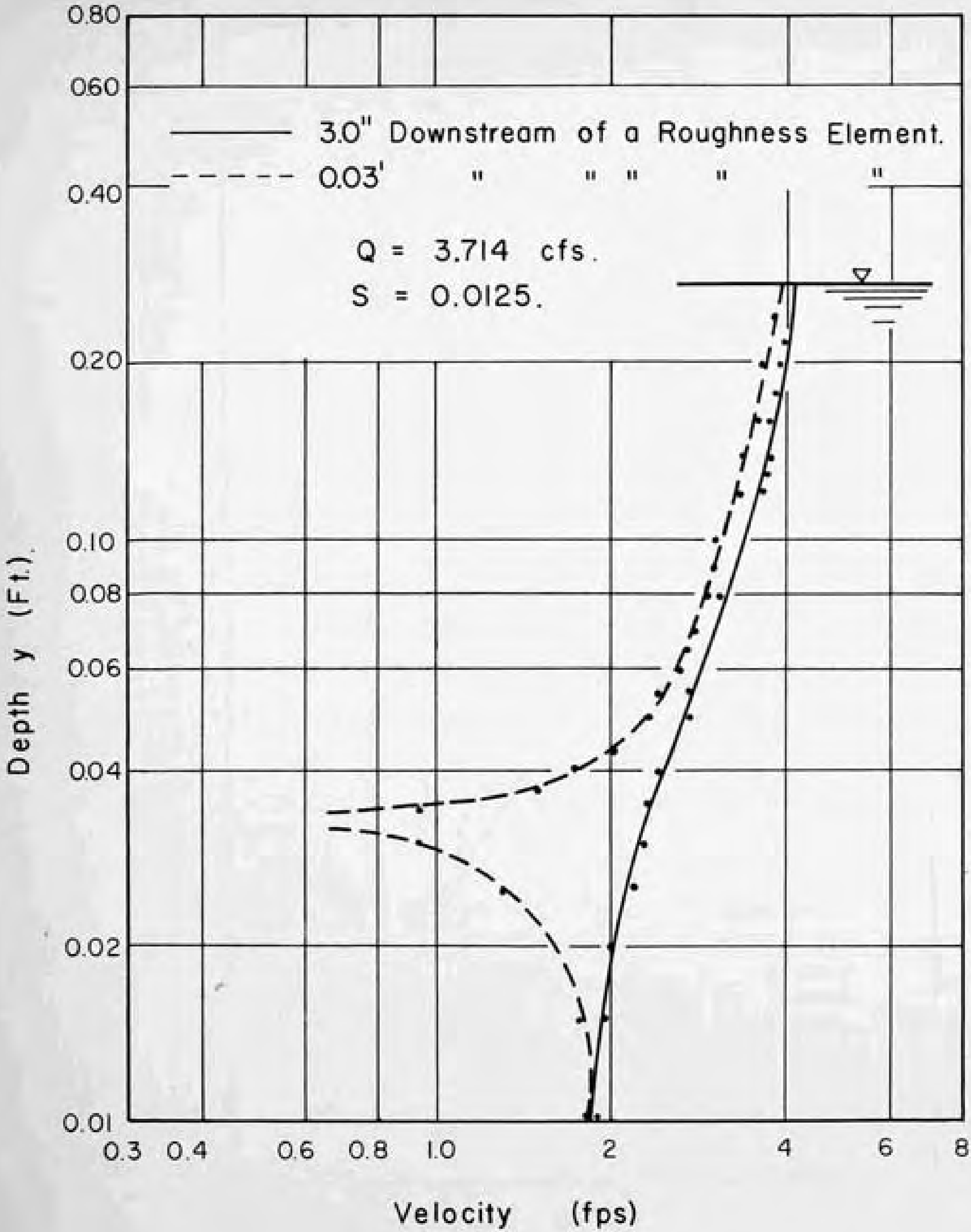

FIGURE 16 - EFFECT OF BARS ON VELOCITY.

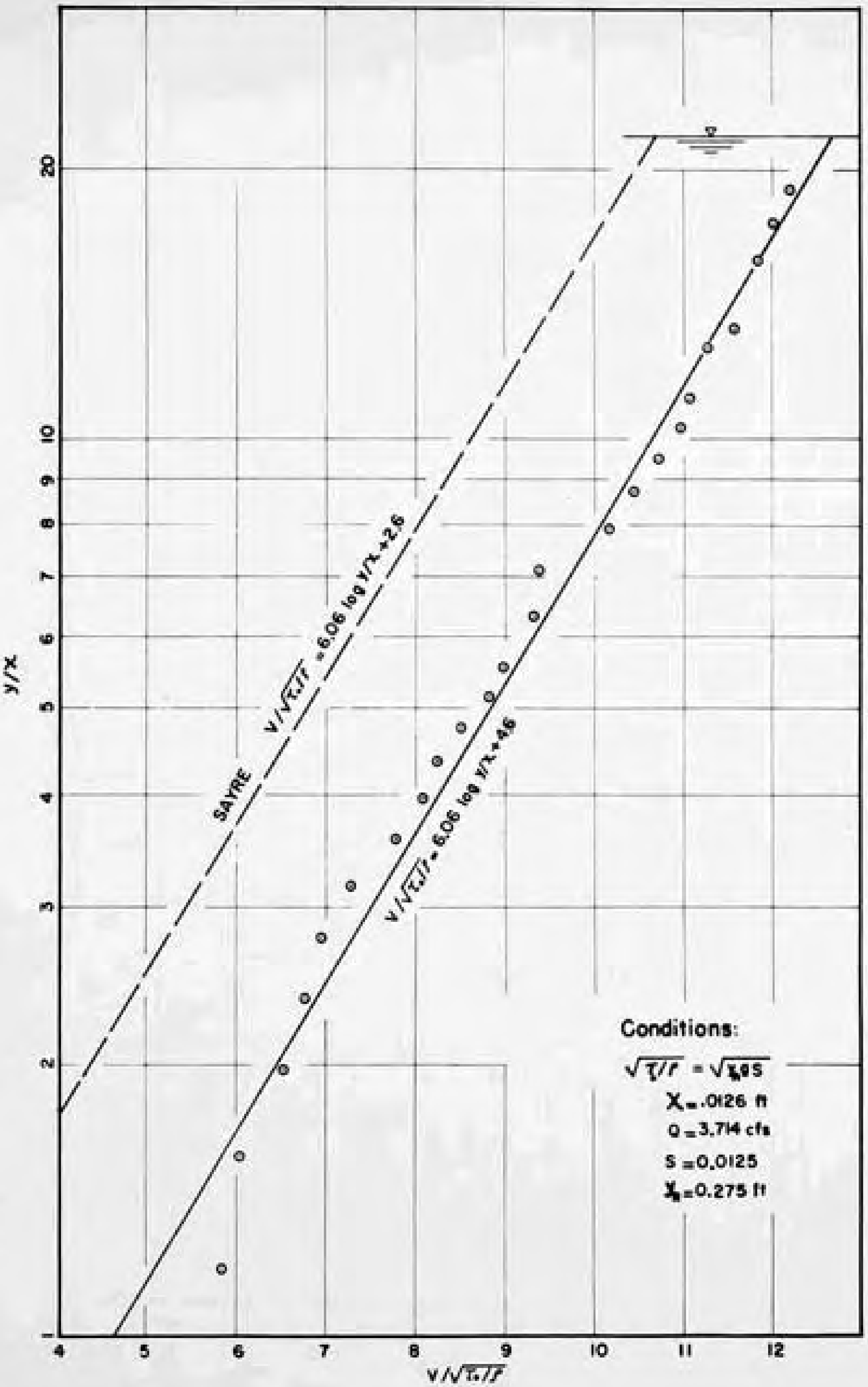

FIGURE 17 – DIMENSIONLESS VELOCITY PROFILE

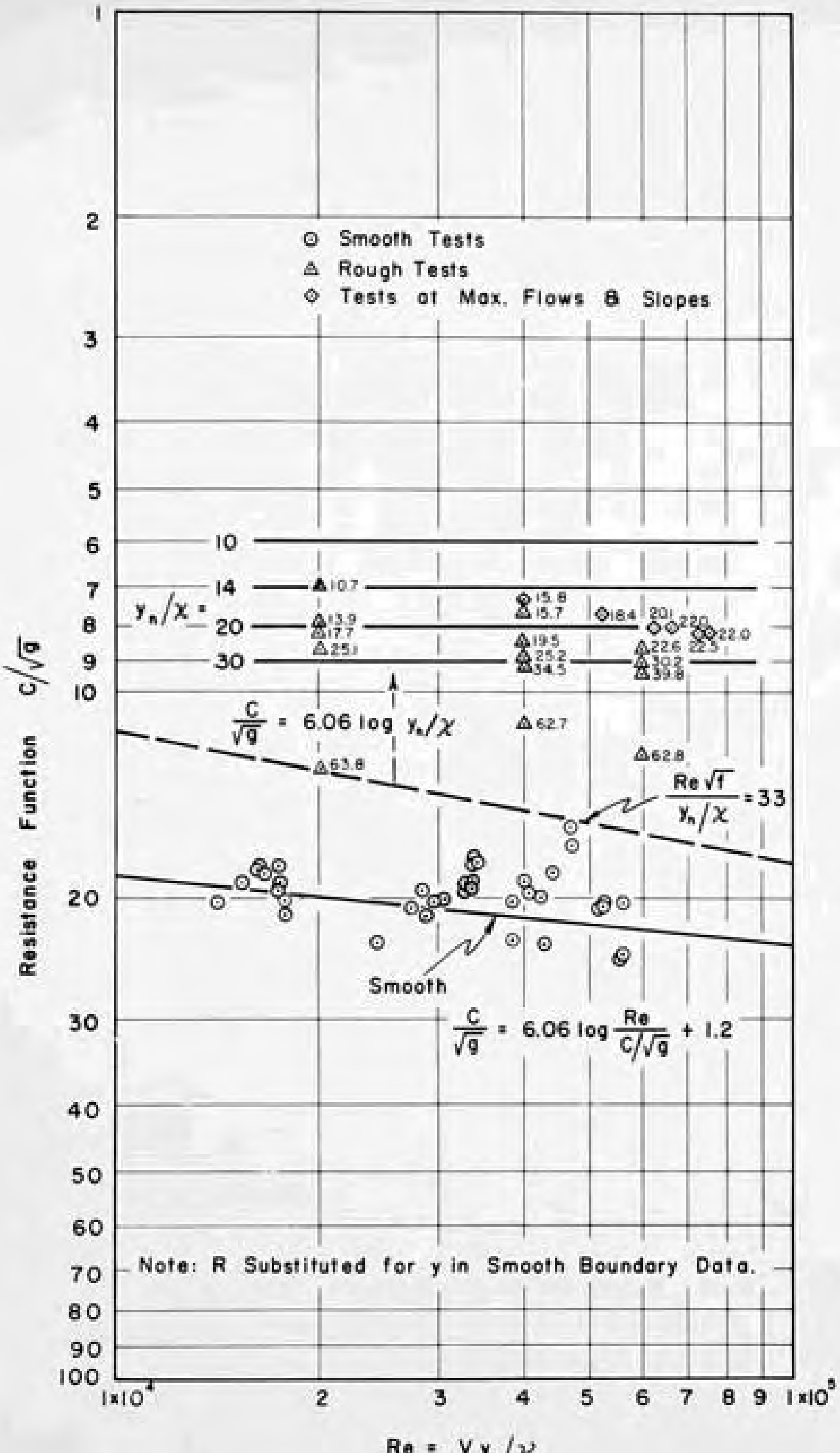

FIGURE 18 - GENERAL RESISTANCE DIAGRAM FOR UNIFORM FLOW IN OPEN CHANNELS (SAYRE)