EVALUATION OF CATCH BASIN GRATES

by

Sheldon M. Law
Assistant Research Engineer

and

Samuel J. Vaccaro
Research Specialist III

Final Report
Research Report No. 66

Research Project No. 71-3H(B)
Louisiana HPR 1(10)

Conducted by
LOUISIANA DEPARTMENT OF HIGHWAYS
Research and Development Section
In Cooperation with
U. S. Department of Transportation
FEDERAL HIGHWAY ADMINISTRATION

October 1972

ACKNOWLEDGMENTS

The writers express particular appreciation to Mr. Warren Marcum of the Road Design Section and Mr. Allen Cox of the Bridge Design Section of the Louisiana Department of Highways for their contributions in the overall development and completion of the study.

The Civil Engineering Department and the Division of Engineering Research of Louisiana State University are recognized for their cooperation in allowing the use of the LSU Hydraulic Laboratory for the work on the study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

SYNOPSIS

The research study reported herein was developed and undertaken because of the lack of hydraulic performance data for the newly adopted designs for the Standard RCB 22X catch basin grates. Hydraulic performance data was also not available for the RCB 31X Revised welded bar steel grate; therefore, all of these grates were tested on an existing full scale street model in the hydraulic laboratory at Louisiana State University.

The street model was equipped with all the necessary pumps, piping and measuring devices needed for hydraulic capacity tests. All tests were made using a roll-over type curb and with a one-way flow. The street model was adjustable for varying cross and longitudinal slopes. For this study two cross slopes (.020 and .030 ft./ft.) and five longitudinal slopes (.003, .005, .010, .020 and .030 ft./ft.) were used. For each combination of cross and longitudinal slope, four flow rates were used based on uniform increments of the spread of flow (L), which is the distance measured from the back of the curb to the water line in the roadway.

Principal data taken on each test was: (1) cross slope (S_C) and longitudinal slope (S_L), (2) size of orifice and manometer reading, (3) hook gage reading in the return flume and (4) spread of flow (L) measured from the back of the curb opposite the up-stream corner of the inlet to the water line in the roadway.

Performance data to be analyzed is summarized in Tables 1, 2 and 3 of the Appendix. From this data performance curves were evolved and are represented in Figures 24 through 35 of the Appendix. For the RCB 22X grates and the RCB 31X Revised welded bar steel grate, graphs are provided relating the total gutter flow (Q_1), the spread of flow (L), the interception ratio (Q_3/Q_1), the longitudinal slope (S_L) and the cross slope (S_C). A summary of all test data has been provided the Road Design Section of the Louisiana Department of Highways for their information, design purposes and use.

Principal conclusions reached are: (1) the RCB 31X Revised grates, which have a larger grate area and width, are more efficient and will give more flow capacity than the RCB 22X grates and (2) all of the grates tested and studied on this research project are more efficient than the old design RCB 22X cast iron grates. Efficiency is synonomous here with Interception Ratio, Q_3/Q_1.

Principal recommendations made are: (1) since the RCB 22X grates tested on the study are new designs of steel (either welded bar steel or riveted reticuline) and are accepted for use in the field, they should continue to be used because of greater efficiencies than the old design RCB 22X cast iron grates, and (2) any recommendations on cross or longitudinal slopes for design purposes or spacing of inlets should be made by the Road Design Section (Hydraulics Unit) of the Louisiana Department of Highways from data provided herein or any subsequent data provided from further research effort or tests.

IMPLEMENTATION

The present design grates, which were tested here, are now in use on construction projects throughout the state. However, implementation consisted of obtaining, recording and summarizing the data and results from the study, then submitting the entire package of data along with comments to the Road Design Section of the Louisiana Department of Highways for their information and analysis, use and further design application. These results should aid in the design of better storm drainage systems for urban highways, especially in any further improvement of present design criteria such as inlet capacities, cross slope and longitudinal slope effects and spacing of grates and inlets along the streets. Further implementation may be accomplished in the future.

INTRODUCTION

The Louisiana Department of Highways has adopted new designs for the Standard Plans for the RCB 22X catch basin to replace the old standard cast iron grate with either a welded bar steel grate or an alternate riveted steel reticuline grate. This revision was brought about by a request from the manufacturers for a new design of the cast iron grate because of casting problems and previous research which indicated that the cast iron grate was inefficient.

The grate designs were selected on the basis of information gained in conferences with grate manufacturers and limited testing of several preliminary prototypes. This insured that the grates could be economically manufactured. However, hydraulic capacity tests were not run on the final design grates. Data was also not available on the capacity for the RCB 31X Revised welded bar steel grate.

There was an urgent need to determine the hydraulic capacities of these grates under simulated roadway conditions. These results would be helpful to the Road Design Section of the Louisiana Department of Highways in determining the location and spacing requirements for these drains for design storms. There was a definite need also for data on varying cross slopes and longitudinal slopes under roadway conditions to best determine proper slopes.

The researchers evaluated these inlet grates by using the existing street model in the hydraulics laboratory at Louisiana State University. This street model was used on a research study conducted by Louisiana State University and described in the final report A Study of Storm-Water Inlet Capacities by William A. Wintz, Jr. and Yung H. Kuo. (3)

The present study was a sequel or similar study to the Louisiana State University study as referred to above.

PURPOSE AND SCOPE

The specific aim of this research was to study and record the hydraulic performance of the Louisiana Department of Highways' welded bar steel grate and riveted steel reticuline grate (alternate) for the new design Standard Plan RCB 22X (roll-over curb) grates. The RCB 31X Revised welded bar steel grate was also included in the study. Data was to be taken on one-way flow with four flow rates varying from maximum flow to all of the flow entering the inlet and using combinations of cross slopes (.020 and .030 ft./ft.) and longitudinal slopes (.003, .005, .010, .020 and .030 ft./ft.). All data and comments on the performance of these grates along with comparisons with performance data from other designs were to be supplied to the Road Design Section of the Louisiana Department of Highways for their information, analysis and use.

NOMENCLATURE

The following are definitions of symbols used in this report. Figure 1 is a sketch showing the curb configuration and is included in order to better define what the measurements were.

Q_1	=	Total flow quantity (cfs)
Q_2	=	Flow bypassing the inlet (cfs)
Q_3	=	Flow intercepted by inlet (cfs)
IR	=	Q_3/Q_1, Interception ratio
S_c	=	Cross slope (crown slope) (ft. /ft.)
S_l	=	Longitudinal roadway slope (elevation slope, profile slope) (ft. /ft.)
L_1	=	Spread of flow (measured from back of curb) on roadway at upstream edge of roadway grate (ft.)
L_2	=	Spread of flow (measured from back of curb) on roadway at downstream edge of roadway grate (ft.)
T	=	Width of water surface on roadway (ft.)
d	=	Depth of flow at base of curb (in.)

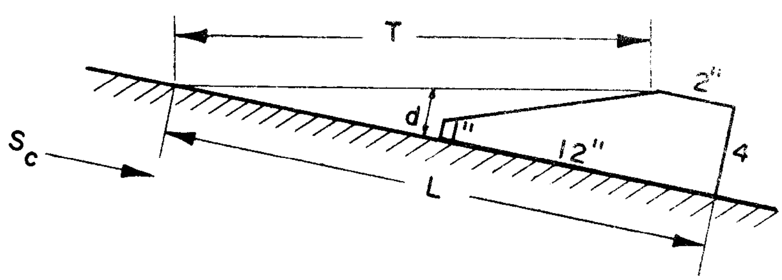


Figure 1

Roll-Over Curb

FACILITIES AND METHODOLOGY

A. Roadway Model

The roadway model used in this study was the full scale street and inlet model located in the LSU Hydraulics Laboratory on the Louisiana State University campus. The model was equipped with all the necessary pumps and measuring devices needed for hydraulic capacity tests. This same street model was used on the research study conducted by Louisiana State University and described in the final report A Study of Storm-Water Inlet Capacities by William A. Wintz, Jr. and Yung H. Kuo. (3)

The design of the street model gave both flexibility and rigidity to the model and the model was completely adjustable for varying cross slopes and longitudinal slopes. The roadway model was 72 feet long and 12 feet wide. A sketch of the model is shown in Figures 2 and 3 in the Appendix.

The Louisiana State University final report on storm-water inlets has a good description of the street model used on this study and an excerpt from that description is as follows:

> "To represent different grades and crown slopes, two large, rigid planes were built to withstand both static and dynamic loading conditions. They were corrected with universal joints near the center (Figures 4 and 5). Each section was supported at the corners by four screw jacks (Figure 6) to allow for complete vertical adjustment.
>
> Longitudinal movement of the structure (maximum of 1. 7 in.) was provided for by rollers under the jacks and sliding bearing plates on the joists. This system allowed complete freedom and eliminated internal stresses and the resulting distortions.
>
> Transverse movement (maximum of 0. 6 in.) was taken up through ball and slot arrangement.
>
> The resulting roadway structure was extremely rigid, but movable in three dimensions. Three steel joists, with X-bridging (Figure 7) and corrugated aluminum subflooring formed each plane structure. The roadway surface was 3/4 inch marine plywood. Between the plywood sheet joints, especially at the 4 foot transitional area between the two rigid sections, elastic joint compounds were used. To allow for possible movement between

plywood sections without buckling, cracking, or tearing, the compounds were required to have good adhesion, with 300 percent elongation.

The actual surface in contact with the water had to represent a concrete surface, yet be flexible in certain areas. For flexibility, a special elastic material ("Cocoon") was chosen. Sand was embedded in the second (top) coat to provide a roughness near that of concrete pavement. The average roughness factor (Manning's n) was found to be 0.010.

The water was supplied through a 10-inch steel pipe to a head tank at one end of the model. (See Figure 8) From the head tank, the water was dispersed through 36 individually - controlled outlets that were located uniformly across the width of the model. The excess head energy (eddies and foaming) was dissipated by a heavily-weighted canvas flap over the outlets and two screen mesh baffles 5 feet from the outlets.

Transverse wave action was prevented by a series of longitudinal vanes farther downstream from the baffles. This stilling system provided a fairly smooth, uniform flow beginning 26-feet upstream from the test area."

B. Measuring Devices

All tests were made with one-way flow and water was supplied from a basement sump in the laboratory by an electrically-driven pump. Test flows ranged from 0.4 cfs to 3.3 cfs. The water was always channeled back to the basement sump for reuse. Full maximum flows to near pump capacity of 4.6 cfs were not attempted because of difficulty of measurements.

Pipe orifice meters were used to measure the flow quantities. Orifice plates of 2-inches, 4-inches and 6-inches were installed respectivity in 4-inch, 6-inch and 10-inch pipes. The set up is shown in Figure 9. Manometer readings were taken and recorded.

The water that bypassed the inlet was measured with a rectangular weir that was set in the flume leading to the sump. This setup is shown in Figure 10.

C. Inlets

Three standard inlet grates in use by the Louisiana Department of Highways were tested for their hydraulic capacities. These included the newly modified RCB-22X (roll-over curb) with the welded bar steel and the riveted steel reticuline grates and the RCB 31X Revised welded bar steel grate. Figures 11 and 12 show the RCB 22X welded bar steel grate and curb grate. Figures 14 and 15 give details on the curb setup of these grate inlets.

D. *Methodology*

In the report A Study of Storm-Water Inlet Capacities the researchers had recommended further studies into a more efficient inlet grate design. Therefore, some of the basic methods used to evaluate the street grates and inlets in the aforementioned study were followed during the course of this study.

It was requested by the Road Design Section of the Louisiana Department of Highways that the roll-over type curb be investigated, thus the evaluation of the RCB 22X and RCB 31X grates.

The model was set to each desired crown or cross slope (S_C) and longitudinal slope or grade (S_L) with an engineer's level and rod through adjustment of the eight screw jacks. Two cross slopes, .020 and .030 ft./ft., along with five longitudinal slopes, .003, .005, .010, .020 and .030 ft./ft., were evaluated.

Four flow rates (Q_1) were used as a variable for each combination of cross and longitudinal slope. These four flow rates were based on uniform increments of L (the spread of flow). Generally, the first flow rate was the near pump-capacity or maximum flow rate, while the second flow rate was the rate at which the inlet intercepted the total one-way flow. Two intermediate flow rates based on uniform increments of L (spread of flow) were also taken thus making a total of four flow rates.

For each run, the high-capacity, low-head pump discharged water into and filled the permanent overhead tank (See Figure 13). The valve on the pipe supplying the head tank of the model was then opened to purge air from the system. The valve to the model was then closed and all the manometers checked for zero readings. The valves to the two orifices not in use were closed, and the valve to the outlet to the head tank at one end of the model was opened and adjusted to obtain the desired quantity.

The zero reading of the hook gage in the return flume was recorded daily.

Adjustments in the head tank orifices and the guide vanes were made to give a uniform flow along the model and to minimize eddies and shock waves near the inlet.

The following data was taken for each hydraulic capacity test:

1. Cross slope (S_c) and longitudinal slope (S_L).
2. Size of orifice and manometer reading
3. Hook gage reading in the return flume.
4. Spread of flow, L_1 and L_2, measured from back of curb at the up-stream and down-stream corners of the inlet respectively. These readings were facilitated by grid lines painted on the model at 1-foot spacings.
5. Depths across section about 12-feet up-stream from the inlet centerline. (These readings, in inches, are shown on the sketch sheet).
6. Numerous depths around the inlet. (These readings are shown on the sketch sheet).
7. Greatest depth, d (next to the curb), down-stream from the inlet.
8. Sketch of the flooded area around the inlet.
9. Extraordinary water surface characteristics were shown on a sketch sheet, and any remarks made. One data sheet was made for every test.

At the conclusion of each series of tests for the combination of cross and longitudinal slopes, the engineer's level and rod were used to change to another combination of slopes by adjustment of the eight screw jacks. This procedure continued until all the necessary tests were completed.

DISCUSSION OF RESULTS

All of the physical test measurements were taken, and data was computed, compiled and summarized for each type of roadway grate tested. Physical tests were made using the RCB 22X welded bar steel grate, the RCB 22X riveted reticuline grate and the RCB 31X Revised welded bar steel grate. Tables 1, 2 and 3 show this data which include spread of water (L) in feet, total gutter flow (Q_1) in cubic feet per second, grate capacity (Q_3) in cubic feet per second and intercept ratio (Q_3/Q_1).

From this data package, and also from information and data obtained for the RCB 31X Revised riveted reticuline grate from the report A Study of Storm-Water Inlet Capacities, curves were evolved showing total quantity gutter flow versus spread of water on the roadway for each type grate, cross slope and longitudinal slope. Along with these curves, other curves were determined showing total quantity gutter flow versus intercept ratio. All of these curves are shown in Figures 30-35.

The total gutter flow (Q_1) was plotted as a function of L (spread of water), for conditons of S_L (longitudinal slope) and S_C (cross slope) on log-log paper for the roll-over type curb and one-way flow. The other set of curves shown on the same Figure is the total gutter flow (Q_1) plotted as a function of intercept ratio (Q_3/Q_1), for conditions of S_L (longitudinal slope) and S_C (cross slope) on semi-log paper for the roll-over type curb and one-way flow.

It is hoped that these tables and curves will be of prime value to the Road Design Section of the Louisiana Department of Highways who can use this data for their own information and design purposes. This study was conceived mainly because of a lack of information on these particular grates, because of the needs of the Road Design Section for design data for these grates and because of a recommendation in Professor Wintz's report that further studies on grate capacities should be made. This was done while the present roadway model was intact at the LSU Hydraulic Laboratory on the Louisiana State University campus. The specific aim of this research effort was to study the hydraulic performance of the Louisiana Department of Highways' welded bar steel grate and riveted reticuline grate (alternate) for the RCB 22X catch basins. From this hydraulic performance data, the Road Design Section can determine the proper spacing requirements for the inlets under various roadway conditions encountered in Louisiana. All of the data obtained on the study has already been supplied to the Road Design Section of the Louisiana Department of Highways.

Figures 24 - 29 are curves, derived from the data obtained, that can be used for comparative efficiencies of the various grates and inlets.

Figures 24 and 25 show intercept ratios versus longitudinal slopes of the grates for a 7 foot spread of water measured from back of curb on the appropriate cross slopes. As one can see from these Figures, the RCB 31X Revised grates are more efficient than the RCB 22X grates, this possibly being due to having a larger grate area and width. As shown in Figure 24 with an .020 ft./ft. cross slope and longitudinal slopes of less than .010 ft./ft., the riveted reticuline grates are more efficient with the RCB 31X Revised grate being the most efficient. However, with longitudinal slopes greater than .010 ft./ft., the welded bar steel grates appear to be more efficient, with the RCB 31X Revised grates having more efficiency than the RCB 22X grates. With an .030 ft./ft. cross slope, the welded bar steel grates generally show more efficiency than their riveted reticuline counterparts from the data obtained on this model study. Data for the curve on the RCB 31X Revised riveted reticuline grate is taken from the report <u>A Study of Storm-Water Inlet Capacities</u> which was published in 1970.

Figures 26 and 27 show grate capacities (Q_3 in cfs) versus longitudinal slopes of the various grates for intercept ratios of 0.90 on the appropriate cross slopes. The riveted reticuline type grates appear to have more capacity at smaller longitudinal slopes and .030 ft./ft. cross slope. However, the reverse is true at steeper longitudinal slopes, with the welded bar steel grates having more capacity. Again the RCB 31X Revised grates are more efficient and have more flow capacity through the grate possibly because of the larger grate area. At a smaller cross slope of .020 ft./ft., both the RCB 22X grates, welded bar steel and riveted reticuline, appear to have about the same flow capacity through the grates. The RCB 31X Revised welded bar steel grate has a slightly higher capacity of flow through the grate than the RCB 22X grates.

Figures 28 and 29 show intercept ratios (Q_3/Q_1) versus longitudinal slopes of the various grates for a constant gutter flow of 1.5 cfs on the appropriate cross slopes. With an .020 ft./ft. cross slope, data for the RCB 22X welded bar steel grates and the RCB 22X riveted reticuline grate appear to coincide very closely while, again, the RCB 31X Revised welded bar steel grate is much more efficient than the RCB 22X grates. For an .030 ft./ft. cross slope, the welded bar steel grates appear more efficient than the respective riveted reticuline grates while the RCB 31X Revised grates are more efficient than the RCB 22X grates.

This data, these curves, these results and these conclusions should be a guide to a better understanding of the hydraulic performance of these grates and should help to lead to better designs for inlet grates and the direction one should take in any future research or design endeavor.

COMMENTS, CONCLUSIONS AND RECOMMENDATIONS

This report is a summary of observations and deductions of hydraulic performance data taken from results of laboratory tests using a full-scale one-lane roadway model with various standard inlet grates for highways in urban areas of Louisiana. Performance curves are evolved from this test data.

Conclusions reached from this study were:

1. The RCB 31X Revised grates, which have a larger grate area and width, are more efficient and will give greater flow capacity through the grate inlet than the RCB 22X grates. Efficiency is synonymous here with Interception Ratio, Q_3/Q_1.

2. All of the grates tested and studied on this research project were more efficient than the old design RCB 22X cast iron grates.

3. At smaller longitudinal slopes (.010 ft./ft. and below), reverse trends appear with the riveted reticuline grates being slightly more efficient than the welded bar steel grates.

4. The RCB 31X Revised grate was the most efficient inlet grate studied.

No conclusions can be reached from this study as far as type of curb or type of flow is concerned because tests were run only with a roll-over type curb and a one-way flow, requested by the Road Design Section of the Louisiana Department of Highways and also because of a limitation on time and monies on the study. However, an excerpt from Professor Wintz's report <u>A Study of Storm-Water Inlet Capacities</u> reads "The type of curb affects the inlet capacities. The effect is more appreciable for the RCB 31X Revised than the RCB 22X."

For the RCB 22X grates and the RCB 31X Revised welded bar steel grates, graphs are provided relating the total gutter flow (Q_1), the spread of water (L), the interception ratio (Q_3/Q_1), the longitudinal slope (S_L) and the cross slope (S_C).

A summary of all test data was provided the Road Design Section of the Louisiana Department of Highways for their information, design purposes and use as was one of the two principal aims of this research study.

Recommendations made from this study were:

1. Since the RCB 22X grates tested on this study are new designs of steel (either welded bar steel or riveted reticuline) and accepted for use in the field, they should continue to be used because of greater efficiencies than the old design RCB 22X cast iron grates.

2. Any recommendations on cross or longitudinal slopes for design purposes or spacing of inlets should be made by the Road Design Section of the Louisiana Department of Highways from data provided herein or any subsequent data provided from future research or tests.

3. Further research effort should be made to provide the necessary hydraulic data to determine the efficiencies of any new designs in the field for urban areas of Louisiana. It should be noted that this data is for some Louisiana storm-water inlets only and should not be applied to other types of inlets since good comparisons are not likely. In any subsequent research a greater variety of longitudinal and cross slopes should be investigated. Longitudinal slopes in the range from .03 to .10 ft./ft. would be very useful.

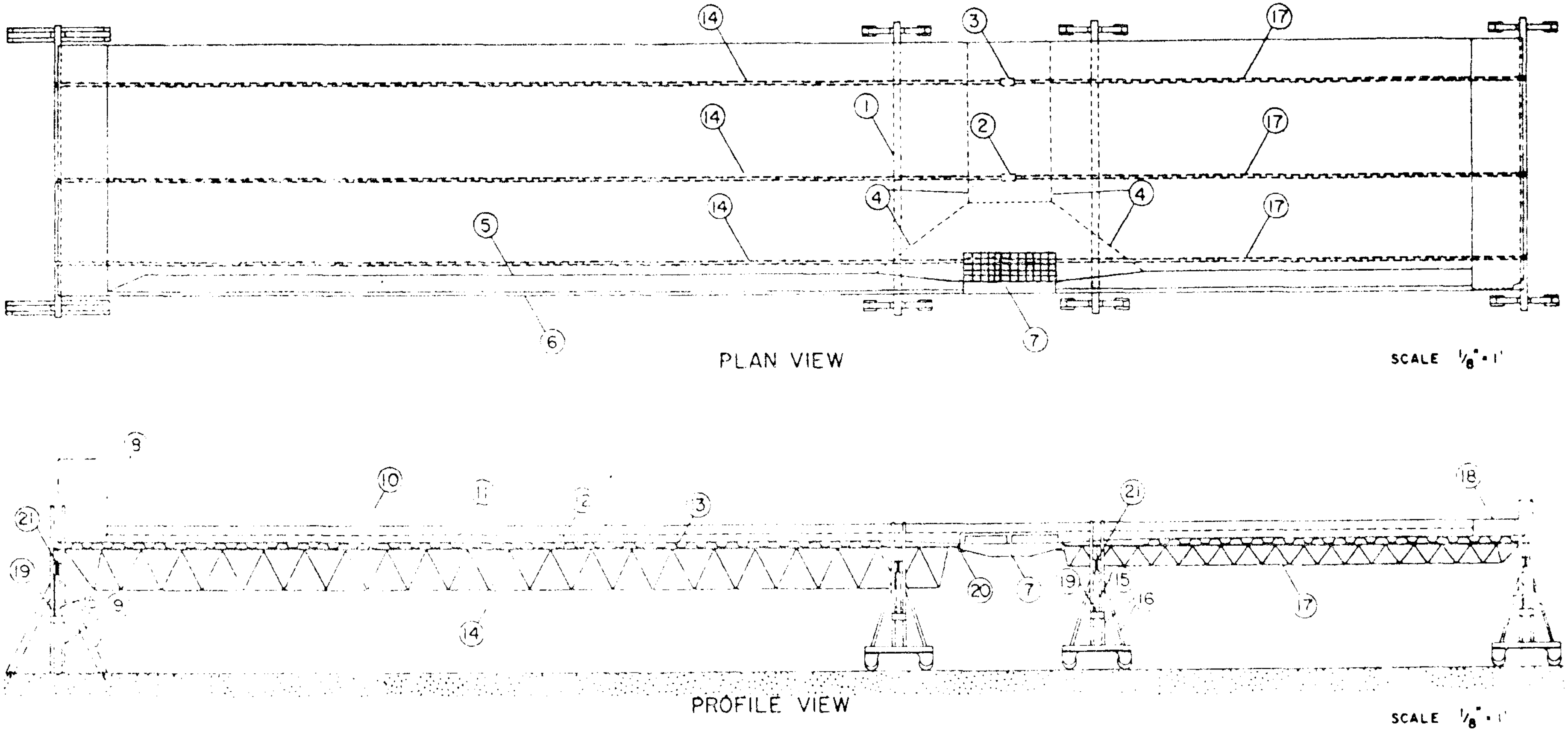
SELECTED BIBLIOGRAPHY

1. Izzard, C. F., "Tentative Results of Capacity of Curb Opening Inlets," Surface Drainage. Highway Research Board, Research Report 11B, Washington: Highway Research Board, 1950.

2. Larson, C. L., "Experiments on Flow Through Inlet Gratings for Street Gutters," Surface Drainage of Highways. Highway Research Board, Research Report 6-B, Washington: Highway Research Board, 1948.

3. Wintz, W. A., Jr. and Kuo Y. H., A Study of Storm-Water Inlet Capacities, Louisiana State University for Louisiana Department of Highways, Research Project No. 65-3H, Baton Rouge: Louisiana State University, 1970.

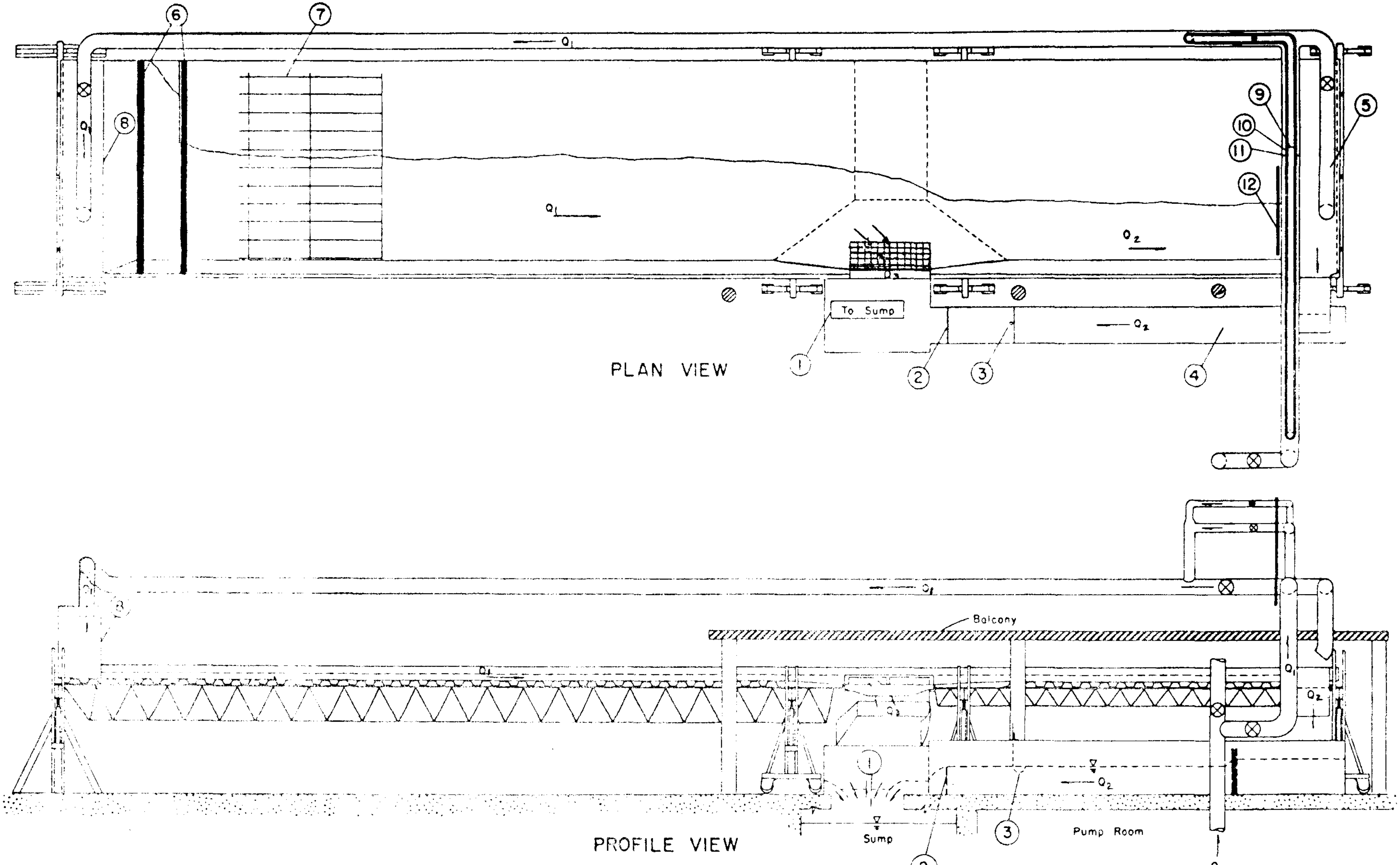
APPENDIX



(1) STANDARD 8WF20 BEAM
(2) UNIVERSAL SLIP JOINT (SEE FIG. 5)
(3) UNIVERSAL JOINT (SEE FIG. 4)
(4) FLEXIBLE TRANSITION JOINT
(5) FRONT EDGE OF CURB
(6) EDGE OF MODEL - THEORETICAL BACK OF CURB
(7) STANDARD RCB-22X DRAIN
(8) HEAD TANK (SEE FIG. 8)
(9) STANDARD FIXED SUPPORT (SEE FIG. 6)
(10) TOP OF OVERFLOW WALL
(11) TOP OF CURB (ROLL-OVER TYPE)
(12) ROADWAY SURFACE
(13) CORRUGATED ALUMINUM TO SUPPORT ROADWAY
(14) 24J8 STEEL BAR JOISTS (SEE FIG 7)
(15) TYPICAL SCREW JACK
(16) STANDARD MOVABLE SUPPORTS
(17) 14J5 STEEL BAR JOISTS
(18) REMOVABLE END (FOR ONE WAY FLOW)
(19) ADJUSTABLE JACK SUPPORT
(20) DRAIN SUPPORT
(21) BALL AND SOCKET ASSEMBLY

STRUCTURAL DESIGN OF MODEL ROADWAY

FIGURE 2



(1) RETURN OPENING TO SUMP
(2) RECTANGULAR WEIR
(3) HOOK GAUGE
(4) BYPASS FLUME (SEE FIG. 10)
(5) INLET PIPE FOR TWO-WAY FLOW ONLY
(6) SCREEN BAFFLES (SEE FIG. 8)
(7) LONGITUDIONAL VEINS (SEE FIG. 8)
(8) HEAD TANK (SEE FIG. 8)
(9) 2 INCH ORIFICE IN 4 INCH PIPE
(10) 4 INCH ORIFICE IN 6 INCH PIPE
(11) 6 INCH ORIFICE IN 10 INCH PIPE
(12) MANOMETER BOARD (SEE FIG. 9)

PIPING AND FLOW DIAGRAM

FIGURE 3

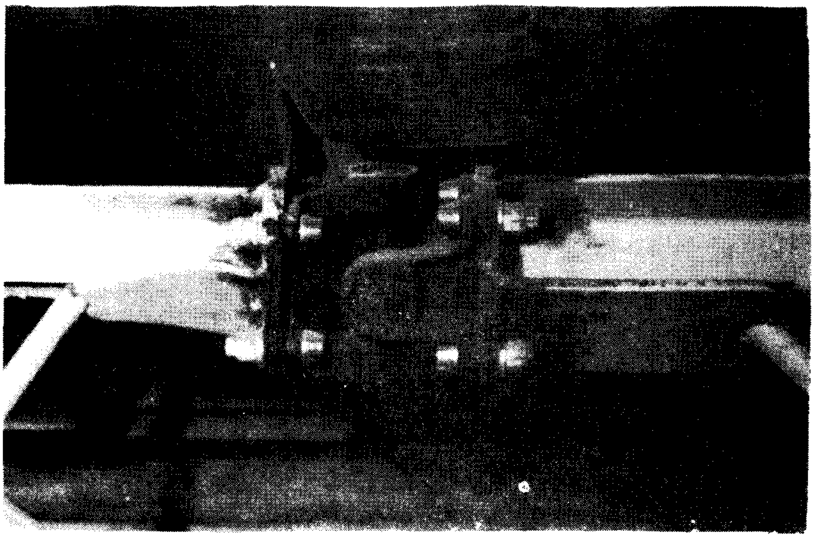


Figure 4
Regular Universal Joint

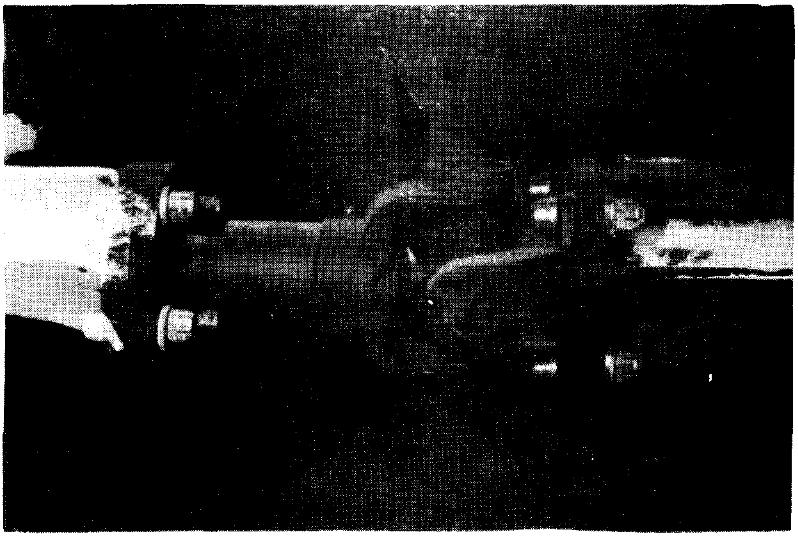


Figure 5
Slip Universal Joint

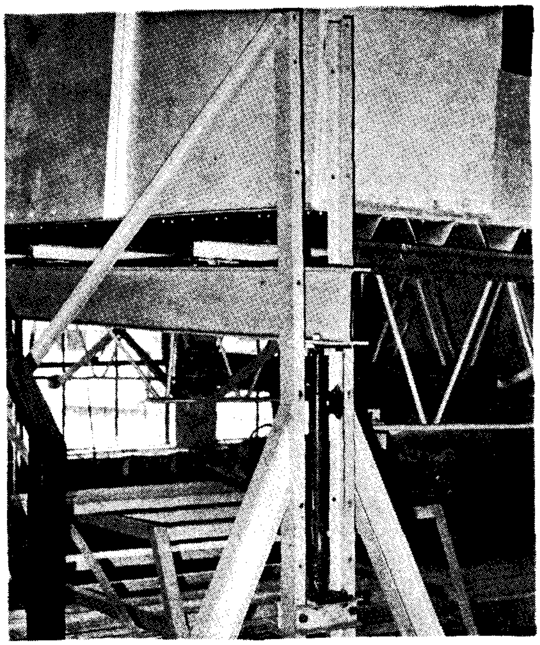


Figure 6
Support and Screw Jack

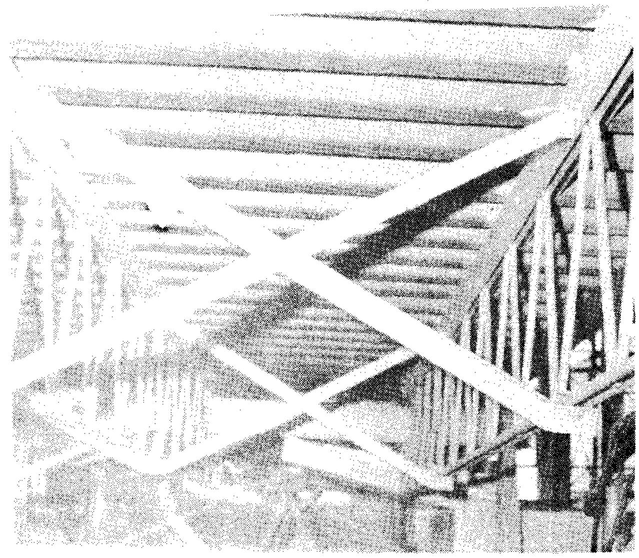


Figure 7
Bar Joists and Cross Bracing

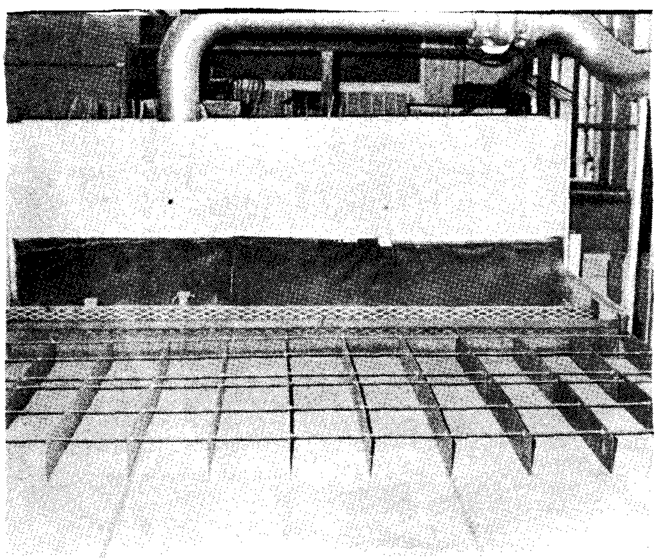


Figure 8
Tank End of Model

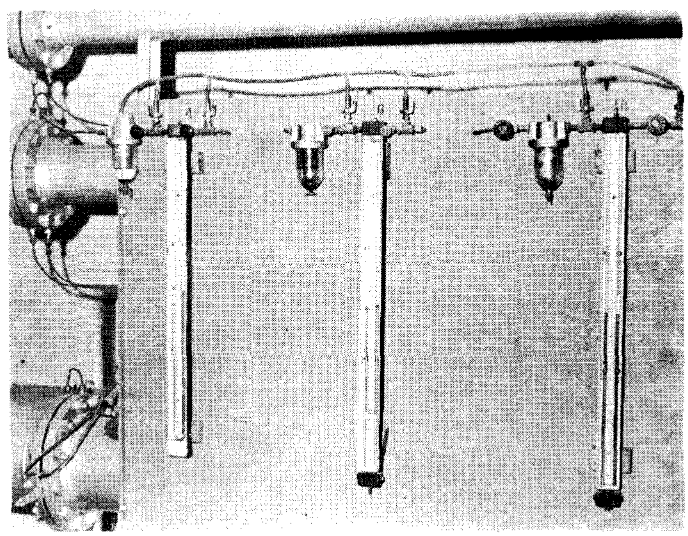


Figure 9
Pipe Orifices and Manometer Board

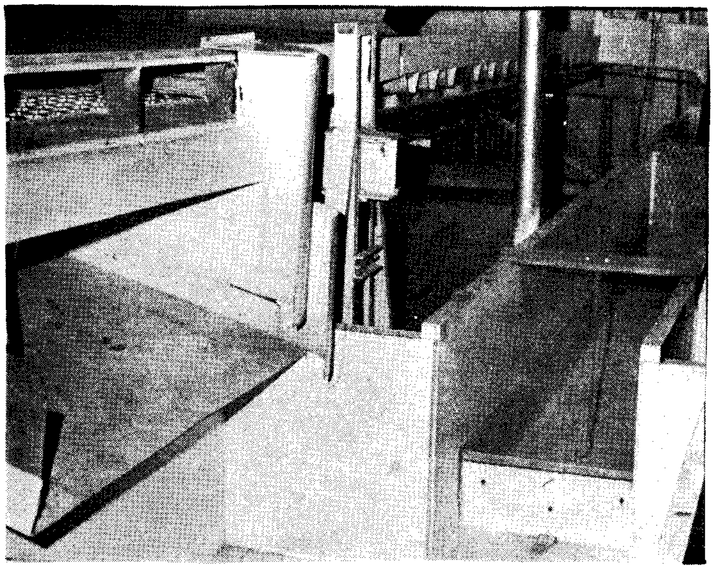


Figure 10
RCB 22X Storm Inlet and Return Flume

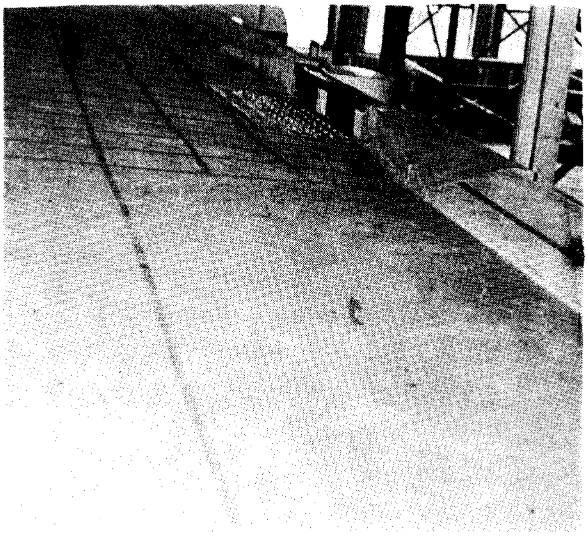


Figure 11
RCB 22X Curb and Grate Setup

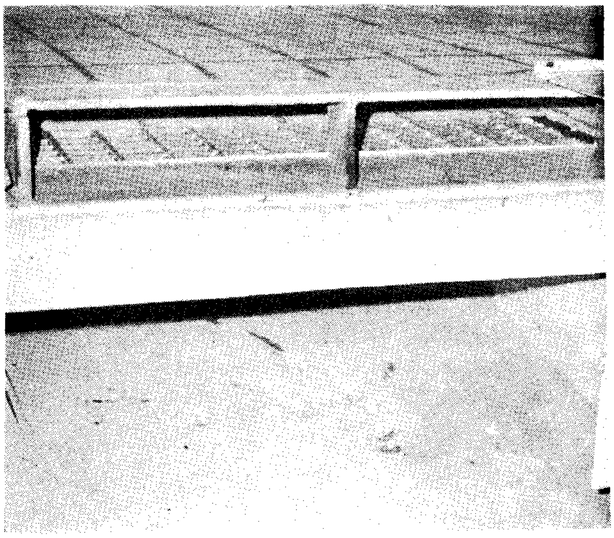


Figure 12
RCB 22X Storm Inlet

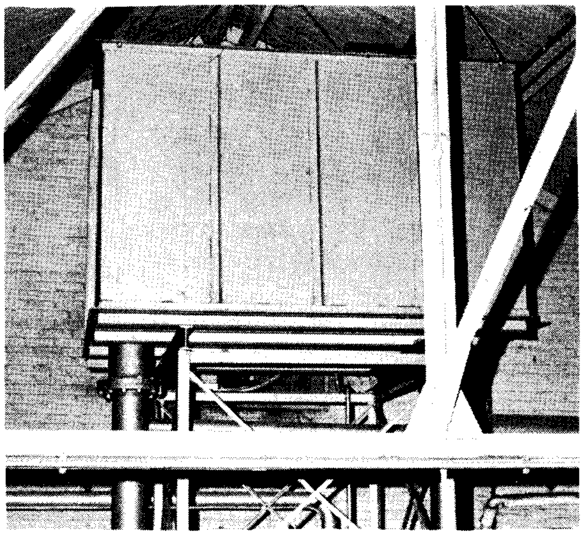


Figure 13
Permanent Overhead Tank

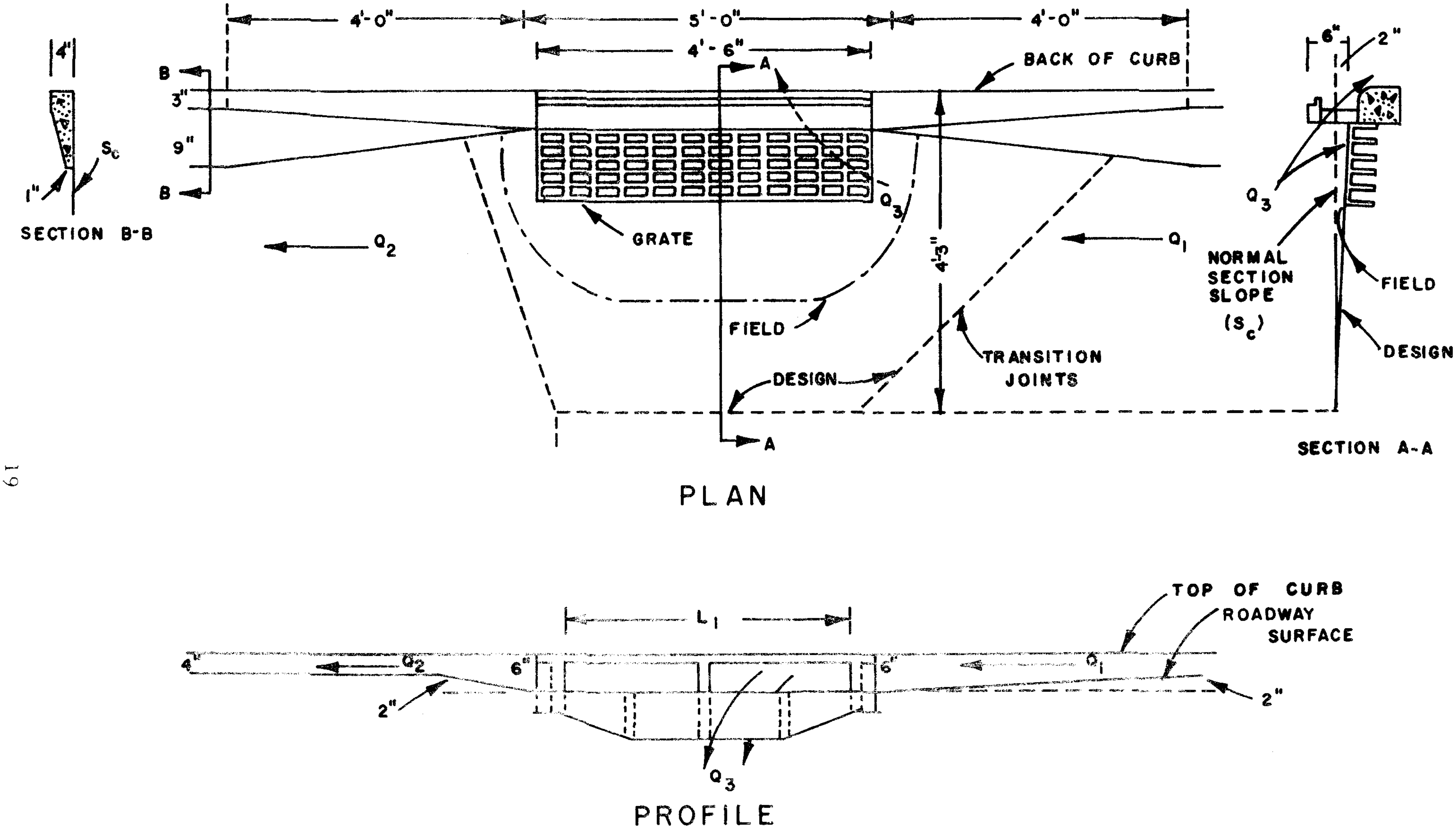


FIGURE 14 RCB-22X (ROLL-OVER CURB) SCALE: 1"=2'

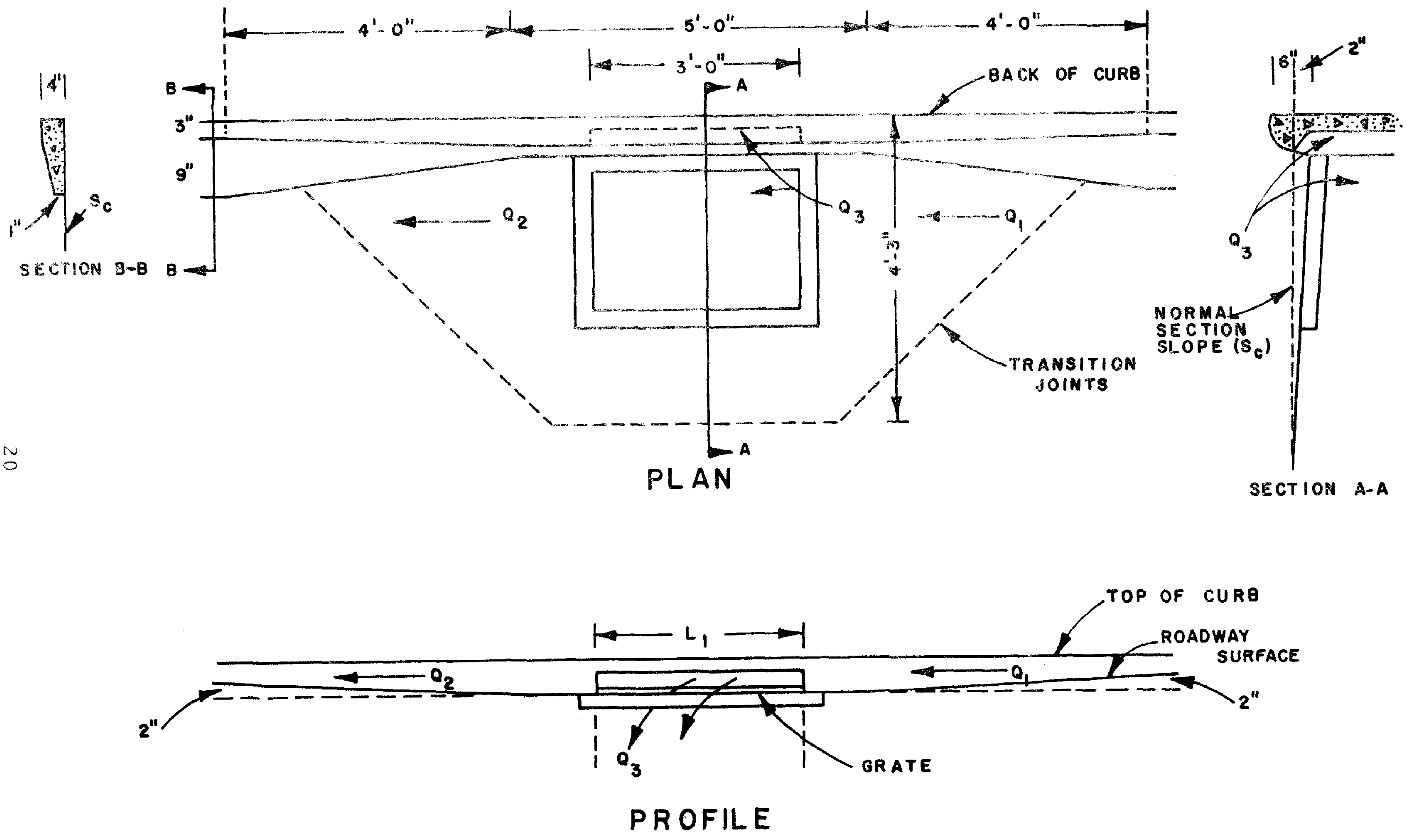


FIGURE 15 RCB-31X REV. (ROLL-OVER CURB) SCALE: 1"=2'

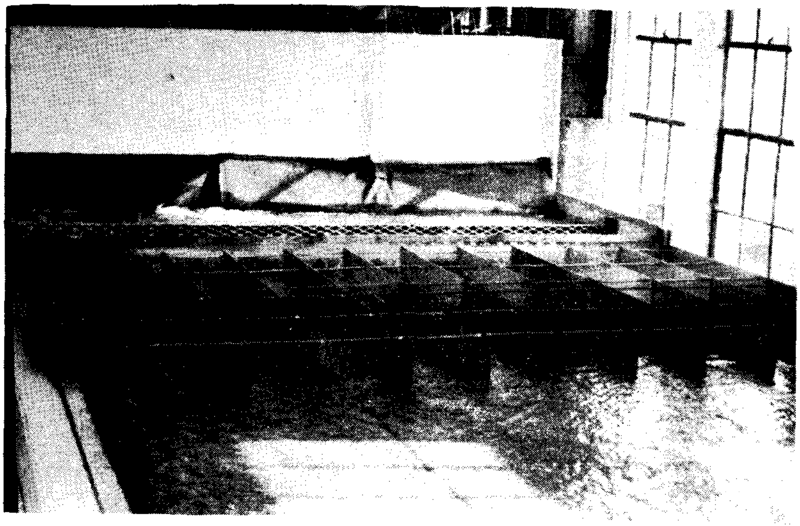


Figure 36
Water Flowing Through Vanes

Figure 37
Water Flowing to Sump From
Catch Basin and Weir

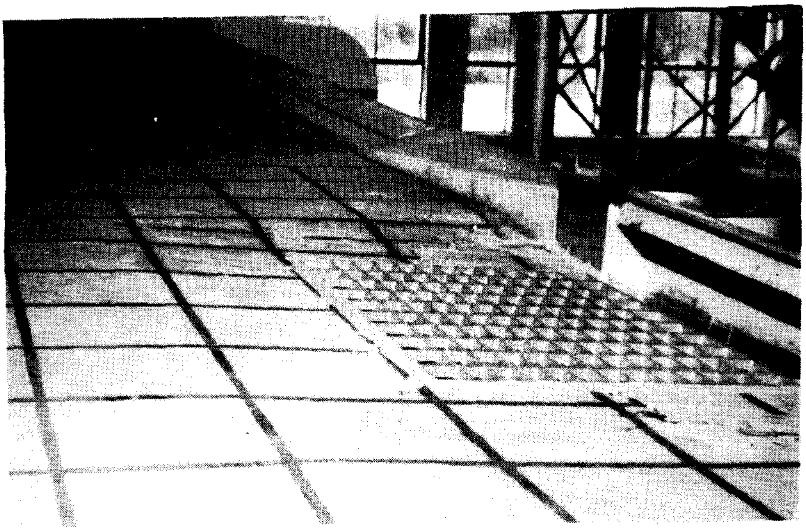
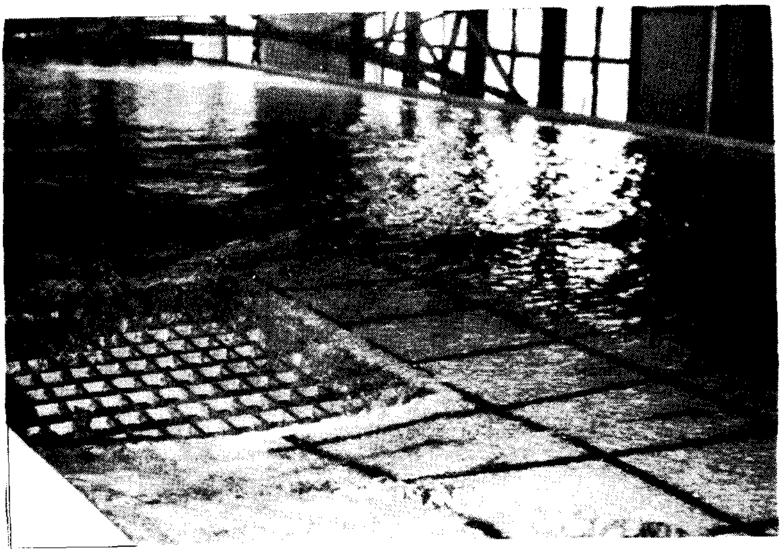
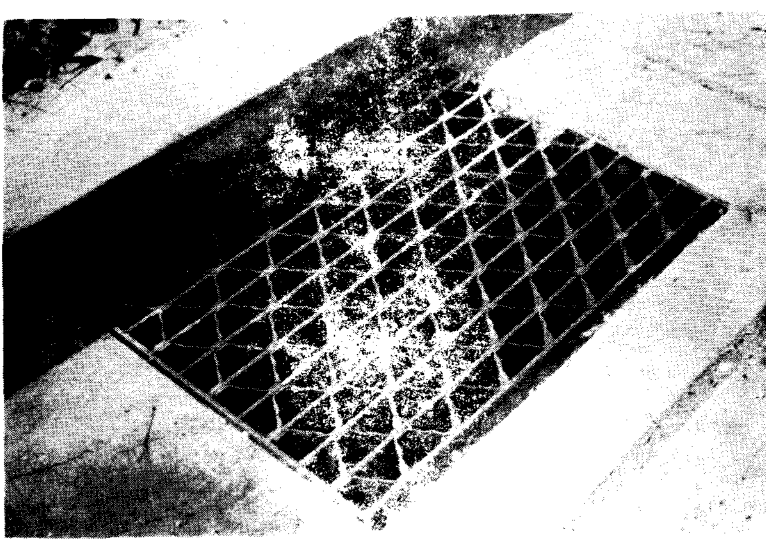


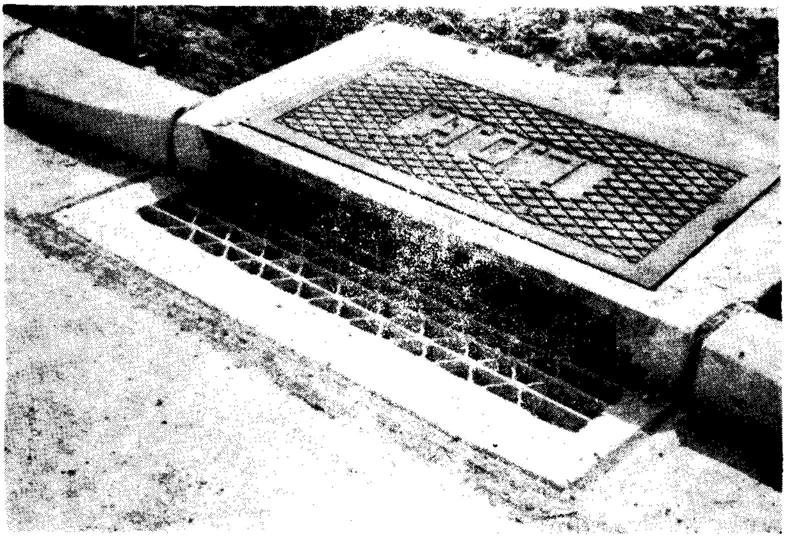
Figure 18
RCB 31X Rev. Grate



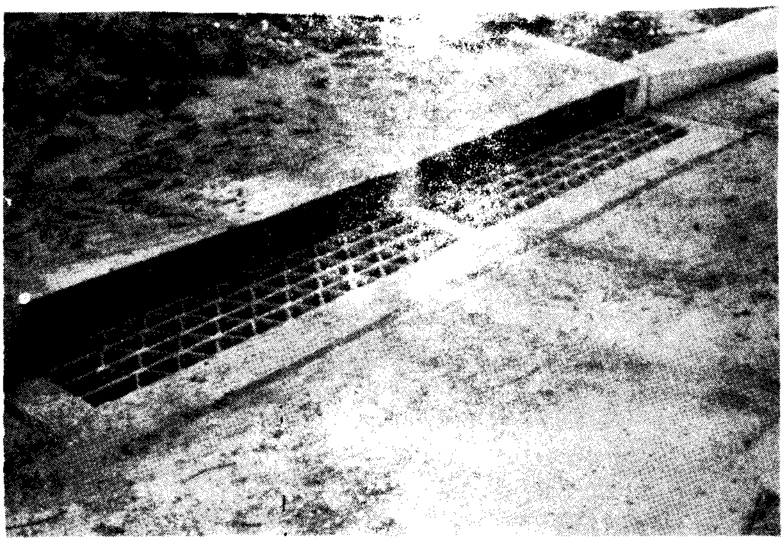
Dov [illegible] ater



RCB [illegible]
Retic [illegible]



RCB 22 [illegible] line



([illegible] eted
Retic [illegible] ield

Cross Slope	0.020 (ft./ft.)				0.030 (ft./ft.)			
Long. Slope	L (ft.)	Q_1(cfs)	Q_3(cfs)	IR Q_3/Q_1	L (ft.)	Q_1(cfs)	Q_3(cfs)	IR Q_3/Q_1
0.003 (ft./ft.)	7.1	0.996	0.996	1.00	6.2	1.050	1.050	1.00
	9.0	1.101	1.081	0.98	7.6	1.643	1.635	0.995
	10.7	1.992	1.768	0.89	8.9	2.348	2.114	0.90
	12.0	2.942	2.035	0.69	10.1	2.923	2.316	0.79
0.005 (ft./ft.)	6.5	0.664	0.664	1.00	6.5	1.328	1.328	1.00
	8.2	1.101	1.087	0.99	7.6	1.626	1.591	0.98
	10.0	1.936	1.626	0.84	8.7	2.264	1.947	0.86
	11.6	3.025	1.921	0.64	9.8	2.758	1.871	0.68
0.010 (ft./ft.)	6.5	0.621	0.621	1.00	5.9	1.220	1.220	1.00
	8.2	1.369	1.191	0.87	7.1	1.741	1.545	0.89
	9.5	1.907	1.371	0.72	8.0	2.451	1.830	0.75
	10.9	2.998	1.400	0.47	9.0	2.951	1.774	0.60
0.020 (ft./ft.)	5.6	0.621	0.621	1.00	5.3	1.076	1.076	1.00
	6.9	1.076	0.907	0.84	6.5	1.725	1.382	0.80
	8.0	1.626	0.987	0.61	7.5	2.177	1.228	0.56
	9.2	3.043	1.345	0.44	8.5	2.895	1.229	0.425
0.030 (ft./ft.)	5.4	0.968	0.968	1.00	3.7	0.575	0.575	1.00
	6.4	1.242	0.943	0.76	5.3	1.150	1.021	0.89
	7.3	1.626	0.931	0.57	6.4	1.660	1.066	0.64
	8.3	2.942	1.218	0.41	7.7	3.202	1.497	0.47

TABLE 1

SUMMARY OF DATA FOR RCB 22X WELDED BAR STEEL GRATES

Cross Slope	0.020 (ft./ft.)				0.030 (ft./ft.)			
Long. Slope	L (ft.)	Q_1 (cfs)	Q_3 (cfs)	IR Q_3/Q_1	L (ft.)	Q_1 (cfs)	Q_3 (cfs)	IR Q_3/Q_1
0.003 (ft./ft.)	6.9	1.050	1.050	1.00	6.3	1.174	1.174	1.00
	8.8	1.197	1.187	0.99	7.5	1.788	1.785	0.998
	10.7	1.936	1.734	0.90	8.7	2.324	2.167	0.93
	12.7	2.895	2.014	0.70	9.7	2.960	2.380	0.80
0.005 (ft./ft.)	5.7	0.742	0.742	1.00	5.5	1.050	1.050	1.00
	8.0	1.050	1.043	0.993	7.2	1.369	1.367	0.999
	10.3	1.936	1.637	0.85	8.5	2.202	1.955	0.89
	12.0	2.988	1.906	0.64	9.7	2.876	2.045	0.71
0.010 (ft./ft.)	5.6	0.939	0.939	1.00	5.0	1.050	1.050	1.00
	7.2	1.076	1.046	0.97	6.5	1.328	1.258	0.95
	9.0	1.660	1.264	0.76	7.4	2.252	1.775	0.79
	10.7	2.876	1.334	0.46	8.6	2.895	1.730	0.60
0.020 (ft./ft.)	5.4	0.470	0.470	1.00	4.5	0.525	0.525	1.00
	6.8	1.050	0.910	0.87	5.7	1.522	1.326	0.87
	8.6	1.992	1.049	0.53	7.0	2.152	1.400	0.65
	9.7	3.202	1.672	0.52	8.1	3.007	1.422	0.47
0.030 (ft./ft.)	4.7	0.406	0.406	1.00	3.5	0.525	0.525	1.00
	6.4	1.150	0.792	0.69	4.9	0.878	0.862	0.98
	7.4	2.202	1.185	0.54	6.3	1.660	1.035	0.62
	8.7	3.202	1.523	0.48	7.7	3.202	1.478	0.46

TABLE 2

SUMMARY OF DATA FOR RCB 22X RIVETED RETICULINE GRATE

ROLL-OVER TYPE CURB

Cross Slope / Long. Slope	0.020 (ft./ft.) L (ft.)	Q_1 (cfs)	Q_3 (cfs)	IR Q_3/Q_1	0.030 (ft./ft.) L (ft.)	Q_1 (cfs)	Q_3 (cfs)	IR Q_3/Q_1
0.003 (ft./ft.)	6.6	0.594	0.594	1.00	6.3	0.968	0.968	1.00
	8.4	1.023	1.011	0.99	8.0	1.964	1.941	0.99
	10.4	1.819	1.698	0.93	9.2	2.440	2.314	0.95
	12.0	3.270	2.631	0.80	10.2	3.304	2.904	0.88
0.005 (ft./ft.)	6.5	0.575	0.575	1.00	6.0	0.846	0.846	1.00
	8.3	1.126	1.103	0.98	7.0	1.349	1.347	0.998
	10.1	1.922	1.708	0.89	8.7	2.336	2.182	0.93
	11.8	3.052	2.222	0.73	10.0	3.304	2.810	0.85
0.010 (ft./ft.)	5.7	0.470	0.470	1.00	5.6	0.813	0.813	1.00
	7.0	0.813	0.808	0.99	6.6	1.369	1.360	0.99
	9.0	1.677	1.430	0.85	7.6	2.202	2.003	0.91
	10.7	3.043	1.867	0.61	8.7	3.070	2.371	0.77
0.020 (ft./ft.)	5.4	0.704	0.704	1.00	5.3	0.846	0.846	1.00
	6.0	0.909	0.906	0.997	6.5	1.660	1.567	0.94
	7.3	1.369	1.229	0.90	7.5	2.152	1.748	0.81
	9.0	2.979	1.924	0.65	8.6	3.007	1.963	0.65
0.030 (ft./ft.)	5.3	0.813	0.813	1.00	5.0	1.878	0.878	1.00
	6.2	1.076	1.031	0.96	6.0	1.409	1.341	0.95
	7.1	1.643	1.390	0.85	7.0	1.849	1.491	0.81
	8.0	3.034	2.101	0.69	7.8	2.951	1.950	0.66

TABLE 3

SUMMARY OF DATA FOR RCB 31X REVISED WELDED BAR STEEL GRATE

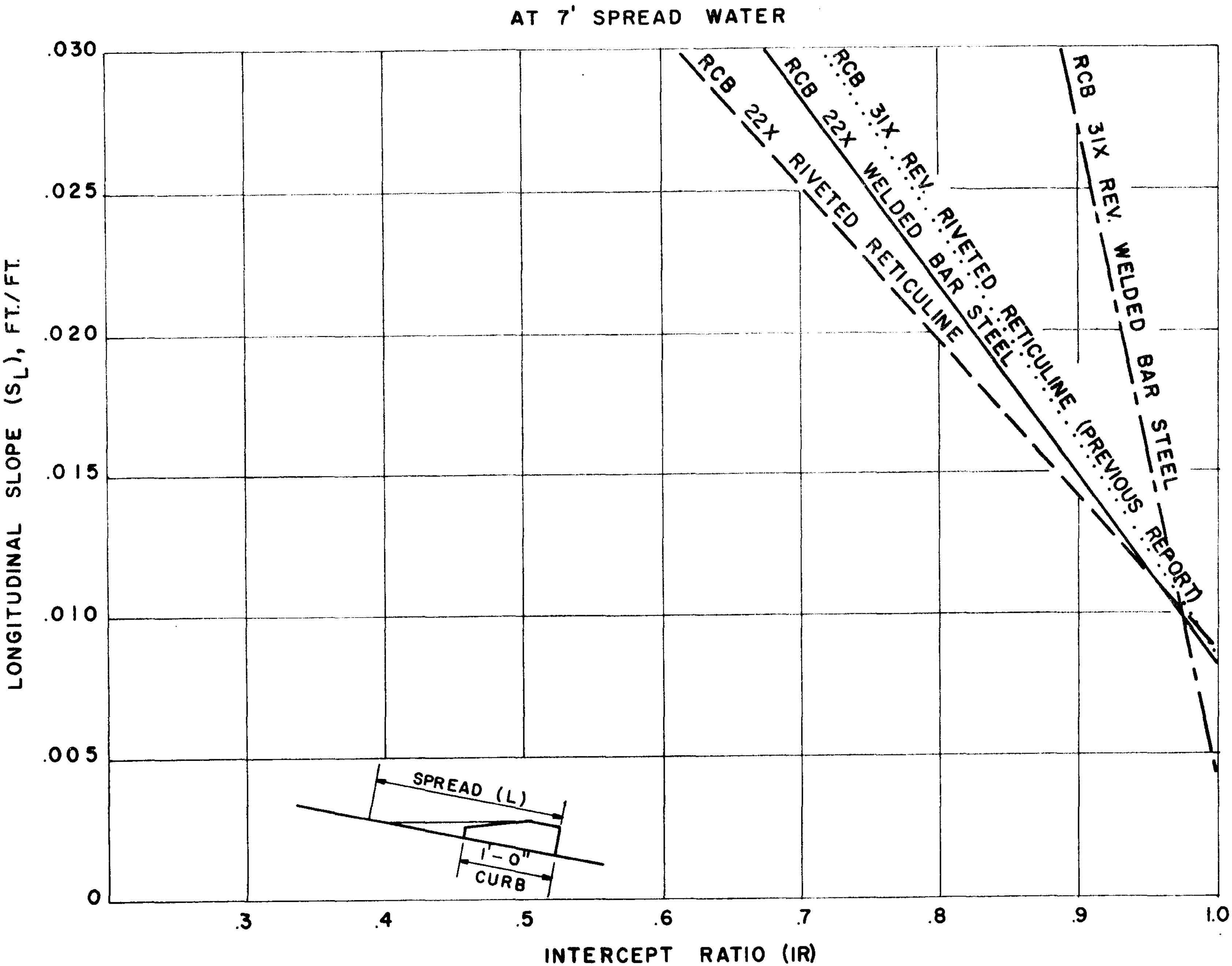


FIGURE 24

COMPARISON GRATE EFFICIENCIES

CROSS SLOPE = .020 FT./FT.

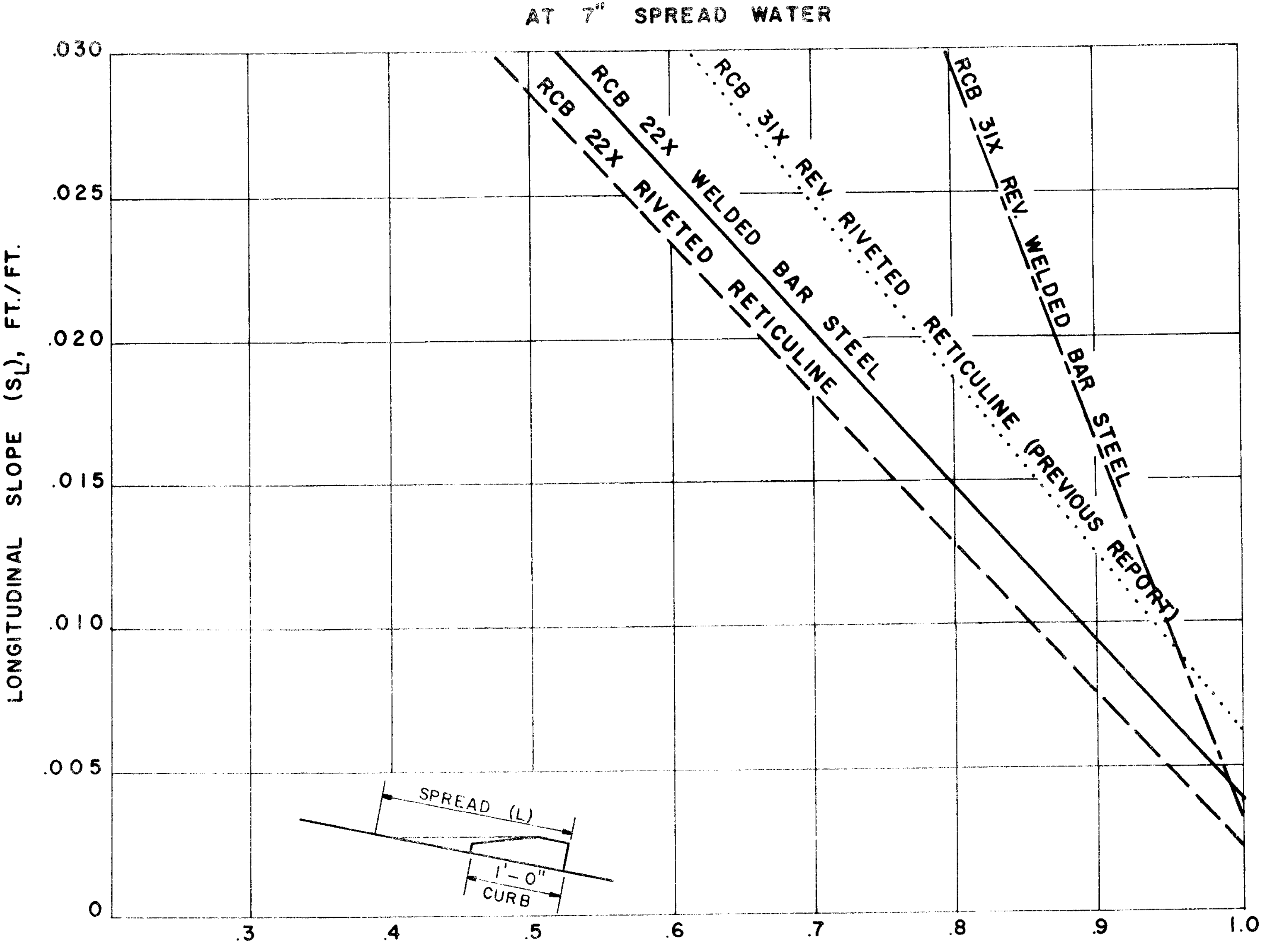


FIGURE 25

COMPARISON GRATE EFFICIENCIES

CROSS SLOPE = .030 FT./FT.

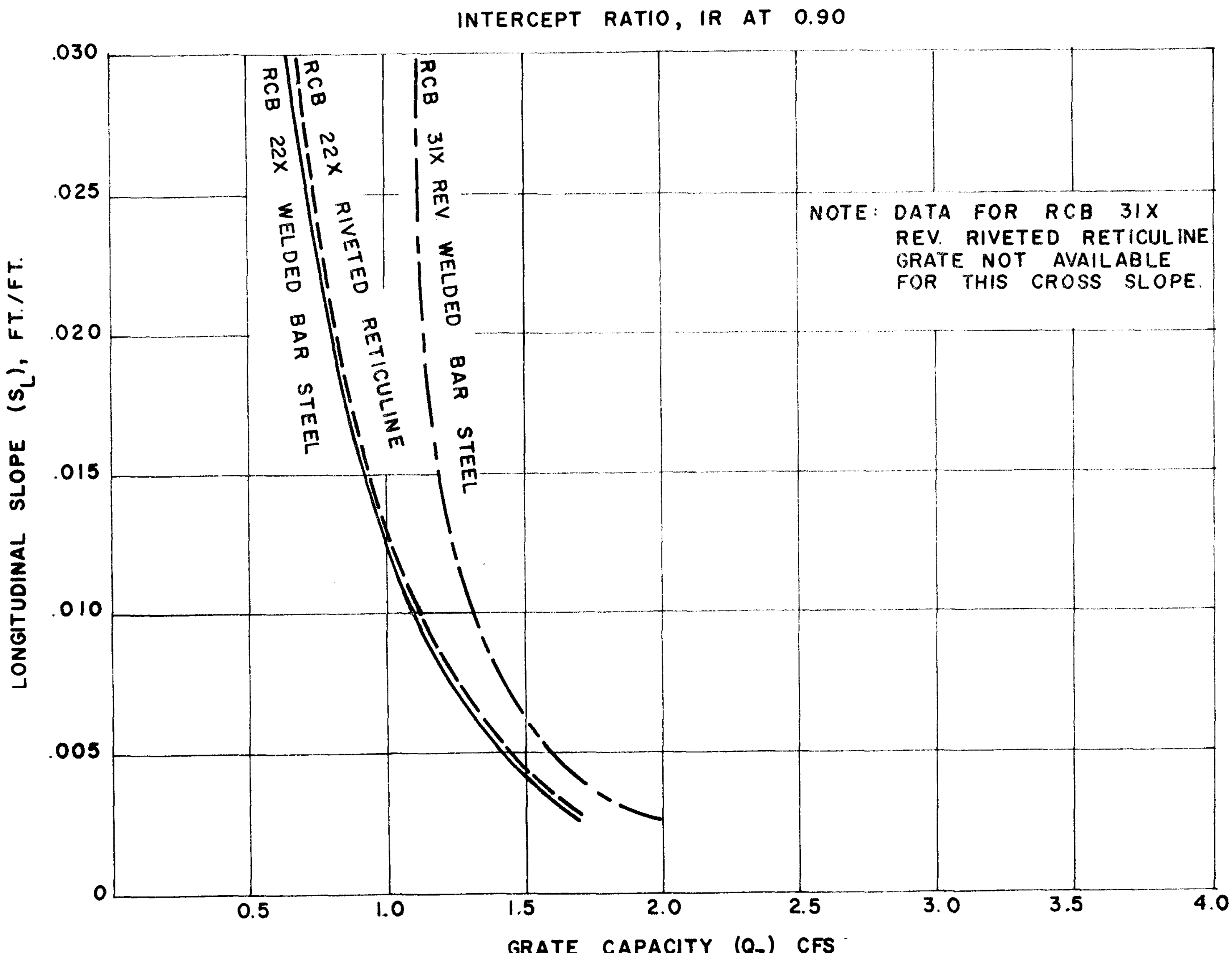


FIGURE 26
COMPARISON GRATE CAPACITIES
CROSS SLOPE = .0 2 0 FT./FT.

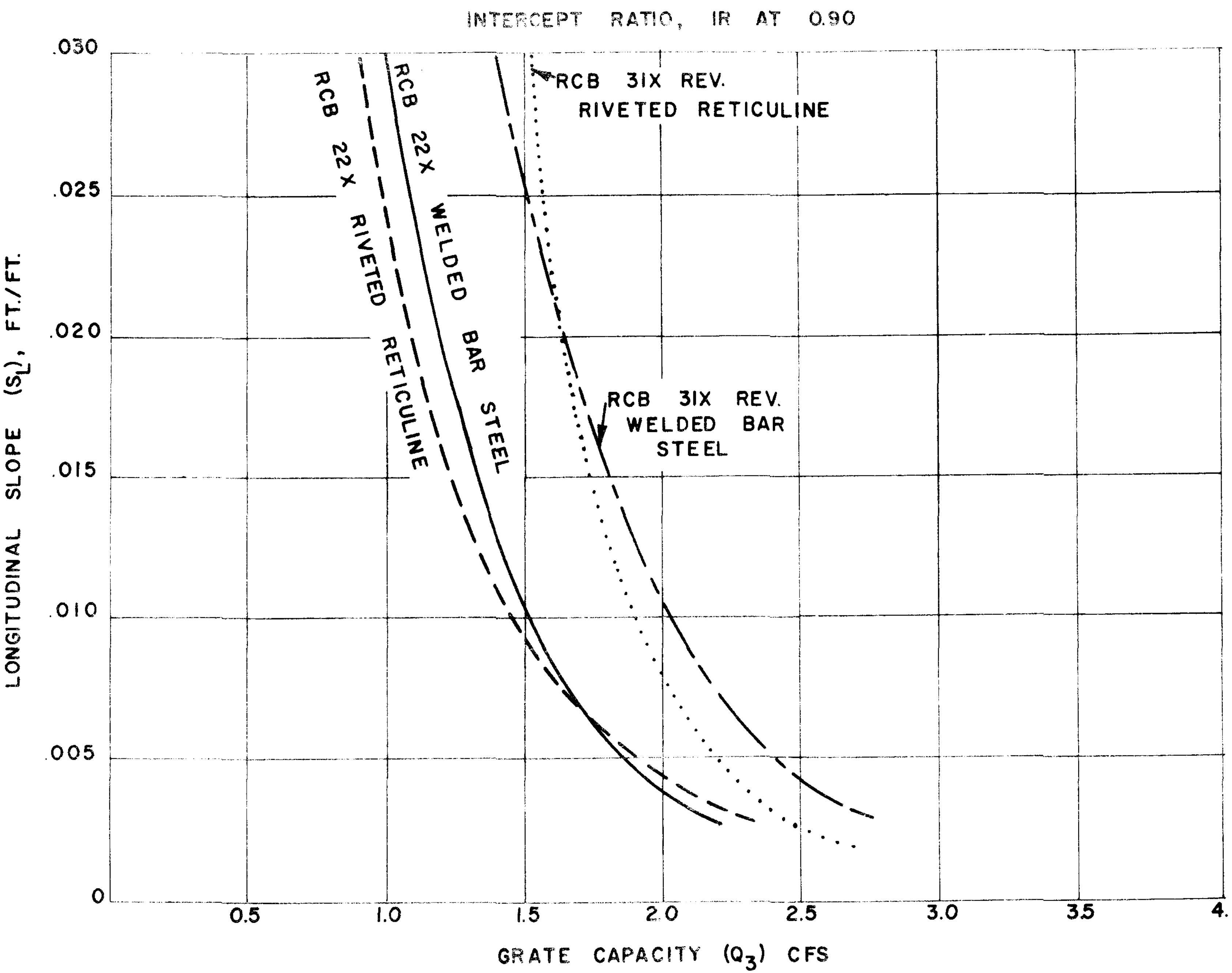


FIGURE 27

COMPARISON GRATE CAPACITIES

CROSS SLOPE = .030 FT./FT.

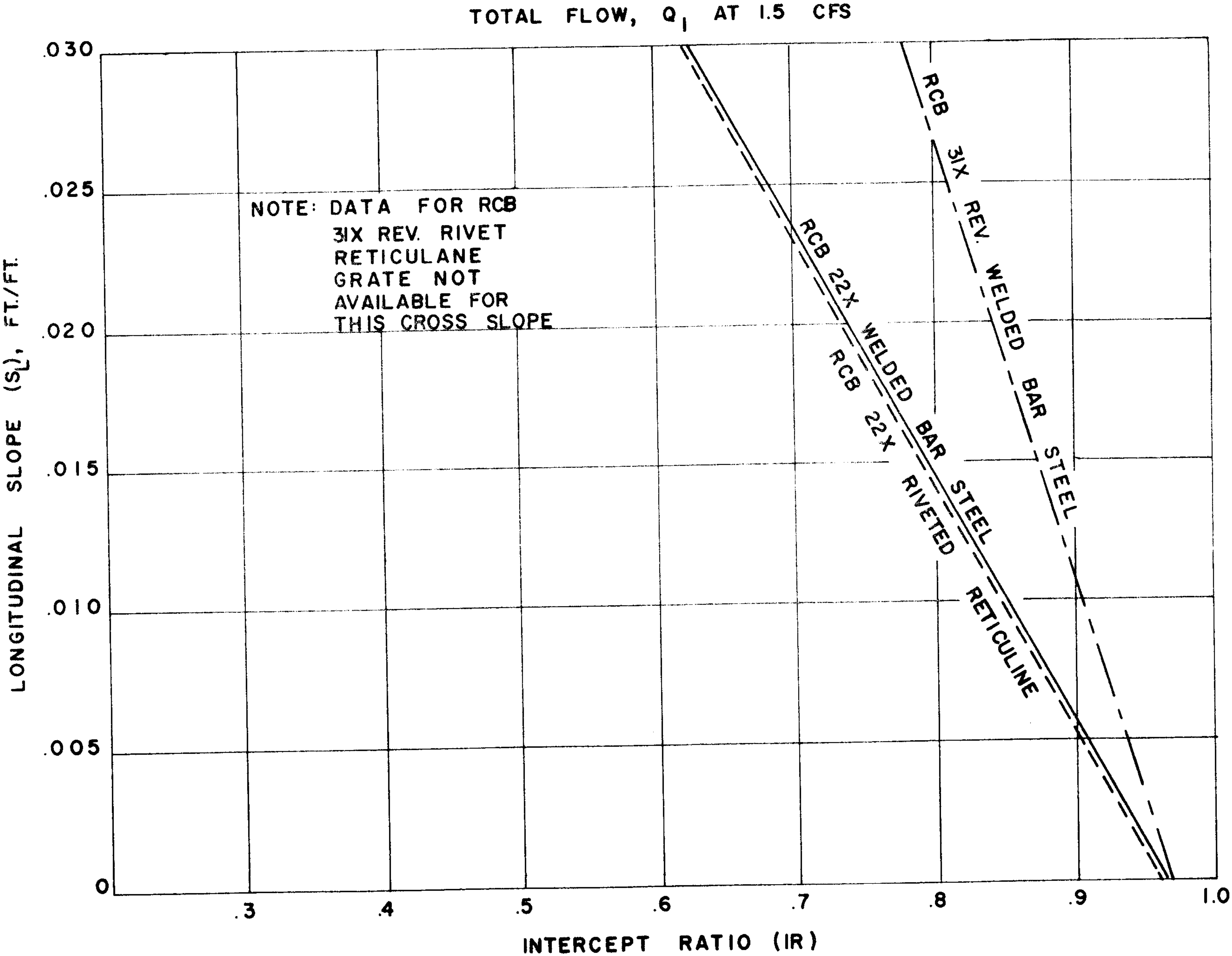


FIGURE 28

COMPARISON GRATE EFFICIENCIES

CROSS SLOPE = .020 FT./FT.

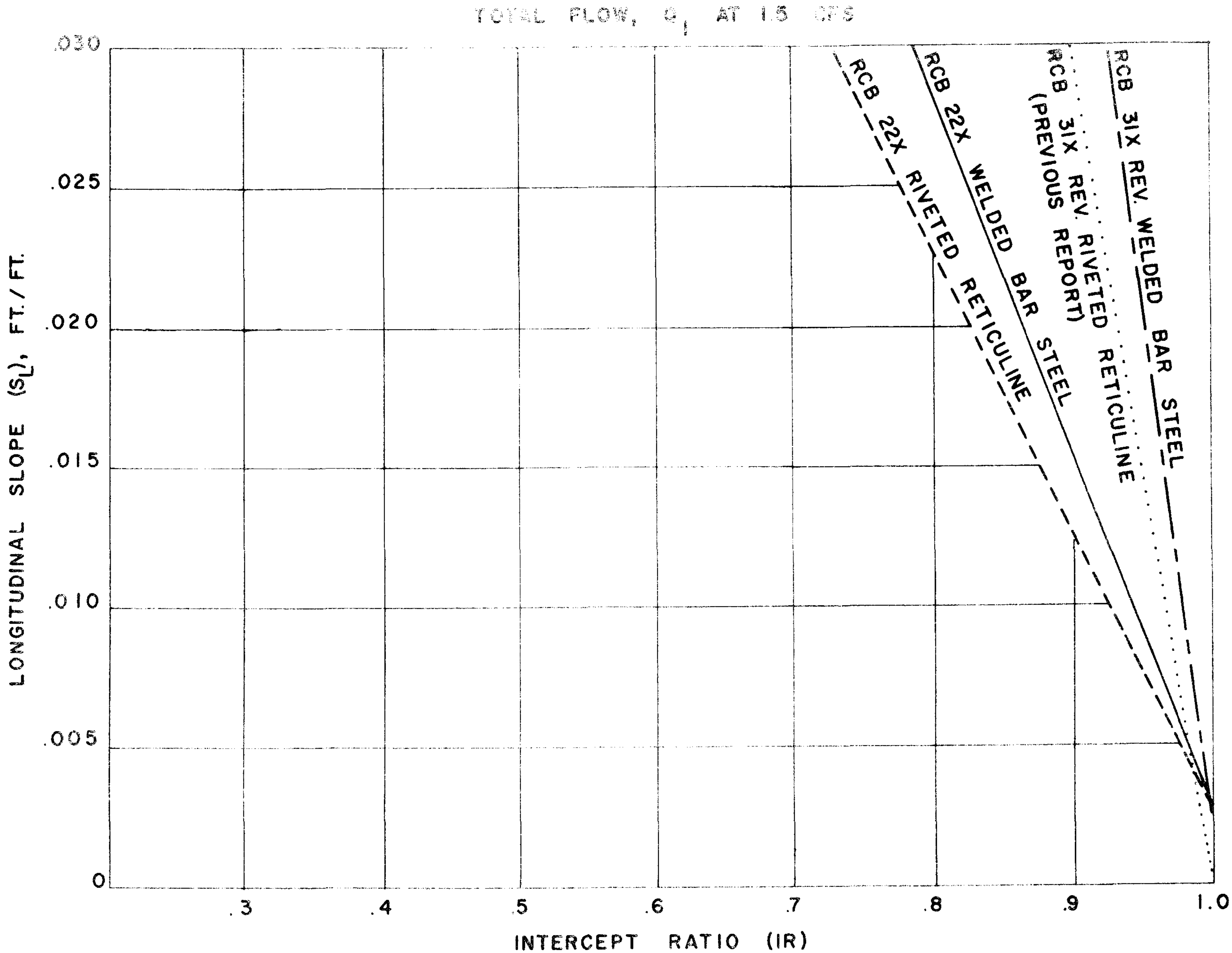


FIGURE 29

COMPARISON GRATE EFFICIENCIES

CROSS SLOPE = .030 FT./FT.

ROLL-OVER TYPE CURB

CROSS SLOPE = .020 FT./FT.

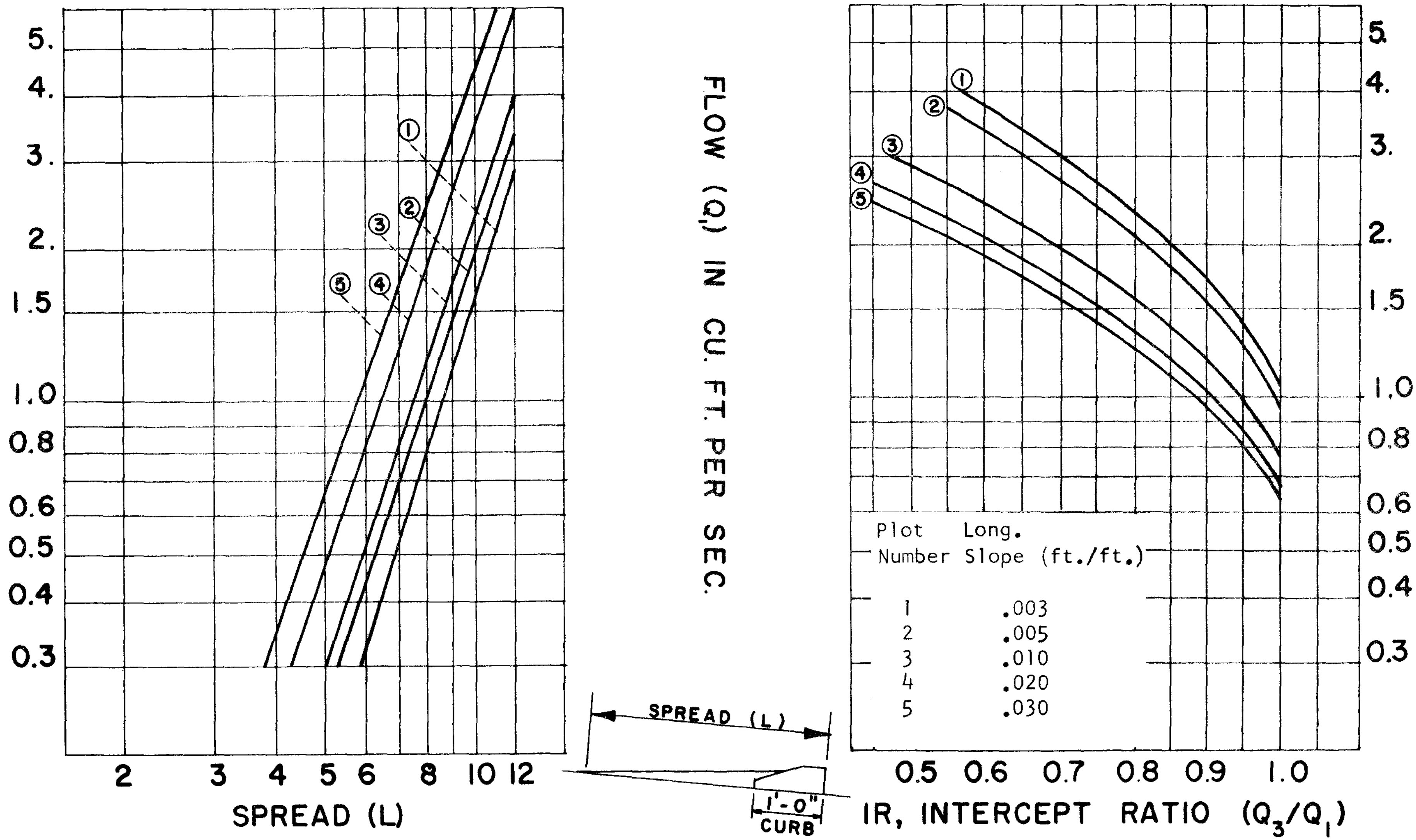


FIGURE 30

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO

RCB 22X WELDED BAR STEEL

ROLL-OVER TYPE CURB
CROSS SLOPE = .030 FT./FT.

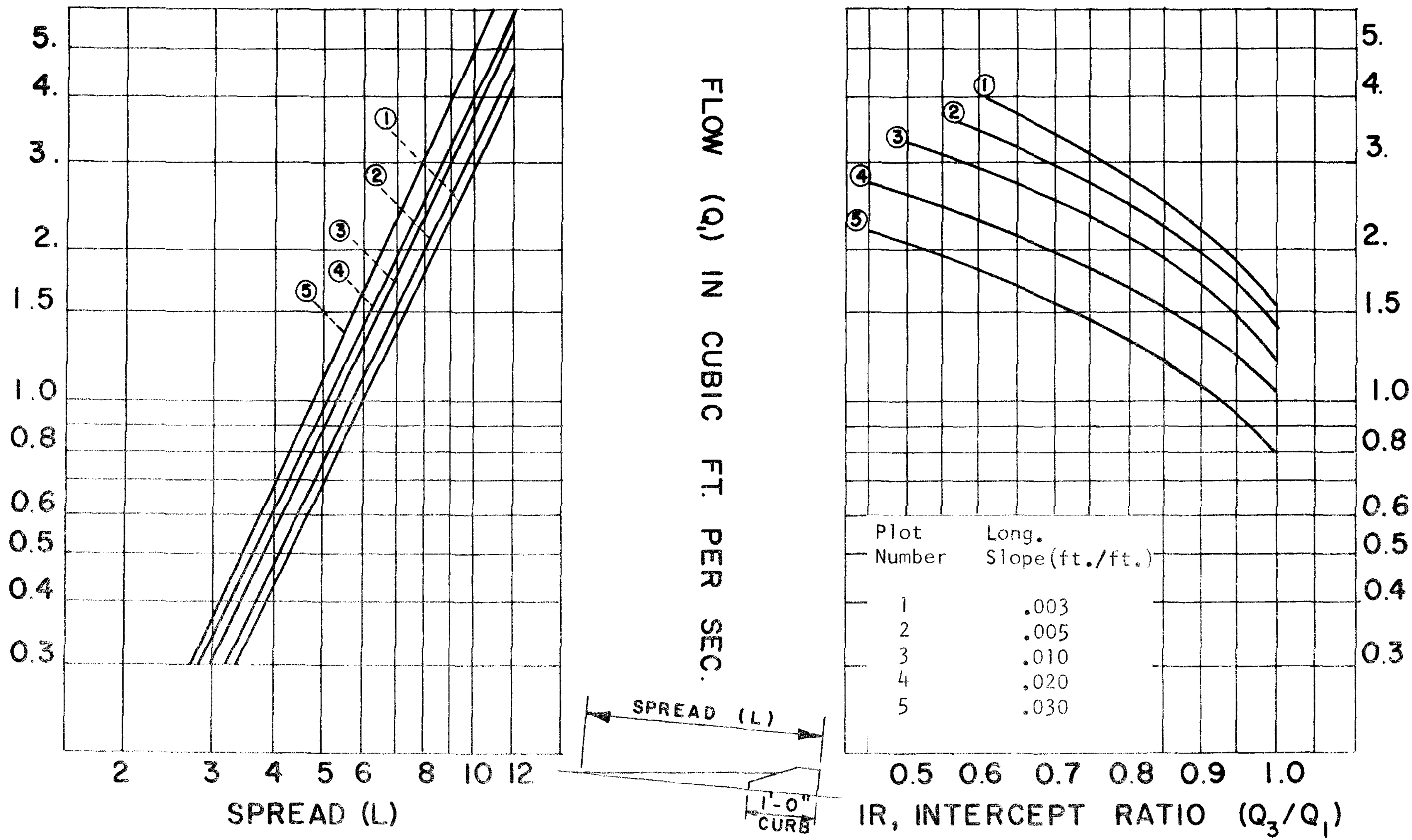


FIGURE 31

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO
RCB 22 X WELDED BAR STEEL

ROLL-OVER TYPE CURB
CROSS SLOPE = .020 FT./FT.

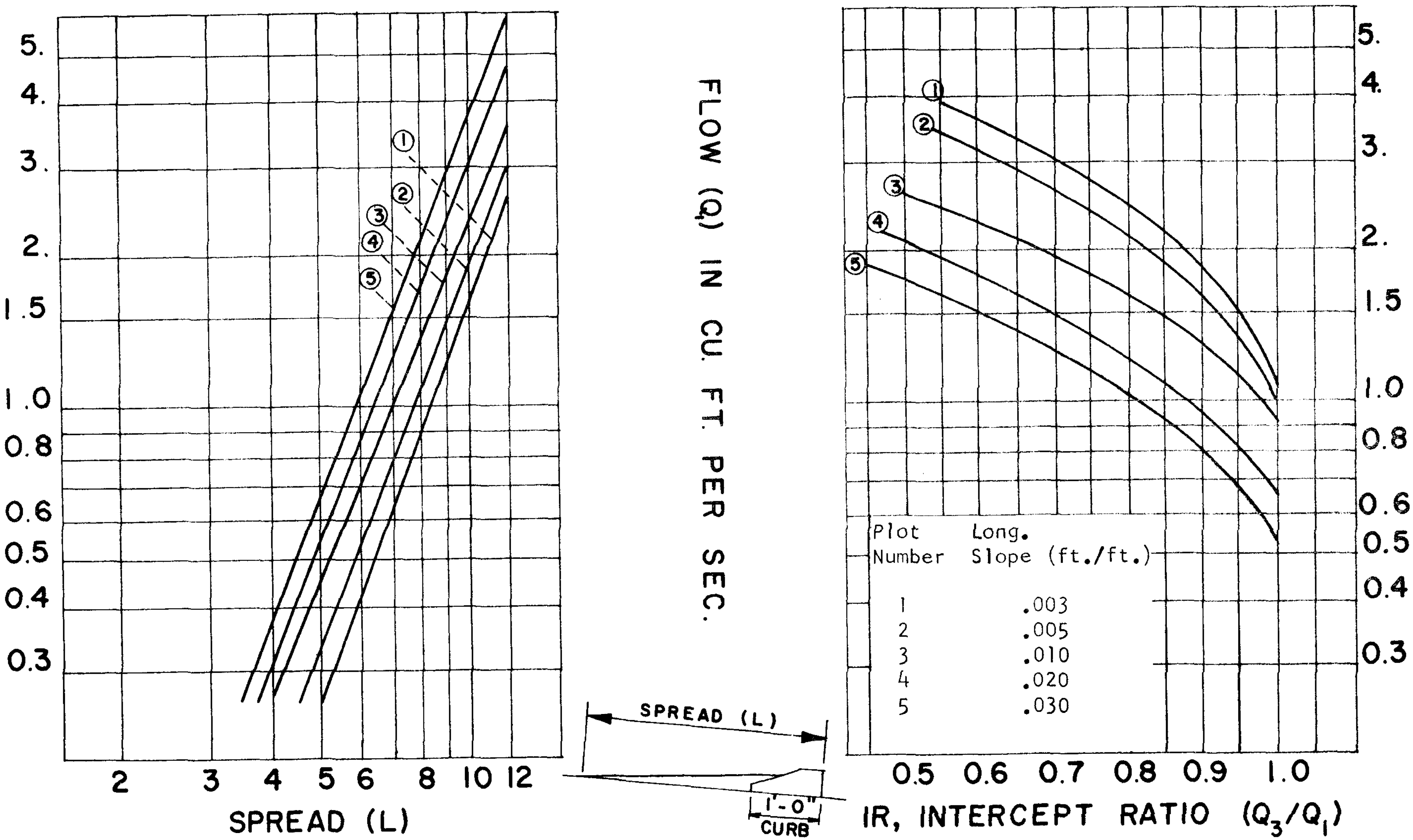


FIGURE 32

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO
RCB 22X RIVETED RETICULINE

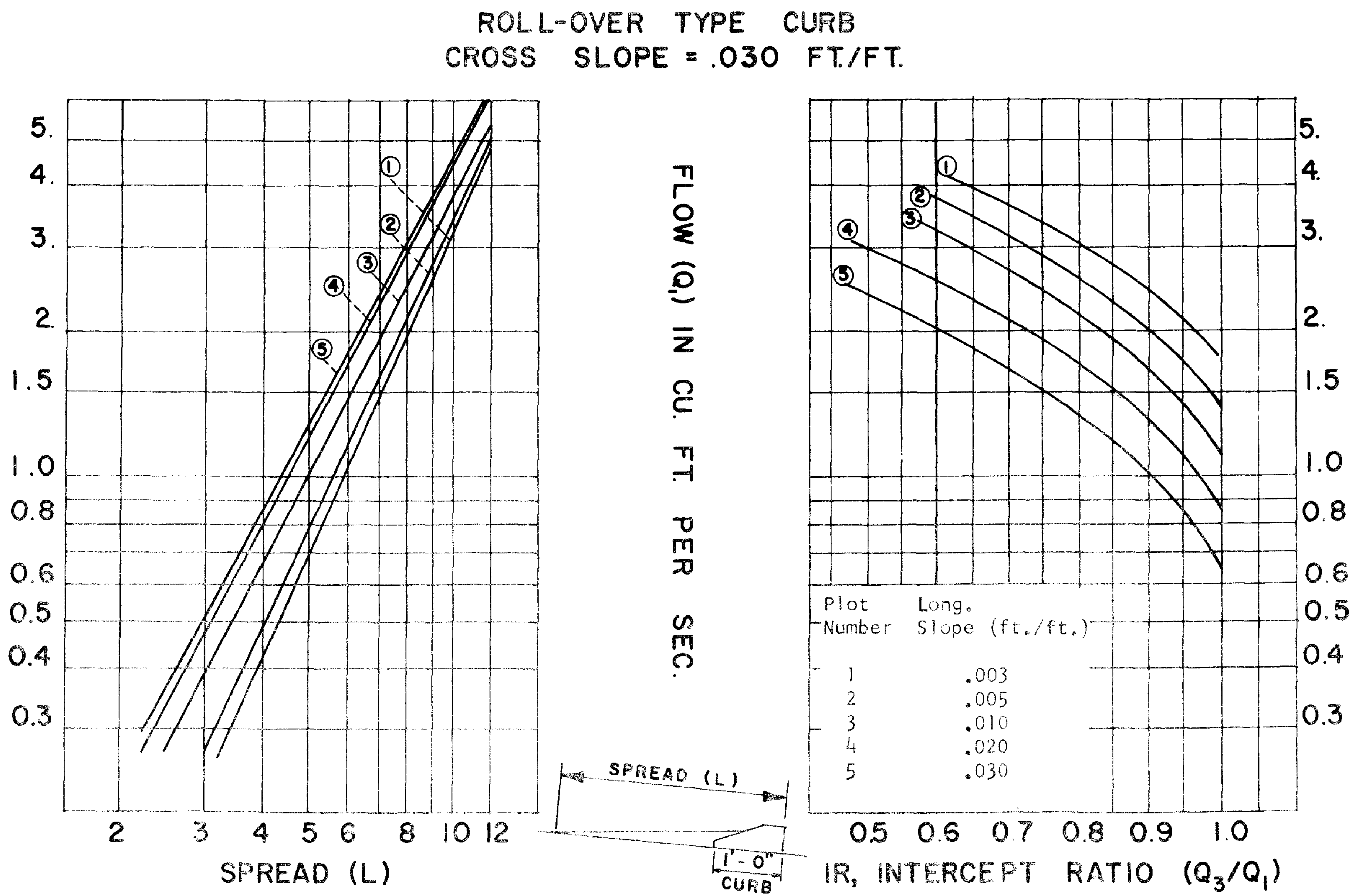


FIGURE 33

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO

RCB 22X RIVETED RETICULINE

ROLL-OVER TYPE CURB
CROSS SLOPE = .020 FT./FT.

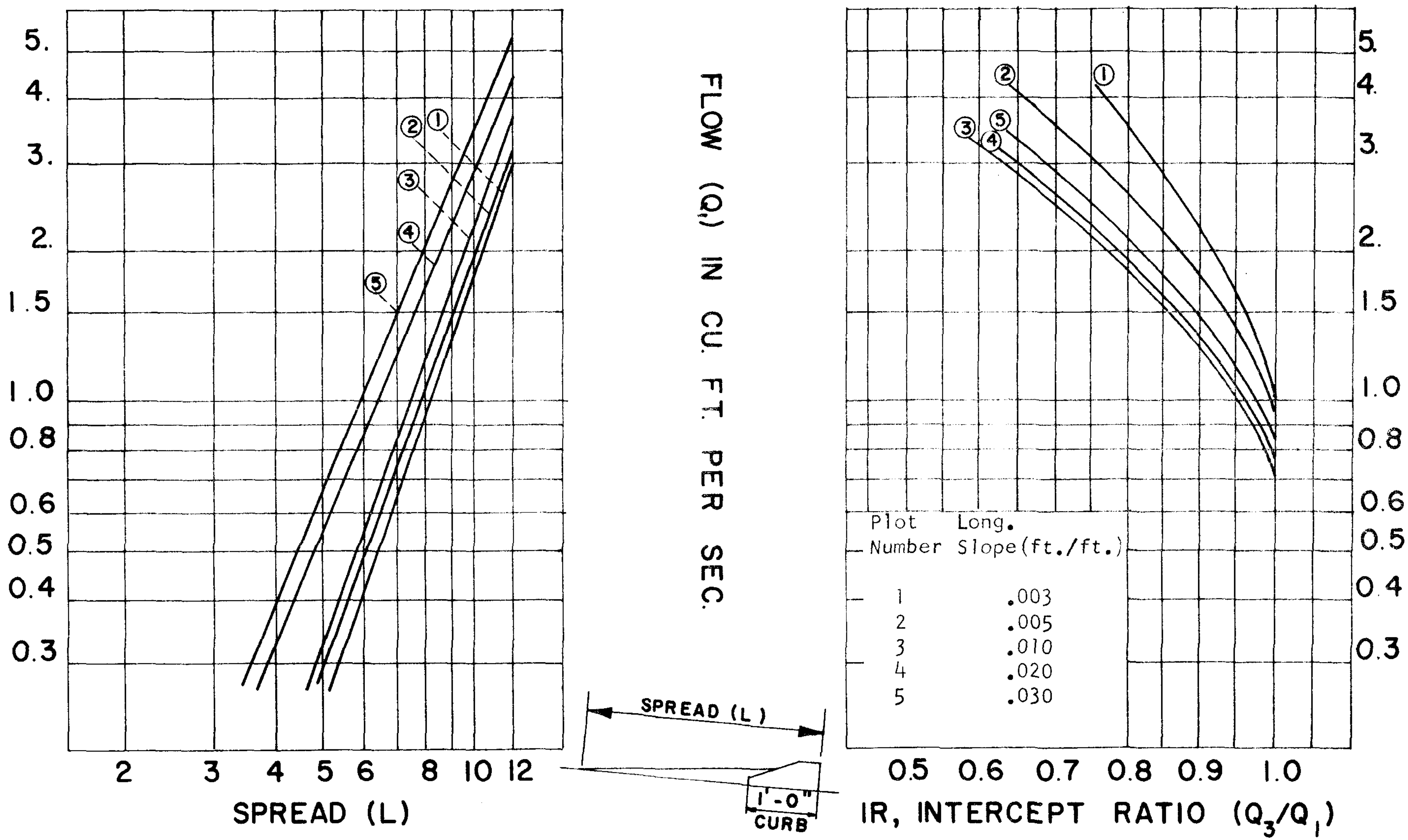


FIGURE 34

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO

RCB 31X REV. WELDED BAR STEEL

ROLL-OVER TYPE CURB
CROSS SLOPE = .030 FT./FT.

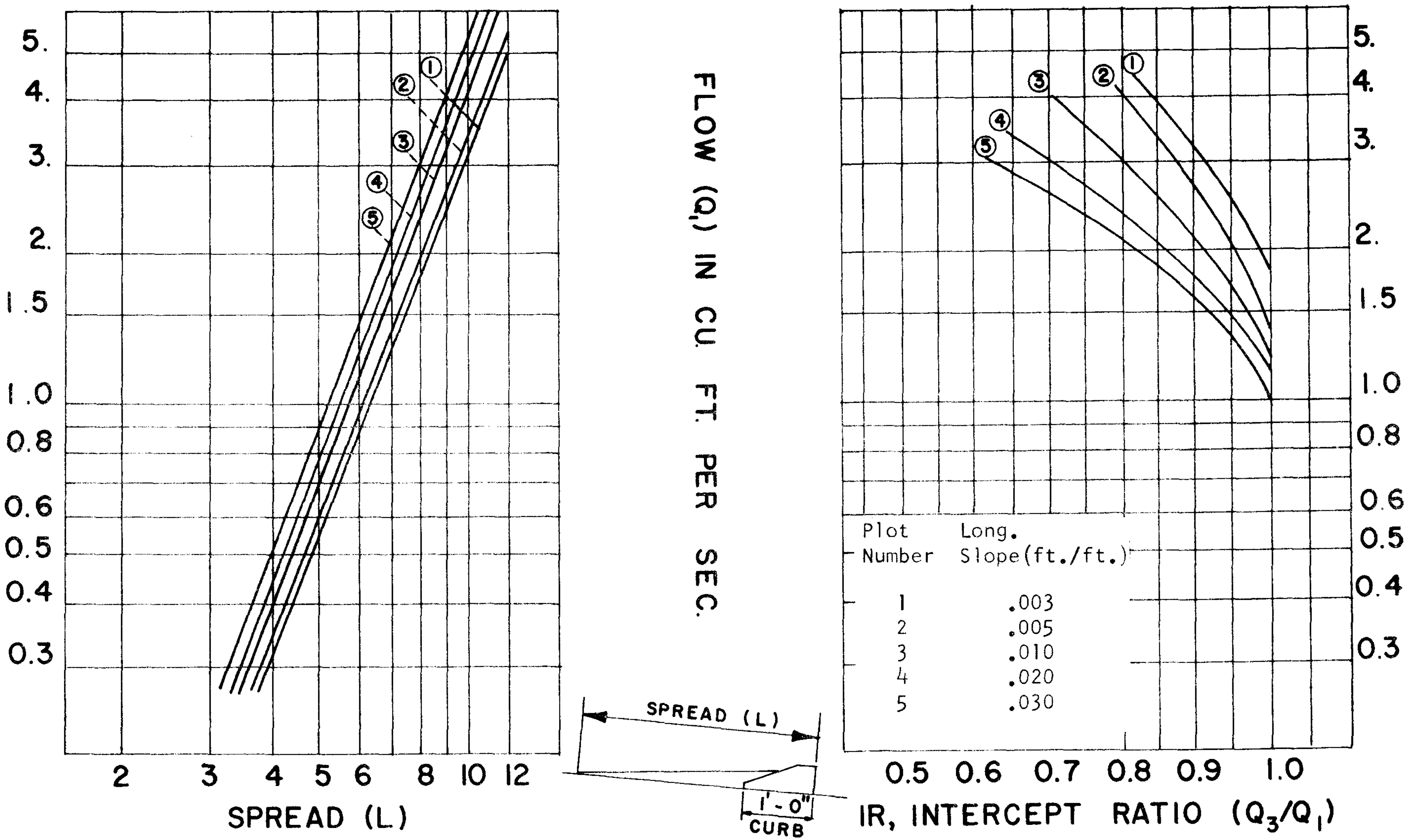


FIGURE 35

FLOW IN ROAD FOR GIVEN SPREAD AND INTERCEPT RATIO

RCB 31X REV. WELDED BAR STEEL