CITY of WACO, TEXAS

ENGINEERING DEPARTMENT

City Hall

Waco, Texas

June 15, 1959

The City of Waco "Storm Drainage Design Manual" prepared for the City of Waco by Forrest and Cotton, was officially adopted by the City Council on June 9, 1959, as the standard manual for all drainage design by and/or requiring the approval of the City Engineering Department.

The City Council also established a standard price of $25.00 per copy for this manual.

T. F. Collins

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Asst. City Engineer

TFC:mf

CITY OF WACO, TEXAS

ENGINEERING DEPARTMENT

STORM DRAINAGE DESIGN MANUAL

FORREST AND COTTON, INC.
CONSULTING ENGINEERS
DALLAS, TEXAS

1959

PREFACE

By authority of the City Commission, the City Manager directed that a storm drainage design manual be prepared in conjunction with the development of the Master Storm Drainage Plan.

The principal objective in compiling the material for this manual has been to present information and data on the design and construction of storm drainage systems in a readily usable form. Sections of the manual have been arranged so the reader may easily follow the descriptive material into more technical details.

Obviously, in so intensive a field as drainage engineering, no one individual or organization could claim personal authorship for all the development in the drainage engineering field which is portrayed in this manual; however, special recognition is acknowledged for the contribution of Mr. W. F. Albritton, of this firm. The technical review and assistance of Mr. I. W. Santry, Professor of Civil Engineering, Southern Methodist University, has been most helpful. Also acknowledged with special thanks is the development work of the Engineers of the U. S. Weather Bureau, U. S. Bureau of Public Roads, U. S. Army Corps of Engineers, U. S. Soil Conservation Service, Johns Hopkins University, Iowa State College, Texas Highway Department, American Concrete Pipe Association, Portland Cement Association, American Association of State Highway Officials and many others. To the engineers of these organizations and agencies goes credit for much of the research and data presented within this manual.

FORREST AND COTTON, INC.
Consulting Engineers

Dallas, Texas
March 1959

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SECTION I

INTRODUCTION

1.01 PURPOSE

The purpose of this drainage manual is to establish standard principles and practices for the design and construction of surface drainage systems within the City of Waco, Texas. The design factors, formulas, graphs and procedures are intended for use as engineering guides in the solution of drainage problems involving determination of the quantity, method of collection, and disposal of storm water.

Methods of design other than those indicated herein may be considered in difficult cases where experience clearly indicates they are preferable. However, there should be no important variations from the practices established herein until the City Engineer has given his approval.

1.02 SCOPE

The manual represents the application of accepted principles of surface drainage engineering and is a working supplement to basic information obtainable from standard drainage books and publications on drainage. It is presented in ten sections that give logical development to the problems of storm drainage.

1.03 DEFINITIONS AND ABBREVIATIONS

<u>a.</u> <u>Definitions</u>. Several important terms used in this manual are defined below:

Angle of Flare	Angle between direction of wing wall and centerline of culvert of storm drain outlet.
Chute	A high-velocity conduit for conveying water to a lower elevation; an inclined drop or fall.
Conduit	Any open or closed device for conveying flowing water.

Control — The hydraulic characteristic which determines the stage-discharge relationship in a conduit. The control is usually critical depth, tailwater or the geometric shape of the channel.

Continuity — Continuity of flow exists between two sections of a pipe or channel when the same quantity of water passes the two cross sections and all intermediate cross sections at any one instant. Therefore for continuous flow $Q = A_1V_1 = A_2V_2$ where A_1 and A_2 are cross sectional areas of the prism of water at the two points and V_1 and V_2 the respective mean velocities at the same points. Q is the quantity of water discharged.

Critical Flow — The flow for a given discharge at which the specific energy is a minimum with respect to the bottom of the conduit.

Entrance Head — The head required to cause flow into a conduit or other structure; it includes both entrance loss and velocity head.

Entrance Loss — The head lost in eddies or friction at the inlet to a conduit, headwall or structure.

Flexible Pipe — Any corrugated metal pipe, pipe-arch, sectional plate pipe or sectional plate pipe-arch.

Flume — Any open conduit of wood, concrete, metal, etc., on a prepared grade, trestle or bridge.

Freeboard — The distance between the normal operating level and the top of the side of an open conduit left to allow for wave action, floating debris, or any other condition or emergency without overtopping the structure.

Frequency Design Storm — The design storm frequency is the rainfall duration that may be expected once every 2, 5 or 10 years, as selected - to produce maximum runoff at a given point.

Hydraulic Grade Line	A line representing the pressure head available at any given point within the system.
Manning Equation	The uniform flow equation used to relate velocity, hydraulic radius and energy gradient slope.
Permeability	The permeability of a soil is its ability to conduct water.
Rational Formula	The means of relating runoff with the area being drained and the intensity of the storm rainfall.
Rigid Pipe	Any concrete, clay or cast iron pipe.
Steady Flow	Constant discharge.
Surcharge	Height of water surface above the crown of a closed conduit at the upstream end.
Swale	A wide shallow ditch.
Time of Concentration	The estimated time in minutes required for run-off to flow from the most remote section of the drainage area to the point at which the flow is to be determined.
Total Head Line (Energy Line)	A line representing the energy in flowing water. It is plotted a distance above the profiles of the flow line of the conduit equal to the normal depth plus the normal velocity head, and plus the pressure head for conduits flowing under pressure.
Uniform Channel	A channel with a constant cross section and roughness.
Uniform Flow (Steady Uniform Flow)	A condition of flow in which the discharge or quantity of water flowing per unit of time and also the velocity is constant. Flows will be at normal depth and can be computed by the Manning Equation.
Watershed	The area drained by a stream or stream system.

b. Abbreviations and Symbols. The following abbreviations and symbols are used in the manual:

A	Drainage area in acres of tributary watershed in Rational Formula. Cross-sectional area of gutter flow corresponding to y (sq. ft.). Cross-sectional area of flow through conduit (sq. ft.).
A_g	Area of clear opening of grate inlet (sq. ft.).
A_o	Cross-sectional area of gutter flow corresponding to y_o (sq. ft.).
a	Depth of gutter depression below gutter grade for grate or curb opening inlets, measured at face of curb in feet.
B	Width of channel, battery, span of pipe or section plate or other arch or width of box culvert (ft.).
C	Runoff Coefficient for use in Rational Formula representing the estimated ratio of runoff to rainfall which is dependent on the slope of the watershed, the land use and the character of soil.
c.f.s.	Cubic feet per second (discharge).
D	Diameter of pipe, height of box or rise of arch (ft.).
d_n	Normal depth of flow in conduit (ft.).
d_c	Critical depth of flow in conduit (ft.).
E	Specific energy of flow (ft.).
FL	Flow line (invert of conduit).
f.p.s.	Feet per second (velocity).

g	Gravitational acceleration (32.2 ft. per sec. per sec.).
H	Head required to force design discharge through a given size of conduit (ft.).
HW	Headwater elevation or depth above invert at storm drain engrance (ft.).
h	Height of opening for curb inlet (ft.).
h_e	Head loss at entrance due to turbulence (ft.).
h_f	Head loss due to friction in a length of conduit, L, equal to s_f L (ft.).
h_j	Head loss at junction structures, inlets, manholes due to turbulence (ft.).
h_v	Velocity head loss (ft.).
i	Intensity, in inches per hour, of rainfall over an entire watershed which may occur during the time of concentration, t_c (see Rational Formula).
K_e	Coefficient of entrance loss.
K_j	Coefficient for head loss at junctions, inlets and manholes.
L	Length of conduit, channel, gutter, inlet or grate (ft.).
L_1	Length of upstream transition of gutter depression (ft.).
L_2	Length of downstream transition of gutter depression (ft.).
L_o	Length of curb opening to capture 100% of gutter flow or length of grate to capture 100% of all flow over the grate (ft.).

L'	Length of grate required to capture outer portion of gutter flow (ft.).
M	Grate inlet coefficient.
n	Coefficient of roughness for use in the Manning Equation.
P	Length of portion of perimeter of opening over which water enters the inlet (ft.).
Q_p	Discharge, peak runoff or peak flow in c.f.s.
Q_o	Total flow in c.f.s. in a gutter.
q	Flow in c.f.s. that goes by an inlet (carry-over).
q_2	Carry-over outside of the grate (c.f.s.).
q_3	Carry-over across the grate (c.f.s.).
Q	Flow intercepted by an inlet drain or culvert, discharge in c.f.s.
R	Ratio of total width of clear openings between bars to width of grate.
r	Hydraulic Radius $= \dfrac{\text{Cross section area of flow in sq. ft.}}{\text{wetted perimeter in ft.}}$
s	Slope of street, gutter or total head line (energy gradient) (ft. per ft.).
s_c	That particular slope in feet per foot of a given uniform conduit operating as an open channel at which normal depth and velocity equal critical depth and velocity for a given discharge.
s_f	Friction slope in feet per foot in a conduit. This represents the rate of loss in the conduit due to friction.

s_o — Slope of the flow line of a conduit or gutter (ft. per ft.).

S_p — Top width of water surface in a gutter or other small triangular channel.

t_c — Time of concentration in minutes.

TW — Tailwater elevation or depth above invert at culvert outlet.

v — Mean velocity of flow at upstream end of inlet opening (ft. per sec.).

v_c — Critical velocity of flow in a conduit (ft. per sec.).

v_o — Normal mean velocity of flow in a conduit or channel (ft. per sec.).

$\frac{v^2}{2g}$ — Velocity head. A measure, in feet, of the kinetic energy in flowing water.

W — Width of grate (ft.).

W_o — Width of depression (ft.).

WP — Wetted perimeter. Length in feet of line of contact between flowing water and the conduit measured on a cross section.

y_o — Depth of gutter flow (ft.).

y — Depth of gutter flow at upstream end of inlet opening (ft.).

Z — Reciprocal of crown slope, $1/\theta_o$

θ_o — Crown slope of pavement (ft. per ft.).

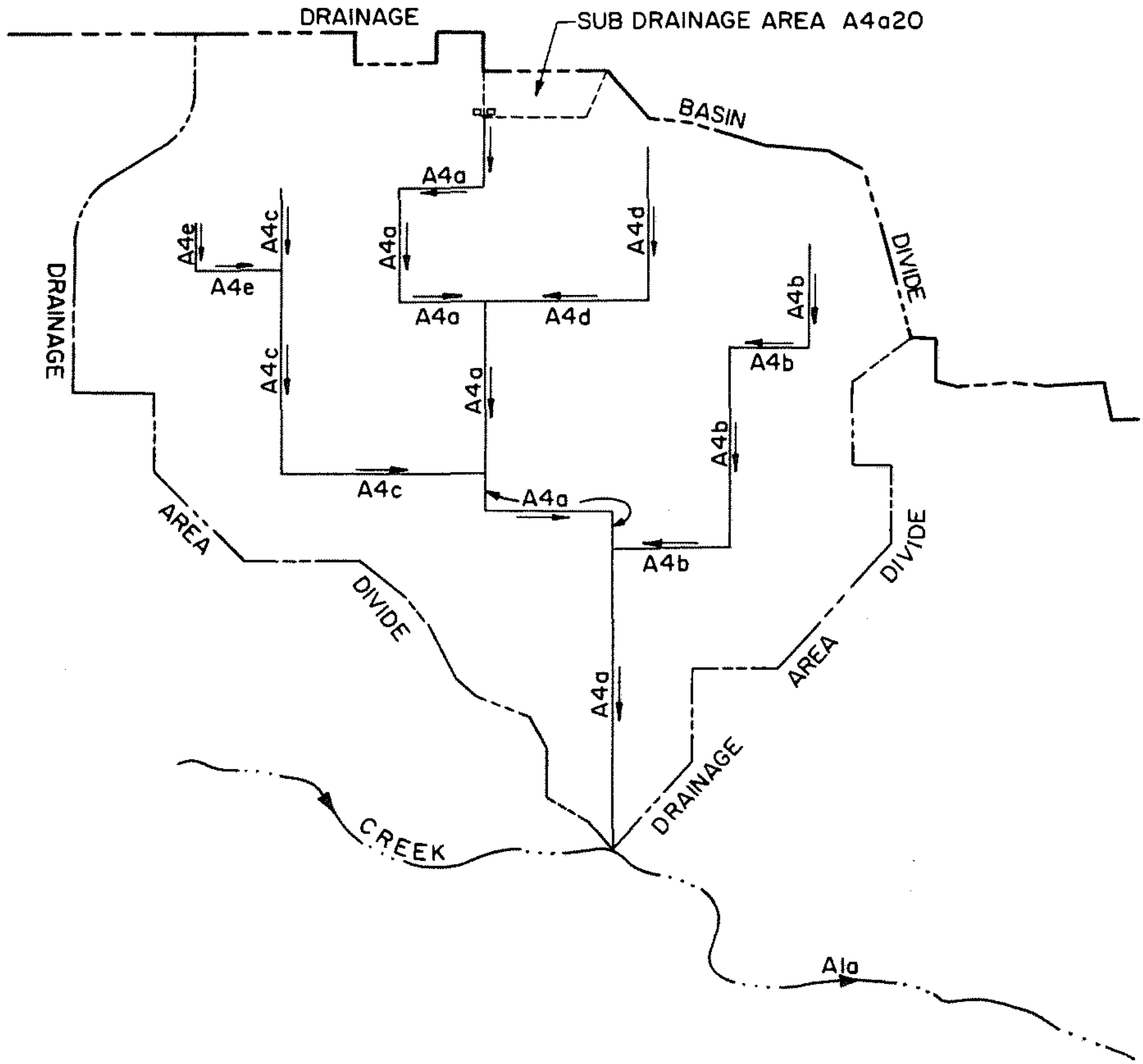
θ — Cross slope of gutter depression (ft. per ft.).

1.04 CODE DESIGNATION OF SYSTEM ELEMENTS

In order to facilitate the filing and identification of material concerning various elements of the storm drainage and flood control system, a system of code identification of the elements of the system has been developed. The code system used is capable of expansion to cover growth of the urban area of the City. Further, the code designation of each element of the system locates that element within the system.

Waco is divided naturally into drainage basins with outlets directly to the Brazos or Bosque Rivers. These basins, in turn, are divided into drainage areas, each area with an outlet to a major tributary to the rivers mentioned. Sub-areas are formed within the drainage areas by the construction of sewers and a sub-area being defined as an area tributary to a single inlet point on the system.

It is proposed that drainage basins be assigned a capital letter, with all elements of the system which function within this basin being identified by a code designation beginning with this letter. Drainage areas will be assigned a number, and all system elements within a given drainage area will carry the same number immediately following the capital letter which designates the drainage basin. Lines which form a part of the system serving a particular drainage area will be assigned an identifying small letter. This letter will, in the code, follow immediately the number identifying the drainage area. Points of inlet to the system along these lines will be numbered, the number to follow the small letter identifying the line. All sub-drainage areas contributing to a single point of entrance will carry the same code designation and any subdivision of this area through the use of multiple inlets will be given a hyphenated number. An example of the manner in which the code is applied to elements of the system is shown in the illustration of Figure 1.



TYPICAL CODE IDENTIFICATION FOR VARIOUS ELEMENTS OF STORM DRAINAGE SYSTEM

LEGEND

MAJOR TRIBUTARY A1a
DRAINAGE BASIN DIVIDE A4
DRAINAGE AREA DIVIDE A4a
SUB DRAINAGE AREA DIVIDE A4a20
A4a STORM DRAIN IDENTIFICATION

FIGURE 1

SECTION II

DETERMINATION OF DESIGN DISCHARGE

2.01 GENERAL

In order to properly determine the design storm runoff for a given installation, consideration must be given to the design storm rainfall, the runoff coefficient as affected by the surface condition and by geometry of the watershed, plus the influence of the time of concentration.

The design of a storm drainage system should be governed by the following six conditions:

(1) The system must adequately dispose of all surface runoff, resulting from the selected design storm, without causing serious damage to physical facilities or serious interruption of normal traffic.

(2) Runoff resulting from storms exceeding the design storm must be disposed of with the least amount of damage to physical facilities and interruption of normal traffic.

(3) The storm drainage system must have a maximum reliability of operation.

(4) The construction costs of the system must be reasonable with relationship to the importance of the facilities it protects.

(5) The storm drainage system must require minimum maintenance and operation.

(6) The storm drainage system must be adaptable to future expansion with the minimum additional cost.

2.02 DETERMINATION OF RUNOFF

a. General. If continuous records showing both the amounts and rates of runoff from urban areas within small localities were as readily available as are records of precipitation, they would provide the best source of data on which to base the design of a storm drainage and flood protection system. Unfortunately, such records are available only in very few areas in sufficient quantity to permit a direct prediction of the probable frequency of occurrence of certain rates and amounts of runoff, and none are available for Waco.

The accepted practice, therefore, is to relate runoff to rainfall, thereby providing a means for predicting the rates and amounts of runoff that may be expected from urban watersheds at given recurrence intervals.

There are several methods of relating runoff to precipitation in more or less general use. Two methods have been accepted and developed for use in the City of Waco. The methods are (1) the use of the Rational Formula, and (2) the use of synthetic unit hydrographs developed from runoff data collected from watersheds judged similar to watersheds within the urban area of the City of Waco.

b. Rational Method. The Rational Method is based on the direct relationship between rainfall and runoff. It is expressed by the equation $Q = CiA$ in which Q = the runoff in c.f.s. for a given area; C = a coefficient of runoff, representing the ratio of runoff to rainfall; i = the intensity of rainfall in inches per hour for a given time of concentration; A = the drainage area in acres.

The relationship between rainfall and runoff is expressed through application of the Rational Method with satisfactory accuracy for small watersheds, but the accuracy diminishes as the watershed to which the procedure is applied increases in size. Without actual records, it is believed that the use of the synthetic unit hydrograph procedure provides the best means for estimating the relationship between rainfall and runoff for the larger watersheds.

The following procedure will provide satisfactorily accurate estimates of the runoff for which the storm drainage and flood control system must be designed.

The Rational Formula will be used until the watershed area reaches approximately 1,000 acres. At that point the peak rate of runoff will be estimated by both the Rational Formula and by the unit hydrograph method. If use of the unit hydrograph produces the greater estimate, it will be used to estimate runoff discharges for all further increases in the watershed area. If the Rational Formula produces the greater estimate, the above comparison will be repeated at incremental increases of approximately 100 acres in watershed area until the unit hydrograph produces the greater result, after which it will be used for further estimates, or until the design of the system serving the watershed is complete.

c. Unit Hydrograph Method. The unit hydrograph used in determining the design runoff for watershed greater than 1,000 acres shall be determined by Snyder's synthetic relationships as set forth in the manual prepared for the Chief of Engineers, Corps of Engineers, U. S. Army, entitled "Engineering Manual for Civil Works Construction", Part CXIV, Chapter 5, dated March 1958.

A unit period of 15 minutes should be used for the determination of the unit hydrograph. Values for watershed coefficients C_t and 640 C_p to be used in Snyder's equation should be computed from the hydrologic records of nearby watersheds having similar characteristics. This procedure shall be continued until sufficient hydrologic records become available for watersheds in the Waco area.

Design runoff may be determined for a given watershed by applying to the developed 15-minute unit hydrograph the rainfall intensity-frequency-duration relationships shown on Figure 3, modified by an estimated infiltration rate of 0.40 inches per hour.

Peak discharge (c.f.s.) versus drainage area (acres) curves may be plotted for a given watershed from the above described procedure; thus making it possible to estimate peak runoff rates for areas beyond the range of acceptable accuracy for the Rational Formula.

2.03 DRAINAGE AREA

The size and shape of the watershed for each installation must be determined. The area of each watershed may be determined through the use of planimetric-topographic maps of the area, supplemented by field surveys in areas where topographic data has changed or where the contour interval is such that direction of flow is questionable.

A drainage area map shall be provided for each installation on a scale no smaller than 1" = 200'.

The outline of the drainage area is to be determined so that all water falling within a given area will enter the proposed storm sewer system at a given inlet and water falling on any point beyond the outline will enter some other inlet. Therefore, the outline must follow actual drainage lines rather than the artificial land divisions used in locating the drainage lines in the design of sanitary sewers. The drainage lines are determined by the pavement slopes, location of downspouts, paved and unpaved yards, grading of lawns and many other features that are altered by the development of a city.

2.04 RUNOFF COEFFICIENT

a. Nature of Surface. The proportion of the total rainfall that will reach the storm drains depends on the relative porosity or imperviousness of the soil, and the slope of the surface. Impervious surface, such as asphaltic pavements or roofs of buildings, will give nearly 100 per cent runoff, regardless of the slope, after the surface has become thoroughly wet.

Future improvements which tend to increase the impervious area, such as sidewalks, pavements and buildings, must be estimated and included in the percentage of impervious surface. Zoning maps and master plans for the City may be used as an aid in establishing the future development and supplemented by on-the-site determinations.

b. Soil. The runoff coefficient "C" in the Rational Formula is also dependent on the character of the soil. The ability of soil to absorb precipitation generally decreases, as the duration of the rainfall increases, until a constant rate is reached. The soil absorption capacities are influenced by existing soil moisture content before a rain, the degree of compaction of the soil, the porosity of the subsoil, and the elevation of the ground water table.

Other factors that affect the soil absorption capacities are the vegetation, depression, storage and temporary retention of water in the topsoil. The infiltration rate for most soils, in the Waco area, vary between 0.20 inches per hour to 0.80 inches per hour depending upon the surface condition.

All of the preceding factors must be considered in determining the runoff coefficient "C" for any given area. Table 1 gives values for the runoff coefficient pertaining to land uses to be used in the determination of storm runoff. Whenever field conditions indicate to the designer that the runoff coefficients for a particular watershed are different from those shown in Table 1, the designer shall submit a report of his findings, investigations and reasons for adjusting the adopted value to the City Engineer. Approval must be obtained from the City Engineer for the particular area in question before proceeding with design. Approval for adjusting the design criteria for a particular area shall apply only to that given area and does not give approval to other areas with similar land use, slopes and soil cover.

TABLE 1

RUNOFF COEFFICIENT "C"

	Runoff Coefficient "C"	
Type of Area or Land Use	Limits of Coefficient "C"	Coefficient to Be Used
Residential	0.30 - 0.60	0.40
Suburban Business	0.70 - 0.90	0.70
Park and Large Estates	0.20 - 0.40	0.30
Commercial	0.80 - 0.90	0.85
Industrial	0.40 - 0.70	0.65

2.05 TIME OF CONCENTRATION

The time of concentration is defined as the longest time, without unreasonable delay, that will be required for a drop of water to flow from the upper limit of a drainage area to the point of concentration. The time of concentration to any point in a storm sewer is a combination of the "inlet time" and the time of flow in the sewer. The inlet time is the time for water to flow over the surface of the ground to the storm sewer inlet. Because the area tributary to most storm sewer inlets is relatively small, it is customary in practice to determine the inlet time on the basis of experience under similar conditions. Inlet time decreases as the slope and the imperviousness of the surface increase, and it increases as the distance over which the water has to travel and the retention by the contact surfaces. The shortest inlet time allowed for an impervious area on a steep slope shall be 5 minutes. The longest inlet time shall be determined from the street and gutter grades according to Figure 2. In general, for the ordinary residential block the inlet time is at least 15 to 20 minutes.

The time of flow in the sewer is the quotient of length of sewer and the flowing full velocity as computed using the hydraulic elements of the sewer. The time of concentration within a sewer is usually less than the actual time for the flood crest to reach a given point of concentration because of the time required, to fill the sewer, known as the time of storage. Although the time of storage may represent an appreciable increment of the time of concentration, particularly in large sewers, it shall be neglected.

TABLE 2

MINIMUM INLET TIME OF CONCENTRATION

Type of Area	Minimum Inlet Time
Residential Areas	15 min.
Suburban Business	10 min.
Parks and Large Estates (Undeveloped Areas)	20 min.
Commercial	10 min.
Industrial Areas	10 min.

Table 2 gives minimum values for inlet time of concentration. All "inlet time" should be verified by direct overland flow computation.

2.06 RAINFALL INTENSITY — DURATION — FREQUENCY

a. General. It is seldom economical to design storm sewers, drains and certain types of culverts to handle the maximum runoff that may be expected to occur. Rather, storm drainage improvements are designed with the expectation that they will be overcharged once in 2, 5, 10 or 25 years on the average, an economic balance being struck between the average annual damages resulting from these occasional floods, on the one hand, and the cost of providing greater capacity on the other.

b. Rainfall Intensity-Duration-Frequency Relations. The relationship between rainfall intensity, storm duration and frequency vary widely from place to place. The "Rainfall Intensity-Duration-Frequency" curves shown on Figure 3 have been developed by the procedures as outlined in Hydrology Handbook, A.S.C.E., 1949, and Technical Paper No. 25, "Rainfall Intensity-Duration-Frequency Curves", U. S. Department of Commerce, Weather Bureau, December 1955.

The curves presented have been determined for durations of 5 minutes to 3 hours and return periods of 2, 5, 10, 25, 50 and 100 years.

The data analyzed for the development of these curves was abstracted from the weighing recording rain gage charts at the U. S. Weather Station at Waco, Texas. Excessive amounts of precipitation were tabulated for each period where the minimum depth of rainfall equaled or exceeded the amount considered excessive by the U. S. Weather Bureau as shown in Table 3.

The curves shown were developed by the annual series method and were compared and adjusted by surrounding weather stations of longer record periods.

TABLE 3

EXCESSIVE PRECIPITATION

Duration in Minutes	Rainfall Depth in Inches
5	0.25
10	0.30
15	0.35
20	0.40
30	0.50
45	0.65
60	0.80
80	1.00
100	1.20
120	1.40
150	1.70
180	2.00

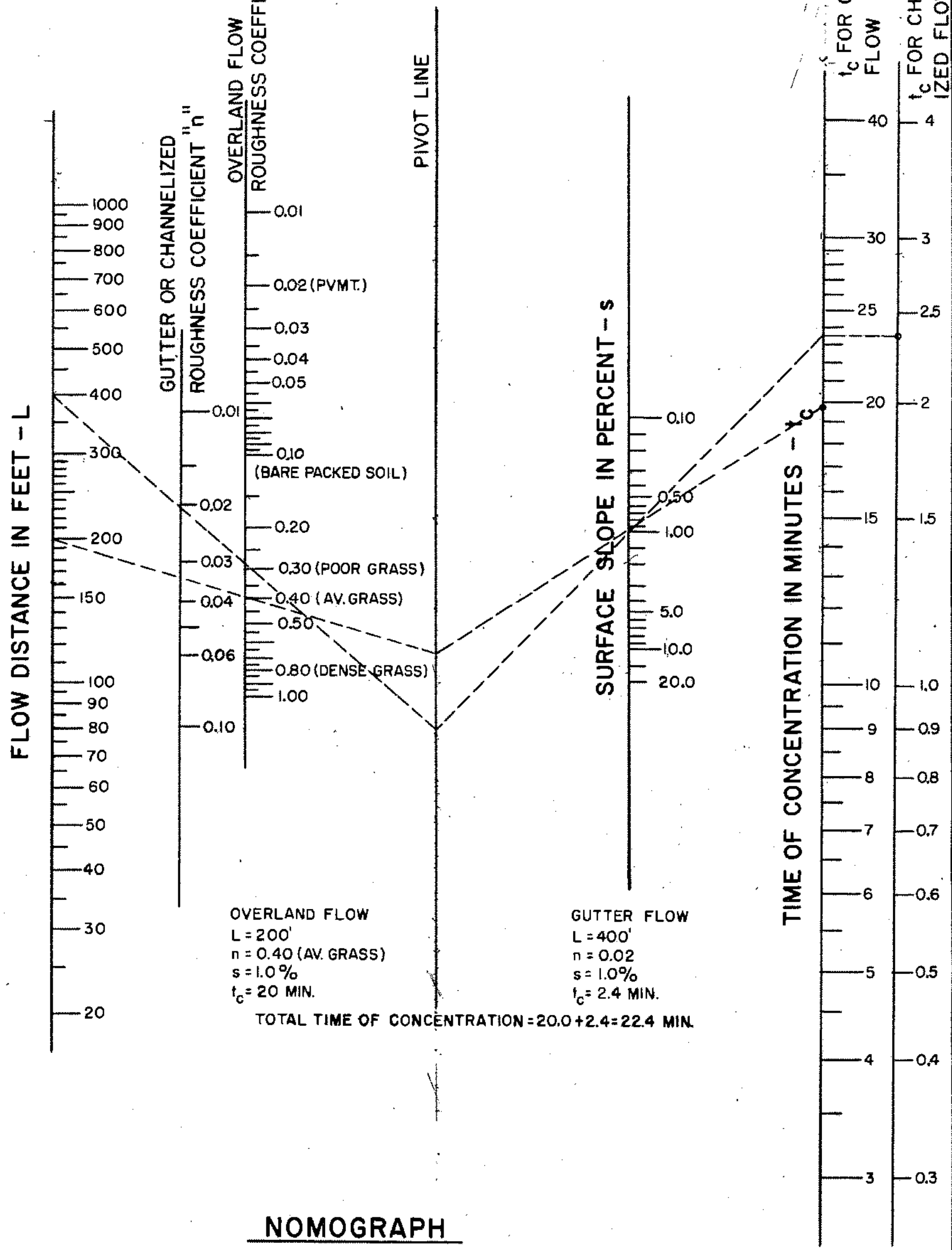
c. Design Storm Frequency. In the design of storm drainage systems, culverts, bridges, creeks, channels, etc., the relationship between the type of facility to be provided, the type of area to be drained, the time of concentration, the size of sewer and the design storm frequency, as shown in Table 4, shall govern. When any of the three conditions listed are exceeded, the design shall be based on the next more severe design frequency.

TABLE 4

DESIGN STORM FREQUENCY

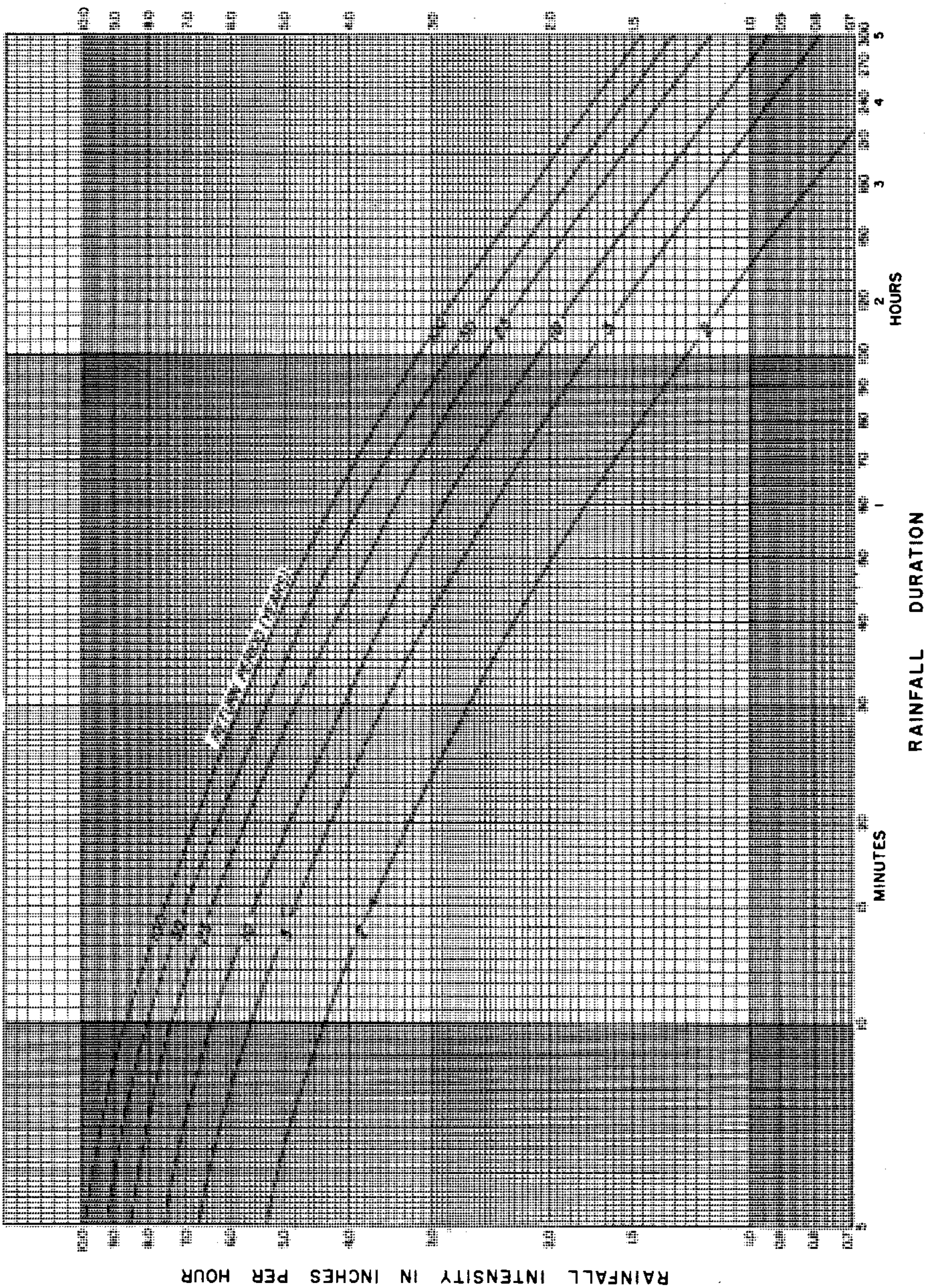
Type of Facility	Description of Area to be Drained	Time of Concentration (Minutes)	Size of Sewer (Inches)	Recommendation Design Frequency (Years)
Storm Sewers	Residential with some scattered business or commercial	30'	84"	2
Storm Sewers	All areas not covered by 2 year frequency	30'	84"	5
Culverts, Bridges, Channels & Creeks	Any type of area less than 100 acres	30'	84"	5
Culverts, Bridges, Channels & Creeks	Any type of area greater than 100 acres but less than 1,000 acres	45'	84"	10
Culverts, Bridges, Channels & Creeks	Any type of area greater than 1,000 acres	60'	84"	25

In connection with the design of facilities described under "Culverts, Bridges, Channels and Creeks" shown in Table 4 for areas greater than 1,000 acres, discharges for a fifty-year frequency shall also be determined and the possible damages resulting therefrom evaluated to determine if such damages would be sufficient to warrant enlargement of the planned facilities. In any area where storm runoff concentrates at low points of grade or where flow is across private property, the designer shall (1) determine discharges greater than the design discharge for all the frequencies listed in Table 4, (2) determine the depth of inundation for these discharges, and (3) evaluate the possible damages resulting therefrom. A report of these investigations shall be presented to the City Engineer for the areas in question and approval must be obtained before proceeding with design.



NOMOGRAPH FOR TIME OF CONCENTRATION

FIGURE 2



RAINFALL DURATION
MINUTES
HOURS
RAINFALL INTENSITY IN INCHES PER HOUR

FIGURE 3

SECTION III

FLOW IN GUTTERS

3.01 GENERAL

Figures 4, 5, 6, and 7 have been prepared to enable direct solution of Manning's equation for various hydraulic properties for uniform flow in pavement gutters or triangular channels. The above mentioned figures have been based on the following equation:

$$Q_o = 0.56 \frac{(Z)}{(n)} s_o^{1/2} y_o^{8/3}$$

Q_o = gutter discharge in c. f. s.
Z = reciprocal of the crown slope ft. per ft.
s_o = street or gutter slope in ft. per ft.
n = roughness coefficient
y_o = depth of flow in gutter in ft.

Figures 4, 5, and 6 have been prepared to determine readily the depth of flow in the gutter, the spread of water into the traffic lane, and the velocity of flow in the gutter, respectively. These figures have been based on an average roughness coefficient for the gutter of 0.015; however, since in the above equation it is shown that the hydraulic properties for this gutter flow are inversely proportional to the roughness coefficient then the values obtained from these figures may be adjusted by a straight proportional basis for other roughness coefficients.

The determination of depth of flow, spread of flow and velocity of flow in a gutter is very important to the design and spacing of storm drain inlets. Paragraph 3.02 gives maximum permissible flow conditions for various types and classifications of streets. The permissible spread of water into the street or thoroughfare shall in all cases govern the hydraulic capacity of a given street.

The nomograph shown on Figure 7 provides for direct solution of flow conditions for triangular channels most frequently encountered in urban drainage design.

3.02 PERMISSIBLE SPREAD OF WATER

a. Expressways

(1) Permissible Spread of Water. The permissible spread of water in gutter of expressways shall be 8 feet measured from the outside face of curb. Gutter flow shall be based on a maximum storm duration of 15 minutes.

(2) Conditions. The maximum allowable spacing between inlets, regardless of street grade and gutter flows, shall be 500 feet. No depressed inlets shall be used unless they are clearly outside all traffic lanes.

b. Major Thoroughfares (Divided)

(1) Permissible Spread of Water. The permissible spread of water in gutters of major thoroughfares shall be limited so that one traffic lane on each side will remain clear during the design storm. Gutter flow shall be based on a maximum storm duration of 15 minutes.

(2) Conditions. Inlets shall preferably be located at street intersections or at low points of grade. Inlets shall be located, when at all possible, on off side streets or alleys when grades permit. The standard gutter depression (2-1/2 inches at inlets) shall be used so long as the depression does not fall within a traffic lane. In no case shall the gutter depression at inlets exceed 2-1/2 inches. In superelevated sections, inlets placed against the center medians shall have no gutter depression.

c. Major Thoroughfares (Not Divided)

(1) Permissible Spread of Water. The permissible spread of water in gutters of major thoroughfares (not divided) shall be limited so that two traffic lanes will remain clear during the design storm. Example: Street width 48 feet, permissible spread of water in each gutter shall be

$$\frac{48'-24'}{2} \quad 12 \text{ feet in each gutter}$$

(assume 2 - 12' traffic lanes clear)

(2) Conditions. Inlets shall preferably be located at street intersections, low points of grades, or where the gutter flow exceeds the permissible spread of water criteria. Inlets shall be located, when at all possible, on the off side streets or alleys when grades permit. The standard gutter depression (2-1/2 inches) shall be used so long as the depression does not fall within a traffic lane. In no case shall the gutter depression at inlets exceed 2-1/2 inches. Depressed inlets will be permitted in a standard parking lane. Where inlets are required in traffic lanes, inlets with no depression shall be used. In superelevated sections, intercept gutter flow at P. V. C. or P. V. T. to prevent flow from crossing thoroughfare.

d. Secondary Streets.

(1) Permissible Spread of Water. The permissible spread of water in gutter of secondary streets shall be limited so that one standard lane of traffic will remain clear during the design storm. Example: Street width 36 feet, permissible spread of water in each gutter shall be:

$$\frac{36' - 12'}{2} = 12 \text{ feet in each gutter}$$

(assume 1 - 12' traffic lane clear)

(2) Conditions. Inlets shall preferably be located at street intersections, low points of grade or where the gutter flow exceeds the permissible spread of water criteria. Inlets shall be located, when at all possible, on off side streets or alleys when grade permits. Inlets with the standard gutter depression (2-1/2 inches) shall be used. In no case shall the gutter depression at inlets exceed 2-1/2 inches.

e. Minor Streets (Residential).

(1) Permissible Spread of Water. The permissible spread of water in gutters for minor streets shall be limited to either a 4-inch depth of flow at the face of curb or when the street is just covered. Whichever procedure produces the least depth shall be used.

Example: Street width 30 feet, pavement crown slope 1/4 inch per foot.

$$\text{Permissible spread of water} = \frac{30'}{2} = 15 \text{ feet}$$

$$\text{Depth of flow at curb} = 15' \times \frac{1}{4} = 3.75''$$

(2) Conditions. Inlets shall be located at street intersections, low points of grade or where the gutter flow exceeds the permissible spread of water criteria. Inlets with depressed standard gutter depression shall be used in all cases unless special grading problems are involved. In no case shall the gutter depression at inlets exceed 2-1/2 inches.

3.03 DESIGN METHOD

In order to facilitate the computations required in determining the various hydraulic properties for gutters and roadway ditches, Computation Sheet No. 1 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 1 and is shown at the end of this subparagraph.

Example:

- Q_p Peak discharge for contributing drainage area 3.52 c.f.s.
- q Carry-over flow from upstream inlet 0.57 c.f.s.
- s_o Gutter slope 0.0050 ft. per ft.
- θ_o Crown slope of pavement 0.25 in. per ft.
- n Pavement roughness coefficient 0.015

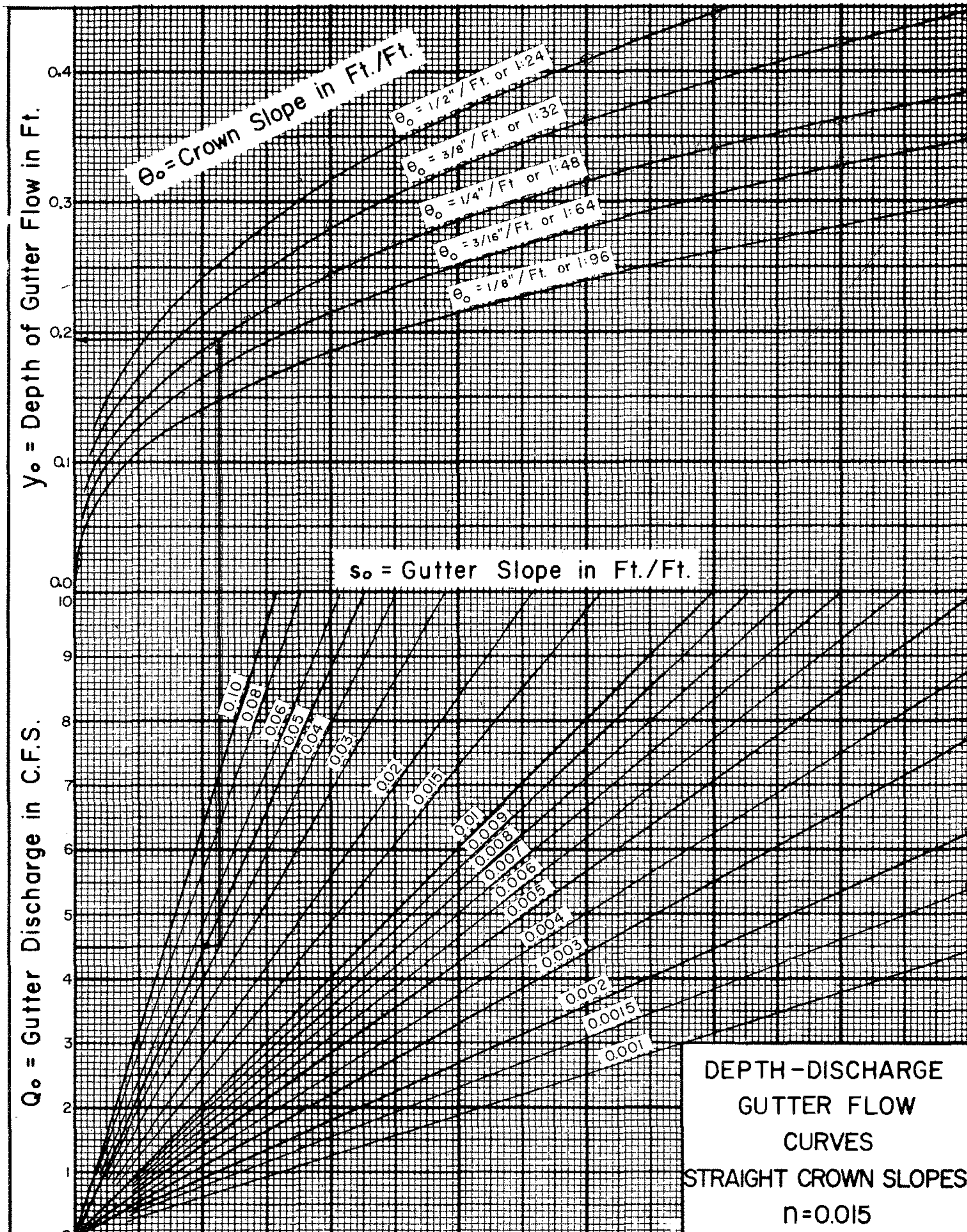
Column 1 Inlet number or designation.

Column 2 Inlet location.

Column 3 Type of inlet.

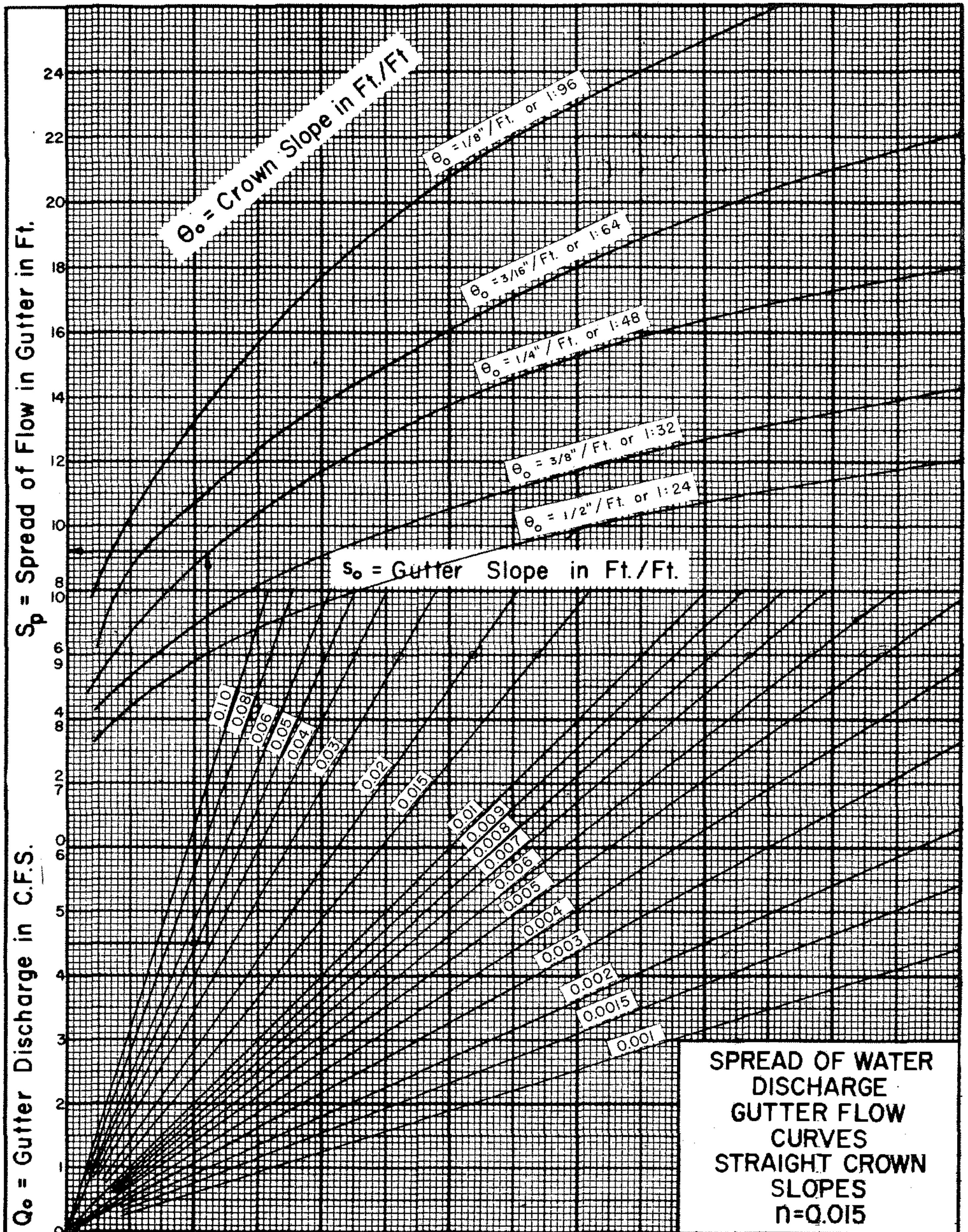
Column 4 Contributing drainage area to inlet in acres.

Column 5	Coefficient of runoff for contributing area shown in Column 4 from Table 1.
Column 6	Inlet time of concentration in minutes from Figure 2 and Table 2.
Column 7	Intensity of rainfall in in. per hr. corresponding to the inlet time shown in Column 6 (obtained from Figure No. 3).
Column 8	Peak runoff in c. f. s. Column 4 times Column 5 times Column 7.
Column 9	Carry-over flow in c. t. s.
Column 10	Total gutter flow in c. f. s. Column 8 plus Column 9.
Column 11	Gutter slope in ft. per ft.
Column 12	Crown slope of pavement in ft. per ft.
Column 13	Maximum depth of flow in gutter y_o in ft.
Column 14	Spread or width of gutter flow from face of curb in ft.



Example: Q_o = 4.5 C.F.S. Gutter Flow
s_o = 0.040 Ft./Ft. Gutter Slope
θ_o = 1:48 or 1/4"/Ft. Crown Slope
Find: y_o = 0.195 Ft, Depth of Flow in Gutter.

FIGURE 4



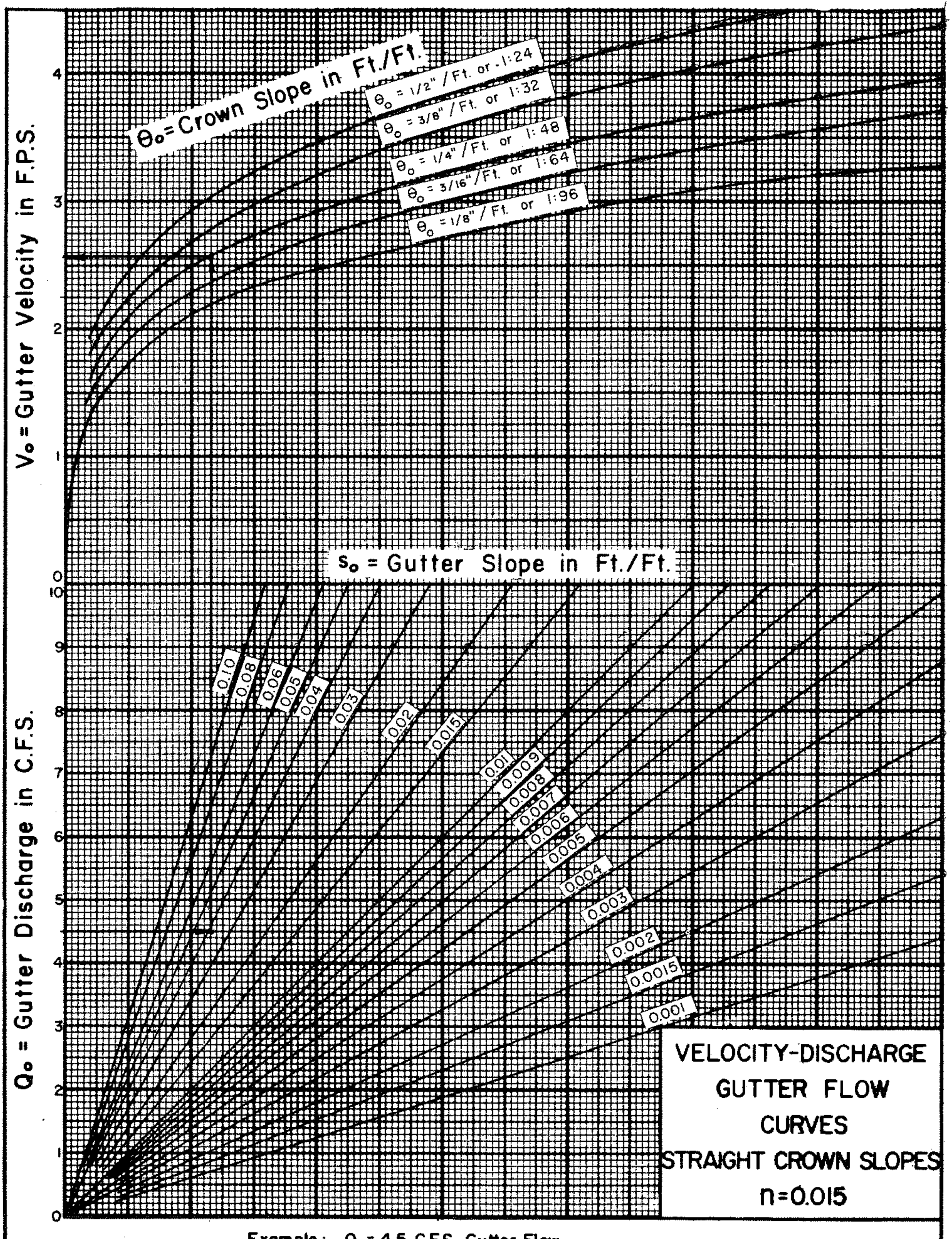
Example: Q_o = 4.5 C.F.S. Gutter Flow

s_o = 0.040 Ft. Ft. Gutter Slope

Θ_o = 1:48 or 1/4"/Ft. Crown Slope

Find: S_p = 9.2 Ft. of Spread of Flow in Gutter

FIGURE 5



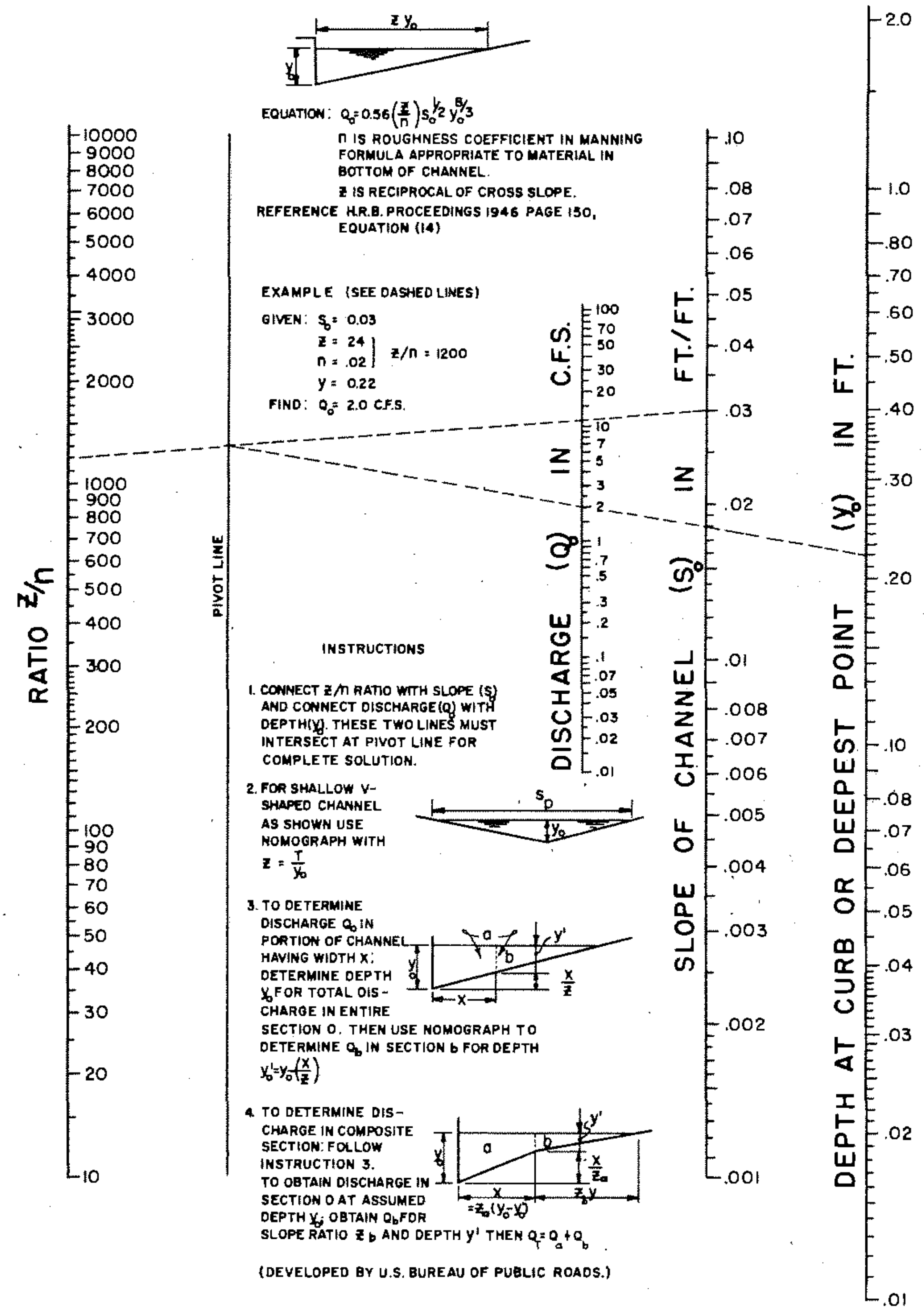
Example: Q_o = 4.5 C.F.S. Gutter Flow

s_o = 0.040 Ft./Ft. Gutter Slope

Θ_o = 1:48 or 1/4"/Ft. Crown Slope

Find: V_o = 2.55 F.P.S. Gutter Velocity

FIGURE 6



NOMOGRAPH FOR FLOW IN TRIANGULAR GUTTERS

FIGURE 7

BY *Designer*
DATE
CK'D. *City Engr's. Office*
DATE

COMPUTATION SHEET NO. 1
FOR DETERMINING DEPTH AND WIDTH OF FLOW
IN GUTTERS OR ROADWAY DITCHES

n= *0.015*

SHEET ~ OF ~
STREET *As Assigned (17th St.)*
MAJOR WATERSHED *As Assigned (4A)*
JOB OR FILE NO. *As Assigned*

INLET NO.	LOCATION	TYPE OF INLET	DRAINAGE AREA A ACRES	RUNOFF COEFF. C	TIME OF CONCENTRAT'N t_c	INTENSITY I IN./HR.	PEAK DISCHARGE Q_p	CARRY-OVER FROM UP STREAM INLET q C.F.S.	TOTAL GUTTER FLOW Q_o C.F.S.	LONGITUDINAL GUTTER SLOPE S_o FT./FT.	CROSS SLOPE OF PVM'T. θ_o FT./FT.	MAX. DEPTH OF FLOW y_o FT.	SPREAD OR WIDTH OF FLOW S_p FT.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
I-C4	*17' Rt. Sta. 7+03 Line A4C*	*CO-3(5')*	*2.38*	*0.40*	*15'*	*3.70*	*3.52*	*0.57*	*4.09*	*0.0050*	*1/48*	*0.28*	*13.5*
				NOTE:									
				Example Shown on Illustrative Drawings No. 1 & No. 5									

REMARKS, SKETCHES AND COMPUTATIONS

SECTION IV

STORM DRAIN INLETS

4.01 GENERAL

Inlets have been classified into three major groups, namely, inlets in sumps, inlets on grade without gutter depression, and inlets on grade with gutter depression. Each of the three major classes includes many varieties. The following are presented herein and are likely to find reasonably wide use.

a. Inlets in Sumps

(1) Curb Opening
(2) Grate
(3) Combination (Grate and Curb Opening)
(4) Drop

b. Inlets on Grade with no Gutter Depression

(1) Grate
(2) Curb Opening
(3) Combination (Grate and Curb Opening)

c. Inlets on Grade with Gutter Depression

(1) Grate
(2) Curb Opening
(3) Combination (Grate and Curb Opening)

4.02 INLETS IN SUMPS

a. General. Inlets in sumps are inlets in low points of surface drainage to relieve ponding. The capacity of inlets in sumps must be known in order to determine the depth and width of ponding for a given discharge. Inlets on street grades less than 1 per cent shall be considered to function as inlets in sumps.

b. Curb Opening Inlets and Drop Inlets.

(1) General. The capacity of unclogged curb opening inlets Type CO-S and drop inlets Type D-S and Type GG-S in a sump or low point can be considered a rectangular weir with a coefficient of discharge of 3.0. The capacity shall be based on the following equation:

$$Q = 3.0\ y^{3/2} L \qquad Q/L \text{ or } Q/P = 3.0\ y^{3/2}$$

Q = Capacity in c.f.s. of curb opening inlet or capacity in c.f.s. of drop inlet.

y = Head at the inlet in feet.

L = Length of curb opening inlet in feet.

P = Length of portion of perimeter of opening which water enters the drop inlet in feet.

The curves shown on Figures 8, 9, and 10 provide for direct solution of the above equation.

Curb opening inlets and drop inlets in sumps have a tendency to collect debris at their entrances. For this reason, the calculated inlet capacity shall be reduced by 10 per cent to allow for this clogging.

(2) Example and Explanation of Computation Sheet. In order to facilitate the computations required in determining the various hydraulic properties for curb opening inlets Type CO-S and drop inlets Type D-S and Type GG-S in sump, Computation Sheet No. 2 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 2 for both a curb opening inlet and drop inlet in a sump and is shown at the end of this sub-paragraph.

Q_o = Gutter flow = 4.0 c.f.s.

s_o = Gutter slope = 0.0050 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015

Column 1 Inlet number and designation

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement in ft. per ft.

Column 4 Total gutter flow in c.f.s. For inlets other than the first inlet in a system, gutter flow is the sum of runoff from contributing area plus carry-over flow from inlet or inlets upstream.

Column 5 Depth of gutter flow in feet from Figure 4 or from direct solution of Manning's equation.

$$y_o = 1.245\ Q_o^{3/8} \frac{n^{3/8}}{s_o^{3/16}} \left(\frac{1}{\tan \theta_o}\right)^{3/8}$$

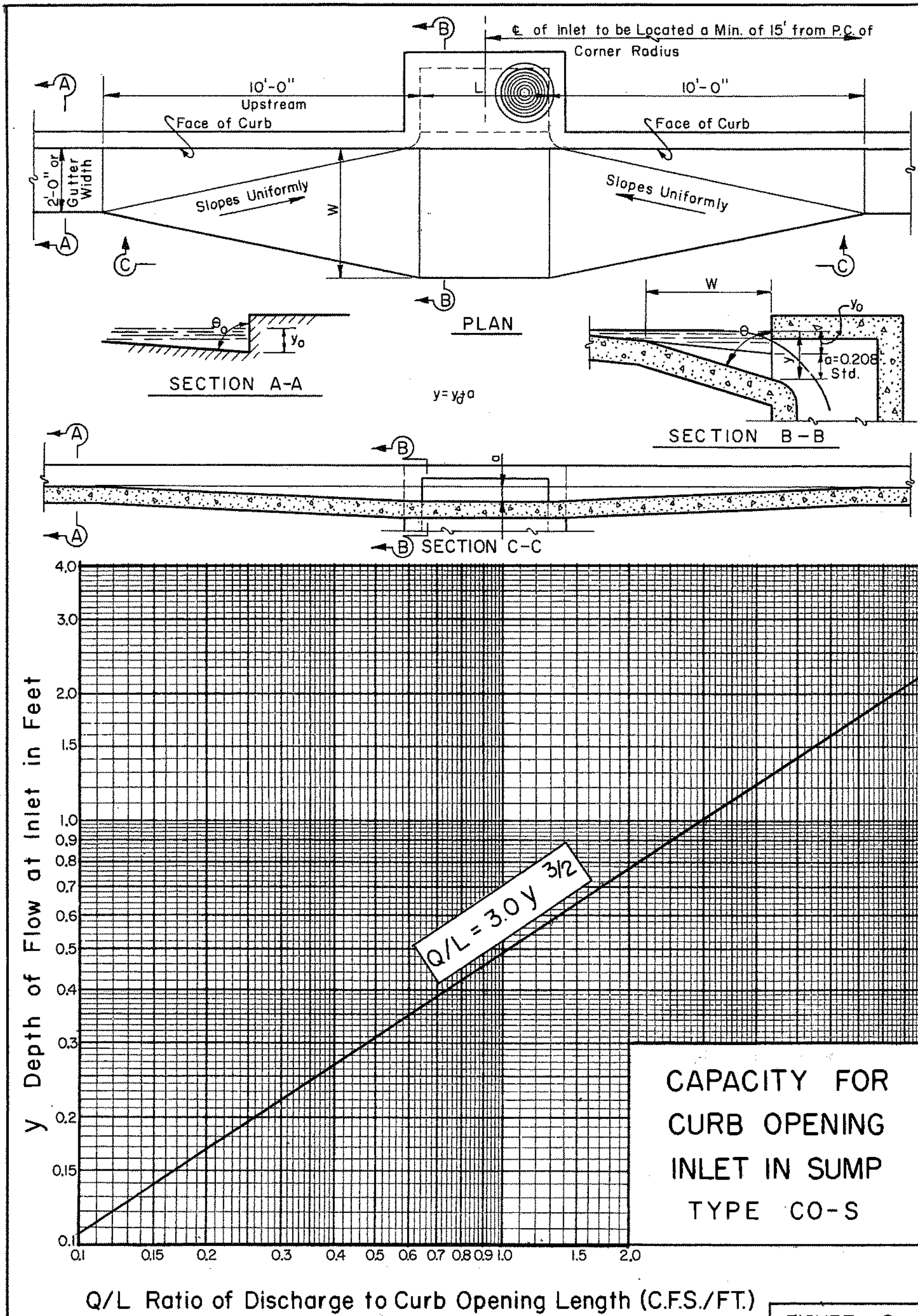
Column 6 Depth of gutter depression in ft.

Column 7 Depth of water at inlet opening in ft. Column 5 plus Column 6.

Column 8 Capacity of curb opening inlet or drop inlet in c.f.s. per ft. of length of opening or perimeter around inlet from Figures 8, 9 or 10 or by direct solution.

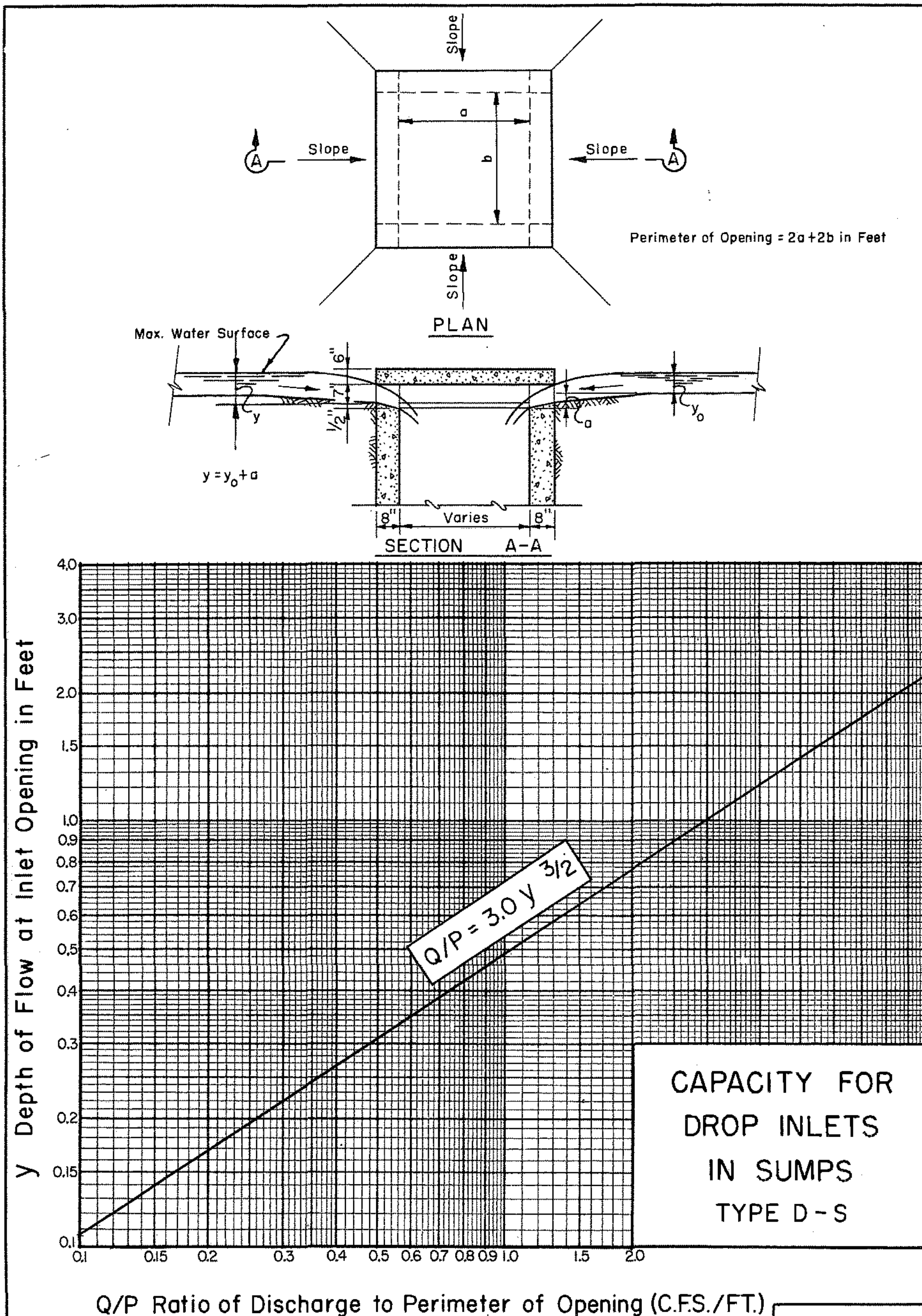
$$\frac{Q}{L} \text{ or } \frac{Q}{P} = 3.0\ y^{3/2}$$

Column 9	Length of inlet opening or perimeter in feet.
Column 10	Capacity of inlet in c. f. s. Column 8 times Column 9.
Column 11	Carry-Over flow passing inlet in c. f. s. Column 4 minus Column 10.
Column 12	Per cent of flow captured by inlet. Column 10 divided by Column 4 times 100.



CAPACITY FOR CURB OPENING INLET IN SUMP TYPE CO-S

FIGURE 8



CAPACITY FOR DROP INLETS IN SUMPS

TYPE D-S

FIGURE 9

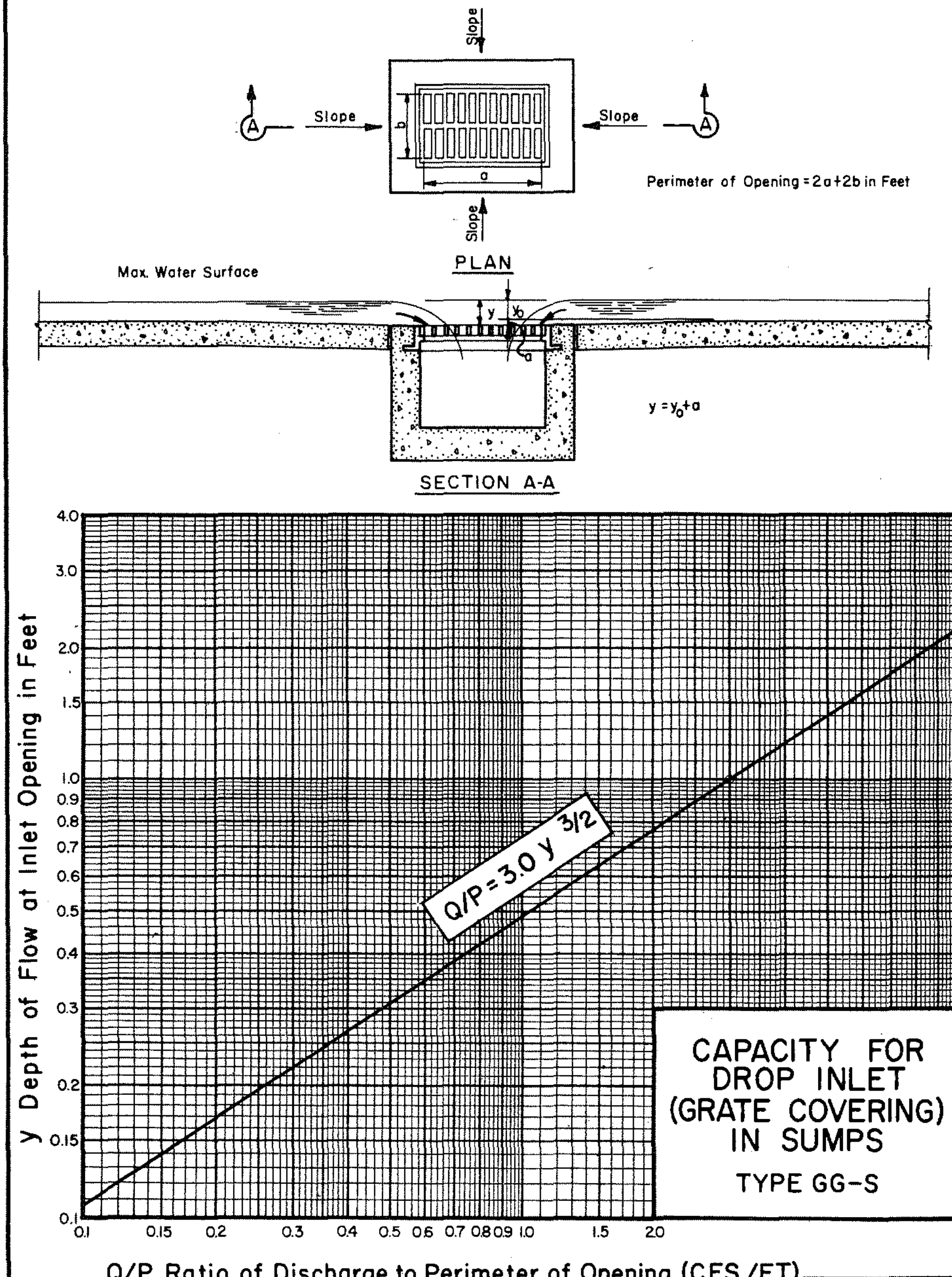

Slope
Slope
Slope
Slope
A
A
b
a
Perimeter of Opening = 2a+2b in Feet
PLAN
Max. Water Surface
y
y_0
a
$y = y_0 + a$
SECTION A-A
$Q/P = 3.0\ y^{3/2}$
y Depth of Flow at Inlet Opening in Feet
Q/P Ratio of Discharge to Perimeter of Opening (C.F.S./FT.)
CAPACITY FOR DROP INLET (GRATE COVERING) IN SUMPS
TYPE GG-S

FIGURE 10

BY *Designer*
DATE
CK'D. *City Engr's. Office* n =
DATE

COMPUTATION SHEET NO. 2
FOR DETERMINING CAPACITY OF CURB OPENING INLETS AND DROP INLETS IN SUMPS OR ON GRADE (UNDEPRESSED)

SHEET ~ OF ~
STREET *As Assigned*
MAJOR WATERSHED *As Assigned*
JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_0 FT/FT.	CROWN SLOPE OF PVMT. θ_0 FT./FT.	GUTTER FLOW Q_0 C.F.S.	DEPTH OF GUTTER FLOW y_0 FT.	DEPTH OF DEPRESSION a FT.	DEPTH OF FLOW AT OPENING y FT.	CAPACITY OF INLET PER FOOT OF LENGTH Q/L or P C.F.S./FT.	LENGTH OF INLET OPENING L or P FT.	CAPACITY OF INLET Q C.F.S.	CARRY-OVER FLOW PASSING INLET q C.F.S.	PERCENT CAPTURED BY INLET	NOTES
1	2	3	4	5	6	7	8	9	10	11	12	13
Type	*CO-S*											
As Assigned	*0.0050*	*1/48*	*4.00*	*0.28*	*0.21*	*0.49*	*1.00*	*4'-0"*	*4.00*	*0.00*	*100%*	*Use 4'-0" CO-S*
Type	*GG-S*						*Assumed*					*See Std. Dwg.* #*1*
	0.0050	*1/48*	*4.00*	*0.28*	*0.21*	*0.49*	*1.00*	*7'-4"*	*7.33*	*0.00*	*100%*	*Use Type GG-1*
Type	*D-S*											*See Std. Dwg.* #*5*
	0.0050	*1/48*	*4.00*	*0.28*	*0.21*	*0.49*	*1.00*	*8'-0"*	*8.00*	*0.00*	*100%*	*Use 2'x2' D-S*
						Use	*2'-0" x 2'-0"*					*See Std. Dwg.* #*4*

REMARKS, SKETCHES AND COMPUTATIONS

c. Grate Inlets.

(1) General. The capacity of an unclogged grate inlet Type CG-S in a sump can be considered an orifice with a coefficient of discharge of 0.60. The capacity shall be based on the following equation:

$$Q = 4.82\ A_g\ y^{1/2} \quad \text{or} \quad \frac{Q}{A_g} = 4.82\ y^{1/2}$$

Q = Capacity in c.f.s.

A_g = Area of clear opening in sq. ft.

g = Gravitational acceleration in ft. per sec. per sec.

y = Depth of flow at inlet or head at sump in feet.

The curve shown on Figure 11 provides for direct solution of the above equation.

Grate inlets in sumps have a tendency to clog when flows carry debris such as leaves and papers. For this reason, the calculated inlet capacity of a grate inlet should be reduced by 25 per cent to allow for clogging. The efficiency of grate inlets in sumps is not affected by the bar arrangement of the grating, however; gratings with bars transverse to the gutter allow for simple and economical construction.

(2) Example and Explanation of Computation Sheet. In order to facilitate the computations required in determining the various hydraulic properties for Grate Inlets Type CG-S in sumps, Computation Sheet No. 3 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 3 and is shown at the end of this sub-paragraph.

Example:

Q_o = Gutter flow = 3.0 c.f.s.

s_o = Gutter slope = 0.0050 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015.

Column 1 Inlet number or designation.

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement in ft. per ft.

Column 4 Total gutter flow in c.f.s. For inlets other than the first inlet in a system, gutter flow is the sum of runoff from contributing area plus carry-over flow from inlet or inlets upstream.

Column 5 Depth of gutter flow in feet from Figure 4, or from direct solution of Manning's equation.

$$y_o = 1.245\, Q_o^{3/8}\ \frac{n^{3/8}}{s_o^{3/16}} \left(\frac{1}{\tan \theta_o}\right)^{3/8}$$

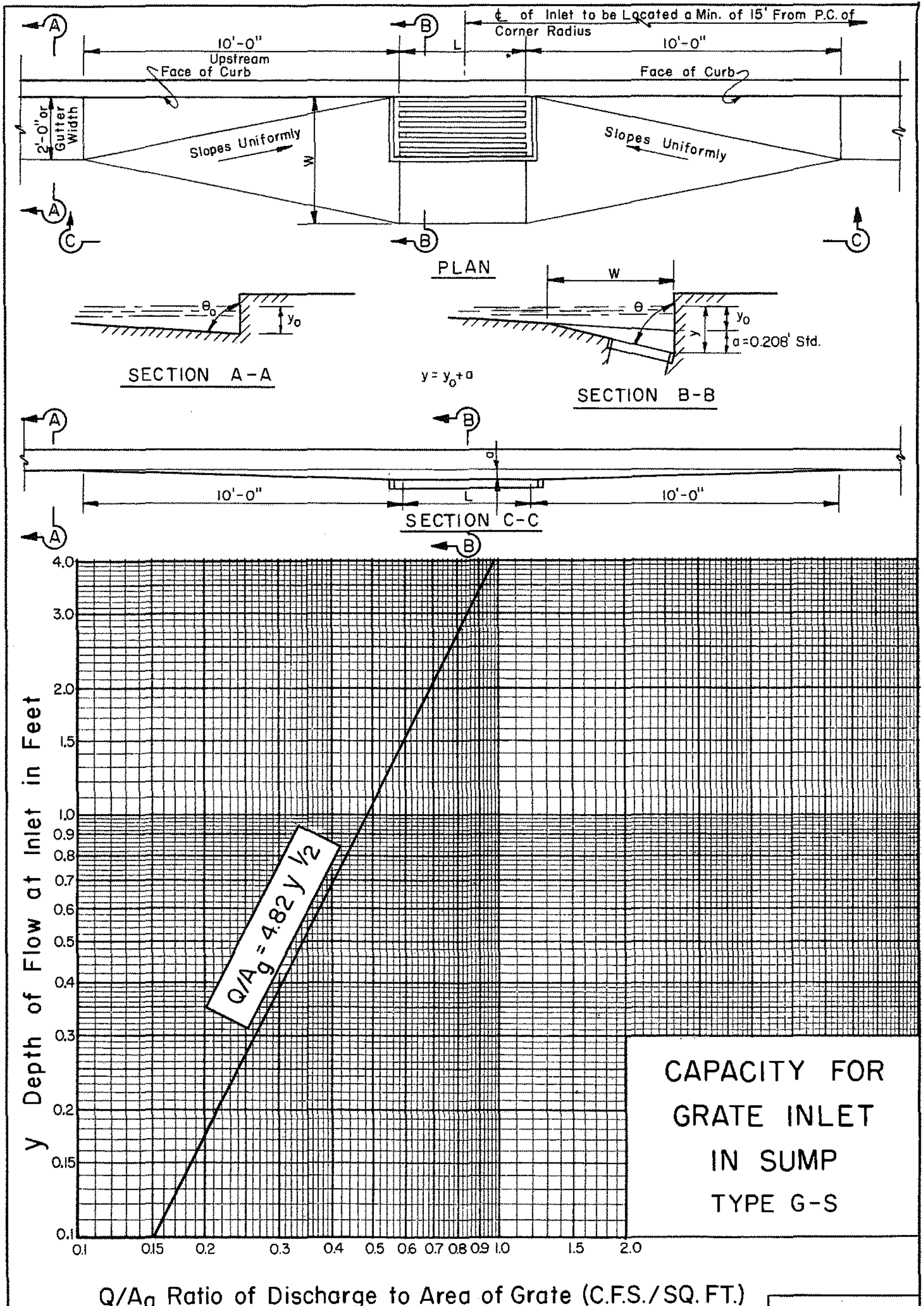
Column 6 Depth of gutter depression in ft.

Column 7 Depth of flow at grate in ft. Column 5 plus Column 6.

Column 8 Capacity of grate inlet in c.f.s. per sq. ft. of area of grate from Figure 11 or by direct solution.

$$\frac{Q}{A_g} = 4.82\, y^{3/2}$$

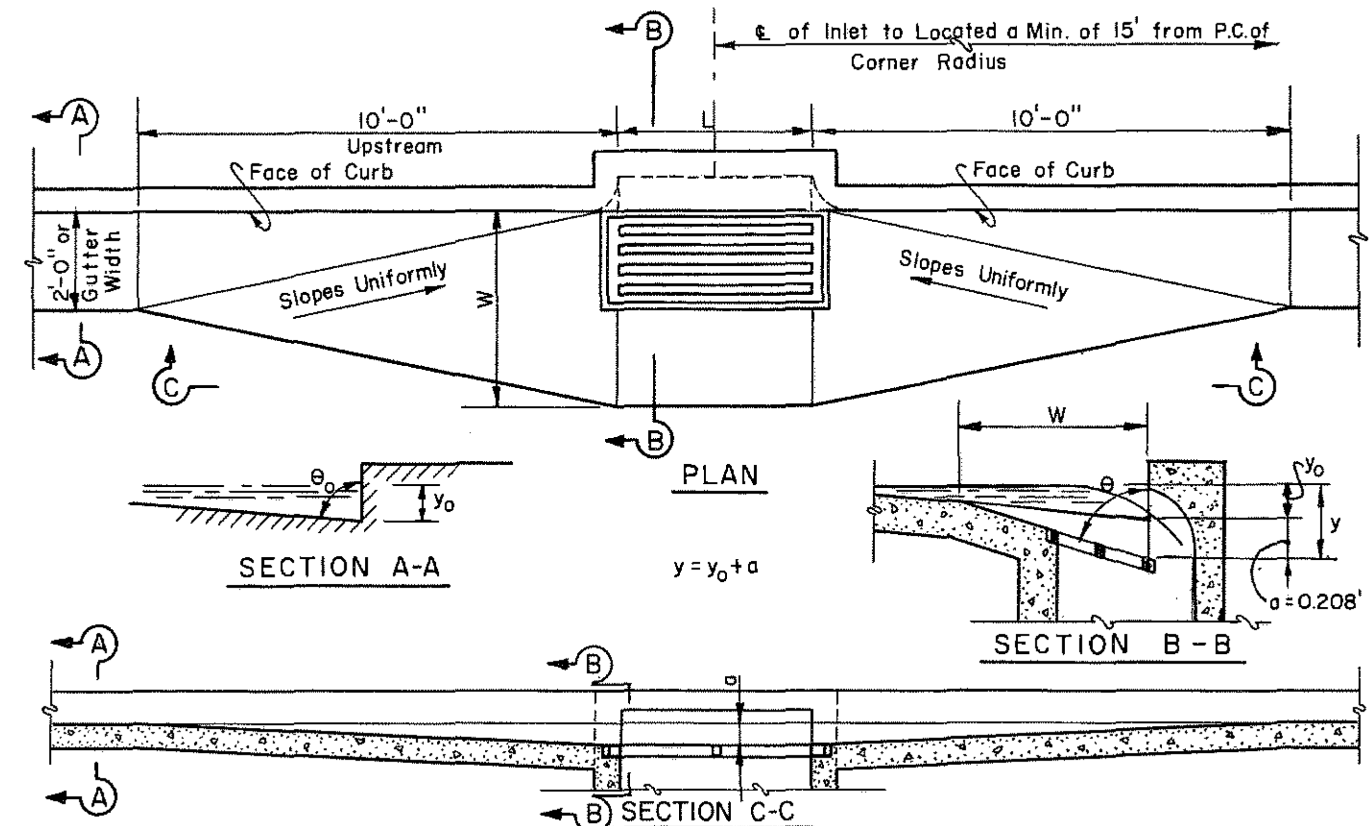
Column 9	Area of grate in sq. ft.
Column 10	Capacity of inlet in c. f. s. Column 8 times Column 9.
Column 11	Carry-over flow passing inlet in c. f. s. Column 10 minus Column 4.
Column 12	Per cent of flow captured by inlet. Column 10 divided by Column 4 times 100.

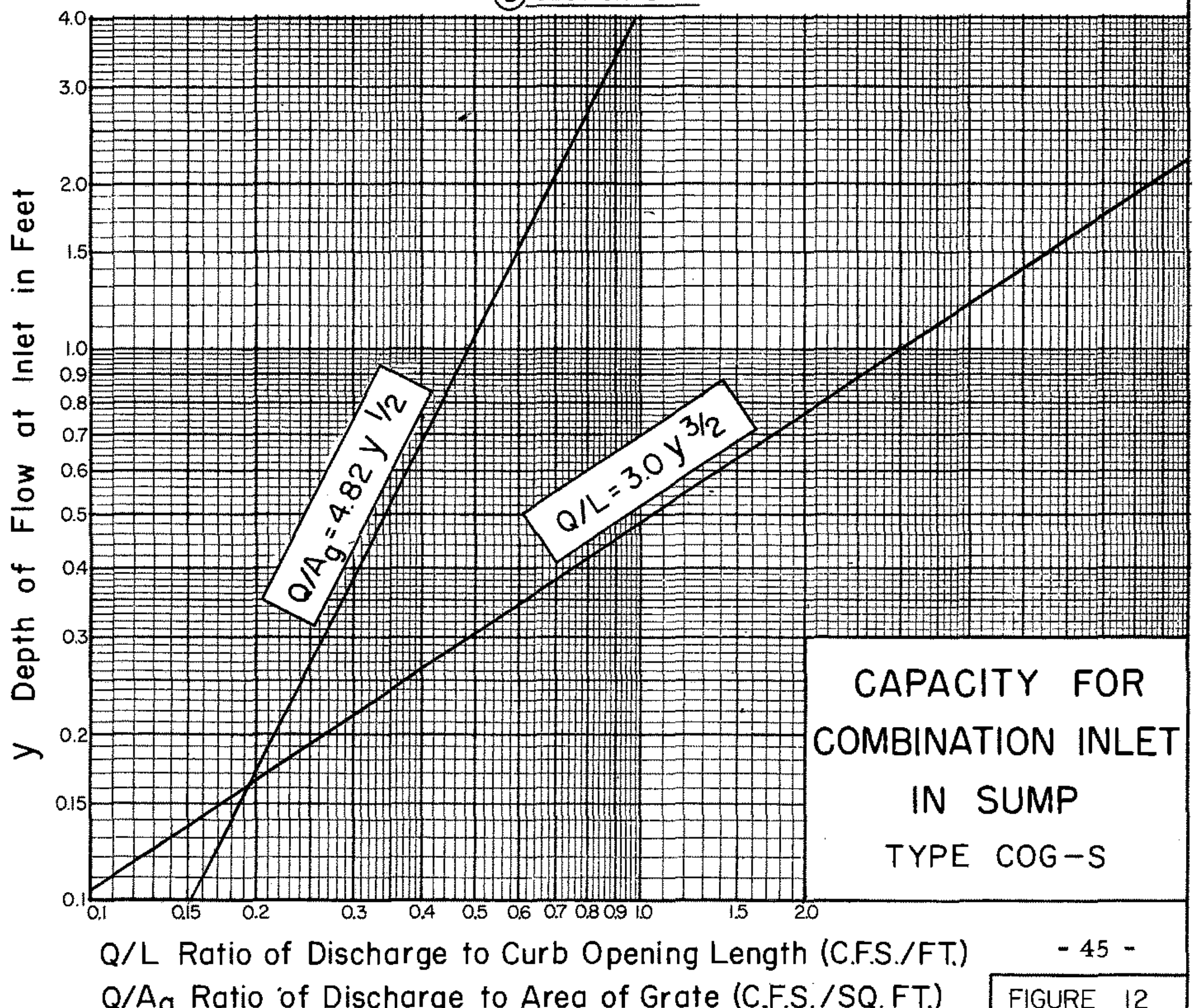


CAPACITY FOR GRATE INLET IN SUMP

TYPE G-S

FIGURE 11





CAPACITY FOR COMBINATION INLET IN SUMP

TYPE COG-S

FIGURE 12

COMPUTATION SHEET NO. 3 FOR DETERMINING CAPACITY OF GRATE INLETS IN SUMPS

BY *Designer*
DATE
CK'D. *City Engr's Ofc.* n= *0.013*
DATE

SHEET *~* OF *~*
STREET *As Assigned*
MAJOR WATERSHED *As Assigned*
JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_o FT./FT.	CROWN SLOPE OF PVMT. θ_o FT/FT.	GUTTER FLOW Q_o C.F.S.	DEPTH OF GUTTER FLOW y_o FT.	DEPTH OF DEPRESSION a FT.	DEPTH OF FLOW AT GRATE y FT.	CAPACITY OF INLET PER SQ. FT. OF GRATE Q/A_g C.F.S./SQ.FT	AREA OF GRATE A_g SQ. FT.	CAPACITY OF INLET Q C.F.S.	CARRY-OVER FLOW PASSING INLET q C.F.S.	PERCENT CAPTURED BY INLET	NOTES
1	2	3	4	5	6	7	8	9	10	11	12	13
Type	*CG-S*											
As Assigned	*0.0050*	*1/48*	*3.0*	*0.25*	*0.21*	*0.46*	*0.33*	*3.67*	*1.21*	*1.79*	*40.3*	*Increase Depth*
												of Flow For
												Greater Efficiency

REMARKS, SKETCHES AND COMPUTATIONS

d. Combination Inlets (Type COG-S). The capacity of a combination inlet Type COG-S consisting of a grate and curb opening inlet in a sump can be considered as the sum of the capacities of an orifice and a weir and shall be determined by the two equations shown in sub-paragraphs 4.02(b.) and (c.). The curves shown on Figure 12 provide for direct solution of the two equations. When the capacity of the gutter is not exceeded, the grate inlet accepts the major portion of the flow. Under severe flooding conditions, however, the curb inlet will accept most of the flow since its capacity varies with $y^{1.5}$ whereas the capacity of the grate inlet varies as $y^{0.5}$. Combination inlets in sumps have a tendency to clog and collect debris at their entrances. For this reason, the calculated inlet capacity should be reduced by 20 per cent to allow for this clogging.

4.03 INLETS ON GRADE WITHOUT GUTTER DEPRESSION

a. Curb Opening Inlets (Undepressed) Type CO-U.

(1) General. The capacity of a curb inlet, like any weir, depends upon the head and length of overfall. In the case of an undepressed curb opening inlet (See Figure 13), the head at the upstream end of the opening is the depth of flow in the gutter. In streets where grades are greater than 1 per cent the velocities are high and the depths of flow are usually small as there is little time to develop cross flow into the curb openings; therefore, undepressed inlets are inefficient when used in streets of appreciable slope, but may be used satisfactorily where the grade is low and the crown slope high or the gutter channelized. Undepressed inlets do not interfere with traffic and usually are free from clogging with water-borne debris. Design and space inlets so that 5 to 15 per cent of gutter flow reaching each inlet will pass on to the next inlet downstream, provided the carry-over is not objectionable to pedestrian or vehicular traffic.

The capacity of an undepressed curb inlet will be based on the following rectangular weir equation:

$$Q = 1.135 \, L \, y^{3/2}$$

L = Length of curb opening inlet in feet.

y = Depth of gutter flow in feet.

The curve shown on Figure 14 provides for direct solution of the above equation.

(2) Example and Explanation of Computation Sheet. In order to facilitate the computations required to determine the various hydraulic properties for Curb Opening Inlets, Type CO-U, on grade (undepressed), Computation Sheet No. 2 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 2 and is shown at the end of this sub-paragraph.

Example:

Q_o = Gutter flow = 2 c.f.s.

s_o = Gutter slope = 0.010 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015.

Column 1 Inlet number or designation.

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement ft. per ft.

Column 4 Total gutter flow in c.f.s. For inlets other than the first inlet in a system, gutter flow is the sum of runoff from contributing area plus carry-over flow from inlet or inlets upstream.

Column 5 — Depth of gutter flow in feet from Figure 4 or from direct solution of Manning's equation.

$$y_o = 1.245\, Q_o^{3/8} \; \frac{n^{3/8}}{s_o^{3/16}} \left(\frac{1}{\tan \theta_o}\right)^{3/8}$$

Column 6 — Not required.

Column 7 — Column 5.

Column 8 — Capacity of curb opening in c. f. s. per ft. of length of opening from Figure 14 or by direct solution:

$$\frac{Q}{L} = 1.135\, y^{3/2}$$

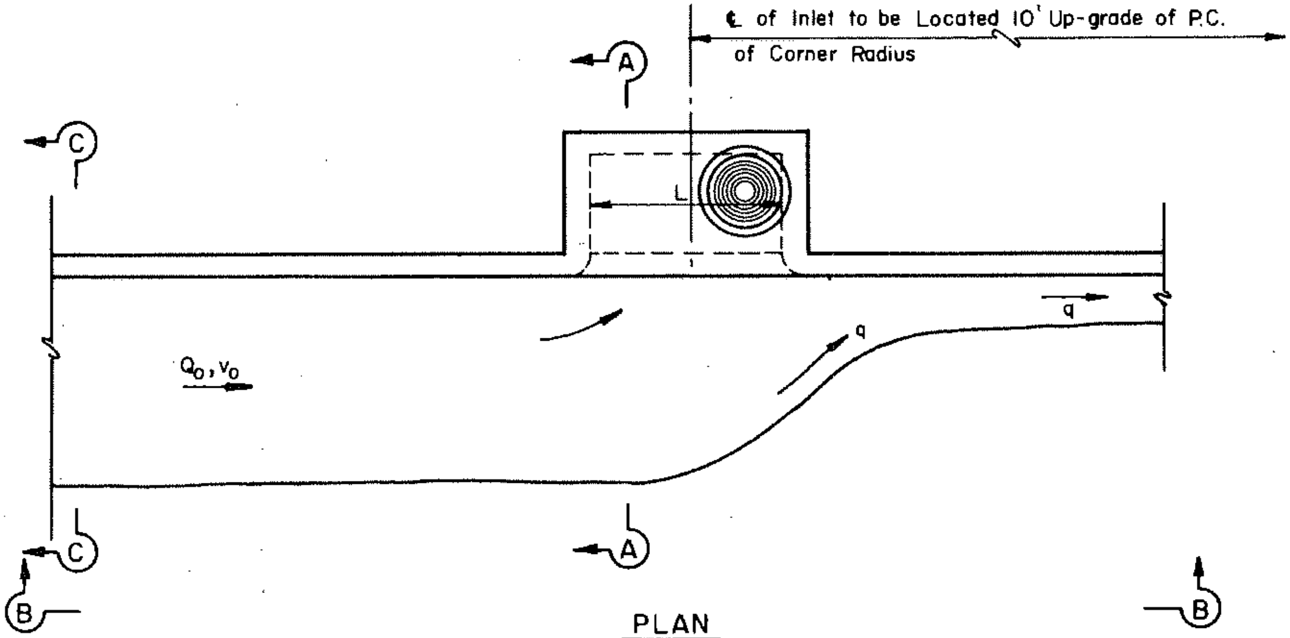
Column 9 — Length of inlet opening in feet.

Column 10 — Capacity of inlet in c. f. s. Column 8 times Column 9.

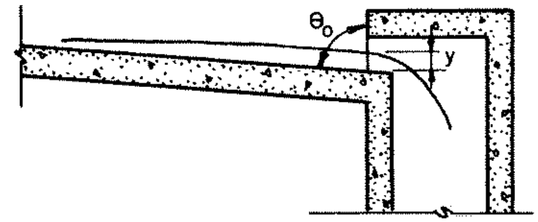
Column 11 — Carry-over flow passing inlet in c. f. s. Column 10 minus Column 4.

Column 12 — Per cent of flow captured by inlet. Column 10 divided by Column 4 times 100.

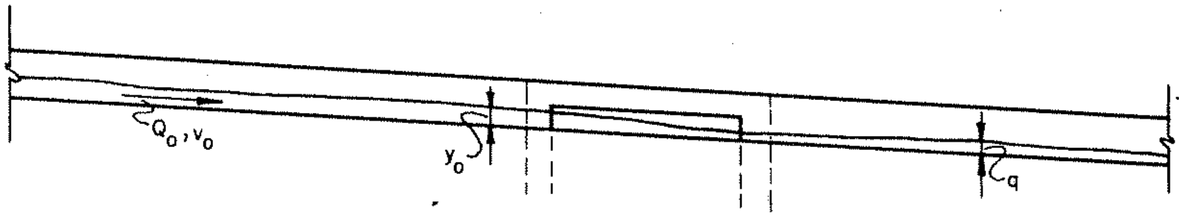
The calculated capacity shall be reduced by 10 per cent to allow for clogging.



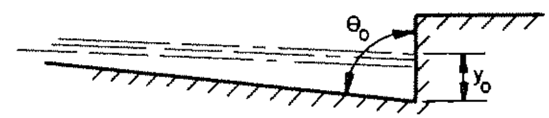
PLAN



SECTION A-A



SECTION B-B

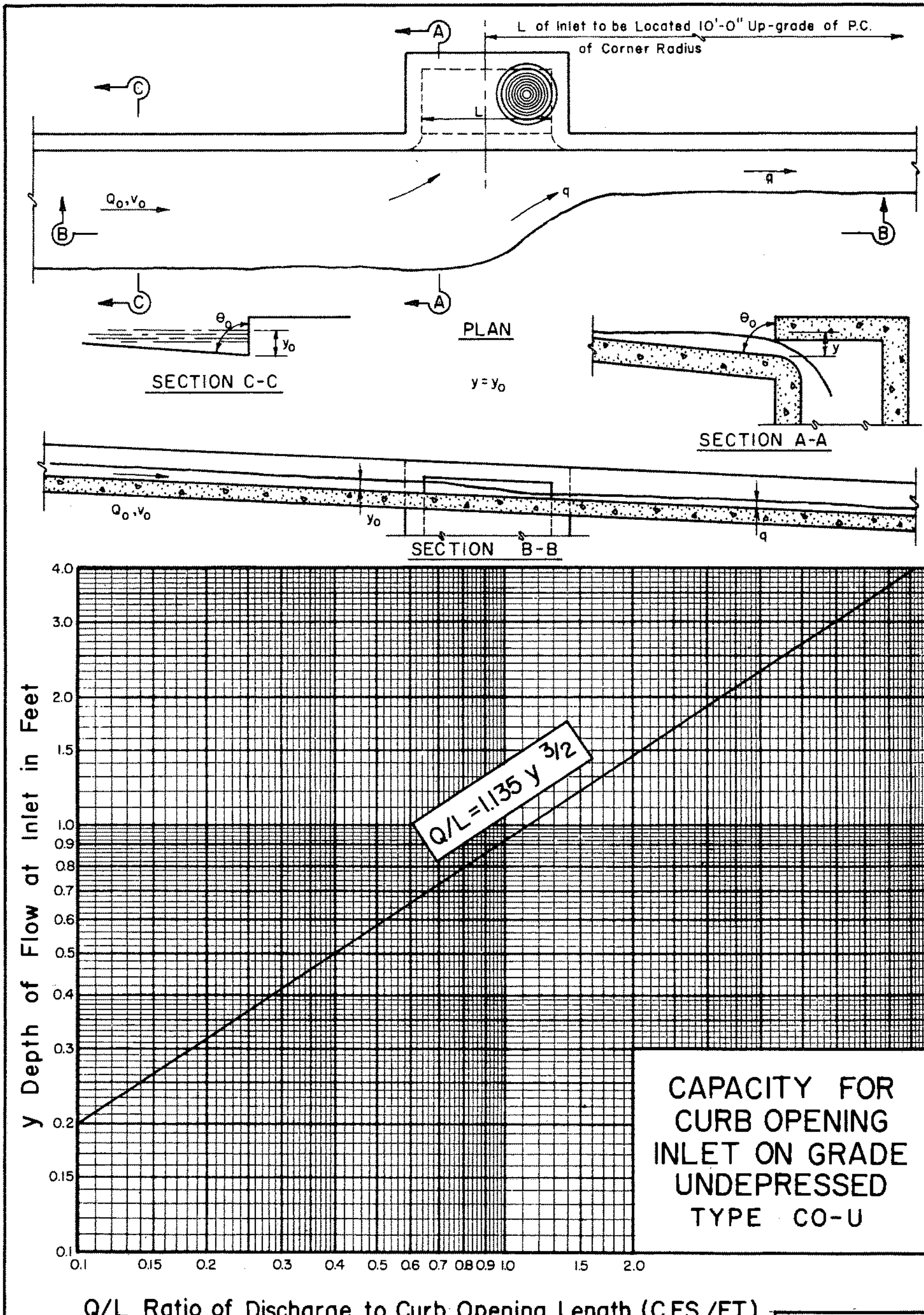


SECTION C-C

$y = y_o$

UNDEPRESSED
CURB – OPENING INLET
ON GRADE TYPE CO–U

FIGURE 13



CAPACITY FOR CURB OPENING INLET ON GRADE UNDEPRESSED TYPE CO-U

FIGURE 14

BY *Designer*
DATE ____
CK'D. *City Engr's. Office* n = ____
DATE ____

COMPUTATION SHEET NO. 2 FOR DETERMINING CAPACITY OF CURB OPENING INLETS AND DROP INLETS IN SUMPS OR ON GRADE (UNDEPRESSED)

SHEET *~* OF *~*
STREET *As Assigned*
MAJOR WATERSHED *As Assigned*
JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_o FT./FT.	CROWN SLOPE OF PVMT. θ_o FT./FT.	GUTTER FLOW Q_o C.F.S.	DEPTH OF GUTTER FLOW y_o FT.	DEPTH OF DEPRESSION a FT.	DEPTH OF FLOW AT OPENING y FT.	CAPACITY OF INLET PER FOOT OF LENGTH Q/L or P C.F.S./FT.	LENGTH OF INLET OPENING L or P FT.	CAPACITY OF INLET Q C.F.S.	CARRY-OVER FLOW PASSING INLET q C.F.S.	PERCENT CAPTURED BY INLET	NOTES
1	2	3	4	5	6	7	8	9	10	11	12	13
As Assigned	*0.010*	*1/48*	*2.0*	*0.19*	*~*	*0.19*	*0.093*	*10'-0"*	*0.93*	*1.07*	*46.5%*	*Use 10'-0" open-*
					Assumed	*Length →*						*ing or Equivalent*

REMARKS, SKETCHES AND COMPUTATIONS

b. Grate Inlet on Grade (Undepressed) Type CG-U

(1) General. Undepressed grate inlets (See Figure 15) on grade basically have a greater hydraulic capacity than curb inlets of the same length so long as they remain unclogged. Grate inlets on grades of one per cent and less shall be considered as inlets in sumps and shall be determined by the procedure for "Inlets in Sumps"; however, grate inlets on grades steeper than one per cent propose a more complex problem. Generally speaking, undepressed grate inlets on grade are inefficient in comparison to other types of inlets; however, they do not interfere with traffic. Grate inlets should be so designed and spaced so that 5 to 15 per cent of the gutter flow reaching each inlet will pass on to the next downstream inlet, provided the carry-over is not objectionable to pedestrian or vehicular traffic.

Grates with bars parallel to the curb should always be used for the above described installations because transverse framing bars create splash which causes the water to jump or ride over the grate. For flows on streets with grades less than one per cent, little or no splashing occurs regardless of the direction of bars.

The calculated capacity for a grate inlet shall be reduced by 25 per cent to allow for clogging.

(2) Example and Explanation of Computation Sheet. In order to facilitate the computations required to determine the various hydraulic properties for Grate Inlets, Type CG-U, on grade (undepressed), Computation Sheet No. 4 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 4 and is shown at the end of this sub-paragraph.

Example:

Q_o = Gutter flow = 2.0 c.f.s.

s_o = Gutter slope = 0.010 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015.

Column 1 Inlet number or designation.

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement in ft. per ft.

Column 4 Total gutter flow in c.f.s. For inlets other than the first inlet in the system, gutter flow is the sum of runoff from contributing area plus the carry-over flow from the inlet or inlets upstream.

Column 5 Depth of gutter flow in feet from Figure 4 or from direct solution of Manning's Equation.

$$y_o = 1.245\, Q_o^{3/8} \quad \frac{n^{3/8}}{s_o^{3/16}} \left(\frac{1}{\tan \theta_o}\right)^{3/8}$$

Column 6 Gutter velocity in feet per second from Figure 5 or from direct solution of continuity equation $v_o = Q_o/A$ where A is the cross-sectional area of flow in gutter or by Manning's Equation.

$$v_o = 1.288\, Q_o^{1/4} \quad \frac{s_o^{3/8}}{n^{3/4}} \left(\frac{1}{\tan \theta_o}\right)^{1/4}$$

Column 7 Length of grate in feet.

Column 8 Column 5 divided by (g) and the quotient raised to the 1/2 power.

Column 9	Length of grate required to capture 100 per cent of all flow over grate in ft.

$$L_o = M\, v_o \left(\frac{y_o}{g}\right)^{1/2}$$

or

L_o = M times Column 6 times Column 8

M = Grate coefficient where: M = 4.0 for grate inlets if no large transverse bars are flush with the grate surface; and M = 8.0 for grate inlets if flush transverse bars are used.

Column 10	Width of grate in feet. Distance from face of curb to outside openings in grate.
Column 11	Tangent of crown slope.
Column 12	Column 10 divided by Column 11.
Column 13	Column 5 minus Column 12.
Column 14	Column 13 divided by (g) and the quotient raised to the 1/2 power.
Column 15	Length of grate required to capture the outer portion of gutter flow in feet.

$$L' = 1.2\, v_o \tan \theta_o \left(\frac{y_o - \frac{W}{\tan \theta_o}}{g} \right)^{1/2}$$

or

L' = 1.2 times Column 6 times Column 11 times Column 14.

Column 16 — Column 15 minus Column 7.

Column 17 — Column 13 raised to the 3/2 power.

Column 18 — Carry-over flow in c.f.s. outside of the grate.

$$q_2 = 1.42\, (L'-L) \left(y_o - \frac{W}{\tan \theta_o}\right)^{3/2}$$

or

q_2 = 1.42 times Column 16 times Column 17.

Column 19 — Column 7 divided by Column 9 raised to the 2 power. Computation not required for combination inlets.

Column 20 — Carry-over flow in c.f.s. between the curb and grate. Computation not required for combination inlets.

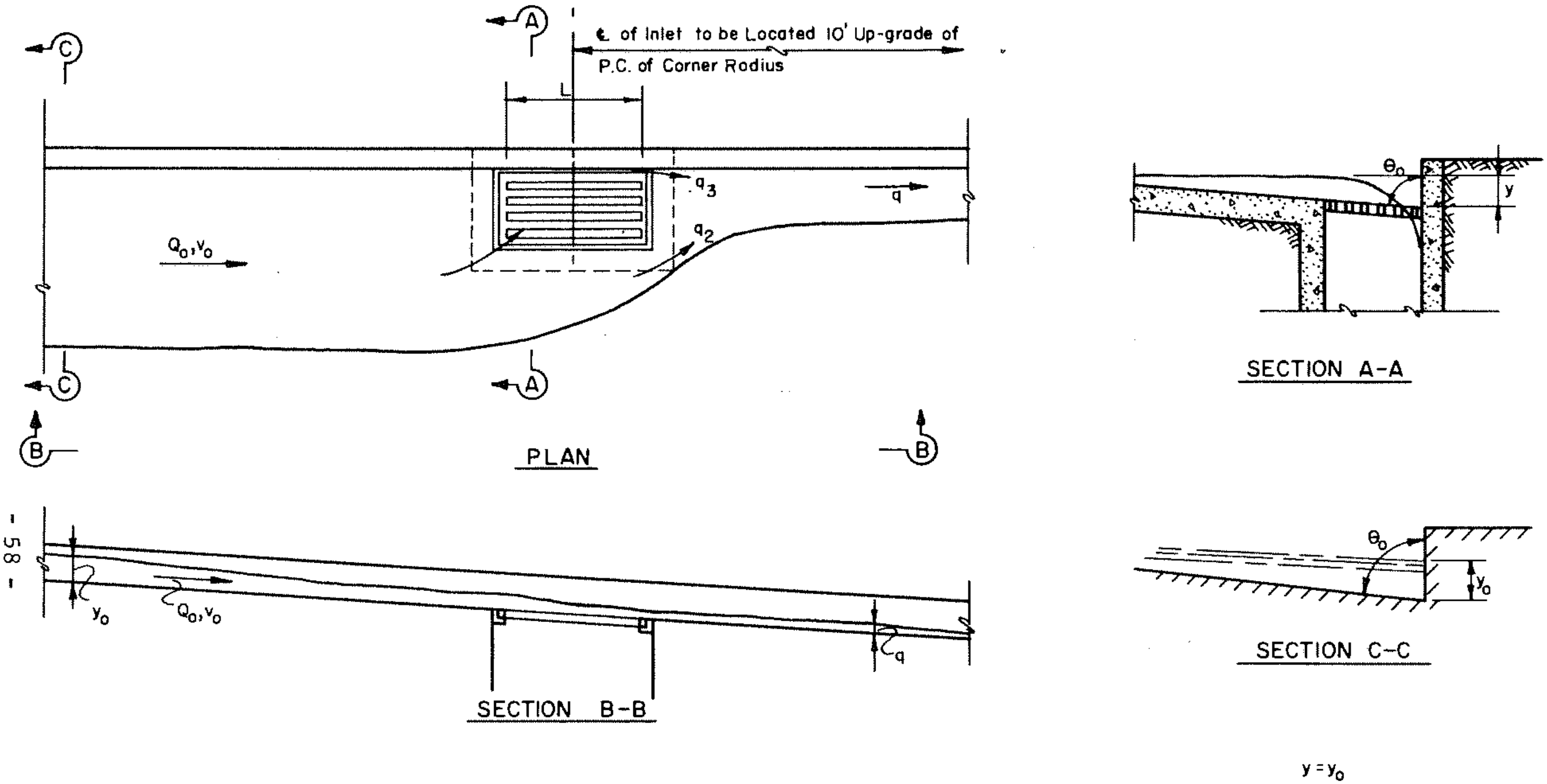
$$q_3 = Q_o \left[1 - \left(\frac{L}{L_o} \right)^2 \right]^2$$

or

q_3 = Column 4 times (1 minus Column 19) raised to the 2 power.

Column 21 — Total carry-over flow in c.f.s. passing grate. Same as Column 18 for combination inlets. $q_2 + q_3$ = Column 18 plus Column 20.

Column 22	Capacity of inlet in c.f.s. Column 4 minus Column 21.
Column 23	Per cent of flow captured by inlet. Column 22 divided by Column 4 times 100.



UNDEPRESSED
GATE INLET
ON GRADE TYPE CG-U

FIGURE 15

BY *Designer*

DATE

CK'D. *City Engr's Office* n = *0.015*

DATE ________

COMPUTATION SHEET NO. 4
FOR DETERMINING CAPACITY OF GRATE OR COMBINATION INLET ON GRADE (UNDEPRESSED)

SHEET *~* OF *~*

STREET *As Assigned*

MAJOR WATERSHED *As Assigned*

JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_o FT/FT.	CROWN SLOPE OF PVMT. θ_o FT/FT.	GUTTER FLOW Q_o C.F.S.	DEPTH OF GUTTER FLOW y_o FT.	GUTTER VELOCITY v_o F.P.S.	LENGTH OF GRATE OR CURB OPENING L FT.	$\left(\frac{y_o}{g}\right)^{1/2}$ SEC.	$L_o = M\, v_o\left(\frac{y_o}{g}\right)^{1/2}$ FT. *	WIDTH OF GRATE W FT.	TAN θ_o	$\frac{W}{\tan\theta_o}$ FT.	$y_o - \frac{W}{\tan\theta_o}$ FT.	$\left(\frac{y_o - \frac{W}{\tan\theta_o}}{g}\right)^{1/2}$ SEC.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	0.010	*1/48*	*2.0*	*0.19*	*2.50*	*4'-0"*	*0.077*	*0.77*	*1.33*	*48*	*0.0277*	*0.16*	*0.071*

L^1 = 1.2 x Col. 6 x Col. 11 x Col. 14 FT.	$L^1 - L$ FT.	$(\text{Col. }13)^{3/2}$ $(\text{FT.})^{3/2}$	q_2 = 1.42 x Col. 16 x Col. 17 C.F.S.	$\left(\frac{L}{L_o}\right)^2$ *	$q_3 = Q_o\left(1-\frac{L^2}{L_o^2}\right)^2$ C.F.S. *	$q_2 + q_3$ C.F.S.	$Q = Q_o - q_2 + q_3$ C.F.S.	$\frac{Q}{Q_o}$ (100) %	NOTES * When $L < L_o$ or L^1 Compute q_3 $L > L_o$ or L^1 $q_3 = 0$ q_3 Not Required For Combination Inlet
15	16	17	18	19	20	21	22	23	24
10.2	*6.2'*	*0.064*	*0.56*	*~*	*~*	*0.56*	*1.44*	*72%*	*Use 1, Type CG-U, Space Further*
									Apart for Greater Efficiency.

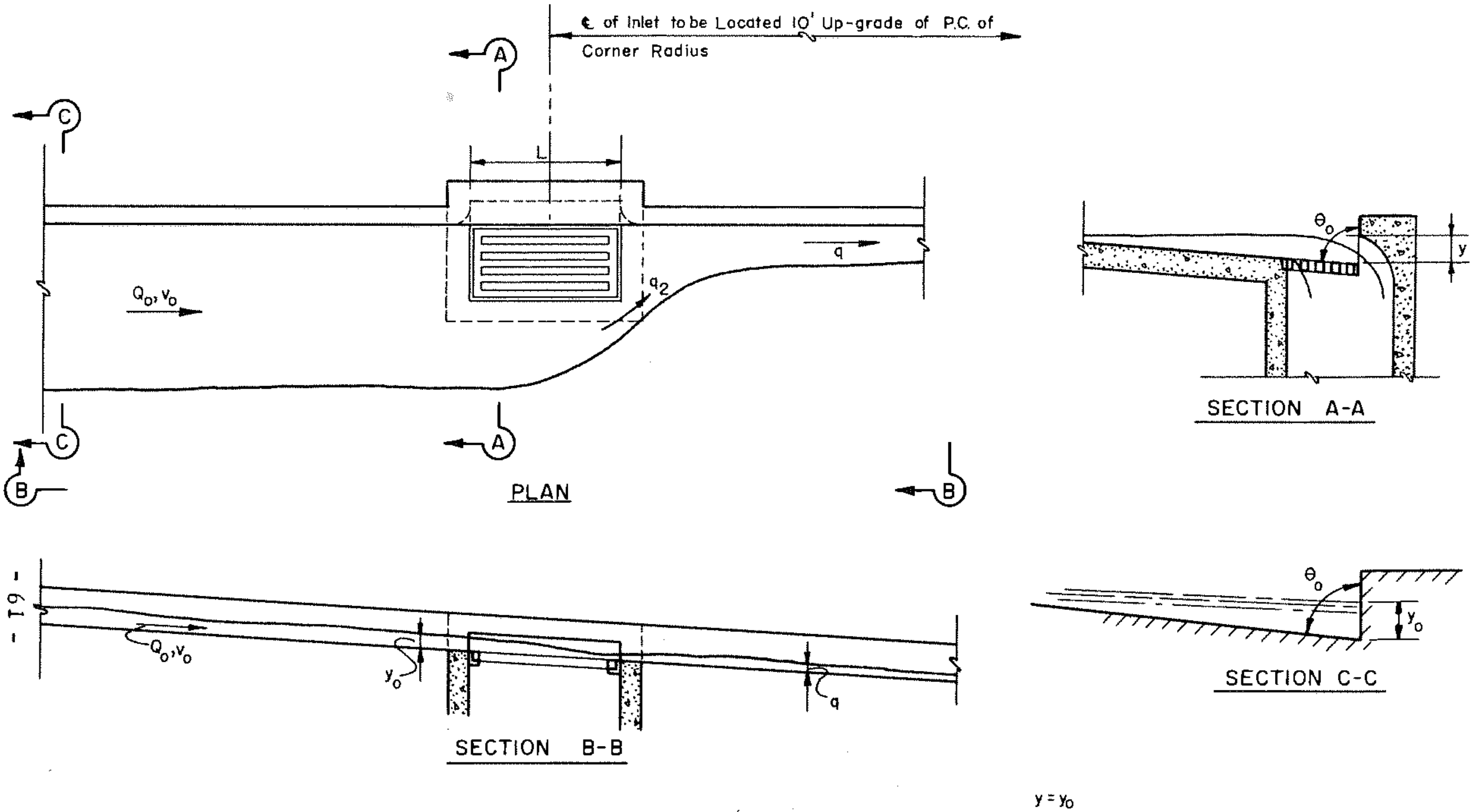
c. Combination Inlet on Grade Undepressed (Type COG-U.

(1) General. Undepressed combination (curb opening and grate) inlets on grade have greater hydraulic capacity than curb inlets or grate inlets of the same length (See Figure 16). Generally speaking, combination inlets are the most efficient of the three types of undepressed inlets presented in this manual. Grates with bars parallel to the curb should always be used. The basic difference between a combination inlet and a grate inlet is that the curb opening receives the carry-over flow that falls between the curb and the first grate opening. The calculated capacity of a combination inlet should be reduced by 20 per cent to allow for clogging.

(2) Example and Explanation of Computation Sheet (Combination Inlet) (Type COG-U). The example of calculating the capacity of an undepressed combination inlet is essentially the case of the undepressed grate inlet and is also shown on Computation Sheet No. 4 in the Appendix of this manual. However, the coefficient "M" used to determine L_o is different for the combination inlet and are as follows:

M = 3.3 for inlets if no large transverse bars are flush with the grate surface.

M = 6.6 for inlets if flush transverse bars are used.



UNDEPRESSED COMBINATION INLET ON GRADE TYPE COG-U

FIGURE 16

4.04 INLETS ON GRADE WITH GUTTER DEPRESSION

a. Curb Opening Inlets on Grade (Depressed) Type CO-D.

(1) General. The depression of the gutter at a curb opening inlet (See Figure 17) below the normal level of the gutter increases the cross-flow towards the opening, thereby increasing the inlet capacity. Also, the downstream transition out of the depression causes backwater which further increases the amount of water captured. Depressed inlets should be used on continuous grades that exceed one per cent although the use in traffic lanes should be avoided whenever possible.

The depression depth, width, length and shape all have significant effects on the capacity of an inlet; therefore, to simplify the design of all new depressed inlets, the following standard depression shall be used:

a = 0.208' or 2-1/2" = Standard depression below standard gutter grade.

W_o=4'-0" = Standard width of depression, measured from face of curb.

L_1=10'-0" = Standard upstream curb and gutter transition.

L_2=5'-0" = Standard downstream curb and gutter transition.

The capacity of a depressed curb inlet will be based on the following equation:

$$Q = (C+0.2)\ 5.68\ L\ y^{3/2}$$

Q = Capacity of inlet in c.f.s.

C = Constant

L = Length of curb opening in ft.

y = Depth of flow at inlet in ft.

(2) Example and Explanation of Computation Sheet for Curb Opening Inlet (Depressed). In order to facilitate the computations required in determining the various hydraulic properties for Curb Opening Inlets Type CO-D on grade (Depressed), Computation Sheet No. 5 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 5 and is shown at the end of this sub-paragraph.

Example:

Q_o = Gutter flow = 4.0 c.f.s.

s_o = Gutter slope = 0.020 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015.

Column 1 Inlet number or designation.

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement in ft. per ft.

Column 4 Gutter flow in c.f.s. For inlets other than the first inlet in the system, gutter flow is the sum of the runoff from contributing area plus carry-over flow from the inlet or inlets upstream.

Column 5 Depth of gutter flow at upstream end of gutter transition in feet from Figure 4 or from direct solution of Manning's Equation:

$$y_o = 1.245\ Q_o^{3/8}\ \frac{n^{3/8}}{s_o^{3/16}} \left(\frac{1}{\tan \theta_o}\right)^{3/8}$$

Column 6 — Gutter velocity in f. p. s. from Figure 5 or direct solution of continuity equation $v_o = Q_o/A$ where A is the cross-sectional area of flow in gutter at the upstream end of gutter transition or by Manning's Equation.

$$v_o = 1.288\, Q_o^{1/4} \left[\frac{s_o^{3/8}}{n^{3/4}} \left(\frac{1}{\tan \theta_o} \right) \right]^{1/4}$$

Column 7 — Gutter velocity head in ft. from Table 30.

Column 8 — Cross slope of gutter depression in ft. per ft.

Column 9 — Depth of depression at face of curb in feet.

Column 10 — Width of depression in feet measured from face of curb out.

Column 11 — Total specific energy of flow in ft. measured at the upstream end of gutter transition.

$$E = y_o + \frac{v_o^2}{2g} + a$$

Column 12 — Depth of flow at curb opening in feet. (See Figure 49 to 53)

Column 13 — Length of inlet opening in feet.

Column 14 — Length of upstream gutter transition in feet.

Column 15 — Length of downstream gutter transition in feet.

Column 16 — Tangent of depression cross slope.

Column 17 $2\left(\frac{E}{y} - 1\right) = 2\left(\frac{\text{Col. } 11}{\text{Col. } 12} - 1\right) = F$

Column 18 Column 13 divided by the product of Column 9 and Column 16.

Column 19 Column 17 times Column 18 = Coefficient M

Column 20 $\frac{0.45}{(1.12)^{\text{Col. } 19}} = C$

Column 21 5.68 times Column 12 raised to the 3/2 power

Column 22 (0.20+C) = 0.20 + Column 20.

Column 23 Capacity of inlet in c.f.s. per ft. of length of curb opening.

$$\frac{Q}{L} = (0.20+C)\ 5.68\ y^{3/2}$$

or

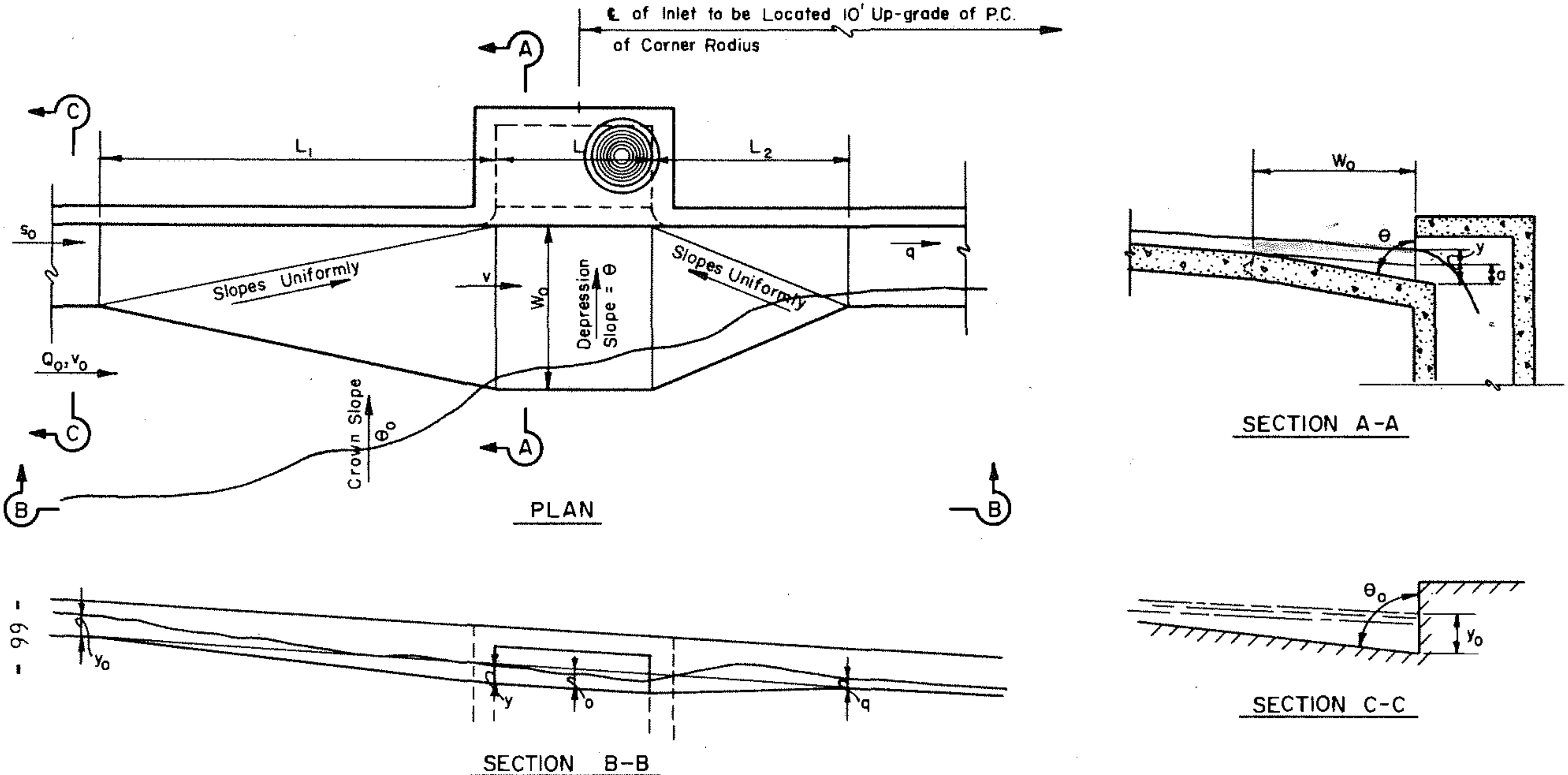
$\frac{Q}{L}$ = Column 22 times Column 21.

Column 24 Capacity of inlet in c.f.s. Column 23 times Column 13.

Column 25 Carry-over flow in c.f.s. passing inlet. Column 4 minus Column 24.

Column 26 Percentage of flow captured by inlet. Column 25 divided by Column 4 times 100.

The calculated capacity shall be reduced by 10 per cent to allow for clogging.



$$E = y_o + \frac{v_o^2}{2g} + a$$

DEPRESSED CURB – OPENING INLET ON GRADE TYPE CO-D

FIGURE 17

Std. Depression

L_1 = 10'–0"
L_2 = 5'–0"
L = Varies
W_o = 4'–0"
a = 0.208'
Θ = Varies
$Θ_o$ = Varies

BY *Designer*

DATE ______

CK'D. *City Engr's Office* n = *0.015*

DATE ______

COMPUTATION SHEET NO. 5
FOR DETERMINING CAPACITY OF
CURB OPENING INLET ON GRADE (DEPRESSED)

SHEET *~* OF *~*

STREET *As Assigned*

MAJOR WATERSHED *As Assigned*

JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_0 FT/FT.	CROWN SLOPE OF PVMT. θ_0 FT/FT.	GUTTER FLOW Q_0 C.F.S.	DEPTH OF GUTTER FLOW y_0 FT.	GUTTER VELOCITY v_0 F.P.S.	GUTTER VELOCITY HEAD $\frac{v_0^2}{2g}$ FT.	DEPRESSION CROSS SLOPE θ FT/FT.	DEPTH OF DEPRESSION a FT.	WIDTH OF DEPRESSION W_0 FT.	SPECIFIC ENERGY OF FLOW $E=y_0+\frac{v_0^2}{2g}+a$ FT.	DEPTH OF FLOW AT OPENING y FT.	LENGTH OF INLET OPENING L FT.	LENGTH OF UP-ST. TRANSITION L_1 FT.	LENGTH OF DN.-ST. TRANSITION L_2 FT.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	0.020	*1/48*	*4.00*	*0.21*	*2.70*	*0.11*	*1/13.8*	*0.21*	*4'-0"*	*0.53*	*0.40*	*4'-0"*	*10'-0"*	*5'-0"*
										As Assumed →				

TAN θ	$F = 2\left(\frac{E}{y}-1\right)$	$\frac{L}{a \tan\theta}$	$M = \frac{LF}{a \tan\theta}$	$C = \frac{0.45}{1.12^M}$	$5.68y^{3/2}$	(0.20+C)	Q/L = Col.21 x Col.22 C.F.S./FT.	CAPACITY OF INLET Q C.F.S.	CARRY-OVER FLOW PASSING INLET q C.F.S.	PERCENT CAPTURED BY INLET Q/Q_0	NOTES
16	17	18	19	20	21	22	23	24	25	26	27
13.8	*0.66*	*1.38*	*0.91*	*0.41*	*1.44*	*0.61*	*0.88*	*3.52*	*0.48*	*88.0%*	*Use 4'-0" Inlet Type CO-D*
											See Std. Dwg. No. 1

b. Grate Inlets on Grade (Depressed) Type CG-D.

(1) General. The depression of the gutter at a grate inlet decreases the flow past the outside of a grate. The effect is the same as that when a curb inlet is depressed, namely the cross slope of the street directs the outer portion of flow towards the grate (See Figure 18).

The bar arrangements for depressed grate inlets on streets with grades greater than one per cent greatly affect the efficiency of the inlet. Grates with longitudinal bars eliminate splash which causes the water to jump and ride over the cross bar grates, and it is recommended that grates have a minimum of transverse or cross-bars for strength only.

For low flows or for streets with grades less than one per cent, little or no splashing occurs regardless of the direction of bars. However, if the flow or street grade increases, the grate with longitudinal bars becomes progressively more superior to the cross bar grate. A few small rounded cross-bars, installed at the bottom of the longitudinal bars as stiffeners or a safety stop for bicycle wheels, do not materially affect the hydraulic capacity of longitudinal bar grates.

Grate inlets in depressions have a tendency to clog when gutter flows carry debris such as leaves and papers. For this reason the calculated inlet capacity of a grate inlet shall be reduced by 25 per cent to allow for clogging.

The depression depth, width, length and shape all have significant effect on the capacity of any inlet; therefore, to simplify the design of all new depressed grate inlets, the standard depression shown in paragraph 4.04 shall be used.

(2) Example and Explanation of Computation Sheet for Grate Inlet on Grade (Depressed) (Type CG-D). In order to facilitate the computation required in determining the various hydraulic properties for grate inlet on grade, Type CG-D (Depressed), Computation Sheet No. 6 has been prepared and is shown in the Appendix of this manual.

The following example is given to illustrate the use of Computation Sheet No. 6 and is shown at the end of this sub-paragraph.

Example:

Q_o = Gutter flow = 4.0 c.f.s.

s_o = Gutter slope = 0.020 ft. per ft.

θ_o = Crown slope of pavement = 0.25 in. per ft.

n = Pavement roughness coefficient = 0.015.

Column 1 Inlet number or designation.

Column 2 Slope of gutter in ft. per ft.

Column 3 Crown slope of pavement in ft. per ft.

Column 4 Total gutter flow in c.f.s. For inlets other than the first in system, gutter flow is the sum of runoff from the contributing area plus the carry-over flow from the inlet or inlets upstream.

Column 5 Depth of gutter flow in feet from Figure 4 or from direct solution of Manning's Equation.

$$y_o = 1.245\ Q_o^{3/8}\ \frac{n^{3/8}}{s_o^{3/16}}\left(\frac{1}{\tan\theta_o}\right)^{3/8}$$

Column 6 Gutter velocity in feet per second from Figure 5 or from direct solution of continuity equation $v_o = Q_o/A$, where A is the cross-sectional area of flow in the gutter or by Manning's Equation.

$$v_o = 1.288\ Q_o^{1/4}\ \frac{s_o^{3/8}}{n^{3/4}}\left(\frac{1}{\tan\theta_o}\right)^{1/4}$$

Column 7	Depth of depression at face of curb in feet.
Column 8	Width of depression measured from face of curb.
Column 9	Cross slope of gutter depression in ft. per ft.
Column 10	Length of grate in feet.
Column 11	Width of grate in feet.
Column 12	R = ratio of total width of clear openings to the width of grate, usually about 0.50 to 0.60 for cast iron or steel grates.
Column 13	Total specific energy of flow in feet measured at the upstream end of gutter transition.

$$E = y_o + \frac{v_o^2}{2g} + a$$

Column 14	Depth of flow at upstream edge of grate in feet (See Figure 49 to 53).
Column 15	Cross-sectional areas of gutter flow at grate in sq. ft. (See Figure 48).
Column 16	Mean velocity of flow at upstream edge of grate in f. p. s. Column 4 divided by Column 16.
Column 17	(Column 14 divided by 32.2) all raised to the 1/2 power.

Column 18 — Length of grate required to capture 100 per cent of all flow over grate in ft.

$$L_o = M\, v_o \left(\frac{y_o}{g}\right)^{1/2}$$

L_o = M times Column 6 times Column 8.

M = Grate coefficient where: M = 4.0 for grate inlets if no large transverse bars are flush with the grate surface; and M = 8.0 for grate inlets if flush transverse bars are used.

Column 19 — Tangent of depression cross slope.

Column 20 — Column 11 divided by Column 19.

Column 21 — Column 14 minus Column 20.

Column 22 — Column 21 divided by 32.2 all raised to the 1/2 power.

Column 23 — Length of grate required to capture the outer portion of gutter flow in feet.

$$L' = 1.2\, v_o \tan\theta_o \left(\frac{y_o - \frac{W}{\tan\theta_o}}{g}\right)^{1/2}$$

or

L' = 1.2 times Column 16 times Column 19 times Column 22.

Column 24 — Column 23 minus Column 10.

Column 25 Column 21 raised to the 3/2 power.

Column 26 Carry-over flow in c.f.s. outside of the grate.

$$q_2 = 1.42\ (L'-L)\ (y_o - \frac{W}{\tan \theta_o})^{3/2}$$

or

q_2 = 1.42 times Column 23 times Column 25.

Column 27 Column 10 divided by Column 18 raised to the 2 power. Computation not required for combination inlets.

Column 28 Carry-over flow in c.f.s. between the curb and grate. Computation not required for combination inlets.

$$q_3 = Q_o \left[1 - \left(\frac{L}{L_o}\right)^2 \right]^2$$

or

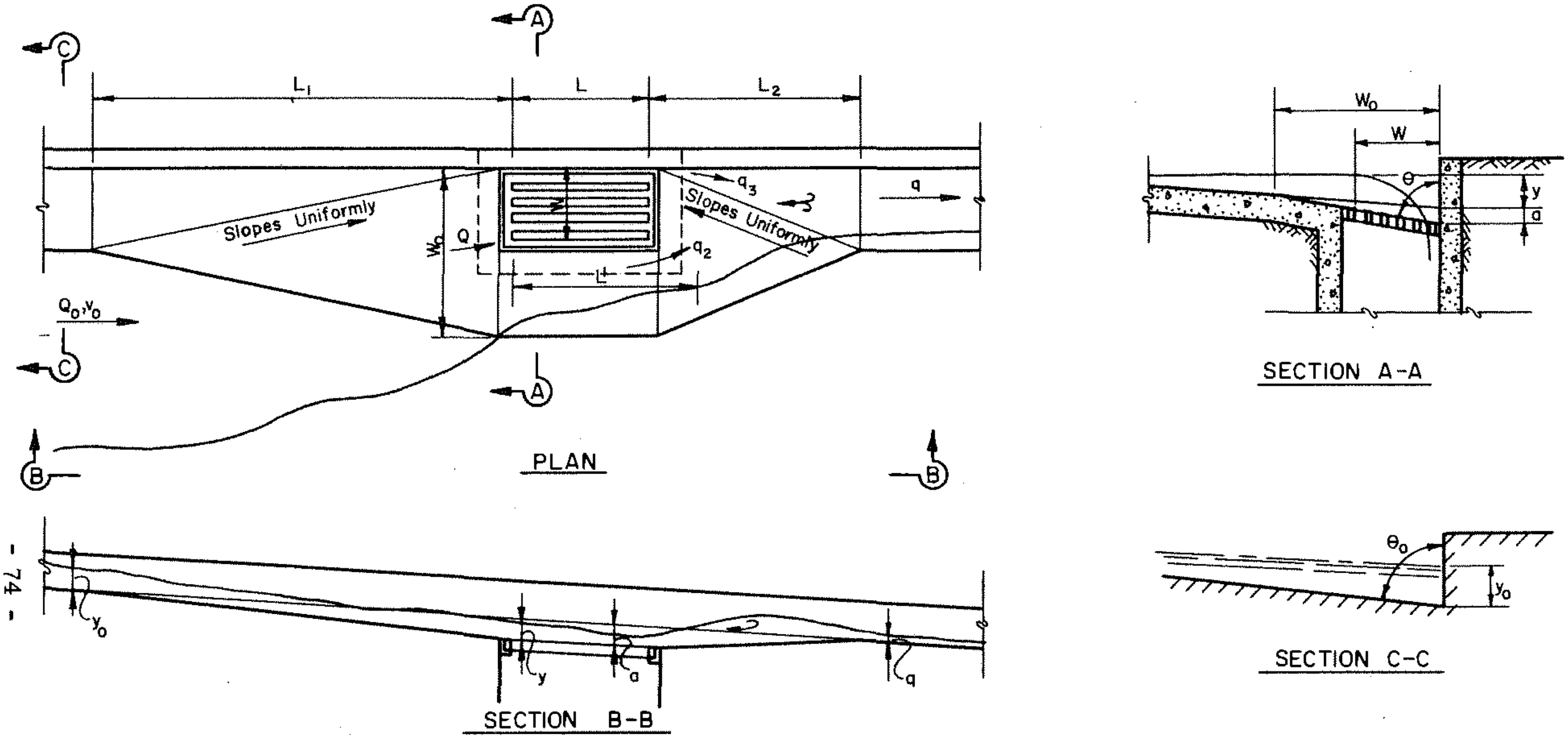
q_3 = Column 4 times (1 minus Column 27) raised to the 2 power.

Column 29 Total carry-over flow in c.f.s. passing grate. Same as Column 26 for combination inlets.

$q_2 + q_3$ = Column 26 plus Column 28.

Column 30	5.68 times Column 10 divided by Column 29.
Column 31	Column 30 raised to the 2/5 power.
Column 32	Column 7 minus L_2 times Column 2 L_2 = Length of downstream gutter transition.
Column 33	Value for abscissa on Figure 54. Column 31 times Column 32.
Column 34	Tan θ divided tan θ_o used to interpolate from Figure 54.
Column 35	Value for ordinate from Figure 54. Interpolate for R (Column 12) and tan θ divided by tan θ_o (Column 34) q divided by sum of q_2 and q_3
Column 36	Carry-over flow in c.f.s. passing the inlet. Column 29 times Column 35.
Column 37	Capacity of inlet in c.f.s. Column 4 minus Column 36.
Column 38	Percentage of flow captured by inlet. Column 37 divided by Column 4 times 100.

The calculated capacity should be reduced by 20 per cent to allow for clogging.



$$E = y_o + \frac{v_o^2}{2g} + a$$

Std. Depression

L_1 = 10'-0"
L_2 = 5'-0"
L = Varies
W_o = 4'-0"
a = 0.208'
θ = Varies
θ_o = Varies

DEPRESSED GRATE INLET ON GRADE TYPE CG-D

FIGURE 18

BY *Designer*

DATE ______

CK'D. *City Engr's Office* n= ______

DATE ______

COMPUTATION SHEET NO. 6
FOR DETERMINING CAPACITY OF GRATE OR COMBINATION INLET ON GRADE (DEPRESSED)

SHEET *~* OF *~*

STREET *As Assigned*

MAJOR WATERSHED *As Assigned*

JOB OR FILE NO. *As Assigned*

INLET NO.	GUTTER SLOPE s_0 FT./FT.	CROWN SLOPE OF PVMT. θ_0 FT./FT.	GUTTER FLOW Q_0 C.F.S.	DEPTH OF GUTTER FLOW y_0 FT.	GUTTER VELOCITY v_0 F.P.S.	DEPTH OF DEPRESSION a FT.	WIDTH OF DEPRESSION W_0 FT.	DEPRESSION CROSS SLOPE θ FT./FT.	LENGTH OF GRATE OR CURB OPENING L FT.	WIDTH OF GRATE W FT.	R=RATIO OF CLEAR OPENING WIDTH TO WIDTH OF GRATE	SPECIFIC ENERGY OF FLOW $E=y_0+\frac{v_0^2}{2g}+a$ FT.	DEPTH OF FLOW AT GRATE y FT.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
	0.020	*1/48*	*4.00*	*0.21*	*2.70*	*0.21*	*4'-0"*	*1/13.8*	*4'-0"*	*1.33*	*0.60*	*0.53*	*0.40*

CROSS SECTIONAL AREA OF FLOW A $(FT)^2$	VELOCITY OF FLOW AT INLET v F.P.S.	$\left(\frac{y}{g}\right)^{1/2}$ SEC.	$L_0 = Mv\left(\frac{y}{g}\right)^{1/2}$ FT. *	TAN θ	$\frac{W}{\tan\theta}$ FT.	$y-\frac{W}{\tan\theta}$ FT.	$\left(\frac{y-\frac{W}{\tan\theta}}{g}\right)^{1/2}$ SEC.	L' = 1.2 x Col.16 x Col.19 x Col.22 FT.	L' − L FT.	$\left(y-\frac{W}{\tan\theta}\right)^{3/2}$ $(FT.)^{3/2}$	q_2 = 1.42 x Col.24 x Col.25 C.F.S.	$\left(\frac{L}{L_0}\right)^2$ *	$q_3 = Q_0\left(1-\frac{L^2}{L_0^2}\right)^2$ C.F.S. *
15	16	17	18	19	20	21	22	23	24	25	26	27	28
1.35	*2.96*	*0.113*	*1.22*	*13.8*	*0.096*	*0.30*	*0.09644*	*4.72'*	*0.72'*	*0.1643*	*0.17*	*~*	*~*

q_2+q_3 C.F.S.	$\frac{(g)^{1/2}\tan\theta}{q_2+q_3}$ $(FT.)^{3/5}$	$(\text{Col. }30)^{2/5}$ $(FT.)^{9/10}$	$(a - s_0 L_2)$ FT. *	Col. 31 x Col. 32	$\frac{\tan\theta}{\tan\theta_0}$	$\frac{q}{q_2+q_3}$	q C.F.S.	$Q = Q_0 - q$ C.F.S.	$\frac{Q}{Q_0}$	NOTES: * When $L < L_0$ or L' Compute q_3; $L > L_0$ or L' $q_3 = 0$; q_3 Not Required For Combination Inlet; L_1 = Upstream Gutter Transition. L_2 = Downstream Gutter Transition.
29	30	31	32	33	34	35	36	37	38	39
0.17	*462*	*11.70*	*0.11*	*1.29*	*0.29*	*0.25*	*0.04*	*3.96*	*99 %*	*Use 4'-0" Type CG-D*
										See Std. Dwg. No. 2

c. Combination Inlet on Grade (Depressed) Type COG-D.

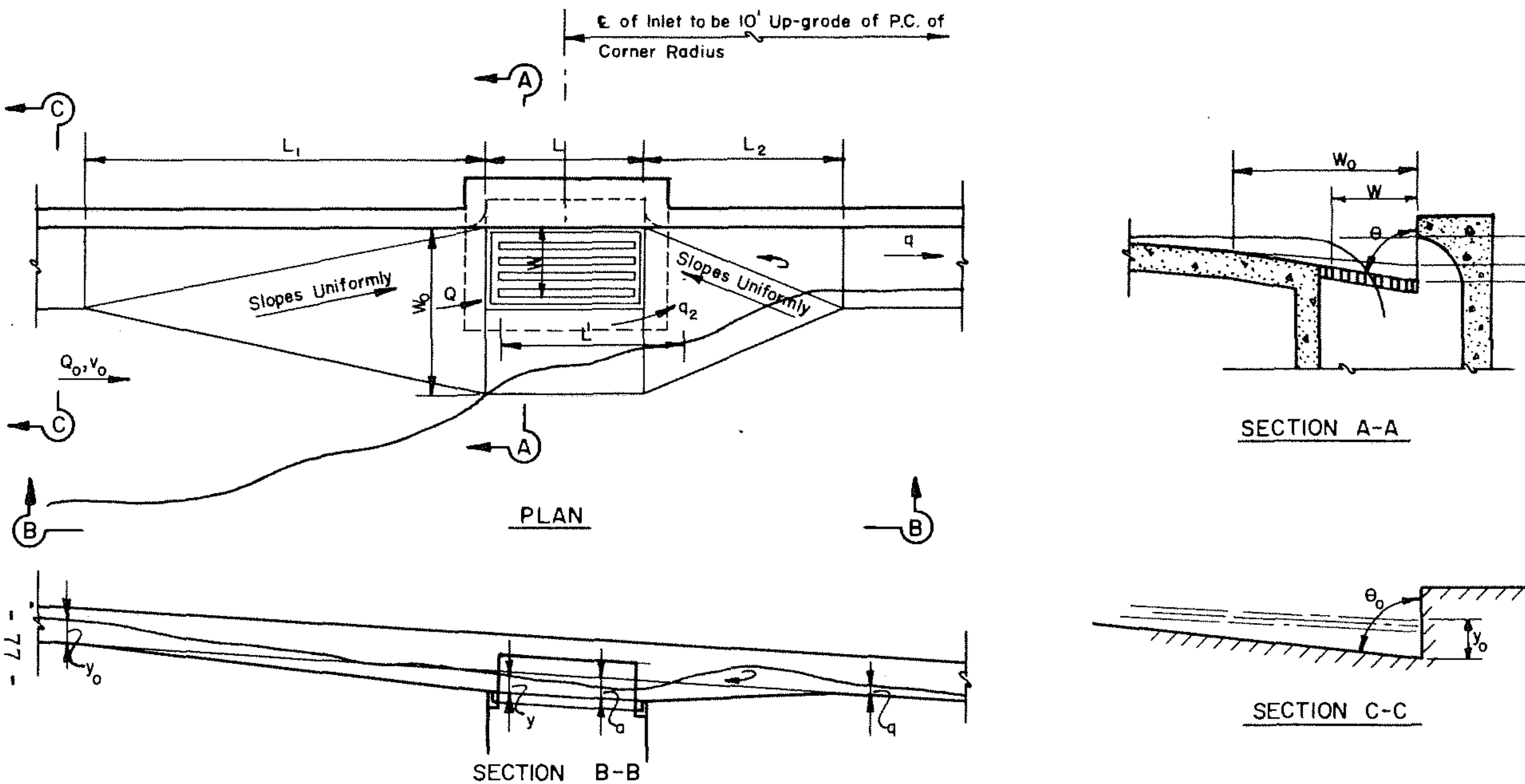
(1) General. Depressed combination inlets (curb opening plus grate) have greater hydraulic capacity than curb opening inlets or grate inlets of the same length. Generally speaking, combination inlets (See Figure 19) are the most efficient of the three types of depressed inlets presented in this manual. Grate with bars parallel to the curb should always be used for maximum efficiency. The basic difference between a combination inlet and a grate inlet is that the curb opening receives the carry-over flow that passes between the curb and the grating. The calculated capacity of a combination inlet should be reduced by 20 per cent to allow for clogging.

The depression depth, width, length and shape all have significant effect on the capacity of any inlet; therefore, to simplify the design of all new depressed combination inlets, the standard depression shown in Paragraph 4.04 shall be used.

(2) Example and Explanation of Computation Sheet for Combination Inlet on Grade (Depressed) (Type COG-D). The example of calculating the capacity of a depressed combination inlet is essentially the case of the depressed grate inlet and is also shown on Computation Sheet No. 6 in the Appendix. However, the coefficient "M" used to determine L_o are different for combination inlets and are as follows:

M = 3.3 for inlets if no large transverse bars are flush with the grate surface.

M = 6.6 for inlets if flush transverse bars are used.



$$E = y + \frac{v_o^2}{2g} + a$$

DEPRESSED COMBINATION INLET ON GRADE TYPE COG-D

Std. Depression

L_1 = 10-0"
L_2 = 5'-0"
L = Varies
W_o = 4'-0"
a = 0.208'
θ = Varies
$θ_o$ = Varies

FIGURE 19

SECTION V

FLOW IN STORM DRAINS AND THEIR APPURTENANCES

5.01 GENERAL

Since a general description of storm drainage systems and the quantities of storm runoff has been discussed in Section II of this manual, it is the purpose of this section of the manual to consider the significance of the hydraulic elements of storm drains and their appurtenances to storm drainage system.

Hydraulically, storm drainage systems are conduits (open or closed) in which unsteady and non-uniform free flow exists. Storm drains accordingly are designed for open-channel flow to satisfy as well as possible the requirements for unsteady and non-uniform flow. In many instances steady flow conditions may be either uniform or non-uniform.

5.02 VELOCITIES AND GRADES

a. Minimum Grades. Storm drains should operate with velocities of flow sufficient to prevent excessive deposits of solid materials; otherwise objectionable clogging may result. The controlling velocity is near the bottom of the conduit and considerably less than the mean velocity of the sewer. Storm drains shall be designed to have a minimum mean velocity flowing full of 2.5 f.p.s. Table 5 indicates the minimum grades for both concrete pipe ($n = 0.013$) and for corrugated metal pipe ($n = 0.024$), flowing at 2.5 f.p.s.

b. Maximum Velocities. Maximum velocities in sewers are important mainly because of the possibilities of excessive erosion on the storm drain inverts. Table 6 shows the limiting conditions of maximum velocity for most storm drainage design..

TABLE 5

MINIMUM GRADES FOR STORM DRAINS

Pipe Size (Inches)	Concrete Pipe Slope Ft./Ft.	Corrugated Metal Pipe Slope Ft./Ft.
15	0.0023	0.0076
18	0.0018	0.0060
21	0.0015	0.0049
24	0.0013	0.0041
27	0.0011	0.0035
30	0.0009	0.0031
33	0.0008	0.0027
36	0.0007	0.0024
39	0.0006	0.0022
42	0.0006	0.0020
45	0.0005	0.0018
48	0.0005	0.0016
54	0.0004	0.0014
60	0.0004	0.0012
66	0.0004	0.0011
72	0.0003	0.0010
78	0.0003	0.0009
84	0.0003	0.0008
96	0.0002	0.0007

TABLE 6

MAXIMUM VELOCITY IN STORM DRAINS

Description	Maximum Permissible Velocity
Culverts (all types)	15 f.p.s.
Storm Drains (inlet laterals)	No Limit
Storm Drains (Collectors)	15 f.p.s.
Storm Drains (Mains)	12 f.p.s.

5.03 MATERIALS

In selecting roughness coefficient for concrete pipe, between 0.013 and 0.015, consideration will be given to the average conditions at the site during the useful life of the structure. The "n" value of 0.017 for concrete pipe shall be used primarily in analyzing old sewers where alignment is poor and joints have become rough. If, for example, concrete pipe is being designed at a location where it is considered suitable, and there is reason to believe that the roughness would increase through erosion or corrosion of the interior surface, slight displacement of joints, or entrance of foreign materials, a roughness coefficient will be selected which, in the judgment of the designer, will represent the average condition. Any selection of "n" values below the minimum or above the maximum, either for monolithic concrete structures, concrete pipe or corrugated metal pipe, will have to have the written approval of the City Engineer.

The following recommended coefficients of roughness are listed in Table 7 and are for use in the nomographs contained herein, or by direct solution of Manning's Equation.

TABLE 7

ROUGHNESS COEFFICIENTS "n" FOR STORM DRAINS

Materials of Construction	Manning Coefficient
Monolithic Concrete Structure	0.015
Concrete Pipe	
Good alignment, smooth joints	0.013
Fair alignment, ordinary joints	0.015
Poor alignment, poor joints	0.017
Corrugated Metal Pipe	
Standard, unpaved with or without bitiminous coating	0.024
Paved invert, 25% of periphery paved	0.021
Paved invert, 50% of periphery paved	0.018
100% paved and bituminous coated	0.013

5.04 FULL OR PART FULL FLOW IN STORM DRAINS

a. General. All storm drains shall be designed by the application of the Manning Equation either directly or through the appropriate charts or nomographs.

$$Q = \frac{1.486}{n} A\ r^{2/3}\ s^{1/2}$$

Figures 30 through 47 (Appendix) have been prepared to facilitate either for part full or full conditions for the computation of flow in circular conduits of the size 12 inches in diameter through 96 inches. When read in conjunction with the superimposed lines of slope and normal depth of flow, the abcissa and ordinate scales represent discharge and normal velocity for these roughness coefficients.

b. Explanation of Pipe Flow Charts (Figures 30 through 47). Depths and velocities shown on these charts for partly full flow apply only in cases where length of pipe on a constant slope exists such that uniform flow at normal depth has been established which is not affected by back water condition.

Depth of uniform flow for a given discharge (Q) in a given size of pipe on a given slope with roughness coefficients of n = 0.013, 0.018 and 0.024, may be determined directly from the charts for that size by entering on the appropriate Q-scale and reading depth at the intersection of the appropriate slope line (or the interpolated slope). The corresponding velocity may be read on the appropriate V-scale opposite the same point. The procedure may be reversed to determine discharge at any given depth of flow.

When the Q-scale intersects a given slope line in the area near its right terminus, two alternate depths will be indicated if the normal depth is greater than 0.82 of the diameter. Flow for these cases will occur at the lesser of the alternate depths.

For pipe roughness coefficients other than those shown on the charts, enter the chart on the inner scale n = 0.013 with a value of design (Q) times proposed (n) divided by 0.013 to determine depth and velocity. Read directly from the chart at the pipe slope line and obtain velocity by dividing the value read on the V-scale for n = 0.013 by the same ratio (n) divided by 0.013.

The maximum rate of uniform flow discharge of any circular conduit on a given slope, not flowing under pressure, will occur with the depth of flow of 0.94 diameter. Therefore, to determine the maximum capacity of a pipe on a given slope not flowing under pressure, read the Q-scale for the appropriate value of "n" at the maximum value reached by the sharply curved slope line. Interpolated slope lines follow the same pattern as the designated lines.

When the Q-scale passes to the right of the sharply curved slope line for a given pipe slope, the pipe will flow full and under pressure. For this case, the charts may be used to determine the slope of the hydraulic gradient and energy lines which are parallel when the pipe flows full. The slope is the frictional slope, or the rate at which energy is lost by resistance to flow. Enter the chart with rate of flow or an adjusted rate of flow for the appropriate "n" value, and intersect the line at full depth equal to the pipe diameter, reading the frictional slope by interpolation on the slope scale. The discharge capacity for a pipe flowing full with a given frictional gradient may be found by reading the discharge at the proper slope point along the line for depth equal to the pipe diameter. Regardless of the roughness value the critical depth for a given discharge is obtained by interpolation from the depth lines at the point where the Q-scale for n = 0.013 and the critical depth curve intersect. Critical velocity is the reading on the V-scale for n = 0.013 for this same point. Critical depths greater than that represented by the last depth line of the charts just less than a diameter have little significance since wave action may intermittently fill the pipe.

Critical slopes will vary with the roughness of the pipe. When n = 0.013, the critical slope is read corresponding to the critical depth point as described above. To determine the critical slope for values of roughness coefficient other than 0.013, it is first necessary to determine the critical depth. The critical slope is then interpolated from the slope lines at the intersection of this depth with the Q-scale value for the appropriate "n", or with an adjusted value of Q-scale value for "n" values other than shown on the charts.

5.05 HYDRAULIC GRADIENT AND PROFILE OF STORM DRAIN

In storm drain systems flowing full, all losses of energy through resistance of flow in pipes, by changes of momentum or by interference with flow patterns at junctions, must be accounted for by the accumulative head losses along the system from its initial upstream inlet to its outlet. The purpose of accurate determinations of head losses at junctions is to include these values in a progressive calculation of the hydraulic gradient along the storm drain system. In this way, it is possible to determine the water surface elevation which will exist at each structure. The rate of loss of energy through the storm drain system shall be represented by the hydraulic grade line, since the hydraulic grade line measures the pressure head available at any given point within the system.

The hydraulic grade line shall be established for all storm drainage design. In open channels, the water surface itself is the hydraulic grade line. The hydraulic grade line is often controlled by the conditions of the sewer outfall; therefore, the elevation of the tailwater pool must be known. The hydraulic gradient is constructed upstream from the outlet, taking into account all of the head losses that may occur along the line.

The friction head loss shall be determined by direct application of Manning's Equation or by appropriate nomographs as discussed in Paragraph 5.03. Minor losses due to turbulence at structures shall be determined by the procedure of Paragraph 5.08.

The hydraulic grade line shall in no case be closer to the surface of the ground or street than 2 feet. Allowance of head must be provided for at some future date if the proposed storm drainage system is to be extended.

5.06 **MANHOLES**

a. General. All manholes shall be constructed in accordance with the Standard Details unless otherwise instructed by the City Engineer. The following conditions shall govern the use of the various types of manholes.

b. Types of Manholes

(1) Standard Manhole Types B-1, B-2, B-3 and B-4

(a) Maximum permissible depth - 12' (from ground to top of pipe).

(b) Minimum permissible depth - 4' (from ground to top of pipe).

(c) For pipes 36 inches in diameter and smaller use 4'-0" diameter manhole (straight run). Where manhole is used for junction of three or more lines (36" and smaller) use 5'-0" diameter manhole.

(d) For pipes 39" - 48" in diameter use 5'-0" diameter manhole (straight run). Where manhole is used for junction of three or more lines (48" and smaller) use 6'-0" diameter manhole.

(2) Standard Manhole Types T-1, T-2, T-3 and T-4

Same provisions as for Type B manholes.

(3) Standard Manhole Types P-1 and P-2

(a) Minimum permissible depth 12' (from ground to top of box) unless pipe size exceeds 48" in diameter.

(b) For pipes 54" in diameter and larger.

(4) Standard Manhole Type C

For any manhole condition where depth is less than 4'-0" (from ground surface to outside top of pipe).

c. Location. Manholes shall be located at intervals not to exceed 600 feet for pipe 24 inches in diameter or smaller. Manholes shall preferably be located at street intersections, sewer junctions, changes of grade and changes of alignment.

Manholes for sewers greater than 24 inches in diameter shall be located at points where design indicates entrance into the sewer is desirable; however, in no case should the distance between openings or entrances be greater than 1,200 feet.

5.07 PIPE CONNECTIONS

Prefabricated wye and tee connections are usually available up to and including 24" x 24". Connections larger than 24-inches will be made by field connections. This recommendation is based primarily on the fact that field connections are more easily fitted to a given alignment than are precast connections. Regardless of the amount of care exercised by the Contractor in laying the pipe, gainage in footage invariably throws precast connections slightly out of alignment - this error increases in magnitude as the size of pipe increases.

5.08 MINOR HEAD LOSSES AT STRUCTURES

The following head losses at structures shall be determined for inlets, manholes, wye branches or bends in the design of closed conduits. See Figures 20 and 21 for details of each case. Minimum head loss used at any structure shall be 0.10 foot.

The basic equation for most cases, where there is both upstream and downstream velocity, takes the form as set forth below with the various conditions of the coefficient "K_j" shown in Table 8.

$$h_j = \frac{v_2^2}{2g} - K_j \frac{v_1^2}{2g}$$

h_j = Junction or structure head loss in feet.

v_1 = Velocity in upstream pipe in f. p. s.

v_2 = Velocity in downstream pipe in f. p. s.

K_j = Junction or structure coefficient of loss.

In the case where the inlet or manhole is at the very beginning of a line or the line is laid with bends or on a curve, the equation becomes the following without any velocity of approach.

$$h_j = K_j \frac{v_2^2}{2g}$$

TABLE 8

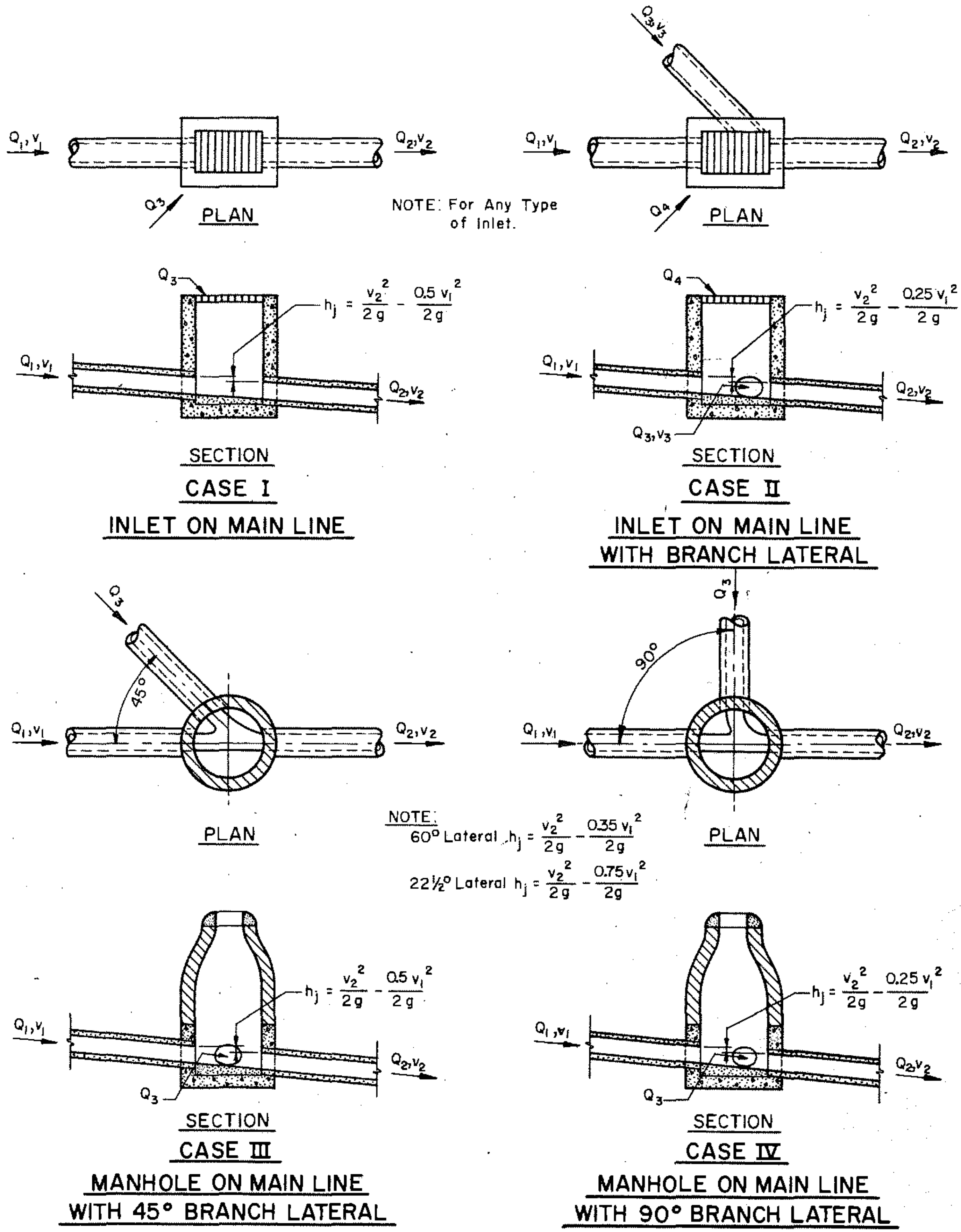
JUNCTION OR STRUCTURE

COEFFICIENT OF LOSS

Case No.	Reference Figure	Description of Condition	Coefficient K_j
I	20	Inlet on Main Line	0.50
II	20	Inlet on Main Line with Branch Lateral	0.25
III	20	Manhole on Main Line with 45° Branch Lateral	0.50
IV	20	Manhole on Main Line with 90° Branch Lateral	0.25
V	21	45° Wye Connection or cut-in	0.75
VI	21	Inlet or Manhole at Beginning of line	1.25
VII	21	Conduit on Curves for 90° *	
		Curve radius = diameter	0.50
		Curve radius = (2 to 8) diameter	0.25
		Curve radius = (8 to 20) diameter	0.40
VIII	21	Bends where radius is equal to diameter	
		90° Bend	0.50
		60° Bend	0.43
		45° Bend	0.35
		22-1/2° Bend	0.20
		Manhole on line with 60° Lateral	0.35
		Manhole on line with 22-1/2° Lateral	0.75

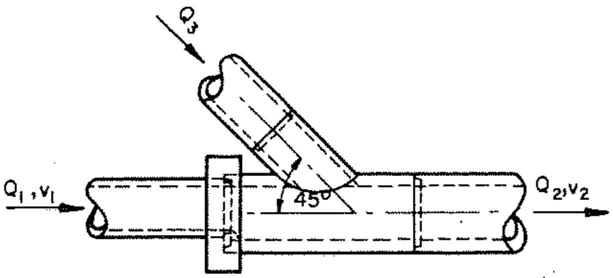
*Where bends other than 90° are used, the 90° bend coefficient can be used with the following percentage factor applied:

60° Bend - 85%; 45° Bend - 70%; 22-1/2° Bend - 40%

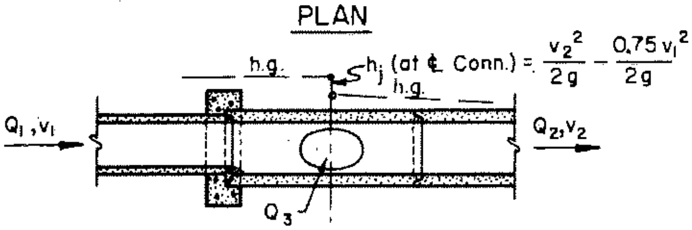


MINOR HEAD LOSSES DUE TO TURBULENCE AT STRUCTURES

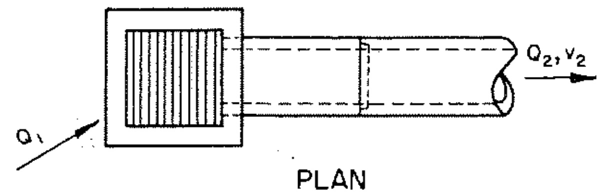
FIGURE 20



PLAN



SECTION



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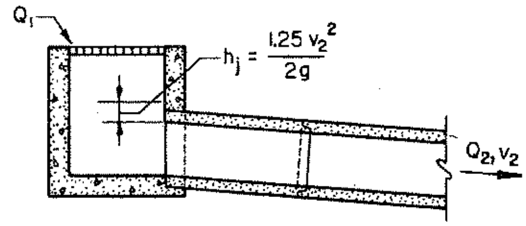
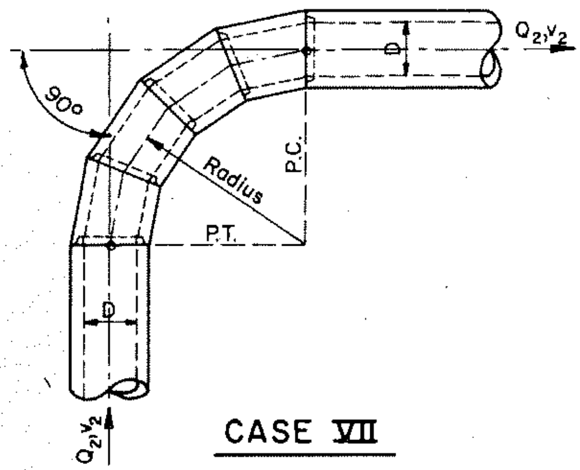


SECTION

CASE V
45° WYE CONNECTION OR CUT IN

CASE VI
INLET OR MANHOLE AT BEGINNING OF LINE



CASE VII
CONDUIT ON 90° CURVES*

NOTE: Head loss applied at P.C. for length of curve.

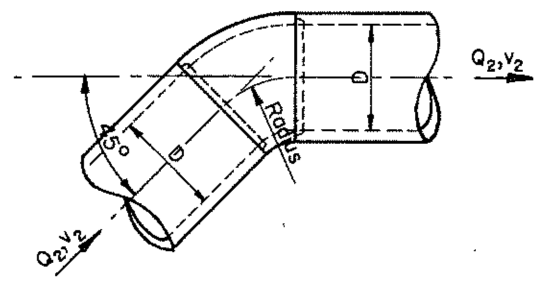
Radius = Dia. of Pipe $h_j = 0.50 \frac{v_2^2}{2g}$

Radius = (2-8) Dia. of Pipe $h_j = 0.25 \frac{v_2^2}{2g}$

Radius = (8-20) Dia. of Pipe $h_j = 0.40 \frac{v_2^2}{2g}$

Radius = Greater than 20 Dia. of Pipe $h_j = 0$

*When curves other than 90° are used, apply the following factors to 90° curves.
60° curve 85%
45° curve 70%
22 ½° curve 40%



CASE VIII
BENDS WHERE RADIUS IS EQUAL TO DIAMETER OF PIPE

NOTE: Head loss applied at begining of bend

90° Bend $h_j = 0.50 \frac{v_2^2}{2g}$

60° Bend $h_j = 0.43 \frac{v_2^2}{2g}$

45° Bend $h_j = 0.35 \frac{v_2^2}{2g}$

22 ½° Bend $h_j = 0.20 \frac{v_2^2}{2g}$

MINOR HEAD LOSSES DUE TO TURBULENCE AT STRUCTURES

FIGURE 21

5.09 UTILITIES

a. General. In the design of a storm drainage system, the engineer is frequently confronted with the problem of intersections between the proposed storm drain and existing utilities such as water, gas and sanitary sewer lines.

b. Water Lines. All existing water lines in the immediate vicinity of the proposed storm drains shall be clearly indicated on both the plan and profile sheets. When design clearly indicates that an intersection of the storm drain line and the water main exists and the proposed storm drain cannot be economically relocated, then the existing water line shall be adjusted. The existing water main may be adjusted in alignment and elevation depending upon the size, type of pipe, and other factors. The City Engineer shall be notified before the final storm sewer grade is laid where adjustments of water lines 12-inches and larger are required.

c. Sanitary Sewers. All existing or proposed sanitary sewers in the immediate vicinity of the proposed storm drains shall be clearly indicated on both plan and profile sheets. When design clearly indicates that an intersection of the storm drain line and the sanitary sewer exist and the proposed storm drain cannot be economically relocated, then the existing sanitary sewer shall be adjusted by relocation. Inverted siphons shall be used only when authorized by the City Engineer and the siphons shall be constructed of cast iron pipe in accordance with standard detail. All trench crossings for sanitary sewers shall be replaced with cast iron pipe in accordance with the standard detail.

d. Gas Lines and Other Utilities. All existing gas lines and other utilities in the immediate vicinity of the proposed storm drain shall be clearly indicated on both the plan and profile sheets.

Gas lines and other utilities, not controlled by elevation, shall be adjusted when the design clearly indicates that an intersection of the storm drain line and the utility exists and the proposed storm drain cannot be economically relocated. The City Engineer shall be notified when such design is contemplated and approval secured before proceeding with design.

SECTION VI

DESIGN OF CLOSED STORM DRAINAGE SYSTEM

6.01 GENERAL

All storm drains shall be designed by the application of the Manning Equation either directly or through appropriate charts or nomographs. In the preparation of hydraulic designs, a thorough investigation shall be made of all existing structures and their performance on the waterway in question.

An example of the use of the method used in the manual for the design of a storm drainage system is outlined in Paragraphs 6.03 and 6.04 and shown on Computation Sheet No. 7 and Drawings 1 to 5 in the Appendix of this manual. The design theory has been presented in the preceding sections with their corresponding tables and graphs of information.

6.02 PRELIMINARY DESIGN CONSIDERATIONS

a. Prepare a drainage map of the entire area to be drained by proposed improvements. Contour maps serve as excellent drainage area maps, when supplemented by field reconnaissance. (Scale 1" - 200'). See Drawing No. 1 in the Appendix of this manual.

b. Make a tentative layout of the proposed storm drainage system, locating all inlets, manholes, mains, laterals, ditches, culverts, etc.

c. Outline the drainage area for each inlet in accordance with present and future street development.

d. Indicate on each drainage area the code identification number, the amount of area, the direction of surface runoff by small arrows, and the coefficient of runoff for the area.

e. Show all existing underground utilities.

f. Establish design rainfall frequency.

g. Establish minimum inlet time of concentration.

h. Establish the typical cross section of each street.

i. Establish permissible spread of water on all streets within the drainage area.

6.03 RUNOFF COMPUTATIONS

The runoffs are shown on the Storm Drain Computation Sheet No. 7 at the end of this section. The first 15 columns of the computation sheet cover the tabulation for runoff computations.

Column 1 Enter the storm drain inlet point number. Design should start at the farthest upstream point.

Column 2 Enter the storm drain inlet point number of inlet point immediately downstream. In numbering inlets and manholes, it is customary to start numbering inlets and manholes at the beginning of the storm drainage system, proceeding upstream. In order to facilitate the filing and identification of material covering various elements of the storm drainage system, the code identification procedure shown in Section 1.04 shall be used.

Column 3 Enter the distance (in feet) between storm drain inlet point shown in Column 1 and 2. Column 1 stationing minus Column 2 stationing.

Column 4	Record the identification code number of each different drainage area to correspond to the numbers shown on the drainage area map.
Column 5	Record the area in acres for each of the individual areas of Column 4.
Column 6	Record the total drainage area in acres within the system corresponding to storm drain inlet point shown in Column 1.
Column 7	Record the coefficient of runoff "C" for each drainage area shown in Column 5.
Column 8	Multiply Column 5 by Column 7 for each area.
Column 9	Determine the total "CA" for the drainage system corresponding to the inlet or manhole shown in Column 1.
Column 10	Determine inlet time of concentration (See Figure 2 and Table 2).
Column 11	Determine flow time in sewer in minutes. The flow time in sewer is equal to the length from Column 3 divided by 60 times the velocity of flow through the sewer.
Column 12	Total time of concentration in minutes. Column 10 plus Column 11.
Column 13	Design frequency established by Design Criteria from Table 4.

Column 14	Intensity of rainfall in inches per hour corresponding to time of concentration shown in Column 12. Use Figure 3, Rainfall Intensity-Duration-Frequency Curves.
Column 15	Design Discharge or Runoff in c. f. s. Column 9 times Column 14.

6.04 HYDRAULIC DESIGN

After the computation of the quantity of storm runoff entering each inlet, the size and gradient of pipe required to carry off the design storm are determined. It should be borne in mind that the quantity of flow to be carried by any particular section of storm drain is not the sum of the inlet design quantities of all inlets above that section of pipe, but is less than the straight total. This situation is due to the fact that as the time of concentration increases the rainfall intensity decreases. Columns 16 through 29 of the computation sheet cover the minimum necessary hydraulic requirements to establish the hydraulic grade line for a storm drain and is shown at the end of this section.

Column 16	The size of pipe is chosen in such a manner that the pipe when, flowing full, will carry an amount of flow equal to or greater than the computed discharge with a desirable velocity.
Column 17	The slope of the frictional gradient (hydraulic gradient) is chosen so that the pipe when flowing full, will carry an amount of flow equal to or greater than the computed discharge. The pipe shall be constructed on a grade such that the inside crown of the pipe coincides with hydraulic gradient or is below the developed hydraulic gradient when flowing full.

Column 18 and 19	Record the hydraulic gradient elevations at the upstream end and downstream end of pipe section in question. The elevation of the hydraulic gradient of the upstream end of pipe is equal to the elevation of the downstream (hydraulic gradient) plus the product of Column 3 and Column 17.
Column 20	Velocity of flow in incoming pipe (main line) at junction, inlet or manhole at design point. (Column 1).
Column 21	Velocity of flow in outgoing pipe (main line) at junction, inlet or manhole at design point. (Column 1).
Column 22	Velocity head loss for outgoing velocity (main line) at junction, inlet or manhole at design point (Column 1) from Table 30.
Column 23	Velocity head loss for incoming velocity (main line) at junction, inlet or manhole at design point (Column 1) from Table 30.
Column 24	Head loss coefficient "K_j", at junction, inlet or manhole at design point from Table 8 or Figure 20 and 21.
Column 25	Multiply Column 23 by Column 24.
Column 26	Column 22 minus Column 25.
Column 27	Column 18 plus Column 26.

Column 28	Invert elevation at design point for incoming pipe.
Column 29	Invert elevation at design point for outgoing pipe.

BY W.F.A.
DATE Nov. 1958
CK'D. ______
DATE ______

COMPUTATION SHEET NO. 7
HYDRAULIC COMPUTATIONS FOR STORM DRAINS

LINE "A 4 3"   "n" = 0.013

LOCATION 17th St. FROM 15th Ave. TO 17th Ave.
MAJOR WATERSHED "A"
CONTRACT OR FILE NO. As Assigned

MANHOLE OR INLET: FROM (DESIGN POINT)	MANHOLE OR INLET: TO	DISTANCE BETWEEN MANHOLE OR INLET	DRAINAGE AREA: INCREMENT AREA NO.	DRAINAGE AREA: INCREMENT AREA AREA	DRAINAGE AREA: TOTAL AREA	COEFFICIENT OF RUNOFF "C"	INCREMENTAL "CA"	TOTAL "CA"	TIME OF CONCENTRATION: INLET TIME	TIME OF CONCENTRATION: FLOW TIME IN SEWER	TIME OF CONCENTRATION: TOTAL TIME	DESIGN FREQUENCY	INTENSITY	DISCHARGE "Q"	SELECTED SIZE OF PIPE	SLOPE OF FRICTIONAL GRADIENT	HYDRAULIC GRADIENT ELEVATIONS: UP STREAM	HYDRAULIC GRADIENT ELEVATIONS: DOWN STREAM	HEAD LOSS AT CHANGE IN SECTION: v_1 INFLOW	v_2 OUTFLOW	$\frac{v_2^2}{2g}$	$\frac{v_1^2}{2g}$	K_j	$\frac{K_j v_1^2}{2g}$	h_j	ELEV. H.G. AT DESIGN POINT COL. 18 + COL. 26	ELEV. OF INVERT AT DESIGN POINT (COL. 1): INCOMING PIPE	ELEV. OF INVERT AT DESIGN POINT (COL. 1): OUTGOING PIPE	NOTES
		FT.		ACRES	ACRES				MIN.	MIN.	MIN.	YEARS	IN/HR.	C.F.S.	INCHES	FT/FT.	FT. M.S.L.	FT. M.S.L.	FT./SEC.	FT./SEC.	FT.	FT.	CONSTANT	FT.	FT.	FT. M.S.L.	FT. M.S.L.	FT. M.S.L.	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
I-c6	MH-c2	24'	A4c7	2.54		0.35	0.89		15	~	15	2	3.70	[illegible]	12														Lateral
I-c7	MH-c2	24'	A4c6	4.03		0.35	1.41		15	~	15	2	3.70	[illegible]	12														Lateral
MH-c2	I-c4 I-c5	650'		6.57	6.57		2.30	2.30	~	~	15	2	3.70	8.50	21	0.00286	367.36	365.61	~	3.5	0.19	~	1.25	0.24	0.24	367.60	~	364.60	Main
I-c4	Main	24'	A4c4	2.38		0.40	0.95		15'	~	15	2	3.70	[illegible]	12												362.25		Lateral
I-c5	Main	24'	A4c5	2.75		0.40	1.10		15'	~	15	2	3.70		12												362.25		Lateral
I-c4 I-c5	MH-c1	35'		5.13	11.70		2.05	4.35	~	650'÷60x3.5=3.1	18.1	2	3.40	14.8	24	0.0043	365.46	365.31	3.5	4.7	0.34	0.19	0.50	0.10	0.15	365.61	362.00	361.60	MAIN
I-c3	MH-c1	56'	A4c3	2.65		0.40	1.06		20'	~	20	2	3.25		12												362.10		Lateral
MH-c1	I-c1 I-c2	612'		2.65	14.35		1.06	5.41	~	35'÷60x4.7=0.1	18.2	2	3.40	18.4	24	0.00662	364.93	360.89	4.7	5.9	0.54	0.34	0.50	0.17	0.37	365.31	361.60	361.60	Main
I-c1	Main	24'	A4c1	3.69		0.35	1.29		15	~	15	2	3.70		12												358.18		Lateral
I-c2	Main	24'	A4c2	2.43		0.45	1.10		15	~	15	2	3.70		12												358.18		Lateral
I-c1 I-c2	MH-a3	63'		6.12	20.47		2.39	7.80	~	612'÷60x5.9=1.7	19.9	2	3.25	25.4	30	0.0033	360.74	360.50	5.9	5.2	0.42	0.54	0.50	0.27	0.15	360.89	357.93	357.43	Main

REMARKS, SKETCHES AND COMPUTATIONS

Note:

SECTION VII

FLOW IN DITCHES AND CHANNELS

7.01 GENERAL

Open ditches and channels shall be used for collecting or concentrating storm runoff and drainage outlets where pipe lines or conduits cannot be justified on the basis of such factors as initial cost, maintenance cost, serviceability, health and safety. There should be no unprotected deep ditches or channels and steep side slopes adjacent to roads, streets, schools, parks, or other areas subject to frequent use. In urban development, only enough ditches to supplement the pipe system should be provided. The City Engineer should be consulted when extensive ditch or channel work is planned.

7.02 CHANNEL DISCHARGE

Careful attention must be given to the design of drainage ditches to assure adequate capacity and minimum maintenance to overcome the result of erosion, silting, sloughing of banks or similar occurrences. The hydraulic characteristics of the ditches and channels shall be determined by the Manning formula.

$$Q = \frac{1.486}{n} A\, r^{2/3}\, s^{1/2}$$

Q = Total discharge in c. f. s.

n = Coefficient of roughness

A = Cross-section area of channel in sq. ft.

r = Hydraulic radius of channel in feet.

s = Slope of the frictional gradient in feet.

7.03 **GRADIENTS**

Ditches should have trapezoidal sections and adequate waterway areas to take care of uncertainties in run-off estimates, changes in channel coefficients, channel obstructions and silt accumulations.

Where practicable, unpaved ditches should have sufficient gradient, depending upon the type of soil, to provide velocities that will be self-cleaning but will not be so great as to create erosion. Manning roughness factors and maximum permissible velocities are shown in Table 9. A minimum of horizontal curves or changes in alignment is desirable. Paved ditches, drop structures, ditch checks or paved spillways may be required to control erosion that results from the high velocities of large volumes of water on steep grades.

TABLE 9

MINIMUM ROUGHNESS COEFFICIENTS AND MAXIMUM PERMISSIBLE VELOCITIES FOR CHANNELS

Channel Description	Coefficient of Roughness "n"	Max. Permissible Mean Velocity fps
Vegetated Channels		
Clays (Bermuda Grass)	0.035	5 to 8
Sandy and Silty Soils (Bermuda Grass)	0.035	3 to 5
Non-vegetated Channels		
Concrete lined channels	0.015	15
Riprap (broken concrete)	0.030	15
Natural earth channels without vegetation:		
Sandy Soils	0.030	1.5 to 2.5
Silts	0.030	0.7 to 1.5
Sandy Silts	0.030	2.5 to 3.0
Clays	0.030	3.0 to 5.0
Coarse gravels	0.030	5.0 to 8.0
Shale	0.030	6.0 to 10.0
Rock	0.025	15

7.04 **SIDE SLOPES**

Also to prevent erosion, ditches and channels should have smooth sloping sides. Where it is economically feasible to develop and maintain turfed side slopes, these slopes should not be steeper than three horizontal to one vertical.

7.05 **SEDIMENTATION**

To prevent sedimentation in wide ditches or channels with flat side slopes and low velocities, a secondary or pilot channel may be required to increase the channel velocity during low flows.

7.06 **BRANCHES**

Branches should join the main ditch or channel at an acute angle to avoid deposition of debris at the junction and erosion of the opposite bank.

7.07 **DITCH LINING**

a. Turf. Earth channels normally require some type of lining, such as strong turf which is not susceptible to rank growth. Bermuda grass is ideally suited for turfing and should be used unless otherwise instructed. In particularly erosive soils, special methods may be necessary to establish the turf quickly or to provide supplemental protection, by mulching or similar means.

Erosion frequently becomes a problem involving ditches, especially on steep slopes, prior to the establishment of a vigorous turf. Should erosion be so rapid as to render turf establishment impossible, other erosion control measures should be taken.

b. Paved Lining. Lining or partial lining may be required where erosion may be caused by soil conditions or by high velocities from comparatively steep gradients, excessive flow of water, steep side slopes, changes in direction of channel, etc. Ditch lining should be utilized only where clearly justified for health and safety or to prevent excessive maintenance costs. The ditch lining may be of plain or reinforced concrete, bituminous materials, or plain or grouted riprap.

SECTION VIII

DESIGN OF CULVERTS

8.01 GENERAL

The function of a drainage culvert is to pass storm flow from the upstream side of a highway, road or railroad to the downstream side without causing excessive backwater head and without creating excessive downstream velocities. The designer shall keep the losses of head and discharge velocities within safe limits while selecting the most economical structure that will provide the satisfactory service.

8.02 QUANTITY OF FLOW

The quantity of flow shall be determined by the Rational Method as set forth in Section II of this manual. Culverts in size up to and including an 84-inch diameter pipe shall be designed on a frequency of 10 years while structures larger shall be designed on a 25-year frequency. All culverts shall be checked for a 50-year frequency to determine the upstream backwater conditions as well as downstream velocities and flooding conditions. (See Section II).

For areas where the proposed culvert or culverts will eventually become part of the palnned storm drainage system, the alignment, location and grade must be predetermined to insure the most economical development of the planned drainage system. The designer shall consult the "Master Drainage Plan" before proceeding with the design of any storm drainage improvement. In the event the particular watershed or waterway is not covered by the "Master Storm Drainage Plan", then the designer shall proceed with the design from the nearest downstream control, as instructed by the City Engineer, keeping in mind the future expansion of the drainage improvements.

8.03 HEADWALLS AND ENDWALLS

a. General. The normal functions of properly designed deadwalls and endwalls are to anchor the storm drain or culvert pipe, to prevent disjointing due to lateral pressures, to control erosion and scour resulting from excessive velocities and turbulence and to prevent adjacent soil from sloughing in to the waterway opening. All headwalls shall be constructed of reinforced concrete and may be of either straight parallel headwalls, flared headwalls or warped headwalls with or without aprons and cutoff walls as may be required by local conditions. Definite design criteria applicable to all conditions cannot be formulated, but the following conditions should dictate the requirements for most headwall and endwall installations.

b. Conditions at Entrance. In considering the designs for entrance conditions for culverts, it is important to remember that the operating characteristics of a culvert may be completely changed by the shape or condition at the inlet or entrance. Therefore, all culverts shall be provided with headwalls of either standard or special design as instructed by the City Engineer. The entrance head losses may be determined in terms of the following equation.

$$h_e = K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right)$$

h_e = Entrance head loss in feet.

v_2 = Velocity of flow in culvert.

v_1 = Velocity of approach in f.p.s.

K_e = Entrance loss coefficient as shown in Table 10.

TABLE 10

VALUES OF ENTRANCE LOSS COEFFICIENTS "K_e"

Type of Structure and Entrance Design	Value of K_e
Concrete Pipe (with Concrete Headwall)	
Groove End Upstream	0.3
Square End Upstream	0.5
Round Entrance	0.2 (4" Radius)
Corrugated Metal Pipe	
Square End Upstream	0.5
Round Entrance	0.2 (4" Radius)
Concrete Box Culvert	
Square End Upstream	0.5
Round Entrance	0.2 (4" Radius)

In order to compensate for the retarding effect on the velocity of approach in channels produced by the creation of the headwater pools at culvert entrances, the velocity of approach shall be reduced by the factors as shown in Table 11.

TABLE 11

REDUCTION FACTORS FOR VELOCITY OF APPROACH

Limits of Velocity of Approach "v_1" (f. p. s.)	Description of Conditions	Reduction Factor for Velocity of Approach
0 - 6	For all culverts	0
Above 6	For culverts where the alignment of the approach channel is good and where a headwater pool is permissible within the right-of-way	0.5
Above 6	For culverts where the alignment of the approach channel is good, where the channel slopes have been lined and where a limited backwater pool is permissible within the right-of-way	1.0

c. Installations.

(1) Parallel Headwall and Endwall. Parallel or straight headwalls and endwalls should be used where approach velocities are low (below 6 f. p. s.), where backwater pools may be formed, where approach channels are undefined, where unlimited right-of-way is available, and where no downstream channel protection is required.

(2) Flared Headwalls and Endwalls. Flared headwalls and endwalls should be used for a well defined channel, where moderate approach velocities (6 to 10 f. p. s.) and medium amounts of debris exist. The wings of flared walls should be located with respect to the axis of the approach channel velocity instead of the culvert axis

(3) Warped Headwalls and Endwalls. Warped headwalls should be used for a well defined channel to obtain a gradual transition with minimum head loss (concrete lined), where moderate to high approach velocities (8 to 20 f.p.s.) and medium amounts of debris exist. These headwalls are effective with drop down aprons to accelerate flow through culvert, and are effective endwalls for transition flow from closed conduit flow to open channel flow. This type of headwall should only be used for large drainage installations with limited right-of-way.

8.04 CULVERT DISCHARGE VELOCITIES

The velocity of discharge from culverts should be limited as shown in Table 12. Consideration must be given to the effect of high velocities, eddies or other turbulence on the natural channel, downstream property and roadway embankment.

TABLE 12

CULVERT DISCHARGE - VELOCITY LIMITATIONS

Culvert Discharging On To	Maximum Allowable Velocity (f.p.s.)
Earth	6 f.p.s.
Sod Earth	8 f.p.s.
Paved or Riprap Apron	15 f.p.s.
Shale	10 f.p.s.
Rock	15 f.p.s.

8.05 CULVERT SIZE

a. General. Culverts shall be designed to provide sufficient waterway area for the following cases:

Case I Flowing Full with Submerged Outlet

Case II Flowing Full with Free Outlet

Case III Flowing Part Full with Outlet Control

Case IV Flowing Part Full with Inlet Control

b. Culverts with Submerged Outlets - Case I. Most culverts flow with free outlet, but depending on topography, a tailwater pool of a depth sufficient to submerge the outlet may form at some installation. Generally, these culverts will flow full when the inlet is also submerged. Control will be considered at the outlet. For an outlet to be submerged, the depth at the outlet must be equal to or greater than the diameter of pipe or height of box. The capacity of a culvert flowing full with a submerged outlet shall be governed by the following equation when the approach velocity is considered zero. See Figures 22 and 27 for additional criteria.

$$HW = TW + (1+K_e)\frac{v_2^2}{2g} + s_f L - s_o L$$

HW = Depth of backwater above invert of upstream end of culvert in feet.

TW = Depth of tailwater above invert of downstream end of culvert in feet. The elevation of the tailwater shall be determined from the channel characteristics downstream from culvert site.

K_e = Coefficient for entrance head loss.

$\frac{v_2^2}{2g}$ = Velocity head in feet at the exit.

s_f = Slope of frictional gradient in feet per foot.

s_o = Slope of culvert grade in feet per foot.

L = Length of culvert in feet.

Submergence of the outlet does not necessarily insure full flow. Culverts on steep grades may flow partly full to a point inside the pipe. Here, a hydraulic jump forms because of the submerged outlet. Such type installations provide an excellent way of controlling the downstream velocities as well as keeping the backwater pool to a minimum.

When the approach velocity is greater than zero for submerged outlet culverts, the following equation shall be used:

$$HW = TW + \frac{v_2^2}{2g} + K_e \left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g} \right) + s_f L - s_o L$$

$\frac{v_1^2}{2g}$ = Velocity head of approach in feet.

c. Culverts with Free Outlets - Case II. A culvert with a free outfall will flow full when the normal depth of flow through the pipe or box is equal to the diameter of the pipe or height of box, respectively, and the slope of the frictional gradient is equal to the slope of the culvert grade.

The capacity of a culvert flowing full with a free outlet shall be governed by the following equation when the approach velocity is considered zero. For additional criteria see Figures 22 and 27.

$$HW = D + (1 + K_e) \frac{v_2^2}{2g}$$

HW = Depth of backwater above the invert of upstream end of culvert in feet.

D = Diameter of pipe or height of box in feet.

K_e = Coefficient of entrance head loss.

$\frac{v_2^2}{2g}$ = Velocity head at exit in feet.

When the approach velocity is greater than zero, the following equation shall be used:

$$HW = D + \frac{v_2^2}{2g} + K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right)$$

$\frac{v_1^2}{2g}$ = Velocity head of approach in feet.

d. Capacity of Culvert Flowing Part Full with Outlet Control - Case III. In culvert design, it is generally considered that the head water pool maintains a constant level during the design storm. If this level does not submerge the culvert inlet, the culvert flows part full. To determine the discharge through this culvert, the location of the channel cross section at which critical flow occurs must be known. In culvert design, two possibilities for this location are considered, one at or near the outlet and the other near the inlet.

If critical flow occurs at the outlet the culvert is said to have "Outlet Control". A culvert flowing part full with outlet control will require the depth of flow in the barrel of the culvert to be greater than critical depth while passing through critical depth at the outlet.

The capacity of a culvert flowing part full with outlet control shall be governed by the following equation when the approach velocity is considered zero. For additional criteria see Figure 23.

$$HW = d_c + (1 + K_e)\ \frac{v_2^2}{2g} + s_f L - s_o L$$

HW = Depth of backwater above the invert of the upstream end of culvert in feet.

d_c = Critical depth of flow in feet.

K_e = Coefficient of entrance head loss.

$\frac{v_2^2}{2g}$ = Velocity head of exit in feet.

s_f = Slope of frictional head loss in ft. per ft.

s_o = Slope of culvert grade in ft. per ft.

L = Length of culvert in feet.

When approach velocity is greater than zero, the following equation shall be used.

$$HW = d_c + \frac{v_2^2}{2g} + K_e \left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) + s_f L - s_o L$$

$\frac{v_1^2}{2g}$ = Velocity head of approach in feet.

e. <u>Culvert Flow with Inlet Control - Case IV.</u> If critical flow occurs near the inlet, the culvert is said to have "Inlet Control". The maximum discharge through a culvert flowing part full occurs when flow is at critical depth for a given energy head. To assure that flow passes through critical depth near the inlet, the culvert must be laid on a slope equal to or greater than critical slope for the design discharge. Placing culverts which are to flow part full on slopes greater than critical slope will increase the outlet velocities but will not increase the discharge. The discharge is limited by the section near the inlet at which critical flow occurs.

The capacity of a culvert flowing part full with control at the inlet shall be governed by the following equation when the approach velocity is considered zero. For additional criteria, see Figures 23, 28, and 29.

$$HW = d_c + (1 + K_e) \frac{v_2^2}{2g}$$

HW = Depth of backwater above the invert of upstream end of culvert in feet.

d_c = Critical depth of flow in feet.

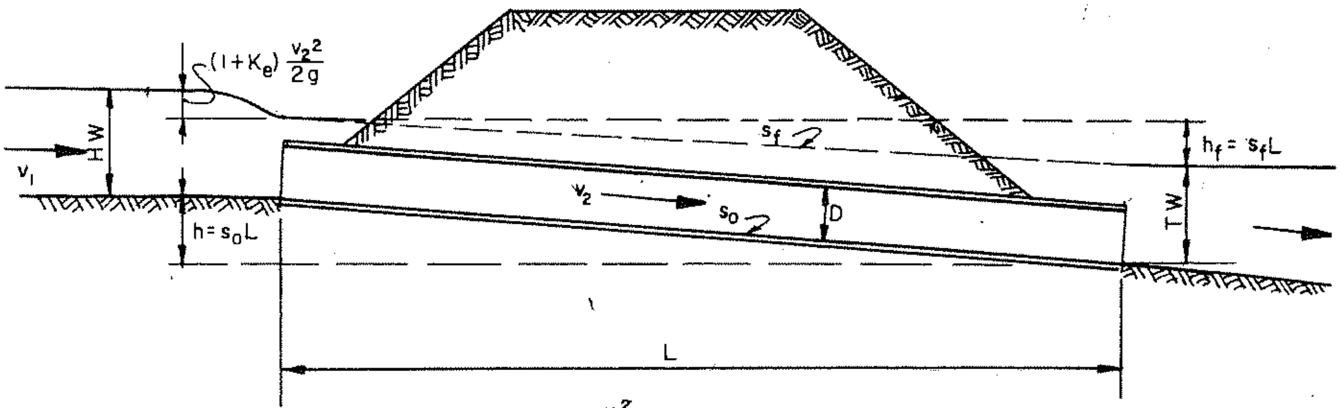
K_e = Coefficient of entrance head loss.

$\frac{v_2^2}{2g}$ = Velocity head at exit in feet.

When approach velocity is greater than zero, the following equation shall be used:

$$HW = d_c + \frac{v_2^2}{2g} + K_e \left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g} \right)$$

$\frac{v_1^2}{2g}$ = Velocity head of approach in feet.



$$HW = TW + (1+K_e)\frac{v_2^2}{2g} + s_f L - s_o L \quad \text{(Eq.1)}$$

$$HW = TW + \frac{v_2^2}{2g} + K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) + s_f L - s_o L \quad \text{(Eq.2)}$$

When $TW > D$

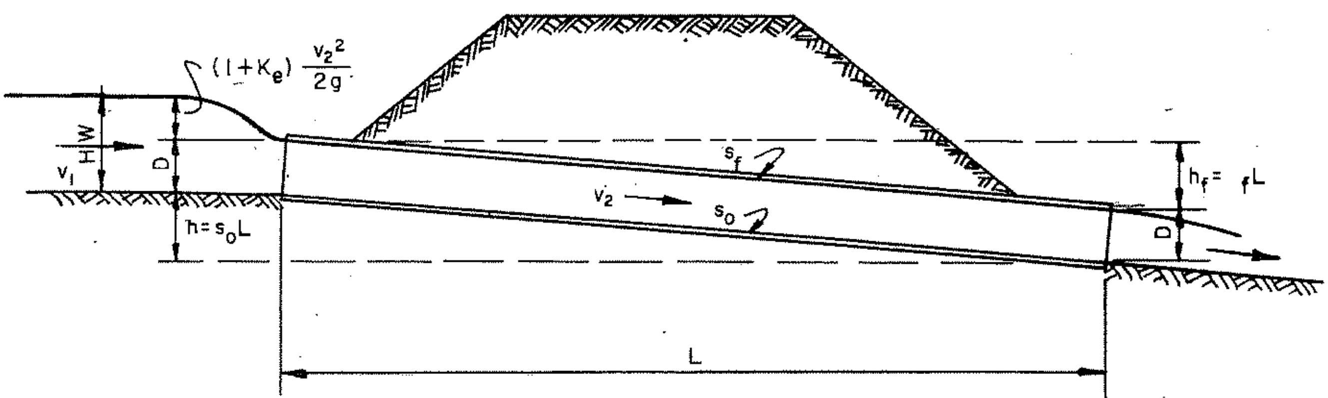
$s_f \geq s_o \leq s_c$

$d_n \geq D > d_c$

$v_1 = 0$ (Eq.1)(Illustrated)

$v_1 > 0$ (Eq.2)

CASE I
FULL FLOW
SUBMERGED OUTLET



$$HW = D + (1+K_e)\frac{v_2^2}{2g} \quad \text{(Eq.3)}$$

$$HW = D + \frac{v_2^2}{2g} + K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) \quad \text{(Eq.4)}$$

When $s_f = s_o \leq s_c$

$d_n = D > d_c$

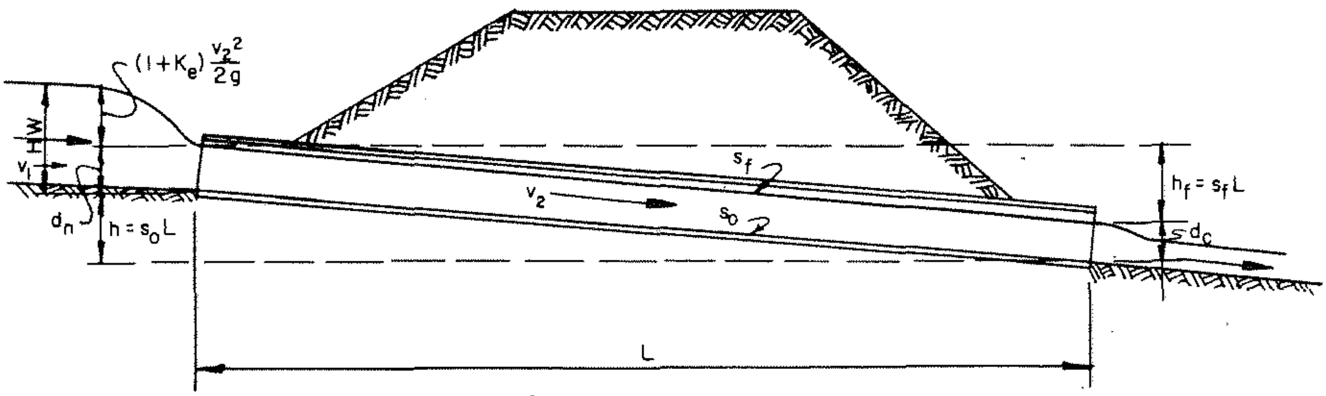
$v_1 = 0$ (Eq.3)(Illustrated)

$v_1 > 0$ (Eq.4)

CASE II
FULL FLOW
FREE OUTLET

CULVERT FLOW CONDITIONS

FIGURE 22

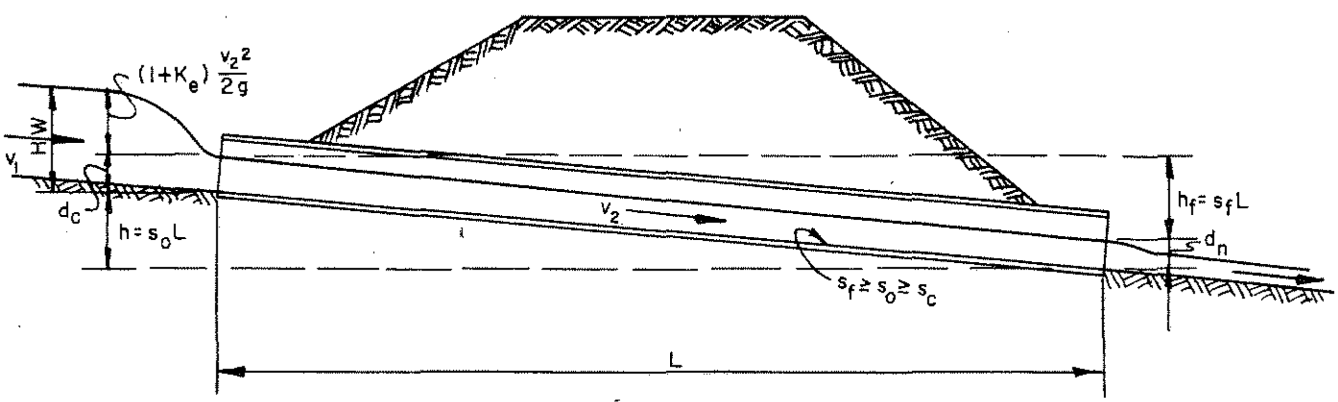


$$HW = d_c + (1+K_e)\frac{v_2^2}{2g} + s_fL - s_oL \text{ (Eq.5)}$$

$$HW = d_c + \frac{v_2^2}{2g} + K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) + s_fL - s_oL \text{ (Eq.6)}$$

When $d_n \geq d_c$
$s_f \geq s_o \leq s_c$
$v_1 = 0$ (Eq.5) (Illustrated)
$v_1 > 0$ (Eq.6)

CASE III
PART FULL FLOW
OUTLET CONTROL



$$HW = d_c + (1+K_e)\frac{v_2^2}{2g} \text{ (Eq.7)}$$

$$HW = d_c + \frac{v_2^2}{2g} + K_e\left(\frac{v_2^2}{2g} - \frac{v_1^2}{2g}\right) \text{ (Eq.8)}$$

When $d_n \leq d_c$
$s_f \geq s_o \geq s_c$
$v_1 = 0$ (Eq.7) (Illustrated)
$v_1 > 0$ (Eq.8)

CASE IV
PART FULL FLOW
INLET CONTROL

CULVERT FLOW CONDITIONS

FIGURE 23

SECTION IX

STRUCTURAL DESIGN OF STORM DRAINS

9.01 GENERAL

The following criteria for the structural design of storm drains, are based on the assumption that the storm drains will be buried in trenches entirely below the natural ground surface, that the sides of the trench will be virtually vertical below the top of the pipe and will have no flatter slopes than one horizontal to two vertical above the top of the pipe, and that the trench width at the top of the pipe will be relatively narrow. Under these conditions the following trench widths should be used for pipe installations:

12" to 33" diameter pipe, outside diameter of pipe plus 16"

36" diameter pipe and larger, outside diameter of pipe plus 24"

In the cases where storm drains would be laid in fills that have not become thoroughly compacted, the supporting strength of the pipe shall be determined by the methods outlined in the Iowa State College Bulletin 112, "The Supporting Strength of Rigid Pipe Culvert".

9.02 MINIMUM HEIGHT OF FILL

a. Rigid Pipe. The minimum height of fill between the top of a rigid pipe storm drain and the finished grade of any type roadway shall be 2.00 feet.

b. Flexible Metal Pipe. The minimum height of fill between the top of a flexible metal pipe storm drain and the finished grade of any type of roadway shall be 2.00 feet.

9.03 SUPPORTING STRENGTH OF STORM DRAINS

a. Rigid Pipe. The supporting strength of a pipe storm drain depends primarily upon the strength of the pipe itself and the manner in which it is laid in the trench. The following classes of embedment shall be used to yield the factors of safety used in design to provide for uncertainties:

Class "A" Embedment (Figure 24) Load factor 3.0
Class "B" Embedment (Figure 25) Load factor 1.9
Class "C" Embedment (Figure 26) Load factor 1.5

Pipe laid in Class "A" Embedment, illustrated in Figure 24, would support approximately 100 per cent more load than if laid in Class "C" Embedment as illustrated in Figure 26; however, Class "A" Embedment shall primarily be used when rock foundations are encountered. Normally, Class "C" Embedment is satisfactory for most foundations. The designer shall thoroughly investigate the soil conditions before selecting the type and class of pipe material.

Figures 24, 25 and 26 set forth the conditions for the use of Reinforced Concrete Pipe (C 76-57) Class II and III. When trench depths exceed those shown on the figures, pipe strength shall then be determined by the methods outlined in the Iowa State College Bulletin 112, "Supporting Strength of Rigid Pipe Culverts".

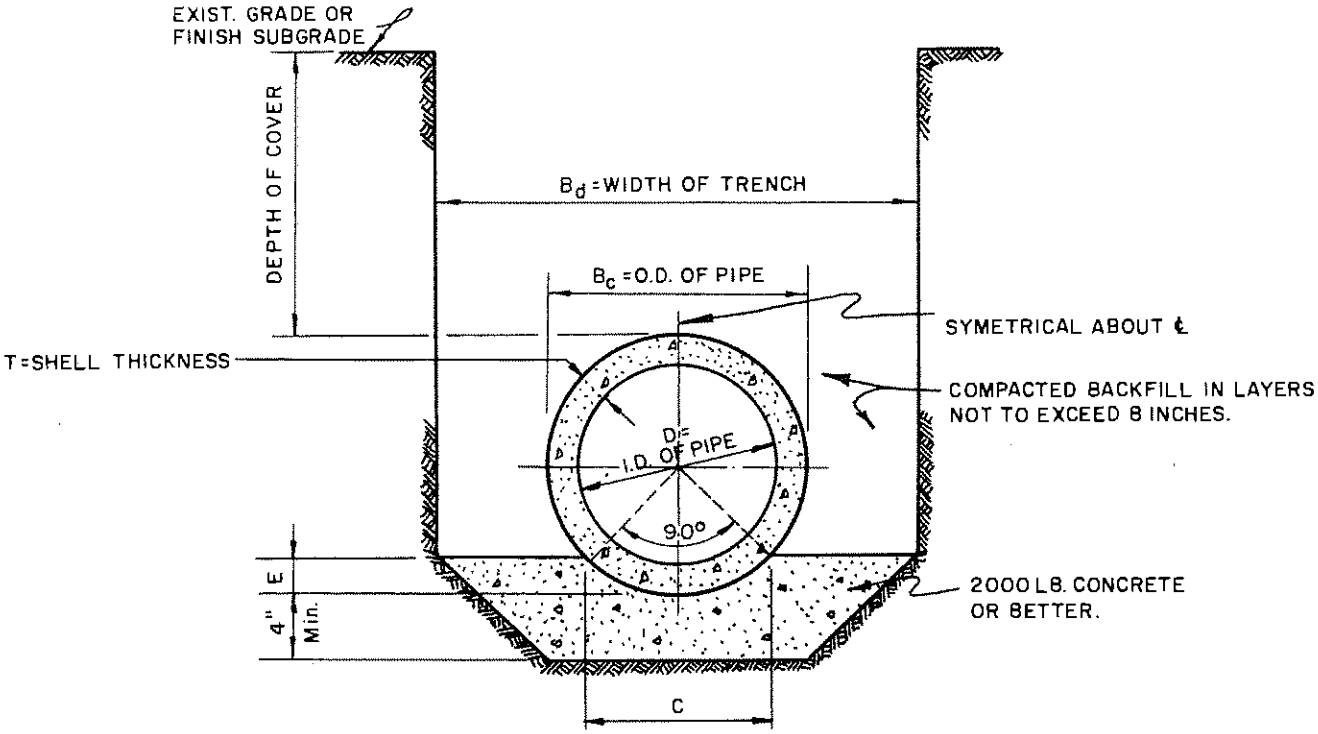
b. Flexible Metal Pipe. The supporting strengths for various types and shapes of corrugated metal pipes are shown in Figures 24, 25 and 26. When the depth of cover exceeds that shown in the above mentioned tables, then the supporting strength for flexible pipes shall be determined by the methods outlined in the Iowa College Bulletin 153, "The Structural Design of Flexible Pipe Culverts". Trench widths shall be the same for flexible pipes as those for rigid pipes.

c. Monolithic Concrete Storm Drains. The design of all reinforced concrete culverts, boxes, structures, sewers and appurtenances shall be designed in accordance with the latest addition of American Association of State Highway Officials, "Standard Specifications for Highway Bridges".

Concrete shall have a minimum compressive strength of 3,000 p. s. i. at 28 days. The modular ratio used in flexural calculations shall be 10.

All reinforcing steel shall be deformed, new billet, intermediate grade, conforming to the latest American Society of Testing Materials Specifications A-15 and A-305.

Reinforcing steel shall have allowable working stresses of 20,000 p. s. i. for bars of intermediate and hard grades, 18,000 p. s. i. for bars of structural grade.



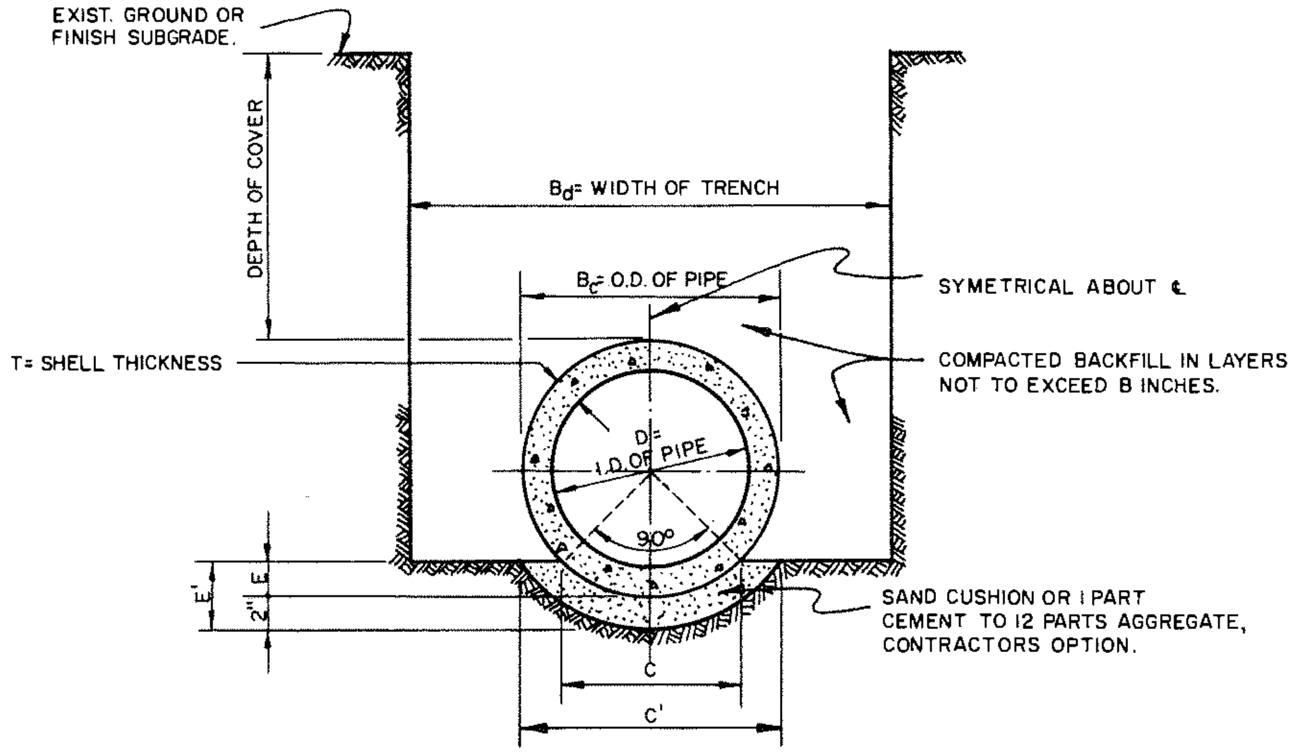
REINF. CONC. PIPE CLASS "A" EMBEDMENT						DEPTH OF COVER			
						CL. II R.C.P.		CL. III R.C.P.	
D	B_d	B_c	T	E	C	100 lb. SOIL	130 lb. SOIL	100 lb. SOIL	130 lb. SOIL
12"	2'-8"	1'-4"	2"	2 3/8"	11 3/8"	↑	22	↑	↑
15"	3'-0"	1'-7 1/2"	2 1/4"	2 7/8"	1'-1 3/4"		25		
18"	3'-3"	1'-11"	2 1/2"	3 3/8"	1'-4 1/4"		27		NO LIMIT
21"	3'-6"	2'-2 1/2"	2 3/4"	3 7/8"	1'-6 3/4"		29		
24"	3'-8"	2'-4"	3"	4 3/8"	1'-7 3/4"		29		
27"	4'-2"	2'-9 1/2"	3 1/4"	4 7/8"	1'-11 3/4"		30		↓
30"	4'-6"	3'-1"	3 1/8"	5 3/8"	2'-2 1/2"		30		76
33"	4'-9"	3'-4 1/2"	3 3/4"	5 7/8"	2'-4 5/8"		30		72
36"	5'-8"	3'-8"	4"	6 1/2"	2'-7 1/8"		24		37
39"	6'-0"	3'-11 1/2"	4 1/4"	7"	2'-9 3/4"		25		37
42"	6'-3"	4'-3"	4 1/2"	7 1/2"	3'-0"	NO LIMIT	25	NO LIMIT	39
45"	6'-6 1/2"	4'-6 1/2"	4 3/4"	8"	3'-2 1/2"		25		39
48"	6'-10"	4'-10"	5"	8 1/2"	3'-5"		25		40
54"	7'-5"	5'-5"	5 1/2"	9 1/2"	3'-10"		27		40
60"	8'-0"	6'-0"	6"	10 1/2"	4'-3"		28		40
66"	8'-7"	6'-7"	6 1/2"	11 5/8"	4'-7 7/8"		29		40
72"	9'-2"	7'-2"	7"	1'-0 5/8"	5'-0 7/8"		29		41
78"	9'-9"	7'-9"	7 1/2"	1'-1 5/8"	5'-5 3/4"		30		42
84"	10'-4"	8'-4"	8"	1'-2 3/8"	5'-10 3/4"		31		42
90"	11'-0"	8'-11"	8 1/2"	1'-3 5/8"	6'-3 5/8"		32		43
96"	11'-6"	9'-6"	9"	1'-4 3/4"	6'-8 5/8"	↓	32	↓	43

NOTES

1. CLASS II (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED IN AREAS OUTSIDE OF PAVEMENT.
2. CLASS III (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED UNDER PAVEMENT AREAS.
3. FOR TRENCH DEPTHS EXCEEDING THOSE SHOWN IN TABLE; PIPE STRENGTH SHALL BE INVESTIGATED FOR ITS SAFE LOAD CAPACITY.
4. LOAD-FACTOR FOR CLASS "A" EMBEDMENT SHALL BE CONSIDERED TO BE 3.0.
5. CLASS "A" EMBEDMENT (CONC. CRADLE) SHALL BE USED WHERE ROCK FOUNDATIONS ARE ENCOUNTERED.

CLASS "A" EMBEDMENT
(CONC. CRADLE) FOR REINF. CONC. PIPE

FIGURE 24



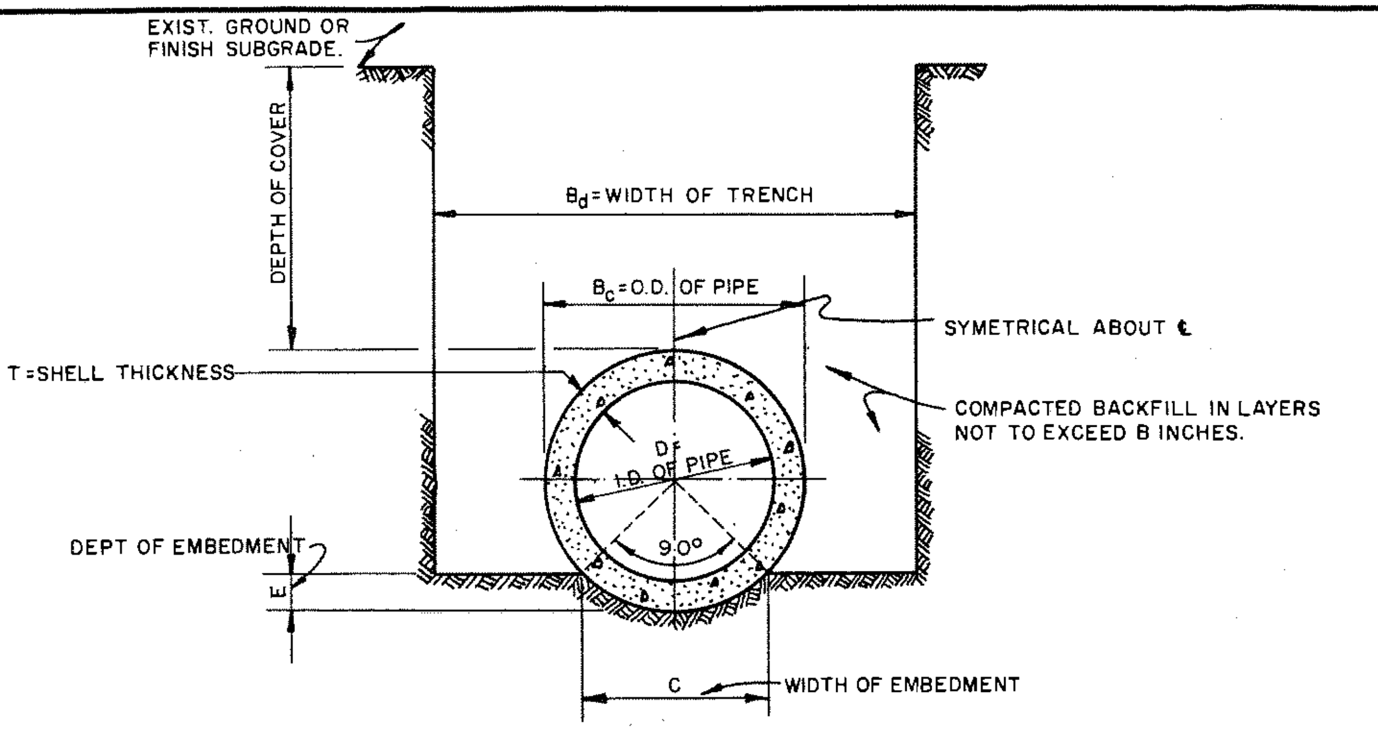
REINF. CONC. PIPE CLASS "B" EMBEDMENT								DEPTH OF COVER			
								CL.II R.C.P.		CL.III R.C.P.	
D	B_d	B_c	T	E	E'	C	C'	100 lb. SOIL	130 lb. SOIL	100 lb. SOIL	130 lb. SOIL
12"	2'-8"	1'-4"	2"	2 3/8"	4 3/8"	11 3/8"	1'-4 1/2"	NO LIMIT	8	NO LIMIT	12
15"	3'-0"	1'-7 1/2"	2 1/4"	2 7/8"	4 7/8"	1'-1 3/4"	1'-7"		10		15
18"	3'-3"	1'-11"	2 1/2"	3 3/8"	5 3/8"	1'-4 1/4"	1'-9 1/2"		11		17
21"	3'-6"	2'-2 1/2"	2 3/4"	3 7/8"	5 7/8"	1'-6 3/4"	2'-0"		12		17
24"	3'-8"	2'-4"	3"	4 3/8"	6 3/8"	1'-7 3/4"	2'-2 5/8"		13		18
27"	4'-2"	2'-9 1/2"	3 1/4"	4 7/8"	6 7/8"	1'-11 3/4"	2'-5"	40	13		19
30"	4'-6"	3'-1"	3 1/2"	5 3/8"	7 3/8"	2'-2 1/2"	2'-7 1/2"	35	14		19
33"	4'-9"	3'-4 1/2"	3 3/4"	5 7/8"	7 7/8"	2'-4 5/8"	2'-10"	30	14		20
36"	5'-8"	3'-8"	4"	6 1/2"	8 1/2"	2'-7 1/8"	3'-0 3/4"	21	13	41	17
39"	6'-0"	3'-11 1/2"	4 1/4"	7"	9"	2'-9 3/4"	3'-3"	21	13	41	17
42"	6'-3"	4'-3"	4 1/2"	7 1/2"	9 1/2"	3'-0"	3'-5 5/8"	21	14	39	18
45"	6'-6"	4'-6 1/2"	4 3/4"	8"	10"	3'-2 1/2"	3'-8"	21	14	39	18
48"	6'-10"	4'-10"	5"	8 1/2"	10 1/2"	3'-5"	3'-10 1/2"	21	15	38	19
54"	7'-5"	5'-5"	5 1/2"	9 1/2"	11 1/2"	3'-10"	4'-3 1/2"	23	16	38	20
60"	8'-0"	6'-0"	6"	10 1/2"	1'-0 1/2"	4'-3"	4'-8 3/8"	23	17	37	21
66"	8'-7"	6'-7"	6 1/2"	11 5/8"	1'-1 5/8"	4'-7 7/8"	5'-1 1/4"	24	17	37	22
72"	9'-2"	7'-2"	7"	1'-0 5/8"	1'-2 5/8"	5'-0 7/8"	5'-6 1/2"	24	18	37	23
74"	9'-9"	7'-9"	7 1/2"	1'-1 5/8"	1'-3 5/8"	5'-5 3/4"	5'-11 3/8"	25	19	37	24
84"	10'-4"	8'-4"	8"	1'-2 3/8"	1'-4 3/8"	5'-10 3/4"	6'-7 5/8"	26	19	37	24
90"	11'-0"	8'-11"	8 1/2"	1'-3 5/8"	1'-5 5/8"	6'-3 5/8"	6'-9 1/8"	26	20	37	25
96"	11'-6"	9'-6"	9"	1'-4 3/4"	1'-6 3/4"	6'-8 5/8"	7'-2 1/4"	27	21	37	25

NOTES

1. CLASS II (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED IN AREAS OUTSIDE OF PAVEMENT.
2. CLASS III (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED UNDER PAVEMENT AREAS.
3. FOR TRENCH DEPTHS EXCEEDING THOSE SHOWN IN TABLE; PIPE STRENGTH SHALL BE INVESTIGATED FOR ITS SAFE LOAD CAPACITY.
4. LOAD-FACTOR FOR CLASS "B" EMBEDMENT SHALL BE CONSIDERED TO BE 1.9
5. CLASS "B" EMBEDMENT TO BE USED FOR HARD UNYIELDING FOUNDATION MATERIALS.

CLASS "B" EMBEDMENT
FOR REINFORCED CONCRETE PIPE

FIGURE 25



REINF. CONC. PIPE CLASS "C" EMBEDMENT						DEPTH OF COVER			
						CL. II R.C.P.		CL. III R.C.P.	
D	B_d	B_c	T	E	C	100 lb. SOIL	130 lb. SOIL	100 lb. SOIL	130 lb. SOIL
12"	2'-8"	1'-4"	2"	2 3/8"	11 3/8"	13	7	NO LIMIT	9
15"	3'-0"	1'-7 1/2"	2 1/4"	2 7/8"	1'-1 3/4"	15	8		11
18"	3'-3"	1'-11"	2 1/2"	3 3/8"	1'-4 1/4"	17	9		12
21"	3'-6"	2'-2 1/2"	2 3/4"	3 7/8"	1'-6 3/4"	18	9		13
24"	3'-8"	2'-4"	3"	4 3/8"	1'-7 3/4"	18	10		14
27"	4'-2"	2'-9 1/2"	3 1/4"	4 7/8"	1'-11 3/4"	19	11		14
30"	4'-6"	3'-1"	3 1/2"	5 3/8"	2'-2 1/2"	19	11		15
33"	4'-9"	3'-4 1/2"	3 3/4"	5 7/8"	2'-4 5/8"	19	12	45	15
36"	5'-8"	3'-8"	4"	6 1/2"	2'-7 1/8"	15	11	23	14
39"	6'-0"	3'-11 1/2"	4 1/4"	7"	2'-9 3/4"	15	11	23	14
42"	6'-3"	4'-3"	4 1/2"	7 1/2"	3'-0"	16	11	24	15
45"	6'-6 1/2"	4'-6 1/2"	4 3/4"	8"	3'-2 1/2"	16	11	24	15
48"	6'-10"	4'-10"	5"	8 1/2"	3'-5"	17	12	25	16
54"	7'-5"	5'-5"	5 1/2"	9 1/2"	3'-10"	18	13	25	17
60"	8'-0"	6'-0"	6"	10 1/2"	4'-3"	19	14	26	17
66"	8'-7"	6'-7"	6 1/2"	11 5/8"	4'-7 7/8"	19	15	26	18
72"	9'-2"	7'-2"	7"	1'-0 5/8"	5'-0 7/8"	20	15	26	19
78"	9'-9"	7'-9"	7 1/2"	1'-1 5/8"	5'-5 3/4	21	16	27	19
84"	10'-4"	8'-4"	8"	1'-2 3/8"	5'-10 3/4"	21	17	28	20
90"	11'-0"	8'-11"	8 1/2"	1'-3 5/8"	6'-3 5/8"	22	17	29	21
96"	11'-6"	9'-6"	9"	1'-4 3/4"	6'-8 5/8"	23	18	29	21

NOTES

1. CLASS II (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED IN AREAS OUTSIDE OF PAVM'T.
2. CLASS III (ASTM C76-57) REINF. CONC. PIPE SHALL BE USED IN UNDER PAVEMENT AREAS.
3. FOR TRENCH DEPTHS EXCEEDING THOSE SHOWN IN TABLE; PIPE STRENGTH SHALL BE INVESTIGATED FOR ITS SAFE LOAD CAPACITY.
4. LOAD-FACTOR FOR CLASS "C" EMBEDMENT SHALL BE CONSIDERED TO BE 1.50.
5. CLASS C EMBEDMENT TO BE USED FOR ORDINARY FOUNDATION MATERIALS.

CLASS "C" EMBEDMENT

FOR REINFORCED CONCRETE PIPE

FIGURE 26

SECTION X

APPENDIX A

10.01 REFERENCE SOURCES USED FOR DESIGN CRITERIA

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4. Corps of Engineers, "Hydrologic and Hydraulic Analysis," Civil Works Construction, Part CXIV, Chapter 5, Supt. of Doc., Washington, D. C.

5. U. S. Navy, Storm Drainage Systems, Technical Publication TT-Pw-1, Bureau of Yards and Docks, Washington, D. C., 1952.

6. U. S. Weather Bureau, Rainfall Intensity-Duration-Frequency Curves, Technical Paper No. 25, Supt. of Doc., Washington, D. C., Dec., 1955.

7. Texas Highway Department, Rational Design of Culverts and Bridges, Austin, Texas.

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12. Spangler, M. G., Soil Engineering, International Textbook Company, Scranton, Pa., 1951.

13. Rational Design Procedure, City of Dallas, Texas.

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SECTION X

APPENDIX B

10.02 TABLES, FIGURES, CHARTS, NOMOGRAPHS AND COMPUTATION SHEETS

TABLE 13

STANDARD SIZES CIRCULAR SECTIONS (FLOWING FULL)

AND HYDRAULIC ELEMENTS

MIN. GRADES SEE PG. 80	Inside Diameter (Inches) D		Shell Thickness (For Conc. Pipe) (Inches) A		Area (Square Feet)	Wetted Perimeter (Feet) W. P.	Hydraulic Radius (Feet) R	$R^{2/3}$	$R^{4/3}$	$AR^{2/3}$
	12	300 mm	2.00	0.050 m	0.79	3.14	0.250	0.397	0.158	0.312
.23%	15	375 mm	2.25	0.057 m	1.23	3.93	0.313	0.461	0.212	0.566
.18%	18	450 mm	2.50	0.0635 m	1.77	4.71	0.375	0.520	0.270	0.919
.15%	21	525 mm	2.75	[illegible]	2.41	5.50	0.438	0.576	0.332	1.385
.13%	24	600 mm	3.00	[illegible]	3.14	6.28	0.500	0.630	0.397	1.979
[illegible]	27	675 mm	3.25	0.0825 m	3.97	7.07	0.563	0.681	0.465	2.708
.09%	30	750 mm	3.50	0.0889 m	4.91	7.85	0.625	0.731	0.534	3.588
.08%	33	825 mm	3.75	[illegible]	5.94	8.63	0.688	0.781	0.607	4.639
.07%	36	900 mm	4.00	[illegible]	7.07	9.43	0.750	0.825	0.681	5.832
.06%	39		4.25	0.108 m	8.30	10.21	0.812	0.869	0.755	7.204
.06%	42	1050 mm	4.50	0.114 m	9.62	11.00	0.875	0.915	0.837	8.803
.05%	45		4.75	0.121 m	11.04	11.78	0.937	0.960	0.911	10.59
.05%	48	1200 mm	5.00	0.127 m	12.57	12.57	1.000	1.000	1.000	12.566
	51		5.25	0.133 m	14.19	13.35	1.062	1.040	1.074	14.75
.04%	54	1350 mm	5.50	0.139 m	15.90	14.14	1.125	1.082	1.170	17.208
.04%	60	1500 mm	6.00	[illegible]	19.64	15.71	1.250	1.160	1.347	22.777
.04%	66	1650 mm	6.50	0.165 m	23.76	17.28	1.375	1.236	1.536	29.365
.03%	72	1800 mm	7.00	0.178 m	28.27	18.85	1.500	1.310	1.717	37.039
.03%	78	1950 mm	7.50	[illegible]	33.18	20.42	1.625	1.382	1.918	45.859
.03%	84	2100 mm	8.00	0.203 m	38.49	21.99	1.750	1.452	2.109	55.880
	90	2250 mm	8.50	[illegible]	44.18	23.56	1.875	1.521	2.320	67.196
.027	96	2400 mm	9.00	[illegible]	50.27	25.13	2.000	1.587	2.520	79.772

TABLE 14

STANDARD SIZES OF CORRUGATED METAL PIPE ARCHES AND HYDRAULIC ELEMENTS

Span Inches	Rise Inches	Area Sq. Ft.	Perimeter Feet	Hydraulic Radius Feet	$R^{4/3}$
18	11	1.1	3.93	0.280	0.183
22	13	1.6	4.71	0.339	0.236
25	16	2.2	5.50	0.400	0.295
29	18	2.8	6.28	0.446	0.341
36	22	4.4	7.85	0.560	0.462
43	27	6.4	9.43	0.679	0.597
50	31	8.7	11.00	0.792	0.733
58	36	11.4	12.57	0.908	0.879
65	40	14.3	14.14	1.011	1.014
72	44	17.6	15.71	1.120	1.163

TABLE 15

STANDARD SIZES OF RECTANGULAR SECTIONS

AND HYDRAULIC ELEMENTS

Size Span x Height	Area A	Wetted Perimeter W. P.	Hydraulic Radius R	$R^{2/3}$	$AR^{2/3}$	$R^{4/3}$
2 x 2	4.0	8.0	0.50	0.630	2.520	0.3969
3 x 2	6.0	10.0	0.60	0.711	4.266	0.5061
4 x 2	8.0	12.0	0.67	0.765	6.120	0.5863
3 x 3	9.0	12.0	0.75	0.825	7.425	0.6814
4 x 3	12.0	14.0	0.86	0.904	10.848	0.8178
5 x 3	15.0	16.0	0.94	0.960	14.400	0.9208
6 x 3	18.0	18.0	1.00	1.000	18.00	1.000
4 x 4	16.0	16.0	1.00	1.000	16.000	1.000
5 x 4	20.0	18.0	1.11	1.072	21.440	1.149
6 x 4	24.0	20.0	1.20	1.129	27.096	1.275
7 x 4	28.0	22.0	1.23	1.149	32.172	1.318
8 x 4	32.0	24.0	1.33	1.209	38.688	1.463
5 x 5	25.0	20.0	1.25	1.160	29.000	1.347
6 x 5	30.0	22.0	1.36	1.227	36.810	1.507
7 x 5	35.0	24.0	1.46	1.287	45.045	1.656
8 x 5	40.0	26.0	1.54	1.334	53.360	1.778
9 x 5	45.0	28.0	1.61	1.374	61.830	1.887
10 x 5	50.0	30.0	1.67	1.408	70.400	1.981
6 x 6	36.0	24.0	1.50	1.310	47.160	1.717
7 x 6	42.0	26.0	1.62	1.379	57.918	1.903
8 x 6	48.0	28.0	1.71	1.430	68.640	2.045
9 x 6	54.0	30.0	1.80	1.480	79.920	2.190
10 x 6	60.0	32.0	1.88	1.523	91.380	2.320
7 x 7	49.0	28.0	1.75	1.452	71.148	2.109
8 x 7	56.0	30.0	1.87	1.518	85.008	2.304
9 x 7	63.0	32.0	1.97	1.571	98.973	2.470
10 x 7	70.0	34.0	2.06	1.619	113.190	2.621
8 x 8	64.0	32.0	2.00	1.587	101.568	2.520
9 x 8	72.0	34.0	2.12	1.650	118.800	2.723
10 x 8	80.0	36.0	2.22	1.702	136.160	2.896
9 x 9	81.0	36.0	2.25	1.717	139.077	2.948
10 x 9	90.0	38.0	2.37	1.777	159.930	3.160
10 x 10	100.0	40.0	2.50	1.842	184.200	3.393

TABLE 16

ALLOWANCE HEIGHT OF FILL

FOR VARIOUS DIAMETERS AND GAGES OF

CORRUGATED METAL PIPE

Diam. Inches	Fills Up to 15 ft.	15 to 20 ft. Fill	20 to 25 ft. Fill	25 to 30 ft. Fill	30 to 35 ft. Fill	35 to 40 ft. Fill	40 to 45 ft. Fill	45 to 50 ft. Fill	50 to 60 ft. Fill	60 to 70 ft. Fill	70 to 80 ft. Fill	80 to 100 ft. Fill
15	14	14	14	14	14	14	14	14	14	14	12	12
18	14	14	14	14	14	14	14	14	14	12	12	12
21	14	14	14	14	14	14	14	14	12	12	12	10
24	14	14	14	14	14	14	14	12	12	12	10	10
30	14	14	14	14	12	12	12	10	10	10	8	8
36	12	12	12	12	10	10	10	8	8	8	8	8
42	12	12	12	10	10	8	8	8	8	8	8	8
48	12	12	12	10	10	8	8	8	8	8	8	8
54	12	12	10	10	10	8	8	8	8	8	8	
60	10	10	10	8	8	8						
66	10	10	8	8								
72	10	8	8									
78	8	8	8									
84	8	8										
90	8											
96	8											

Use Structural Plate Pipe Culverts

(Culverts below the upper heavy line above shall be shop strutted before installation.)

TABLE 17

ALLOWABLE HEIGHT OF FILL FOR VARIOUS DIAMETERS AND GAGES

SECTIONAL PLATE PIPE - STRUTTED

Diameter Inches	Height of Cover - Feet																Height of Cover Limit 1 Gage - 6 Bolts
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-70	71-80	81-90	91-100	
60	12	12	12	12	12	12	12	12	12	12	10	10	8	7	5	5	200
66	12	12	12	12	12	12	12	12	12	10	10	8	8	7	5	3	180
72	12	12	12	12	12	12	12	12	10	10	8	8	7	5	3	1	165
78	12	12	12	12	12	12	12	10	10	8	8	8	5	3	1	-	150
84	12	12	12	12	12	12	12	10	10	8	8	7	5	3	1		140
90	12	12	12	12	12	12	10	10	8	8	7	5	3	1	-		130
96	12	12	12	12	12	10	10	10	8	7	7	5	3	1			125
102	12	12	12	12	10	10	10	8	8	7	5	5	1	-			115
108	12	12	12	10	10	10	10	8	7	5	5	3	1				110
114	10	12	10	10	10	10	8	8	7	5	5	3	1				105
120	10	12	10	10	10	10	8	7	5	5	3	1	-				100
126	10	12	10	10	10	10	8	7	5	3	3	1					95
132	10	10	10	10	10	8	8	7	5	3	1	1					90
138	10	10	10	10	10	8	7	5	3	3	1	-					85
144	10	10	10	10	8	8	7	5	3	1	1						80
150	10	10	10	8	8	8	7	5	3	1	-,						80
156	10	10	10	8	8	8	5	3	1	1							75
162	10	10	10	8	8	7	5	3	1	-							70
168	10	10	10	8	8	7	5	3	1								70
174	8	10	8	8	8	7	5	3	1								65
180	8	10	8	8	8	5	3	1	-								65

For structures in this zone use 1 gage with six bolts per foot of longitudinal seam with height of cover limits as shown in column at right.

The gages shown are the minimum structural requirements for use with adequate backfill.
Bottom plates are frequently designed of heavier gage to resist wear.
Gages are for finished construction; during construction adequate cover must be provided to protect the structure from damage.
The last column under "Strutted" shows the greatest height of cover that can be placed on pipes specially fabricated to have six bolts per foot in each longitudinal seam in 1 gage metal.
Pipe diameters are to inside crests and are subject to manufacturing tolerances.

TABLE 18

ALLOWABLE HEIGHT OF FILL FOR VARIOUS DIAMETERS AND GAGES

SECTIONAL PLATE PIPE - UNSTRUTTED

Diameter Inches	Height of Cover - Feet															
	1-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40	41-45	46-50	51-55	56-60	61-70	71-80	81-90	91-100
60	12	12	12	12	12	10	10	10	10	10	8	8	8	7	5	5
66	12	12	12	12	10	10	10	10	8	8	8	8	8	7	5	3
72	12	12	12	10	10	10	10	8	8	8	8	7	7	5	3	1
78	12	12	12	10	10	10	8	8	8	8	7	7	5	3	1	-
84	10	12	10	10	10	8	8	8	8	7	7	5	5	3	1	
90	10	12	10	10	8	8	8	7	7	7	5	5	3	1	-	
96	10	12	10	10	8	8	8	7	7	5	5	5	3	1		
102	10	10	10	8	8	8	7	7	5	5	5	5	1	-		
108	10	10	10	8	8	7	7	5	5	5	5	3	1			
114	10	10	10	8	8	7	5	5	5	3	3	3	1			
120	8	10	8	8	7	5	5	5	3	3	3	1	-			
126	8	10	8	7	7	5	5	3	3	3	1	1				
132	8	10	8	7	5	5	5	3	3	3	1	1				
138	8	10	8	7	5	5	3	3	3	1	1	-				
144	8	8	8	7	5	5	3	3	1	1	-					
150	7	8	7	5	5	3	3	1	1	1						
156	7	8	7	5	5	3	3	1	1	-						
162	7	8	7	5	3	3	1	1	1							
168	5	8	5	5	3	1	1	-	-							
174	5	7	5	3	3	1	1									
180	5	7	5	3	3	1	-									

The gages shown are the minimum structural requirements for use with adequate backfill.
Bottom plates are frequently designed of heavier gage to resist wear.
Gages are for finished construction; during construction adequate cover must be provided to protect the structure from damage.
Pipe diameters are to inside crests and are subject to manufacturing tolerances.

TABLE 19

ALLOWABLE HEIGHT OF FILL FOR VARIOUS SIZES AND GAGES

PIPE-ARCH CONDUITS

Size		Height of Fill in Feet				
Span in Inches	Rise in Inches	1	2-4	5-9	10-15	16-20
18	11	14	14	14	14	14
22	13	14	14	14	14	14
25	16	14	14	14	14	14
29	18	14	14	14	14	14
36	22	14	14	14	14	14
43	27	12	12	12	12	12
50	31	12	12	12	12	10
58	36	10	12	12	10	10
65	40	10	12	12	10	8
72	44	8	10	10	8	-

TABLE 20

HEIGHT-SPAN-GAGE

FOR SECTIONAL PLATE CORRUGATED METAL PIPE ARCHES

(Side and Top Plates and Gages)

Height of Cover in Feet	Span of Pipe-Arch in Inches* 60	72	84	96	108	120	132	144	156	168	180	192
1	12	12	10	10	10	8	8	7	5	5	3	1
2	12	12	12	10	10	8	8	8	7	5	5	3
3	12	12	12	10	10	10	8	8	8	7	5	5
4	12	12	12	12	10	10	10	8	8	7	7	5
5	12	12	12	12	10	10	10	8	8	8	7	7
6	12	12	12	12	10	10	10	8	8	8	7	7
7	12	12	12	12	10	10	10	8	8	8	7	7
8	12	12	12	12	10	10	10	8	8	7	7	5
9	12	12	12	12	10	10	10	8	8	7	5	3
10	12	12	12	12	10	10	8	8	7	5	3	3
11	12	12	12	12	10	10	8	8	7	5	3	1
12	12	12	12	10	10	8	8	7	5	3	1	1
13	12	12	12	10	10	8	7	5	5	3	1	-
14	12	12	10	10	8	8	7	5	3	1	-	-
15	12	12	10	10	8	7	5	3	1	1	-	-

* Pipe-Arches are available in a range of spans, rises and areas.
Tabular values are for gage determination.

TABLE 21

TWO-THIRDS POWERS OF NUMBERS

FOR $R^{2/3}$ IN MANNING'S FORMULA

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.000	.046	.074	.097	.117	.136	.153	.170	.186	.201
.1	.215	.229	.243	.256	.269	.282	.295	.307	.319	.331
.2	.342	.353	.364	.375	.386	.397	.407	.418	.428	.438
.3	.448	.458	.468	.477	.487	.497	.506	.515	.525	.534
.4	.543	.552	.561	.570	.578	.587	.596	.604	.613	.622
.5	.630	.638	.647	.655	.663	.671	.679	.687	.695	.703
.6	.711	.719	.727	.735	.743	.750	.758	.765	.773	.781
.7	.788	.796	.803	.811	.818	.825	.832	.840	.847	.855
.8	.862	.869	.876	.883	.890	.897	.904	.911	.918	.925
.9	.932	.939	.946	.953	.960	.966	.973	.980	.987	.993
1.0	1.000	1.007	1.013	1.020	1.027	1.033	1.040	1.046	1.053	1.059
1.1	1.065	1.072	1.078	1.085	1.091	1.097	1.104	1.110	1.117	1.123
1.2	1.129	1.136	1.142	1.148	1.154	1.160	1.167	1.173	1.179	1.185
1.3	1.191	1.197	1.203	1.209	1.215	1.221	1.227	1.233	1.239	1.245
1.4	1.251	1.257	1.263	1.269	1.275	1.281	1.287	1.293	1.299	1.305
1.5	1.310	1.316	1.322	1.328	1.334	1.339	1.345	1.351	1.357	1.362
1.6	1.368	1.374	1.379	1.385	1.391	1.396	1.402	1.408	1.413	1.419
1.7	1.424	1.430	1.436	1.441	1.447	1.452	1.458	1.463	1.469	1.474
1.8	1.480	1.485	1.491	1.496	1.502	1.507	1.513	1.518	1.523	1.529
1.9	1.534	1.539	1.545	1.550	1.556	1.561	1.566	1.571	1.577	1.582
2.0	1.587	1.593	1.598	1.603	1.608	1.613	1.619	1.624	1.629	1.634
2.1	1.639	1.645	1.650	1.655	1.660	1.665	1.671	1.676	1.681	1.686
2.2	1.691	1.697	1.702	1.707	1.712	1.717	1.722	1.727	1.732	1.737
2.3	1.742	1.747	1.752	1.757	1.762	1.767	1.772	1.777	1.782	1.787
2.4	1.792	1.797	1.802	1.807	1.812	1.817	1.822	1.827	1.832	1.837
2.5	1.842	1.847	1.852	1.857	1.862	1.867	1.871	1.876	1.881	1.886
2.6	1.891	1.896	1.900	1.905	1.910	1.915	1.920	1.925	1.929	1.934
2.7	1.939	1.944	1.949	1.953	1.958	1.963	1.968	1.972	1.977	1.982
2.8	1.987	1.992	1.996	2.001	2.010	2.010	2.015	2.020	2.024	2.029
2.9	2.034	2.038	2.043	2.048	2.052	2.057	2.062	2.066	2.071	2.075
3.0	2.080	2.085	2.089	2.094	2.099	2.103	2.108	2.112	2.117	2.122
3.1	2.126	2.131	2.135	2.140	2.144	2.149	2.153	2.158	2.163	2.167
3.2	2.172	2.176	2.180	2.185	2.190	2.194	2.199	2.203	2.208	2.212
3.3	2.217	2.221	2.226	2.230	2.234	2.239	2.243	2.248	2.252	2.257
3.4	2.261	2.265	2.270	2.274	2.279	2.283	2.288	2.292	2.296	2.301
3.5	2.305	2.310	2.314	2.318	2.323	2.327	2.331	2.336	2.340	2.345
3.6	2.349	2.353	2.358	2.362	2.366	2.371	2.375	2.379	2.384	2.388
3.7	2.392	2.397	2.401	2.405	2.409	2.414	2.418	2.422	2.427	2.431
3.8	2.435	2.439	2.444	2.448	2.452	2.457	2.461	2.465	2.469	2.474
3.9	2.478	2.482	2.486	2.490	2.495	2.499	2.503	2.507	2.511	2.516
4.0	2.520	2.524	2.528	2.532	2.537	2.541	2.545	2.549	2.553	2.558
4.1	2.562	2.566	2.570	2.574	2.579	2.583	2.587	2.591	2.595	2.599
4.2	2.603	2.607	2.611	2.616	2.620	2.624	2.628	2.632	2.636	2.640
4.3	2.644	2.648	2.653	2.657	2.661	2.665	2.669	2.673	2.677	2.681
4.4	2.685	2.689	2.693	2.698	2.702	2.706	2.710	2.714	2.718	2.722
4.5	2.726	2.730	2.734	2.738	2.742	2.746	2.750	2.754	2.758	2.762
4.6	2.766	2.770	2.774	2.778	2.782	2.786	2.790	2.794	2.798	2.802
4.7	2.806	2.810	2.814	2.818	2.822	2.826	2.830	2.834	2.838	2.842
4.8	2.846	2.850	2.854	2.858	2.862	2.865	2.869	2.873	2.877	2.881
4.9	2.885	2.889	2.893	2.897	2.901	2.904	2.908	2.912	2.916	2.920

TABLE 22

THREE-EIGHTHS POWERS OF NUMBERS

FOR INLET CALCULATIONS

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.00	.18	.23	.27	.30	.33	.35	.37	.39	.41
.1	.42	.44	.45	.47	.48	.49	.50	.51	.53	.54
.2	.55	.56	.57	.58	.59	.59	.60	.61	.62	.63
.3	.64	.65	.65	.66	.67	.67	.68	.69	.70	.70
.4	.71	.72	.72	.73	.74	.74	.75	.75	.76	.77
.5	.77	.78	.78	.79	.79	.80	.80	.81	.82	.82
.6	.83	.83	.84	.84	.85	.85	.86	.86	.87	.87
.7	.87	.88	.88	.89	.89	.90	.90	.91	.91	.92
.8	.92	.92	.93	.93	.94	.94	.94	.95	.95	.96
.9	.96	.97	.97	.97	.98	.98	.98	.99	.99	1.00
1.0	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03	1.03	1.03
1.1	1.04	1.04	1.04	1.05	1.05	1.05	1.06	1.06	1.06	1.07
1.2	1.07	1.07	1.08	1.08	1.08	1.09	1.09	1.09	1.10	1.10
1.3	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.13	1.13	1.13
1.4	1.13	1.14	1.14	1.14	1.15	1.15	1.15	1.16	1.16	1.16
1.5	1.16	1.17	1.17	1.17	1.18	1.18	1.18	1.18	1.19	1.19
1.6	1.19	1.20	1.20	1.20	1.20	1.21	1.21	1.21	1.21	1.22
1.7	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.24	1.24
1.8	1.25	1.25	1.25	1.25	1.26	1.26	1.26	1.26	1.27	1.27
1.9	1.27	1.27	1.28	1.28	1.28	1.28	1.29	1.29	1.29	1.29
2.0	1.30	1.30	1.30	1.30	1.31	1.31	1.31	1.31	1.32	1.32
2.1	1.32	1.32	1.33	1.33	1.33	1.33	1.33	1.34	1.34	1.34
2.2	1.34	1.35	1.35	1.35	1.35	1.36	1.36	1.36	1.36	1.36
2.3	1.37	1.37	1.37	1.37	1.38	1.38	1.38	1.38	1.38	1.39
2.4	1.39	1.39	1.39	1.40	1.40	1.40	1.40	1.40	1.41	1.41
2.5	1.41	1.41	1.41	1.42	1.42	1.42	1.42	1.42	1.43	1.43
2.6	1.43	1.43	1.44	1.44	1.44	1.44	1.44	1.45	1.45	1.45
2.7	1.45	1.45	1.46	1.46	1.46	1.46	1.46	1.47	1.47	1.47
2.8	1.47	1.47	1.48	1.48	1.48	1.48	1.48	1.48	1.49	1.49
2.9	1.49	1.49	1.49	1.50	1.50	1.50	1.50	1.50	1.51	1.51
3.0	1.51	1.51	1.51	1.52	1.52	1.52	1.52	1.52	1.52	1.53
3.1	1.53	1.53	1.53	1.53	1.54	1.54	1.54	1.54	1.54	1.54
3.2	1.55	1.55	1.55	1.55	1.55	1.56	1.56	1.56	1.56	1.56
3.3	1.56	1.57	1.57	1.57	1.57	1.57	1.58	1.58	1.58	1.58
3.4	1.58	1.58	1.59	1.59	1.59	1.59	1.59	1.59	1.60	1.60
3.5	1.60	1.60	1.60	1.61	1.61	1.61	1.61	1.61	1.61	1.62
3.6	1.62	1.62	1.62	1.62	1.62	1.63	1.63	1.63	1.63	1.63
3.7	1.63	1.63	1.64	1.64	1.64	1.64	1.64	1.64	1.65	1.65
3.8	1.65	1.65	1.65	1.65	1.66	1.66	1.66	1.66	1.66	1.66
3.9	1.67	1.67	1.67	1.67	1.67	1.67	1.68	1.68	1.68	1.68
4.0	1.68	1.68	1.68	1.69	1.69	1.69	1.69	1.69	1.69	1.70
4.1	1.70	1.70	1.70	1.70	1.70	1.71	1.71	1.71	1.71	1.71
4.2	1.71	1.71	1.72	1.72	1.72	1.72	1.72	1.72	1.73	1.73
4.3	1.73	1.73	1.73	1.73	1.73	1.74	1.74	1.74	1.74	1.74
4.4	1.74	1.74	1.75	1.75	1.75	1.75	1.75	1.75	1.75	1.76
4.5	1.76	1.76	1.76	1.76	1.76	1.77	1.77	1.77	1.77	1.77
4.6	1.77	1.77	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.79
4.7	1.79	1.79	1.79	1.79	1.79	1.79	1.80	1.80	1.80	1.80
4.8	1.80	1.80	1.80	1.81	1.81	1.81	1.81	1.81	1.81	1.81
4.9	1.81	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.83	1.83

TABLE 23

SQUARE ROOTS OF DECIMAL NUMBERS

FOR $S^{1/2}$ IN MANNING'S FORMULA

No.	.---0	.---1	.---2	.---3	.---4	.---5	.---6	.---7	.---8	.---9
.00001	.003162	.003317	.003464	.003606	.003742	.003873	.004000	.004123	.004243	.004359
.00002	.004472	.004583	.004690	.004796	.004899	.005000	.005099	.005196	.005292	.005385
.00003	.005477	.005568	.005657	.005745	.005831	.005916	.006000	.006083	.006164	.006245
.00004	.006325	.006403	.006481	.006557	.006633	.006708	.006782	.006856	.006928	.007000
.00005	.007071	.007141	.007211	.007280	.007348	.007416	.007483	.007550	.007616	.007681
.00006	.007746	.007810	.007874	.007937	.008000	.008062	.008124	.008185	.008246	.008307
.00007	.008367	.008426	.008485	.008544	.008602	.008660	.008718	.008775	.008832	.008888
.00008	.008944	.009000	.009055	.009110	.009165	.009220	.009274	.009327	.009381	.009434
.00009	.009487	.009539	.009592	.009644	.009695	.009747	.009798	.009849	.009899	.009950
.00010	.010000	.010050	.010100	.010149	.010198	.010247	.010296	.010344	.010392	.010440
.0001	.01000	.01049	.01095	.01140	.01183	.01225	.01265	.01304	.01342	.01378
.0002	.01414	.01449	.01483	.01517	.01549	.01581	.01612	.01643	.01673	.01703
.0003	.01732	.01761	.01789	.01817	.01844	.01871	.01897	.01924	.01949	.01975
.0004	.02000	.02025	.02049	.02074	.02098	.02121	.02145	.02168	.02191	.02214
.0005	.02236	.02258	.02280	.02302	.02324	.02345	.02366	.02387	.02408	.02429
.0006	.02449	.02470	.02490	.02510	.02530	.02550	.02569	.02588	.02608	.02627
.0007	.02646	.02665	.02683	.02702	.02720	.02739	.02757	.02775	.02793	.02811
.0008	.02828	.02846	.02864	.02881	.02898	.02915	.02933	.02950	.02966	.02983
.0009	.03000	.03017	.03033	.03050	.03066	.03082	.03098	.03114	.03130	.03146
.0010	.03162	.03178	.03194	.03209	.03225	.03240	.03256	.03271	.03286	.03302
.001	.03162	.03317	.03464	.03606	.03742	.03873	.04000	.04123	.04243	.04359
.002	.04472	.04583	.04690	.04796	.04899	.05000	.05099	.05196	.05292	.05385
.003	.05477	.05568	.05657	.05745	.05831	.05916	.06000	.06083	.06164	.06245
.004	.06325	.06403	.06481	.06557	.06633	.06708	.06782	.06856	.06928	.07000
.005	.07071	.07141	.07211	.07280	.07348	.07416	.07483	.07550	.07616	.07681
.006	.07746	.07810	.07874	.07937	.08000	.08062	.08124	.08185	.08246	.08307
.007	.08367	.08426	.08485	.08544	.08602	.08660	.08718	.08775	.08832	.08888
.008	.08944	.09000	.09055	.09110	.09165	.09220	.09274	.09327	.09381	.09434
.009	.09487	.09539	.09592	.09644	.09695	.09747	.09798	.09849	.09899	.09950
.010	.10000	.10050	.10100	.10149	.10198	.10247	.10296	.10344	.10392	.10440
.01	.1000	.1049	.1095	.1140	.1183	.1225	.1265	.1304	.1342	.1378
.02	.1414	.1449	.1483	.1517	.1549	.1581	.1612	.1643	.1673	.1703
.03	.1732	.1761	.1789	.1817	.1844	.1871	.1897	.1924	.1949	.1975
.04	.2000	.2025	.2049	.2074	.2098	.2121	.2145	.2168	.2191	.2214
.05	.2236	.2258	.2280	.2302	.2324	.2345	.2366	.2387	.2408	.2429
.06	.2449	.2470	.2490	.2510	.2530	.2550	.2569	.2588	.2608	.2627
.07	.2646	.2665	.2683	.2702	.2720	.2739	.2757	.2775	.2793	.2811
.08	.2828	.2846	.2864	.2881	.2898	.2915	.2933	.2950	.2966	.2983
.09	.3000	.3017	.3033	.3050	.3066	.3082	.3098	.3114	.3130	.3146
.10	.3162	.3178	.3194	.3209	.3225	.3240	.3256	.3271	.3286	.3302

TABLE 24

EIGHT-THIRDS POWERS OF NUMBERS

FOR INLET CALCULATIONS

No.	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.1	.002	.003	.004	.004	.005	.006	.008	.009	.010	.012
.2	.014	.016	.018	.020	.022	.025	.028	.030	.034	.037
.3	.040	.044	.048	.052	.056	.061	.066	.071	.076	.081
.4	.087	.093	.099	.105	.112	.119	.126	.134	.141	.149
.5	.157	.166	.175	.184	.193	.203	.213	.223	.234	.245
.6	.256	.268	.279	.292	.304	.317	.330	.344	.358	.372
.7	.386	.401	.416	.432	.448	.464	.481	.498	.516	.533
.8	.552	.570	.589	.608	.628	.648	.669	.690	.711	.733
.9	.755	.778	.801	.824	.848	.872	.897	.922	.948	.973
1.0	1.000	1.027	1.054	1.082	1.110	1.139	1.168	1.198	1.228	1.258
1.1	1.29	1.32	1.35	1.39	1.42	1.45	1.49	1.52	1.55	1.59
1.2	1.63	1.66	1.70	1.74	1.77	1.81	1.85	1.89	1.93	1.97
1.3	2.01	2.05	2.10	2.14	2.18	2.23	2.27	2.32	2.36	2.41
1.4	2.45	2.50	2.55	2.60	2.64	2.69	2.74	2.79	2.84	2.90
1.5	2.95	3.00	3.05	3.11	3.16	3.22	3.27	3.33	3.39	3.44
1.6	3.50	3.56	3.62	3.68	3.74	3.80	3.86	3.93	3.99	4.05
1.7	4.12	4.18	4.25	4.31	4.38	4.45	4.51	4.58	4.65	4.72
1.8	4.79	4.87	4.94	5.01	5.08	5.16	5.23	5.31	5.39	5.46
1.9	5.54	5.62	5.69	5.77	5.85	5.93	6.02	6.10	6.18	6.26
2.0	6.35	6.43	6.52	6.61	6.69	6.78	6.87	6.96	7.05	7.14
2.1	7.23	7.32	7.42	7.51	7.60	7.70	7.80	7.89	7.99	8.09
2.2	8.19	8.29	8.39	8.49	8.59	8.69	8.80	8.90	9.00	9.11
2.3	9.22	9.32	9.43	9.54	9.65	9.76	9.87	9.98	10.10	10.21
2.4	10.33	10.44	10.56	10.67	10.79	10.91	11.03	11.15	11.27	11.39
2.5	11.51	11.64	11.76	11.88	12.01	12.14	12.26	12.39	12.52	12.65
2.6	12.8	12.9	13.0	13.2	13.3	13.4	13.6	13.7	13.9	14.0
2.7	14.1	14.3	14.4	14.6	14.7	14.8	15.0	15.1	15.3	15.4
2.8	15.6	15.7	15.9	16.0	16.2	16.3	16.5	16.6	16.8	16.9
2.9	17.1	17.3	17.4	17.6	17.7	17.9	18.1	18.2	18.4	18.6
3.0	18.7	18.9	19.1	19.2	19.4	19.6	19.7	19.9	20.1	20.3
3.1	20.4	20.6	20.8	21.0	21.1	21.3	21.5	21.7	21.9	22.1
3.2	22.2	22.4	22.6	22.8	23.0	23.2	23.4	23.6	23.7	23.9
3.3	24.1	24.3	24.5	24.7	24.9	25.1	25.3	25.5	25.7	25.9
3.4	26.1	26.3	26.6	26.8	27.0	27.2	27.4	27.6	27.8	28.0
3.5	28.2	28.5	28.7	28.9	29.1	29.3	29.5	29.8	30.0	30.2
3.6	30.4	30.7	30.9	31.1	31.4	31.6	31.8	32.0	32.3	32.5
3.7	32.7	33.0	33.2	33.5	33.7	33.9	34.2	34.4	34.7	34.9
3.8	35.2	35.4	35.7	35.9	36.2	36.4	36.7	36.9	37.2	37.4
3.9	37.7	37.9	38.2	38.5	38.7	39.0	39.3	39.5	39.8	40.0
4.0	40.3	40.6	40.9	41.1	41.4	41.7	42.0	42.2	42.5	42.8
4.1	43.1	43.3	43.6	43.9	44.2	44.5	44.8	45.1	45.3	45.6
4.2	45.9	46.2	46.5	46.8	47.1	47.4	47.7	48.0	48.3	48.6
4.3	48.9	49.2	49.5	49.8	50.1	50.4	50.7	51.0	51.4	51.7
4.4	52.0	52.3	52.6	52.9	53.3	53.6	53.9	54.2	54.5	54.9
4.5	55.2	55.5	55.9	56.2	56.5	56.8	57.2	57.5	57.9	58.2
4.6	58.5	58.9	59.2	59.5	59.9	60.2	60.6	60.9	61.3	61.6
4.7	62.0	62.3	62.7	63.0	63.4	63.8	64.1	64.5	64.8	65.2
4.8	65.6	65.9	66.3	66.7	67.0	67.4	67.8	68.1	68.5	68.9
4.9	69.3	69.6	70.0	70.4	70.8	71.2	71.6	71.9	72.3	72.7
5.0	73.1	73.5	73.9	74.3	74.7	75.1	75.5	75.9	76.3	76.7

TABLE 25

THREE-HALVES POWERS OF NUMBERS

FOR INLET CALCULATIONS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.00	.0000	.0000	.0001	.0002	.0003	.0004	.0005	.0006	.0007	.0009
.01	.0010	.0012	.0013	.0015	.0017	.0018	.0020	.0022	.0024	.0026
.02	.0028	.0030	.0033	.0035	.0037	.0040	.0042	.0044	.0047	.0049
.03	.0052	.0055	.0057	.0060	.0063	.0065	.0068	.0071	.0074	.0077
.04	.0080	.0083	.0086	.0089	.0092	.0095	.0099	.0102	.0105	.0108
.05	.0112	.0115	.0119	.0122	.0125	.0129	.0132	.0136	.0140	.0143
.06	.0147	.0151	.0154	.0158	.0162	.0166	.0170	.0173	.0177	.0181
.07	.0185	.0189	.0193	.0197	.0201	.0205	.0210	.0214	.0218	.0222
.08	.0226	.0231	.0235	.0239	.0243	.0248	.0252	.0257	.0261	.0265
.09	.0270	.0275	.0279	.0284	.0288	.0293	.0297	.0302	.0307	.0312
.10	.0316	.0321	.0326	.0331	.0335	.0340	.0345	.0350	.0355	.0360
.11	.0365	.0370	.0375	.0380	.0385	.0390	.0395	.0400	.0405	.0411
.12	.0416	.0421	.0426	.0431	.0436	.0442	.0447	.0452	.0458	.0463
.13	.0469	.0474	.0480	.0485	.0491	.0496	.0502	.0507	.0513	.0518
.14	.0524	.0529	.0535	.0541	.0546	.0552	.0558	.0564	.0569	.0575
.15	.0581	.0587	.0593	.0598	.0604	.0610	.0616	.0622	.0628	.0634
.16	.0640	.0646	.0652	.0658	.0664	.0670	.0676	.0682	.0688	.0695
.17	.0701	.0707	.0713	.0720	.0726	.0732	.0738	.0745	.0751	.0757
.18	.0764	.0770	.0776	.0783	.0789	.0796	.0802	.0809	.0815	.0822
.19	.0828	.0835	.0841	.0848	.0854	.0861	.0868	.0874	.0881	.0888
.20	.0894	.0901	.0908	.0915	.0921	.0928	.0935	.0942	.0949	.0955
.21	.0962	.0969	.0976	.0983	.0990	.0997	.1004	.1011	.1018	.1025
.22	.1032	.1039	.1046	.1053	.1060	.1067	.1074	.1081	.1089	.1096
.23	.1103	.1110	.1118	.1125	.1132	.1139	.1146	.1154	.1161	.1168
.24	.1176	.1183	.1191	.1198	.1205	.1213	.1220	.1228	.1235	.1243
.25	.1250	.1258	.1265	.1273	.1280	.1288	.1295	.1303	.1311	.1318
.26	.1326	.1333	.1341	.1349	.1356	.1364	.1372	.1380	.1387	.1395
.27	.1403	.1411	.1419	.1426	.1434	.1442	.1450	.1458	.1466	.1474
.28	.1482	.1490	.1498	.1506	.1514	.1522	.1530	.1538	.1546	.1554
.29	.1562	.1570	.1578	.1586	.1594	.1602	.1611	.1619	.1627	.1635
.30	.1643	.1652	.1660	.1668	.1676	.1684	.1693	.1701	.1709	.1718
.31	.1726	.1734	.1743	.1751	.1760	.1768	.1776	.1785	.1793	.1802
.32	.1810	.1819	.1827	.1836	.1844	.1853	.1861	.1870	.1879	.1887
.33	.1896	.1904	.1913	.1922	.1930	.1939	.1948	.1956	.1965	.1974
.34	.1983	.1991	.2000	.2009	.2018	.2026	.2035	.2044	.2053	.2062
.35	.2071	.2080	.2089	.2097	.2106	.2115	.2124	.2133	.2142	.2151
.36	.2160	.2169	.2178	.2187	.2196	.2205	.2214	.2223	.2232	.2242
.37	.2251	.2260	.2269	.2278	.2287	.2296	.2306	.2315	.2324	.2333
.38	.2342	.2352	.2361	.2370	.2380	.2389	.2398	.2408	.2417	.2426
.39	.2436	.2445	.2454	.2464	.2473	.2483	.2492	.2501	.2511	.2520
.40	.2530	.2539	.2549	.2558	.2568	.2578	.2587	.2597	.2606	.2616
.41	.2625	.2635	.2645	.2654	.2664	.2674	.2683	.2693	.2703	.2712
.42	.2722	.2732	.2741	.2751	.2761	.2771	.2781	.2790	.2800	.2810
.43	.2820	.2830	.2840	.2849	.2859	.2869	.2879	.2889	.2899	.2909
.44	.2919	.2929	.2939	.2949	.2959	.2969	.2979	.2989	.2999	.3009
.45	.3019	.3029	.3039	.3049	.3059	.3069	.3079	.3089	.3100	.3110
.46	.3120	.3130	.3140	.3150	.3161	.3171	.3181	.3191	.3202	.3212
.47	.3222	.3232	.3243	.3253	.3263	.3274	.3284	.3294	.3305	.3315
.48	.3325	.3336	.3346	.3357	.3367	.3378	.3388	.3399	.3409	.3420
.49	.3430	.3441	.3451	.3462	.3472	.3483	.3493	.3504	.3514	.3525

TABLE 25 (Continued)

THREE-HALVES POWERS OF NUMBERS

FOR INLET CALCULATIONS

No.	.000	.001	.002	.003	.004	.005	.006	.007	.008	.009
.50	.3536	.3546	.3557	.3567	.3578	.3589	.3599	.3610	.3621	.3631
.51	.3642	.3653	.3664	.3674	.3685	.3696	.3707	.3717	.3728	.3739
.52	.3750	.3761	.3771	.3782	.3793	.3804	.3815	.3826	.3837	.3847
.53	.3858	.3869	.3880	.3891	.3902	.3913	.3924	.3935	.3946	.3957
.54	.3968	.3979	.3990	.4001	.4012	.4023	.4035	.4046	.4057	.4068
.55	.4079	.4090	.4101	.4112	.4123	.4135	.4146	.4157	.4168	.4179
.56	.4191	.4202	.4213	.4224	.4236	.4247	.4258	.4269	.4281	.4292
.57	.4303	.4315	.4326	.4337	.4349	.4360	.4372	.4383	.4394	.4406
.58	.4417	.4429	.4440	.4451	.4463	.4474	.4486	.4497	.4509	.4520
.59	.4532	.4544	.4555	.4566	.4578	.4590	.4601	.4613	.4624	.4636
.60	.4648	.4659	.4671	.4682	.4694	.4706	.4718	.4729	.4741	.4752
.61	.4764	.4776	.4788	.4799	.4811	.4823	.4835	.4847	.4858	.4870
.62	.4882	.4894	.4906	.4917	.4929	.4941	.4953	.4965	.4977	.4988
.63	.5000	.5012	.5024	.5036	.5048	.5060	.5072	.5084	.5096	.5108
.64	.5120	.5132	.5144	.5156	.5168	.5180	.5192	.5204	.5216	.5228
.65	.5240	.5253	.5265	.5277	.5289	.5301	.5313	.5325	.5338	.5350
.66	.5362	.5374	.5386	.5399	.5411	.5423	.5435	.5447	.5460	.5472
.67	.5484	.5496	.5509	.5521	.5533	.5546	.5558	.5570	.5583	.5595
.68	.5607	.5620	.5632	.5645	.5657	.5669	.5682	.5694	.5707	.5719
.69	.5732	.5744	.5757	.5769	.5782	.5794	.5806	.5819	.5832	.5844
.70	.5857	.5869	.5882	.5894	.5907	.5919	.5932	.5945	.5957	.5970
.71	.5983	.5995	.6008	.6020	.6033	.6046	.6059	.6071	.6084	.6097
.72	.6109	.6122	.6135	.6148	.6160	.6173	.6186	.6199	.6212	.6224
.73	.6237	.6250	.6263	.6276	.6288	.6301	.6314	.6327	.6340	.6353
.74	.6366	.6379	.6392	.6404	.6417	.6430	.6443	.6456	.6469	.6482
.75	.6495	.6508	.6521	.6534	.6547	.6560	.6573	.6586	.6599	.6612
.76	.6626	.6639	.6652	.6665	.6678	.6691	.6704	.6717	.6730	.6744
.77	.6757	.6770	.6783	.6796	.6809	.6823	.6836	.6849	.6862	.6876
.78	.6889	.6902	.6915	.6929	.6942	.6955	.6968	.6982	.6995	.7008
.79	.7022	.7035	.7048	.7062	.7075	.7088	.7102	.7115	.7129	.7142
.80	.7155	.7169	.7182	.7196	.7209	.7223	.7236	.7250	.7263	.7276
.81	.7290	.7303	.7317	.7331	.7344	.7358	.7371	.7385	.7398	.7412
.82	.7425	.7439	.7453	.7466	.7480	.7493	.7507	.7521	.7534	.7548
.83	.7562	.7575	.7589	.7603	.7616	.7630	.7644	.7658	.7671	.7685
.84	.7699	.7712	.7726	.7740	.7754	.7768	.7781	.7795	.7809	.7823
.85	.7837	.7850	.7864	.7878	.7892	.7906	.7920	.7934	.7947	.7961
.86	.7975	.7989	.8003	.8017	.8031	.8045	.8059	.8073	.8087	.8101
.87	.8115	.8129	.8143	.8157	.8171	.8185	.8199	.8213	.8227	.8241
.88	.8255	.8269	.8283	.8297	.8311	.8326	.8340	.8354	.8368	.8382
.89	.8396	.8410	.8425	.8439	.8453	.8467	.8481	.8495	.8510	.8524
.90	.8538	.8552	.8567	.8581	.8595	.8609	.8624	.8638	.8652	.8667
.91	.8681	.8695	.8709	.8724	.8738	.8752	.8767	.8781	.8796	.8810
.92	.8824	.8839	.8853	.8868	.8882	.8896	.8911	.8925	.8940	.8954
.93	.8969	.8983	.8998	.9012	.9026	.9041	.9056	.9070	.9085	.9099
.94	.9114	.9128	.9143	.9157	.9172	.9186	.9201	.9216	.9230	.9245
.95	.9259	.9274	.9289	.9303	.9318	.9333	.9347	.9362	.9377	.9391
.96	.9406	.9421	.9435	.9450	.9465	.9480	.9494	.9509	.9524	.9539
.97	.9553	.9568	.9583	.9598	.9613	.9627	.9642	.9657	.9672	.9687
.98	.9702	.9716	.9731	.9746	.9761	.9776	.9791	.9806	.9821	.9835
.99	.9850	.9865	.9880	.9895	.9910	.9925	.9940	.9955	.9970	.9985

TABLE 26

FRACTIONAL POWERS OF PIPE DIAMETERS

Pipe Diameter Inches	Feet (D)	$D^{1/3}$	$D^{2/3}$	$D^{4/3}$	$D^{8/3}$	$D^{5/2}$
6	0.50	0.794	0.630	0.397	0.157	0.177
8	0.67	0.874	0.763	0.582	0.339	0.363
9	0.75	0.909	0.825	0.681	0.464	0.487
10	0.83	0.941	0.885	0.784	0.615	0.634
12	1.00	1.000	1.000	1.000	1.000	1.000
15	1.25	1.077	1.160	1.347	1.813	1.747
16	1.33	1.101	1.212	1.468	2.154	2.053
18	1.50	1.145	1.310	1.717	2.948	2.756
21	1.75	1.205	1.452	2.109	4.447	4.051
24	2.00	1.260	1.587	2.520	6.35	5.657
27	2.25	1.310	1.717	2.948	8.69	7.594
30	2.50	1.357	1.842	3.393	11.51	9.882
33	2.75	1.401	1.963	3.853	14.85	12.54
36	3.00	1.442	2.080	4.327	18.72	15.59
39	3.25	1.481	2.194	4.814	23.17	19.04
42	3.50	1.518	2.305	5.314	28.24	22.92
45	3.75	1.554	2.414	5.826	33.94	27.23
48	4.0	1.587	2.520	6.35	40.32	32.00
54	4.5	1.651	2.726	7.43	55.20	42.96
60	5.0	1.710	2.924	8.55	73.10	55.90
66	5.5	1.765	3.116	9.71	94.25	70.94
72	6.0	1.817	3.302	10.90	118.8	88.2
78	6.5	1.866	3.483	12.13	147.1	107.7
84	7.0	1.913	3.659	13.39	179.3	129.6
90	7.5	1.957	3.832	14.68	215.5	154.0
96	8.0	2.000	4.00	16.00	256.	181.0
102	8.5	2.041	4.17	17.35	301.	210.6
108	9.0	2.080	4.33	18.72	350.	243.0
114	9.5	2.118	4.49	20.12	405.	278.2
120	10.0	2.155	4.64	21.54	464.	316.
132	11.0	2.224	4.95	24.46	598.	401.
144	12.0	2.290	5.24	27.47	755.	499.
156	13.0	2.351	5.53	30.57	934.	609.
168	14.0	2.410	5.81	33.74	1140.	733.
180	15.0	2.466	6.08	36.99	1370.	871.

TABLE 27

AREA, WETTED PERIMETER AND HYDRAULIC RADIUS OF PARTIALLY FILLED CIRCULAR PIPE AS A FUNCTION OF DIAMETER

$\frac{d}{D}$	$\frac{area}{D^2}$	$\frac{wet. per.}{D}$	$\frac{hyd. rad.}{D}$	$\frac{d}{D}$	$\frac{area}{D^2}$	$\frac{wet. per.}{D}$	$\frac{hyd. rad.}{D}$
0.01	0.0013	0.2003	0.0066	0.51	0.4027	1.5908	0.2531
0.02	0.0037	0.2838	0.0132	0.52	0.4127	1.6108	0.2561
0.03	0.0069	0.3482	0.0197	0.53	0.4227	1.6308	0.2591
0.04	0.0105	0.4027	0.0262	0.54	0.4327	1.6509	0.2620
0.05	0.0147	0.4510	0.0326	0.55	0.4426	1.6710	0.2649
0.06	0.0192	0.4949	0.0389	0.56	0.4526	1.6911	0.2676
0.07	0.0242	0.5355	0.0451	0.57	0.4625	1.7113	0.2703
0.08	0.0294	0.5735	0.0513	0.58	0.4723	1.7315	0.2728
0.09	0.0350	0.6094	0.0574	0.59	0.4822	1.7518	0.2753
0.10	0.0409	0.6435	0.0635	0.60	0.4920	1.7722	0.2776
0.11	0.0470	0.6761	0.0695	0.61	0.5018	1.7926	0.2797
0.12	0.0534	0.7075	0.0754	0.62	0.5115	1.8132	0.2818
0.13	0.0600	0.7377	0.0813	0.63	0.5212	1.8338	0.2839
0.14	0.0688	0.7670	0.0871	0.64	0.5308	1.8546	0.2860
0.15	0.0739	0.7954	0.0929	0.65	0.5404	1.8755	0.2881
0.16	0.0811	0.8230	0.0986	0.66	0.5499	1.8965	0.2899
0.17	0.0885	0.8500	0.1042	0.67	0.5594	1.9177	0.2917
0.18	0.0961	0.8763	0.1097	0.68	0.5687	1.9391	0.2935
0.19	0.1039	0.9020	0.1152	0.69	0.5780	1.9606	0.2950
0.20	0.1118	0.9273	0.1206	0.70	0.5872	1.9823	0.2962
0.21	0.1199	0.9521	0.1259	0.71	0.5964	2.0042	0.2973
0.22	0.1281	0.9764	0.1312	0.72	0.6054	2.0264	0.2984
0.23	0.1365	1.0003	0.1364	0.73	0.6143	2.0488	0.2995
0.24	0.1449	1.0239	0.1416	0.74	0.6231	2.0714	0.3006
0.25	0.1535	1.0472	0.1466	0.75	0.6318	2.0944	0.3017
0.26	0.1623	1.0701	0.1516	0.76	0.6404	2.1176	0.3025
0.27	0.1711	1.0928	0.1566	0.77	0.6489	2.1412	0.3032
0.28	0.1800	1.1152	0.1614	0.78	0.6573	2.1652	0.3037
0.29	0.1890	1.1373	0.1662	0.79	0.6655	2.1895	0.3040
0.30	0.1982	1.1593	0.1709	0.80	0.6736	2.2143	0.3042
0.31	0.2074	1.1810	0.1755	0.81	0.6815	2.2395	0.3044
0.32	0.2167	1.2025	0.1801	0.82	0.6893	2.2653	0.3043
0.33	0.2260	1.2239	0.1848	0.83	0.6969	2.2916	0.3041
0.34	0.2355	1.2451	0.1891	0.84	0.7043	2.3186	0.3038
0.35	0.2450	1.2661	0.1935	0.85	0.7115	2.3462	0.3033
0.36	0.2546	1.2870	0.1978	0.86	0.7186	2.3746	0.3026
0.37	0.2642	1.3078	0.2020	0.87	0.7254	2.4038	0.3017
0.38	0.2739	1.3284	0.2061	0.88	0.7320	2.4341	0.3008
0.39	0.2836	1.3490	0.2102	0.89	0.7384	2.4655	0.2996
0.40	0.2934	1.3694	0.2142	0.90	0.7445	2.4981	0.2980
0.41	0.3032	1.3898	0.2181	0.91	0.7504	2.5322	0.2963
0.42	0.3130	1.4101	0.2220	0.92	0.7560	2.5681	0.2944
0.43	0.3229	1.4303	0.2257	0.93	0.7612	2.6061	0.2922
0.44	0.3328	1.4505	0.2294	0.94	0.7662	2.6467	0.2896
0.45	0.3428	1.4706	0.2331	0.95	0.7707	2.6906	0.2864
0.46	0.3527	1.4907	0.2366	0.96	0.7749	2.7389	0.2830
0.47	0.3627	1.5108	0.2400	0.97	0.7785	2.7934	0.2787
0.48	0.3727	1.5308	0.2434	0.98	0.7816	2.8578	0.2735
0.49	0.3827	1.5508	0.2467	0.99	0.7841	2.9412	0.2665
0.50	0.3927	1.5708	0.2500	1.00	0.7854	3.1416	0.2500

TABLE 28

THE DISCHARGE OF A CIRCULAR CHANNEL

FLOWING PART FULL WHEN FLOW IS AT CRITICAL DEPTH

BASED ON DIAMETER

Let $\frac{\text{depth of water}}{\text{diameter of channel}} = \frac{d_c}{D}$ and let c = tabulated value. Then $Q = cD^{5/2}$

$\frac{d_c}{D}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0		.0006	.0025	.0055	.0098	.0153	.0220	.0298	.0389	.0491
.1	.0605	.0731	.0868	.1016	.1176	.1347	.1530	.1724	.1928	.2144
.2	.2371	.2609	.2857	.3116	.3386	.3666	.3957	.4259	.4571	.4893
.3	.523	.557	.592	.628	.666	.704	.743	.784	.825	.867
.4	.910	.955	1.000	1.046	1.093	1.141	1.190	1.240	1.291	1.343
.5	1.396	1.449	1.504	1.560	1.616	1.674	1.733	1.792	1.853	1.915
.6	1.977	2.041	2.106	2.172	2.239	2.307	2.376	2.446	2.518	2.591
.7	2.666	2.741	2.819	2.898	2.978	3.061	3.145	3.231	3.320	3.411
.8	3.505	3.602	3.702	3.806	3.914	4.028	4.147	4.272	4.406	4.549
.9	4.70	4.87	5.06	5.27	5.52	5.81	6.18	6.67	7.41	8.83

TABLE 29

THE DISCHARGE OF A CIRCULAR CHANNEL

FLOWING PART FULL WHEN FLOW IS AT CRITICAL DEPTH

BASED ON CRITICAL DEPTH

Let $\frac{\text{depth of water}}{\text{diameter of channel}} = \frac{d_c}{D}$ and c the tabulated value. Then $Q = cd_c^{5/2}$

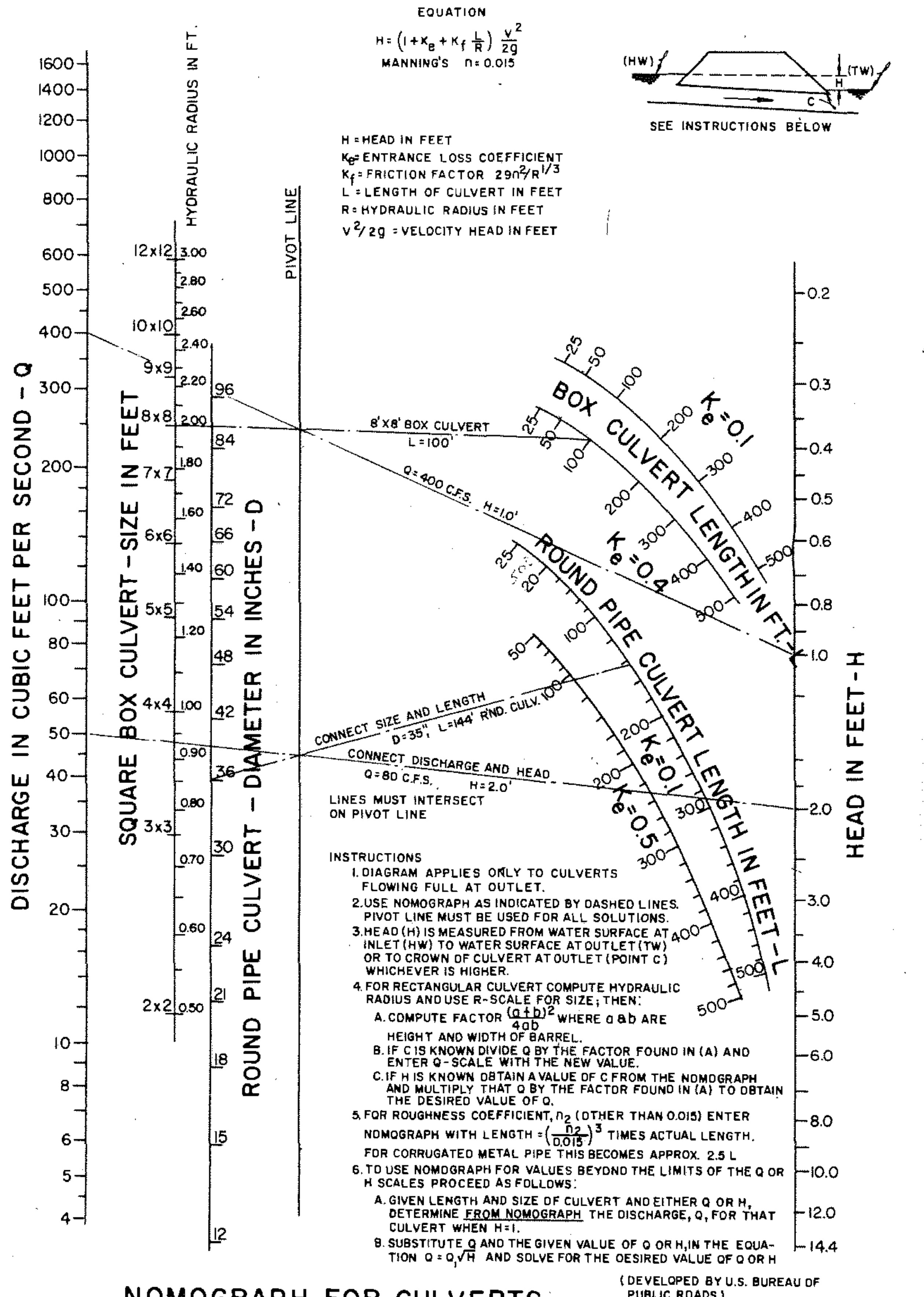
$\frac{d_c}{D}$	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0		61.59	43.49	35.43	30.62	27.33	24.90	22.98	21.48	20.21
.1	19.13	18.20	17.39	16.68	16.04	15.46	14.94	14.46	14.03	13.63
.2	13.25	12.91	12.59	12.28	12.00	11.73	11.48	11.24	11.02	10.80
.3	10.60	10.41	10.22	10.05	9.88	9.71	9.56	9.41	9.27	9.13
.4	9.00	8.87	8.74	8.63	8.51	8.40	8.29	8.19	8.09	7.99
.5	7.89	7.80	7.71	7.63	7.54	7.46	7.38	7.31	7.23	7.16
.6	7.09	7.02	6.96	6.89	6.83	6.77	6.71	6.66	6.60	6.55
.7	6.50	6.45	6.41	6.36	6.32	6.28	6.25	6.21	6.18	6.15
.8	6.12	6.10	6.08	6.06	6.05	6.05	6.05	6.05	6.06	6.09
.9	6.12	6.17	6.23	6.32	6.44	6.61	6.84	7.20	7.79	9.05

TABLE 30

VELOCITY HEADS

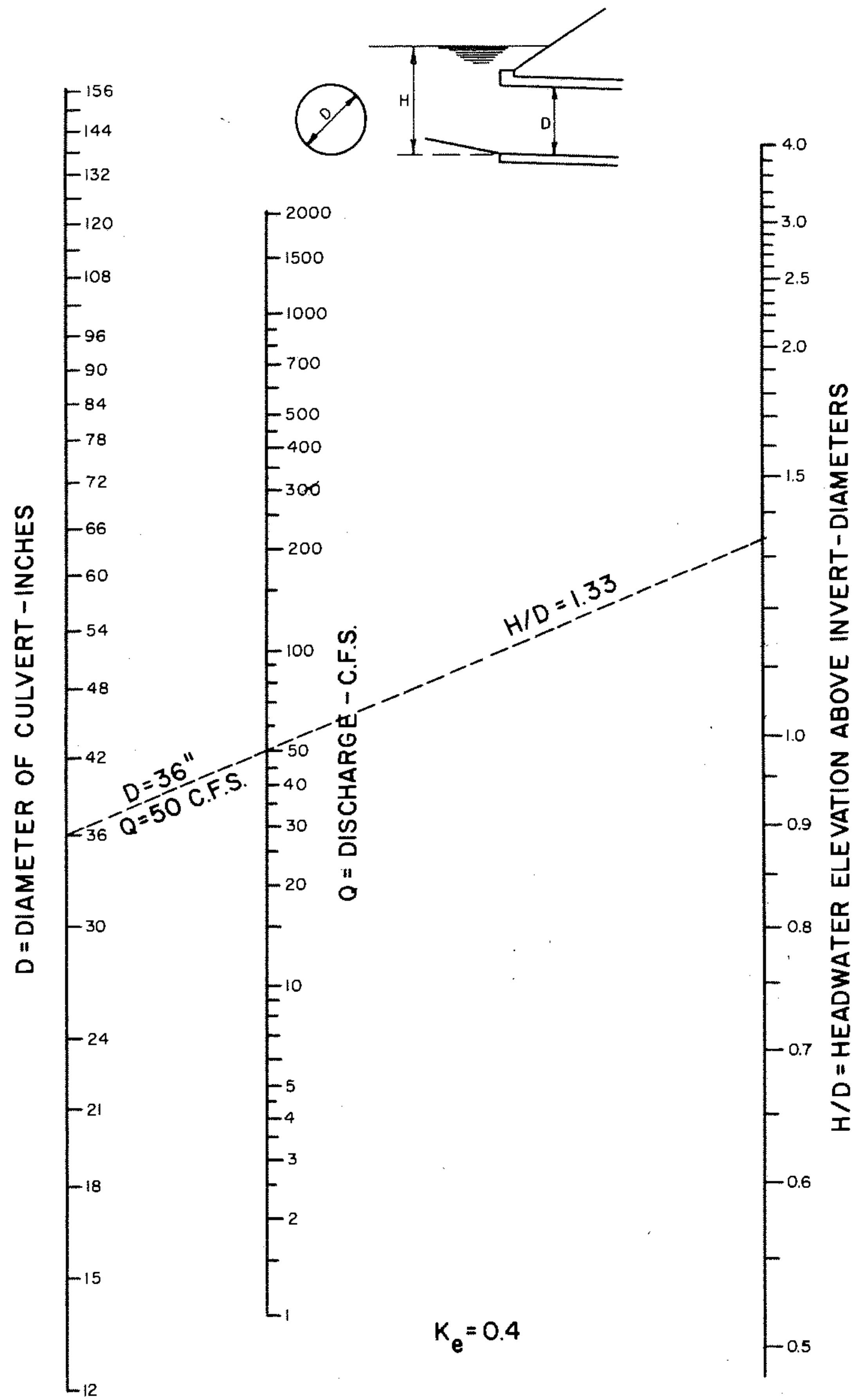
$V^2/2g$

Velocity (f. p. s.)	Velocity Head (ft.)	Velocity (f. p. s.)	Velocity Head (ft.)	Velocity (f. p. s.)	Velocity Head (ft.)
1.0	0.016	7.0	0.762	13.0	2.627
1.1	0.019	7.1	0.784	13.1	2.668
1.2	0.022	7.2	0.806	13.2	2.709
1.3	0.026	7.3	0.828	13.3	2.750
1.4	0.030	7.4	0.851	13.4	2.792
1.5	0.035	7.5	0.874	13.5	2.834
1.6	0.040	7.6	0.898	13.6	2.876
1.7	0.045	7.7	0.922	13.7	2.918
1.8	0.050	7.8	0.946	13.8	2.961
1.9	0.056	7.9	0.970	13.9	3.004
2.0	0.062	8.0	0.995	14.0	3.047
2.1	0.069	8.1	1.020	14.1	3.091
2.2	0.075	8.2	1.045	14.2	3.135
2.3	0.082	8.3	1.071	14.3	3.179
2.4	0.090	8.4	1.097	14.4	3.224
2.5	0.097	8.5	1.123	14.5	3.269
2.6	0.105	8.6	1.150	14.6	3.314
2.7	0.113	8.7	1.177	14.7	3.360
2.8	0.122	8.8	1.204	14.8	3.406
2.9	0.131	8.9	1.231	14.9	3.452
3.0	0.140	9.0	1.259	15.0	3.498
3.1	0.149	9.1	1.287	15.1	3.545
3.2	0.159	9.2	1.316	15.2	3.592
3.3	0.169	9.3	1.345	15.3	3.639
3.4	0.180	9.4	1.374	15.4	3.687
3.5	0.190	9.5	1.403	15.5	3.735
3.6	0.202	9.6	1.433	15.6	3.784
3.7	0.213	9.7	1.463	15.7	3.832
3.8	0.224	9.8	1.494	15.8	3.881
3.9	0.236	9.9	1.524	15.9	3.931
4.0	0.249	10.0	1.555	16.0	3.980
4.1	0.261	10.1	1.586	16.1	4.030
4.2	0.274	10.2	1.618	16.2	4.080
4.3	0.288	10.3	1.650	16.3	4.131
4.4	0.301	10.4	1.682	16.4	4.182
4.5	0.315	10.5	1.714	16.5	4.233
4.6	0.329	10.6	1.747	16.6	4.284
4.7	0.343	10.7	1.780	16.7	4.336
4.8	0.358	10.8	1.813	16.8	4.388
4.9	0.373	10.9	1.847	16.9	4.440
5.0	0.389	11.0	1.881	17.0	4.493
5.1	0.404	11.1	1.916	17.1	4.546
5.2	0.420	11.2	1.950	17.2	4.600
5.3	0.437	11.3	1.985	17.3	4.653
5.4	0.453	11.4	2.021	17.4	4.707
5.5	0.470	11.5	2.056	17.5	4.761
5.6	0.487	11.6	2.092	17.6	4.816
5.7	0.505	11.7	2.128	17.7	4.871
5.8	0.523	11.8	2.165	17.8	4.926
5.9	0.541	11.9	2.202	17.9	4.982
6.0	0.560	12.0	2.239	18.0	5.037
6.1	0.579	12.1	2.276	18.1	5.093
6.2	0.598	12.2	2.314	18.2	5.150
6.3	0.617	12.3	2.352	18.3	5.207
6.4	0.637	12.4	2.391	18.4	5.264
6.5	0.657	12.5	2.429	18.5	5.321
6.6	0.677	12.6	2.468	18.6	5.379
6.7	0.698	12.7	2.508	18.7	5.437
6.8	0.719	12.8	2.547	18.8	5.495
6.9	0.740	12.9	2.587	18.9	5.554



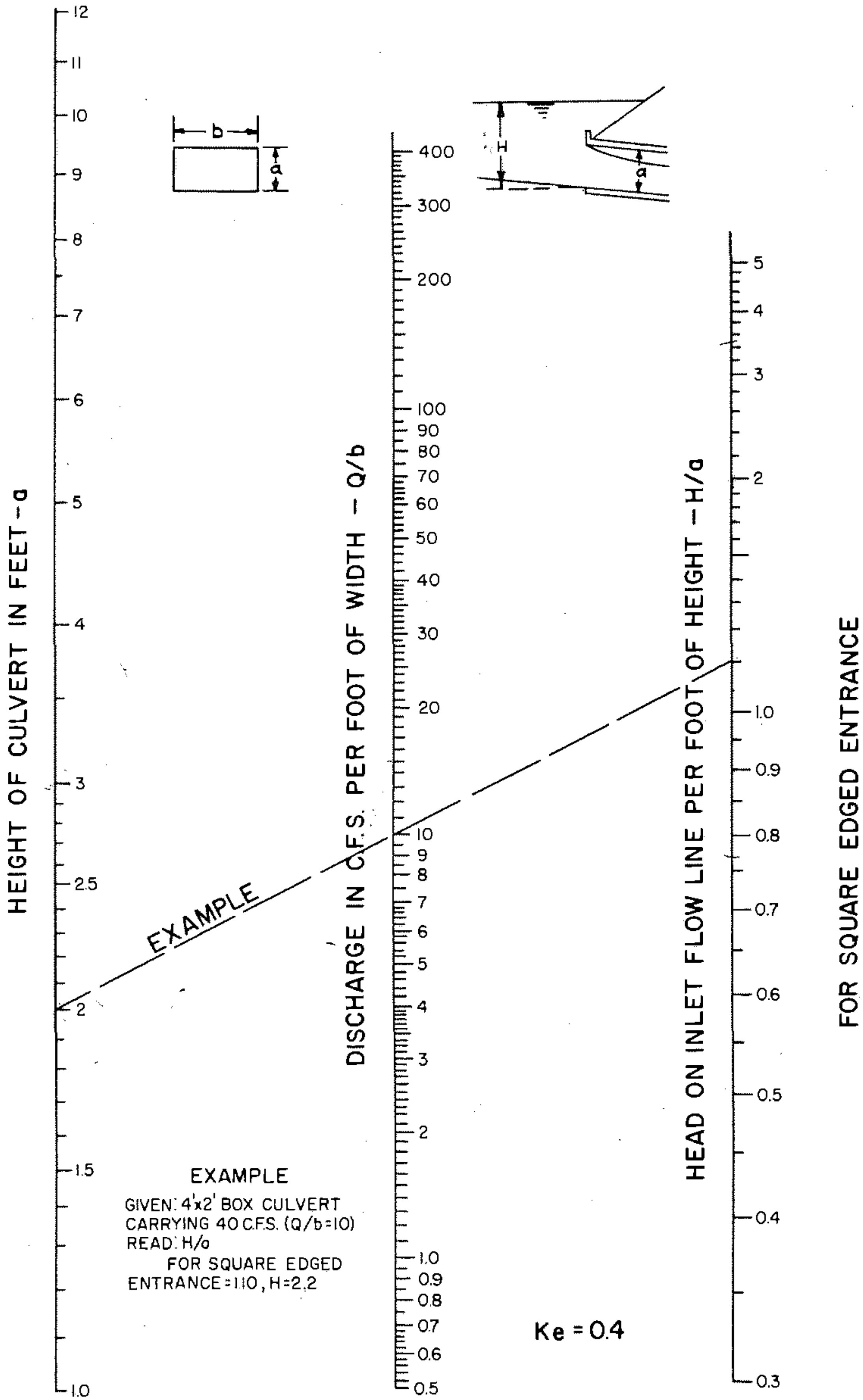
NOMOGRAPH FOR CULVERTS FLOWING FULL

FIGURE 27



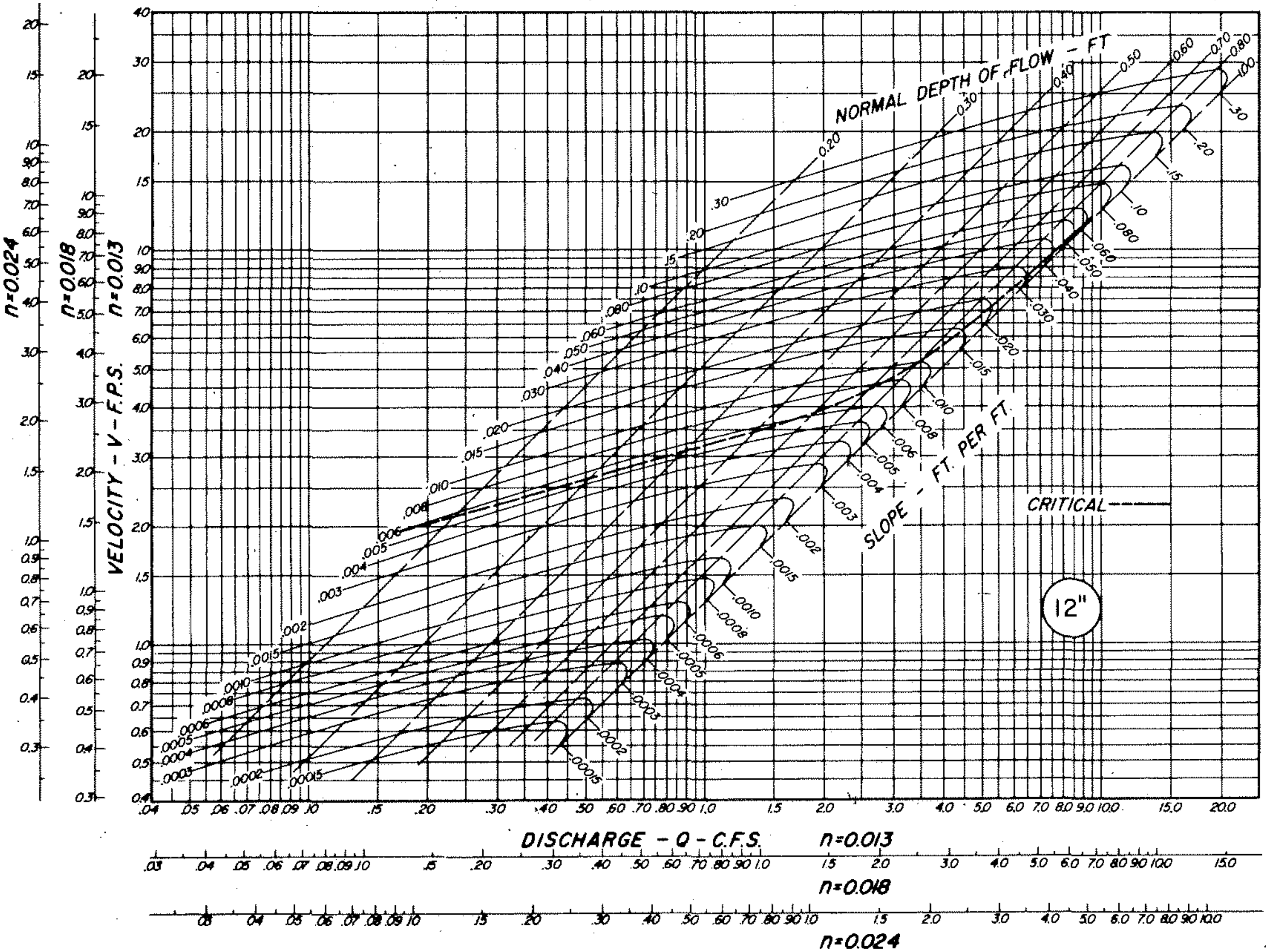
NOMOGRAPH FOR PIPE CULVERTS WITH ENTRANCE CONTROL

FIGURE 28



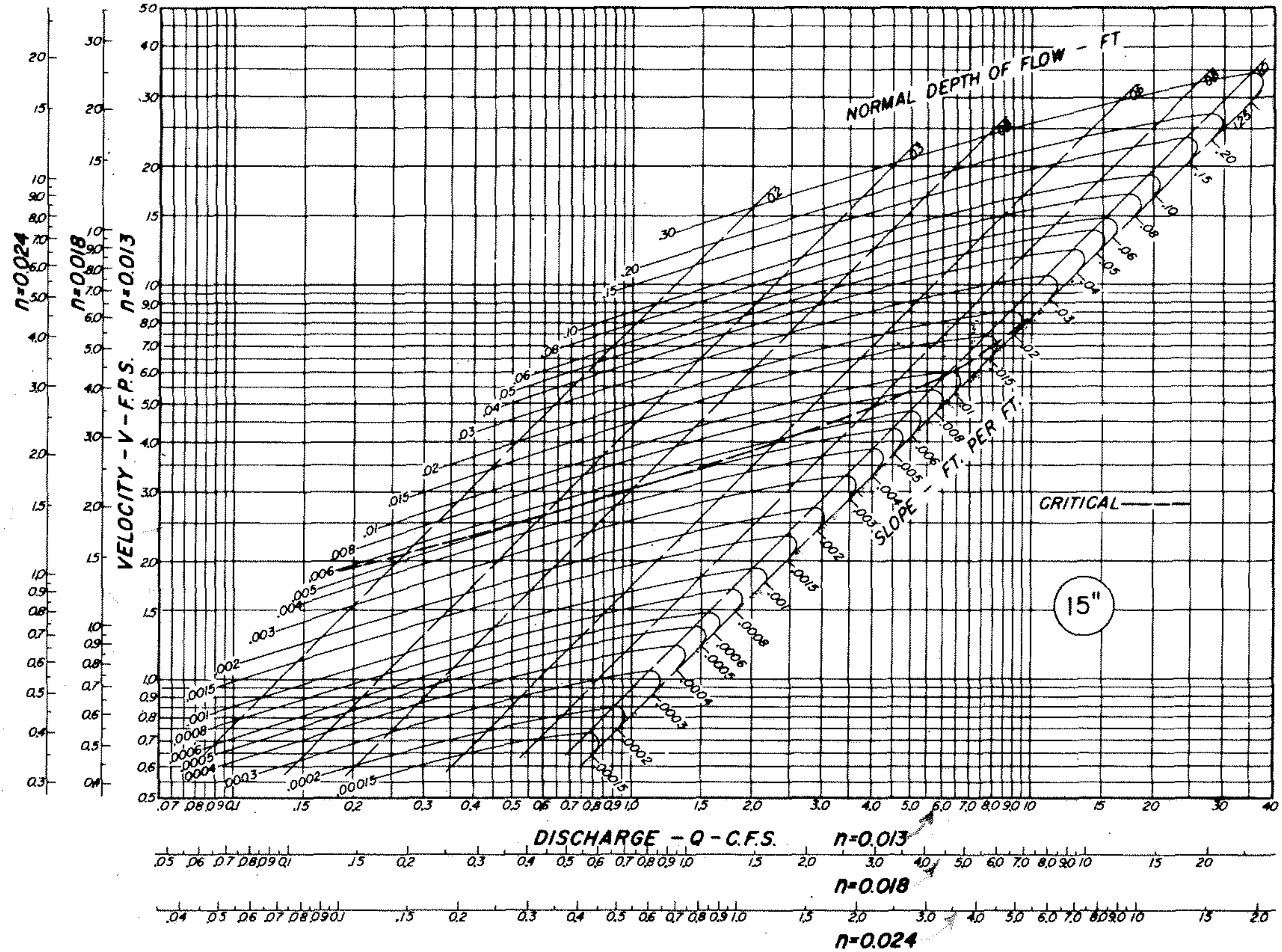
NOMOGRAPH FOR BOX CULVERTS WITH ENTRANCE CONTROL

FIGURE 29



PIPE FLOW CHART
12 INCH DIAMETER

FIGURE 30



PIPE FLOW CHART
15 INCH DIAMETER

FIGURE 31

PIPE FLOW CHART
18 INCH DIAMETER

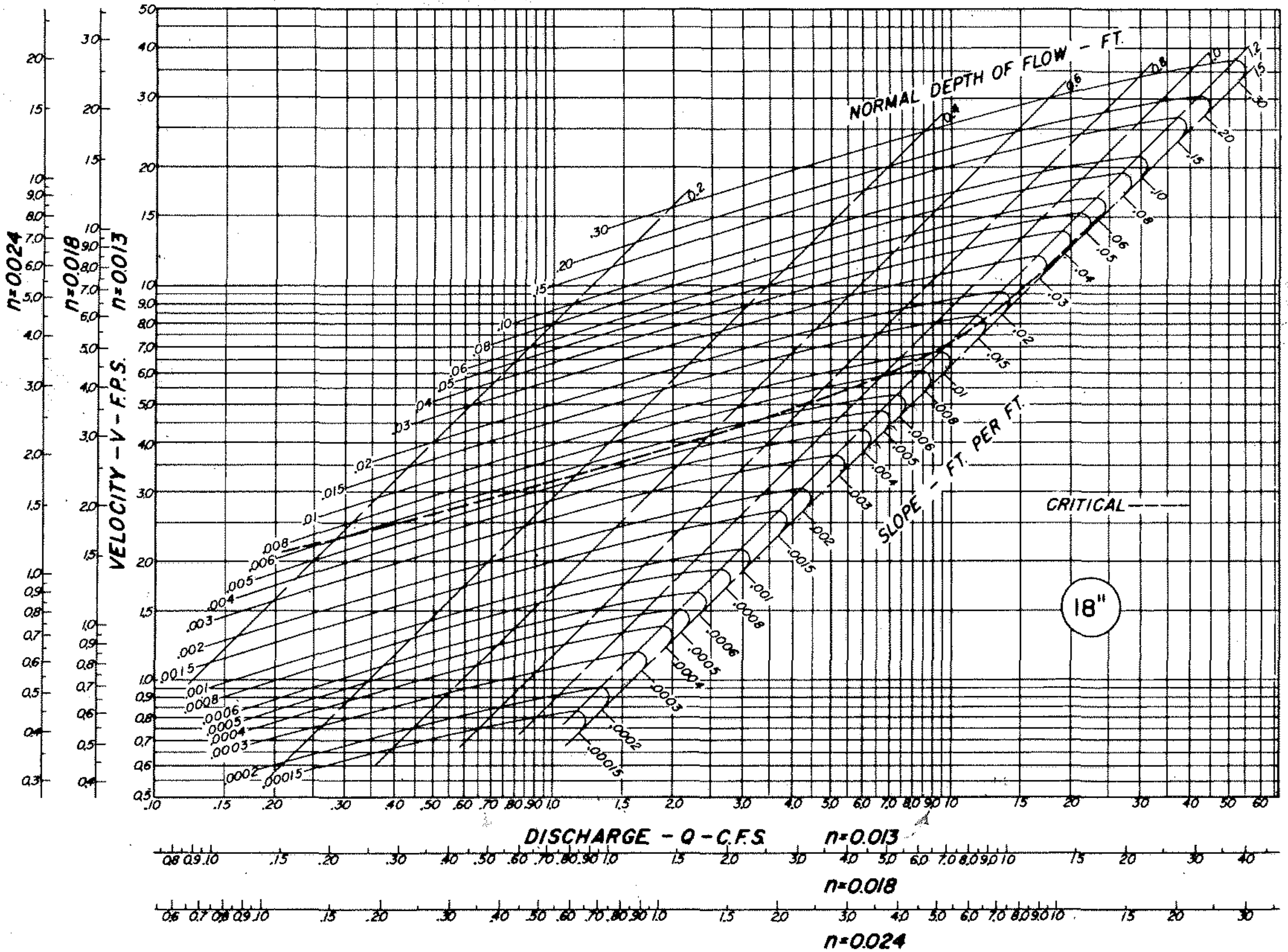


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FIGURE 32

PIPE FLOW CHART
21 INCH DIAMETER

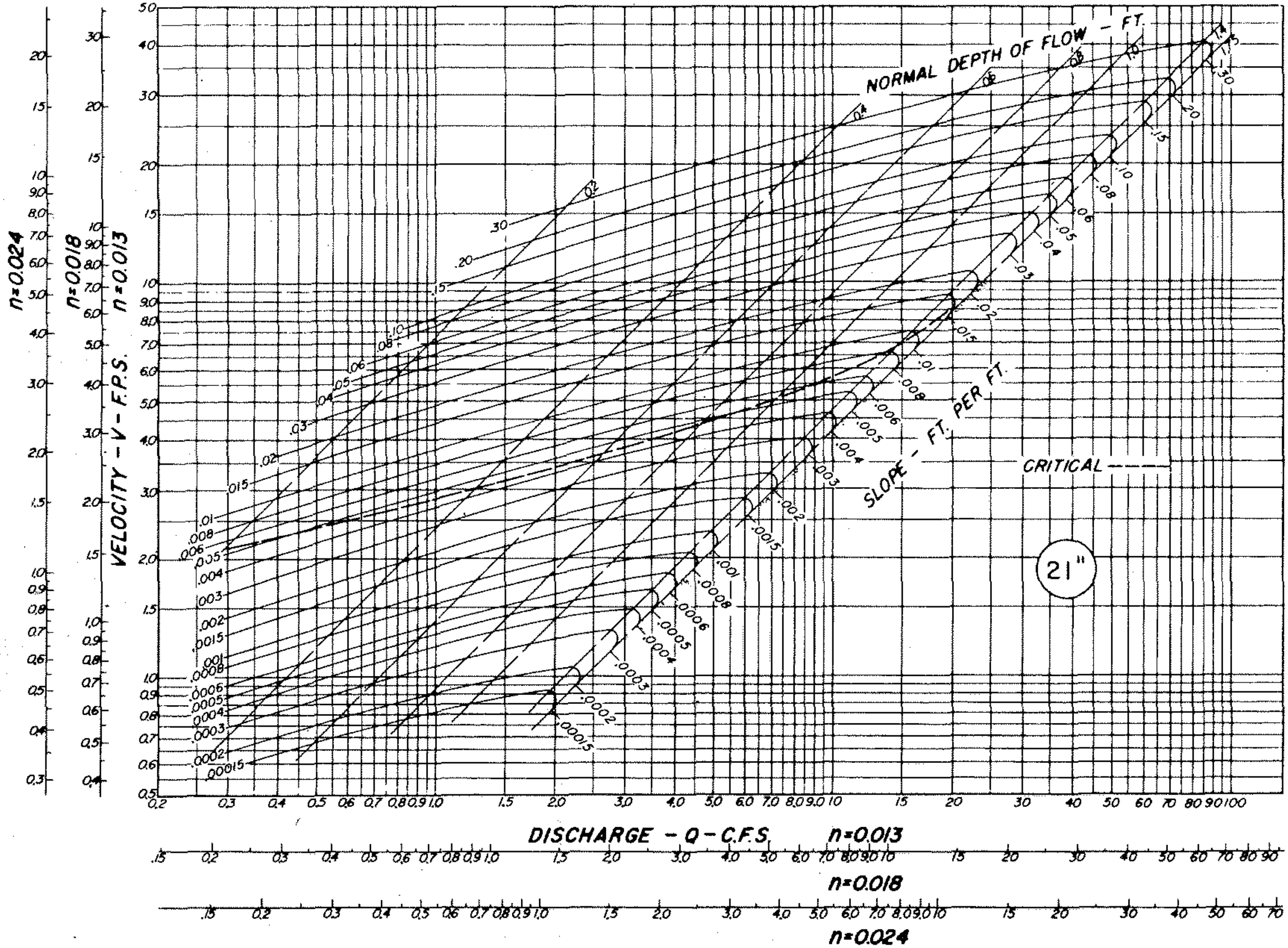
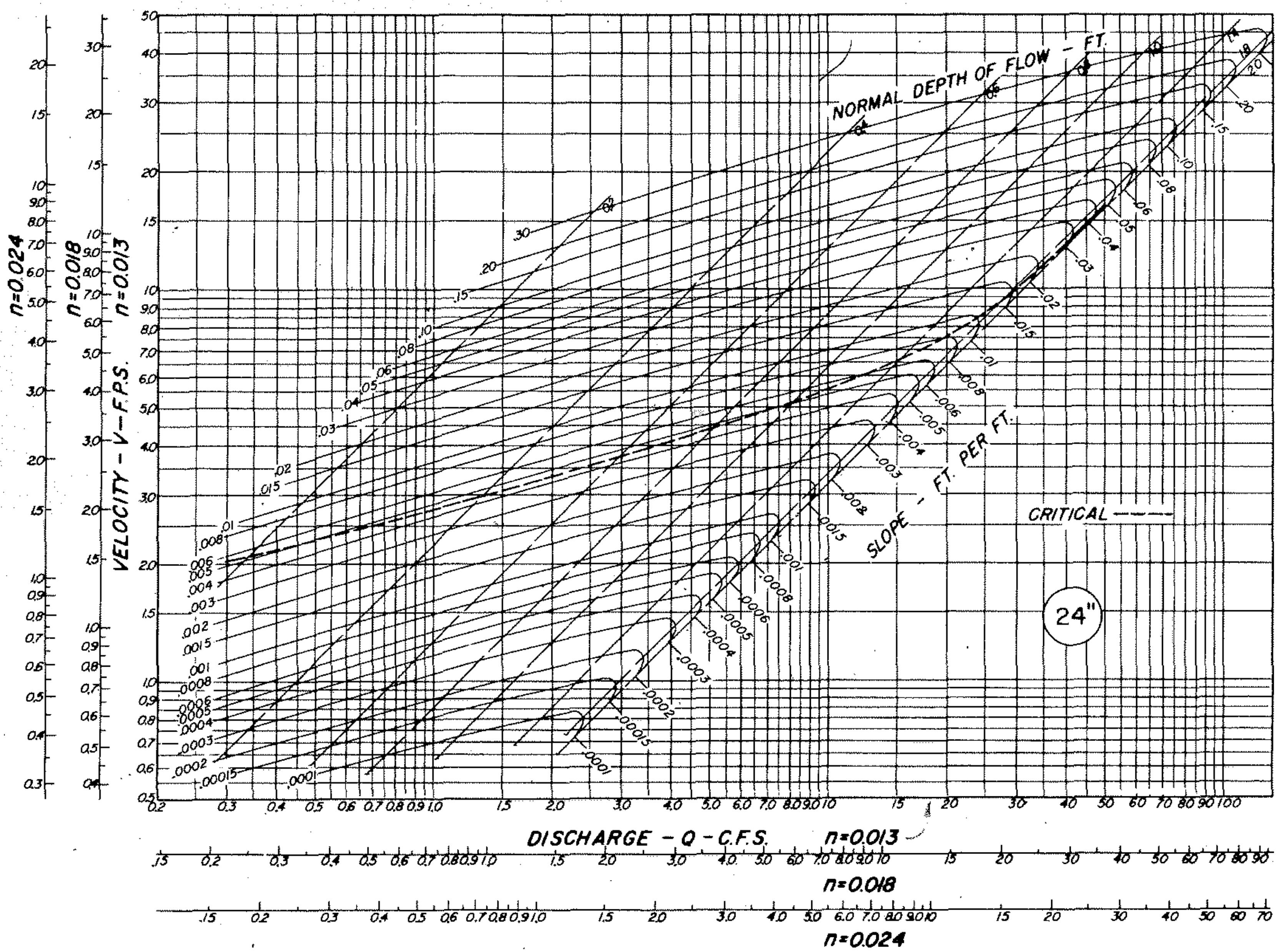


FIGURE 33



PIPE FLOW CHART

24 INCH DIAMETER

FIGURE 34

PIPE FLOW CHART
27 INCH DIAMETER

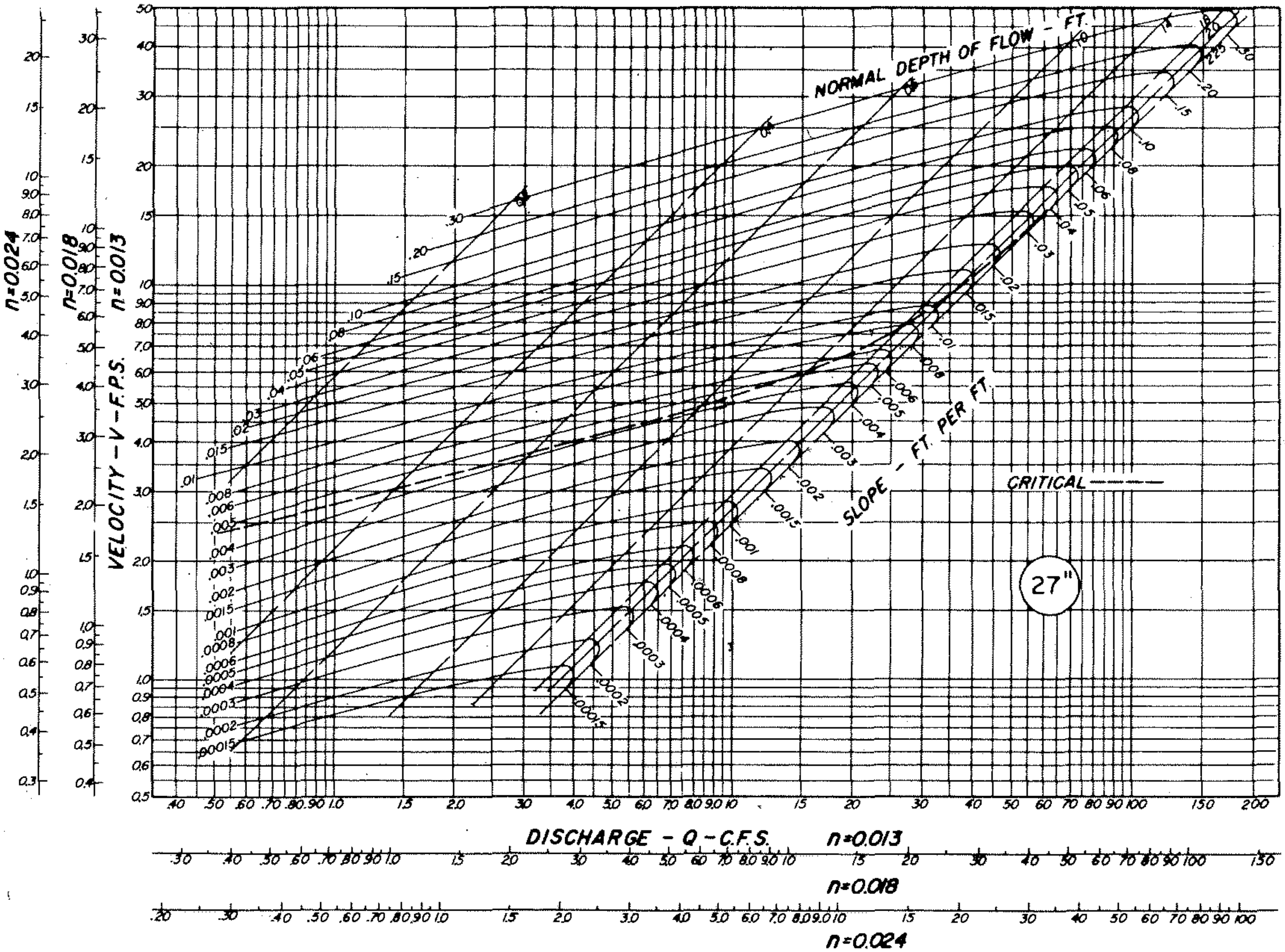
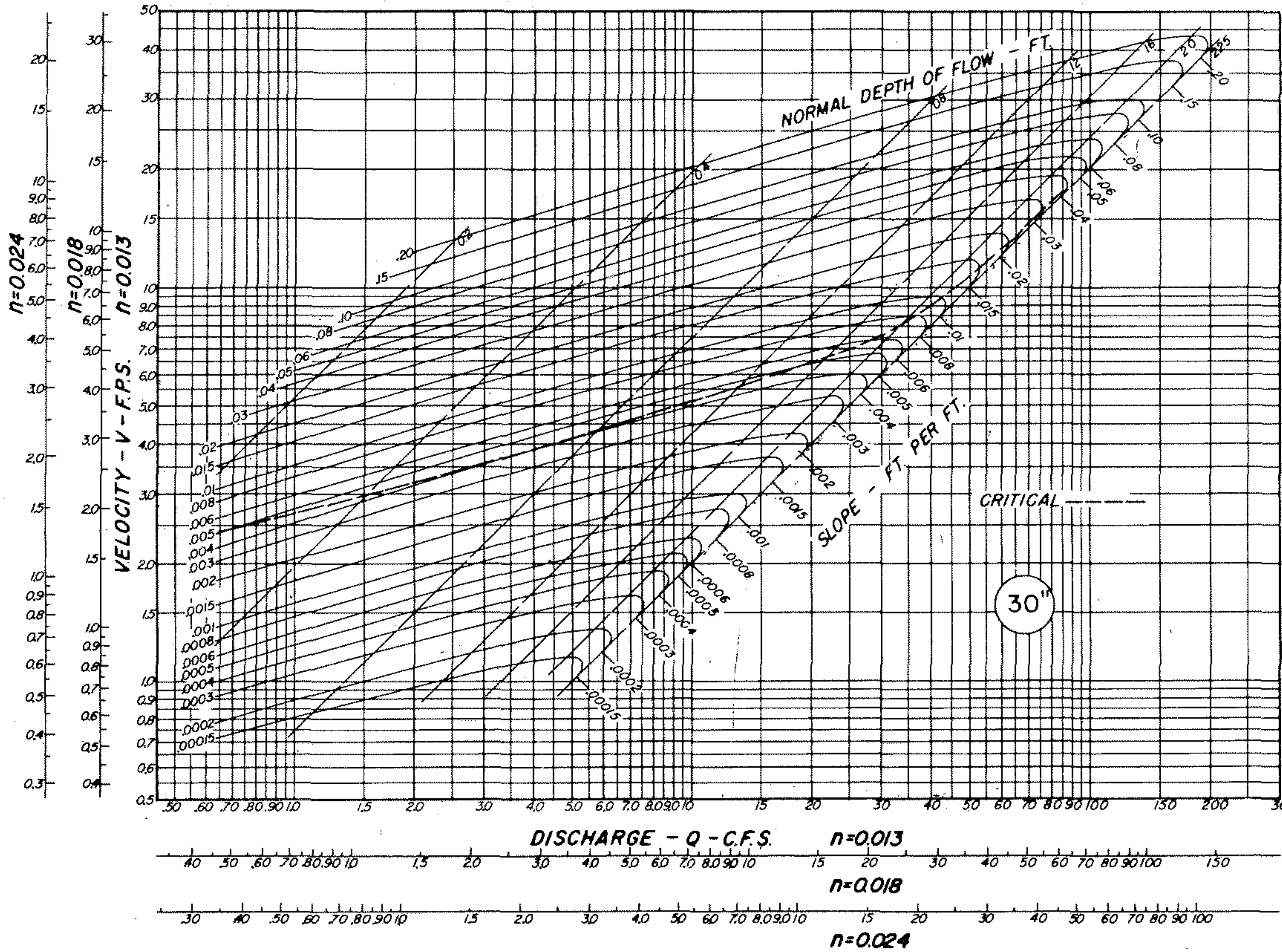


FIGURE 35



PIPE FLOW CHART
30 INCH DIAMETER

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FIGURE 36

PIPE FLOW CHART
33 INCH DIAMETER

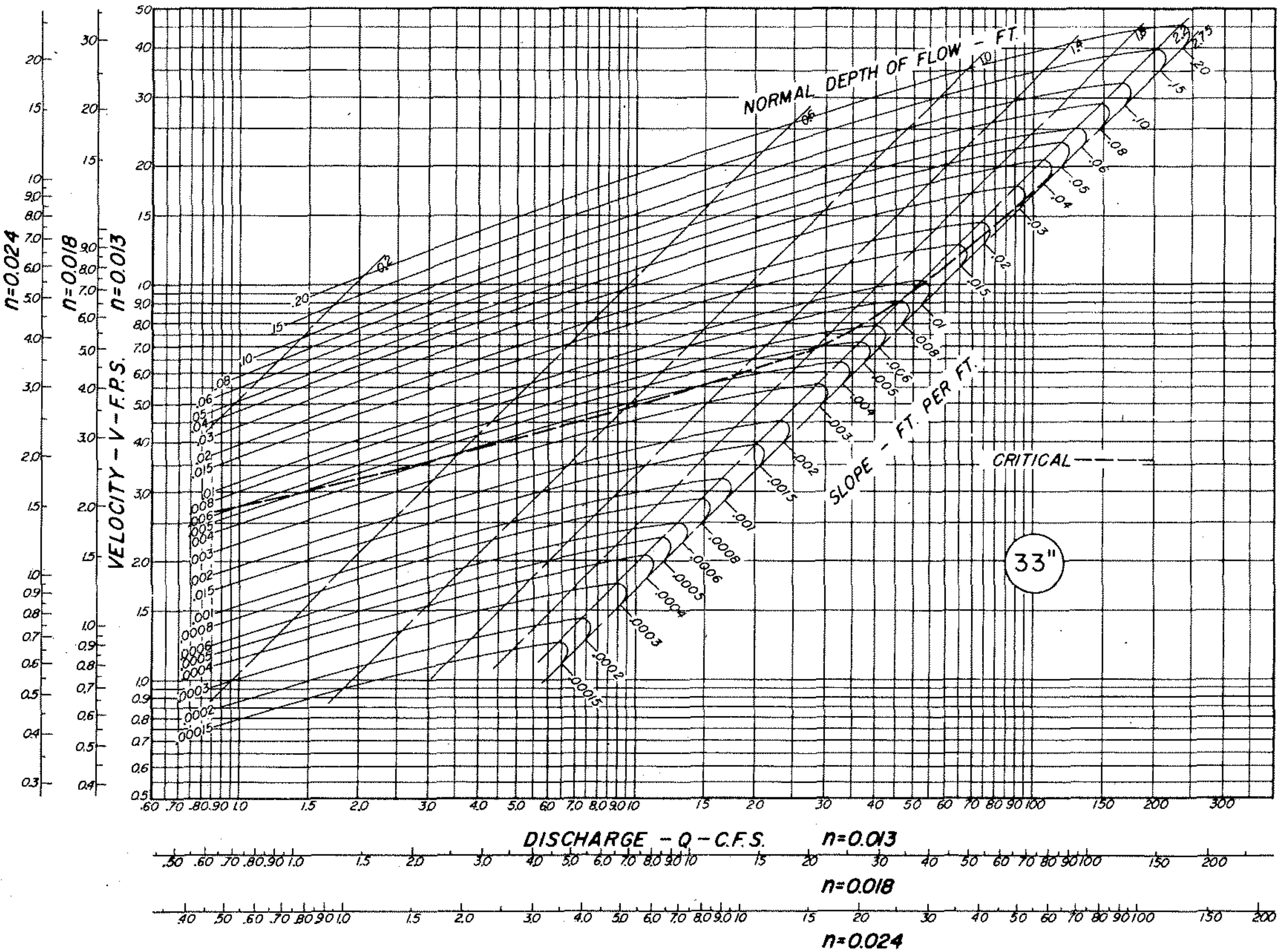
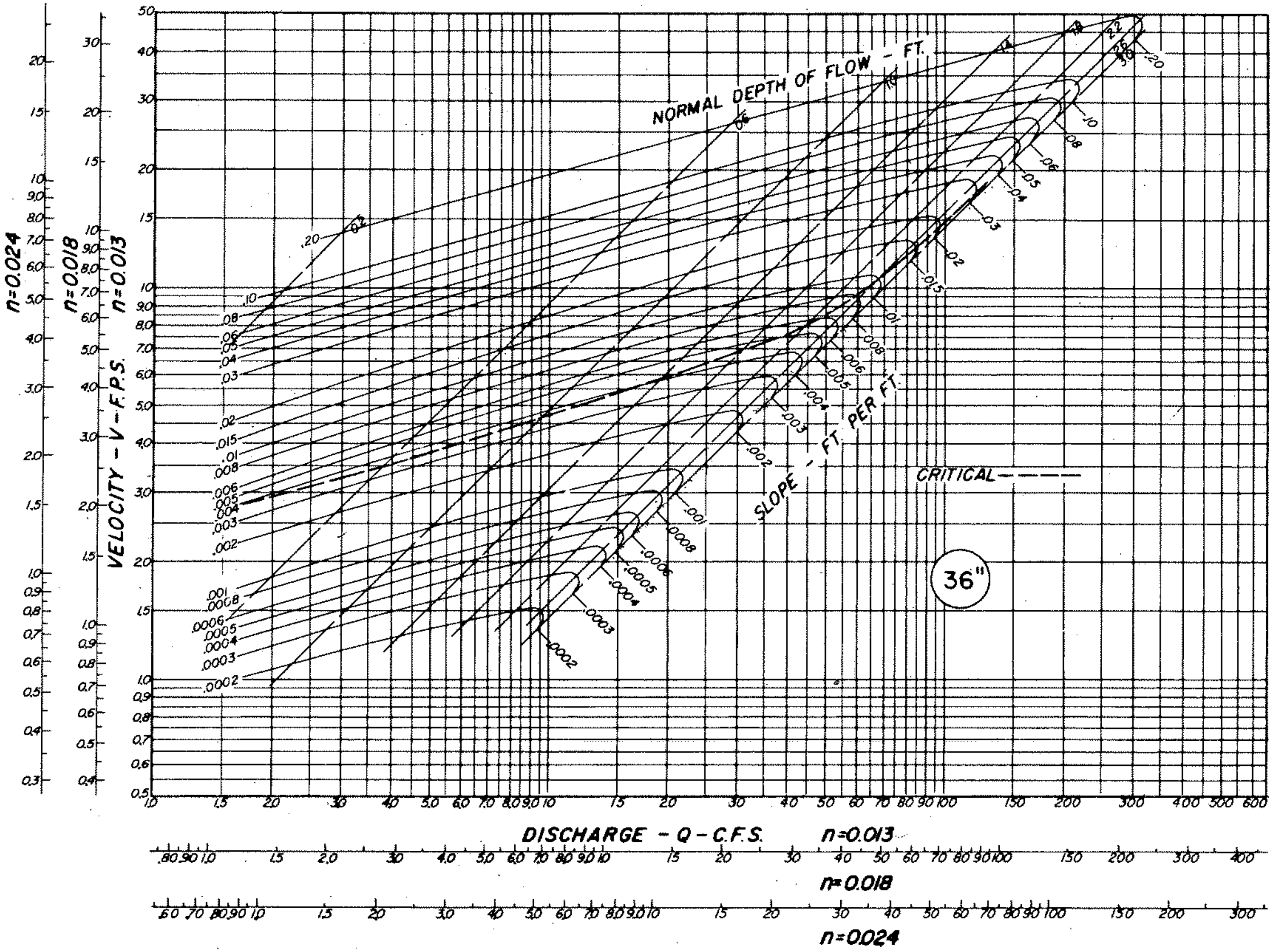


FIGURE 37



PIPE FLOW CHART
36 INCH DIAMETER

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FIGURE 38

PIPE FLOW CHART
42 INCH DIAMETER

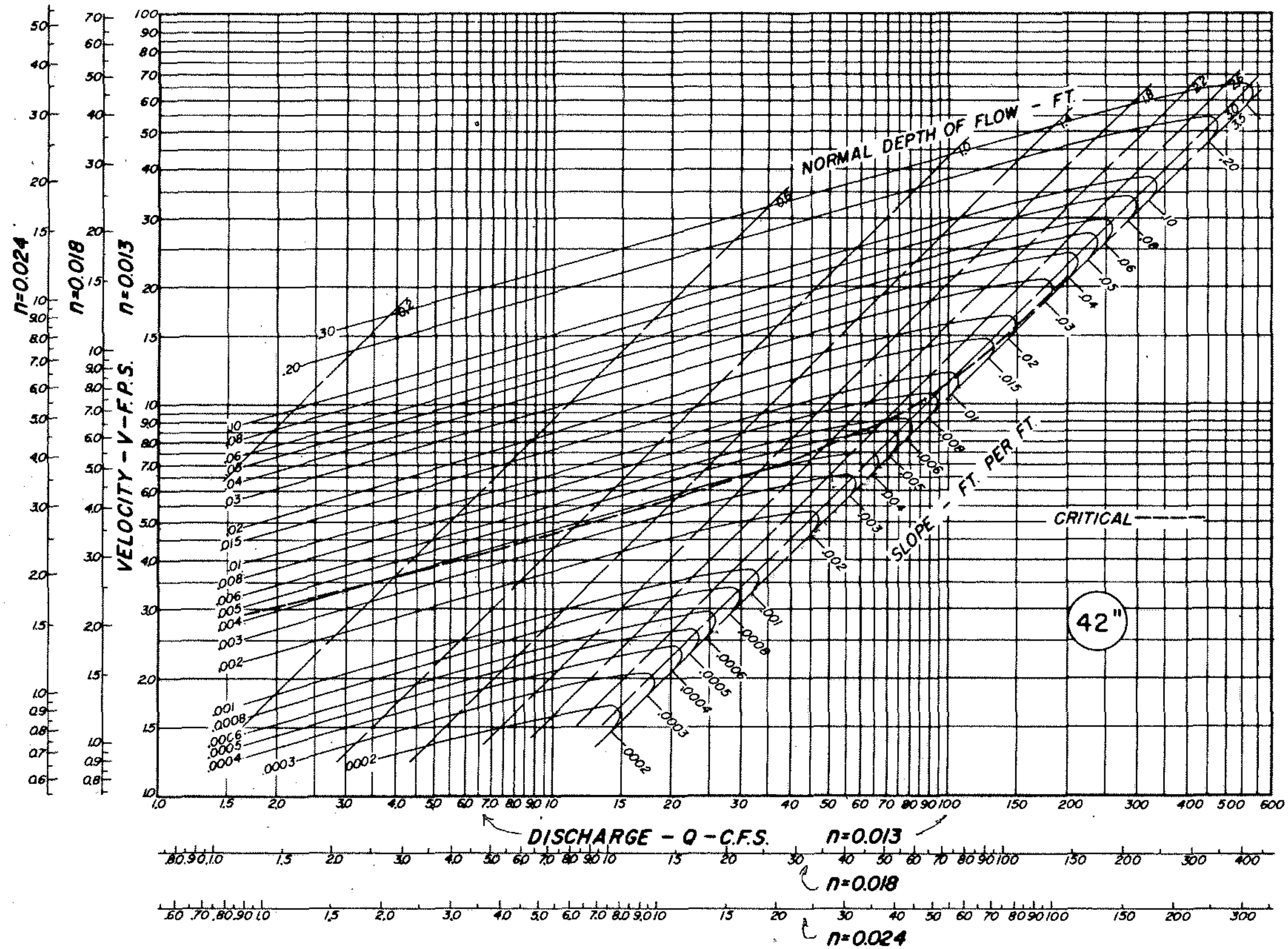


FIGURE 39

PIPE FLOW CHART
48 INCH DIAMETER

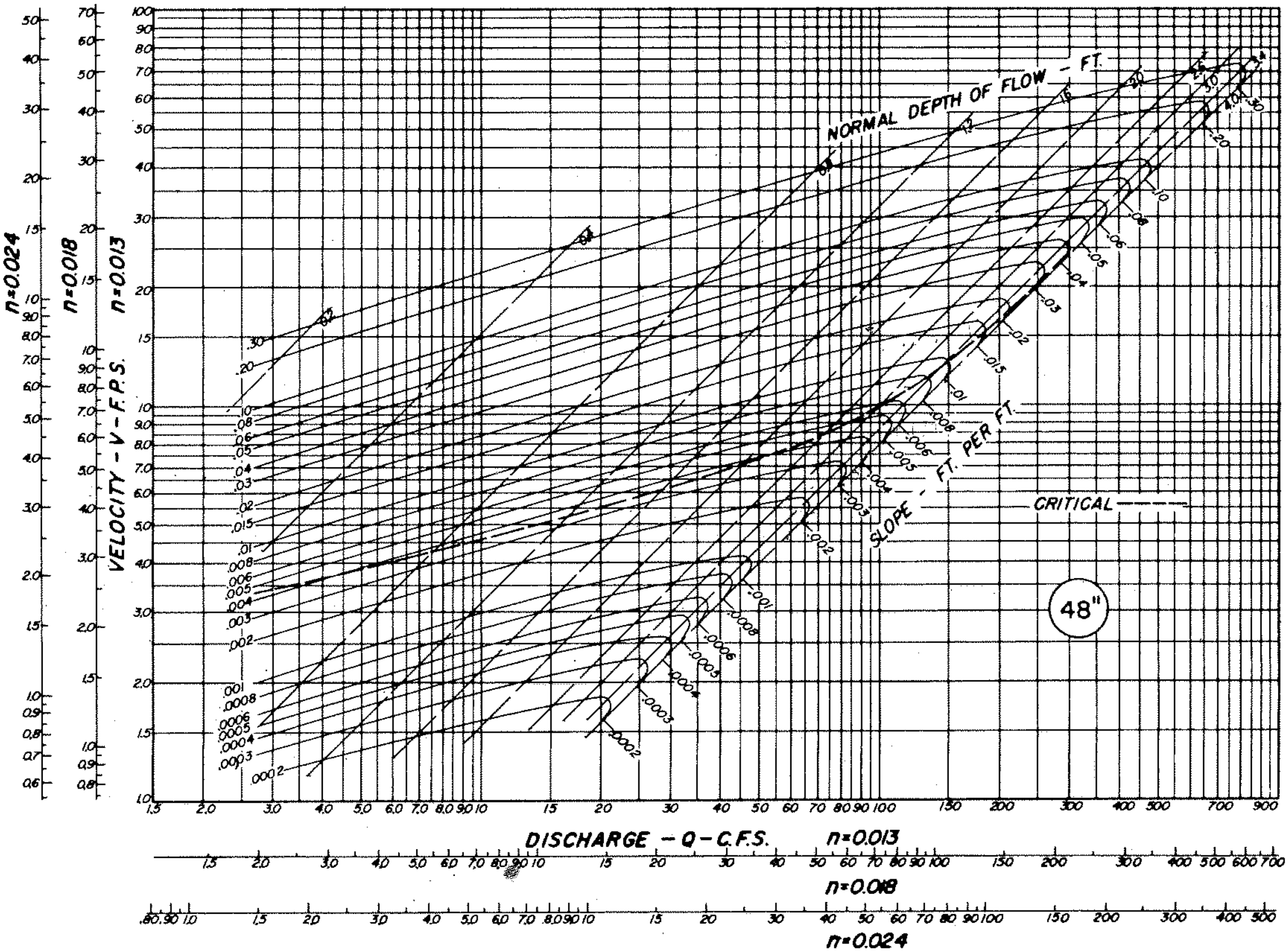
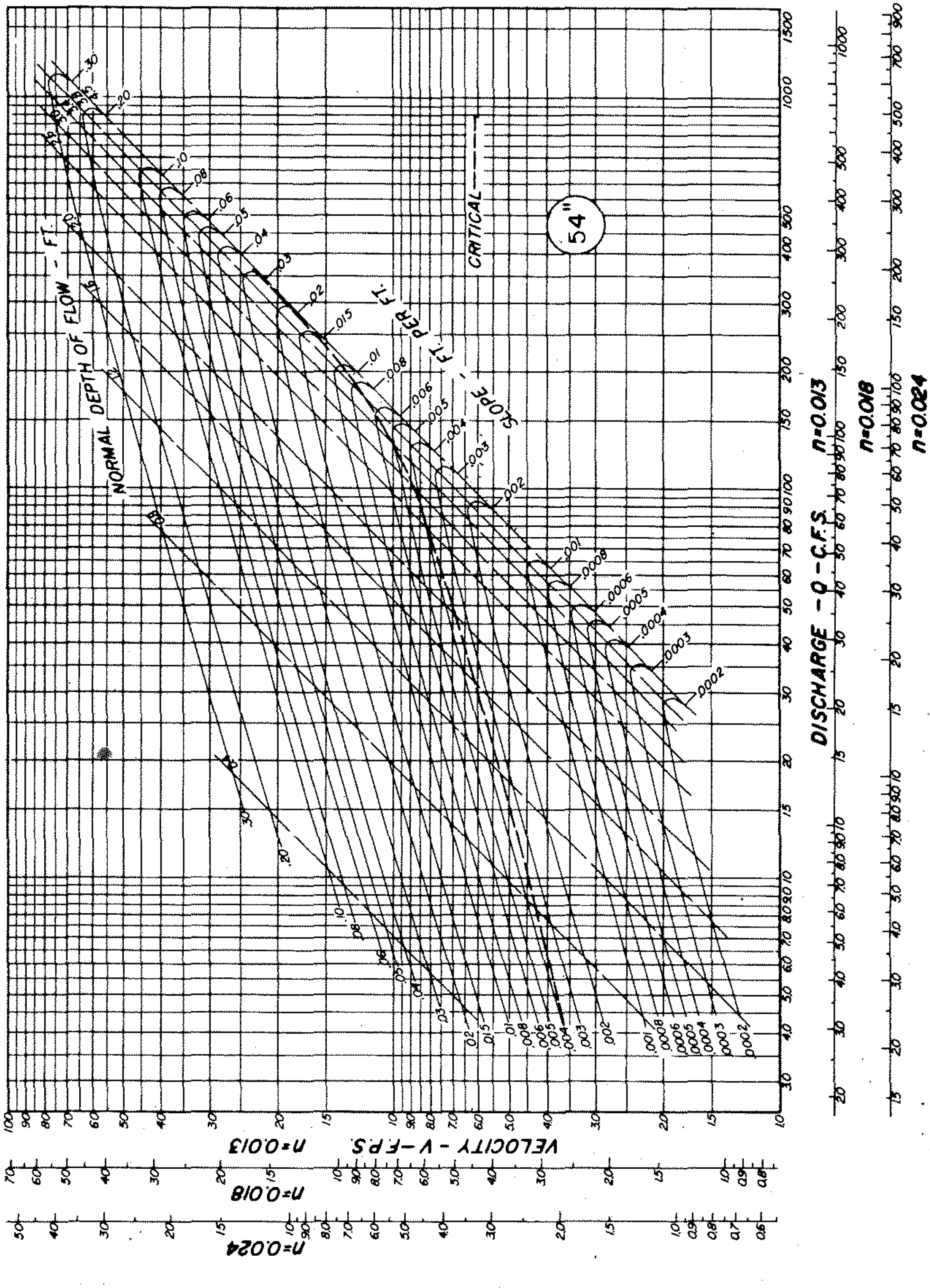


FIGURE 40



PIPE FLOW CHART
54 INCH DIAMETER

FIGURE 41

PIPE FLOW CHART
60 INCH DIAMETER

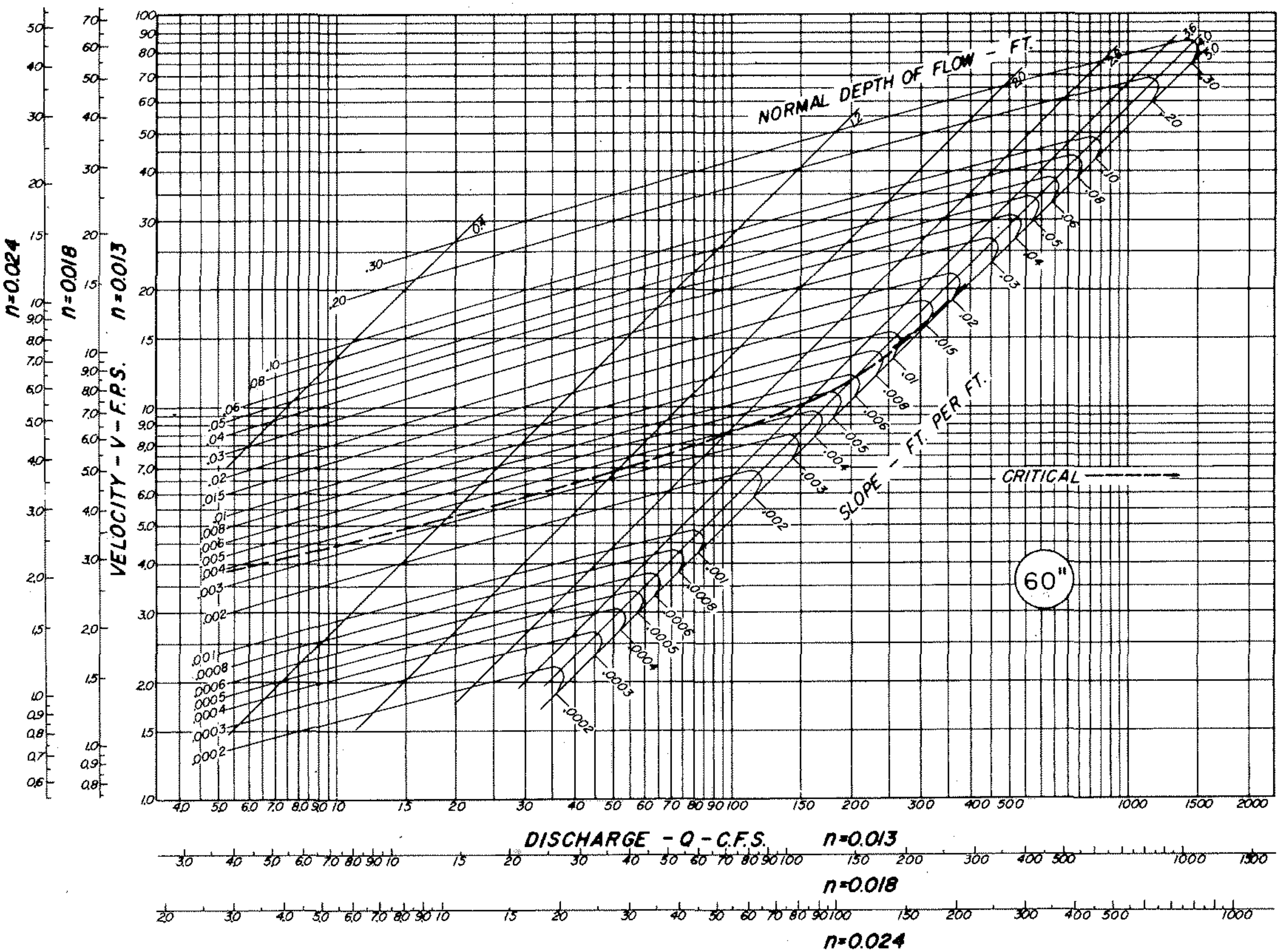
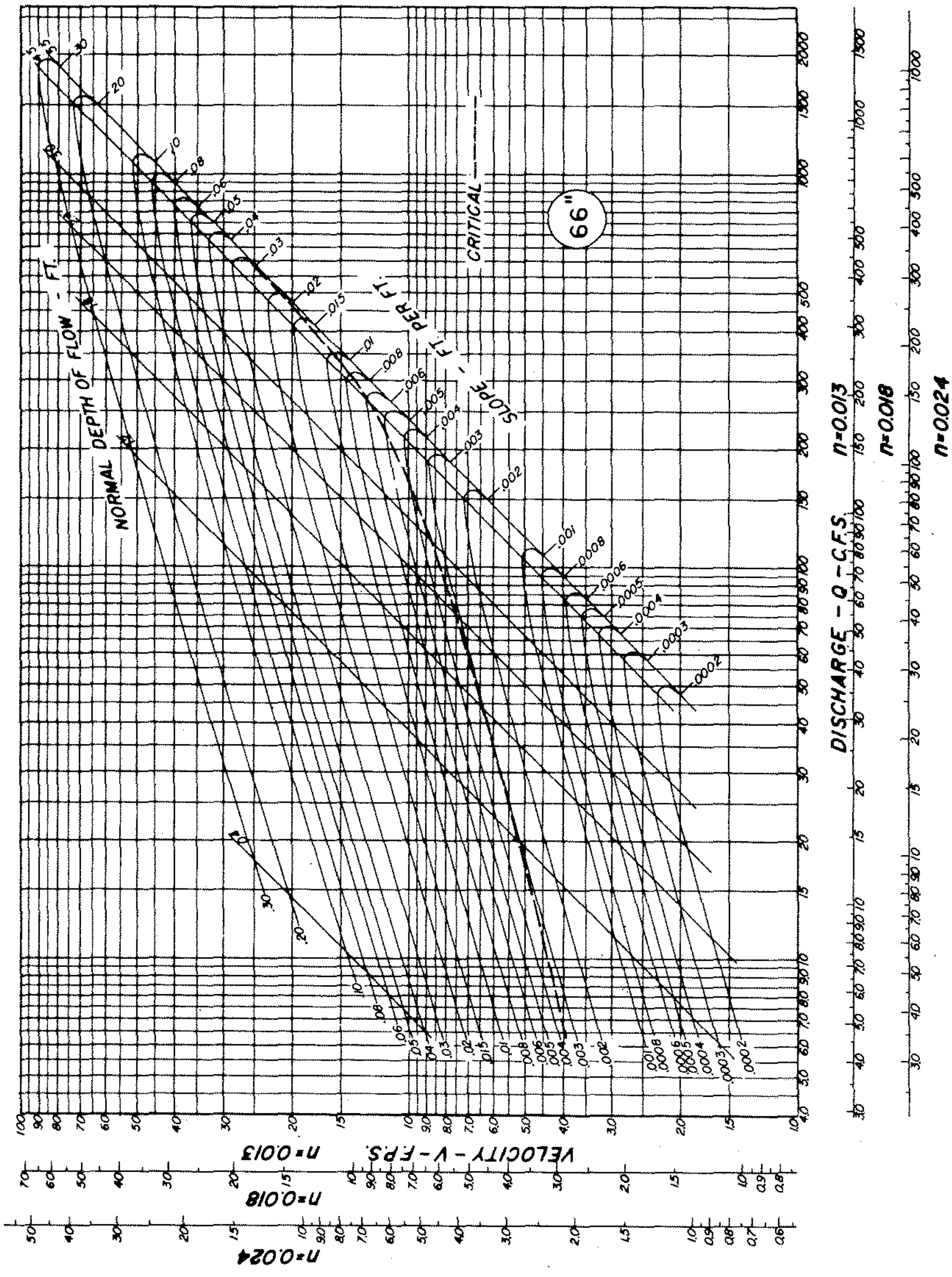
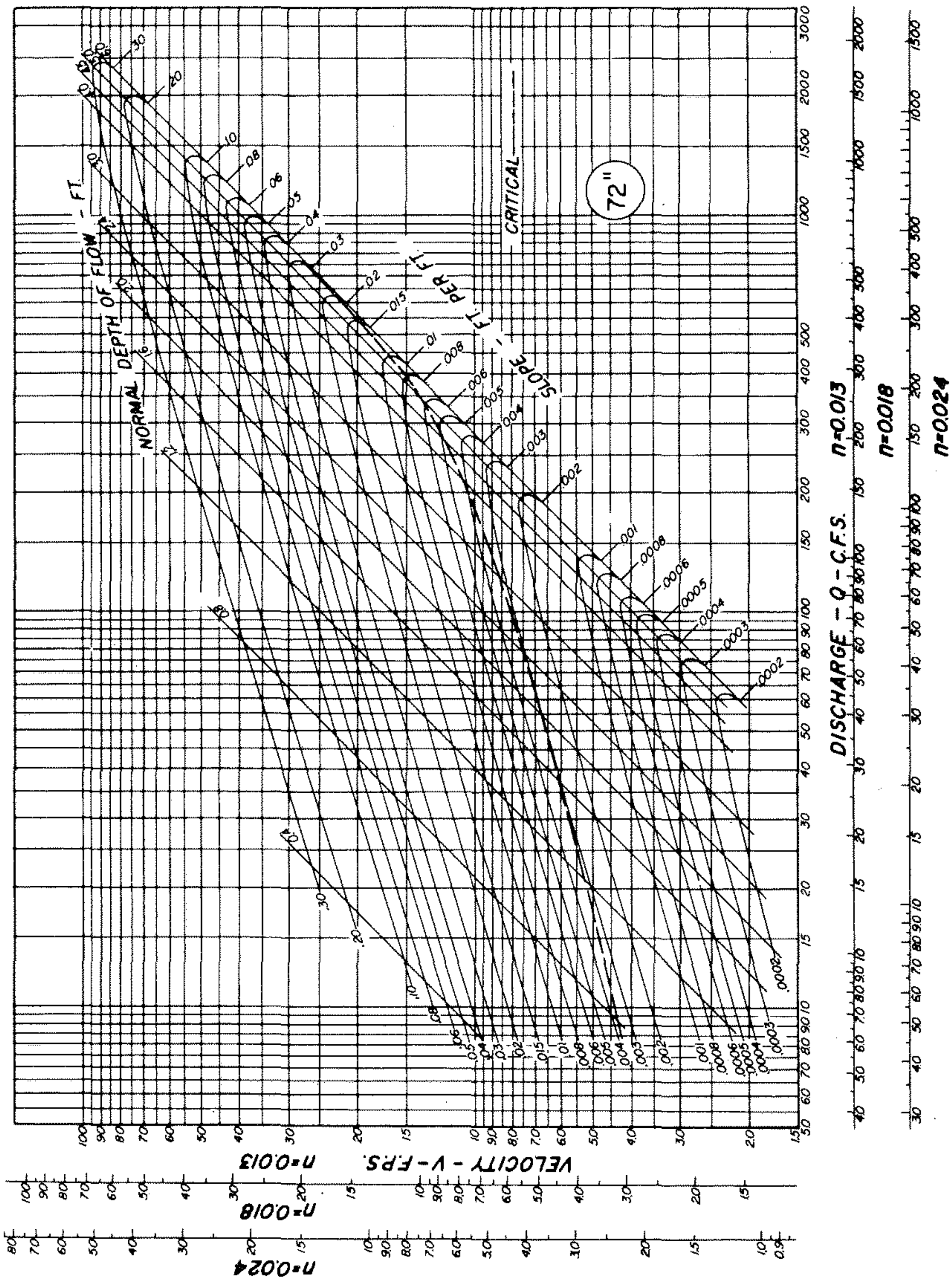


FIGURE 42



PIPE FLOW CHART
66 INCH DIAMETER

FIGURE 43



PIPE FLOW CHART
72 INCH DIAMETER

FIGURE 44

PIPE FLOW CHART
78 INCH DIAMETER

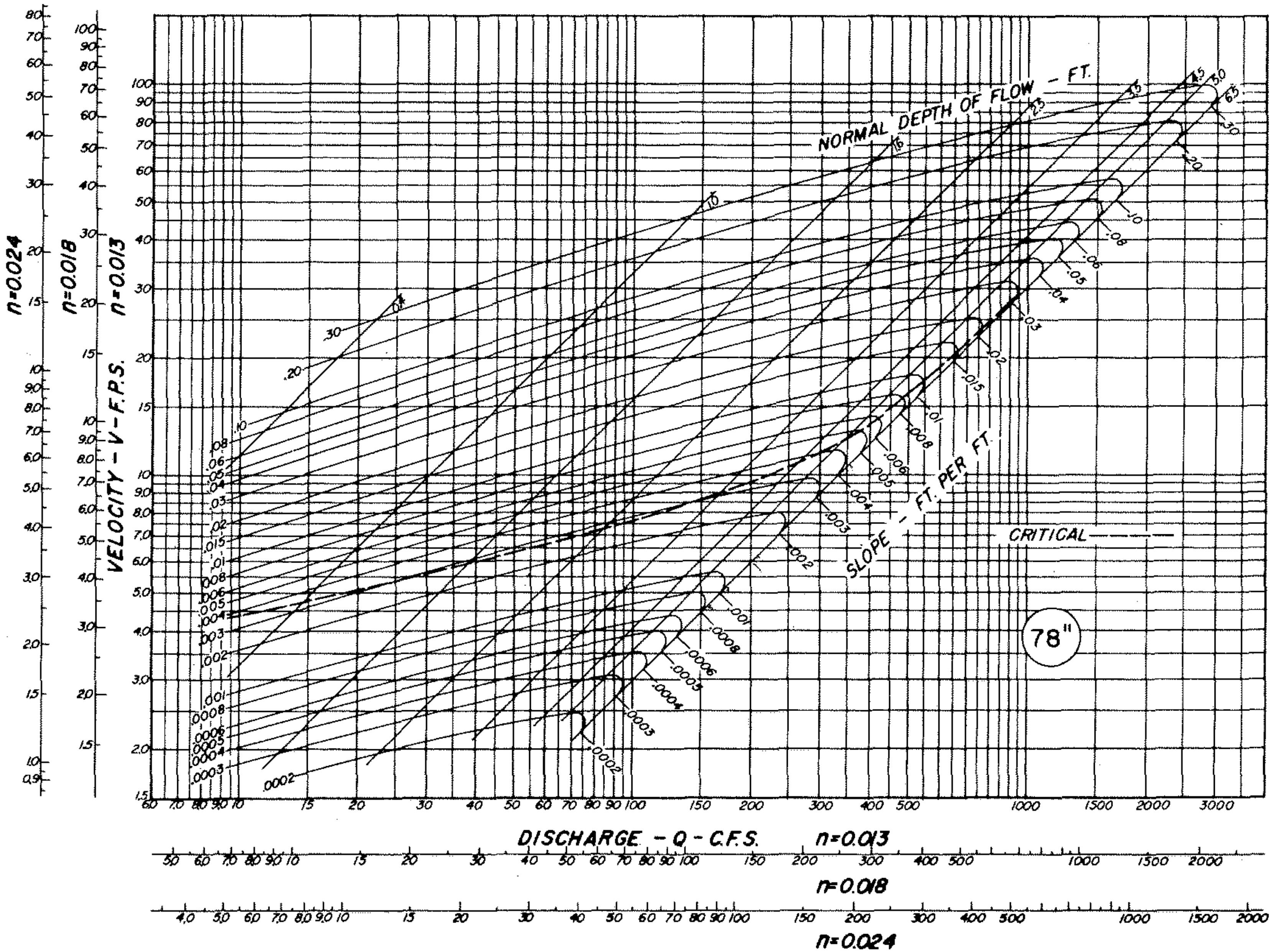


FIGURE 45

PIPE FLOW CHART
84 INCH DIAMETER

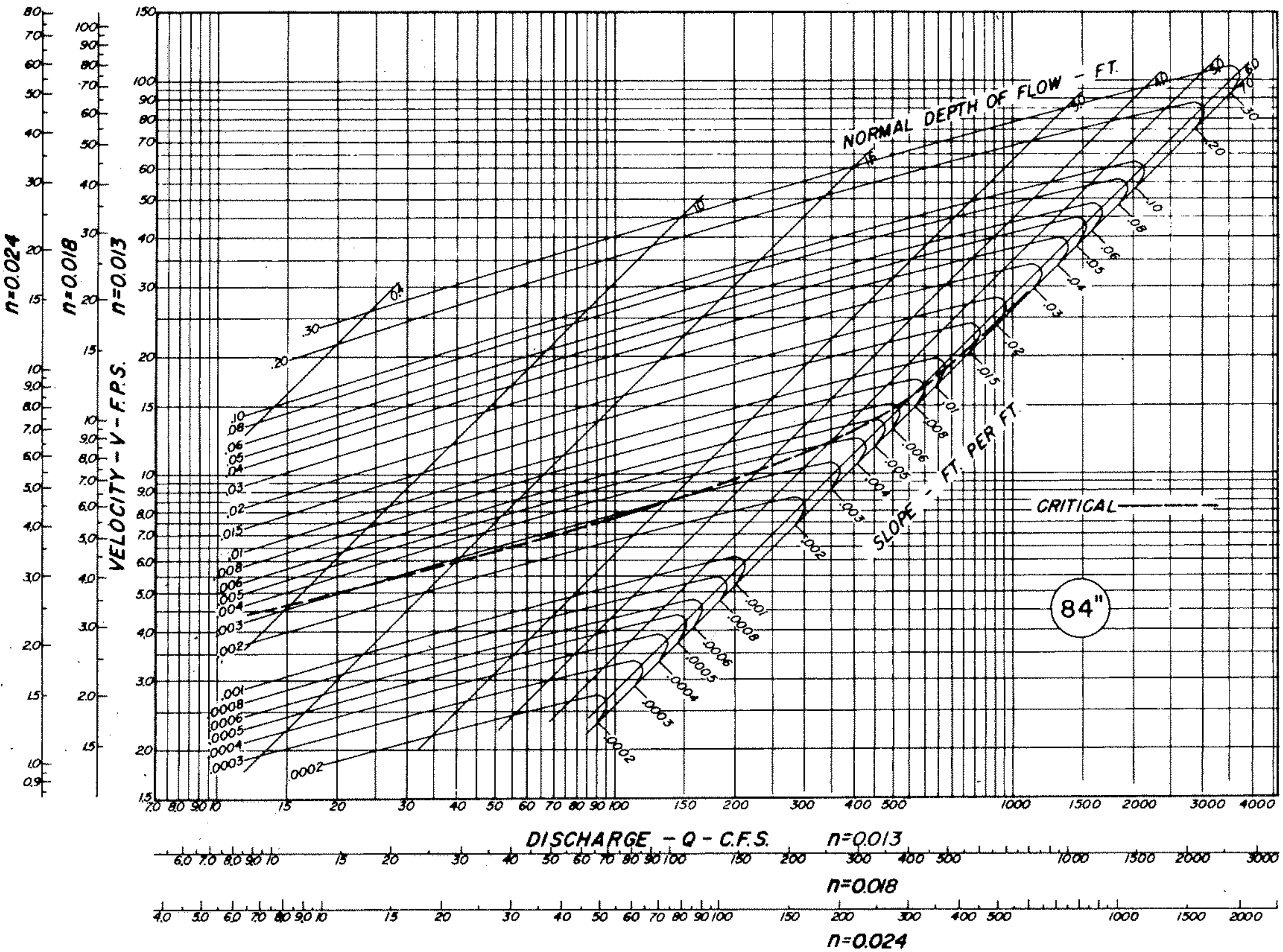


FIGURE 46

PIPE FLOW CHART
96 INCH DIAMETER

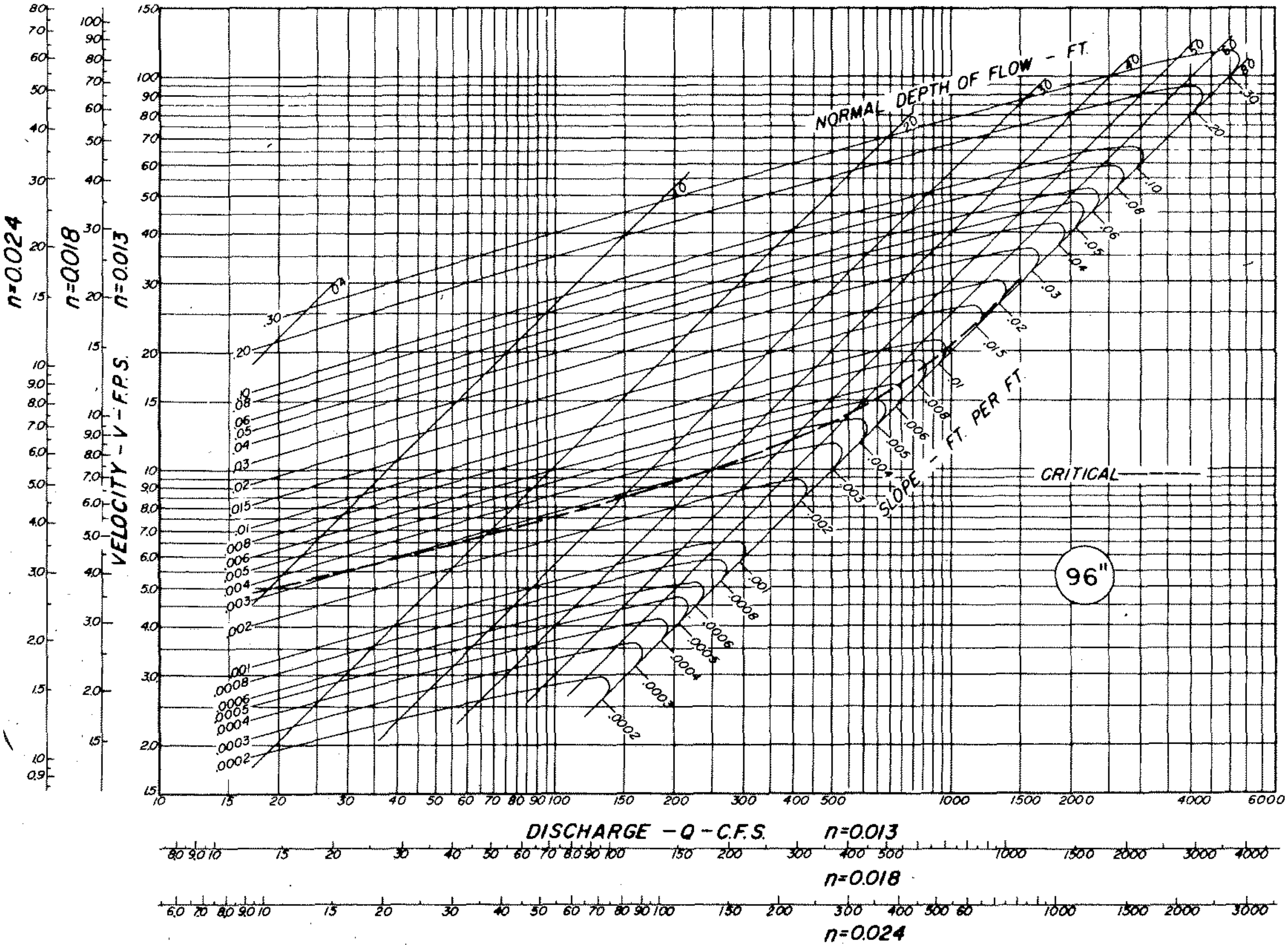


FIGURE 47

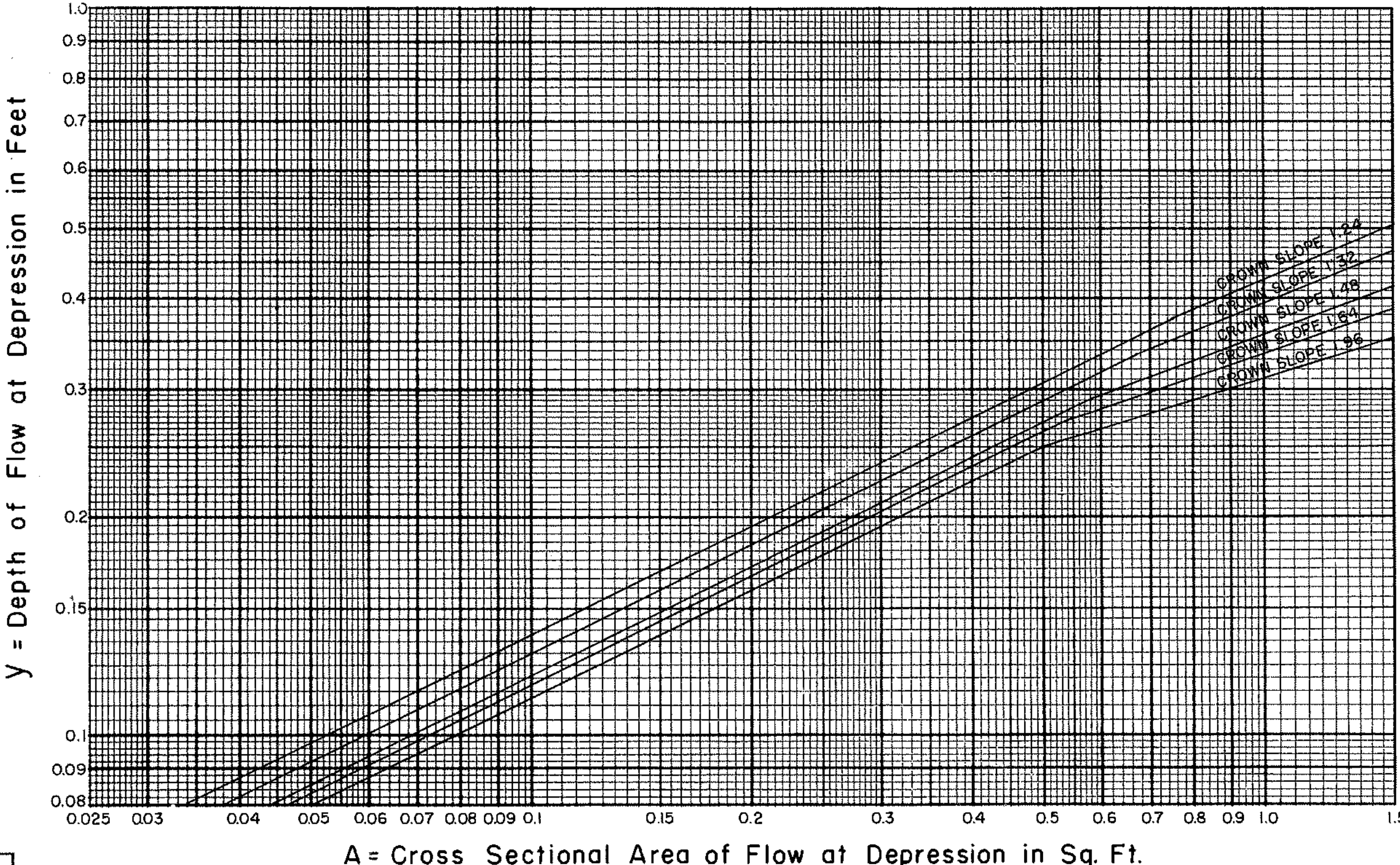


FIGURE 48

Std. Depression

a = 0.208' or 2 ½"

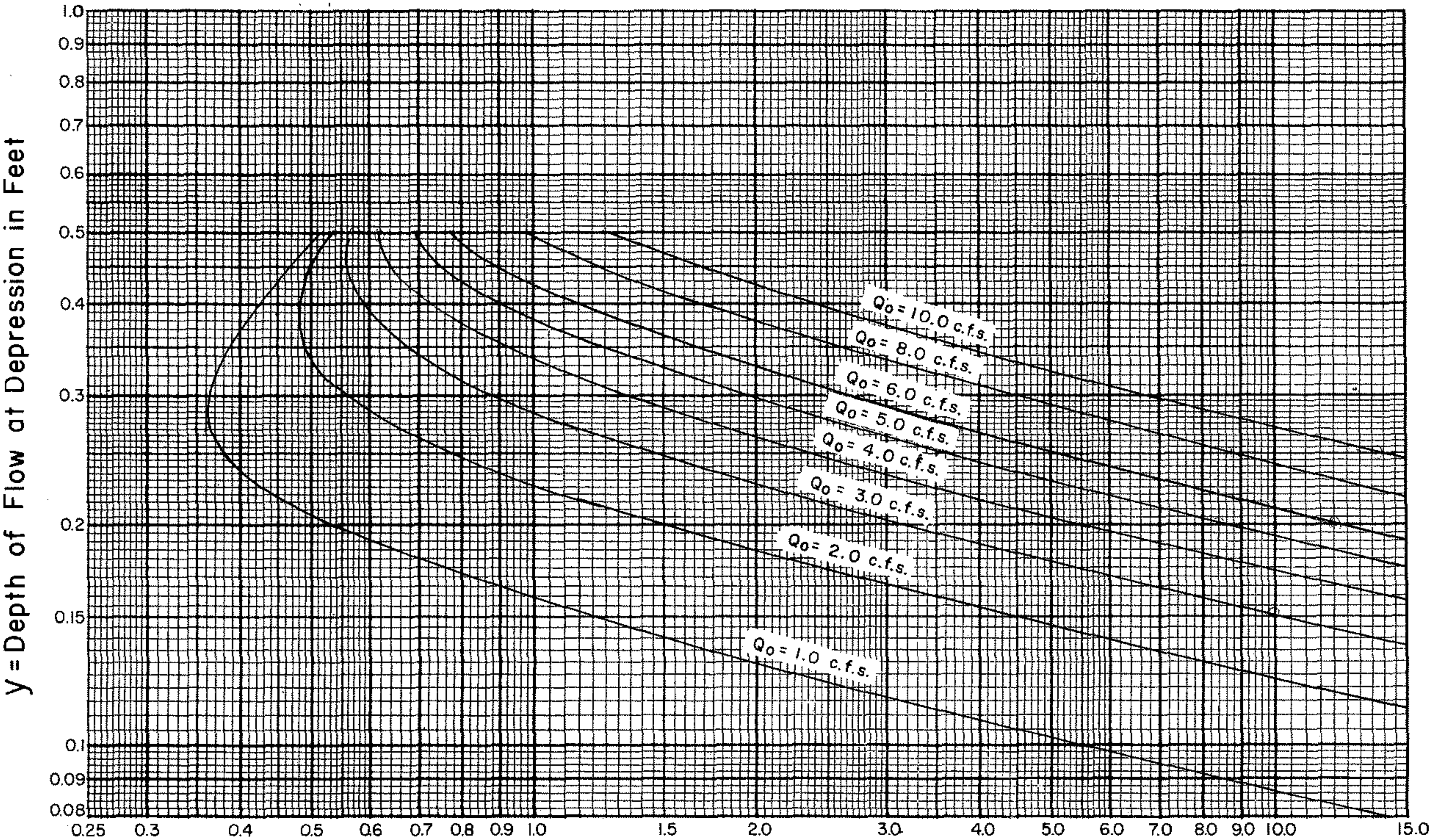
W_o = 4'–0"

n = 0.015

Note: When $y < W_o/\tan\theta$ $\quad A = y^2 \tan\frac{\theta}{2}$

When $y > W_o/\tan\theta$ $\quad A = \frac{1}{2} aW + \frac{1}{2}(y-a)^2 \tan\theta_o$

Where $\tan\theta = \dfrac{W_o}{\dfrac{W_o}{\tan\theta_o} + a}$



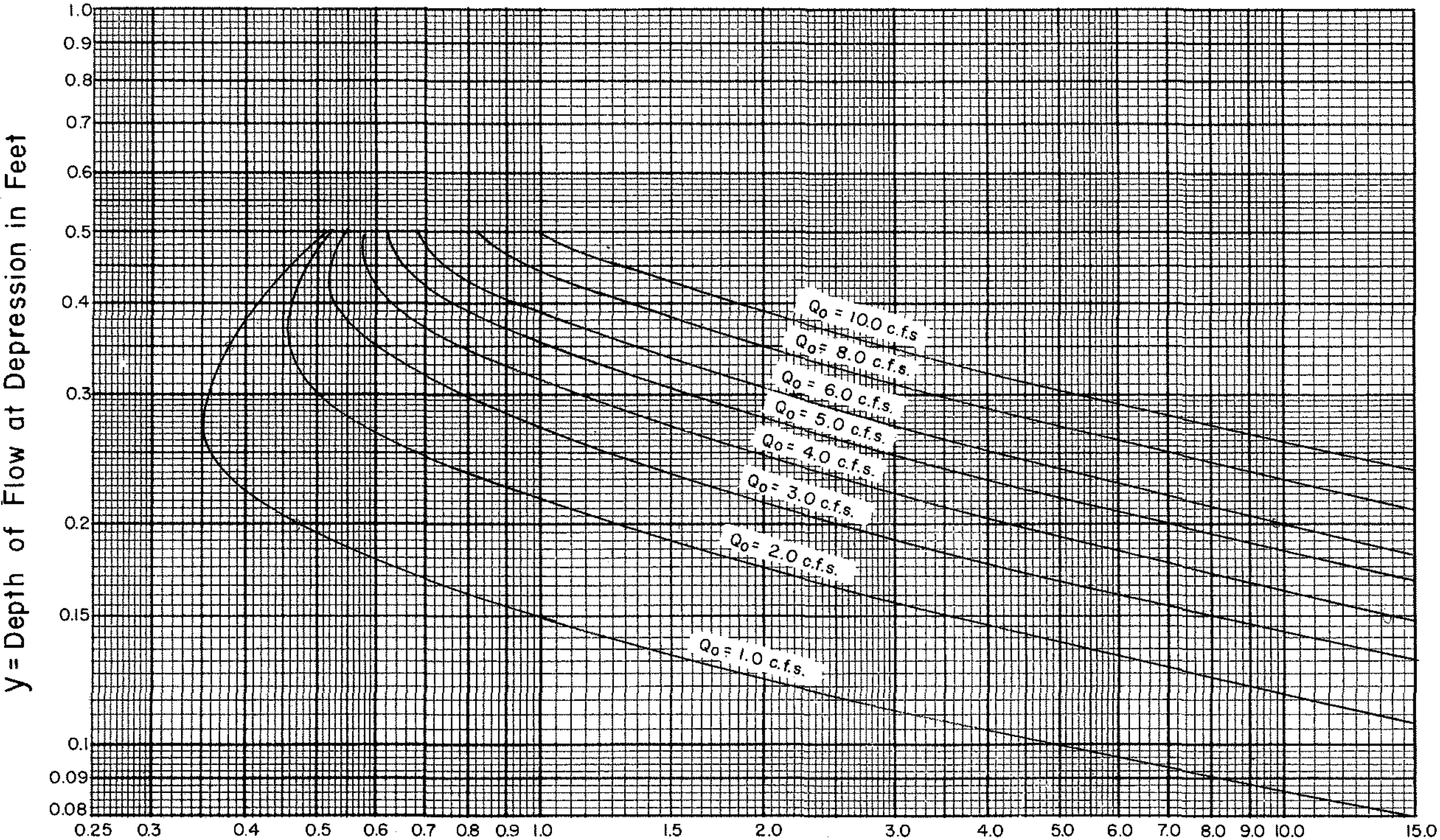
Specific Energy of Flow in Feet

$$E = y_o + \frac{V_o^2}{2g} + a$$

Std. Depression

$a = 0.208'$ or $2\frac{1}{2}''$
$W_o = 4'-0''$
Crown Slope = 1:24 or $\frac{1}{2}''$/ft.
$n = 0.015$
$\tan\theta_o = 24$ $\tan\theta = 10.7$

FIGURE 49



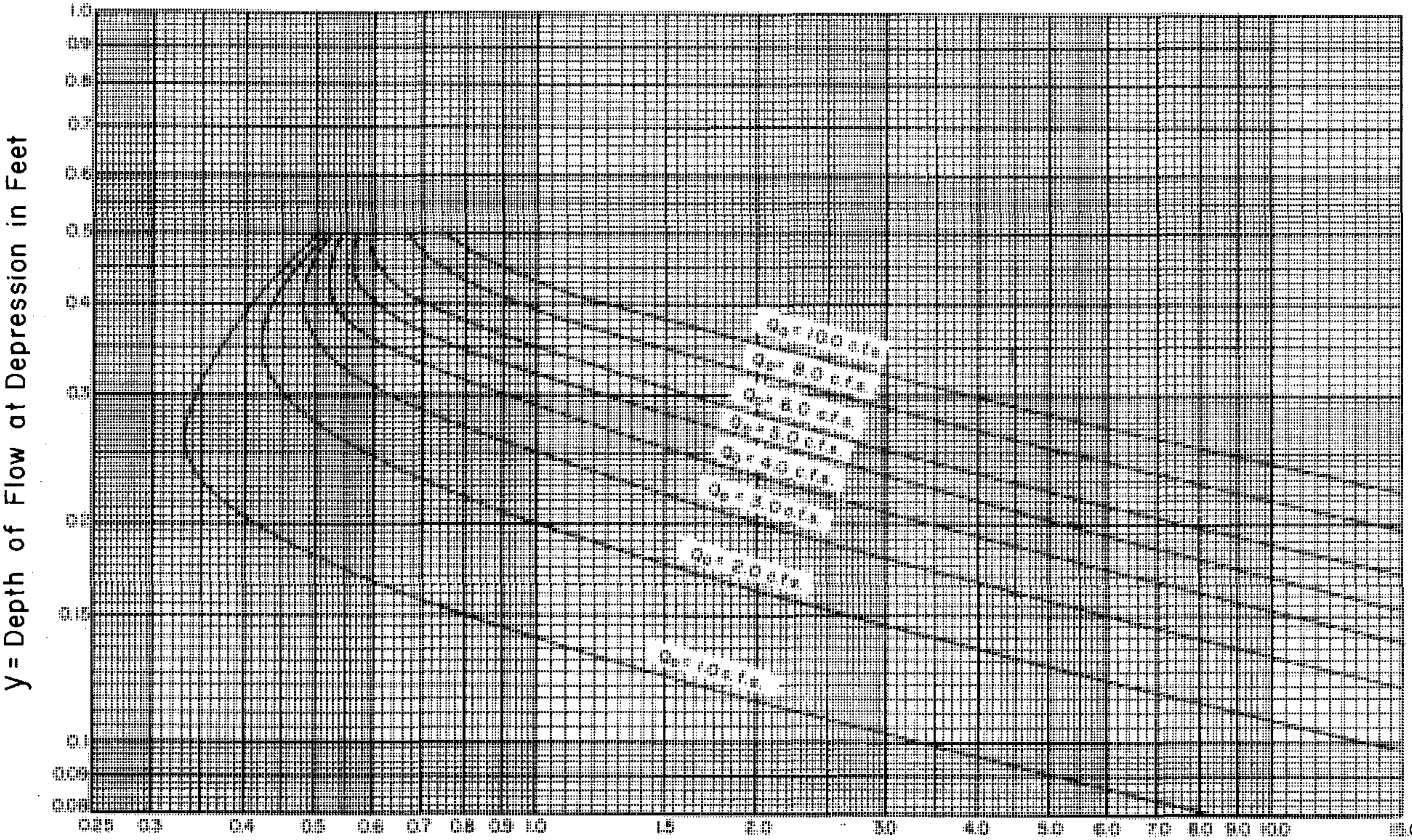
Specific Energy of Flow in Feet

$$E = y_0 + \frac{V_0^2}{2g} + a$$

Std. Depression

a = 0.208' or 2½"
W_0 = 4'–0"
Crown Slope = 1:32 or ⅜"/ft.
n = 0.015
$\tan \Theta_o = 32$ $\tan \Theta = 12$

FIGURE 50



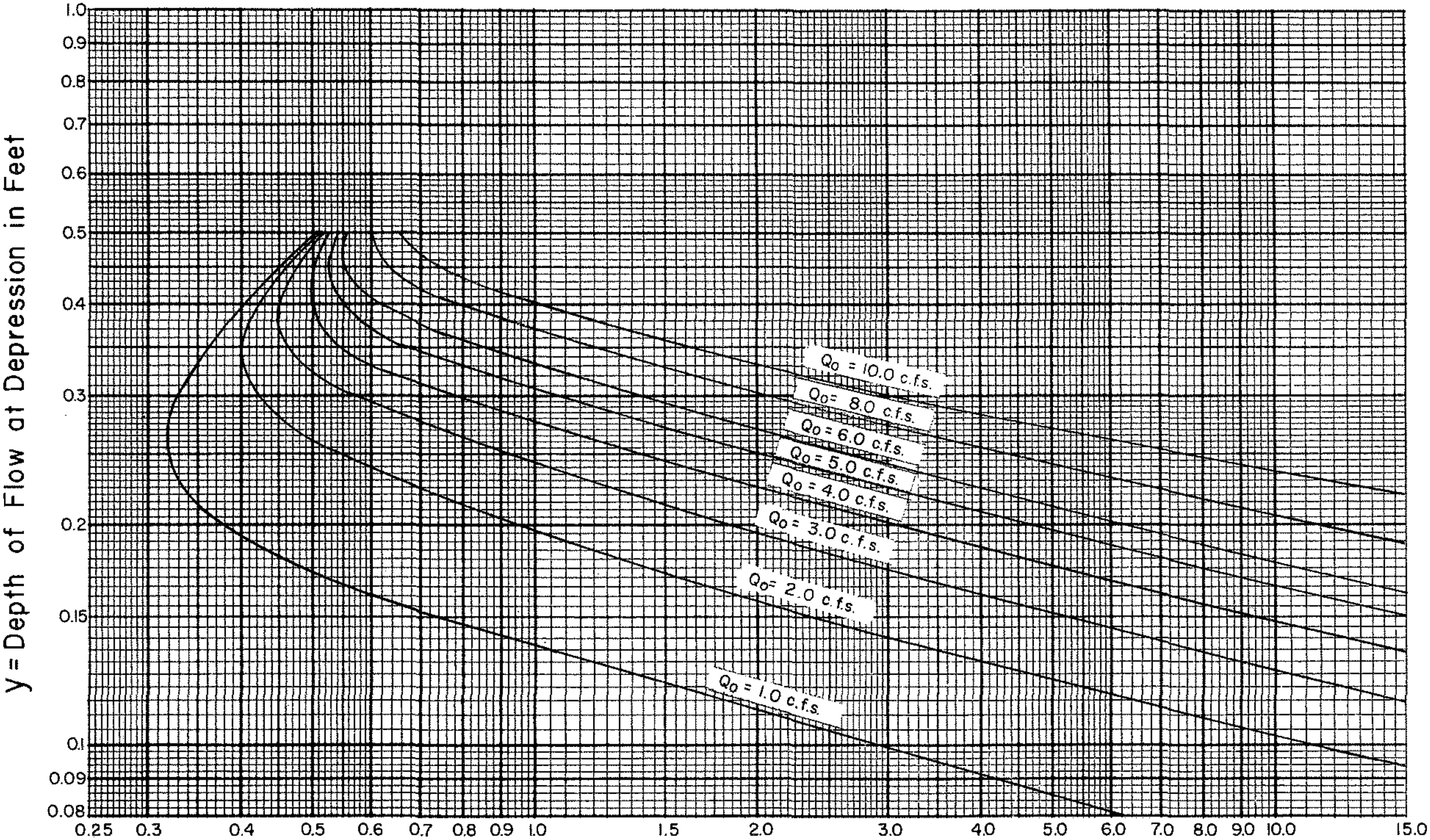
Specific Energy of Flow in Feet

$$E = y_0 + \frac{V_0^2}{2g} + a$$

Std. Depression

a = 0.208' or 2½"
W_0 = 4'-0"
Crown Slope = 1:48 or ¼"/ft.
n = 0.015
Tan θ_0 = 48 Tan θ = 13.8

FIGURE 51



Specific Energy of Flow in Feet

$$E = y_0 + \frac{V_0^2}{2g} + a$$

Std. Depression

$a = 0.208'$ or $2\frac{1}{2}''$

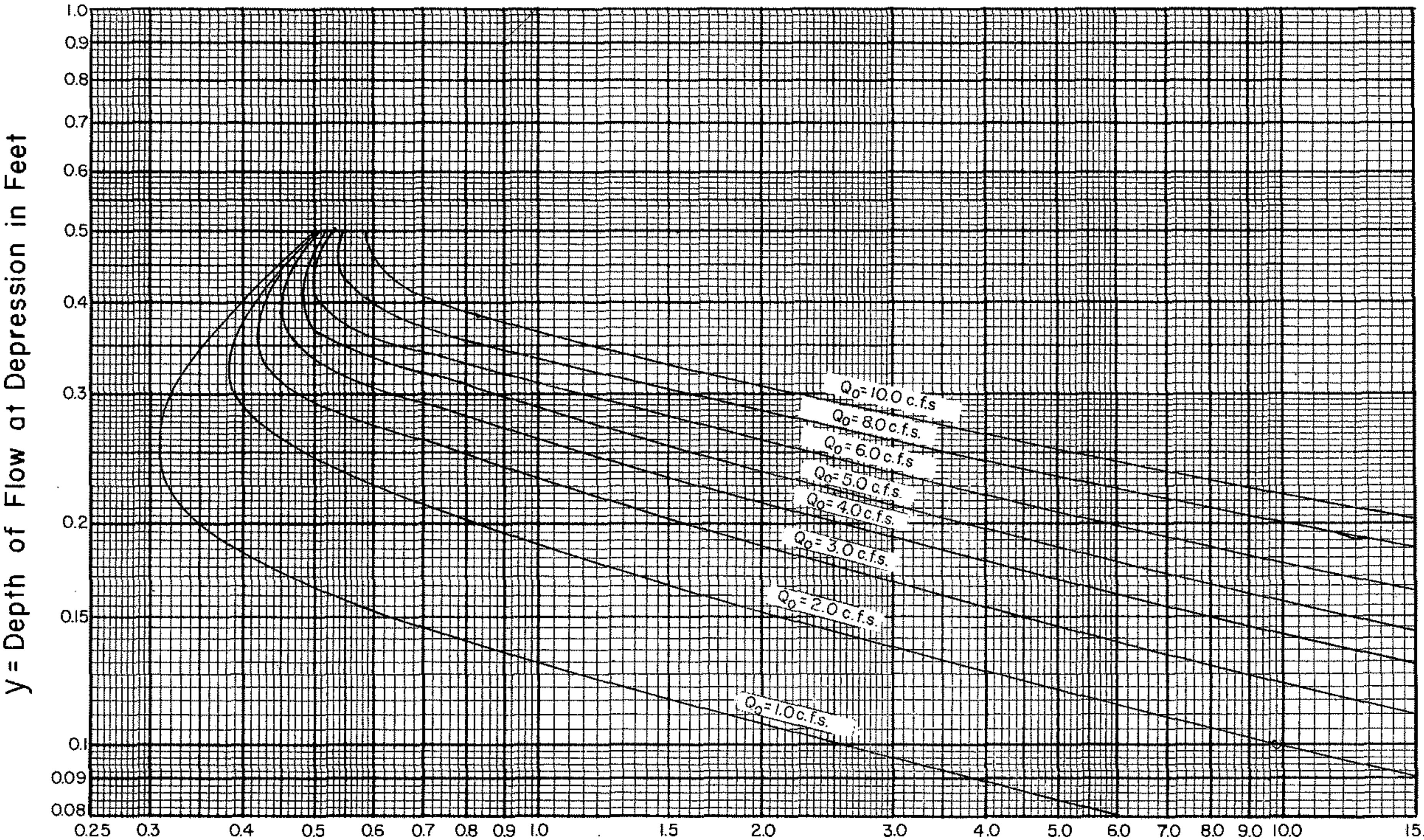
$W_0 = 4'-0''$

Crown Slope = 1:64 or $\frac{3}{16}''$/ft.

n = 0.015

$\tan\theta_0 = 64$ $\tan\theta = 14.7$

FIGURE 52



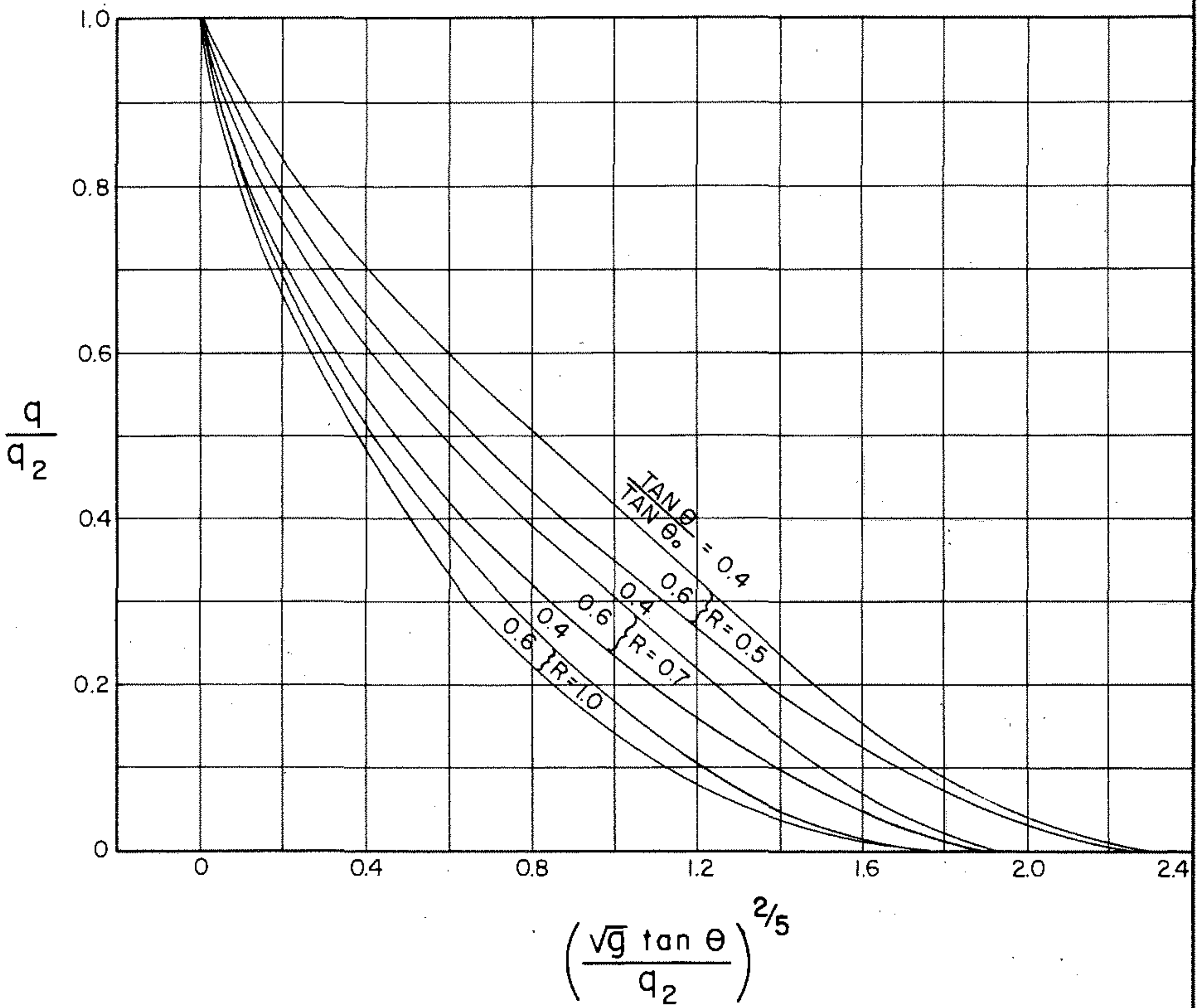
Specific Energy of Flow in Feet

$$E = y_0 + \frac{V_a^2}{2g} + a$$

Std. Depression

$a = 0.208'$ or $2\frac{1}{2}''$
$W_0 = 4'-0''$
Crown Slope = 1:96 or 1/8"/ft.
$n = 0.015$
$\tan \theta_0 = 96$ $\tan \theta = 16$

FIGURE 53



SOLUTION FOR CARRY-OVER FLOW q FOR INLETS ON GRADE (DEPRESSED)

From Figure 22, Page 107, "The Design of Storm Water Inlets", John Hopkins University, 1956

FIGURE 54