
Intake Design and Spacing

A. Introduction

Storm sewer intakes are the main access points by which urban runoff enters the storm sewer system. In fact, the storm sewer intake is an important element of the design in its own right. The hydraulics of flow into an intake are based on principles of weir and orifice flow, modified by laboratory and field observation of entrance losses under controlled conditions.

Curb and gutter intakes are installed along street sections having curbs and gutters to intercept stormwater runoff and to allow its passage into a storm sewer. Intakes can be located at low points (sumps), directly upstream from street intersections, and at intermediate locations. The spacing of these intermediate curb intakes depends on several criteria but is usually controlled by rate of flow and the permissible water spread toward the street crown. The classification of road is also important since the greater the speed and volume of traffic, the greater the potential for hydroplaning. On the other hand, it is also considered acceptable practice to allow some periodic and temporary flooding of low speed, low volume streets (see [Section 2A-3](#) for criteria).

B. Definitions

Bypass Flow: Bypass flow is defined as the flow in the gutter that is not intercepted by a given intake. Bypass flow is calculated by subtracting the allowable capacity of the given intake from the design flow assigned to that intake. Bypass flow is added to the design storm runoff for the next downstream intake. As a minimum, intakes at a low point will have design capacity equal to the assigned storm discharge plus upstream bypass flows.

Design Flow: Design flow is defined as the quantity of water at a given point calculated from the design storm runoff. For gutter applications, design flow should include bypass flow from upstream intakes.

Frontal Flow: The portion of the flow that passes over the upstream side of a grate.

Low Flow: Low flow is defined as the peak runoff rate from the one-year storm event.

Side-flow Interception: Flow that is intercepted along the side of a grate intake, as opposed to frontal interception.

Splash-over: Portion of the frontal flow at a grate that skips or splashes over the grate and is not intercepted.

C. Intake Types

A storm sewer intake is an opening into a storm sewer system for the entrance of surface storm runoff. There are four basic types of intakes:

1. **Grate Intakes:** Grate intakes, as a class, perform satisfactorily over a wide range of gutter grades. Grate intakes generally lose capacity with increase in grade, but to a lesser degree than curb opening intakes. The principal advantage of grate intakes is that they are installed along the roadway where the water is flowing. Their principal disadvantage is that they may be clogged by floating trash or debris. Additionally, where bicycle traffic occurs, grates should be bicycle safe.
2. **Curb Opening:** Curb-opening (open-throat) intakes are most effective on flatter slopes, in sags, and with flows which typically carry significant amounts of floating debris. The interception capacity of curb-opening intakes decreases as the longitudinal gutter grade steepens. Consequently, the use of curb-opening intakes is recommended in sags and on grades less than 3%. Of course, they are bicycle safe as well.
3. **Combination Intakes:** Combination intakes provide the advantages of both curb opening and grate intakes. This combination results in a high capacity intake that offers the advantages of both grate and curb opening intakes.
4. **Slotted Drain Intakes:** Slotted drain intakes can be used in areas where it is desirable to intercept sheet flow before it crosses onto a section of roadway. Their principal advantage is their ability to intercept flow over a wide section. However, slotted intakes are very susceptible to clogging from sediments and debris, and are not recommended for use in environments where significant sediment or debris loads may be present. Slotted intakes on a longitudinal grade do have the same hydraulic capacity as curb openings when debris is not a factor. Slotted drain intakes are not commonly utilized within the public right-of-way; therefore, the detailed design for these intakes is not included herein. For additional information on slotted drain intakes, refer to HEC-22.

D. Intake Capacity

The capacity of an intake is decreased by such factors as debris plugging, pavement overlaying, etc. Therefore, the allowable capacity of an intake is determined by applying the applicable reduction factor from the following table to the theoretical capacity calculated from the design procedures outlined in this section. These reduction factors are based on vane grates, which are required on all curb grate intakes within the street. Other intake grates may be approved by the Jurisdictional Engineer outside of the street right-of-way. The Iowa DOT normally requires curb opening intakes on primary roads.

Table 2C-3.01: Reduction Factors to Apply to Intakes

Figure No. ¹	Location	Reduction Factor ²	Intake Description
6010.501 , 6010.502 , 6010.503 , and 6010.504	Continuous Grade	90% Vane Grates with Curb	Single Grate with Curb Opening
	Low Point	80% Vane Grates with Curb	
6010.505 and 6010.506	Continuous Grade	90% Vane Grates with Curb	Double Grate with Curb Opening
	Low Point	80% Vane Grates with Curb	
6010.507 and 6010.508	Continuous Grade	80% Curb Only (No Grate)	Single Open-throat
	Low Point	70% Curb Only (No Grate)	
6010.509 and 6010.510	Continuous Grade	80% Curb Only (No Grate)	Double Open-throat
	Low Point	70% Curb Only (No Grate)	
6010.501 and 6010.502 (Driveway Grate)	Continuous Grade	75% Grate Only (No Curb Opening)	Single Grate Only
	Low Point ³	50% Grate Only (No Curb Opening)	

¹ The figure numbers listed in this table refer to figures from the SUDAS Specifications.

² Minimum reduction factor is to be used to reduce intake capacity.

³ Use of driveway grates at low points is discouraged due to their tendency to become plugged with debris and flood the surrounding area. Obtain permission of the Jurisdictional Engineer prior to placing a driveway grate in a low point. If allowed, the Jurisdictional Engineer may also require installation of standard curb intake(s) immediately upstream of the driveway.

E. Design of Intakes On-grade

- 1. Intake Efficiency:** Intake interception capacity (Q_i) is the flow intercepted by an intake under a given set of conditions. The efficiency (E) of an intake is the percent of the total flow that the intake will intercept for those conditions. The efficiency of an intake is dependent on the cross slope, longitudinal slope, total gutter flow, and pavement roughness. Efficiency is defined by the following equation:

$$E = \frac{Q_i}{Q_t} \quad \text{Equation 2C-3.01}$$

where:

E = intake efficiency

Q_t = total gutter flow, cfs

Q_i = intercepted gutter flow, cfs

Flow that is not intercepted by an intake is termed carryover or bypass flow and is defined by:

$$Q_b = Q_t - Q_i \quad \text{Equation 2C-3.02}$$

where:

Q_b = flow that is not intercepted by the intake and must be included in the evaluation of downstream gutters, channels, and intakes.

The interception capacity of all intake configurations increases with increasing flow rates while intake efficiency generally decreases with increasing flow rates. Factors affecting gutter flow also affect intake interception capacity. The depth of water next to the curb is the major factor in the interception capacity of both grate intakes and open-throat intakes.

The interception capacity of a grate intake depends on the amount of water flowing over the grate, the size and configuration of the grate and the velocity of flow in the gutter.

Interception capacity of an open-throat intake is largely dependent on flow depth at the curb and curb opening length. Flow depth at the curb and consequently, open-throat intake interception capacity and efficiency, can be increased by the use of local gutter depression at the curb-opening.

The interception capacity of a combination intake, consisting of a grate placed alongside an open-throat section, does not differ significantly from that of a grate alone. Interception capacity and efficiency are computed by neglecting the curb opening.

Intakes on-grade should be designed to intercept a minimum of 50% of the design flow.

2. **Grate Intakes (On-grade):** In order to determine the capacity of an intake on-grade, the amount of frontal flow (flowing perpendicularly over the grate), and side flow (flowing longitudinally along the side of the grate) must be determined.

The ratio of frontal flow to total gutter flow (E_0) for straight cross slope is expressed by the following equation:

$$E_0 = 1 - \left(1 - \frac{W}{T}\right)^{2.67} \quad \text{Equation 2C-3.03}$$

where:

E_0 = ratio of frontal flow to total gutter flow

W = width of depressed gutter or grate, ft

T = total spread of water, ft

At low velocities, all of the frontal flow passes over the grate and is intercepted by the intake. As the longitudinal slope of the gutter is increased, the velocity of the flow also increases until the flow begins to skip or splash over the grate, reducing the efficiency of the grate. The velocity at which this occurs is termed the splash-over velocity, and is dependent upon the design of the grate and the length of the grate.

The splash-over velocity for the SUDAS style intake grates is indicated in Table 2C-3.01.

Table 2C-3.02: Splash-over Velocity for SUDAS Intake Grates

Figure No. ¹	Casting Type	Typical Use	Splash-over Velocity, fps		
			<i>Single</i>	<i>Double</i>	<i>Triple</i>
6010.603	Type Q	Driveway	1.5	2.4	2.9
6010.603	Type R	Combination / Median	7.4	11.4	16.2
6010.603	Type S	Combination / Median	8.3	13.0	20.7

¹ The figure numbers listed in this table refer to figures from the SUDAS Specifications.

Source: Type Q - Colorado State University, 2009 (CDOT Type 13)

Type R/S - HEC-22 (Curved vane) (CDOT Type 16)

The ratio of frontal flow intercepted to total frontal flow (R_f) or frontal flow interception efficiency is expressed by:

$$R_f = 1 - 0.09(V - V_0) \quad (\text{see note below}) \quad \text{Equation 2C-3.04}$$

where:

V = velocity of flow in the gutter, ft/s

V_0 = gutter velocity where splash over first occurs, ft/s

Note: R_f cannot exceed 1.0. If V is less than V_0 , $R_f=1$ – meaning that all flow is intercepted. If V is greater than V_0 , R_f is less than 1, meaning that only a portion of the flow is intercepted.

In addition to frontal flow, the intake also intercepts a portion of the side flow, flowing adjacent to the intake. Only a small portion of the side flow is intercepted.

The ratio of side flow intercepted to total side flow (R_s) or side flow interception efficiency is expressed by:

$$R_s = \frac{1}{1 + \left(\frac{0.15V^{1.8}}{S_x L^{2.3}} \right)} \quad (\text{see note below}) \quad \text{Equation 2C-3.05}$$

where:

V = velocity of flow in the gutter, ft/s

L = length of the grate, ft

S_x = cross slope, ft/ft

Note: R_s cannot exceed 1.0. If V is less than V_0 , $R_s = 1$ meaning that all flow is intercepted. If V is greater than V_0 , R_s is less than 1, meaning that only a portion of the flow is intercepted.

The efficiency (E) of a grate is expressed as:

$$E = R_f E_0 + R_s (1 - E_0) \quad \text{Equation 2C-3.06}$$

The interception capacity (Q_i) of a grate intake on-grade is equal to the efficiency of the grate multiplied by the total gutter flow:

$$Q_i = E Q_t = Q_t [R_f E_0 + R_s (1 - E_0)] \quad \text{Equation 2C-3.07}$$

3. **Open-throat Intakes (On-grade):** Open-throat intakes are effective in draining pavements where the flow depth at the curb is sufficient for the intake to perform efficiently. Open-throat intakes are less susceptible to clogging and offer little interference to traffic operations. They are a viable alternative to grates where grates would be in traffic lanes or would be hazardous to pedestrians or bicycles.

The length of open-throat intakes required for total interception of gutter flow on a pavement section with a straight cross slope is expressed by:

$$L_T = 0.6Q_t^{0.42}S_L^{0.3}\left(\frac{1}{nS_x}\right)^{0.6} \quad \text{Equation 2C-3.08}$$

where:

L_T = length of throat opening required to intercept 100% of the gutter flow, ft

S_x = cross slope in ft/ft

n = Manning's coefficient for the pavement

Q_t = total gutter flow, cfs

S_L = longitudinal slope, ft/ft

The efficiency of an open-throat intake shorter than the length required for total interception is expressed by:

$$E = 1 - \left(1 - \frac{L}{L_T}\right)^{1.8} \quad \text{Equation 2C-3.09}$$

where:

L = length of throat opening, ft

Most open-throat intakes incorporate a locally depressed gutter section through the length of the throat opening. This depression aids in increasing the interception capacity of the intake. For depressed open-throat intakes the interception capacity can be found by use of an equivalent cross slope (S_e) in the following equation:

$$S_e = S_x + S'_w E_0 \quad \text{Equation 2C-3.10}$$

where:

S'_w = cross slope of the gutter measured from the cross slope of the pavement = a/W , ft/ft

a = gutter depression, ft

for standard SUDAS/Iowa DOT open-throat intakes, $a = 6''$

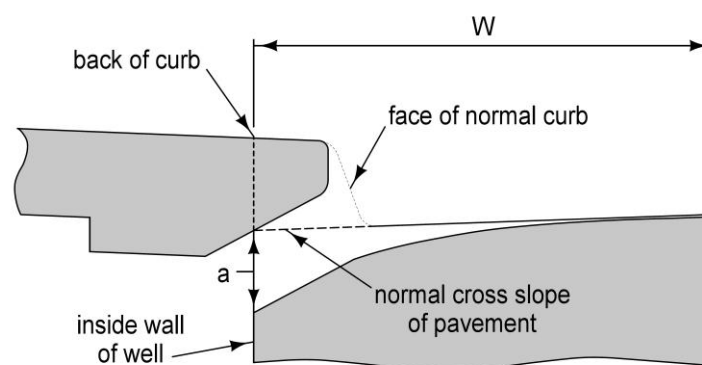
W = width of depressed gutter section, ft

for standard SUDAS/Iowa DOT open-throat intakes, $W = 3'$ typical and $1.5'$ min.

E_0 = Ratio of flow in the depressed section to total gutter flow. It is determined by the gutter configuration upstream of the intake.

S_x = roadway cross slope, ft/ft

Note: S_e can be used to calculate the length of the throat opening by substituting S_e for S_x in Equation 2C-3.08

Figure 2C-3.01: Open-throat Intake Depression - On-grade

4. **Combination Intakes (On-grade):** The interception capacity of a combination intake with the open throat segment immediately behind the grate is determined by neglecting the open-throat portion and treating the intake as a grate.

F. Design of Intakes in Sag Locations

Intakes in sag locations operate as weirs under low-head conditions and orifices at greater depths. When grate head is developed they function as an orifice. Flow may fluctuate between weir and orifice control depending on the grate size, grate configuration, or the curb-opening height. At depths between those at which weir flow definitely prevails and those at which orifice flow definitely prevails, flow is in a transition stage. At these depths, control is ill-defined and flow may fluctuate between weir and orifice control. Design procedures presented here are based on a conservative approach to estimating the capacity of intakes in sump locations.

The efficiency of intakes in passing debris is critical in sag locations because all runoff that enters the sag must be passed through the intake. Total or partial clogging of intakes in these locations can result in hazardous ponded conditions. Grate intakes alone are not recommended for use in sag locations because of the tendencies of grates to become clogged. Combination intakes or open-throat intakes are recommended for use in these locations.

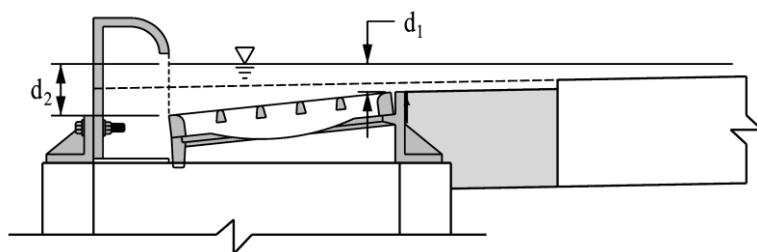
1. **Grate Intakes in Sags:** A grate inlet in a sag location operates as a weir to depth dependent on the size of the grate and as an orifice at greater depths. Grates of larger dimension will operate as weirs to greater depths than smaller grates.

The capacity of a grate intake operating as a weir is:

$$Q_i = 3.0Pd^{1.5} \quad \text{Equation 2C-3.11}$$

where:

- Q_i = Grate intake capacity, cfs
- P = Perimeter of the grate disregarding the side against the curb, ft
- d = average depth across the grate, ft (see Figure 2C-3.02 below)

Figure 2C-3.02: Average Depth for Grate Intakes

Average depth (d) is determined as follows:

$$d = \frac{d_1 + d_2}{2}$$

The capacity of a grate intake operating as an orifice is:

$$Q_i = 0.67A_g(2gd)^{0.5} \quad \text{Equation 2C-3.12}$$

where:

A_g = Clear opening of the grate, ft^2

g = gravitational constant = 32.16 ft/s^2

In order to determine if an intake is operating under weir flow or orifice flow, both equations should be solved for a given depth. The equation resulting in the lowest calculated flow determines the control type.

Figure No. ¹	Grate Type	Description	Perimeter ^{2,4} P (ft)	Open Area ⁴ A_g (sq-ft)	Weir to Orifice ³ Transition (ft)
6010.603	Type Q	Driveway	9.91	2.62	0.4
6010.603	Type R	Curb Inlet with Vane	5.86	1.95	0.5
6010.603	Type S	Median Barrier	7.52	2.3	0.4
6010.604	Type 3A	Beehive for 18" RCP	5.2	1.2	0.4
6010.604	Type 3B	Beehive for 24" RCP	6.77	1.64	0.5
6010.604	Type 4A	Flat Round for 18" RCP	5.2	0.8	0.3
6010.604	Type 4B	Flat Round for 24" RCP	6.82	1.29	0.3
6010.604	Type 4C	Flat Round for 30" RCP	8.41	2.2	0.5
6010.604	Type 4D	Flat Round for 36" RCP	9.99	2.93	0.5
6010.604	Type 5	Stool Type for 24" to 30" RCP	6	3.06	0.9
6010.604	Type 6	30" x 42" Rectangular	10.54	2.91	0.5

¹ The figure numbers listed in this table refer to figures from the SUDAS Specifications.

² Perimeter length disregards side against curb for curb inlets.

³ This is the approximate depth at which the intake transitions from weir flow to orifice flow and should be verified by the designer.

⁴ Average of Neenah Foundry and East Jordan Iron Works values.

- Open-throat Intakes in Sags:** The capacity of an open-throat intake in a sag depends on the water depth at the curb, the length of the throat opening, and the height of the throat opening. The intake operates as a weir to depths equal to the curb opening height and as an orifice at depths greater than 1.4 times the opening height. At depths between 1.0 and 1.4 times the opening height, flow is in a transition stage.

The equation for the interception capacity of a depressed open-throat intake operating as a weir is:

$$Q_i = 2.30(L + 1.8W)d^{1.5} \quad \text{Equation 2C-3.13}$$

where:

L = Length of curb opening, ft

W = Lateral width of depression, ft

d = depth at curb measured from the normal cross slope (i.e. $d = T \times S_x$)

The weir equation is applicable to depths at the curb approximately equal to the height of the opening plus the depth of the depression. Thus, the limitation on the use of Equation 2C-3.13 for a depressed open-throat intake is:

$$d \leq h + a/12 \quad \text{Equation 2C-3.14}$$

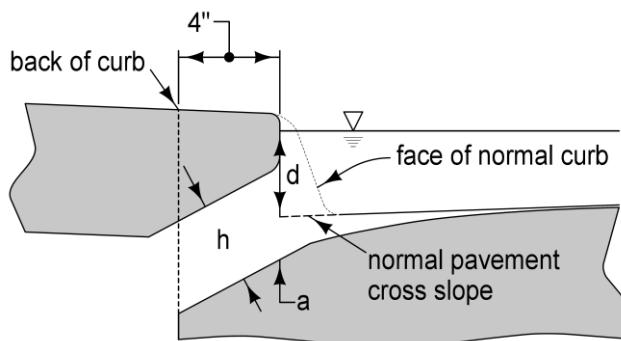
where:

h = height of curb opening, ft

a = depth of depression, in

for standard SUDAS/Iowa DOT open-throat intakes, $a = 4''$

Figure 2C-3.03: Open-throat Intake Depression - in Sag



The weir equation for open-throat intakes without depression is:

$$Q_i = 3.0Ld^{1.5} \quad \text{Equation 2C-3.15}$$

Open-throat intakes operate as orifices at depths greater than approximately 1.4 times the opening height. The interception capacity can be computed by Equations 2C-3.16 or 2C-3.17. These equations are applicable to both depressed and undepressed open-throat intakes. The depth at the intake includes any gutter depression.

$$Q_i = 0.67hL(2gd_0)^{0.5} \quad \text{Equation 2C-3.16}$$

or

$$Q_i = 0.67A_g \left[2g \left(d_i - \left(\frac{h}{2} \right) \right) \right]^{0.5} \quad \text{Equation 2C-3.17}$$

where:

d_0 = Effective head on the center of the orifice throat, ft - (see note below)

d_i = Depth at the lip of the curb opening, ft (see Figure 2C-3.04)

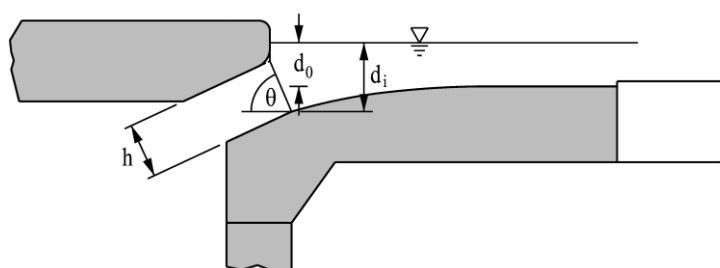
L = Length of the open-throat section, ft

A_g = Clear area of opening, ft²

h = Height of open-throat orifice, ft

Note: the configuration of the SUDAS/Iowa DOT style intakes is an “inclined throat” according to HEC-22. Based upon this configuration HEC-22 provides the following definition: $d_0 = d_i - (h/2) \sin \theta$

Figure 2C-3.04: Standard SUDAS/Iowa DOT Open-throat Curb Section



The following apply for SUDAS/Iowa DOT open-throat intakes:

$$h = 5''$$

$$\theta = 66.7^\circ$$

$$(h/2)\sin \theta = 2.3'' = 0.19'$$

$$A_g = 1.67 \text{ ft}^2 \text{ - single intake}$$

$$A_g = 3.33 \text{ ft}^2 \text{ - double intake}$$

Unless otherwise approved by the Jurisdictional Engineer, intakes at low points or on dead-end streets on downgrades should be designed to intercept 100 percent of the design flow

3. **Combination Intakes in Sags:** Combination intakes consisting of a grate and open-throat curb section are recommended for use in sags and locations where hazardous ponding can occur because of their superior hydraulic capacity and debris handling capabilities.

The interception capacity of a combination intake, where the open-throat section is equal in length to, and immediately behind, the grate, is essentially equal to that of a grate intake alone operating under weir flow conditions. In orifice flow, the capacity of a combination intake is equal to the capacity of the grate plus the capacity of the curb opening.

Where the depth at the curb is such that orifice flow occurs, the interception capacity of the intake is computed by adding equations 2C-3.12 and 2C-3.16.

$$Q_i = 0.67A_g(2gd)^{0.5} + 0.67hL(2gd_0)^{0.5} \quad \text{Equation 2C-3.18}$$

where:

A_g = Clear opening of the grate, ft²

g = Gravitational constant = 32.16 ft/s²

d = Depth at the curb, ft

H = Height of the open-throat orifice, ft

L = length of open-throat section, ft

d_0 = effective depth at the center of the open-throat orifice, ft

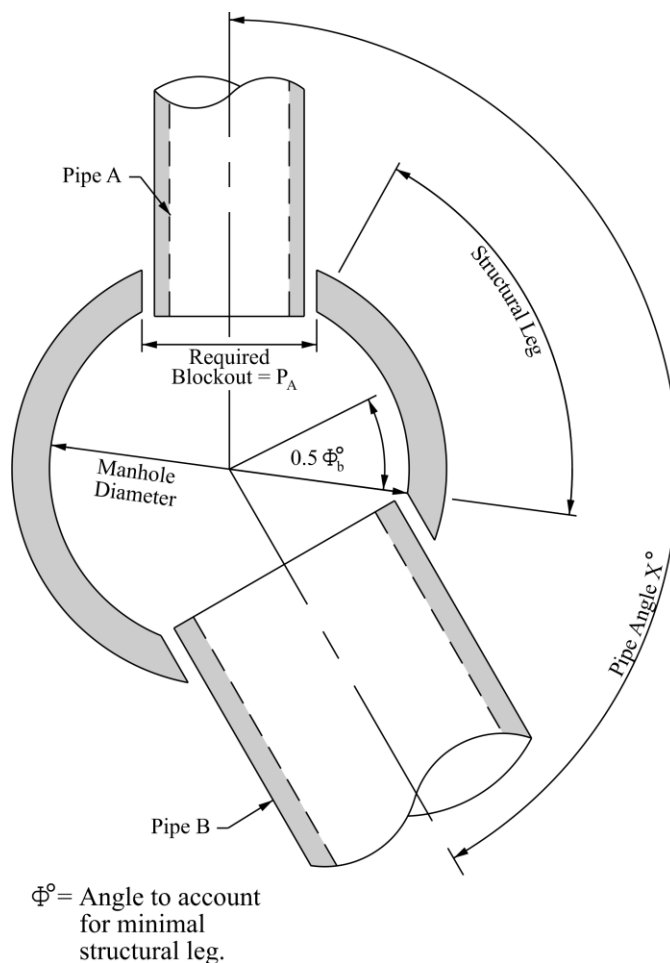
G. Storm Sewer Structure Requirements

1. Manholes or Intakes: Manholes or intakes are required under the following conditions:

- a. At the end of each sewer line.
- b. At all changes in pipe size, elevation and grade, or alignment, and at all bends.
- c. At all sewer pipe intersections, except where the size of the storm sewer conduit (54 inches diameter or greater pipe) eliminates the need for a manhole. Manholes are required for 54 inches or greater pipes when direct access is desired every 400 feet.
- d. At all sewer pipe intersections and at intervals not exceeding 400 feet. If owner has adequate cleaning equipment, the allowable spacing may be increased to 500 feet for sewers 24 inches and larger.

2. Openings:

- a. **Standard:** The minimum size for a manhole is 48 inches in diameter. Jurisdictions require concentric manholes, without built-in steps, with the manhole opening over the centerline of the pipe or on an offset not to exceed 12 inches. Some Jurisdictions may allow for eccentric manholes.
- b. **Special:** For square or rectangular manholes, the manhole openings should be over the centerline of the pipes or on an offset not to exceed 12 inches. The distance from the centerline of the manhole opening to the face of the inside manhole wall should not exceed 30 inches to better facilitate video inspection and maintenance equipment. This may require more than one manhole opening.
- c. **Determining Diameters:** When utilizing circular precast manholes, it is necessary to determine the diameter required to maintain the structural integrity of the manhole. As a general rule, a minimum structural leg of 12 inches should remain between the manhole blockouts for adjacent pipes. Determining the required manhole diameter to provide this minimum distance may be done as follows:
 - 1) Determine the diameters of, and the angle between, the pipes in question.

Figure 2C-3.05: Manhole Sizing Requirements

- 2) Determine the blockout diameters for each opening. The blockout is the opening provided in the manhole for the pipe. Blockout dimensions are based on the outside diameter of the pipe. For storm sewer, a circular or doghouse type opening is provided with additional clearance to allow for the insertion of the pipe and sufficient space to accommodate placement of concrete grout in the opening. Typical blockout dimensions for various pipe sizes and materials are given in Table 2C-3.04 below.

Table 2C-3.03: Manhole Blockout Sizes

Pipe Diameter (inches)	Manhole Blockout (inches)		
	<i>RCP</i>	<i>PVC</i>	<i>DIP</i>
12	21	16	16
14	N/A	16	18
15	24	19	N/A
16	N/A	N/A	20
18	28	22	23
20	N/A	N/A	24
21	31	25	N/A
24	35	28	29
27	38	31	N/A
30	42	35	36
33	47	N/A	N/A
36	48	42	41
42	57	N/A	N/A
48	64	N/A	N/A
54	71	N/A	N/A
60	78	N/A	N/A

- 3) Select a manhole size. If unsure start with the diameter for the largest penetration from Table 2C-3.04.

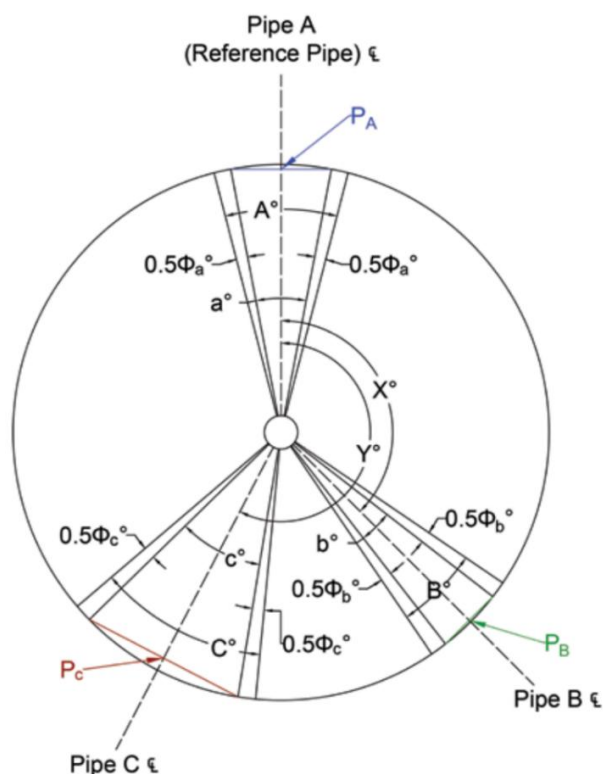
Table 2C-3.04: Minimum Manhole Diameter Required for Pipe Size

Pipe Diameter (inches)	Minimum Manhole Diameter (inches)		
	<i>RCP</i>	<i>PVC</i>	<i>DIP</i>
8	N/A	48	48
10	N/A	48	48
12	48	48	48
14	N/A	N/A	48
15	48	48	N/A
16	N/A	N/A	48
18	48	48	48
20	N/A	N/A	48
21	48	48	N/A
24	48	48	48
27	*60	48	N/A
30	*60	*60	*60
33	*60	N/A	N/A
36	*60	*60	*60
42	*72		
48	*84		
54	*96		
60	*96		

*48 inch diameter Tee-section manhole may be used for pipes 27 inches and greater.

The determination of acceptability of each entering pipe relative to all the other incoming pipe is based on the reference pipe, which is arbitrarily selected by the designer. For ease of design, it is best to use the largest pipe diameter as the reference pipe. The other incoming pipe are determined by their angle, X, Y, and Z (not shown in the figure below), to this reference pipe. The figure below and corresponding equations are used for making these verifiable calculations:

Figure 2C-3.06: Three Pipe Configuration



Variables:

r	=	manhole internal radius (in inches)
S	=	minimum structural leg (in inches) (recommended 12 inches)
P_A, P_B, P_C, P_D	=	penetration in manhole to accommodate specified pipe (inches)

Pipe Penetration Equation:

P_A, P_B, P_C, P_D = pipe OD (in inches) + additional allowance for insertion (if unsure use 6 inches)

Table 2C-3.05: Design Parameters for Two Pipes

Pipe Penetrations in Manhole	Pipe Angle with Respect to Reference Point	Pipe Angle Equations		Final Angle	Allowable Angle Range
		Initial Angle	Additional Angle to Account for Structural Leg		
Pipe A (Reference Pipe)	0°	$a^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_A}{r} \right)$	$\Phi_a^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$A^\circ = a^\circ + \Phi_a^\circ$	$A^\circ < 180^\circ$
Pipe B	X°	$b^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_B}{r} \right)$	$\Phi_b^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$B^\circ = b^\circ + \Phi_b^\circ$	$X^\circ - \frac{B^\circ}{2} > \frac{A^\circ}{2}$

Table 2C-3.06: Design Parameters for Three Pipes

Pipe Penetrations in Manhole	Pipe Angle with Respect to Reference Point	Pipe Angle Equations		Final Angle	Allowable Angle Range
		Initial Angle	Additional Angle to Account for Structural Leg		
Pipe A (Reference Pipe)	0°	$a^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_A}{r} \right)$	$\Phi_a^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$A^\circ = a^\circ + \Phi_a^\circ$	$A^\circ < 180^\circ$
Pipe B	X°	$b^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_B}{r} \right)$	$\Phi_b^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$B^\circ = b^\circ + \Phi_b^\circ$	$X^\circ - \frac{B^\circ}{2} > \frac{A^\circ}{2}$
Pipe C	Y°	$c^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_C}{r} \right)$	$\Phi_c^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$C^\circ = c^\circ + \Phi_c^\circ$	$Y^\circ - \frac{C^\circ}{2} > X^\circ + \frac{B^\circ}{2}$ and $Y^\circ + \frac{C^\circ}{2} < 360^\circ - \frac{A^\circ}{2}$

Table 2C-3.07: Design Parameters for Four Pipes

Pipe Penetrations in Manhole	Pipe Angle with Respect to Reference Point	Pipe Angle Equations		Final Angle	Allowable Angle Range
		Initial Angle	Additional Angle to Account for Structural Leg		
Pipe A (Reference Pipe)	0°	$a^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_A}{r} \right)$	$\Phi_a^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$A^\circ = a^\circ + \Phi_a^\circ$	$A^\circ < 180^\circ$
Pipe B	X°	$b^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_B}{r} \right)$	$\Phi_b^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$B^\circ = b^\circ + \Phi_b^\circ$	$X^\circ - \frac{B^\circ}{2} > \frac{A^\circ}{2}$
Pipe C	Y°	$c^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_C}{r} \right)$	$\Phi_c^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$C^\circ = c^\circ + \Phi_c^\circ$	$Y^\circ - \frac{C^\circ}{2} > X^\circ + \frac{B^\circ}{2}$
Pipe D	Z°	$d^\circ = 2 \times \sin^{-1} \left(\frac{0.5 \times P_D}{r} \right)$	$\Phi_d^\circ = \frac{S \times 180^\circ}{\pi \times r}$	$D^\circ = d^\circ + \Phi_d^\circ$	$Z^\circ - \frac{D^\circ}{2} > Y^\circ + \frac{C^\circ}{2}$ and $Z^\circ + \frac{D^\circ}{2} < 360^\circ - \frac{A^\circ}{2}$

NOTE: Pipe D is not displayed on Figure 2C-3.05, but it would follow the same convention as Pipe A, Pipe B, and Pipe C as displayed on the diagram.

- 3. Intake/Manhole Combination:** Intake/manhole combinations will be used when the size of the connecting pipes so indicate or when horizontal clearance is necessary behind the back of curb. The Engineer is encouraged to utilize intake/manhole combinations for storm sewers that are parallel to the street. This will prevent storm sewers from being installed under pavement; improving maintenance access without requiring pavement removal.
- 4. Cleanouts:** Lamp holes or cleanout structures are required at the beginning of footing drains and subdrains in street right-of-way. Cleanouts may be allowed in place of a manhole at the end of lines that are less than 150 feet in length. Approval to use cleanouts is required.
- 5. Access Spacing:** Storm sewer structures (manholes, intakes, combination intakes, or cleanouts) in street right-of-way must be located in areas that allow direct access by maintenance vehicles.

Areas outside the street right-of-way will be subject to the approval of the Jurisdictional Engineer.

- a. **Manhole Spacing:** Manholes are to be spaced at intervals not exceeding 400 feet or at intervals not exceeding 500 feet when adequate cleaning equipment is available.
 - b. **Intake Spacing:** Locate street intakes upgrade from intersections, sidewalk ramps, and outside of intersection radii. At least one intake is to be installed at the low point of the street grade.
 - 1) **First Intake:** An intake should be located no further than 500 feet from the street high point.
 - 2) **Remaining Intakes:** To be spaced at a distance no greater than 400 feet, regardless of gutter flow capacity, in order to meet maintenance needs.
6. **Invert Drop:** When there is a change in pipe size at a structure, the invert of the smaller sewer must be raised to maintain the same energy gradient. An approximate method of doing this is to place the 0.8 depth point of both sewers at the same elevation. When the outgoing and incoming pipes are the same diameter and when there is a change in alignment between storm sewer of 45 degrees or greater, the suggested drop in the flow line is 0.3 foot and the minimum drop is 0.10 foot.

H. Manhole and Intake Standards

1. Manhole Standards to be Utilized:

Figure No. ¹	Description	Use	
		Main Pipe Size	Depth Restrictions
6010.401	Circular Storm Sewer Manhole	12" min. See table on Figure 6010.401 for max. pipe size	N/A
6010.402	Rectangular Storm Sewer Manhole	12" to 54"	8' max.
6010.403	Deep Well Rectangular Storm Sewer Manhole	12" to 72"	12' max.
6010.404	Rectangular Base/Circular Top Storm Sewer Manhole	12" to 96"	12' min. to 22' max.
6010.405	Tee-section Storm Sewer Manhole	12" or greater	N/A

¹ The figure numbers listed in this table refer to figures from the SUDAS Specifications.

2. Manhole Castings to be Utilized:

Figure No. ¹	Casting Type	Number of Pieces	Ring/Cover	Bolted Frame	Bolted Cover (Floodable)	Gasket
6010.602	E	2	Fixed ²	Yes	No	No
6010.602	F	3	Adjustable ³	No	No	No

¹ The figure numbers listed in this table refer to figures from the SUDAS Specifications.

² Typically used with non-paved or flexible surfaces, including HMA, seal coat, gravel, and brick.

³ Typically used with PCC surfaces, including castings in concrete boxouts.

3. Intake Standards to be Utilized:

Intake Type ¹	Intake Casting ¹	Standard	Conditions
Curb-Grate 6010.501	6010.603 Type Q	Single, poured 6" walls	Intake depth $\leq 7'$ Pipe size: 18" max. on 2' side, 30" max. on 3' side
Curb-Grate 6010.502	6010.603 Type Q	Single, precast walls	Intake depth $> 7'$ Pipe size: 24" max. for 48" diameter
Curb-Grate (Combination) 6010.503/6010.504	6010.603 Type Q	Single, poured 6" walls	Intake depth $\leq 6' 6''$ Pipe size: 30" max. on 3' side, 36" max. on 6' side
Curb-Grate 6010.505	6010.603 Type Q	Double, poured 6" walls	Intake depth $\leq 7'$ Pipe size: 18" max. on 2' side, 66" max. on 6' 8" side
Curb-Grate (Combination) 6010.506	6010.603 Type Q	Double, poured 6" walls	Intake depth $\leq 6' 6''$ Pipe size: 30" max. on 3' side, 36" max. on 6' side, 48" max. on 6' 8" side
Curb Only 6010.507	N/A	Single open-throat, poured 6" walls	Intake depth $\leq 10'$ Pipe size: 30" max. on 3' side, 36" max. on 4' side
Curb Only 6010.508	N/A	Single open-throat, poured 6" walls	Intake depth $\leq 16'$ Pipe size: 36" max.
Curb Only 6010.509	N/A	Double open-throat, poured 6" reinforced walls	Intake depth $\leq 10'$ Pipe size: 30" max. on 3' side, 66" max. on 8' side
Curb Only 6010.510	N/A	Double open-throat, poured 6" reinforced walls	Intake depth $< 10'$ Pipe size: 36" max. on 4' side, 66" max. on 8' side
Driveway or Alley Grate Intake 6010.511	6010.604 Type 6	Single (Surface Intake), poured 6" walls	Intake depth $\leq 7'$ Pipe size: 18" max. on 2' side, 30" max. on 3' side
Area Intake 6010.512	6010.604 Type 3, 4, or 5	Precast, Area Intake	Intake depth $> 7'$ Pipe size varies on structure size
Ditch Intake 6010.513	6010.602 Type G	Area Intake (side open intake), poured 6" walls	Intake depth $\leq 7'$ Pipe size varies on structure size

¹ The figure numbers listed in this table (e.g. [6010.501](#)) refer to figures from the SUDAS Specifications.

I. References

Comport, Thornton, & Cox. *Hydraulic Efficiency of Grate and Curb Inlets for Urban Storm Drainage*. Colorado State University. 2009.

U.S. Department of Transportation. *Urban Drainage Design Manual*. Hydraulic Engineering Circular No. 22. Third Ed. 2009.