Inlet Control Theory

The design equations used to develop the inlet control nomographs are based on the research conducted by the National Bureau of Standards (NBS) under the sponsorship of the Bureau of Public Roads (now the Federal Highway Administration). Seven progress reports were produced as a result of this research. Of these, the first and fourth through seventh reports dealt with the hydraulics of pipe and box culvert entrances, with and without tapered inlets (4,7 to 10) These reports were one source of the equation coefficients and exponents, along with other references and unpublished FHWA notes on the development of the nomographs. (56,57)

The two basic conditions of the inlet control depend upon whether the inlet end of the culvert is or is not submerged by the upstream headwater. If the inlet is not submerged, the inlet performs as a weir. If the inlet is submerged, the inlet performs as an orifice. Equations are available for each of the above conditions.

Between the unsubmerged and the submerged conditions there is a transition zone for which the NBS research provided by drawing a curve between and tangent to the curves defined by the unsubmerged and submerged equations. In most cases, the transition zone is the short and the curve is easily constructed.

Below are the unsubmerged and submerged inlet control design equations. Note that there are two forms of the unsubmerged equation. Form (1) is based on the specific head at critical depth, adjusted with two correction factors, Form (2) is an exponential equation similar to a weir equation. Form (1) is preferable from a theoretical standpoint, but form (2) is easier to apply and is the only documented form of equation for some of the inlet control nomographs. Either form of unsubmerged inlet control equation will produce adequate results.

Inlet Control Design Equations

UNSUBMERGED

Form (1)

$$\frac{HW_i}{D} = \frac{H_c}{D} + K\left[\frac{Q}{AD^{0.5}}\right] - 0.55^2$$

Form (2)

$$\frac{HW_i}{D} = K\left[\frac{Q}{AD^{0.5}}\right]^M$$

SUBMERGED

$$\frac{HW_i}{D} = c\left[\frac{Q}{AD^{0.5}}\right]^2 + Y - 0.55$$

Definitions:

HWi = Headwater depth above inlet control section invert, metres or feet

D = Interior height of culvert barrel, metres or feet

Hc = Specific height of culvert barrel, metres or feet

Q = Discharge, m3/s or ft3/s

A = Full cross sectional area of culvert barrel, metres2 or feet2

S = Culvert barrel slope m/m or ft/ft

K, M, c, Y = Constants from the table

⚠

1. Equations for unsubmerged apply up to about Q/AD0.5 = 3.5
2. For mitered inlets use + 0.75 instead of – 0.55 as the slope correction factor
3. Equation for submerged applies above about Q/AD0.5 = 4.0

Constants for inlet control design equations

Inlet Type	Description	Index Value
Circular Concrete	Square edge with headwall	1
	Groove end with headwall	2
	Groove end projecting	3
Circular Corrugated Metal Pipe	Headwall	4
	Mitered to slope	5
	Projecting	6
Circular Pipe, Beveled Ring Entrance	45 deg. bevels	7
	33.7 deg. bevels	8
Rectangular Box; Flared Wingwalls	30-75 deg. wingwall flares	9
	90 or 15 deg. wingwall flares	10
	0 deg. wingwall flares (straight sides)	11
Rectangular Box; Flared Wingwalls and Top Edge Bevel	45 deg flare; 0.43D top edge bevel	12
	18-33.7 deg. flare; 0.083D top edge bevel	13
Rectangular Box, 90-deg Headwall, Chamfered / Beveled Inlet Edges	Chamfered 3/4-in.	14
	Beveled 1/2-in/ft at 45 deg. (1:1)	15
	Beveled 1-in/ft at 33.7 deg. (1:1.5)	16
Rectangular Box, Skewed Headwall, Chamfered / Beveled Inlet Edges	3/4" chamfered edge, 45 deg. skewed headwall	17
	3/4" chamfered edge, 30 deg. skewed headwall	18
	3/4" chamfered edge, 15 deg. skewed headwall	19
	45 deg. beveled edge, 10-45 deg. skewed headwall	20
Rectangular Box, Non-offset Flared Wingwalls, 3/4" Chamfer at Top of Inlet	45 deg. (1:1) wingwall flare	21
	18.4 deg. (3:1) wingwall flare	22
	18.4 deg. (3:1) wingwall flare, 30 deg. inlet skew	23
Rectangular Box, Offset Flared Wingwalls, Beveled Edge at Inlet Top	45 deg. (1:1) flare, 0.042D top edge bevel	24
	33.7 deg. (1.5:1) flare, 0.083D top edge bevel	25
	18.4 deg. (3:1) flare, 0.083D top edge bevel	26
Corrugated Metal Box	90 deg. headwall	27
	Thick wall projecting	28
	Thin wall projecting	29
Horizontal Ellipse Concrete	Square edge with headwall	30
	Grooved end with headwall	31
	Grooved end projecting	32
Vertical Ellipse Concrete	Square edge with headwall	33

	Grooved end with headwall	34
	Grooved end projecting	35
Pipe Arch, 18" Corner Radius, Corrugated Metal	90 deg. headwall	36
	Mitered to slope	37
	Projecting (FHWA 1974)	38
Pipe Arch, 18" Corner Radius, Corrugated Metal	Projecting (Bossy 1963)	39
	No bevels	40
	33.7 deg. bevels	41
Pipe Arch, 31" Corner Radius,Corrugated Metal	Projecting	42
	No bevels	43
	33.7 deg. bevels	44
Arch, Corrugated Metal	90 deg. headwall	45
	Mitered to slope	46
	Thin wall projecting	47
Circular Culvert	Smooth tapered inlet throat	48
	Rough tapered inlet throat	49
Elliptical Inlet Face	Tapered inlet, beveled edges	50
	Tapered inlet, square edges	51
	Tapered inlet, thin edge projecting	52
Rectangular	Tapered inlet throat	53
Rectangular Concrete	Side tapered, less favorable edges	54
	Side tapered, more favorable edges	55
	Slope tapered, less favorable edges	56
	Slope tapered, more favorable edges	57