Gravity Flow in Concrete Circular Pipe

Design Parameters

Symbol	Description	Units
d_0	Pipe Diameter	in
s	Average Bed Slope	$^{\text{ft}}/_{\text{ft}}$

Given Constants

Symbol	Description	Value	Units
$^{d}/_{d_0}$	Flow Depth Ratio	0.813	$^{\text{in}}/_{\text{in}}$
ϕ	Manning's Unit Conversion	1.486	$\frac{\text{ft}^{1/3}}{\text{s}}$
n	Manning's Roughness (Concrete)	0.013	$^{\text{in}}/_{\text{in}}$
g	Acceleration of Gravity	32.2	$^{\text{ft}}/_{\text{s}^2}$

Other Variables

Symbol	Description	Units
θ	Flow Angle	rad
A	Flow Area	ft^2
P	Wetted Perimeter	ft
R	Hydraulic Radius	ft
D	Hydraulic Depth	ft

Symbol	Description	Units
Q_{cfs}	Average Flow	$^{\text{ft}^3}/_{\text{s}}$
Q_{gpm}	Average Flow	$^{\text{gal}}/_{\text{min}}$
v_c	Critical Velocity	$^{\text{ft}}/_{\text{s}}$
$Q_{c,\text{ cfs}}$	Critical Discharge	$^{\text{ft}^3}/_{\text{s}}$
$Q_{c,\text{ gpm}}$	Critical Discharge	$^{\text{gal}}/_{\text{min}}$
s_c	Critical Bed Slope	$^{\text{ft}}/_{\text{ft}}$

Considering Average Flow

$$d = d_0\left(\frac{d}{d_0}\right) \tag{1}$$

$$\theta = \pi + 2\sin^{-1}\left[2\left(\frac{d}{d_0} - \frac{1}{2}\right)\right] \tag{2}$$

$$A = \left[\frac{\theta - \sin(\theta)}{8}\right]\left[d_0\left(\frac{1\text{ ft}}{12\text{ in}}\right)\right]^2 \tag{3}$$

$$P = \frac{\theta}{2}\left[d_0\left(\frac{1\text{ ft}}{12\text{ in}}\right)\right] \tag{4}$$

$$R = \frac{1}{4}\left[1 - \frac{\sin(\theta)}{\theta}\right]\left[d_0\left(\frac{1\text{ ft}}{12\text{ in}}\right)\right] \tag{5}$$

$$D = \frac{1}{8}\left[\frac{\theta - \sin(\theta)}{\sin(^{\theta}/_{2})}\right]\left[d_0\left(\frac{1\text{ ft}}{12\text{ in}}\right)\right] \tag{6}$$

$$v = \frac{\phi}{n}\left(R^{\frac{2}{3}}\right)\sqrt{s} \tag{7}$$

$$Q_{\text{cfs}} = Av \tag{8}$$

$$Q_{\text{gpm}} = Q_{\text{cfs}}\left[\left(60\ \frac{\text{s}}{\text{min}}\right)\left(7.481\ \frac{\text{gal}}{\text{ft}^3}\right)\right] \tag{9}$$

$$\tag{10}$$

Considering Critical Flow

$$v_c = g\sqrt{D} \tag{11}$$

$$Q_{c,\text{ cfs}} = (v_c)\,A \tag{12}$$

$$Q_{c,\text{ gpm}} = Q_{c,\text{ cfs}}\left[\left(60\ \frac{\text{s}}{\text{min}}\right)\left(7.481\ \frac{\text{gal}}{\text{ft}^3}\right)\right] \tag{13}$$

$$s_c = \left[\frac{n v_c}{\phi R^{2/3}}\right]^2 \tag{14}$$

Conditions

$$s < s_c \tag{15}$$

$$Q_{\text{gpm}} > Q_{\text{required}} \tag{16}$$

$$v > 3\ {}^{\text{ft}}/{}_{s} \tag{17}$$