Graphs and Equations Used In Culvert Design (Nomographs, Part-full Flow, Critical Depth, Full Flow)

Drain · https://mes100.com/docs/graphs-and-equations-used-in-culvert-design-nomographs-part-full-flow-critical-depth-full-flow/

This blog post continues from previous **blog post** which is created to let users understand better towards the graphs provided in the MSMA and derived equation used in MiTS to calculate culvert design.

Entrance Loss Coefficient

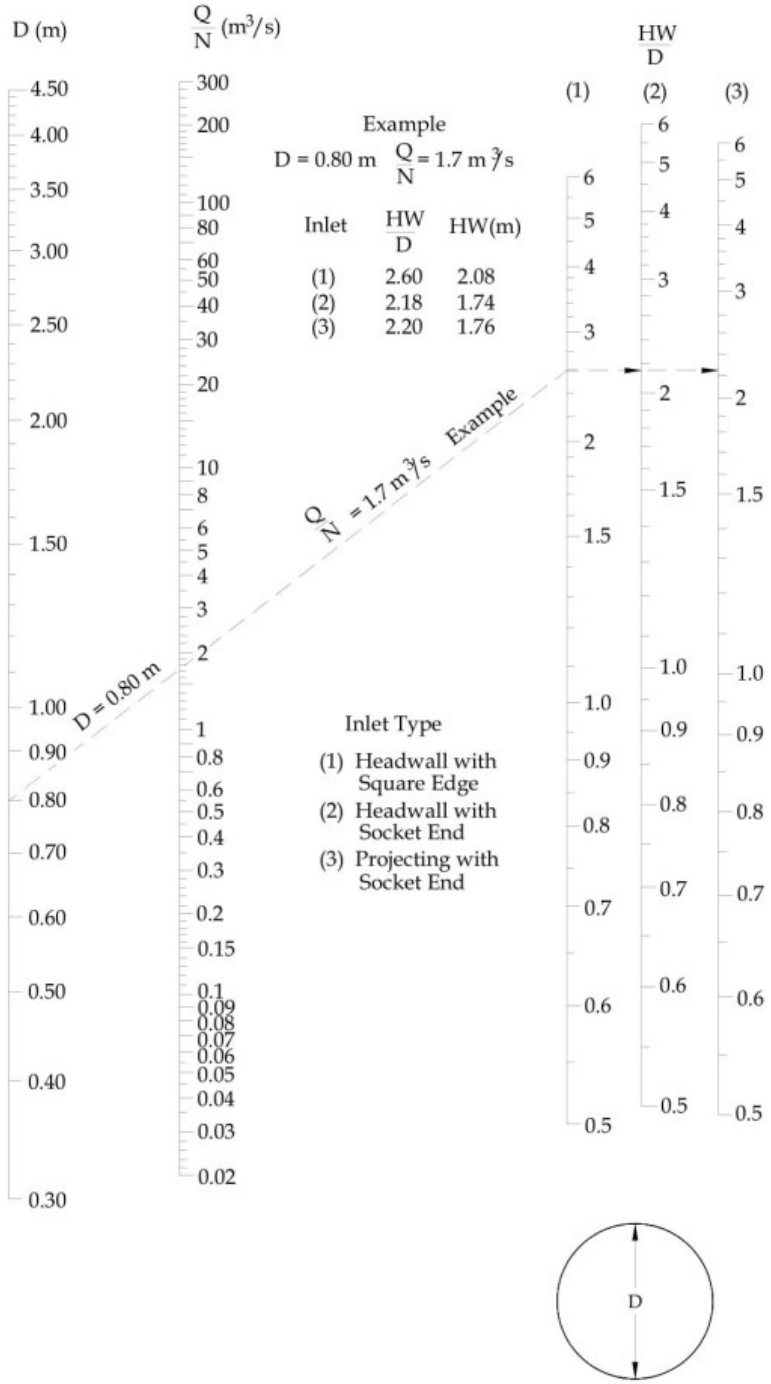
The entrance loss coefficient depends on the inlet/outlet geometry primarily through effect it has on contraction of the flow. This can be referred in MSMA 2nd Edition in Table 18.A1.

Design Table 18.A1: Entrance Loss Coefficients

Type of Barrel And Inlet	Loss Coefficients
Pipe, Concrete	K_e
Projecting from fill, socket end	0.2
Projecting from fill, square cut end	0.5
Headwall or headwall and wingwalls	
Socket end of pipe	0.2
Square-edge	0.5
Rounded (radius = 1/12 D)	0.2
Mitred to conform to fill slope	0.7
End-section conforming to fill slope (standard precast)	0.5
Bevelled edges, 33.7° or 45° bevels	0.2
Side-tapered or slope-tapered inlets	0.2
Pipe, or Pipe-Arch, Corrugated Steel	
Projecting from fill	0.9
Headwall or headwall and wingwalls, square edge	0.5
Mitred to conform to fill slope	0.7
End-section conforming to fill slope (standard prefab)	0.5
Bevelled edges, 33.7° or 45° bevels	0.25
Side-tapered or slope-tapered inlets	0.2
Box, Reinforced Concrete	
Headwall	
Square-edged on 3 edges	0.5
Rounded on 3 edges to radius of 1/12 barrel dimension,	
Or bevelled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
Square-edged at crown	0.4
Crown edge rounded to radius of 1/12 barrel dimension	
Or bevelled top edge	0.2
Wingwalls at 10° to 25° to barrel	
Square-edged at crown	0.5
Wingwalls parallel (extension of sides)	
Square-edged at crown	0.7
Side-tapered or slope-tapered inlet	0.2
Projecting	
Square-edged	0.7*
Bevelled edges, 33.7° or 45° bevels	0.2*
* Estimated	

Inlet Control Nomograph for Pipe Culvert and Box Culvert

Headwater depth for inlet control of **pipe culvert** can be determined by plotting the relationship between diameter and discharge of each of the culvert number with the Inlet Type, which can be referred in Design Chart 18.A2 in MSMA 2nd Edition.



Design Chart 18.A2: Inlet Control Nomograph – Concrete Pipe Culvert

The equation to alternate the graph is as follows;

$$ \style{font-family:Arial}{{\mathrm{HW}}_{\mathrm i}\;=\;\mathrm c{(\frac{\mathrm{Ku}.\mathrm Q}{\mathrm A.\mathrm D^{0.5}})}^2\;+\;\mathrm Y\;+\;\mathrm{Ks}.\mathrm S} $$

HWi = Headwater depth (m)

D = Diameter of culvert barrel (m)

c = Constant from Table 1.1, Table 1.2

Ku = Unit Conversion, 1.811 SI unit

Q = Discharge (m3/s)

A = Full cross sectional area of culvert barel (m2)

Y = Constant from Table 1.1, Table 1.2

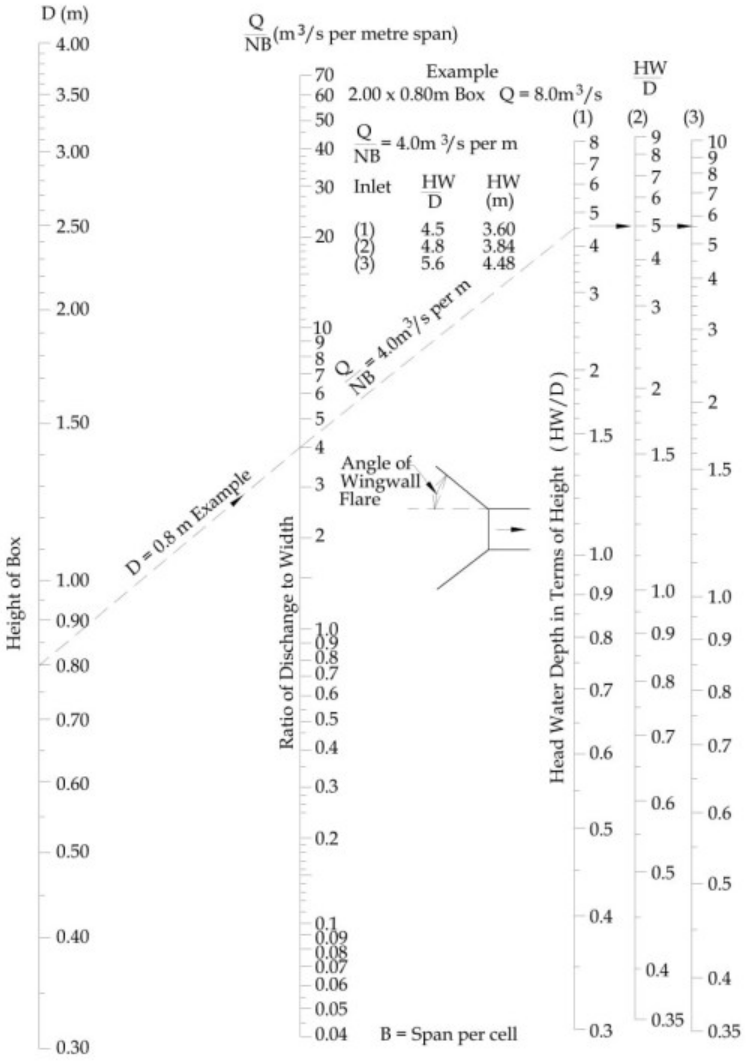
Ks = Slope correction, -0.5

S = Culvert barrel slope (m/m)

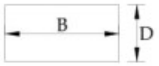
Nomograph Scale	**Inlet Type**	**K**	**c**	**Y**
[1]	Headwall with Square Edge	0.0098	0.0398	0.67
[2]	Headwall with Socket End	0.0018	0.0292	0.74
[3]	Projecting with Socket End	0.0045	0.0317	0.69

Table 1.1 Constants for Inlet Control Equation of Pipe Culvert

Headwater depth for inlet control of **box culvert** also can be determined by plotting the diameter to the discharge, which can be referred to Design Chart 18.A3 in MSMA 2nd Edition.



Wingwall Flare	HW/D Scale
30° - 75°	1
90° (headwall)	2
0° (parallel)	3



Design Chart 18.A3: Inlet Control Nomograph – Box Culvert

Same Equation 1.1 can be used for box calculation, but with different constants, refer to Table 1.2.

Nomograph Scale	Wingwall Flare Type	K	c	Y
[1]	30° - 75°	0.026	0.0347	0.81

[2]	90°	0.061	0.04	0.8
[3]	0°	0.061	0.0423	0.82

Table 1.2 Constants for Inlet Control Equation for Box Culvert

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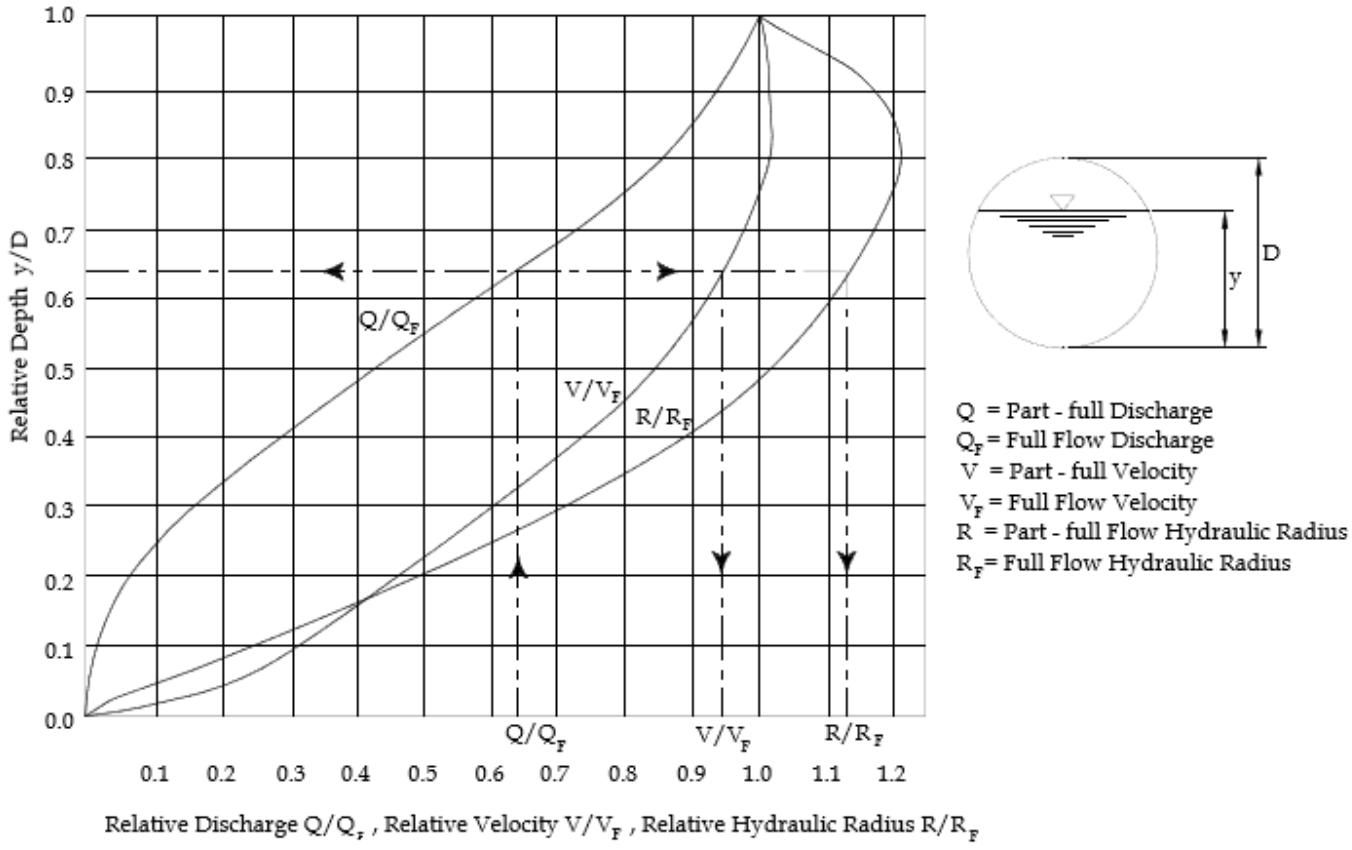
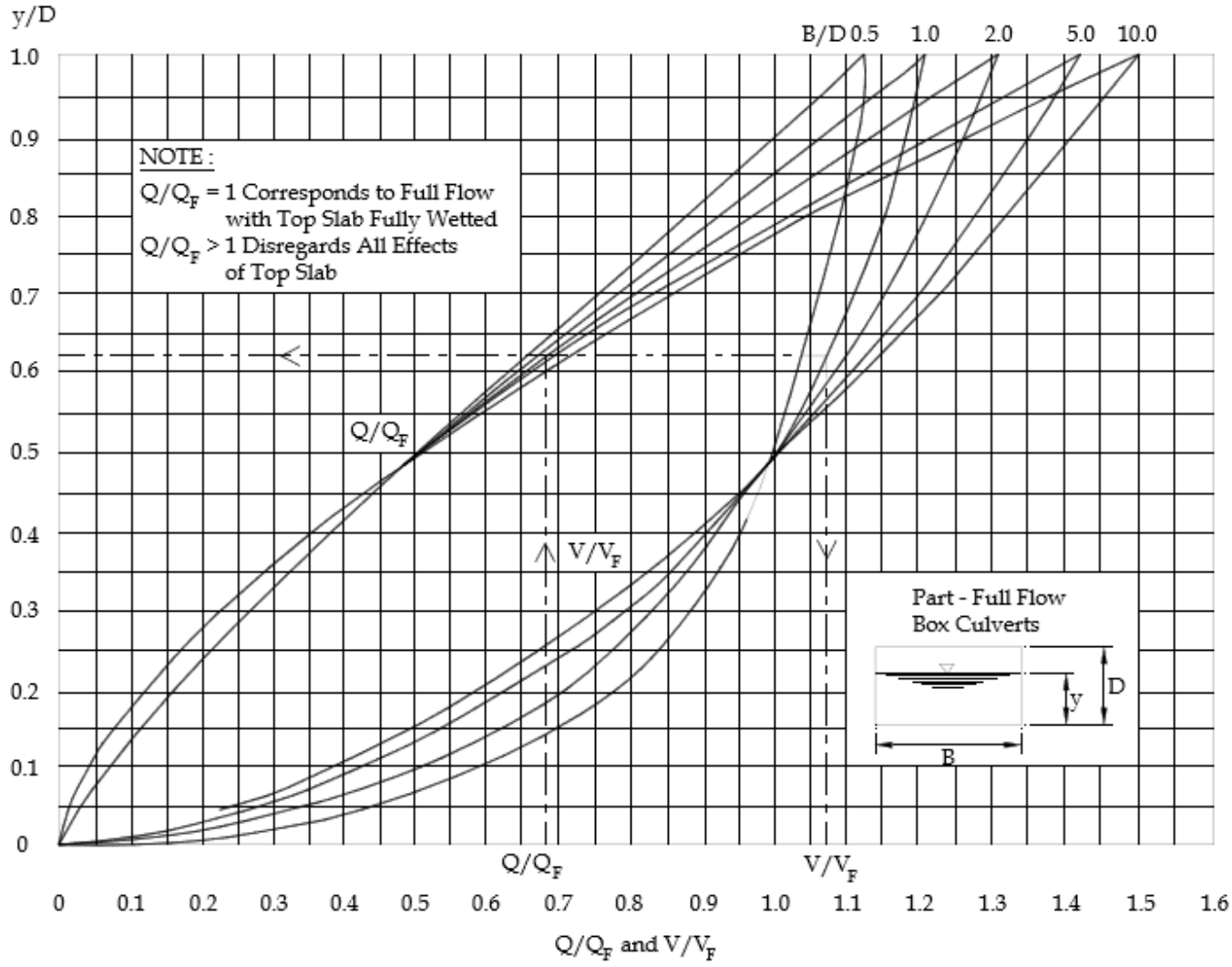
Relative Discharge, Velocity and Hydraulic Radius in Part-full Pipe Culvert and Box Culvert Flow

Design Chart 18.A5 and Chart 18.A6 in MSMA 2nd Edition are used to determine the discharge, velocity and hydraulic radius within partially full flow of **pipe culvert** and **box culvert**, respectively.



Design Chart 18.A5: Relative Discharge, Velocity and Hydraulic Radius in Part-full Pipe Flow.



Design Chart 18.A6: Relative Discharge, Velocity and Hydraulic Radius in Part-full Box Culvert Flow

These two graphs quite complicated to get the output since several variables need to be determined first before obtaining the end result. The calculation of the partially full flow can be calculated by using Manning equation but with modified n value *(H. B. Harlan, Spreadsheet Use for Partially Full Pipe Flow Calculations)*. The n/nfull as function of y/D is as Table 1.3.

y/D	**n/nfull**
0 < y/D <= 0.03	1 + (y/D)/(0.3)
0.03 < y/D <= 0.1	1.1 + (y/D - 0.03)(12/7)
0.1 < y/D <= 0.2	1.22 + (y/D - 0.1)(0.6)
0.2 < y/D <= 0.3	1.29

0.3 < y/D <= 0.5	1.29 - (y/D - 0.3)(0.2)
0.5 < y/D <= 1	1.25 - (y/D - 0.5)(0.5)

Table 1.3 n/nfull as function of y/D

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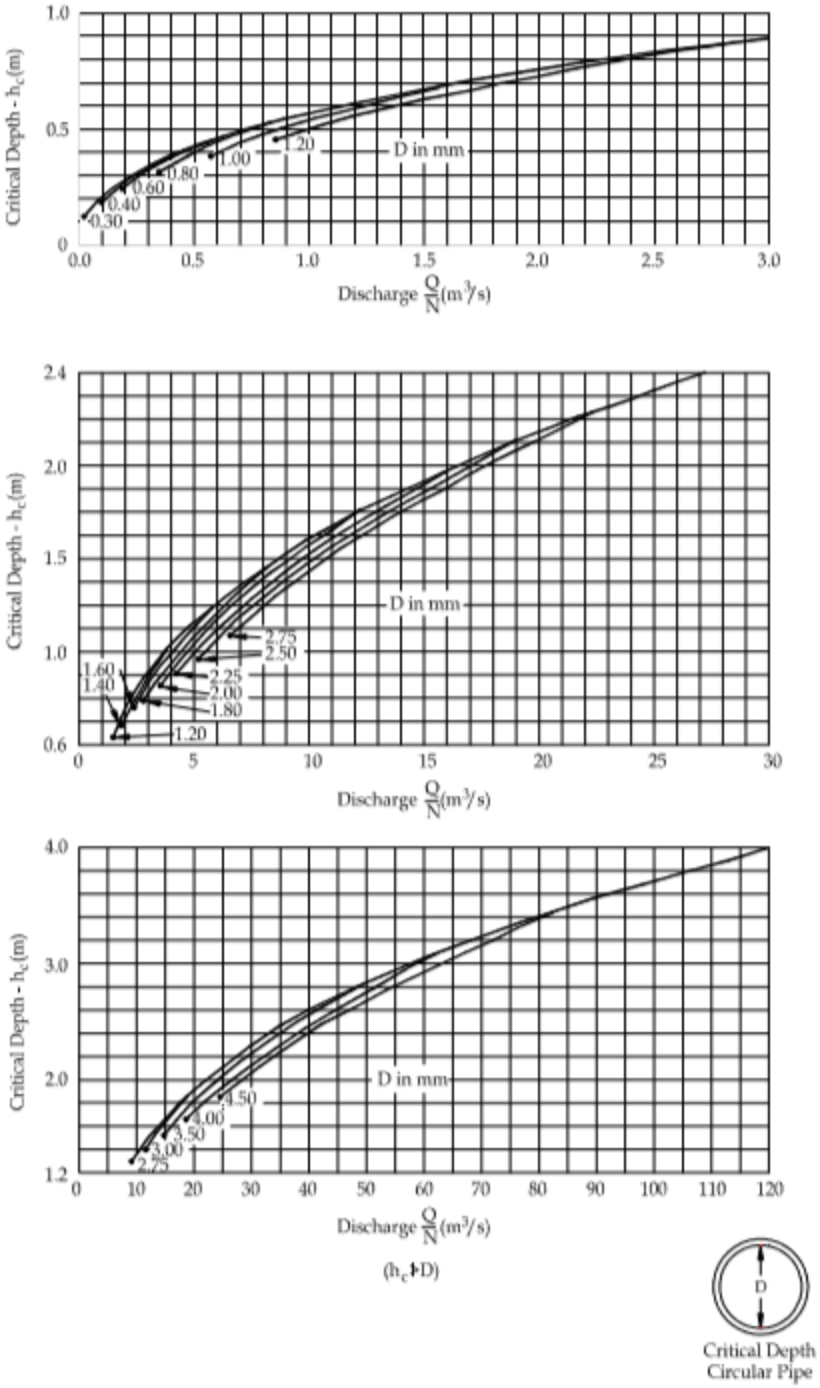
Critical Depth in a Circular Pipe and Box Culvert

For circular pipe, users can plot the critical depth by using Design Chart 18.A7 provided in MSMA 2nd Edition.



Design Chart 18.A7: Critical Depth in a Circular Pipe

Other than plotting, equation also can be used as an alternative to calculate the pipe culvert critical depth.

$$ \style{font-family:Arial}{{\mathrm h}_{\mathrm c}\;=\;\frac{\mathrm{CQ}^{1.5}}{\mathrm D^{0.25}}} $$

(eq. 1.2)

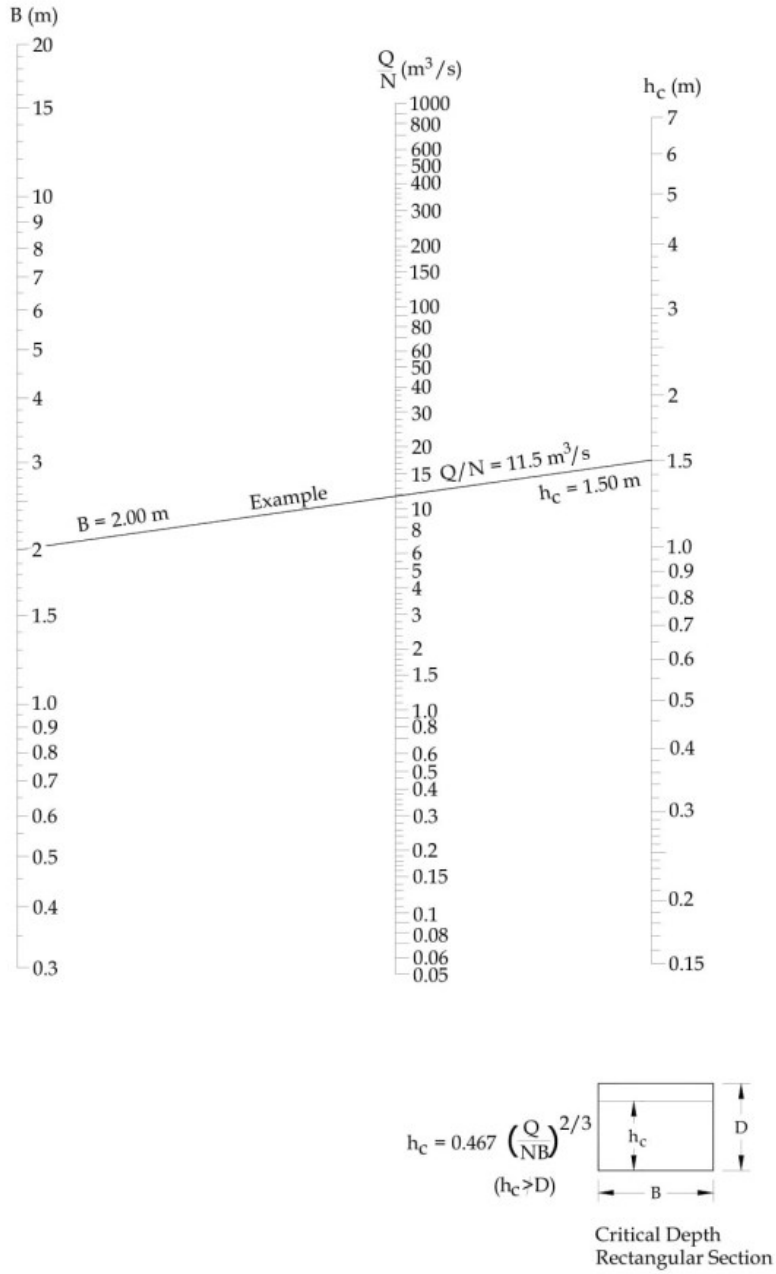
hc = Critical depth (m)

C = Constant, 0.562

Q = Discharge (m3/s)

D = Diameter (m)

Critical depth of **box culvert** also can be determined by using the nomograph Chart Design 18.A8 provided in MSMA 2nd Edition by interrelate the width dimension with discharge.



Design Chart 18.A8: Critical Depth in a Rectangular (Box) Section

Equation 1.3 can be used to calculate box critical depth.

$$ \style{font-family:Arial}{{\mathrm h}_{\mathrm c}\;=\;\frac{\mathrm C.\mathrm Q^{\displaystyle\frac23}}{\mathrm B}} $$

(eq. 1.3)

hc = Critical depth (m)

C = Constant, 0.319

Q = Discharge (m3/s)

B = Width of culvert (m)

Outlet Control Nomograph of Pipe Culvert and Box Culvert

Equation 18.9 in MSMA 2nd Edition is referred to calculate the outlet headwater and the Head is calculated by using Design Chart 18.A9 and Design Chart 18.A10 for **pipe culvert** and **box culvert**, respectively. But, users can alternate to equation to calculate those Head for pipe and box culvert. The equations are shown below the graphs.

HWo = ho + H - Ls

H = Head determined by Design Chart 18.A9 and Design Chart 18.A10

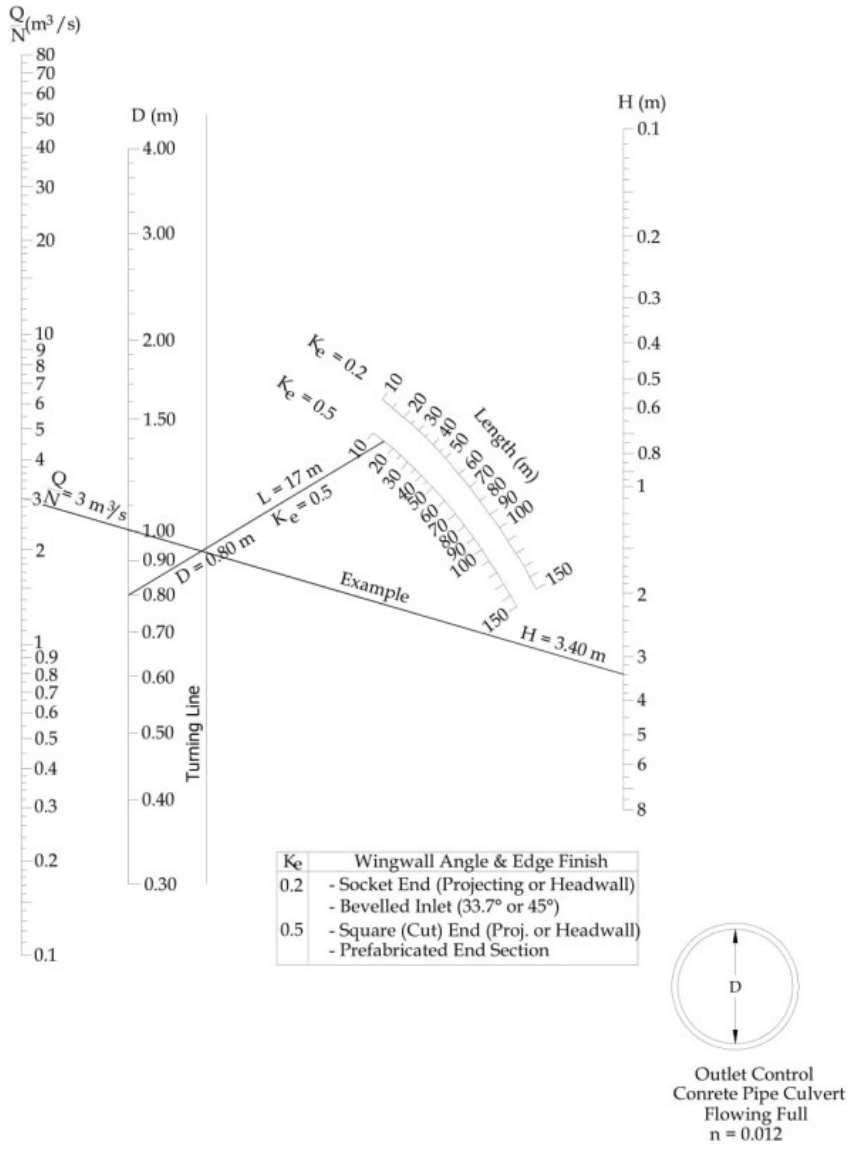
ho = Greater of TW and (hc + D)/2

hc = Critical depth (m)

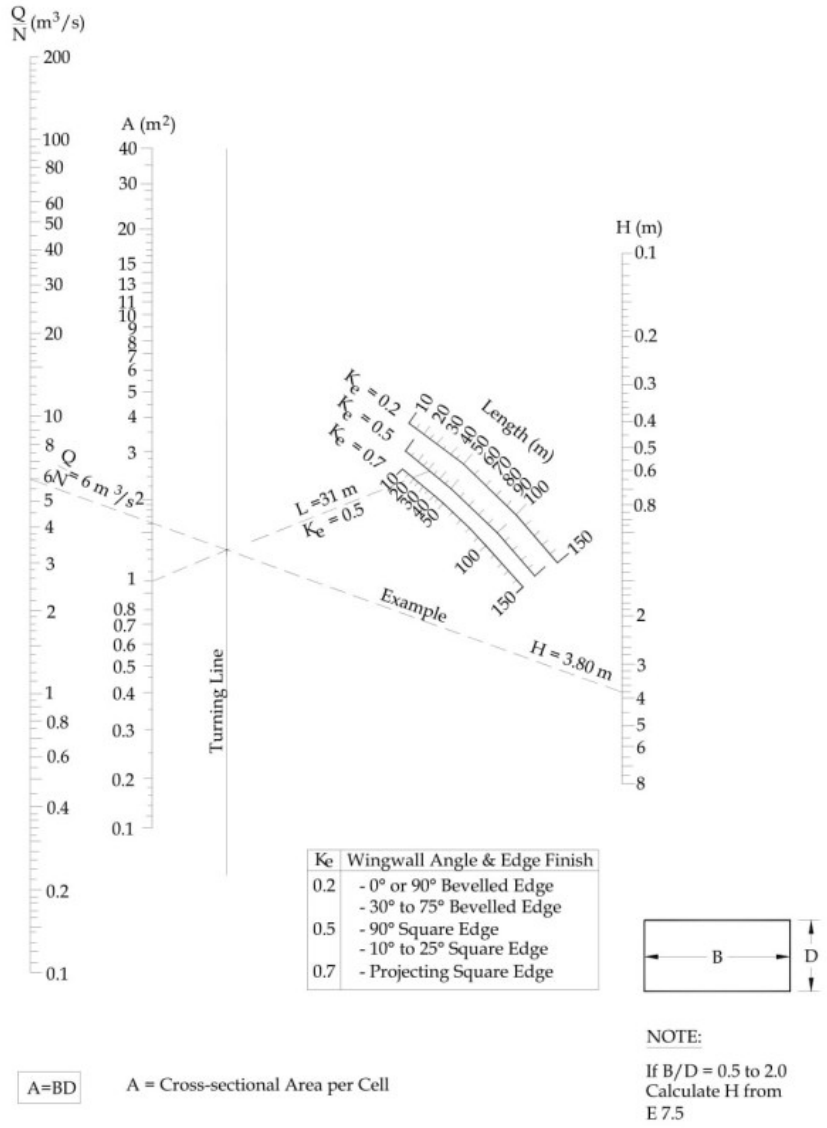
L = Length of culvert

S = Slope (m/m)

Head depth for outlet control of pipe culvert and box culvert can be determined based on MSMA 2nd Edition, accordance with Design Chart 18.A9 and Design Chart 18.A10 respectively.



Design Chart 18.A9: Outlet Control Nomograph – Concrete Pipe Culvert Flowing Full with n = 0.012



Design Chart 18.A10: Outlet Control Nomograph Concrete Box Culvert Flowing Full with n = 0.012

The following equation can be used to calculate the head depth for both pipe and box culvert, only the constant varies based on the culvert type used.

$$ \style{font-family:Arial}{\mathrm H\;=\;(1\;+\;\mathrm k<\mathrm{em}>\mathrm e\;+\;\frac{\mathrm k<\mathrm{/em}>\mathrm u.\mathrm n^2.\mathrm L}{\mathrm R^{1.33}})\;(\frac{\mathrm V^2\;}{2\mathrm g})} $$

(eq. 1.4)

H = Barrel loss (m)

Ke = Constant

Ku = Constant, 19.63 SI Unit

n = Manning rougness coefficient

L = Length of culvert barrel (m)

R = Hydraulic radius of the full culvert barrel (m)

V = Velocity in the barrel (m/s)

g = Gravitational accelaration, 9.81 m/s/s SI unit

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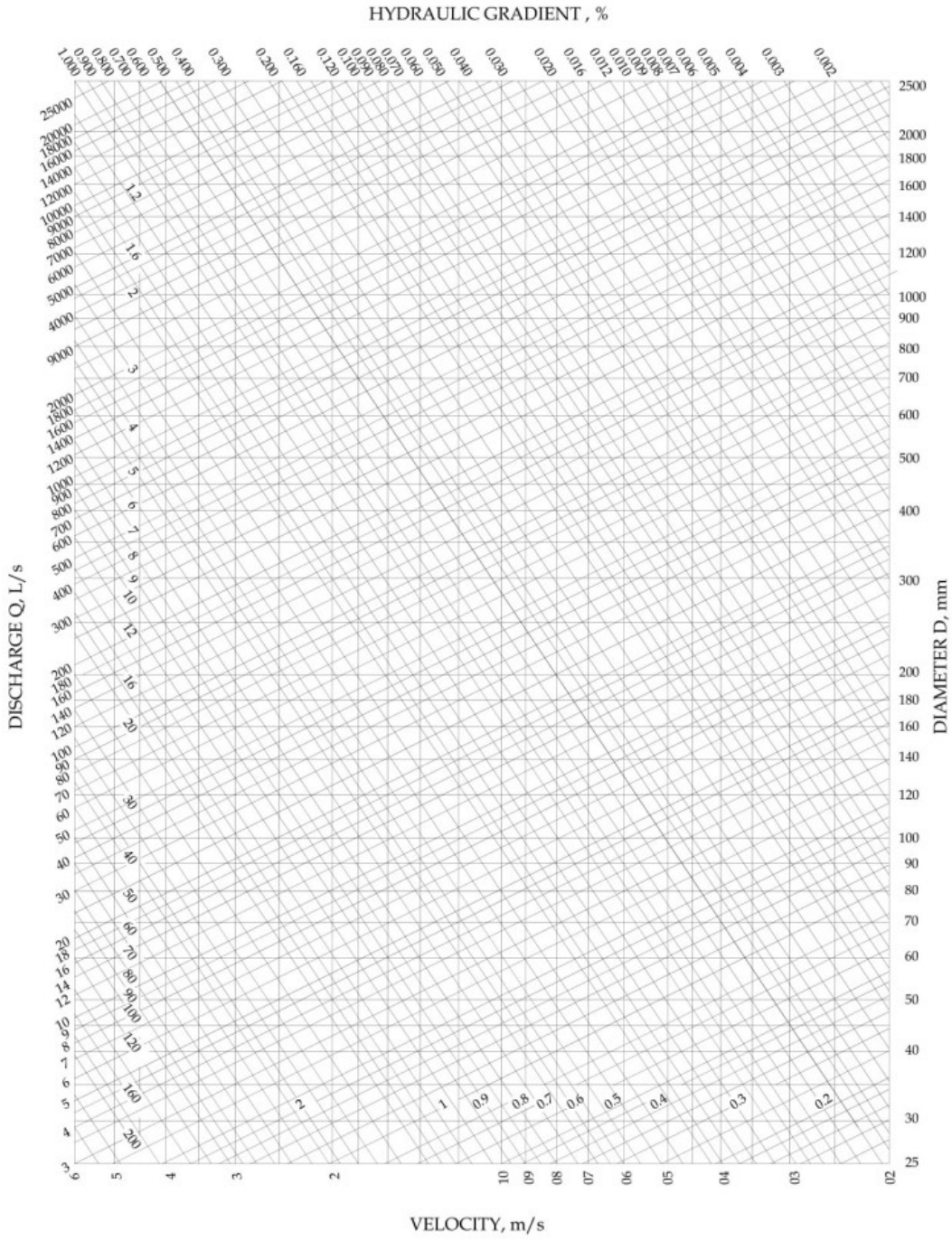
Hydraulic Design of Pipes - Colebrook-White Formula - k = 0.60 mm

Hydraulic design of pipes can be determined by using the complicated Design Chart 18.A2 obtained from MSMA 2nd Edition, whereby users need to plot the 4 axis graph to determine the output.



Design Chart 18.A12: Hydraulic Design of Pipes – Colebrook-White Formula – k = 0.60 mm

You can also use the Colebrook-White equation as below;

$$ \style{font-family:Arial}{\mathrm V\;=\;-2(2.\mathrm g.\mathrm D.\mathrm S)\;\log(\frac{\mathrm k}{3.7\mathrm D}\;+\;\frac{2.51\mathrm v}{\mathrm D(2.\mathrm g.\mathrm D.\mathrm S)\;\;})} $$

(eq. 1.5)

V = Velocity (m/s)

G = Gravitational acceleration, 9.81 m/s/s SI unit

D = Diameter (m)

S = Slope (m/m)

k = Colebrook-White roughness coefficient

□□ = Kinematic viscosity of water, 0.00000113

We also provide you the **calculator** for you to calculate the output.

All graphs and equations explained above are the one that are used in the culvert calculation based on MSMA 2nd Edition. We also carry out several calculation example to **benchmark** between the equation derived with the graphs provided.

Related



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