Circular culvert / Throttling pipe flow estimator

Based on chapters 9.1 - 9.33 , Willi H Hager "Wastewater Hydraulics" Springer 1999

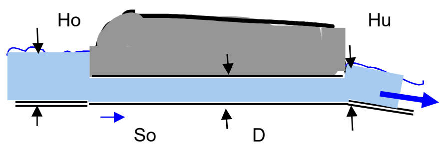
D	Ho	Hu	So	n	L	χ	Yo	Flow type
m	m	m	m/m		m	full pipe		
0.3	0.37	0.95	0.08	0.013	9.4	5.684	1.233	**pressurised**
								N/A

Project No	17D83 South
Date	14-Feb-18

Draft 3

R*d	Rd	jd	Hd	h/l culvert	qd	Q	χ	
			m	m		cub.m/sec	free	transitional flow type
-0.0019	0.0776	2.5067	0.172	0.9847	N/A	**0.092**	5.635	**N/A**

Operational Diagram



Qc max	Qcr	Q uni	Qgate tr	Qpress tr	Qpress	Qgate	Quni
							free
N/A	0.093	0.021	0.084	0.184	0.092	0.084	0.281
f	Yt	Cd	Q simple culvert	Qor	Sf	Fd	Qunifull
0.166	2.15	0.64	N/A	0.083	0.1048	N/A	0.281

Logic:

Ho and **Hu** are Energy Heads u/s and d/s of culvert respectively. **So** and **Sf** are Energy and pipe's gradients respectively. D is a pipe diameter.
χ is pipe roughness characteristic (5.31). **L** is culvert's length. **Yo** =Ho/D and **Fd** is pipe Froude number
Free Flow in the culvert can be either critical, uniform or gated. Flow is critical wh χ >2. Maximum filling ratio should be 95%. Yo is generally lower than 1.20.
If **Sf** exceeds **So** hydraulic jump may develop in the pipe leading to the formation of standing waves and if filling ratio is larger than 90% to choking of the pipe (usually near the outlet)
For larger approach level 1.2<Yo<1.5 and free culvert flow, gated flow appears when the u/s section is submerged sealing the culvert's inlet against airflow.
Pressurised flow develops when outlet of the culvert is submerged (choked) and Yo is equal or larger than 1.0.
Transition between gated and pressurised flow is analysed using roughness characteristics **Rd** and **Rd*** as per chapter 9.33 as well as possibilities of outlet choking due to hydraulic jump formation and/or high filling ratio. Then the choice is made between gated and pressurised flow for a transitional flow type (this selection is automatic).
It is a well known fact that for the culvert flow situation a free surface flow often needs more head than pressurised flow. Also supercritical flow in the pipe is unstable leading to formation of waves,h/jumps etc thus discharge under these conditions (described as "critical" in the program) may be lower than that under the "uniform" flow conditions.
Please note that the sharp-crested inlet configuration (Cd=0.64) is considered for transitional gated flow. For **Qgate** coefficient **Cd** can be changed in cell C15.
The approach taken in this spreadsheet is based on formulas valid for a long culvert (L/D>=10).
This spreadsheet is set up to automatically compute the discharge through the pipe/culvert for the flow situation described by the input parameters(Ho;Hu;n;So;D;L;Cd).
The final flow rate appears in cell G9 (brown font).
Flowrates for each flow situation are displayed in cells A13-H13 and D15,E15 and H15. It allows the user to compare the floweret selected by the program to other relevant Flowrates and make his/her own judgements. The Flowrates calculated by this spreadsheet are on the conservative side.

To use this program please follow these easy steps:

1 Type input data in yellow cells
2 Read flow type in cells I5 and I9
3 Read culvert discharge in cell G9

Good luck

Abbreviations and formulas used in the spreadsheet

Qcmax	Maximum free flow discharge for this situation (9.6)
Qcr	Discharge for "critical" flow situation χ > 2
Quni	Discharge for "uniform" flow situation
Qgate tr.	Discharge for transitional-gated flow situation
Q press. tr	Discharge for transitional-pressurised flow situation
Q press. tr	Discharge for "pressurised" flow situation
Qgate	Discharge for "gated" flow situation
Q uni free	Free uniform discharge
Q uni full	Uniform discharge for the 95% full pipe
Q simple culvert	Discharge calculated using formulas for a "simple culvert" (9.9 - 9.13)
Qor	Discharge calculated using small orifice formulae with Cor = 0.64

1. Free flow

Uniform flow

$$\frac{Hon}{D}=\frac{2}{\sqrt{3}}\left(\frac{nQ}{So^{\frac{1}{2}}D^{\frac{8}{3}}}\right)^{\frac{1}{2}}\frac{1}{2}\left[1+\left(\frac{9}{16}\chi^{2}\right)\right] \quad (5.31)$$

Critical flow

$$\frac{Hoc}{D}=\frac{5}{3}\left[\frac{Q}{\left(gD^{5}\right)^{\frac{1}{2}}}\right]^{\frac{3}{5}};Q c\max=0.61\left(gD^{5}\right)^{\frac{1}{2}}$$

2. Gate flow

$$Q=Cd\left(\frac{\pi}{4}\right)D^{2}\left[2g(Ho-CdD)\right]^{\frac{1}{2}}$$

3. Pressurised flow

$$Qp=\left(\frac{\pi}{4}\right)D^{2}\left[\frac{2gHd}{1+\sum\xi}\right]^{\frac{1}{2}}$$

5. Other formulas used

$$q_{n}=\frac{nQ}{So^{\frac{1}{2}}D^{\frac{8}{3}}}=\frac{3}{4}y_{n}^{2}\left(1-\frac{7}{12}y_{n}^{2}\right) \quad (5.14)$$

$$\chi(roughness)=\frac{So^{\frac{1}{2}}D^{\frac{1}{6}}}{ng^{\frac{1}{2}}}$$

$$Fd=\frac{Q}{(gDh^{4})^{\frac{1}{2}}} \quad (6.35;9.9-9.13)$$

$$h/l\,culvert=\sum\xi=12.64\left(\frac{gLn^{2}}{D^{\frac{4}{3}}}\right)$$

$$Hd=Ho+SoLd-Hu$$

flow is critical if $\chi \geq 2$

for trans. flow regime

$Rd < R*d$ – gated flow

$Rd > R*d$ – pressur. flow

4. Transitional flow

$$R*d=\frac{1}{9}\left[1.75\frac{Yo-0.90}{Yo-0.64}-1\right]$$

$$Rd=\frac{gL_{d}n^{2}}{D^{\frac{4}{3}}}$$

$$Q=q_{d}(gD^{5})^{\frac{1}{2}};$$

$$gated\ flow\ q_{d}=0.71(Yo-0.64)^{\frac{1}{2}}$$

$$Pressurised\ flow\ q_{d}=0.94\left[\frac{Yo+j_{d}-1}{1+9j_{d}\chi_{d}^{-2}}\right]^{\frac{1}{2}}$$

$$Yo=\frac{Ho}{D},\ j_{d}=So\frac{L_{d}}{D}$$