APPENDIX 3.5.5

Hydraulic analysis and design of a Round Culvert- EXAMPLE

Site Parameter	**Value**
Site location	Northwest side Vancouver Island
Fish inventory	Not fish bearing
Average Q2 HWM stream channel width	2.7 m
Upstream Drainage area	34 ha or 0.34 km^2
Longest channel path	450 m
Average stream gradient	36%
Stream gradient 100m upstream of crossing	25%
Channel substrate	Gravel 40%, cobbles 40%, boulders 20%
Rational C value	0.7
Mannings n value	0.05

Example of Culvert sizing procedure.

No stream gauge in close proximity

- Closest IDF rain gauge- Port Hardy – North East side Vancouver Island (receives less rain than West side)

3 X Bankfull Method:

(see Appendix 3.5.4 for detailed description of procedure)

Average Q2 HWM width X Depth = 2.7 m X 0.3 m= 0.81 m^2 x 3 = 2.43 m^2 - from table below design crossing with **1800mm** pipe.

Table 3.5.5.2

Cross Sectional area of pipe opening Ac (m^2)	**Pipe diameter (mm)**
0.13	400
0.20	500
0.28	600
0.50	800
0.64	900
0.79	1000
1.13	1200
1.54	1400

2.01	1600
2.54	1800

However this is only ONE method, and it depends on how closely the reach immediately upstream of the crossing represents the parameters of the stream as a whole.

Rational Method:

Time of Concentration: small drainage area less than 5km^2 – 15 minutes

Use this as an input when using the IDF_CC tool to determine Rainfall Intensity under chosen climate change impact conditions.

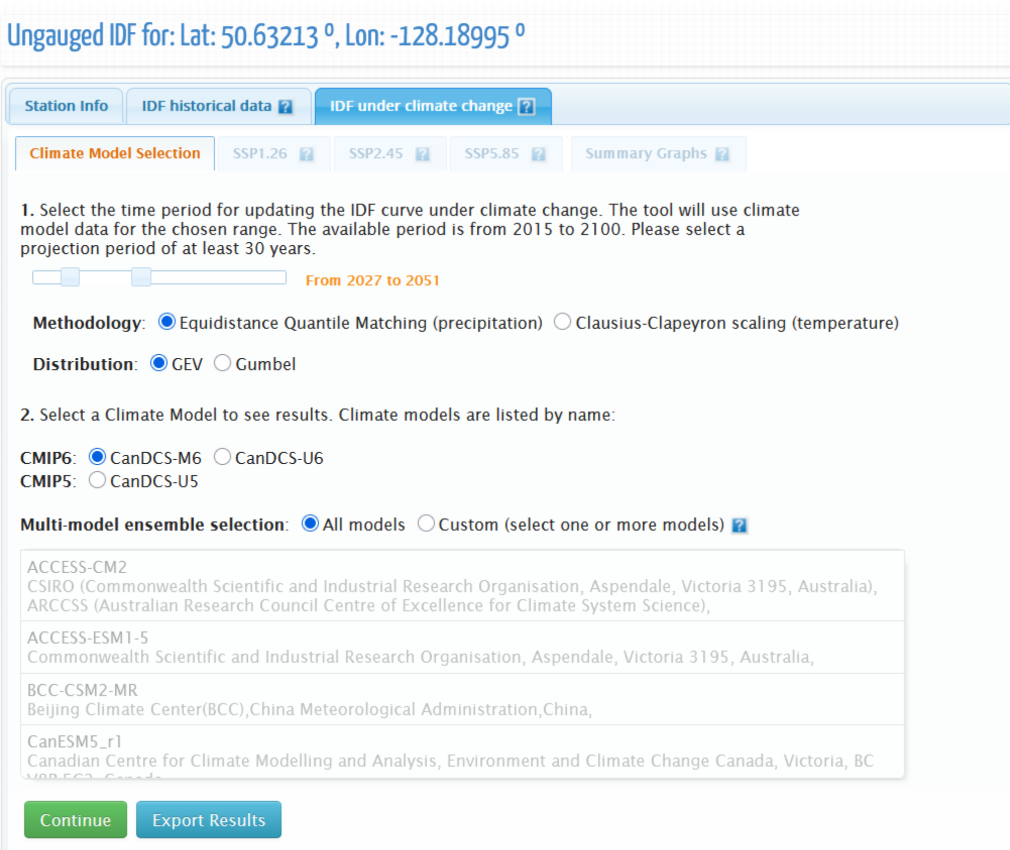
Access IDF_CC website at: www.idf-cc-uwo.ca/home#

Create a free account for yourself and take note of your password for future.

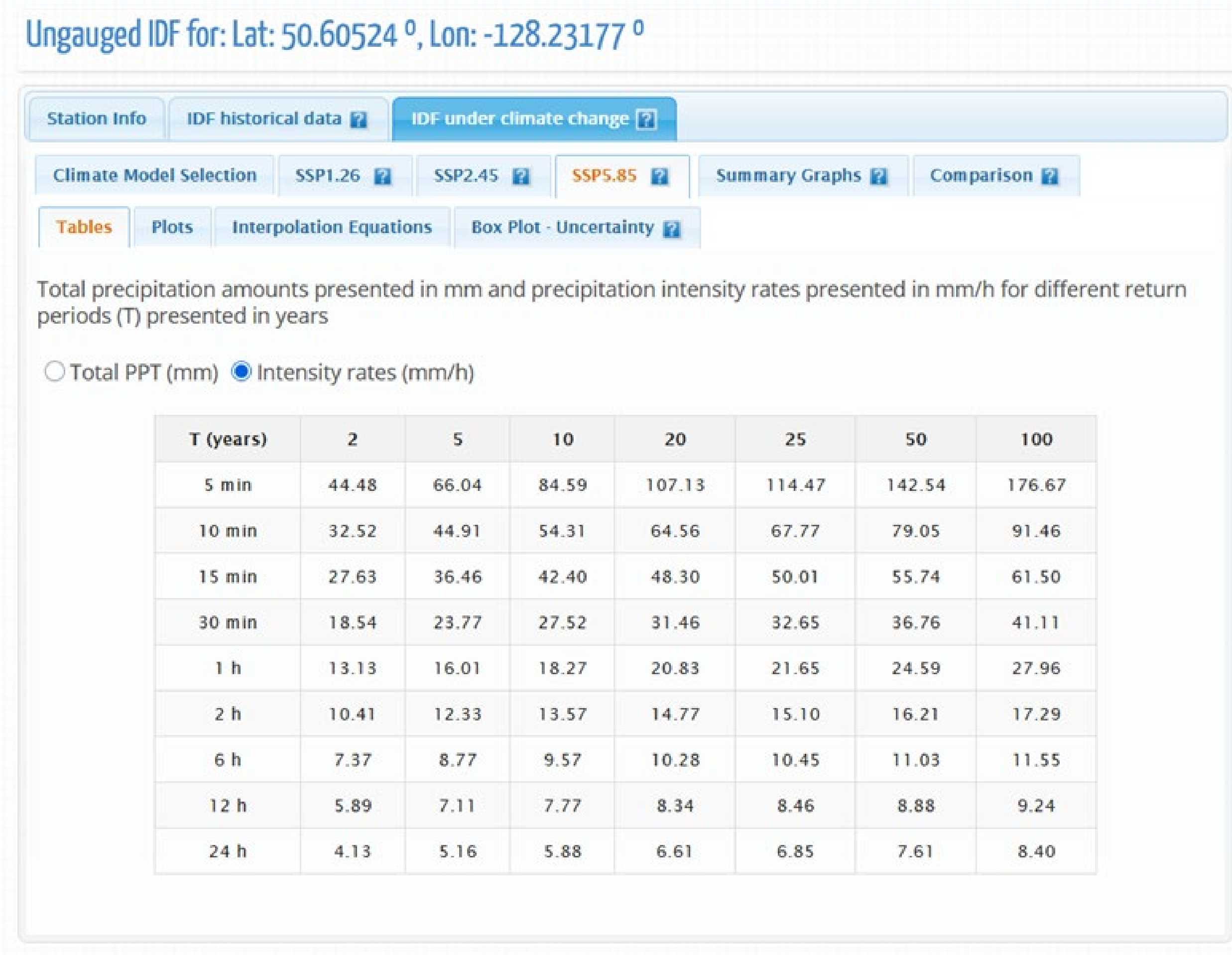
Use the map of IDF's for ungauged locations and select a point as near as possible to your crossing site.

Choose the IDF under climate change tab.

Select the time period which matches the required life span of your crossing.



Choose desired SSP 5.85 as this is the most conservative. Choose intensity rates (mm/h).



Ungauged IDF for: Lat: 50.60524 °, Lon: -128.23177 °

Station Info | IDF historical data | IDF under climate change

Climate Model Selection | SSP1.26 | SSP2.45 | SSP5.85 | Summary Graphs | Comparison

Tables | Plots | Interpolation Equations | Box Plot - Uncertainty

Total precipitation amounts presented in mm and precipitation intensity rates presented in mm/h for different return periods (T) presented in years

Total PPT (mm) Intensity rates (mm/h)

T (years)	2	5	10	20	25	50	100
5 min	44.48	66.04	84.59	107.13	114.47	142.54	176.67
10 min	32.52	44.91	54.31	64.56	67.77	79.05	91.46
15 min	27.63	36.46	42.40	48.30	50.01	55.74	61.50
30 min	18.54	23.77	27.52	31.46	32.65	36.76	41.11
1 h	13.13	16.01	18.27	20.83	21.65	24.59	27.96
2 h	10.41	12.33	13.57	14.77	15.10	16.21	17.29
6 h	7.37	8.77	9.57	10.28	10.45	11.03	11.55
12 h	5.89	7.11	7.77	8.34	8.46	8.88	9.24
24 h	4.13	5.16	5.88	6.61	6.85	7.61	8.40

Intensity for 100-year return (ToC = 15 mins) with worst case scenario climate change factor applied: 61.5 mm/hr

This is the input 'i' in the Rational formula:

Rational formula (metric):

Q_p=CiA/362

Q_{100} = (0.7) (61.5 mm/hr) (34ha) / 362 = **4.04 m^3/s**

This is the volume of flow per second of the stream at the 100 year design storm in the natural channel, just before it enters the culvert barrel.

CULVERT HYDRAULICS

Though the 3X bankfull method resulted in a cross-sectional area for the peak flow just before it enters the culvert pipe barrel, water is obviously not a solid and does not maintain the same shape as it travels through the pipe. The movement of water and the effects of friction and head or head loss are described as the flow regime or the hydraulics of the fluid system.

Hydraulic calculations are typically more complicated for culverts than for bridges due to factors such as shape, burial depth, and the potential for full-pipe flow. Professional Engineers should be engaged when considering the hydraulics of a major culvert.

To determine whether a particular pipe diameter is adequate to manage the design flow under the desired flow conditions, designers must select a trial size and then determine whether this pipe size is adequate to handle the flow under both **inlet control** and **outlet control** conditions or flow regimes. The trial size could be selected based on channel width and site conditions, or selected from the results of the 3X Bankfull Method.

See **Engineering Manual Section 3.5.4.1.2** for description of Inlet Controlled and Outlet Controlled Flow.

Returning to the example with Q_{100} discharge estimated at **4.04 m^3/s**. Start with proposed pipe diameter of 1800 mm with projecting pipe at the inlet. (This was the proposed culvert size from the 3X Bankfull method). The Inlet and Outlet Regime tests will confirm whether this proposed culvert size is adequate for the Q_{100} design flow of 4.04m^3/s.

Use the appropriate Inlet Control nomograph (see **Appendix 3.5.5.1** for all nomographs)

For example, if we were to start with a smaller pipe- a 1200mm pipe does not result in a Hw/D <1.0, therefore it does not meet the design standard. Try a larger pipe diameter- ie. The 1800mm pipe suggested by the 3X Bankfull example.

Use of nomograph for Inlet Control

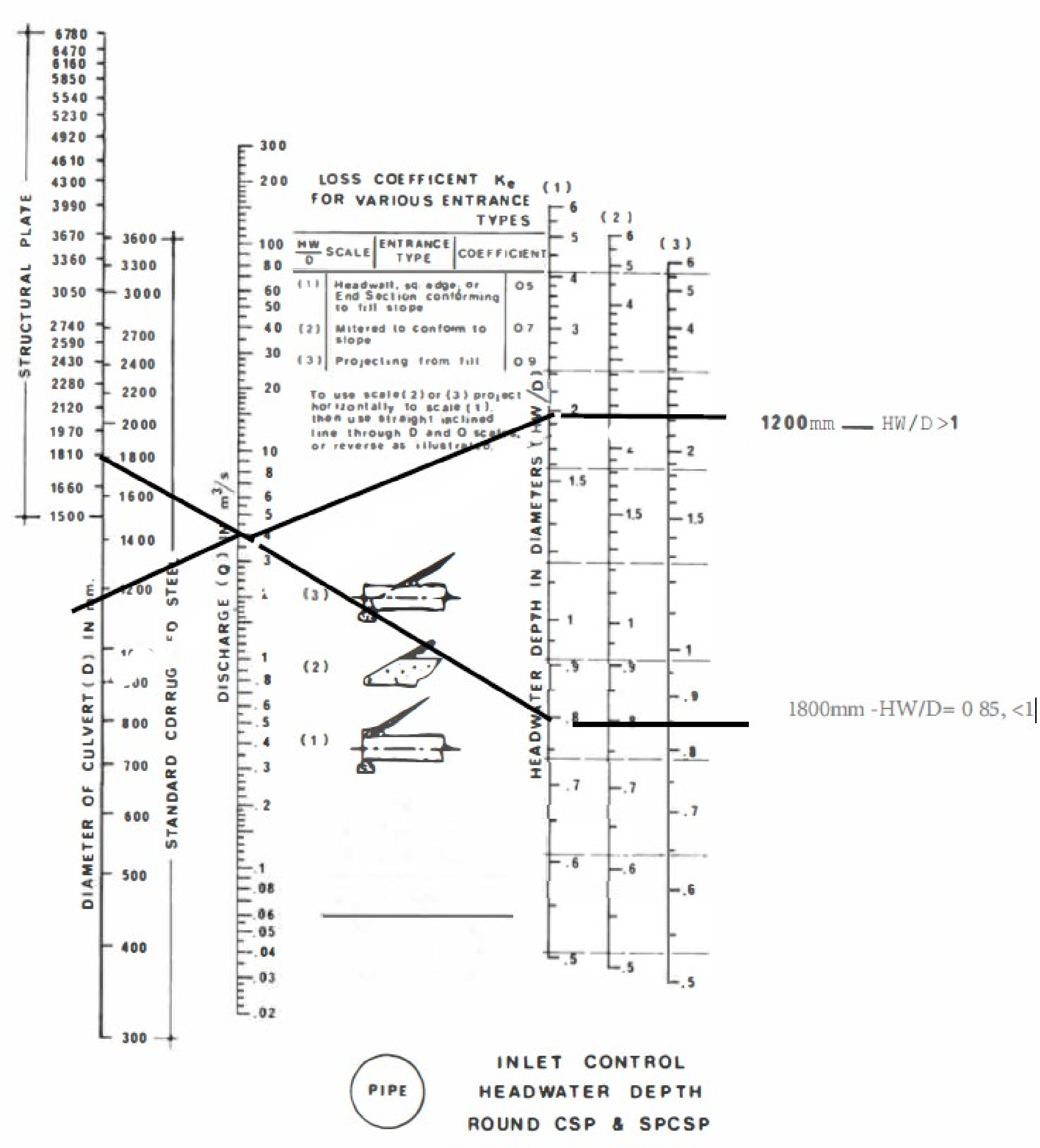


Figure 4.10 Headwater depth for round corrugated steel pipe and structural plate corrugated steel pipe under inlet control.

Inlet control suggests an 1800mm pipe diameter to meet requirement of HW/D < 1.0.

Culvert Length

Determine the culvert length (measured along the invert or bottom of the culvert) from the distance between the toes of the embankment, plus 1 m in gravelly soils or 2 m in silty soils.

This length may be estimated at this stage, using the road width and fill depth.

Check with nomograph for Outlet Control.

Source of nomographs: '*Handbook of Steel Drainage and Highway Construction*', Canadian Corrugated Steel Pipe Institute

To check HW under outlet control, use the following formula:

$HW = h_0 + H - LS_0$

Where $h_0 =$ the greater of tailwater (TW) or $(d_c + D)/2$, where d_c is the critical depth- found from the following nomograph: (*$(d_c + D)/2$ is usually greater than the TW when the water surface elevation downstream of the pipe is low, allowing the outlet to flow freely. The 25% gradient of the example crossing indicates that this is the case*.)

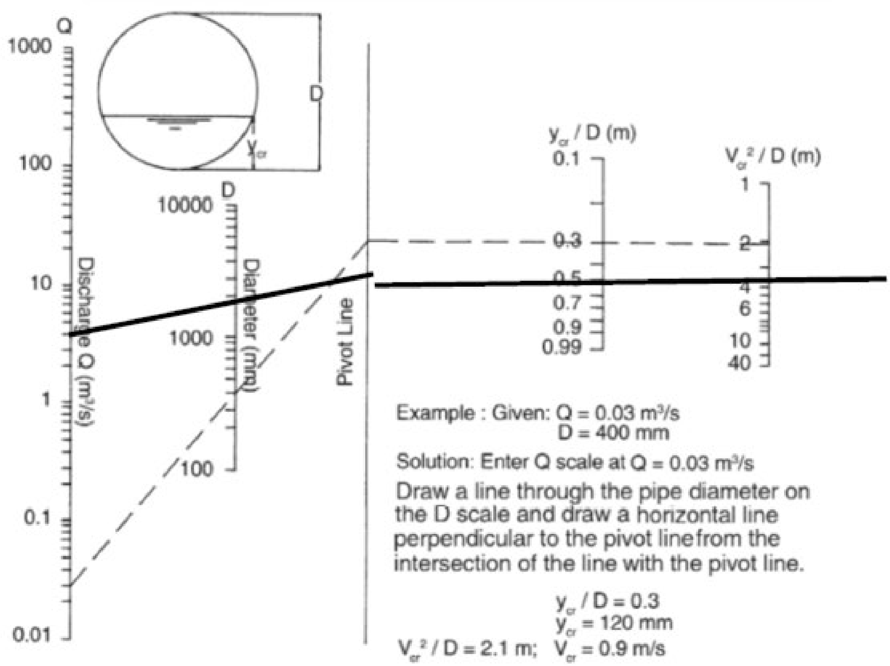


Figure 4.25 Critical depth for round corrugated steel and structural plate corrugated steel pipe.

Ycr/D= 0.5
D=1.8m
Ycr=0.9m
= critical
depth

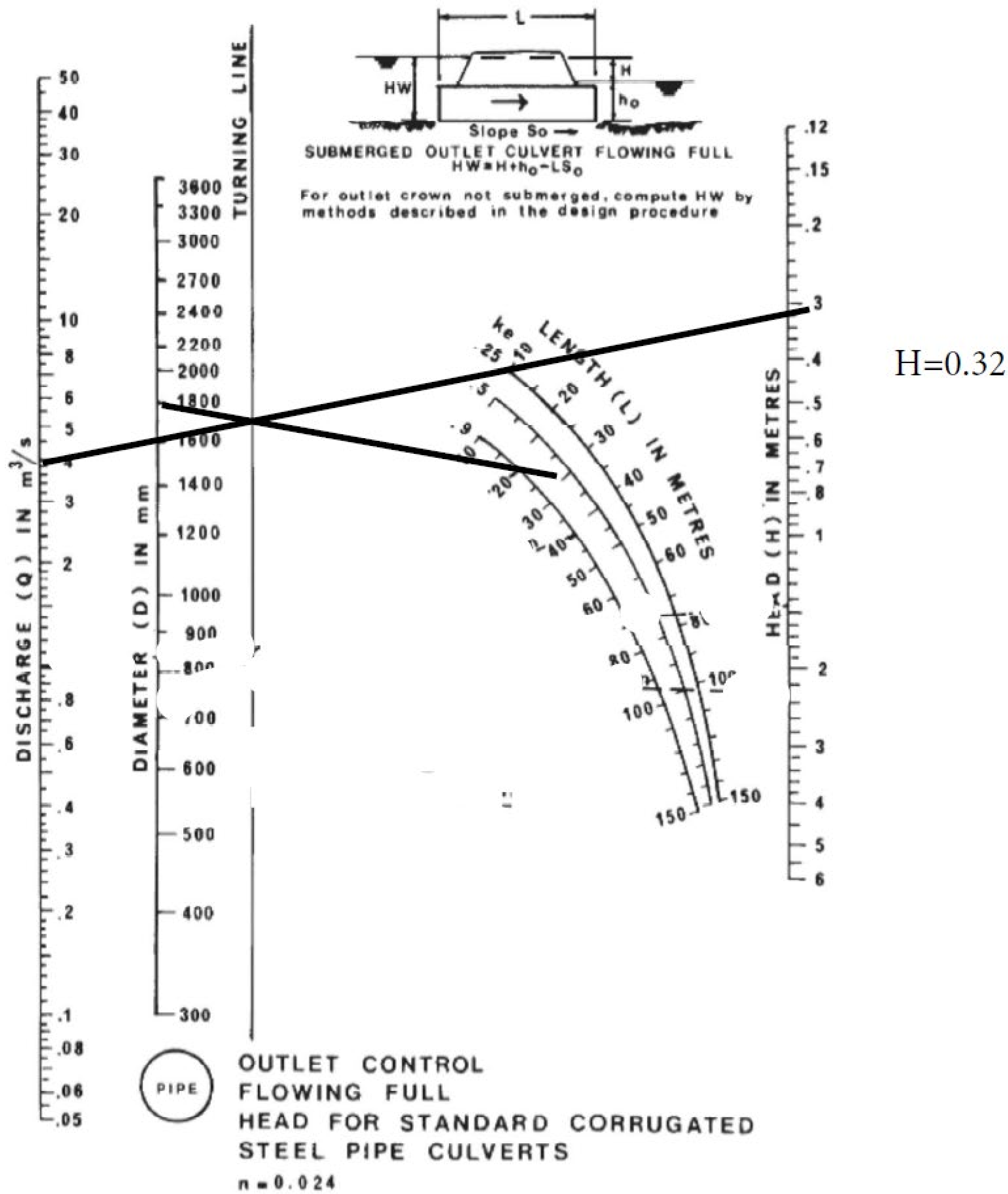


Figure 4.17 Head for round corrugated steel pipe flowing full under outlet control.

So h_0= (0.9 m +1.8 m) / 2= 1.35

HW= 1.35 +0.32 – (15 m) (0.25)

HW= -2.1 m, HW/D= -1.16

As HW/D under inlet control (0.85) is greater than HW/D under outlet control (-1.167), the culvert should be designed for inlet control and a diameter of **1800 mm meets the design criteria**.

For areas with significant topographic relief, culverts are generally inlet controlled, whereas culverts in low-lying, flat terrain areas may be under inlet control for low flow conditions but will typically be under outlet control for design flows and high discharge conditions.

Cover/ fill depth on top of round pipe culverts

Ensure road fill on top of culverts is well drained, coarse grained, well graded material. Cover fill must be compacted to a minimum density of 85% Standard Proctor. The minimum depth of cover should be in accordance with the Canadian Highway Bridge Design Code (CHBDC), as follows:

The largest depth of either:

A) 0.6 m
B) $D_h/6 *(D_h/D_v)^{1/2}$, in m
C) $0.4*(D_h/D_v)^2$, in m

Where D_h = horizontal dimension of the structure- diameter of pipe/ arch

D_v = vertical dimension of the structure, height of arch

For a round pipe $D_h/D_v = 1$

The depth of cover will also depend on the thickness and corrugation profile of the culvert pipe. The maximum cover depth will also depend on the design loading as at deeper depths, cover fill contributes more to dead load than to the strength of the soil metal structure.

See Appendix 3.5.5.2 for Cover depths for soil metal structures from the Handbook of Steel Drainage and Highway Construction.