TEXAS TECH UNIVERSITY
J. H. MURDOUGH
ASCE STUDENT CHAPTER

HW #8

NAME ______ DATE ______

COURSE CE 5360 ______ SHEET ______ OF ______

16.2.2 Given: Rework Ex. 16.2.1 w/ 5ft x 5ft culvert, 45° beveled-edge entrance

$Q = 300$ cfs Shoulder Elev = 113.5 ft

Stream bed elev @ culvert face = 100.0 ft $= EL_i$

Natural slope = 2.0% Tailwater depth = 4.0 ft

$L = 250$ ft no fall

Max allowable HW elev = 110.0 ft

Designed for outlet control

Find: Is culvert performance acceptable?

Consider outlet control & EL_{ho}

20 total

(1) Tailwater depth $TW = 4.0$ ft Given

(2) Critical depth $d_c = \left[\frac{q^2}{g}\right]^{1/3}$

$$q = \frac{Q}{b} = \frac{300 \text{ cfs}}{5 \text{ ft}} = 60 \text{ ft}^2/\text{s}$$

$$d_c = \left[\frac{(60 \text{ ft}^2/\text{s})^2}{32.2 \text{ ft/s}^2}\right]^{1/3} = 4.82 \text{ ft}$$

(3) $$\frac{d_c + D}{2} = \frac{4.82 \text{ ft} + 5.0 \text{ ft}}{2} = 4.91 \text{ ft}$$

(4) $h_o = \max\left[TW, \frac{d_c+D}{2}\right] = \max\left[4.82 \text{ ft}, 4.91 \text{ ft}\right]$

$h_o = 4.91$ ft

(5) Table 16.2.3 entrance loss coefficient $K_e = 0.2$

(6) Head losses through culvert barrel

$$H = \left[1 + K_e + \frac{29 n^2 L}{R^{4/3}}\right]\frac{V^2}{2g}$$

$$V = \frac{Q}{A} = \frac{300 \text{ cfs}}{(5 \text{ ft})(5 \text{ ft})} = 12 \text{ ft/sec}$$

$$R = \frac{A}{P} = \frac{(5 \text{ ft})(5 \text{ ft})}{4(5 \text{ ft})} = 1.25 \text{ ft} \qquad n = 0.012$$

$$H = \left[1 + 0.2 + \frac{29(0.012)^2(250 \text{ ft})}{(1.25 \text{ ft})^{4/3}}\right]\frac{(12 \text{ ft/s})^2}{2(32.2 \text{ ft/s}^2)}$$

$$= \left[1 + 0.2 + 0.78\right] 2.24 \text{ ft}$$

$H = 4.43$ ft

(7) $\underset{4 \text{ ft}}{TW} < \underset{5 \text{ ft}}{D}$, Partly full flow at exit. Backwater would be better

(8) $EL_{ho} = EL_o + H + h_o$

$EL_o = EL_i - S_o L = 100 \text{ ft} - (0.02)(250 \text{ ft}) = 95 \text{ ft}$

$EL_{ho} = 95 \text{ ft} + 4.43 \text{ ft} + 4.91 \text{ ft} = 104.34 \text{ ft}$

(9) $EL_{hi} = HW_i + EL_i$

$$\frac{HW}{D} = C\left[\frac{Q}{AD^{0.5}}\right]^2 + Y + Z$$

Table 16.2.1 $C = 0.034$ $Y = 0.82$

90° headwall w/45° bevels

If $c = 0.0327$, $Y = 0.75$
45° bevels, 10-45° w/alls
$c = 0.0123$
$Y = 0.82$

$$\frac{HW}{D} = 0.034\left[\frac{(300cfs)}{(25ft^2)(5ft)^{1/2}}\right]^2 + 0.82 - 0.5(0.02)$$

$$\frac{HW}{D} = 1.71$$

$\frac{HW}{D} = 1.68$ 2.02

Check $\frac{Q}{AD^{0.5}} = \frac{300\,cfs}{(25ft^2)(5ft)^{1/2}} = \underline{5.37 > 4}$ ok

$$HW_i = \left[\frac{HW}{D}\right]D = (1.71)5ft = 8.56ft$$

$HW_i = 8.40$ ft 10.1

$\underline{EL_{hi}} = 8.56ft + 100ft = \underline{108.56ft}$

108.40 ft $\underline{110.1}$

$EL_{hi} > EL_{ho}$ ✓ $EL_{hi} < 110 ft$ ✓ $\underline{ok}$

108.56 ft 104.34 ft

16.2.4 Given: Culvert Design for $Q = 200$ cfs. Circular CMP w/ std $2\text{-}2/3 \times 1/2$ corrugations & beveled edges. $L = 200$ ft, $S_0 = 1\%$, No Fall

Elev at culvert surface $= 100$ ft, Shoulder Elev $= 110$ ft, 2-ft FB

$TW = 3.5$ ft

Find: Select Diameter & analyze design

20 Total

1st Trial: I'll use $D = 5$ ft w/ headwall

(1) $TW = 3.5$ ft

(2) critical depth $\dfrac{Q^2 B_c}{g A_c^3} = 1 \Rightarrow \dfrac{Q^2}{g} = \dfrac{A_c^3}{B_c} = \dfrac{\left[(\theta - \sin\theta)\frac{D^2}{8}\right]^3}{D \sin\theta/2}$

$\theta = 2\cos^{-1}\left[1 - 2\frac{y}{D}\right]$

$D = 5$ ft, $Q = 200$ cfs, $g = 32.2$ ft/s²

Using Goal Seek in Excel $y_c = 4.04$ ft

(3) $\dfrac{d_c + D}{2} = \dfrac{4.04\text{ ft} + 5\text{ ft}}{2} = 4.52$ ft

(4) $h_o = \max\left[TW, \frac{d_c + D}{2}\right] = \max[3.5\text{ ft}, 4.52\text{ ft}] = 4.52$ ft

(5) Table 16.2.3 $K_e = 0.2$ CMP, beveled edges

(6) $H = \left[1 + K_e + \dfrac{29 n^2 L}{R^{4/3}}\right]\dfrac{V^2}{2g}$

$n = 0.022$ to 0.027 → I'll use 0.025 Table 16.2.2

$R = \dfrac{A}{P} = \dfrac{D}{4} = \dfrac{5\text{ ft}}{4} = 1.25$ ft

$V = \dfrac{Q}{A} = \dfrac{200\text{ cfs}}{\pi(2.5\text{ ft})^2} = 10.1$ ft/s

$H = \left[1 + 0.2 + \dfrac{29(0.025)^2(200\text{ ft})}{(1.25\text{ ft})^{4/3}}\right]\dfrac{(10.1\text{ ft/s})^2}{2(32.2\text{ ft/s}^2)} = [1 + 0.2 + 2.69](1.58\text{ ft})$

$H = 6.15$ ft

(7) $TW < D$, partly full at exit

(8) $El_{h_o} = El_o + H + h_o$

$El_o = El_i - S_o L = 100\text{ ft} - 0.01(200\text{ ft}) = 98$ ft

$El_{h_o} = 98\text{ ft} + 6.15\text{ ft} + 4.52\text{ ft} = 108.67$ ft

(9) $El_{h_i} = HW_i + El_i$

$\dfrac{HW_i}{D} = c\left[\dfrac{Q}{AD^{0.5}}\right]^2 + Y + Z$ Table 16.2.1 $c = 0.0379$, $Y = 0.69$

$= 0.0379\left[\dfrac{200\text{ cfs}}{(19.6\text{ ft}^2)(5\text{ ft})^{1/2}}\right]^2 + 0.69 - 0.5(0.01) = 1.47$

check $\dfrac{Q}{AD^{0.5}} = \dfrac{200\text{ cfs}}{(19.6\text{ ft}^2)(5\text{ ft})^{1/2}} = 4.56 > 4$ ok

$HW_i = D\left(\dfrac{HW_i}{D}\right) = 5\text{ ft}(1.47) = 7.35$ ft

$El_{h_i} = 7.35\text{ ft} + 100\text{ ft} = 107.35$ ft

$El_{h_o} > El_{h_i}$, $El_{h_o} > 108$ ft so no good

108.67 107.35

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I'll do a second trial just to get one that works.

Set $\underline{D = 6\text{ ft}}$

① $TW = 3.5\text{ ft}$

② Critical depth $D = 6\text{ ft}$, $Q = 200\text{ cfs}$ ⇒ Goal Seek ⇒ $\underline{y_c = 3.87\text{ ft}}$

③ $\dfrac{d_c + D}{2} = \dfrac{3.87\text{ ft} + 6\text{ ft}}{2} = \underline{4.94\text{ ft}}$

④ $\underline{h_o} = \max\left[TW, \dfrac{d_c + D}{2}\right] = \max\left[3.5\text{ ft}, 4.94\text{ ft}\right] = \underline{4.94\text{ ft}}$

⑤ $k_e = 0.2$

⑥ $V = \dfrac{Q}{A} = \dfrac{200\text{ cfs}}{\pi(3\text{ ft})^2} = \dfrac{200\text{ cfs}}{28.3\text{ ft}^2} = 7.07\text{ fps}$

$R = \dfrac{D}{4} = \dfrac{6\text{ ft}}{4} = 1.5\text{ ft}$

$H = \left[1 + 0.2 + \dfrac{29(0.025)^2(200\text{ ft})}{(1.5\text{ ft})^{4/3}}\right]\dfrac{(7.07\text{ fps})^2}{2(32.2\text{ ft/s}^2)} = [1.2 + 2.1]\ 0.78\text{ ft}$

$\underline{H = 2.58\text{ ft}}$

⑦ $TW < D$, partly full at outlet

⑧ $EL_{ho} = EL_o + H + h_o$

$= 98\text{ ft} + 2.58\text{ ft} + 4.94\text{ ft}$

$\underline{EL_{ho} = 105.52\text{ ft}}$

⑨ $\dfrac{Q}{AD^{0.5}} = \dfrac{200\text{ cfs}}{(28.3\text{ ft}^2)(6\text{ ft})^{1/2}} = 2.88 < 4.0$

$\dfrac{HW_i}{D} = K\left[\dfrac{Q}{AD^{0.5}}\right]^M + Z$ $K = 0.0078$ $M = 2.0$ Table 16.2.1

$= 0.0078\,[2.88]^2 - 0.5(0.01)$

$= 0.060$

$HW_i = (6\text{ ft})(0.060) = 0.36\text{ ft}$

$\underline{EL_{hi}} = HW_i + EL_i = 0.36\text{ ft} + 100\text{ ft} = \underline{100.36\text{ ft}}$

$EL_{ho} > EL_{hi}$, $\underline{EL_{hi} < 108\text{ ft}}$ OK

105.52 100.36

↑

30 total

16.2.6 Given: Rework Ex. 16.2.2 for performance curve for 8ft x 7ft (vertical) concrete box culvert, square edged entrance.

$L = 200\,ft$ centerline roadway elevation = 116 ft

Q (cfs)	TW (ft)	Elev (ft)	Q width (ft)
400	2.6	116	0
600	3.1	116.5	100
800	3.8	117	150
1000	4.1	117.5	200
1200	4.5	118	250
		119	300

Find: Performance Curve

$D = 7\,ft$ $\quad K_e = 0.5$ (Table 16.2.3) $\quad n = 0.012$ $\quad C = 0.0423$ $\quad Y = 0.82$

like 16.2.1 Example
you can choose others

$$S_0 = \frac{100 - 90\,ft}{200\,ft} = 0.05$$

Setup equations for spreadsheet

(1) $$d_c = \left[\frac{q_c^2}{g}\right]^{1/3} = \left[\frac{(Q/8ft)^2}{32.2\,ft/s^2}\right]^{1/3}$$ if $d_c > 7\,ft$ set $d_c = 7\,ft = D$

TW in table above

(2) $$\frac{d_c + D}{2} = \frac{d_c + 7ft}{2}$$

(3) $$h_o = \max\left[TW, \frac{d_c + D}{2}\right]$$

$\boxed{10}$

(4) $$H = \left[1 + K_e + \frac{29 n^2 L}{R^{4/3}}\right]\frac{V^2}{2g}$$

$$V = \frac{Q}{(7ft)(8ft)} = \frac{Q}{56\,ft^2}$$

$$R = \frac{A}{P} = \frac{(8ft)(7ft)}{2(8ft + 7ft)} = 1.87\,ft$$

$$H = \left[1 + 0.5 + \frac{29(0.012)^2(200ft)}{(1.87ft)^{4/3}}\right]\frac{Q^2}{2(32.2\,ft/s^2)(56ft^2)} = 1.86\left[4.95\times10^{-6} Q^2\right]$$

(5) $K_e = 0.5$

(6) $EL_{h_o} = EL_o + H + h_o$

$EL_o = EL_i - S_0 L = 90\,ft$

(7) $EL_{h_i} = HW_i + EL_i$

$EL_i = 100\,ft$

$$\frac{HW}{D} = 0.0423\left[\frac{Q}{(56ft^2)(7ft)^{1/2}}\right]^2 + 0.82 - 0.5(0.05)$$ if $\frac{Q}{AD^{0.5}} > 4.0$

$$HW_i = D\left(\frac{HW}{D}\right) = 7ft\left[\frac{HW}{D}\right]$$

if $\frac{Q}{AD^{0.5}} < 3.5$ $\quad \frac{HW}{D} = K\left[\frac{Q}{AD^{0.5}}\right]^M + Z$

$K = 0.061$
$M = 0.75$

(8) If controlling EL is above 116 ft

$Q_{over} = C_d L (HW_r)^{3/2}$

C_d from figs

Problem 16.2.6

Given

L =	200 ft	ELi =	100 ft	Lr =	40 ft
Road elev =	116 ft	ELo =	90 ft		
D =	7 ft				
W =	8 ft				
Ke =	0.5				
C =	0.0423	K =	0.061		
Y =	0.82	M =	0.75		
So =	0.05				

		Inlet Control			Outlet Control						Control
Inlet Q	Q/(AD^0.5)		HWi	ELhi	TW	dc	(dc+D)/2	ho	H	ELho	
(cfs)		HW/D	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	(ft)	Elev (ft)
400	2.70	0.10	0.72	100.72	2.60	4.27	5.63	5.63	1.47	97.11	100.72
600	4.05	1.49	10.42	110.42	3.10	5.59	6.30	6.30	3.31	99.61	110.42
700	4.72	1.74	12.17	112.17	3.40	6.20	6.60	6.60	4.51	101.11	112.17
750	5.06	1.88	13.15	113.15	3.50	6.49	6.74	6.74	5.18	101.92	113.15
800	5.40	2.03	14.20	114.20	3.80	6.77	6.89	6.89	5.89	102.78	114.20
850	5.74	2.19	15.31	115.31	3.88	7.00	7.00	7.00	6.65	103.65	115.31
900	6.07	2.36	16.49	116.49	3.95	7.00	7.00	7.00	7.46	104.46	116.49
950	6.41	2.53	17.74	117.74	4.03	7.00	7.00	7.00	8.31	105.31	117.74
1000	6.75	2.72	19.05	119.05	4.10	7.00	7.00	7.00	9.21	106.21	119.05

Inlet Q	Control	HWr	L	HWr/Lr	Cd	Qo	Total Q
(cfs)	Elev (ft)	(ft)	(ft)			(cfs)	(cfs)
400	100.72	-	-	-	-	0	400
600	110.42	-	-	-	-	0	600
700	112.17	-	-	-	-	0	700
750	113.15	-	-	-	-	0	750
800	114.20	-	-	-	-	0	800
850	115.31	-	-	-	-	0	850
900	116.49	0.49	100	0.01	2.70	93	993
950	117.74	1.74	224	0.04	2.93	1504	2454
1000	119.05	3.05	300	0.08	3.04	4866	5866

C_d from Figure 16.2.11(b) $k_t = 1$