TEXAS TECH UNIVERSITY
J. H. MURDOUGH
ASCE STUDENT CHAPTER

HW #8

NAME ______ DATE ______

COURSE CE 5360 ______ SHEET ______ OF ______

20 total

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 fill

Max allowable HW elev = 110.0 ft

Designed for outlet control

Find: Is culvert performance acceptable?
Consider outlet control & $EL_{ho}$

(1) Tailwater depth $\underline{TW = 4.0 \text{ ft}}$  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) $$h_o = \max\left[TW, \frac{d_c + D}{2}\right] = \max\left[4.82 \text{ ft}, 4.91 \text{ ft}\right]$$

$$\underline{h_o = 4.91 \text{ ft}}$$

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

(6) Head losses through culvert barrel

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

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

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

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

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

$$\underline{H = 4.43 \text{ ft}}$$

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

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

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

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

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(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

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

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

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

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

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

$EL_{hi} > EL_{ho}$ ✓
108.56 ft  104.34 ft

$EL_{hi} < 110\,ft$ ✓ ok

If $C = 0.0327$, $Y = 0.75$
45° bevels, 10–45° w/ [illegible]
$C = 0.0423$
$Y = 0.82$

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

$HW_i = 8.40\,ft$  10.1

108.40 ft  110.1

16.2.41 Given: Culvert Design for $Q = 200$ cfs. Circular CMP w/ std 2-2/3 x 1/2 corrugations & beveled edges. $L = 200$ ft $S_o = 1\%$ No Fall

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

$TW = 3.5$ ft

Find: Select Diameter & analyze design

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

20 Total

① $TW = 3.5$ ft

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

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

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

Using Goal Seek in Excel $y_c = 4.04$ ft

③ $\frac{d_c + D}{2} = \frac{4.04\text{ ft} + 5\text{ ft}}{2} = 4.52$ 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 $H = \left[1 + K_e + \frac{29 n^2 L}{R^{4/3}}\right]\frac{V^2}{2g}$

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

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

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

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

$H = 6.15$ 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 $El_{h_i} = HW_i + El_i$

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

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

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

$HW_i = D\left(\frac{HW_i}{D}\right) = 5\text{ ft}(1.47) = 7.35$ 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 $D = 6$ ft

① TW = 3.5 ft

② Critical depth $D = 6$ ft, $Q = 200$ cfs ⟹ Goal Seek ⟹ $y_c = 3.87$ ft

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

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

⑤ $k_e = 0.2$

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

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

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

$H = 2.58$ ft

⑦ TW < D, partly full at outlet

⑧ $EL_{ho} = EL_o + H + h_o$
$= 98\text{ ft} + 2.58\text{ ft} + 4.94\text{ ft}$

$EL_{ho} = 105.52$ ft

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

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

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

$= 0.060$

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

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

$EL_{ho} > EL_{hi}$ , $EL_{hi} < 108$ 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 $K_e = 0.5$ (Table 16.2.3) $n = 0.012$ $C = 0.0423$ $Y = 0.82$

$S_0 = \dfrac{100 - 90\text{ft}}{200\text{ft}} = 0.05$ like 16.2.1 Example you can choose others

Setup equations for spreadsheet

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

TW in table above

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

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

$\boxed{10}$

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

$V = \dfrac{Q}{(7\text{ft})(8\text{ft})} = \dfrac{Q}{56\text{ft}^2}$

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

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

(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

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

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

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

$K = 0.061$
$M = 0.75$

(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) $k_t = 1$