Exercise:
4) Culvert Design Exercise 4
Culvert Design Exercise 4

Problem: A hydrological analysis was completed for a basin above a proposed roadway and culvert crossing on SR 530. The analysis found that the 25-year flow event was 300 cfs and the 100-year flow event was 390 cfs. In the vicinity of the round culvert, the preferable roadway profile would place the centerline at elevation 1,530 feet, about 10 feet higher than the existing channel bottom. The tailwater depth was found to be 5 feet during the 25-year flow event and 5.5 feet during the 100-year flow event. Also, there are no fish passage concerns at this location. Assume that the culvert will be 100 ft long and will match the existing channel slope of 0.005 ft/ft (0.5%).

Determine the culvert size, and calculate the controlling headwater elevation and corresponding outlet velocity for both the 25- and 100-year events.
Culvert Design Exercise 4

Assumptions:
• Culvert will be circular and concrete
• Headwater to diameter ratio will be < or = 1.25 for the 25-year flow
• Culvert end will be left projecting out of the fill since the culvert ends will be out of the clear zone
Culvert Design Exercise 4

Question: Where do I begin? What’s the next step?

Where to start?
1. Use WSDOT Hydraulics Manual Figure 3-3.6B Culvert Hydraulic Calculations Form to document the culvert design
   a) Work in groups to figure out next steps!
   b) Use the Nomographs packet!
### Culvert Design Exercise 4

#### Hydrologic and Channel Information

- **Q1:** ____
- **TW1:** ____
- **Q2:** ____
- **TW2:** ____
- **Q3:** ____
- **TW3:** ____

#### Sketch

- **AHW:** ____
- **TW:** ____
- **Station:** ____

#### Headwater Computations

<table>
<thead>
<tr>
<th>Culvert Type</th>
<th>Q</th>
<th>Size</th>
<th>Inlet Control</th>
<th>Outlet Control</th>
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#### Summary and Recommendations:

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**Culvert Hydraulic Calculations Form**

*Figure 3-2.6b*

(WSDOT Form 235-006)
Culvert Design Exercise 4

STEPS TO SUCCESS!!!!

1) Fill out the culvert design form HM 3-3.6B
2) Use the 25-year storm coefficients and values
3) Determine the headwater elevation based on inlet control
4) Determine the headwater elevation based on outlet control
5) The higher of the 2 headwaters values will be controlling the culvert
6) Use the corresponding inlet or outlet control velocity equations to determine the outlet velocity and outlet protection
Culvert Design Exercise 4

1. Fill out HM 3-3.6B
2. Culvert type = “round”
3. Q25 = 300 cfs (given in problem statement)
4. To determine the culvert size, use Figure 3-3.4.2A “Concrete Pipe Inlet Control Nomograph”
   a) We know we want a HW/D of 1.25 or less so we assume a HW/D = 1.25
   b) Entrance type = Groove end projecting based on assumptions so use (3) column
Culvert Design Exercise 4

c) Draw horizontal line from 1.25 across to the left and stop on the (1) line (on 1.38)
d) Draw a straight line from that point through Q = 300 cfs and stop on the Diameter of Culvert line at about 74 inches.
e) Round up to the next culvert size = 84 inches
f) From 84 inches, draw a straight line through Q = 300 cfs and stop on the (1) line (on 1.05)
g) Draw a horizontal line across to (3) to show a HW/D = 1.0
Diameter = about 74” so round up to 84”
Culvert Design Exercise 4

Using an 84” diameter culvert, we get an HW/d of 1.0.
Culvert Design Exercise 4

h) On Figure 3-3.6B, list Size = “84 inches”
i) HW/D = “1.0”;
j) HW = 1.0 x 84/12 = “7.0 feet”
### Hydrologic and Channel Information

- **Q1:** __
- **TW1:** __
- **Q2:** __
- **TW2:** __
- **Q3:** __
- **TW3:** __

### Sketch

- **EL:** __
- **C:** __
- **AHW:** __
- **TW:** __
- **Station:** __
- **S0:** __
- **L:** __

### Headwater Computations

<table>
<thead>
<tr>
<th>Culvert Type</th>
<th>Q</th>
<th>Size</th>
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<th>Outlet Control</th>
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<td>HW D</td>
<td>HW</td>
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<td></td>
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<td>HW</td>
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### Summary and Recommendations:

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**Culvert Hydraulic Calculations Form**

*Figure 3-2.6b*

(WSDOT Form 235-006)
Culvert Design Exercise 4

5. We are done with inlet calculations. Now we start on outlet calculations to determine what the HW is.

6. $Ke = "0.2"$ for a concrete pipe projecting from fill using HM Figure 3-3.4.5H

7. Use Figure 3-3.4.5I to determine the critical depth for a $Q = 300$ cfs and diameter = 7.0 feet. $Dc = "4.6 feet"$
For a flow of 300 cfs and Diameter of 7 feet, Critical Depth = 4.6 feet
8. \((dc+D)/2 = (4.6+7)/2 = \text{"5.8 feet"}\)
9. \(Ho = \text{the larger of } (dc+D)/2 \text{ or the tailwater depth} \ (5.0 \text{ feet in problem). } \text{So ho = "5.8 feet"}\)
10. \(H \) (headloss in barrel of pipe and losses at entrance and exit of pipe) = equation 3-4 or use Figure 3-3.4.5B outlet control nomograph for concrete pipe
   a) Draw a line from 84 inch diameter pipe to the length = 100 on the Ke line = 0.2. this will give the cross point on the turning line.
   b) From 300 cfs, draw a line through the cross point on the turning line to the "H" line
Culvert Design Exercise 4

c) This will give $H = "1.2"$
The outlet control nomograph shows a head of 1.2 feet.
11. $L \times S_0 = 100 \times 0.005 = 0.5$ feet

12. HW for outlet control = equation 3-15 = $H + h_o - L \times S_0 = 1.2 + 5.8 - 0.5 = 6.5$ feet

13. Cont. HW = controlling headwater = larger of the inlet headwater vs outlet headwater = “7.0” feet; culvert is operating under inlet control

14. To determine the outlet velocity under inlet control conditions, see HM 3-3.5.1. For outlet control, see HM 3-3.5.2.

15. Velocity = “13.2 feet/sec” using equation 3-9
Culvert Design Exercise 4

**Culvert Design**

For circular culverts, a simplified version of Manning’s equation can be used to calculate the velocity in the culvert. The simplified equation for partial flow (10%-80%) is given by equation (3-9):

\[ V_n = \frac{0.863S^{0.66}Q^{0.268}}{D^{0.648}n^{0.732}} \]  

(3-9)

Where:

- \( S \) = Pipe slope (ft/ft)
- \( Q \) = Flow rate (cfs)
- \( D \) = Pipe diameter (ft)
- \( N \) = Manning’s roughness coefficient
- \( V_n \) = Normal velocity for partial flow (ft/s)
**Hydrologic and Channel Information**

<table>
<thead>
<tr>
<th>Q1:</th>
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<td>TW2:</td>
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<td>Q3:</td>
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**Sketch**

![Sketch of culvert design](image)

**Headwater Computations**

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<th>Culvert Type</th>
<th>Q</th>
<th>Size</th>
<th>HW D</th>
<th>HW</th>
<th>k₀</th>
<th>dₖ</th>
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**Inlet Control**

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<th>Outlet Vel.</th>
<th>Comments</th>
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**Summary and Recommendations:**

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**Culvert Hydraulic Calculations Form**

*Figure 3-3.6b*

(WSDOT Form 235-006)
16. Since the outlet velocity = 13.2 ft/sec, that is high per HM Figure 3-4.7.1 Outlet Protection Material Size; specify light loose riprap for outlet protection.

<table>
<thead>
<tr>
<th>Outlet Velocity (ft/sec)</th>
<th>Material</th>
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<tbody>
<tr>
<td>6-10 Quarry</td>
<td>Spalls</td>
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<tr>
<td>10-15</td>
<td>Light Loose Riprap</td>
</tr>
<tr>
<td>&gt;15 Heavy</td>
<td>Loose Riprap</td>
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</tbody>
</table>

Designers should provide geotextile or filter material between any outlet material and the existing ground for soil stabilization. See section 4-6.3.2 for information.
Culvert Design Exercise 4

We just finished calculations for the 25-year event. Next we want to repeat calculations for the 100-year flow $Q_{100} = 390$ cfs. First we will calculate the headwater for the inlet control case.
1. $HW/D = 1.18$ feet
2. $HW$ inlet control = 8.2 feet
Using and 84” diameter culvert, we get an HW/d of 1.18 at Q100 = 390 cfs

HW = 1.18 x 7 = 8.2 feet
### Culvert Design Exercise 4

#### Hydrologic and Channel Information

- **Q1:** __________
- **TW1:** __________
- **Q2:** __________
- **TW2:** __________
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#### Headwater Computations

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<td><strong>HW</strong></td>
<td><strong>D</strong></td>
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#### Sketch

- **Station:** __________

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**Culvert Hydraulic Calculations Form**  
*Figure 3-2.6b*

*(WSDOT Form 235-006)*
Culvert Design Exercise 4

Now we need to calculate the headwater for the outlet control condition and compare it to the inlet control headwater. Whatever is higher is the controlling headwater.

3. $\text{Ke} = 0.2$, look up in HM Figure 3-3.4.5H
4. $\text{dc} = 5.1$ feet
For a flow of 390 cfs and Diameter of 7 feet, Critical Depth = 5.1 feet
5. \( \frac{(dc+D)}{2} = \frac{(5.1 + 7)}{2} = 6.05 \text{ feet} \)

6. \( Ho = \) the larger of \( \frac{(dc+D)}{2} \) or the tailwater depth (5.5 feet at the 100-year event in problem).  \textbf{So ho = “6.05 feet”}

7. Need to calculate the headloss \( H \). We will use outlet control nomographs for this.
### Hydrologic and Channel Information

- **Q1:** __
- **Q2:** __
- **Q3:** __
- **TW1:** __
- **TW2:** __
- **TW3:** __

### Sketch

- **AHW:** __
- **TW:** __
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### Headwater Computations

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### Summary and Recommendations:

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**Culvert Hydraulic Calculations Form**

*Figure 3-3.6b*

(WSDOT Form 235-006)
Culvert Design Exercise 4

8. \( H \) (headloss in barrel of pipe and losses at entrance and exit of pipe) = equation 3-4 or use Figure 3-3.4.5B outlet control nomograph for concrete pipe
   a) Draw a line from 84 inch diameter pipe to the length = 100 feet on the Ke line = 0.2. this will give the cross point on the turning line.
   b) From 390 cfs, draw a line through the cross point on the turning line to the “H” line
The outlet control nomograph shows a head of 2.2 feet.
Culvert Design Exercise 4

9. \( L \times S_0 = 100 \times 0.005 = 0.5 \) feet
10. **HW for outlet control** = equation 3-15 = \( H + h_o - L \times S_0 = 2.2 + 6.05 - 0.5 = 7.75 \) feet
11. **Cont. HW = controlling headwater** = larger of the inlet headwater (8.2 feet) vs outlet headwater (7.75 feet) = “8.2” feet; culvert is operating under inlet control
12. To determine the outlet velocity under inlet control conditions, see HM 3-3.5.1. For outlet control, see HM 3-3.5.2.
13. Velocity = “14.1 feet/sec” using equation 3-9
Culvert Design

For circular culverts, a simplified version of Manning’s equation can be used to calculate the velocity in the culvert. The simplified equation for partial flow (10%–80%) is given by equation (3-9):

$$V_n = \frac{0.863S^{0.66}Q^{0.268}}{D^{0.648}N^{0.732}}$$  \hspace{1cm} (3-9)

Where:

- $S = \text{Pipe slope (ft/ft)}$
- $Q = \text{Flow rate (cfs)}$
- $D = \text{Pipe diameter (ft)}$
- $N = \text{Manning’s roughness coefficient}$
- $V_n = \text{Normal velocity for partial flow (ft/s)}$
### Culvert Design Exercise 4

#### Hydrologic and Channel Information

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#### Sketch

- ![Sketch Diagram](image)

#### Headwater Computations

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<th>Q</th>
<th>Size</th>
<th>HW</th>
<th>HW</th>
<th>k_o</th>
<th>d_k</th>
<th>d_k + D/2</th>
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<th>H</th>
<th>L</th>
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### Culvert Hydraulic Calculations Form

- **Figure 3-3.6b**

(WSDOT Form 235-006)
14. Since the outlet velocity = 14.1 ft/sec, that is high per HM Figure 3-4.7.1 Outlet Protection Material Size; specify light loose riprap for outlet protection
Culvert Design Exercise 4

We have completed Exercise 4 Culvert Design