Poll Question #1
PIPE

FL OTATION

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&
Jennifer Schaff
Outline

• Why do we care?
• What is buoyancy?
• TWO methods to account for this our designs
• Factors of Safety
• Where the rubber meets the road...example problems!
Flotation Failure
U.S. 2019 Billion-Dollar Weather and Climate Disasters

This map denotes the approximate location for each of the 14 separate billion-dollar weather and climate disasters that impacted the United States during 2019.
NOAA forecasters predict widespread flooding this spring, but do not expect it to be as severe or prolonged overall as the historic floods in 2019. Major to moderate flooding is likely in 23 states from the Northern Plains south to the Gulf Coast, with the most significant flood potential in parts of North Dakota, South Dakota and Minnesota.
Various levels of buoyancy depending on weight of the submerging body
HOW DOES SHE FLOAT?
Relative Weights

HDPE: \( \gamma = 60 \text{ lbs/ft}^3 \)

WATER: \( \gamma = 62.4 \text{ lbs/ft}^3 \)

CONCRETE: \( \gamma = 150 \text{ lbs/ft}^3 \)

STEEL: \( \gamma = 490 \text{ lbs/ft}^3 \)
Pipe Weights

V = 18.35 ft³/ft

62.4 lb/ft³

WATER
W = 1145 lb/ft

CONCRETE
W = 867 lb/ft

HDPE
W = 26 lb/ft

STEEL
W = 48 lb/ft

48” PIPE
Poll Question #2
Flotation Calculation

\[ \gamma = 120 \text{ lbs/ft}^3 \]

Soil Resistance + Pipe Weight – Buoyancy Force \( \geq 0.0 \)
Microstructure of Soil
Buoyant Weight of Soil

\[ \gamma_b = \gamma_t - \gamma_w \]

- \( \gamma_t \) = saturated unit weight of soil (pcf)
- \( \gamma_w \) = unit weight of water (pcf)
Methods of Calculating Soil Resistance for Buoyancy
Flotation of Circular Concrete Pipe

There are several installation conditions where there is the possibility that concrete pipe may float even though the density of concrete is approximately 2.4 times that of water. Some of these conditions are: the use of flooding to consolidate backfill; pipelines in areas which will be inundated, such as, a flood plain or under a future man-made lake; subaqueous pipelines; flowable fill installations; and pipelines in areas with a high groundwater table. When such conditions exist, flotation probability should be checked.

FLOTATION FACTORS

The buoyancy of concrete pipe depends upon the weight of the pipe, the weight of the volume of water displaced by the pipe, the weight of the liquid load carried by the pipe and the weight of the backfill. As a conservative practice in analysis, the line should be considered empty so the weight of any future liquid load is then an additional safety factor.

Pipe Weights

The average density of concrete is 150 pounds per cubic foot and the approximate weight per linear foot of circular concrete pipe may be calculated by the following equation:

\[ W_p = \frac{1}{4} (B_c^2 - D^2) 150 \]

Displaced Water Weight

When water is displaced a buoyant or upward force exists, and, if the buoyant force is greater than the weight of the object displacing the water, flotation will occur. The weight of fresh water displaced per linear foot of circular pipe can be calculated by the following equation:

\[ W_w = \frac{1}{4} (B_c^2) 62.4 \]

where

- \( W_w \) = weight of displaced water per linear foot, pounds,
- \( B_c \) = outside pipe diameter, feet.

The average weights of the volume of fresh water displaced per linear foot of C14 and C76 pipe are presented in Tables 3 and 4.

Backfill Weight

The weight of the backfill directly over the pipe assists in holding the pipe down. The unit weight of compacted backfill material varies with specific gravity, the grain size, and the degree of compaction. For preliminary computations, however, average values for surface dry
2 - Watkins/Moser (W/M)
Utah State
Required Information

\[ \gamma_t = \text{Saturated unit weight of soil (pcf)} \]
ACPA DD 22

\[ R_s = W_s = PL = \gamma_b \left[ H + \frac{D_o (4 - \pi)}{8} \right] D_o \]

Equation 4 – Concrete Pipe Design Manual
$\theta = 45 - \phi / 2$

$R_s = PL + 2X$

$2X = [(H + D_o / 2)^2 \tan(45 - \phi / 2)] \gamma_b$

$\phi = \text{internal angle of friction}$
\[ \phi = \text{internal angle of friction} \]
Poll Question #3

Which method accounts for a larger value for the soil resistance?

a. ACPA DD 22/ Column Method
b. The Bar Method
c. Watkins & Moser Method
d. The Numerical Method
Factors of Safety

Rigid Rugged Resilient
Factors of Safety -
Geotechnical Engineering –
LRFD Bridge Substructures

Slope Stability 1.3 to 1.5
Foundation Bearing Capacity 2 to 3
Foundation Sliding 1.5+
Foundation Overturning 2.0+
Example: RCP

- Buoyancy Force
- Soil Resistance
- Factor of Safety
Given:

- **RC Pipe Weight =** \( W_p = 867 \text{ lb/ft} \)
- **\( \gamma_t = 120 \text{ pcf} \)**
- **\( \phi = 30 \text{ deg} \)**
Is flotation a concern?

RC Pipe Weight = 
\[ W_p = 867 \text{ lb/ft} \]

Weight of Water Displaced = 
\[ W_w = \pi \left( \frac{d_o}{2} \right)^2 \gamma_w \]
\[ W_w = 1,145 \text{ lbs/ft} \]

BF = - 278 lb/ft
ACPA Method Concrete Pipe

What is the Soil Resistance?

\[ R_s = W_s = PL = \gamma_b \left[ H + \frac{D_o (4 - \pi)}{8} \right] D_o \]

Equation 4 – Concrete Pipe Design Manual

\[ R_s = (120 - 62.4) \left[ 1 + \frac{4.833 (4 - \pi)}{8} \right] 4.833 \]

\[ R_s = 423 \text{ lbs/ft} \]
Watkins/Moser Method Concrete Pipe

What is the Soil Resistance?

\[ \theta = 45 - \phi/2 \]

\[ R_s = PL + 2 \times \] \[ \frac{1}{2} \left[ \left( H + \frac{D_o}{2} \right)^2 \tan(45 - \phi/2) \right] \gamma_b \]

\[ 2 \times \left[ \left(1 + 4.833/2 \right)^2 \tan(45 - 30/2) \right] (120-62.4) \]

\[ R_s = 423 + 388 = 811 \text{ lbs/ft} \]
Results

**ACPA Method**

- Net force = (BF x FS) + Rs
  - = (-278 x 1.25) + 423 = 75 lbs

**Watkins/Moser Method**

- Net force = (BF x FS) + Rs
  - = (-278 x 2.0) + 811 = 255 lbs
RCP Results

<table>
<thead>
<tr>
<th>Method</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACPA</td>
<td>-278</td>
<td>423</td>
<td>1.25</td>
<td>75</td>
</tr>
<tr>
<td>W/M</td>
<td>-278</td>
<td>811</td>
<td>2.0</td>
<td>255</td>
</tr>
</tbody>
</table>
Poll Question #4
Example: CMP

- Buoyancy Force
- Soil Resistance
- Factor of Safety
Assume ground water level is at the surface

Existing Ground Surface

Given:

- CM Pipe Weight = \( W_p = 48 \text{ lb/ft} \)
- \( \gamma_t = 120 \text{ pcf} \)
- \( \phi = 30 \text{ deg} \)

- \( D_i = 48 \text{ inches} \)
- \( D_o = 49 \text{ inches} = 4.08 \text{ Ft} \)
Is flotation a concern?

CM Pipe Weight = $W_p = 48 \text{ lb/ft}$

Weight of Water Displaced

$W_w = \pi \left( \frac{d_o}{2} \right)^2 \gamma_w$

$W_w = 817 \text{ lbs/ft}$

$D_o = 49 \text{ inches} = 4.08 \text{ Ft}$

$BF = -769 \text{ lb/ft}$
ACPA Method Metal Pipe

What is soil resistance?

\[ R_s = W_s = PL = \gamma_b \left[ H + \frac{D_o (4 - \pi)}{8} \right] D_o \]

Equation 4 – Concrete Pipe Design Manual

\[ R_s = (120 - 62.4) \left[ 1 + \frac{4.08 (4 - \pi)}{8} \right] 4.08 \]

\[ R_s = 338 \text{ lbs/ft} \]
Watkins/Moser Method Metal Pipe

\[ \theta = 45 - \phi/2 \]

\[ R_s = PL + 2X \]

\[ 2X = [(H + D_o/2)^2 \tan(45 - \phi/2)] \gamma_b \]

\[ 2X = [(1 + 4.08/2)^2 \tan(45 - 30/2)] (120-62.4) \]

\[ R_s = 338 + 307 = 645 \text{ lbs/ft} \]

What is soil resistance?
# Results Metal Pipe

<table>
<thead>
<tr>
<th>Method</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance Rs (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACPA</td>
<td>-769</td>
<td>338</td>
<td>1.25</td>
<td>-623</td>
</tr>
<tr>
<td>W/M</td>
<td>-769</td>
<td>645</td>
<td>2.0</td>
<td>-893</td>
</tr>
</tbody>
</table>
Example: HDPE

- Buoyancy Force
- Soil Resistance
- Factor of Safety
Assume ground water level is at the surface

Existing Ground Surface

Given:

- HDPE Pipe Weight: \( W_p = 26 \text{ lb/ft} \)
- \( \gamma_t = 120 \text{ pcf} \)
- \( \phi = 30 \text{ deg} \)

\( D_i = 48 \text{ inches} \)

\( D_o = 54 \text{ inches} – \text{ use } 51” = 4.25 \text{ Ft} \)
Is flotation a concern?

HDPE Pipe Weight = $W_p = 26 \text{ lb/ft}$

Weight of Water Displaced

$W_w = \pi \left(\frac{d_o}{2}\right)^2 \gamma_w$

$W_w = 885 \text{ lbs/ft}$

$D_o = 51 \text{ inches} = 4.25 \text{ Ft}$

$BF = -859 \text{ lb/ft}$
ACPA HDPE Pipe

Equation 4 – Concrete Pipe Design Manual

\[ R_s = W_s = PL = \gamma_b \left[ H + \frac{D_o (4 - \pi)}{8} \right] D_o \]

\[ R_s = (120 - 62.4) \left[ 1 + \frac{4.25 (4 - \pi)}{8} \right] 4.25 \]

\[ R_s = 356 \text{ lbs/ft} \]
Watkins/Moser HDPE Pipe

\[ \theta = 45 - \phi/2 \]

\[ R_s = PL + 2X \]

\[ 2X = [(H + D_0/2)^2 \tan(45 - \phi/2)] \gamma_b \]

\[ 2X = [(1 + 4.25/2)^2 \tan(45 - 30/2)] (120-62.4) \]

\[ R_s = 356 + 325 = 681 \text{ lbs/ft} \]
## Results HDPE Pipe

<table>
<thead>
<tr>
<th>Method</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACPA</td>
<td>-859</td>
<td>356</td>
<td>1.25</td>
<td>-717</td>
</tr>
<tr>
<td>W/M</td>
<td>-859</td>
<td>681</td>
<td>2.0</td>
<td>-1037</td>
</tr>
</tbody>
</table>
## Comparison – ACPA Method

<table>
<thead>
<tr>
<th>48” Pipe Type</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>-859</td>
<td>356</td>
<td>1.25</td>
<td>-717</td>
</tr>
<tr>
<td>CMP</td>
<td>-769</td>
<td>338</td>
<td>1.25</td>
<td>-623</td>
</tr>
<tr>
<td>RCP</td>
<td>-278</td>
<td>423</td>
<td>1.25</td>
<td>75</td>
</tr>
</tbody>
</table>
## Comparison – W/M Method

<table>
<thead>
<tr>
<th>48” Pipe Type</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>-859</td>
<td>681</td>
<td>2.0</td>
<td>-1037</td>
</tr>
<tr>
<td>CMP</td>
<td>-769</td>
<td>645</td>
<td>2.0</td>
<td>-893</td>
</tr>
<tr>
<td>RCP</td>
<td>-278</td>
<td>811</td>
<td>2.0</td>
<td>255</td>
</tr>
</tbody>
</table>
How Much Fill For a 48 Inch Pipe?

<table>
<thead>
<tr>
<th>Method</th>
<th>RCP</th>
<th>CMP</th>
<th>HDPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACPA</td>
<td>0.8 ft.</td>
<td>3.7 ft.</td>
<td>4 ft.*</td>
</tr>
<tr>
<td>M/W</td>
<td>0.5 ft.</td>
<td>2.8 ft.</td>
<td>3.0 ft.</td>
</tr>
</tbody>
</table>

*For plastic pipe, a good rule of thumb is fill height equal to pipe diameter.*
# ACPA Min Fill to Avoid Flotation

<table>
<thead>
<tr>
<th>Pipe Size (in)</th>
<th>Min. Fill (ft)</th>
<th>Pipe Size (in)</th>
<th>Min. Fill (ft)</th>
<th>Pipe Size (in)</th>
<th>Min. Fill (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>0.1</td>
<td>42</td>
<td>0.6</td>
<td>78</td>
<td>1.5</td>
</tr>
<tr>
<td>24</td>
<td>0.1</td>
<td>48</td>
<td>0.8</td>
<td>84</td>
<td>1.7</td>
</tr>
<tr>
<td>27</td>
<td>0.2</td>
<td>54</td>
<td>0.9</td>
<td>90</td>
<td>1.9</td>
</tr>
<tr>
<td>30</td>
<td>0.3</td>
<td>60</td>
<td>1.1</td>
<td>96</td>
<td>2.0</td>
</tr>
<tr>
<td>33</td>
<td>0.3</td>
<td>66</td>
<td>1.2</td>
<td>102</td>
<td>2.2</td>
</tr>
<tr>
<td>36</td>
<td>0.4</td>
<td>72</td>
<td>1.4</td>
<td>108</td>
<td>2.4</td>
</tr>
</tbody>
</table>
48” RCP Results

<table>
<thead>
<tr>
<th>Shape</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elliptical</td>
<td>-226</td>
<td>471</td>
<td>1.25</td>
<td>188</td>
</tr>
<tr>
<td>Circular</td>
<td>-278</td>
<td>423</td>
<td>1.25</td>
<td>75</td>
</tr>
</tbody>
</table>
Poll Question #5
Figure 5.19. Unanchored thin edge projecting.

Source: FHWA HDS 5
Source: FHWA HDS 5
Source: FHWA HDS 5
Anchors
Building Resilience Reputation and Rapport
Poll Question #6
The End

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Water Table Not up to the Surface
Rigid Rugged Resilient

Do = 67 inches – use 63.5” = 5.29 Ft
Di = 60 inches

Given:

- HDPE Pipe Weight = \( W_p = 62 \text{ lb/ft} \)
- \( \gamma_t = 130 \text{ pcf} \)
- \( \gamma_d = 110 \text{ pcf} \)

\( D_i = 60 \text{ inches} \)
\( D_o = 67 \text{ inches – use 63.5” = 5.29 Ft} \)

Existing Ground Surface
Is flotation a concern?

HDPE Pipe Weight = $W_p = 62 \text{ lb/ft}$

Weight of Water Displaced
$W_w = \pi \left(\frac{d_o}{2}\right)^2 \gamma_w$
$W_w = 1373 \text{ lbs/ft}$

$BF = -1311 \text{ lb/ft}$
Water Table Not up to the Surface

What is soil Resistance?

Net Force = (BF x FS) + Rs
= (-1311 x 1.25) + Rs
If the water table is above the top of the pipe and at or above the ground surface:

\[
P_{sp} = \left( H + 0.11 \frac{D_o}{12} \right) \gamma_b \left( \frac{1}{144} \right)
\]

(12.12.3.7-1)

- If the water table is above the top of the pipe and below the ground surface:

\[
P_{sp} = \frac{1}{144} \left[ \left( H_w - \frac{D_o}{24} \right) + 0.11 \frac{D_o}{12} \right] \gamma_b + \left( H - \left( H_w - \frac{D_o}{24} \right) \right) \gamma_s
\]

(12.12.3.7-2)

- If the water table is below the top of the pipe:

\[
P_{sp} = \left( H + 0.11 \frac{D_o}{12} \right) \gamma_s \left( \frac{1}{144} \right)
\]

(12.12.3.7-3)
Calculation of Soil Resistance

\[ R_s = (\gamma_t - \gamma_w) \left[ H_w + \frac{D_o (4 - \pi)}{8} \right] D_o + \gamma_d (H - H_w)(D_o) \]

\[ R_s = (130 - 62.4) \left[ 1.5 + \frac{5.29 (4 - \pi)}{8} \right] 5.29 + 110 (3 - 1.5)(5.29) \]

\[ R_s = 739 + 873 \]

\[ R_s = 1612 \text{ lbs/ft} \]
## Results HDPE Pipe

<table>
<thead>
<tr>
<th>Method</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACPA</td>
<td>-1311</td>
<td>1612</td>
<td>1.25</td>
<td>-27</td>
</tr>
</tbody>
</table>
Floatation of Horizontal Elliptical Concrete Pipe
Assume ground water level is at the surface.

Existing Ground Surface

Given:

38 x 60 H.E. RCP
Assume ground water level is at the surface.

**Is Flotation a Concern?**

-existing ground surface

RC Pipe Weight = \( W_p = 1000 \text{ lb/ft} \)

\[ \gamma_t = 120 \text{ pcf} \]

\[ \phi = 30 \text{ deg} \]
### Illustration 5.3 Dimensions and Approximate Weights of Elliptical Concrete Pipe

**ASTM C 507-Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe**

<table>
<thead>
<tr>
<th>Equivalent Round Size, inches</th>
<th>Minor Axis, inches</th>
<th>Major Axis, inches</th>
<th>Minimum Wall Thickness, inches</th>
<th>Water-Way Area, square feet</th>
<th>Approximate Weight, pounds per foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>14</td>
<td>23</td>
<td>2 3/4</td>
<td>1.8</td>
<td>195</td>
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<tr>
<td>24</td>
<td>19</td>
<td>30</td>
<td>3 1/4</td>
<td>3.3</td>
<td>300</td>
</tr>
<tr>
<td>27</td>
<td>22</td>
<td>34</td>
<td>3 1/2</td>
<td>4.1</td>
<td>365</td>
</tr>
<tr>
<td>30</td>
<td>24</td>
<td>38</td>
<td>3 3/4</td>
<td>5.1</td>
<td>430</td>
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<tr>
<td>33</td>
<td>27</td>
<td>42</td>
<td>3 3/4</td>
<td>6.3</td>
<td>475</td>
</tr>
<tr>
<td>36</td>
<td>29</td>
<td>45</td>
<td>4 1/2</td>
<td>7.4</td>
<td>625</td>
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<tr>
<td>39</td>
<td>32</td>
<td>49</td>
<td>4 3/4</td>
<td>8.8</td>
<td>720</td>
</tr>
<tr>
<td>42</td>
<td>34</td>
<td>53</td>
<td>5</td>
<td>10.2</td>
<td>815</td>
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<td>48</td>
<td>38</td>
<td>60</td>
<td>5 1/2</td>
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<td>1000</td>
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<td>54</td>
<td>43</td>
<td>68</td>
<td>6</td>
<td>16.6</td>
<td>1235</td>
</tr>
<tr>
<td>60</td>
<td>48</td>
<td>76</td>
<td>6 1/2</td>
<td>20.5</td>
<td>1475</td>
</tr>
<tr>
<td>66</td>
<td>53</td>
<td>83</td>
<td>7</td>
<td>24.8</td>
<td>1745</td>
</tr>
<tr>
<td>72</td>
<td>58</td>
<td>91</td>
<td>7 1/2</td>
<td>29.5</td>
<td>2040</td>
</tr>
</tbody>
</table>
Assume ground water level is at the surface

Existing Ground Surface

1 Ft

Is Flotation a Concern?

RC Pipe Weight = \( W_p = 1000 \text{ lb/ft} \)

Area of Water Displaced = 19.64 ft\(^2\)

Weight of Water Displaced = \( W_w = 1,226 \text{ lbs/ft} \)

BF = - 226 lb/ft
<table>
<thead>
<tr>
<th>Size (in)</th>
<th>Flow Area (ft²)</th>
<th>Total Area (ft²)</th>
<th>Size (in)</th>
<th>Flow Area (ft²)</th>
<th>Total Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 x 38</td>
<td>5.10</td>
<td>8.02</td>
<td>63 x 98</td>
<td>34.6</td>
<td>50.66</td>
</tr>
<tr>
<td>27 x 42</td>
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<td>9.55</td>
<td>68 x 106</td>
<td>40.1</td>
<td>58.14</td>
</tr>
<tr>
<td>29 x 45</td>
<td>7.36</td>
<td>11.44</td>
<td>72 x 113</td>
<td>46.1</td>
<td>66.38</td>
</tr>
<tr>
<td>32 x 49</td>
<td>8.78</td>
<td>13.58</td>
<td>77 x 121</td>
<td>52.4</td>
<td>75.70</td>
</tr>
<tr>
<td>34 x 53</td>
<td>10.2</td>
<td>15.58</td>
<td>82 x 128</td>
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<td>84.09</td>
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<td>19.64</td>
<td>87 x 136</td>
<td>66.4</td>
<td>93.62</td>
</tr>
<tr>
<td>43 x 68</td>
<td>16.7</td>
<td>25.02</td>
<td>92 x 143</td>
<td>73.9</td>
<td>103.95</td>
</tr>
<tr>
<td>48 x 76</td>
<td>20.5</td>
<td>30.49</td>
<td>97 x 151</td>
<td>82.1</td>
<td>114.74</td>
</tr>
<tr>
<td>53 x 83</td>
<td>24.8</td>
<td>36.5</td>
<td>106 x 166</td>
<td>99.2</td>
<td>138.81</td>
</tr>
<tr>
<td>58 x 91</td>
<td>29.4</td>
<td>43.05</td>
<td>116 x 180</td>
<td>118</td>
<td>164.76</td>
</tr>
</tbody>
</table>
What is the Soil Resistance from the Upper Haunch?

Rise = 38 in  Span = 60 in  Wall = 5.5 in

\[ Y = 38 + 2(5.5) = 49 \text{ in} \quad X = 60 + 2(5.5) = 71 \text{ in} \]

Rect. Area = \( X \times Y = \frac{49 \times 71}{144} = 24.16 \text{ ft}^2 \)
Pipe Area = 19.64 ft²
Upper Haunch Area = \( \frac{24.16 - 19.64}{2} = 2.26 \text{ ft}^2 \)

Soil Weight from Upper Haunch = \( 2.26 \text{ ft}^2 \times 1 \text{ ft} \times (120 - 62.4) = 130 \text{ lbs/ft} \)
What is the Soil Resistance from the soil prism above the crown?

\[ R_s = \text{Upper Haunch} + \text{Rectangular Soil Prism} \]

\[ R_s = 130 \text{ lbs/ft} + 1 \text{ ft} \times \left(\frac{71}{12}\right) \times (120-62.4) \]

\[ R_s = 471 \text{ lbs/ft} \]
## 48” RCP Results

<table>
<thead>
<tr>
<th>Shape</th>
<th>Buoyancy Force, BF (lbs/ft)</th>
<th>Soil Resistance $R_s$ (lbs/ft)</th>
<th>Factor of Safety, FS</th>
<th>Net Force (lbs/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elliptical</td>
<td>-226</td>
<td>471</td>
<td>1.25</td>
<td>188</td>
</tr>
<tr>
<td>Circular</td>
<td>-278</td>
<td>423</td>
<td>1.25</td>
<td>75</td>
</tr>
</tbody>
</table>
## Areas of Arch Pipe for Buoyancy Purposes

<table>
<thead>
<tr>
<th>Size (in)</th>
<th>Flow Area (ft²)</th>
<th>Total Area (ft²)</th>
<th>Size (in)</th>
<th>Flow Area (ft²)</th>
<th>Total Area (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 x 28 1/2</td>
<td>2.8</td>
<td>4.5</td>
<td>54 x 88</td>
<td>25.6</td>
<td>37.9</td>
</tr>
<tr>
<td>22 1/2 x 36 1/4</td>
<td>4.4</td>
<td>7.0</td>
<td>62 x 102</td>
<td>34.6</td>
<td>50.4</td>
</tr>
<tr>
<td>26 5/8 x 43 3/8</td>
<td>6.4</td>
<td>9.8</td>
<td>72 x 115</td>
<td>44.5</td>
<td>64.5</td>
</tr>
<tr>
<td>31 5/16 x 51 1/8</td>
<td>8.8</td>
<td>13.2</td>
<td>77 1/2 x 122</td>
<td>51.7</td>
<td>73.5</td>
</tr>
<tr>
<td>36 x 58 1/2</td>
<td>11.4</td>
<td>17.2</td>
<td>87 1/8 x 138</td>
<td>66.0</td>
<td>93.5</td>
</tr>
<tr>
<td>40 x 65</td>
<td>14.3</td>
<td>21.2</td>
<td>96 7/8 x 154</td>
<td>81.8</td>
<td>115.4</td>
</tr>
<tr>
<td>45 x 73</td>
<td>17.7</td>
<td>26.5</td>
<td>106 1/2 x 168 3/4</td>
<td>99.1</td>
<td>131.2</td>
</tr>
</tbody>
</table>
Flowable Fill

\[ A = \frac{1}{2} r_o^2 (\theta - \sin \theta) \]

\[ \theta = \text{invcos}\left[\frac{(r_o - x)}{r_o}\right] \]
Flowable Fill

• Using $\gamma_{ff} = 130$ pcf
• Maximum depths of flowable fill
  • HDPE pipe – 2 to 3 inches
  • CMP pipe – 3 to 4 inches
  • RCP pipe – approximately 40% of $D_o$
References

• ACPA Design Data 22, *Flotation of Circular Concrete Pipe*

• *Buried Pipe Design* by A.P. Moser, second edition, McGraw hill


• *Pipeline Installation* by A. Howard, relativity publishing

• *Soil Engineering* by M. Spangler & R. Handy, Harper & Row

• Federal Highways Administration
The End

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