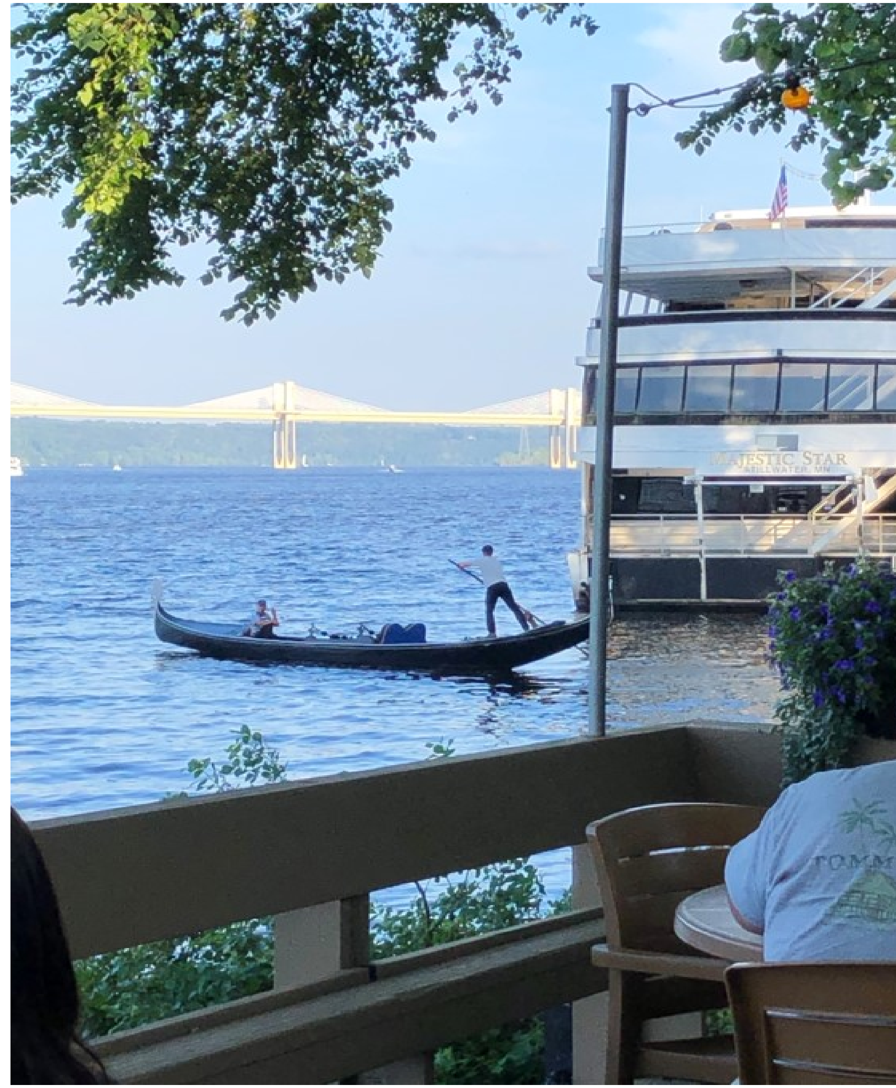
Poll Question #1

American Concrete Pipe Association

PIPE FLOTATION



Josh Beakley
&
Jennifer Schaff

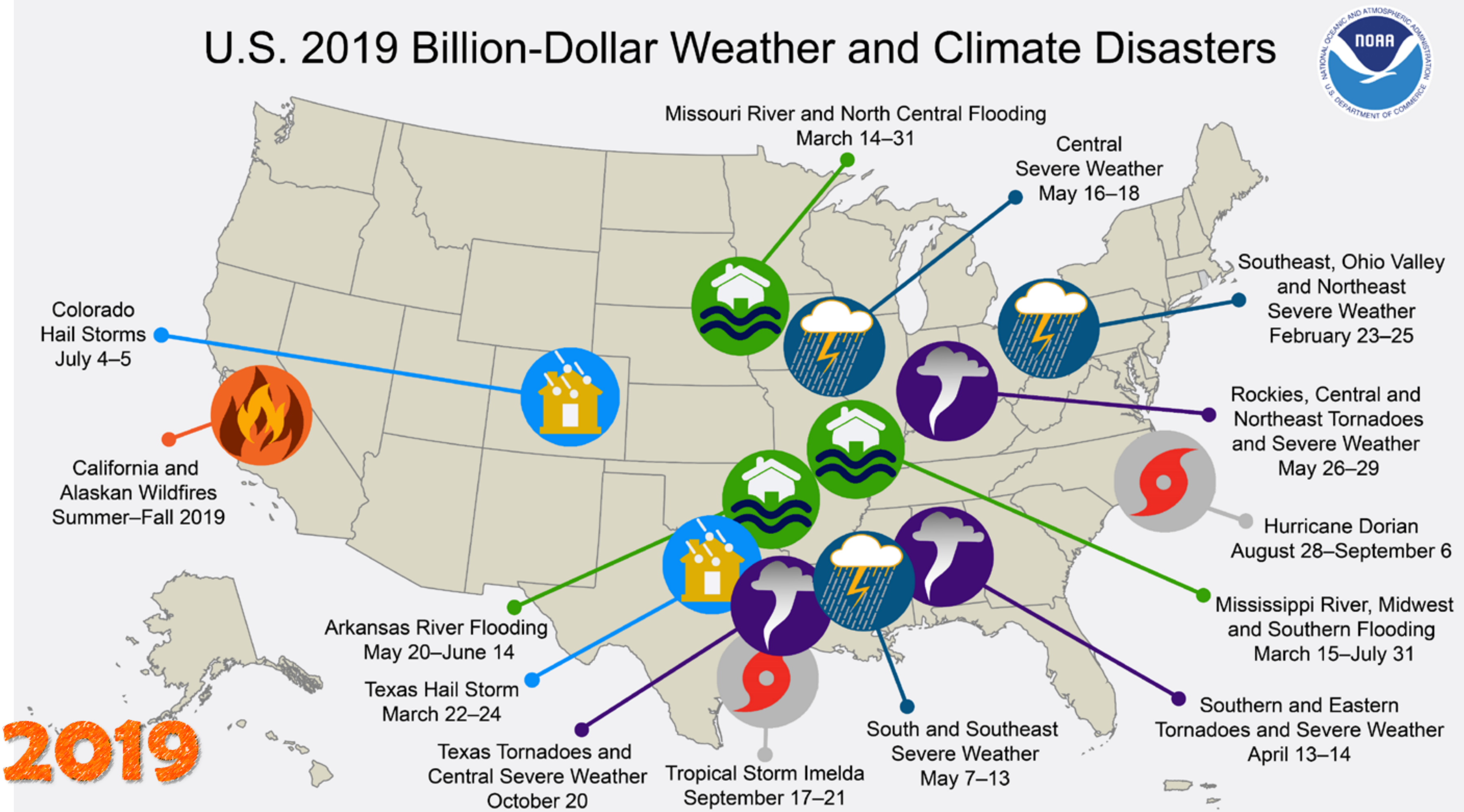
Outline

- 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!

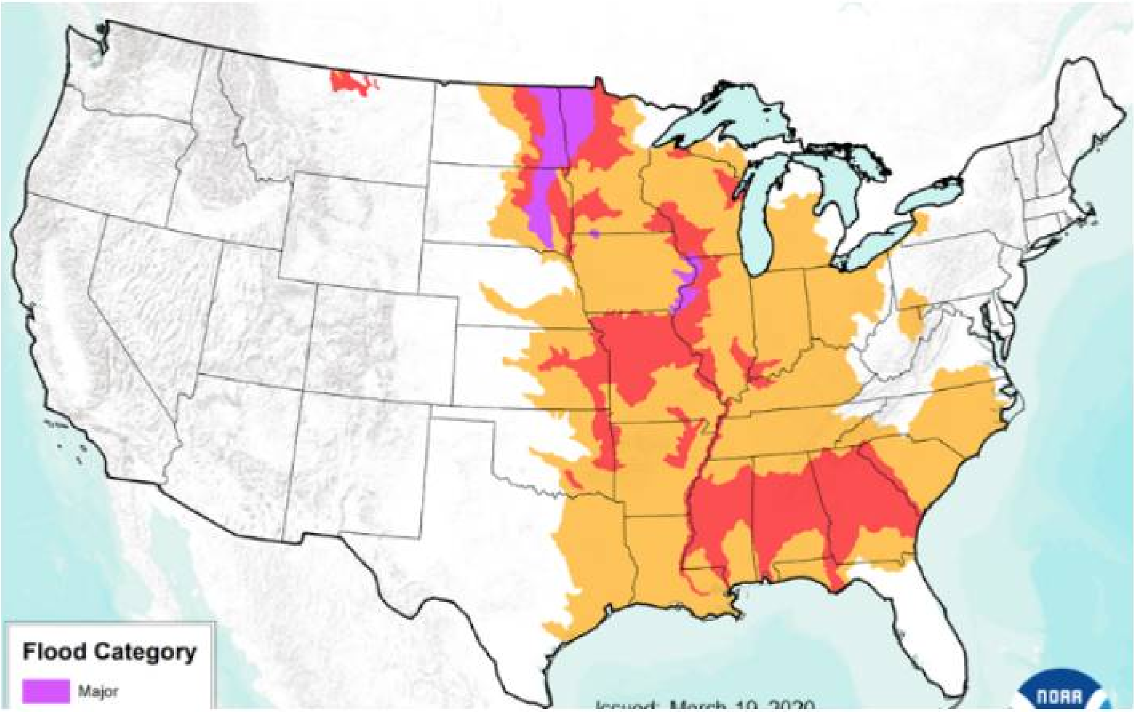
Flotation Failure

American Concrete Pipe Association

U.S. 2019 Billion-Dollar Weather and Climate Disasters



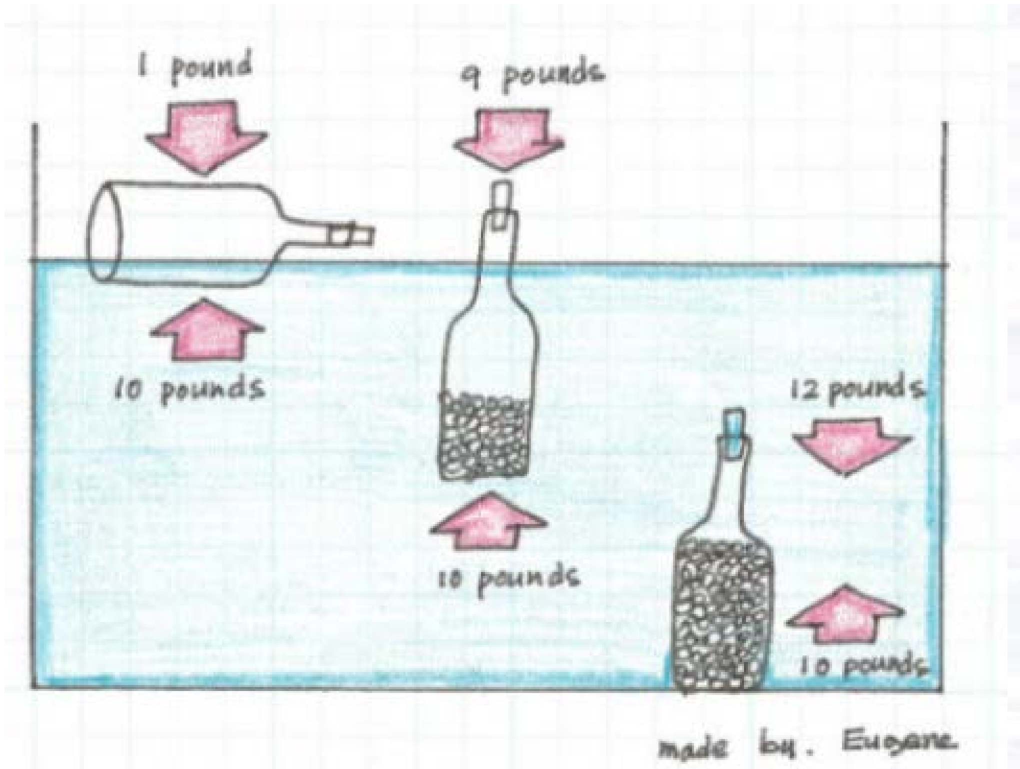
*This map denotes the approximate location for each of the **14 separate billion-dollar weather and climate disasters** that impacted the United States **during 2019**.*



The National Weather Service is predicting major to moderate flooding in the U.S. in 2020.

National Weather Service

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

id

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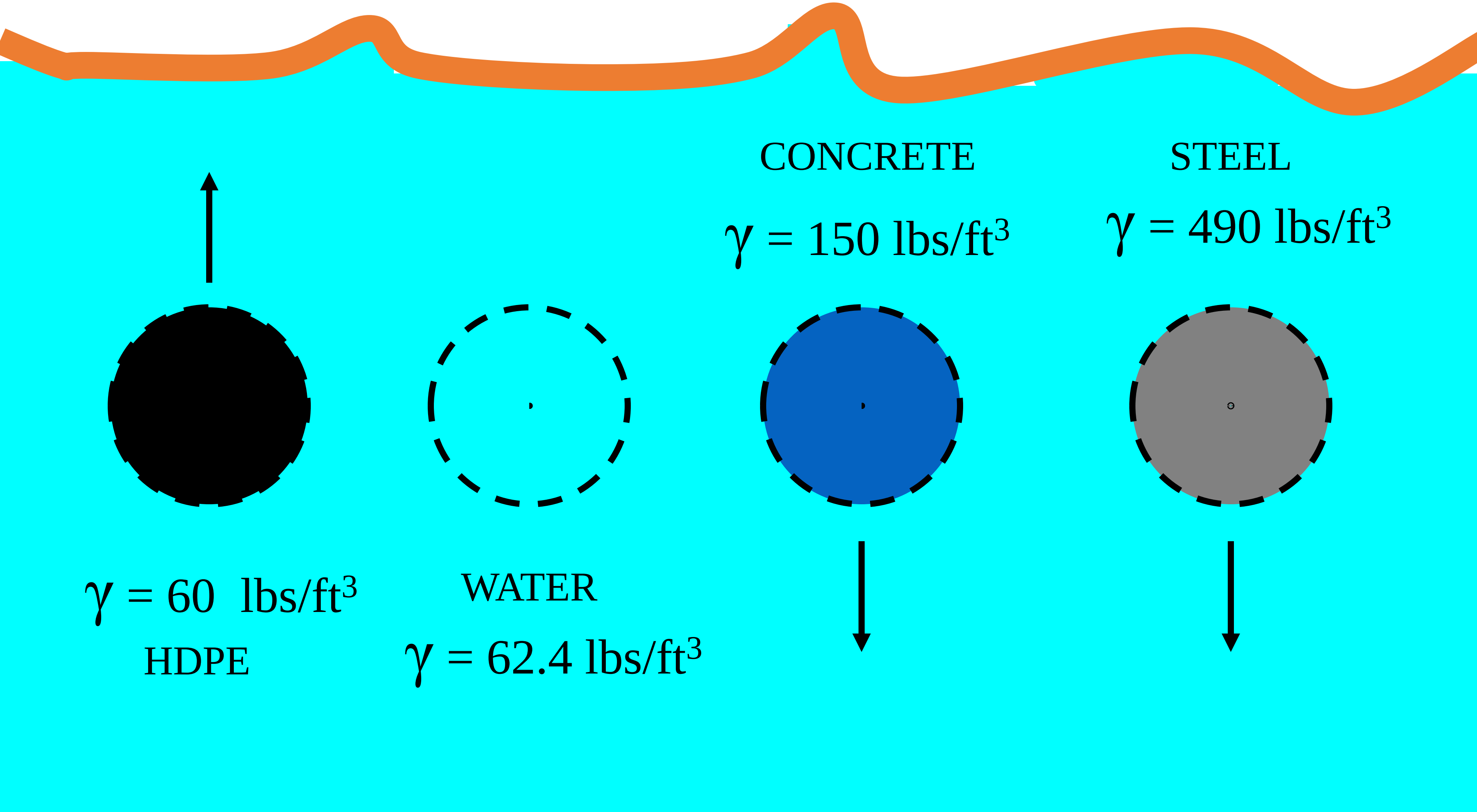
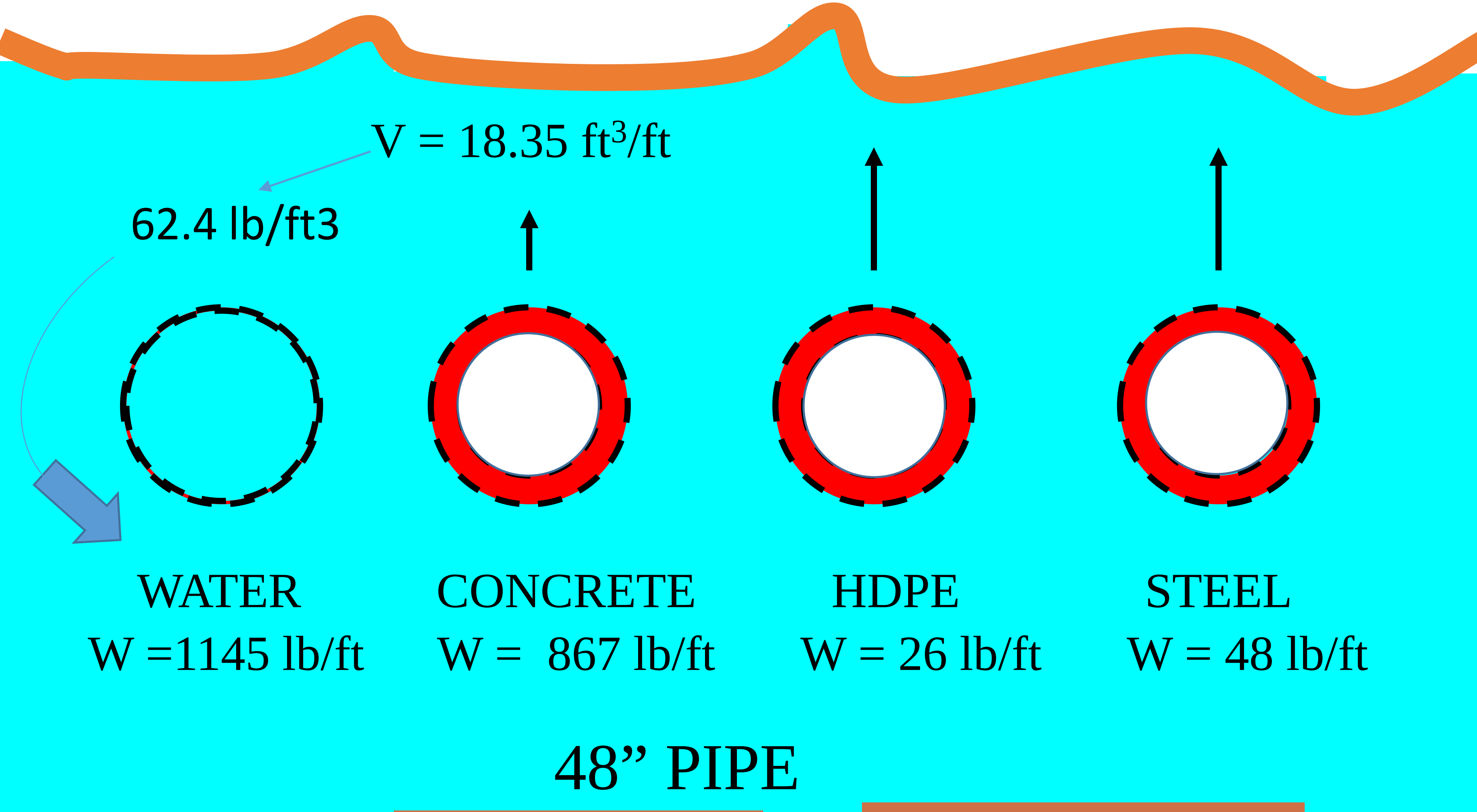
Relative Weights




EVEREST
UNIVERSITY OF NEVADA, RENO
AQUATONE
QUINTESSENCE

Pipe Weights



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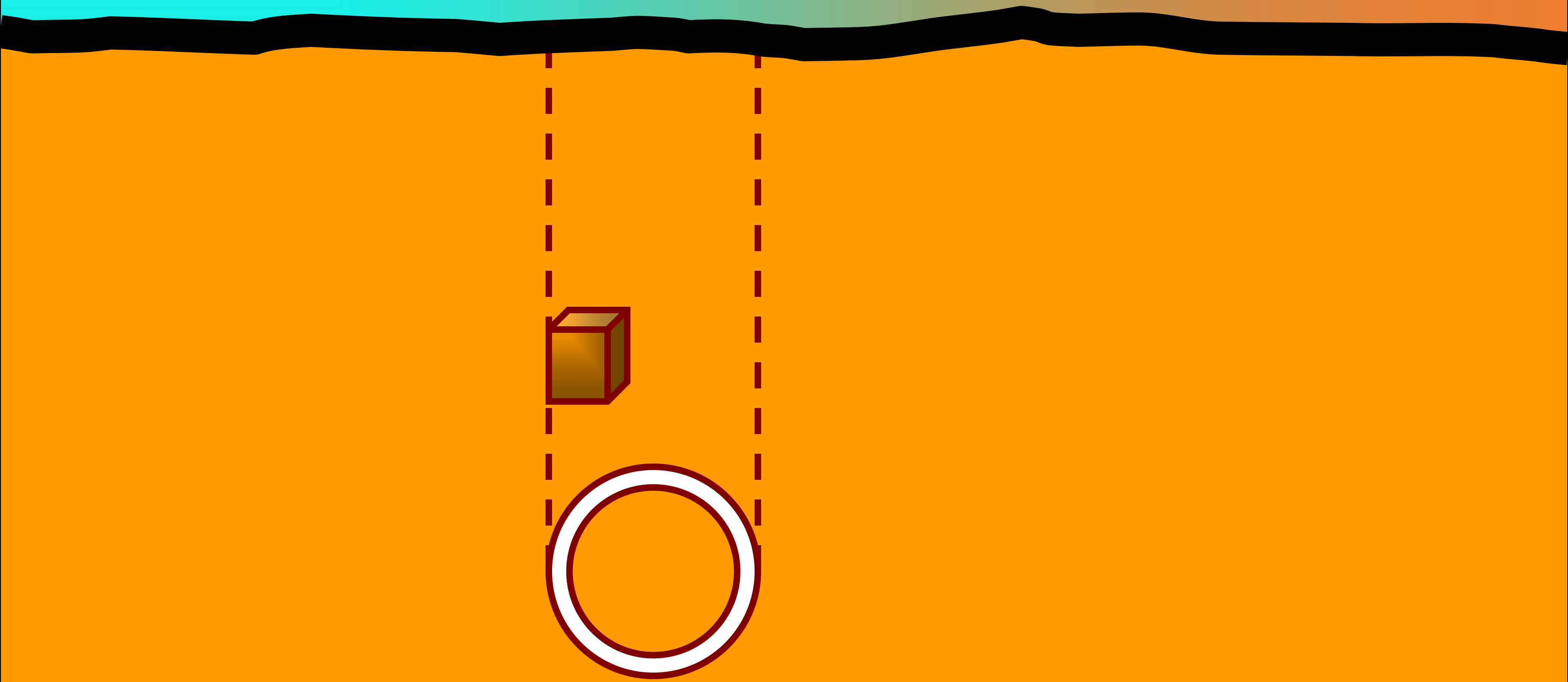
Poll Question #2

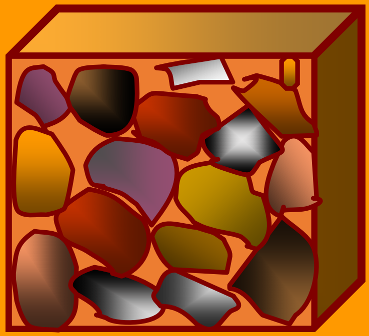
Flotation Calculation

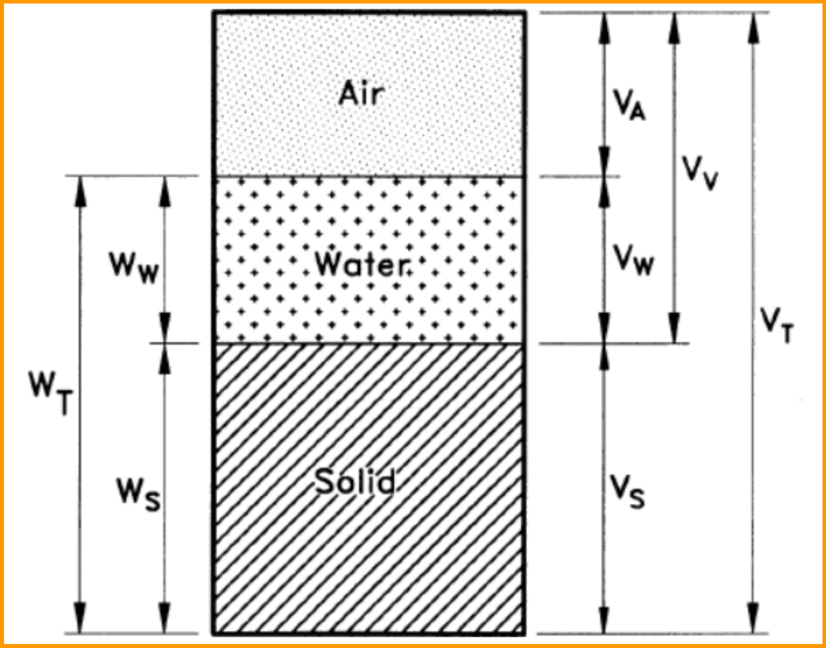


$\gamma = 120 \text{ lbs/ft}^3$

Soil Resistance + Pipe Weight – Buoyancy Force $\geq$ 0.0

Microstructure of Soil





Buoyant Weight of Soil

$$\gamma_b = \gamma_t - \gamma_w$$

- γ_t = saturated unit weight of soil (pcf)
- γ_w = unit weight of water (pcf)

Methods of Calculating Soil Resistance for Buoyancy

1 - American Concrete Pipe Association (ACPA) Design Data (DD) 22

Design Data 22

American Concrete Pipe Association

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:

$$W_p = \frac{\;}{4}(B_c^2 - D^2)\,150 \qquad (1)$$

local conditions should be investigated when seeking solutions for specific projects.

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:

$$W_w = \frac{\;}{4}(B_c^2)\,62.4 \qquad (2)$$

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.

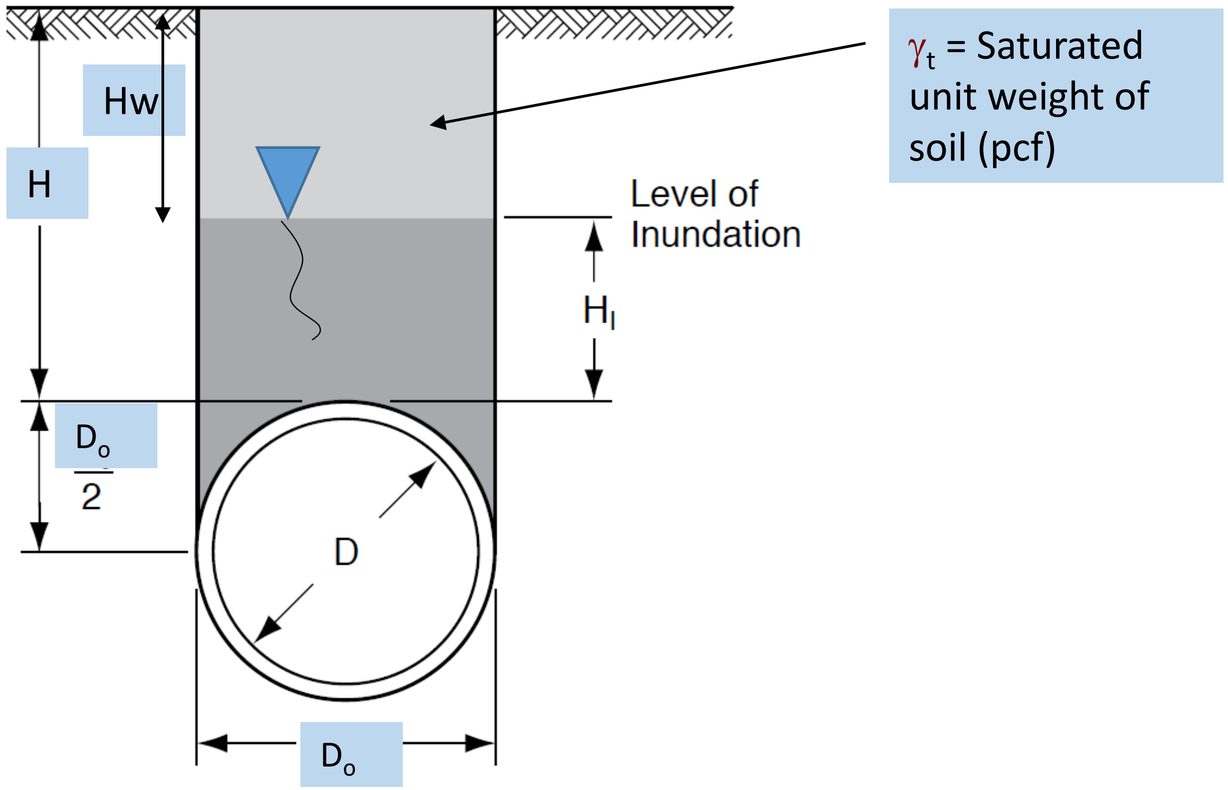
Backfill Weight

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

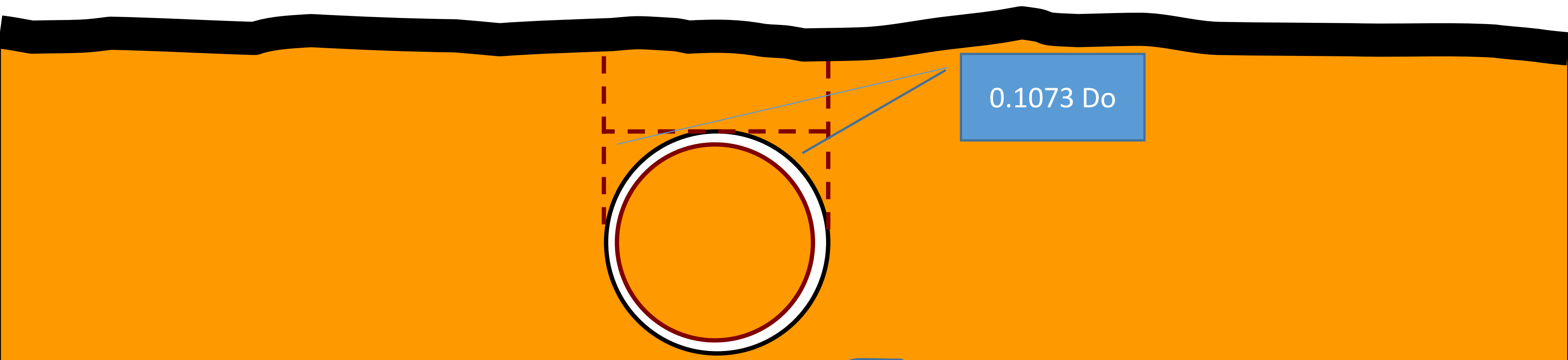
2 - Watkins/Moser (W/M)

Utah State

Required Information



ACPA DD 22

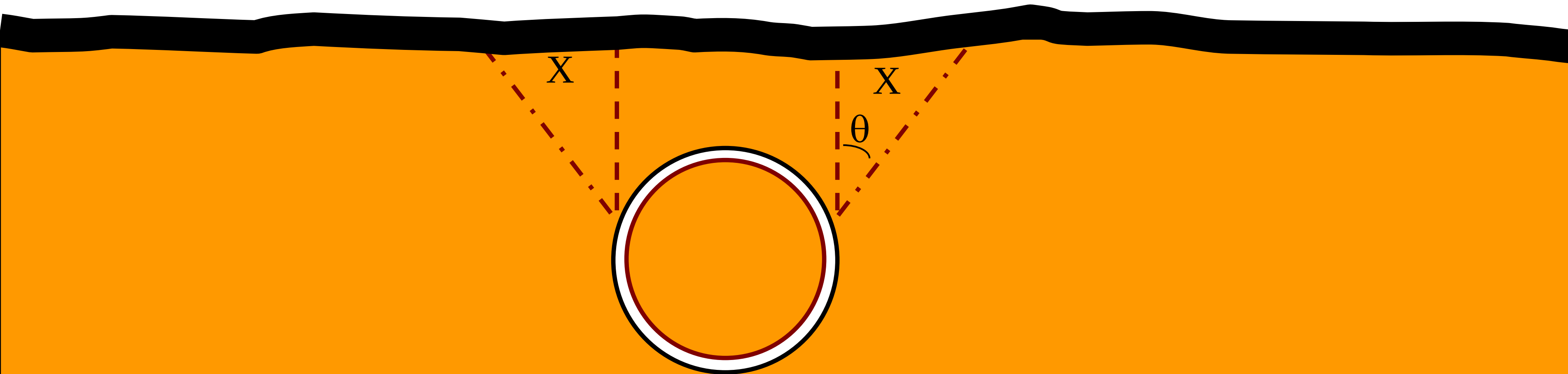


$$R_s = W_s = PL = \gamma_b \left[H + \frac{D_o (4 - \pi)}{8} \right] D_o$$

Equation 4 – Concrete Pipe Design Manual

American Concrete Pipe Association

Watkins/Moser



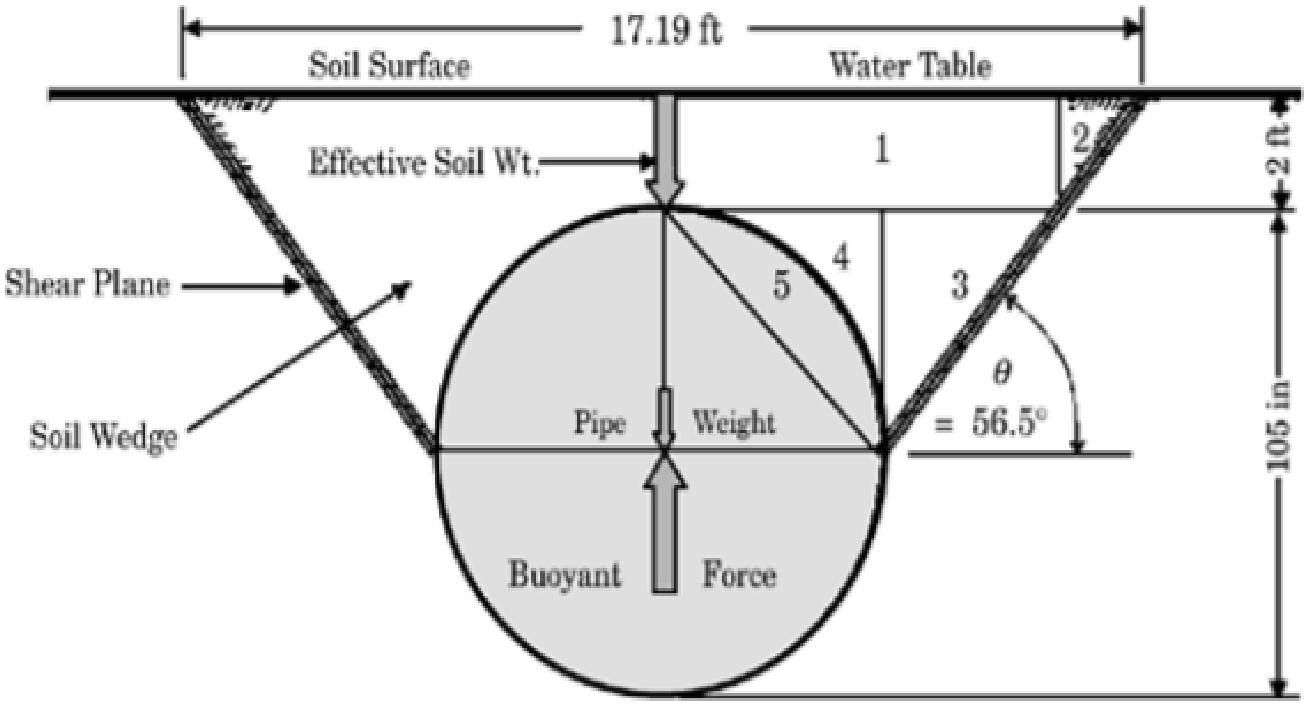
$$\theta = 45 - \phi/2$$

$$R_s = PL + 2X$$

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

ϕ = internal angle of friction

Watkins/Moser



ϕ = internal angle of friction

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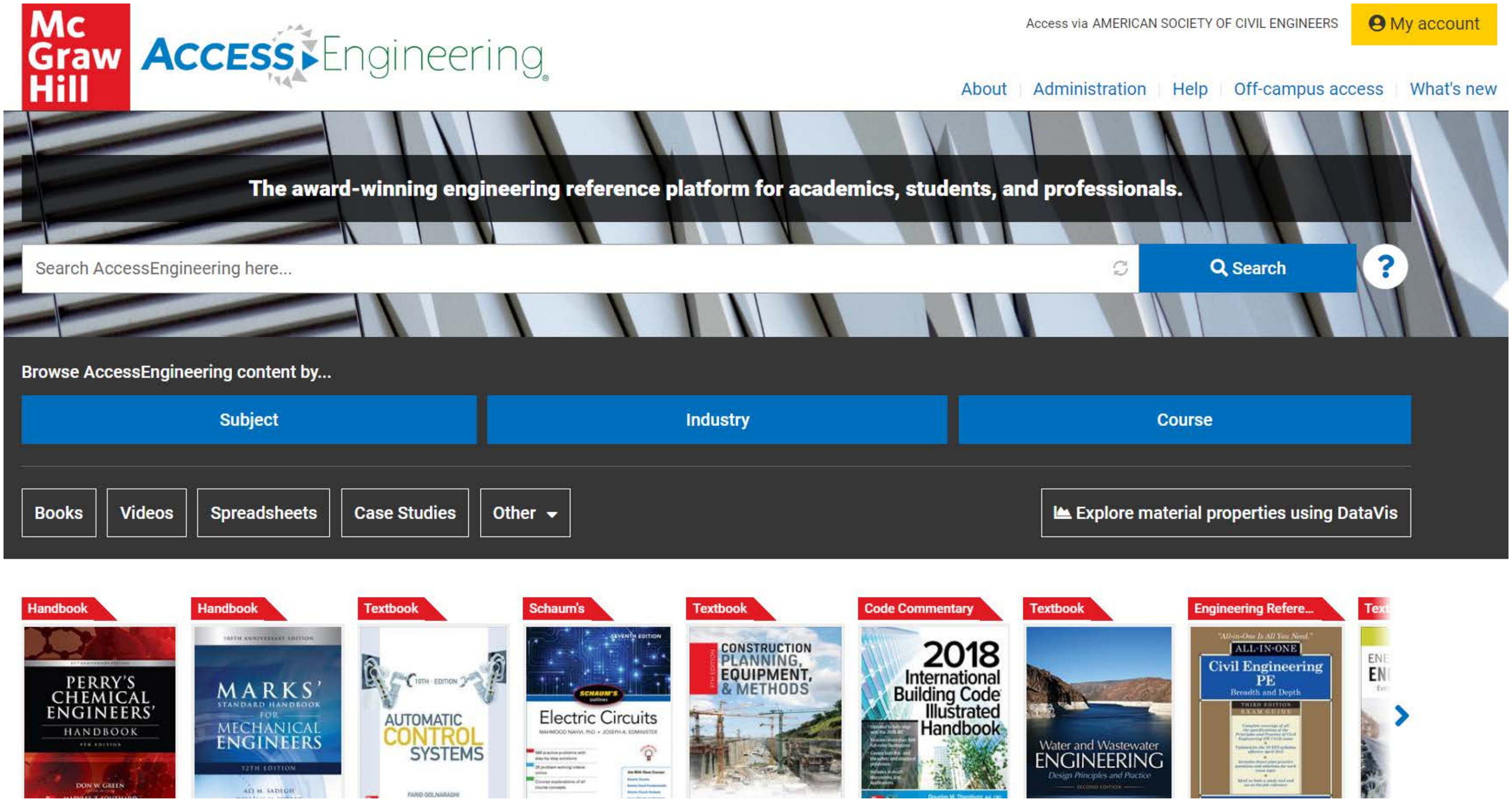
www.asce.org/accessengineering/



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+

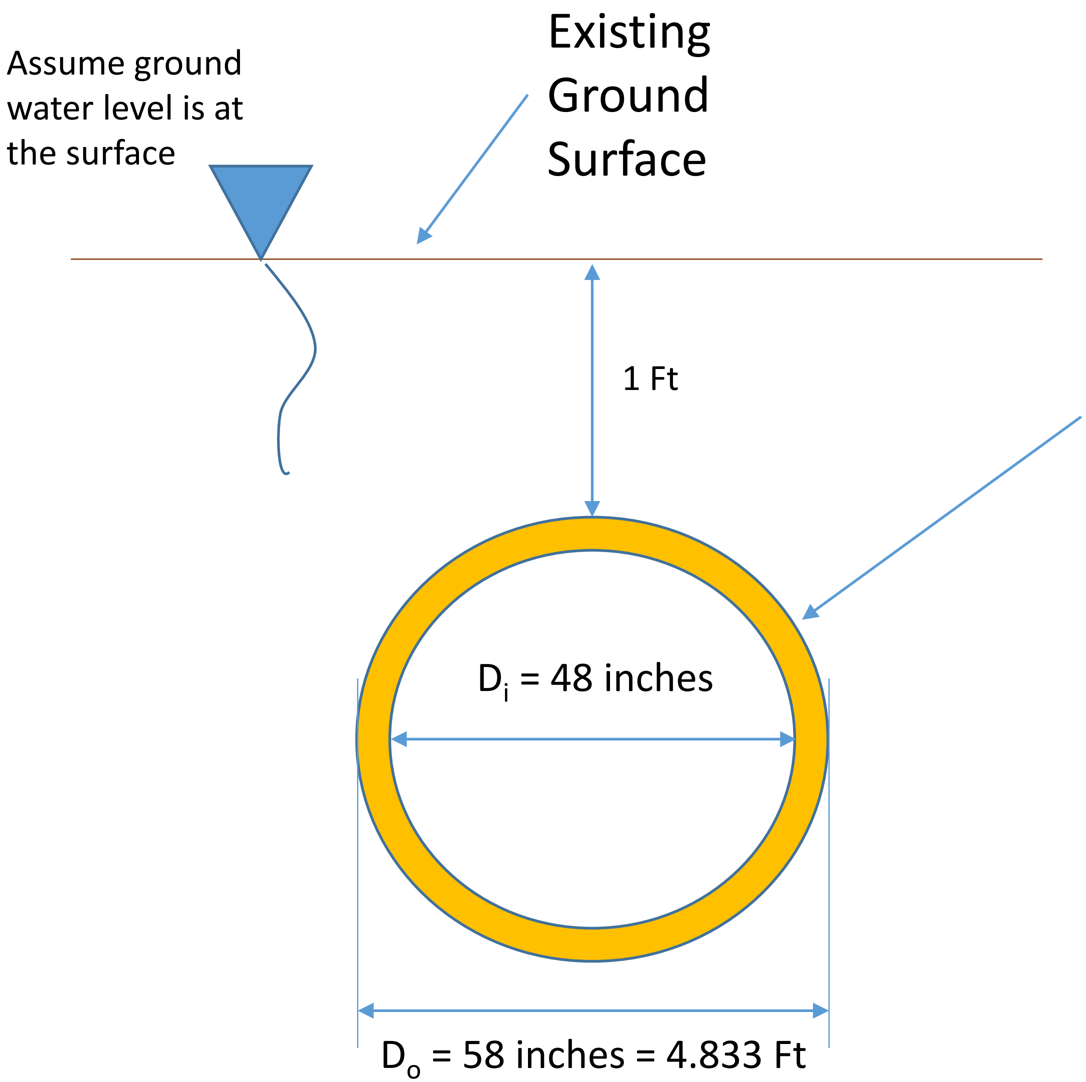
ACPA DD 22 - Factors of Safety -Guidance


WATCH
FOR WATER
OVER ROAD

Example: RCP

- Buoyancy Force
- Soil Resistance
- Factor of Safety

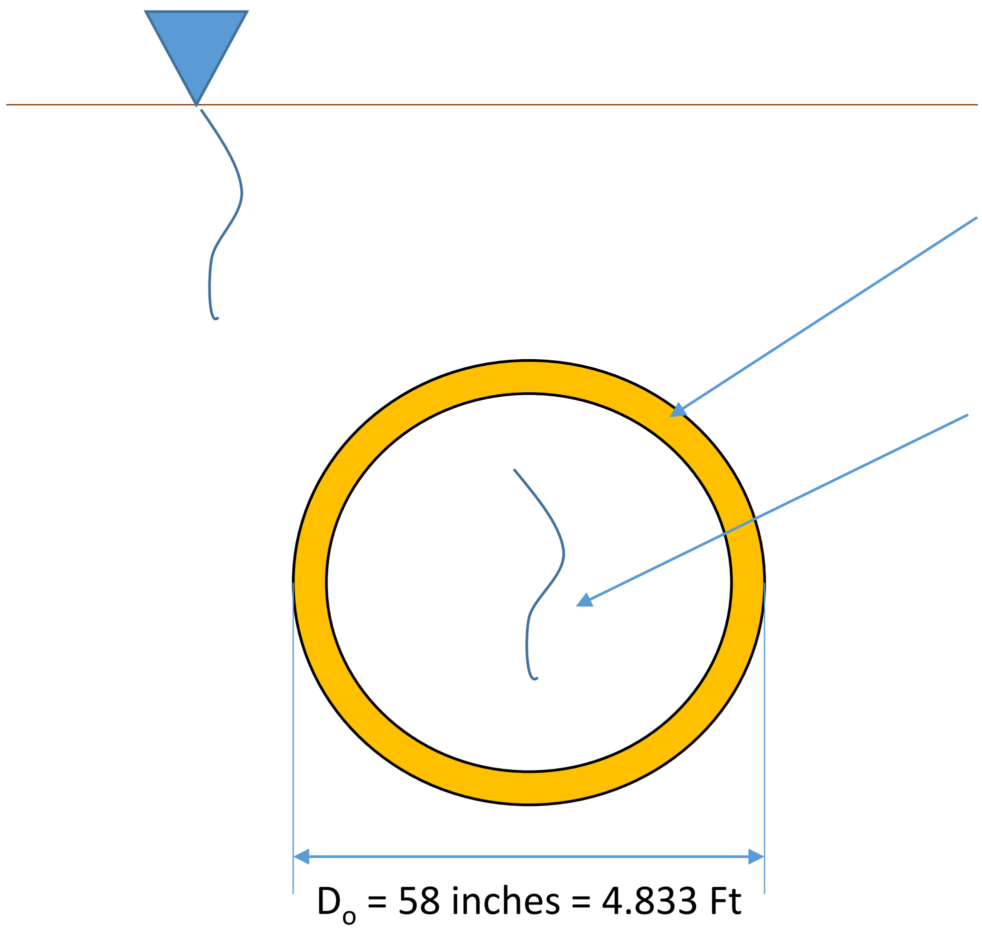
Given:



RC Pipe Weight =
W_p = 867 lb/ft

γ_t = 120 pcf
ϕ = 30 deg

Is flotation a concern?

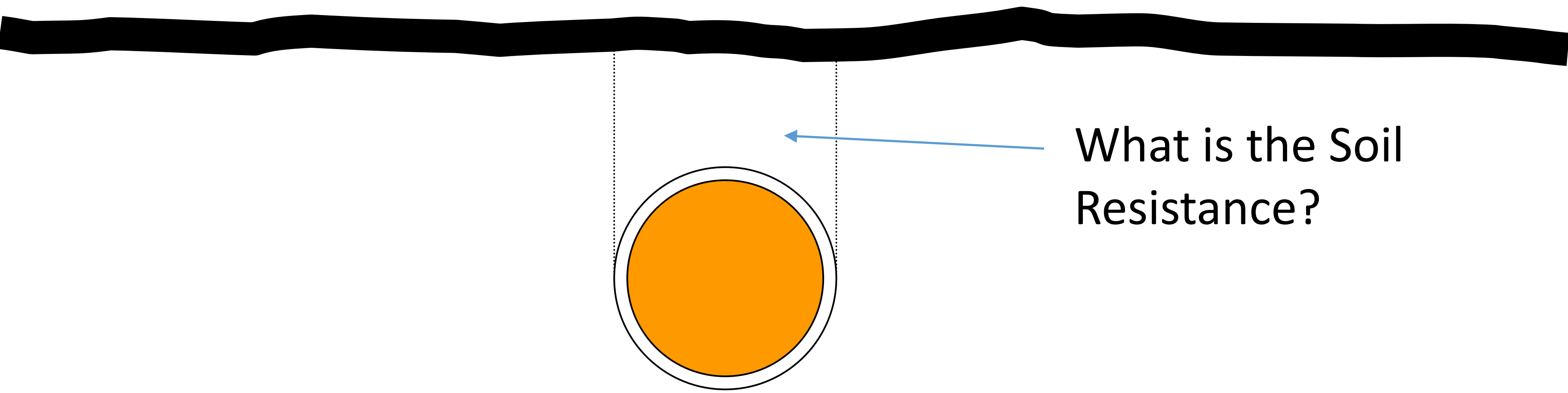


RC Pipe Weight =
W_p = 867 lb/ft

Weight of Water Displaced =
$W_w = \pi (d_o/2)^2 \gamma_w$
W_w = 1,145 lbs/ft

BF = - 278 lb/ft

ACPA Method Concrete Pipe



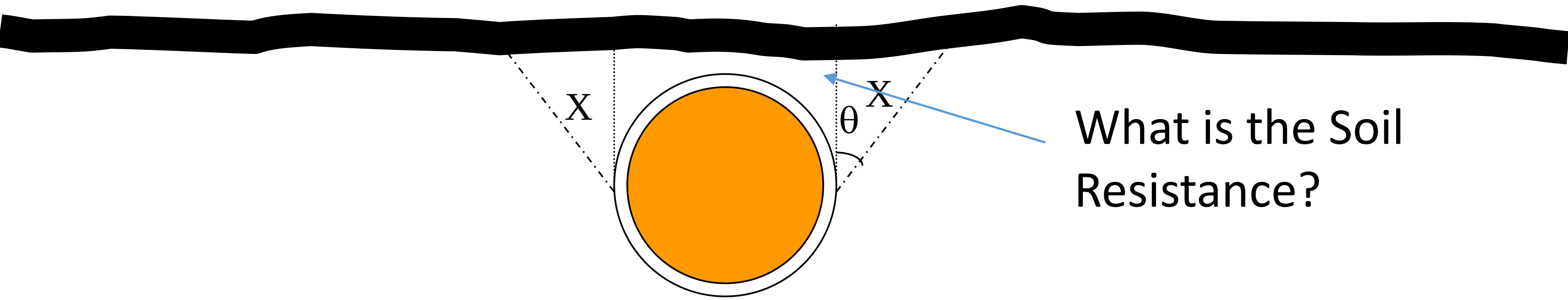
$$R_s = W_s = PL = \gamma_b \left[H + \frac{D_o(4-\pi)}{8} \right] D_o$$

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?

$$\theta = 45 - \phi/2$$

$$R_s = PL + 2X$$

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

$$2X = [(1 + 4.833/2)^2 \tan(45 - 30/2)]\,(120\text{-}62.4)$$

$$R_s = 423 + 388 = 811 \text{ lbs/ft}$$

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Results

ACPA Method

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

Watkins/Moser Method

- Net force = (BF x FS) + R_s
    - = (-278 x 2.0) + 811 = 255 lbs

RCP Results

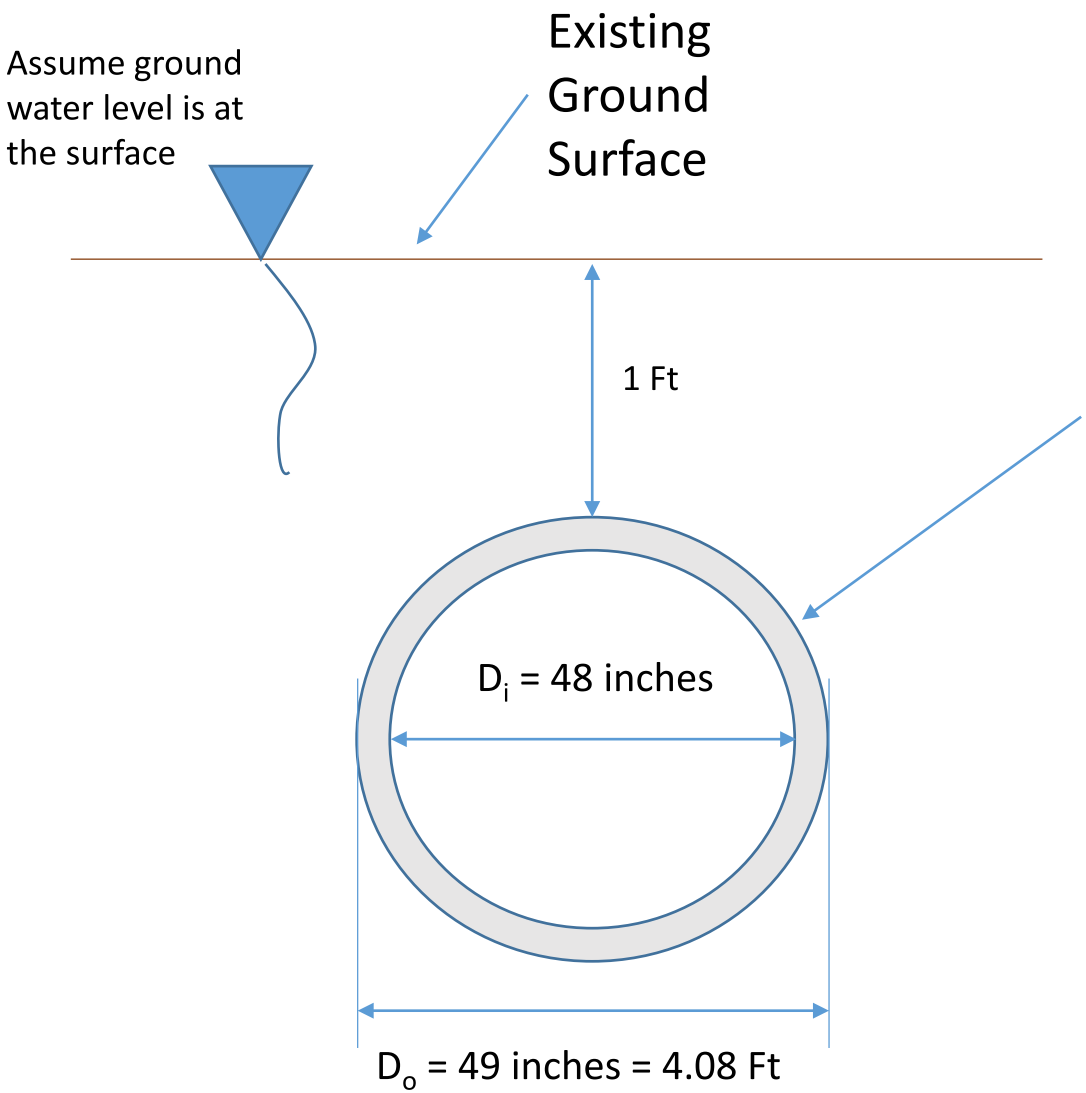
Method	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
ACPA	-278	423	1.25	75
W/M	-278	811	2.0	255

Poll Question #4

Example: CMP

- Buoyancy Force
- Soil Resistance
- Factor of Safety

Given:

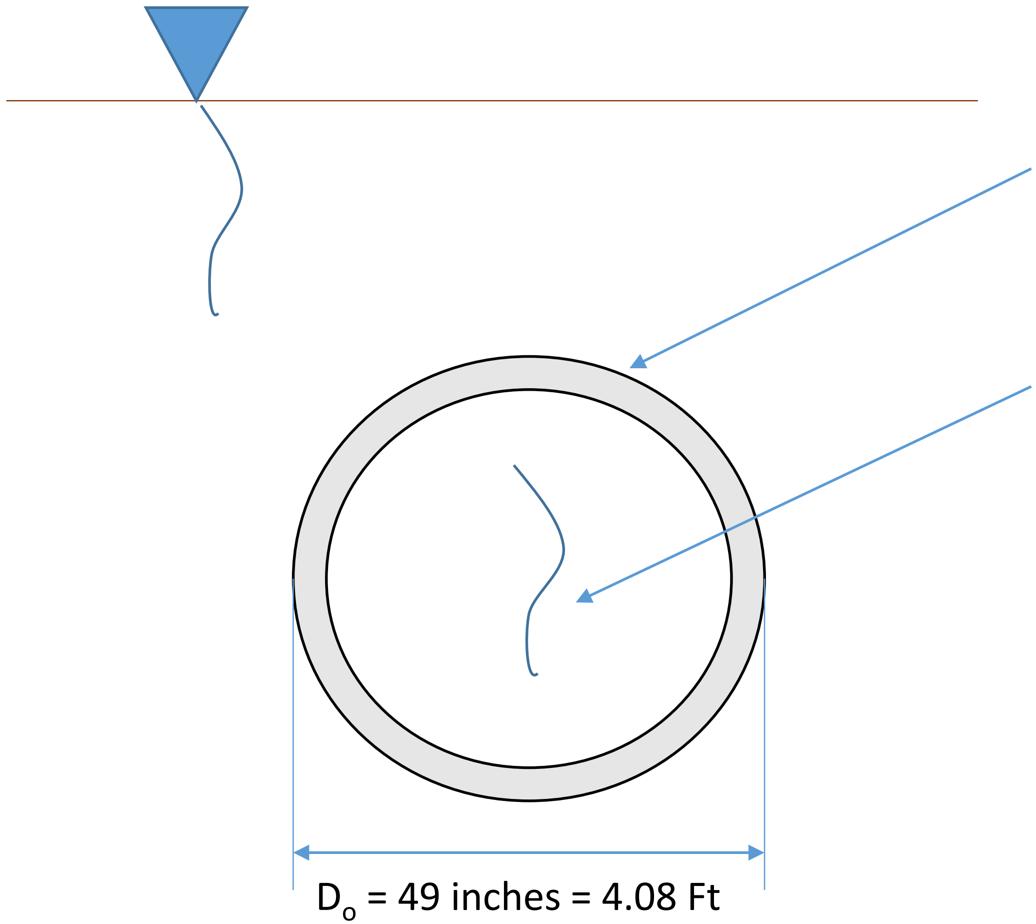


CM Pipe Weight = W_p = 48 lb/ft

γ_t = 120 pcf

ϕ = 30 deg

Is flotation a concern?



CM Pipe Weight =

W_p = 48 lb/ft

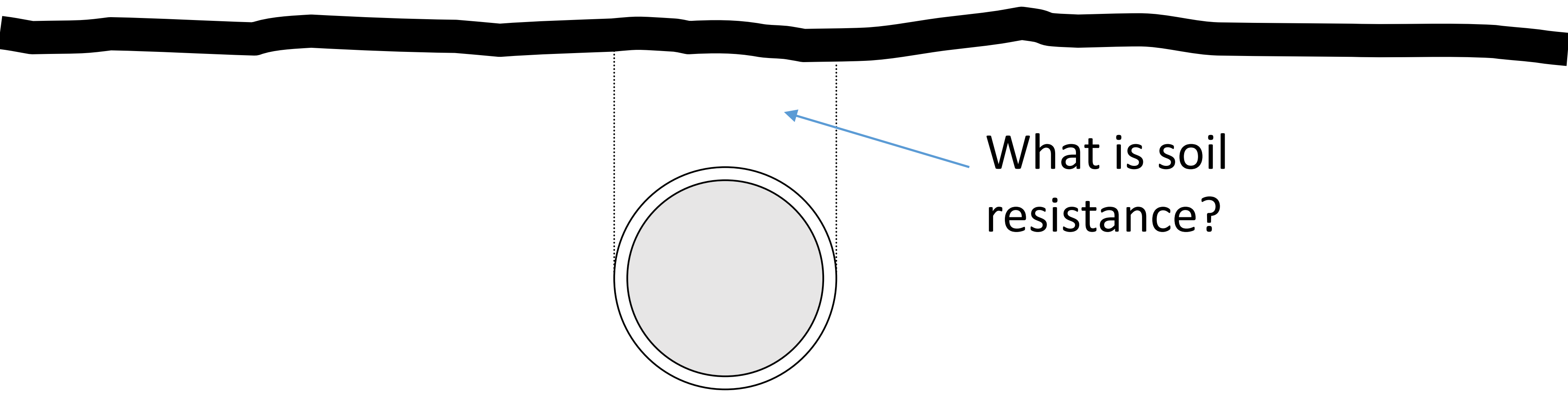
Weight of Water Displaced

$W_w = \pi \, (d_o/2)^2 \, \gamma_w$

W_w = 817 lbs/ft

BF = - 769 lb/ft

ACPA Method Metal Pipe



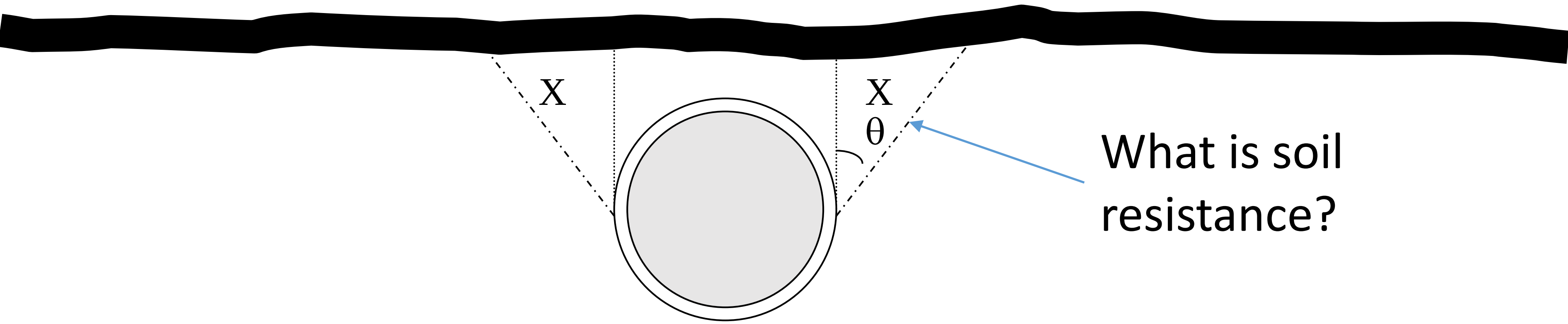
$$R_s = W_s = PL = \gamma_b \left[H + \frac{D_o (4 - \pi)}{8} \right] D_o$$

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



$$\theta = 45 - \phi/2$$

$$R_s = PL + 2\,X$$

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

$$2\,X = [(1 + 4.08/2)^2 \tan(45 - 30/2)]\,(120\text{-}62.4)$$

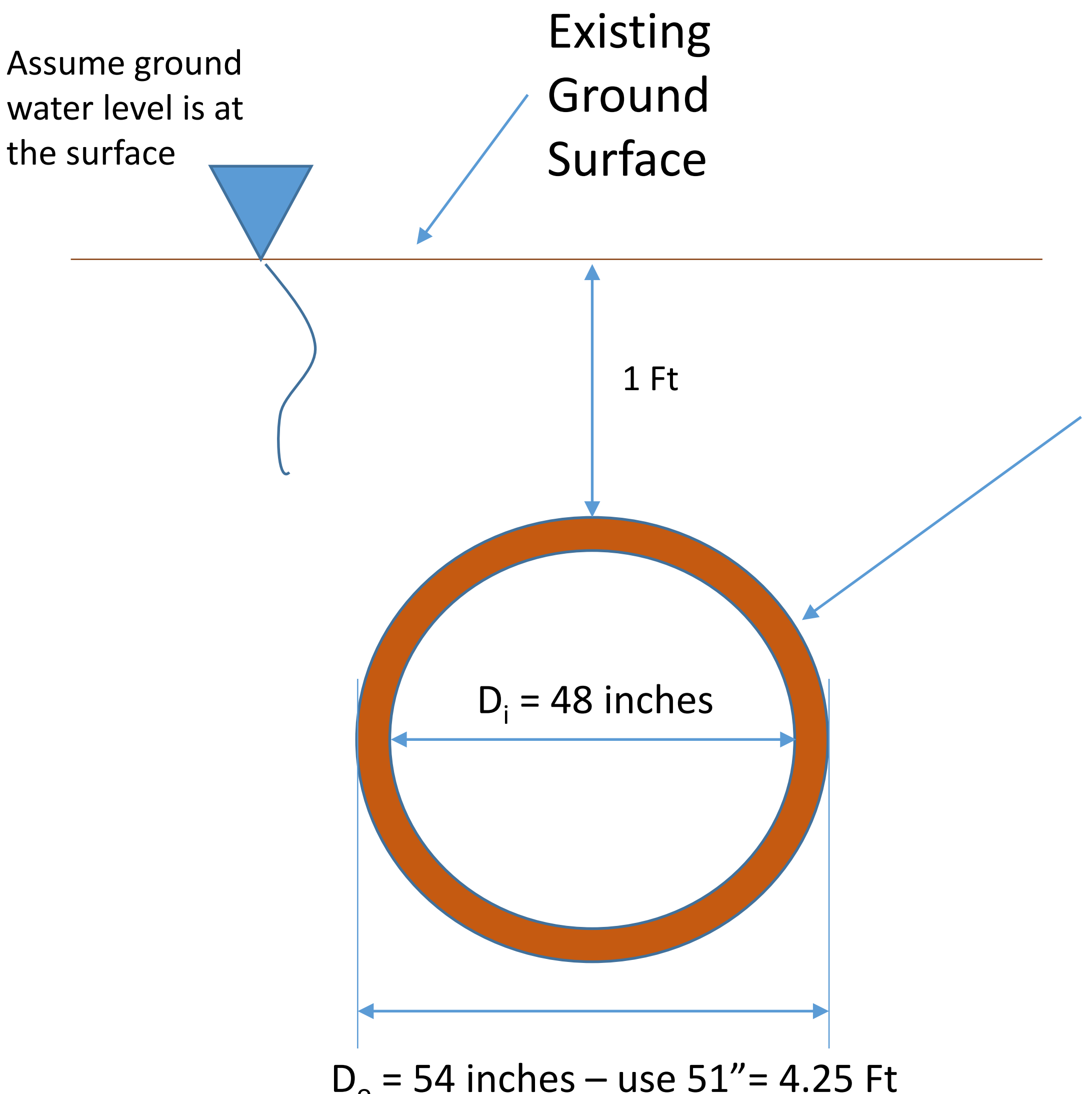
$$R_s = 338 + 307 = 645 \text{ lbs/ft}$$

Results Metal Pipe

Method	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
ACPA	-769	338	1.25	-623
W/M	-769	645	2.0	-893

Example: HDPE

- Buoyancy Force
- Soil Resistance
- Factor of Safety



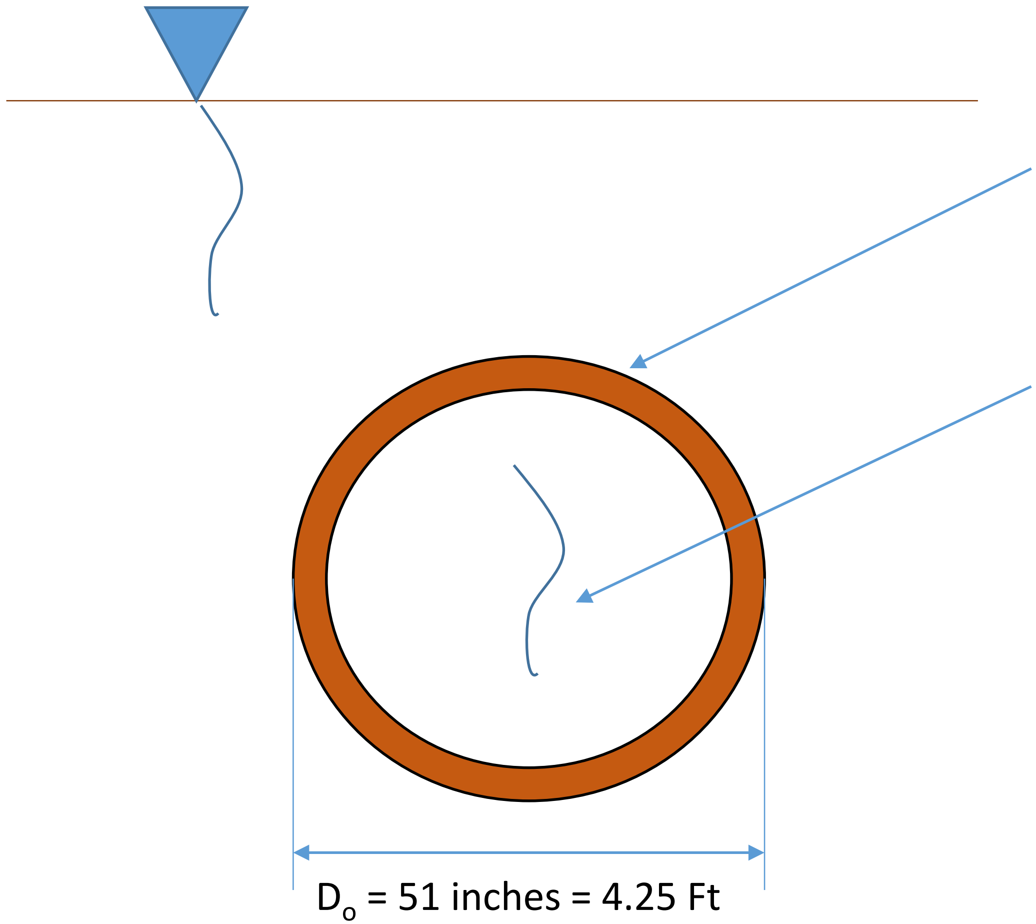
Given:

HDPE Pipe Weight = W_p = 26 lb/ft

γ_t = 120 pcf

ϕ = 30 deg

Is flotation a concern?



HDPE Pipe Weight =

W_p = 26 lb/ft

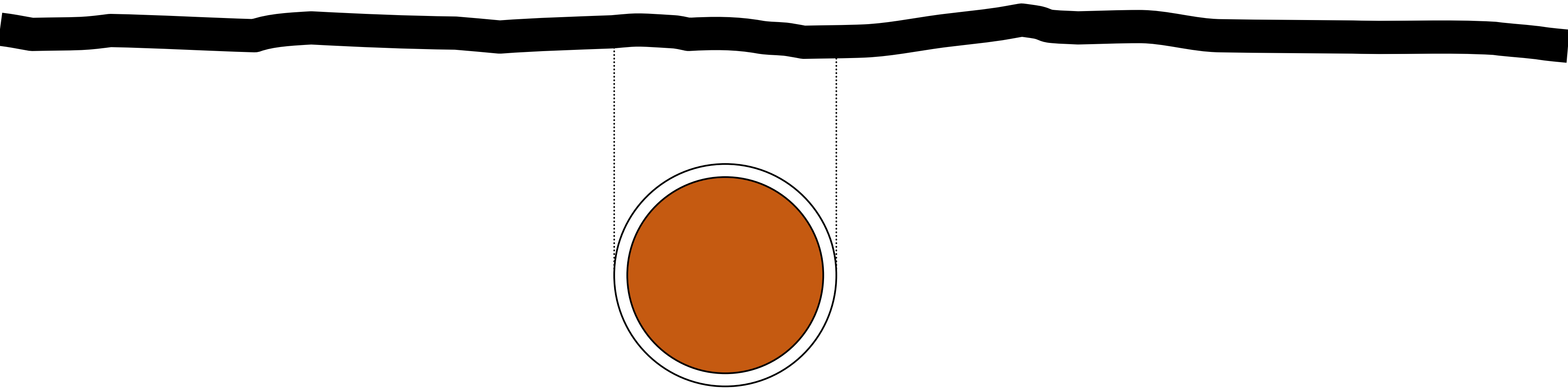
Weight of Water Displaced

$W_w = \pi \, (d_o/2)^2 \, \gamma_w$

W_w = 885 lbs/ft

BF = - 859 lb/ft

ACPA HDPE Pipe



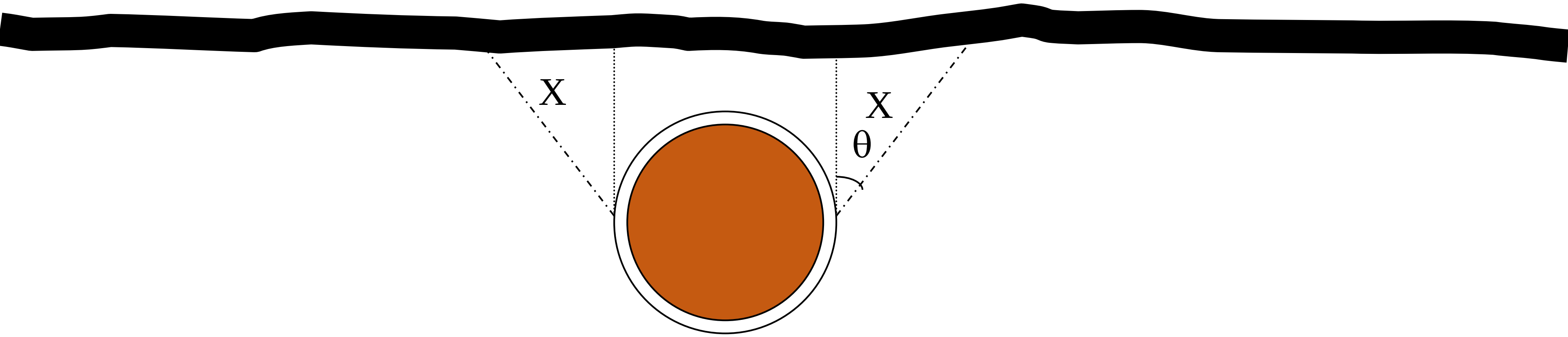
$$R_s = W_s = PL = \gamma_b \left[H + \frac{D_o (4 - \pi)}{8} \right] D_o$$

Equation 4 – Concrete Pipe Design Manual

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

$$R_s = 356 \text{ lbs/ft}$$

Watkins/Moser HDPE Pipe



$$\theta = 45 - \phi/2$$

$$R_s = PL + 2X$$

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

$$2X = [(1 + 4.25/2)^2 \tan(45 - 30/2)]\,(120\text{-}62.4)$$

$$R_s = 356 + 325 = 681 \text{ lbs/ft}$$

Results HDPE Pipe

Method	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
ACPA	-859	356	1.25	-717
W/M	-859	681	2.0	-1037

Comparison – ACPA Method

48" Pipe Type	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
HDPE	-859	356	1.25	-717
CMP	-769	338	1.25	-623
RCP	-278	423	1.25	75

Comparison – W/M Method

48” Pipe Type	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
HDPE	-859	681	2.0	-1037
CMP	-769	645	2.0	-893
RCP	-278	811	2.0	255

How Much Fill For a 48 Inch Pipe?

	Pipe Type		
Method	RCP	CMP	HDPE
ACPA	0.8 ft.	3.7 ft.	4 ft.*
M/W	0.5 ft.	2.8 ft.	3.0 ft.

*For plastic pipe, a good rule of thumb is fill height equal to pipe diameter.

ACPA Min Fill to Avoid Flotation

Pipe Size (in)	Min. Fill (ft)	Pipe Size (in)	Min. Fill (ft)	Pipe Size (in)	Min. Fill (ft)
21	0.1	42	0.6	78	1.5
24	0.1	48	0.8	84	1.7
27	0.2	54	0.9	90	1.9
30	0.3	60	1.1	96	2.0
33	0.3	66	1.2	102	2.2
36	0.4	72	1.4	108	2.4

48” RCP Results

Shape	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
Elliptical	-226	471	1.25	188
Circular	-278	423	1.25	75

Poll Question #5

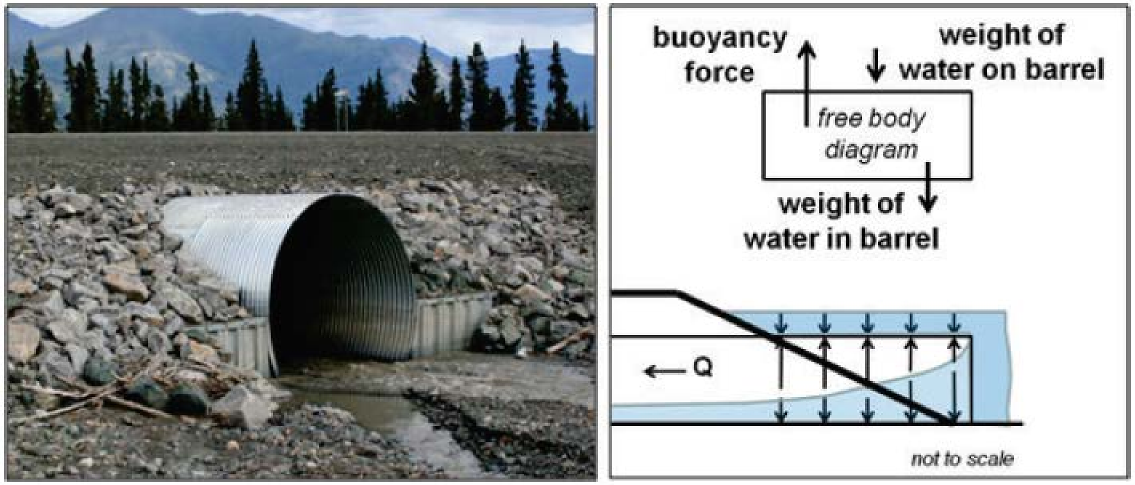
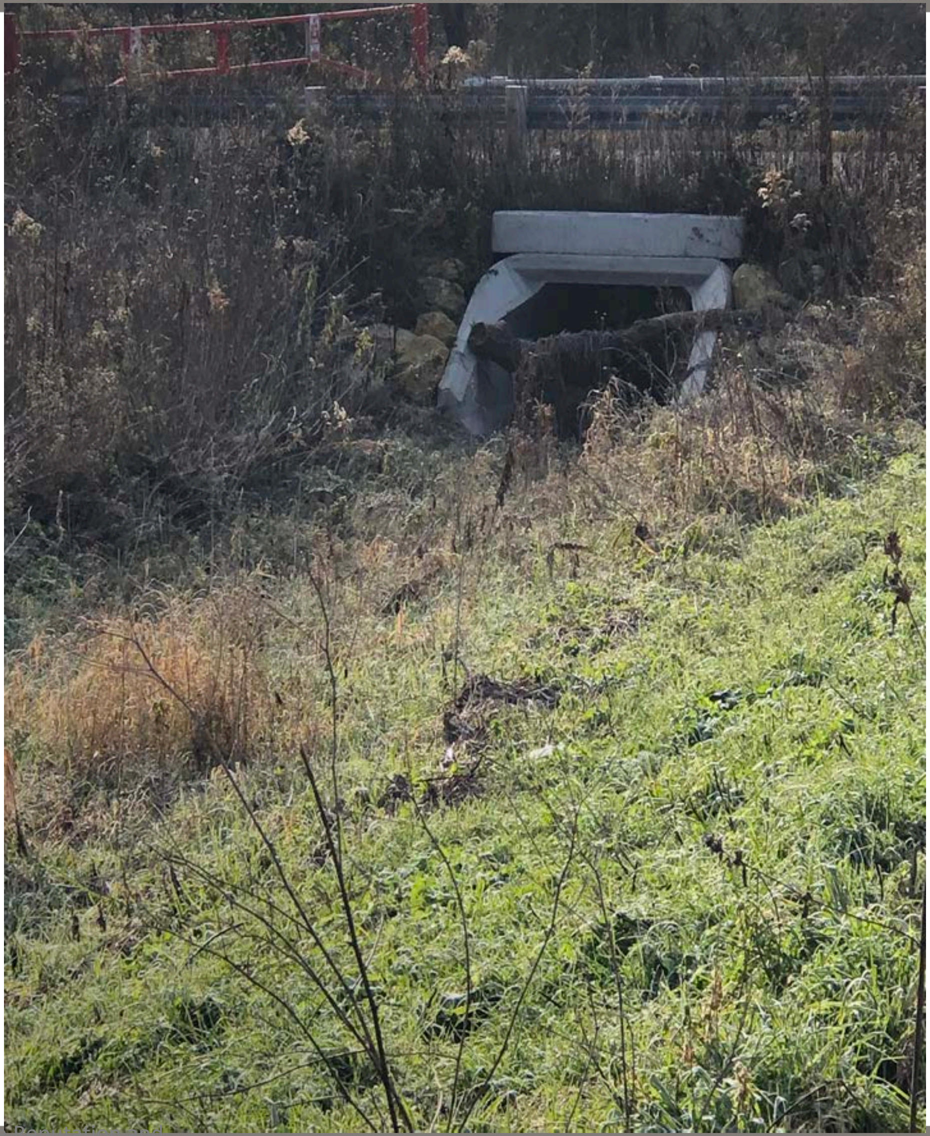


Figure 5.19. Unanchored thin edge projecting.

Source: FHWA HDS 5



Source: FHWA HDS 5

Source: FHWA
HDS 5

Rigid Rugged Resilient

Anchors

American Concrete Pipe Association

Poll Question #6

The End

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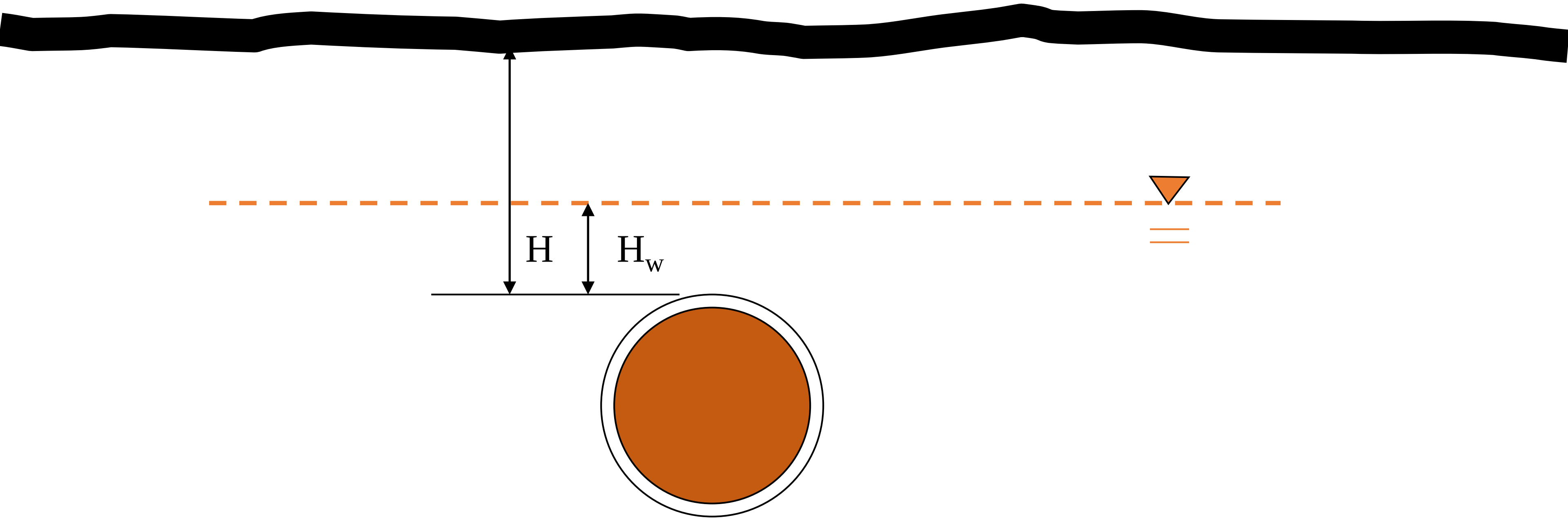
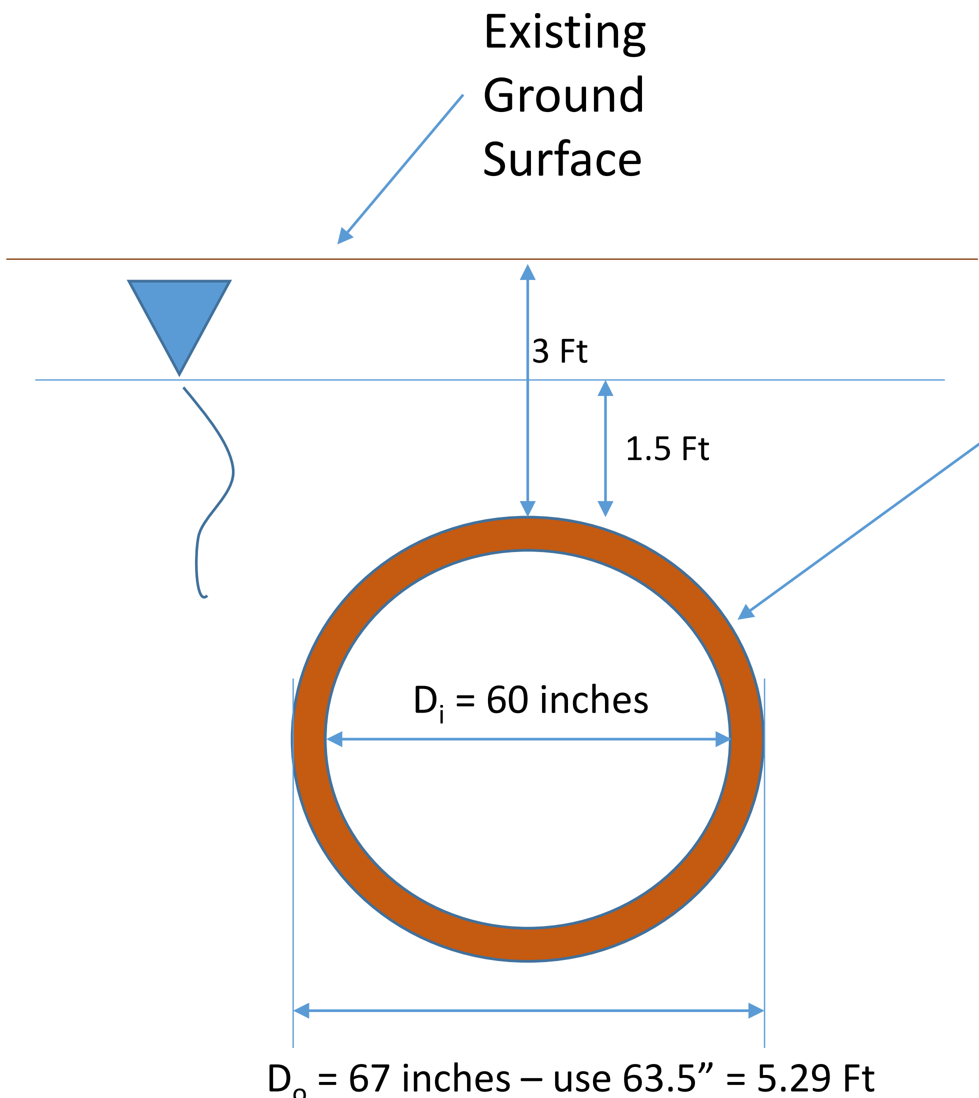
Water Table Not up to the Surface



Given:

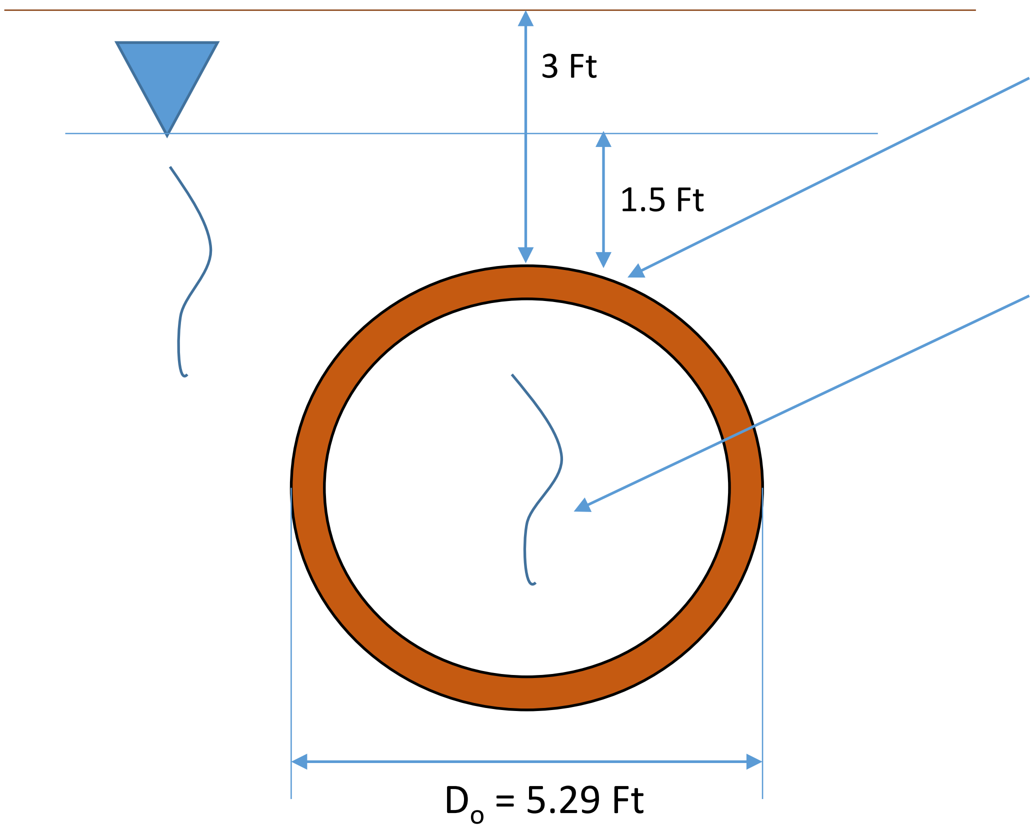


HDPE Pipe Weight = W_p = 62 lb/ft

γ_t = 130 pcf

γ_d = 110 pcf

Is flotation a concern?

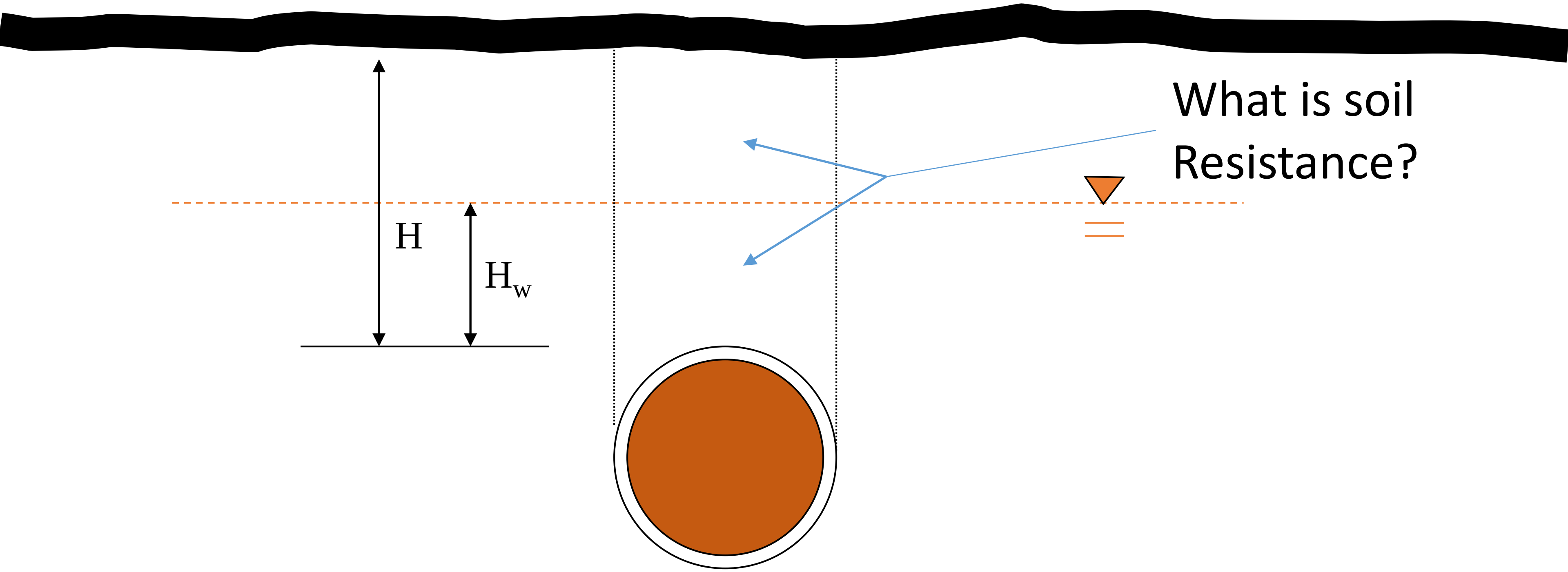


HDPE Pipe Weight =
W_p = 62 lb/ft

Weight of Water Displaced
$W_w = \pi (d_o/2)^2 \gamma_w$
W_w = 1373 lbs/ft

BF = - 1311 lb/ft

Water Table Not up to the Surface



Net Force = (BF x FS) + R_s

= (-1311 x 1.25) + R_s

If the water table is above the top of the pipe and at or above the ground surface:

$$P_{sp} = \frac{\left(H + 0.11\dfrac{D_o}{12}\right)\gamma_b}{144} \qquad (12.12.3.7\text{-}1)$$

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

$$P_{sp} = \frac{1}{144}\left[\begin{array}{c}\left[\left(H_W - \dfrac{D_o}{24}\right) + 0.11\dfrac{D_o}{12}\right]\gamma_b + \\ \left[H - \left(H_w - \dfrac{D_o}{24}\right)\right]\gamma_s\end{array}\right] \qquad (12.12.3.7\text{-}2)$$

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

$$P_{sp} = \frac{\left(H + 0.11\dfrac{D_o}{12}\right)\gamma_s}{144} \qquad (12.12.3.7\text{-}3)$$

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Calculation of Soil Resistance

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

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

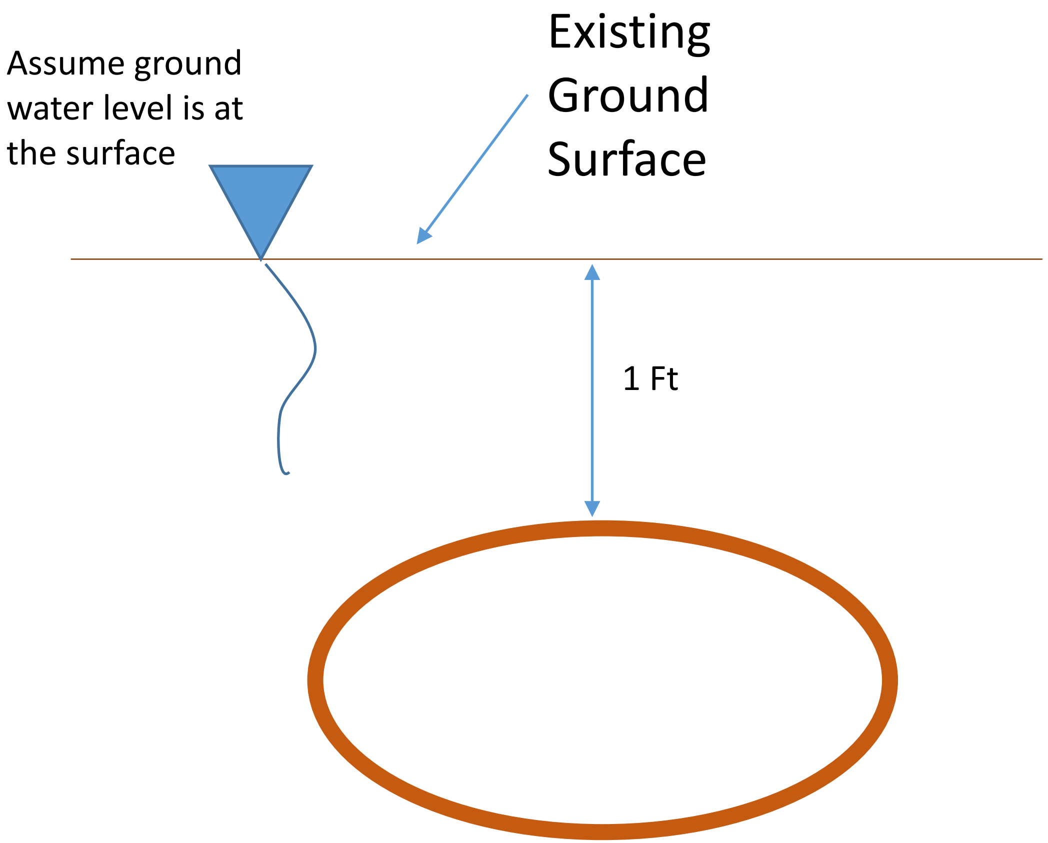
$$R_s = 739 + 873$$

$$R_s = 1612 \text{ lbs/ft}$$

Results HDPE Pipe

Method	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
ACPA	-1311	1612	1.25	-27

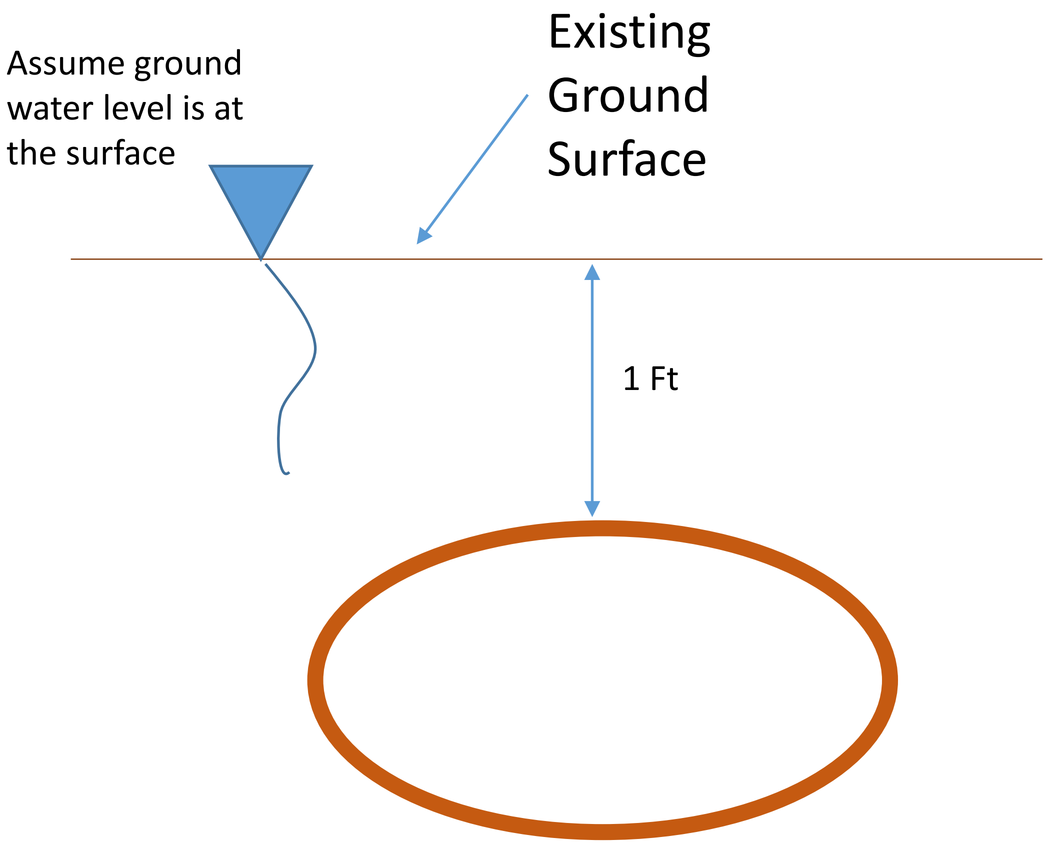
Floatation of Horizontal Elliptical Concrete Pipe



Given:

38 x 60 H.E. RCP

Is Flotation a Concern?



RC Pipe Weight =

W_p = 1000 lb/ft

γ_t = 120 pcf

ϕ = 30 deg

Illustration 5.3 Dimensions and Approximate Weights of Elliptical Concrete Pipe

ASTM C 507-Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	**Minor Axis, inches**	**Major Axis, inches**	**Minimum Wall Thickness, inches**	**Water-Way Area, square feet**	**Approximate Weight, pounds per foot**
18	14	23	2 3/4	1.8	195
24	19	30	3 1/4	3.3	300
27	22	34	3 1/2	4.1	365
30	24	38	3 3/4	5.1	430
33	27	42	3 3/4	6.3	475
36	29	45	4 1/2	7.4	625
39	32	49	4 3/4	8.8	720
42	34	53	5	10.2	815
48	38	60	5 1/2	12.9	1000
54	43	68	6	16.6	1235
60	48	76	6 1/2	20.5	1475
66	53	83	7	24.8	1745
72	58	91	7 1/2	29.5	2040

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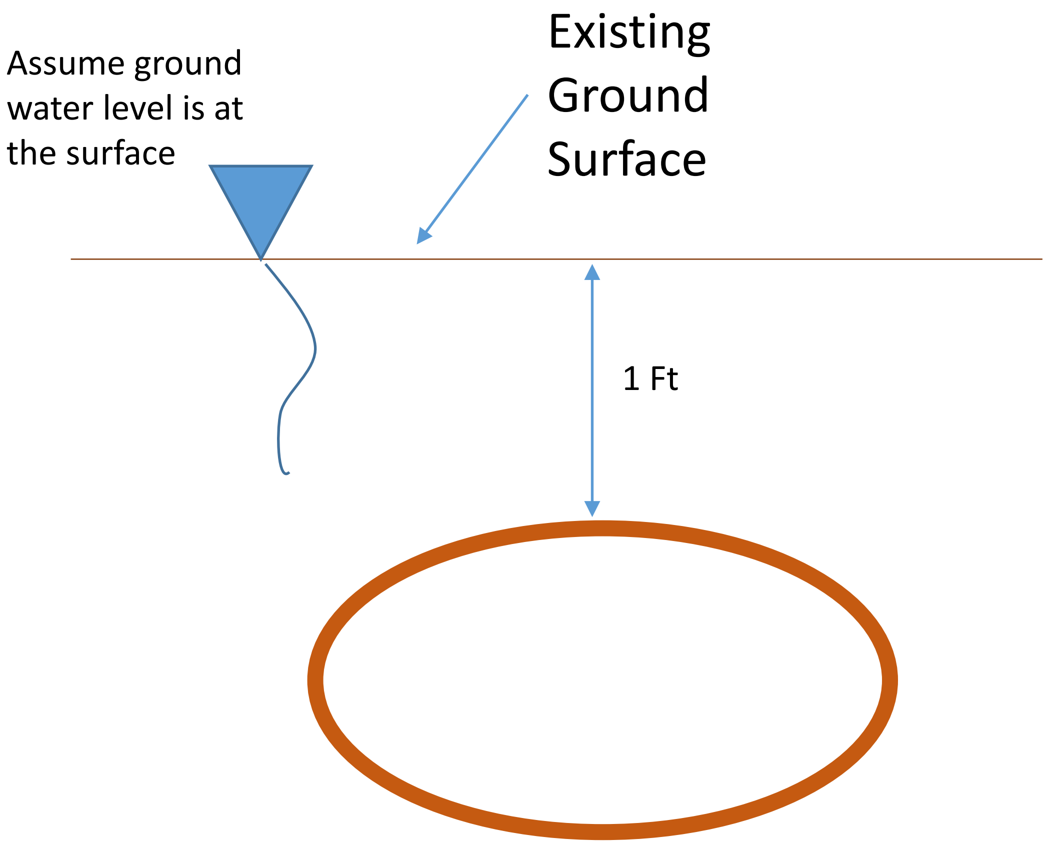


Is Flotation a Concern?

RC Pipe Weight = W_p =1000 lb/ft

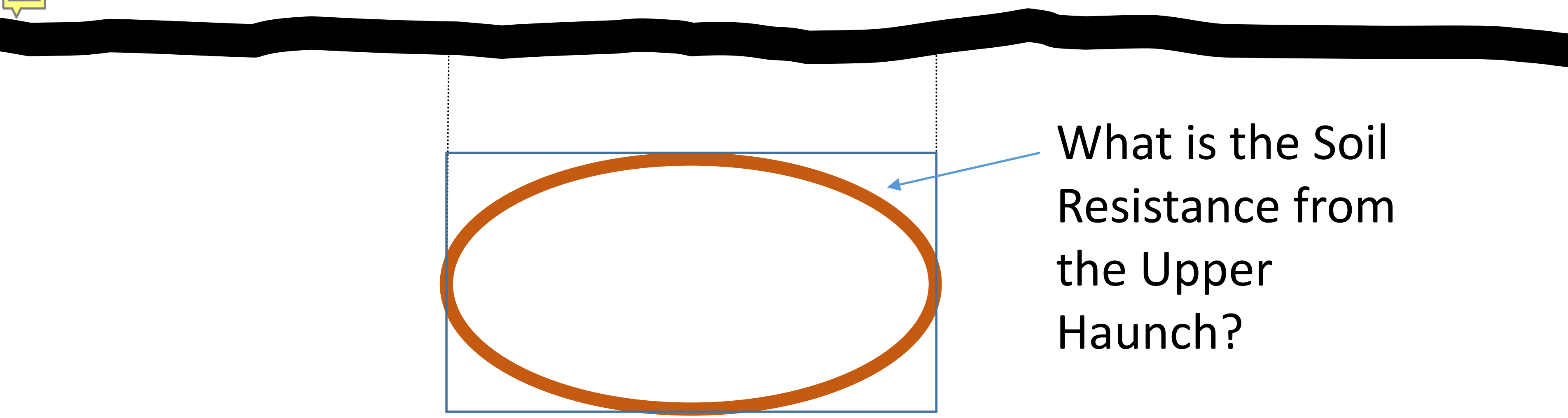
Area of Water Displaced = 19.64 ft^2

Weight of Water Displaced = W_w = 1,226 lbs/ft

BF = - 226 lb/ft

Areas of Elliptical Pipe for Buoyancy Purposes

Size (in)	Flow Area (ft^2)	Total Area (ft^2)	Size (in)	Flow Area (ft^2)	Total Area (ft^2)
24 x 38	5.10	8.02	63 x 98	34.6	50.66
27 x 42	6.33	9.55	68 x 106	40.1	58.14
29 x 45	7.36	11.44	72 x 113	46.1	66.38
32 x 49	8.78	13.58	77 x 121	52.4	75.70
34 x 53	10.2	15.58	82 x 128	59.1	84.09
38 x 60	12.9	19.64	87 x 136	66.4	93.62
43 x 68	16.7	25.02	92 x 143	73.9	103.95
48 x 76	20.5	30.49	97 x 151	82.1	114.74
53 x 83	24.8	36.5	106 x 166	99.2	138.81
58 x 91	29.4	43.05	116 x 180	118	164.76



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

Y = 38 + 2(5.5) = 49 in X = 60 + 2(5.5) = 71 in

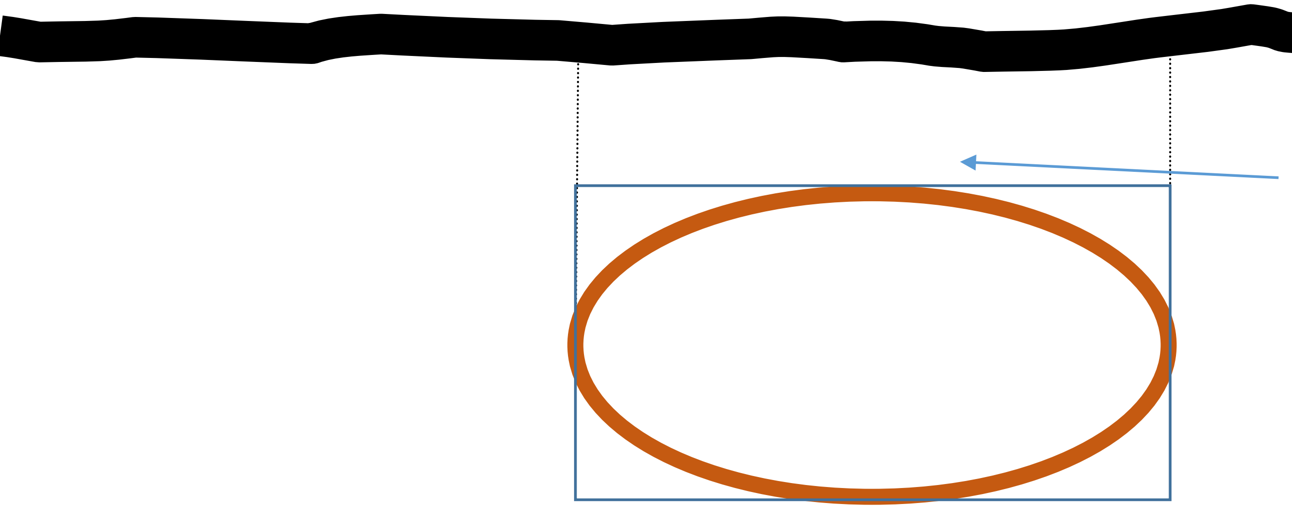
Rect. Area = X*Y = (49 x 71)/144 = 24.16 ft^2

Pipe Area = 19.64 ft^2

Upper Haunch Area = (24.16 – 19.64)/2 = 2.26 ft^2

Soil Weight from Upper Haunch = 2.26 ft^2 x 1 ft x (120 – 62.4) = 130 lbs/ft

ACPA Method Concrete Pipe



What is the Soil Resistance from the soil prism above the crown?

R_s = Upper Haunch + Rectangular Soil Prism

R_s = 130 lbs/ft + 1 ft x (71/12) x (120-62.4)

R_s = 471 lbs/ft

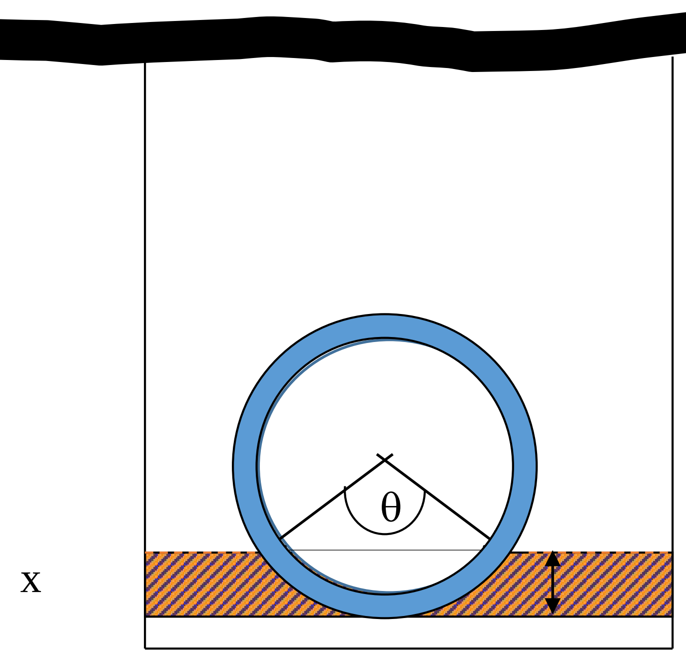
48" RCP Results

Shape	Buoyancy Force, BF (lbs/ft)	Soil Resistance R_s (lbs/ft)	Factor of Safety, FS	Net Force (lbs/ft)
Elliptical	-226	471	1.25	188
Circular	-278	423	1.25	75

Areas of Arch Pipe for Buoyancy Purposes

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

Flowable Fill



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

$$\theta = \text{invcos}[(r_o - x)/r_o]\ 2$$

Flowable Fill

- Using γ_{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

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References

- ACPA Design Data 22, *Flotation of Circular Concrete Pipe*
- *Buried Pipe Design* by A.P. Moser, second edition, McGraw hill
- *Structural Mechanics of Buried Pipes* by R.K. Watkins and L.R. Anderson, CRC press
- *Pipeline Installation* by A. Howard, relativity publishing
- *Soil Engineering* by M. Spangler & R. Handy, Harper & Row
- Federal Highways Administration

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