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Submitted 11/1/2022

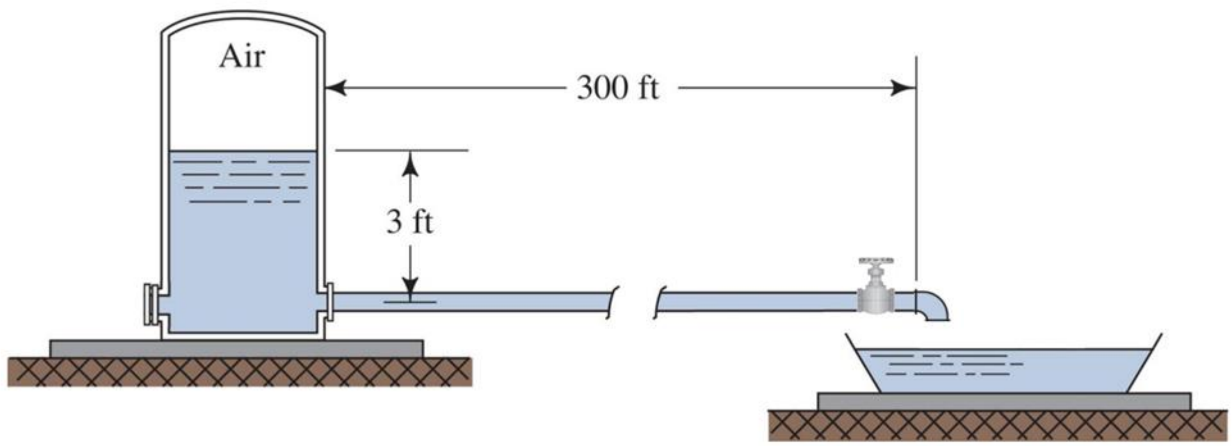
Exam 2

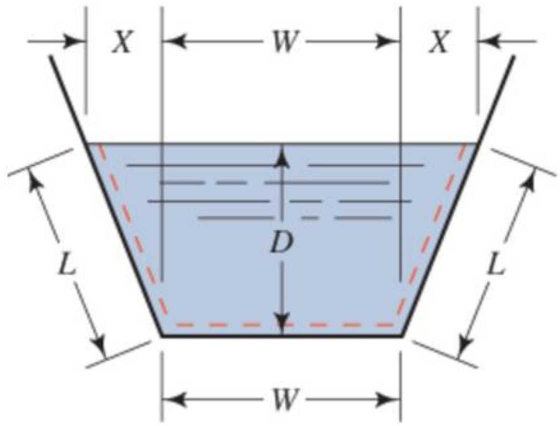
MET 330

Purpose:

Asked to finish designing a water system started by another company. It flows to open-channel that is trapezoidal, where you'll need to calculate the depth of the channel. Calculate the forces acting within the 300ft pipe length (through to the elbow) so the normal force of supports just has to exceed these forces. Determine the volume of a hickory log capable of floating in the open channel, as the channel will be used to transport them. If a flow nozzle is installed to measure flow in the pipe, find the pressure drop across the nozzle. Check that is the valve in the pipe is closed abruptly, the pipe can withstand the water hammer effect with standard wall thickness. Along with, ensure cavitation will not occur. Check that if a log half the size of the max carryable log became stuck to the bottom, the drag force it experienced would not be too great. Lastly, calculate the force on the blind flange on the tank and determine the location of the force.

Drawings and Diagrams:





$A = WD + XD$

$WP = W + 2L$

(c) Trapezoidal channel

Figure 14.2 from Text

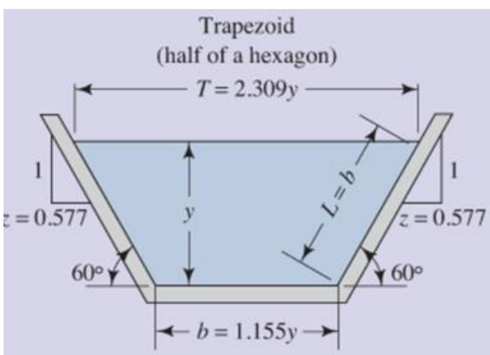
	$1.73y^2$	$3.46y$	$y/2$

Table 14.3 from Text

Table 8.2 Pipe roughness—design values

Material	Roughness ε (m)	Roughness ε (ft)
Glass	Smooth	Smooth
Plastic	3.0×10^{-7}	1.0×10^{-6}
Drawn tubing; copper, brass, steel	1.5×10^{-6}	5.0×10^{-6}
Steel, commercial or welded	4.6×10^{-5}	1.5×10^{-4}

Table 8.2 from Text

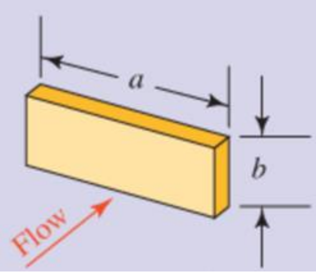
Shape of body	Orientation	a/b	C_D
Rectangular plate Flow is perpendicular to the flat front face.		1	1.16
		4	1.17
		8	1.23
		12.5	1.34
		25	1.57
		50	1.76
		∞	2.00

Table 17.1 from Text

Sources:

Applied Fluid Mechanics, 7th edition by Robert L. Mott and Joseph A. Untener

Design Considerations:

Water is an incompressible fluid. The system is undergoing an isothermal process. Entrance to the pipe from the reservoir is a square-entrance. Standard atmospheric pressure of 14.7psia, 0psig. Length of the hickory long proven to not be a relevant factor in size calculation.

Data and Variables:

$$\gamma_{H20@60F} = \mathbf{62.4}\frac{lb}{ft^3}$$

$$\rho_{H20@60F} = \mathbf{1.94}\frac{lb*s^2}{ft^4}$$

$$\eta_{H20@60F} = \mathbf{2.35*10^{-5}}\frac{lb*s}{ft^2}$$

$$\nu_{H20@60F} = \mathbf{1.21*10^{-5}}\frac{ft^2}{s}$$

$$Q = \mathbf{75}\frac{gal}{\mathbf{min}} = \mathbf{0.167038}\frac{ft^3}{s}$$

$$L = \mathbf{300}ft$$

$$D_{pipe} = \mathbf{1.610}in = \mathbf{0.134167}ft$$

$$E_{steel} = \mathbf{200}GPa = \mathbf{4177109440}\frac{lb}{ft^2}$$

$$\rho_{log} = \mathbf{830}\frac{kg}{m^3} = \mathbf{1.6104}\frac{lb*s^2}{ft^4}$$

$$n_{unfinishedconcrete} = \mathbf{0.017}$$

$$\beta = \mathbf{0.5}$$

$$D_{flange} = D_{pipe} = \mathbf{0.134167}ft$$

Procedure:

Use equation 14-11 to determine $Q_{discharge}$, which is the volume flow rate of the open-channel. Use equation 14-12 and substitute in the values for A and R from table 14.3 that are functions of y, then solve the equation for y which is the height of the channel. Setting the buoyant force equal to the weight of the log (because it is floating), obtain the ratio between the displacement volume and volume of the log. Using table 14.3 ratios of the trapezoidal open-channel, determine the width of the bottom of the channel. Use y and b as the maximum boundaries for the log to determine the maximum Area allowed in the volume of the log (listed as a square face, so width and height are 1:1). For the determined log size, calculate the center of gravity (centroid of the log), the center of buoyancy (centroid of the submerged area), and the distance to the metacenter (used an arbitrary length of 20ft for the log) to determine if the metacenter is above the center of buoyancy. Using Q_{pipe} and the area, determine the velocity of the fluid in the pipe. Determine Reynold's number for the pipe system, and use the given d/D, solve equation 15-7 for C. Solve equation 15-5 for P_1-P_2, which is the pressure drop across the flow nozzle. Take a log ½ the size of the one calculated in part C (now, size wasn't specified – ½ height and width, or ½ area? I chose ½ area). Using $Q_{discharge}$ and the area of the open-flow channel (from table 14.3), calculated the velocity of the open-channel. Use Table 17.1 to determine the discharge coefficient of the log face, and use equation 17-1 to solve for drag force. Draw a free-body diagram of the tank-to-elbow system. Calculate all losses (entrance, friction, valve, elbow). Then use Bernoulli's equation to determine P_1, which will be the pressure of the air in the tank. Reference table 1.3 to obtain the bulk modulus of water. Solve the equation on page 17 of my work to determine this C, which will be relevant to water hammer concerns. Calculate deltap, which will be the change in pressure due to the sudden change due to the valve closing. The pressure at the entrance to the pipe (so P_{air}+gamma*h) will be the highest operating pressure in the system, so add deltap to $P_{pipe-entrance}$ (top of page 21 on my work). Use equation 11-9 to solve for wall thickness needed at $P_{pipe-entrance}$ and ensure the standard wall thickness for a 1 ½ schedule 40 steel pipe exceeds this needed pressure, indicating it can withstand the water hammer. Draw a free-body diagram of the pipe (from entrance to elbow) and calculate forces, remembering that A_1=A_2 and V_1=V_2. Solve for the reactionary forces in both the X and Y directions. Lastly, draw a diagram of the blind flange located opposite the pipe in the tank. Calculate the reactionary force (using F=P*A). Using the height of the pressure distribution triangle as the height (diameter) of the flange, determine the centroid of the triangle (H/3), which is the location of the force.

Calculations:

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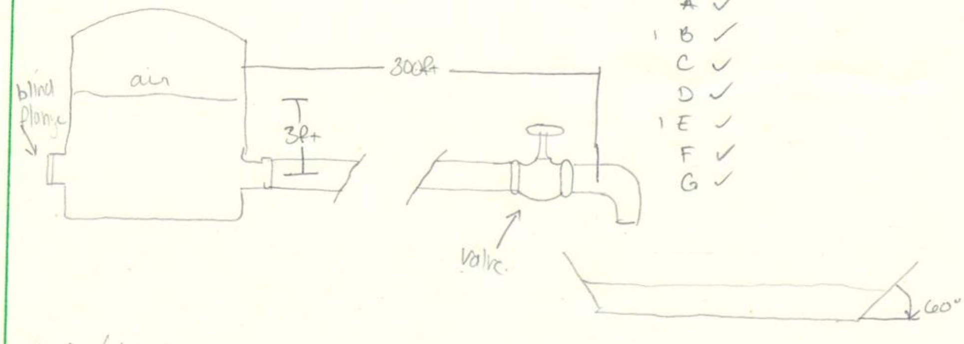
A ✓
B ✓
C ✓
D ✓
E ✓
F ✓
G ✓



Design/data:

H_2O @ 60F

$\gamma_{H_2O} = 62.4\ lb/ft^3$ ✓ $\rho_{H_2O} = 1.94\ \frac{slugs}{ft^3} = 1.94\ \frac{lbf \cdot s^2}{ft^4}$ ✓

$\eta_{H_2O} = 2.35 \times 10^{-5}\ \frac{lb \cdot s}{ft^2}$ ✓ $\nu_{H_2O} = 1.21 \times 10^{-5}\ ft^2/s$

at $75\ \frac{gal}{min}$

$Q = 75\ \frac{gal}{min} \cdot \frac{1\ ft^3/s}{449\ \frac{gal}{min}} = 0.167038\ \frac{ft^3}{s}$ ✓

from a pressurized tank — what pressure?

through 300ft of 1½ sched 40 steel pipe

$L = 300ft$ ✓ $D = 1.610in = 0.134167ft$ ✓

wall thickness $= 0.145in = 0.012083ft$

the modulus of elasticity of steel is 200 GPa

— modulus of elasticity is "bulk modulus"

$E_{steel} = 200\ GPa$

$E_{steel} = 200\ GPa \cdot \frac{1000\,000\,000\ Pa}{1\ GPa} \cdot \frac{1\ lb/ft^2}{47.88\ Pa}$

$E_{steel} = 4,177,109,44\ lb/ft^2$ ✓

to carry hickory logs

$\rho_{logs} = 830\ \frac{kg}{m^3} \cdot \frac{1\ slug/ft^3}{515.4\ \frac{kg}{m^3}} \cdot \frac{1\ \frac{lbf \cdot s^2}{ft}}{1\ slug} = 1.6104\ \frac{lbf \cdot s^2}{ft^4}$ ✓

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Ch14 a)

$\theta_{walls} = 60°$

width at top of water is $T = 2.309y$ · y is depth of water

From Table 14.3 -

$A = 1.73 \cdot y^2$ wetted perimeter $= WP = 3.46 \cdot y$

hydraulic radius $= R = \frac{y}{2}$

bottom width $= b = 1.155 \cdot y$

L = length of sloped walls from bottom to water's height

$L = b$

channel slope is 0.1 percent. $S = 0.1$

meaning it falls 1m per 1000m

$\sin^{-1}(0.001) = 0.057°$

$\sin\theta = \frac{h}{L}$

* h depicted in figure 14.5

a made of unfinished concrete. From table 14.1 -

$n = 0.017$ /

Ch16 b)

Ch5 c)

Ch15 d)

flownozzle to measure flow $\beta = \frac{d}{D} = 0.5$ ✓

* $C = 0.9975 - 6.53 \cdot \sqrt{\beta/Re}$

C is discharge coefficient

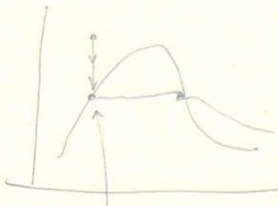
e)

find pressure increment

from 10/25 lecture are most relevant notes.

- no chapter in book - no practice problems.

* will have to refer to thermo book on how to find



this point.

- don't even remember what this is called
- definitely don't know how to find it

if P too low, cavitation begins

so if P in lowest pressure part of system drops below this point, have cavitation.

ch17 f)
find drag force of log 1/2 size of largest carriable log

$$F_D = C_D \cdot \frac{\rho \cdot v^2}{2} \cdot A$$

* reference table 17.1 for C_D based off a/D ratio

ch4 g)
compute force on blind flange + location of force

$D_{flange} = D_{pipe} = 0.134167 ft$

Solving

a)

hydraulic radius, area, wetted perimeter

$$R = \frac{A}{WP}$$

velocity, hydraulic radius, kinematic viscosity

$$Re_{open\ channel} = \frac{u \cdot R}{\nu}$$

Figure 14.2 for trapezoidal channel uses different variables.

here: W = bottom width
D = depth of water
X = L · cos60°
L = same as page 2

WP = W + 2L
A = WD + XD

T = 2.309y
= W + 2X

$$y = D = \frac{T}{2.309} = \frac{W+2X}{2.309}$$

Solving (cont)

Find y/D

a)

From Table 14.3.

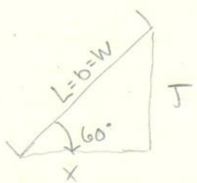
$R = \frac{y}{2} = \frac{D}{2} = \frac{A}{WP}$

$A = 1.73 \cdot y^2 = 1.73 \cdot D^2$

$WP = 3.46 \cdot y = 3.46 \cdot D$

$b = 1.155 \cdot y = W$

$L = b = W$



ratio of X : J

0.577 : 1

- so, we do not have velocity for Reynolds
- all other things we have are ratios to eachother
- if we use Manning's to get Velocity, it will be a ratio to y. cool.

Eq 14.10 - Mannings (U.S)

velocity → $U = \frac{1.49}{n} \cdot R^{2/3} \cdot S^{1/2}$

- $n = 0.017$
- $R = \frac{y}{2}$
- $S = 0.001$ ← 0.1% slope.

(14-11) $Q_{discharge} = \frac{1.49}{n} = A \cdot R^{2/3} \cdot S^{1/2} = A \cdot v.$

aha! finally, a term.

open flow channel. * $Q_{discharge} = \frac{1.49}{0.017} = 87.647059 \frac{ft^3}{s}$

- units guidance from book below equation 14-12.

$Q = U \cdot A$ $\qquad A = 1.73 \cdot y^2 = \quad (ft^2)$

$$\frac{Q}{A} = U = \frac{87.647059 \frac{ft^3}{s}}{1.73 \cdot y^2}$$

$$U = \frac{50.66304 \frac{ft^3}{s}}{y^2}$$

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a)

$$Re = \frac{U \cdot R}{\nu} = \frac{\frac{50.66304 \frac{ft^3}{s}}{y^2 (ft^2)} \cdot \frac{y}{2} (ft)}{1.21 \times 10^{-5} \frac{ft^2}{s}}$$

$\frac{ft}{s} \cdot \frac{1}{ft^2} = \frac{1}{s \cdot ft} \cdot ft = \frac{1}{s}$

- units don't work out; may be going down wrong path.

$$Re = \frac{\frac{25.33152 \frac{ft^3}{s}}{y}}{1.21 \cdot 10^{-5} \frac{ft^2}{s}}$$

- found my unit errors.

$\frac{ft^3}{s} \cdot \frac{1}{ft} \cdot \frac{s}{ft^2}$

* open channel

$$Re = \frac{2.093514 \times 10^6 \, ft}{y}$$

- may not need; unsure.

equation 14-12:

$$A \cdot R^{2/3} = \frac{n \cdot Q}{1.49 \cdot S^{1/2}} = \frac{0.017 \cdot 87.647059 \, ft^3/s}{1.49 \cdot 0.001^{1/2}}$$

$$\underset{ft^2}{A} \cdot \underset{ft^{2/3}}{R^{2/3}} = 31.62278 \frac{ft^3}{s} ?$$

$A = 1.73 \cdot y^2 \qquad R = \frac{y}{2}$

- A is in ft^2.
- R is in ft
- unsure how the s is dropped

$$1.73 \cdot y^2 (ft^2) \cdot \left(\frac{y}{2}\right)^{2/3} = 31.62278 \frac{ft^3}{s}$$

- book states this equation, though.

$$1.73 \cdot y^2 \cdot y^{2/3} \cdot 0.629961 = 31.62278 \, ft^3/s$$

$$1.08983 \cdot y^{2\,2/3} = 31.62278 \, ft^3/s$$

$$y^{2\,2/3} = 29.01625 \, ft^3/s$$

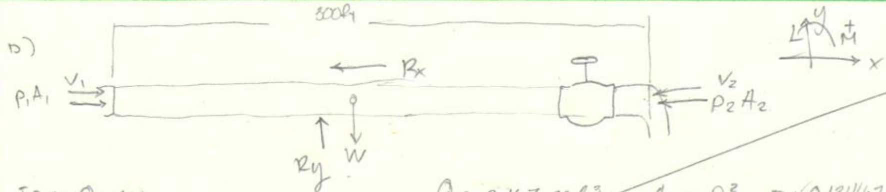
$2^{2/3} = 8/3$

$$\boxed{y = 3.53582 \, ft}$$

- well, this might be half legal at best.

→ have to move on & revisit if uncertainty remains.

D)



$F = \rho \cdot Q \cdot \Delta u$

$Q = 0.167038 \frac{ft^3}{s}$ $A = \frac{\pi \cdot D^2}{4} = \frac{\pi \cdot (0.134167 ft)^2}{4}$

$A = 0.0141378 ft^2$

$Q = V \cdot A$

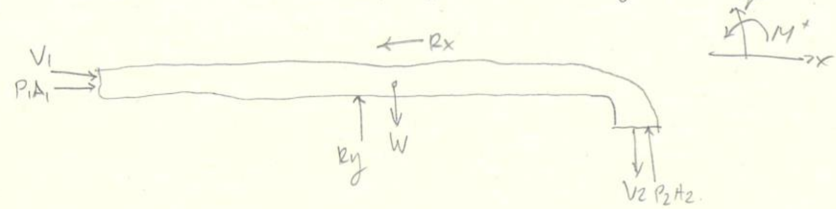
$V = Q / A = 11.81499\ ft/s$

$A_1 = A_2$ · same pipe the whole way. also means $V_1 = V_2$, so

$F = \rho \cdot Q \cdot \Delta u = \emptyset$

$\Sigma F_V: P_1 A_1$

ah, not including elbow. bad engie.



$A_1 = A_2$, $V_1 = V_2$, $P_1A_1 = P_2A_2$

ΣF_x:

$P_1A_1 - R_x = \rho \cdot Q \cdot (\cancel{V_{2x}} - V_{1x})$

ΣF_y:

$P_2A_2 + R_y - W = \rho \cdot Q \cdot (-V_{2y} - \cancel{V_{1y}})$

X:

$P_1 \cdot 0.0141378 ft^2 - R_x = 1.94 \frac{lbf\, s^2}{ft^4} \cdot 0.167038 \frac{ft^3}{s} \cdot -11.81499 \frac{ft}{s}$

tank pressure + $\gamma \cdot h$ to pipe

$-R_x = -3.84395\ lb - P_1 \cdot 0.0141378\ ft^2$

$\Rightarrow R_x = 3.84395\ lb + P_1 \cdot 0.0141378\ ft^2$

Y:

$\underbrace{P_2 \cdot A_2}_{\text{equal to } P_1A_1} + R_y - W = 1.94 \frac{lbf \cdot s^2}{ft^4} \cdot 0.167038 \frac{ft^3}{s} \cdot -11.81499\ ft/s$

C) 5-1

$F_b = \gamma_f \cdot V_d$

· γ_f is of the fluid
· V_d is displaced volume of the fluid

$W = \gamma_{obj} \cdot V$

· γ_{obj} is of the object
· V is volume of the object!

$\rho = \frac{m}{V}$ ← volume

$\gamma = \rho \cdot g$

$\gamma_{object} = \gamma_{log} = 1.6104 \frac{lbf s^2}{ft^4} \cdot 32.2 \frac{ft}{s^2} = 51.85488 \frac{lb}{ft^3}$

· set $F_D = W$ because log floating

$\gamma_{fluid} = 62.4 \frac{lb}{ft^3}$

$\gamma_{fluid} \cdot V_d = \gamma_{log} \cdot V_{log}$

$1.203358 \cdot V_d = V_{log}$

D)

$Re = \frac{\rho \cdot V \cdot D}{\eta}$

* calc Reynolds number.
· given β.
· use both to calc C.

15-7

$C = 0.9945 - 0.53 \sqrt{\beta / Re}$

15-5

$$Q = C \cdot A_1 \cdot \left[\frac{\frac{2g(p_1 - p_2)}{\gamma}}{\left(\frac{A_1}{A_2}\right)^2 - 1} \right]^2$$

$$\frac{Q^2}{C^2 \cdot A_1^2} = \frac{2g \cdot (p_1 - p_2)}{\gamma} \cdot \frac{1}{\left(\frac{A_1}{A_2}\right)^2 - 1}$$

$$\frac{Q^2 \cdot \left[\left(\frac{A_1}{A_2}\right)^2 - 1\right] \cdot \gamma}{C_2 \cdot A_1^2 \cdot 2g} = p_1 - p_2$$

e) Refer to P-V charts from thermodynamics

pg 118 in my book.

psia is relative to zero
where psig is relative to atm.

- looks like we need to calc P_{sat}

- just kidding!

referring to saturation tables in back.

H_2O @40°F saturates at 0.25638 psia

so using Bernoulli's

$$\frac{P_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + \cancel{z_1} = \frac{P_2}{\gamma} + \cancel{\frac{V_2^2}{2g}} + \cancel{z_2} + h_L$$

only friction + entrance losses
because we are before valve.

$$P_2 = \frac{\left(\frac{P_1}{\gamma} - h_{L_{FR}} - h_{L_{ent}}\right)}{\gamma}$$

$$h_{L_{FR}} = f \cdot \frac{L}{D} \cdot \frac{U^2}{2g}$$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)} + \frac{5.74}{Re^{0.9}}\right)\right]^{1/2}}$$

use Re from part D.

Table 8.2
- have D
- ε_{steel} is 1.5×10^{-4} ft

$$h_{L_{ent}} = K \cdot \frac{U^2}{2g}$$

per book guidance, using
$K = 0.5$ for square-edged inlet.

- want $P_2 > P_{sat}$

F) Take V_{avg} from part C and half.

17-1
$$F_D = C_D \cdot \left(\frac{\rho \cdot U^2}{2}\right) \cdot A$$

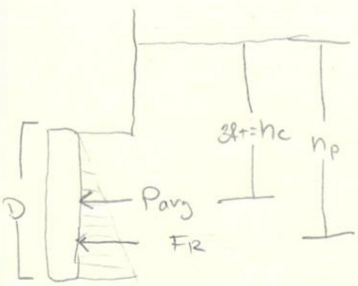
ρ_{H_2O} — remember to use $V_{open\,channel}$, not V_{pipe}

projected area of the log.

use table 17.1 to determine reasonable C_D.

G)
$F = p \cdot A$ $\quad A = \frac{\pi D^2}{4}$ $\quad$ D is same as D_{pipe}

p is from



$P_{air} + \gamma \cdot h$

find centroid of circle, that is where P_{avg} is.

force this time

F_R is located $\frac{2}{3}$ of D of a column face

C)
forgot about stability

$W = \gamma_{obj} \cdot V$

$F_b = \gamma_f \cdot V_d$

$$MB = \frac{I}{V_d}$$

Centroid of log is CoG

centroid of V_d is CoB

MB is location of metacenter from CoB

if MB above COG, stable.

So, the 1st 9 pages were for helping me sort the pretest. Onto the meat.

Calculations

$1 lbf = 1 lb.$

$\gamma_{H_2O} = 62.4 \ lb/ft^3$ $\quad \rho_{H_2O} = 1.94 \frac{lbs^2}{ft^4} \left[\frac{1 lbm \cdot \cancel{32.2 \frac{ft}{s^2}}}{\cancel{1 lbf}}\right]$ (if lbm needed)

$\eta_{H_2O} = 2.35 \cdot 10^{-5} \frac{lb \cdot s}{ft^2}$ $\quad \nu_{H_2O} = 1.21 \cdot 10^{-5} \ ft^2/s$

$Q = 75 \frac{gal}{min} = 0.167088 \frac{ft^3}{s}$ $\quad \theta_{walls} = 60°$ $\quad S = 0.1\% = 0.001$

$T = 2.309 \cdot y$

From Table 14.3 –

$A = 1.73 \cdot y^2$ $\quad R = \frac{y}{2}$ $\quad WP = 3.46 \cdot y$

$b = 1.155 \cdot y$ $\quad L = b$

From Table 14.1 –

n of unfinished concrete is 0.017

Equation 14-11

$$Q_{discharge} = \frac{1.49}{n} = \frac{1.49}{0.017} = 87.647059 \frac{ft^3}{s}$$

Equation 14-12

$$A \cdot R^{2/3} = \frac{n \cdot Q}{1.49 \cdot S^{1/2}} = \frac{0.017 \cdot 87.647059 \ ft^3/s}{1.49 \cdot 0.001^{1/2}}$$

$$A \cdot R^{2/3} = 31.622777 \ ft^3$$

· n is dimensionless, but behaves like 1/s

Substituting in y.

$$\Rightarrow (1.73 \cdot y^2) \cdot \left(\frac{y}{2}\right)^{2/3} = 31.622777 \ ft^3$$

$$1.73 \cdot y^2 \cdot y^{2/3} \cdot 0.6299605 = 31.622777 \ ft^3$$

$$y^{2\,2/3} = 29.015745 \ ft^3$$

$$y = \sqrt[8/3]{29.015745 \ ft^3}$$

$$\boxed{y = 3.535799 \ ft}$$

B)

$\gamma_{H_2O} = 62.4 \frac{lb}{ft^3} \left[\frac{1 ft^3}{7.48 gal} \right]$

· actually, don't think I can progress B until we are give Pair of tank because that + γ_{H_2O} 3ft creates P_1

c) $\rho_{log} = 830 \frac{kg}{m^3} = 1.6104 \frac{lbf \cdot s^2}{ft^4}$

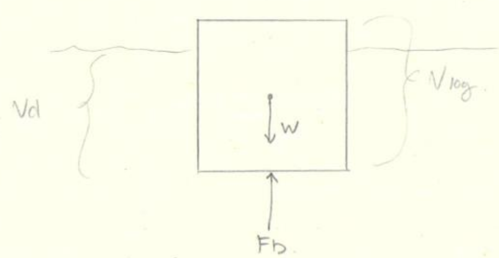
$\gamma_{log} = \rho \cdot g = 1.6104 \frac{lbf \cdot s^2}{ft^4} \cdot 32.2 \frac{ft}{s^2} = 51.85488 \frac{lb}{ft^3}$

$\gamma_{H_2O} = 62.4 \frac{lb}{ft^3}$

$F_b = \gamma_{H_2O} \cdot V_d \qquad W = \gamma_{log} \cdot V_{log}$

· because log is floating, $W = F_b$.

log cross section.



$\gamma_{H_2O} \cdot V_d = \gamma_{log} \cdot V_{log}$

$V_d = \frac{\gamma_{log} \cdot V_{log}}{\gamma_{H_2O}} = \frac{51.85488 \frac{lb}{ft^3} \cdot V_{log}}{62.4 \frac{lb}{ft^3}}$

$V_d = 0.831008 \cdot V_{log}$

this is where I get hesitant.
as long as the height of Vd is less than y of part a, and the width of Vd less than the width of the channel, it seems like it will float.

$y = 3.535799 ft$
$B = 1.155 \cdot y = 4.0838 ft$

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- now, it does specify that the cross section is a square
  w·h of V_{log} is some value squared.
- so can I just will-nilly dimensions? these boundaries feel insufficient.
- Do I create an F_b limit based off the boundaries, then use the V_d to V_{log} ratio to get V_{log} dimensions?

let's try it out

$V_d = b \cdot y \cdot l$

$b_{max} = 4.0898 ft$
$y_{max} = 3.5357794 ft$

· given that slope is 0.1%, slope falls 1ft every 1000ft.
· l must operate w/in that boundary.

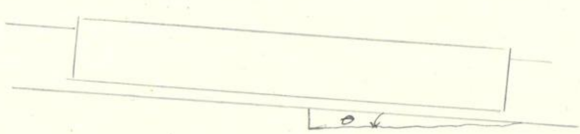
falls 0.05ft every 50ft.

$\approx$

$V_{d\,max} = b_{max} \cdot y_{max} \cdot l$

I just feel like I'm missing something

side view



maybe the slope not really pertinent here.

$V_{log} = \underset{\uparrow \atop b \cdot h}{A} \cdot l$

arbitrary: $4ft = h = b$.
$20ft = l$.

$V_{log} = 320 ft^3$.

$V_d = 0.831008 \cdot 320 ft^3 = 265.92256 ft^3$. ← this is needed to support log.

$V_d = y_{max} \cdot b_{max} \cdot l$

$V_{d\,max\,@20ft} = 288.73335 ft^3$ ← max potential @ 20ft long.

actually close, but I am not sure if that is my misunderstanding setting $F_D = W$.

think think think.

$V_d = 0.831008 \cdot V_{log}$

$y_{max} \cdot b_{max} \cdot \cancel{\ell} = 0.831008 \cdot A \cdot \cancel{\ell}$

$\rightarrow$ so ℓ not relevant

Area max at most be...

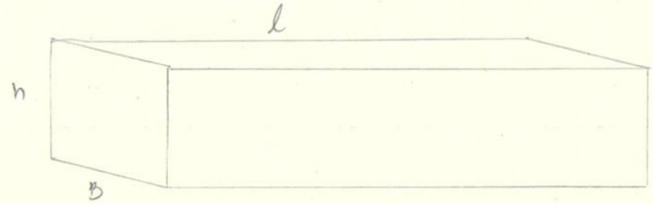
$$A_{max} = \frac{y_{max} \cdot b_{max}}{0.831008} = \frac{3.535799\,ft \cdot 4.0838\,ft}{0.831008}$$

$A_{max} = 17.37588\,08\,ft^2$

$B \cdot h = A_{max}^{1/2} = 4.1684391\,ft$

oh, my 4ft guess was really close.

but this exceeds b channel so that will become my ceiling



oh, just got the pretest email. confirms not to worry about length.

log

$b_{max} = B = h$

$A = B \cdot h = b_{max}^2 = 4.0838\,ft^2 = 16.6774122\,ft^2$.

so

$$\boxed{\begin{aligned} B &= 4.0838\,ft \\ h &= 4.0838\,ft \end{aligned}}$$

ℓ not important

Deferring to email contents before continuing:

B) says to use Bernoulli's for all pressure needs.

now, in a Bernoulli's problem, I would assume $P_2 = \emptyset$ because of being exposed to atmosphere, but that would mean $P_1 = \emptyset$, which sound wrong.

$P_1 > P_2$ because of flow?

! almost forgot elbow loss. thanks Doc!

~

don't like this lack of explanation on tank pressure.

D). specifies to absolutely not use Bernoulli's which...

awesome. wasn't in my plan. ✓

E) specifies to use water hammer equation

and to not use Bernoulli's. there goes that idea x.

$P_{max} = P_{operating} + \Delta p$

$\Delta p = \rho \cdot V \cdot C$

velocity

wave velocity.

$$C = \frac{\left(\frac{E_0}{\rho}\right)^{1/2}}{\left(1 + \frac{E_0 \cdot D}{E \cdot \delta}\right)^{1/2}}$$

- E_0 is bulk modulus of water
  Table 13
  $E_0 = 316{,}000\ psi$
- $\rho = 1.94\ \frac{lb \cdot s^2}{ft^4}$
- $D = D_{pipe} = 0.134167\ ft$
- E is elastic modulus of pipe material

  $E_{steel} = 4{,}177{,}109{,}440\ lb/ft^2$
- δ is pipe thickness

  $\delta = 0.012083\ ft$

G) Says to use Bernoulli's to determine tank pressure

$$\frac{P_1}{\gamma}+\frac{V_1^2}{2g}+z_1=\frac{P_2}{\gamma}+\frac{V_2^2}{2g}+z_2+h_{L_{fr}}+h_{L_{ent}}+h_{L_{valve}}+h_{L_{elbow}}$$

→ guess solve for P_1, assuming $P_2=\emptyset$
→ zref in pipe $=z_2=\emptyset$

$$P_1 \text{ (at water level in tank)} = \frac{h_{L_{fr}}+h_{L_{ent}}+h_{L_{valve}}+h_{L_{elbow}}-z_1}{\gamma}$$

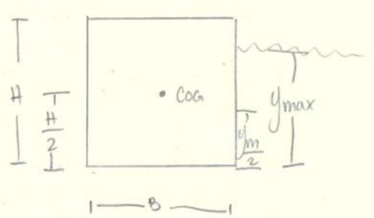
seems solvable.
works in conjunction w/ D.

Well, all right, time to keep going

C) okay, lets find center of gravity 1st.

that will be located at the centroid of the square.
per appendix L, this is located at $\frac{H}{2}$ on square

now center of bouyancy is in the centroid of the submerged area



$CoG_y = H/2 = 2.0419\,ft$
$CoB_y = y_{max}/2 = 1.7679\,ft$

for sake of it, assuming $L=20ft$

$$Ic_{vert}=\frac{B\cdot H^3}{12}$$

$$Ic=\frac{L\cdot B^3}{12}$$

· following figure 5.11's process.

$$Ic=\frac{20ft\cdot(4.0838ft)^3}{12}=113.512096\,ft^4$$

$Vd = y_{max}\cdot B_{max}\cdot 20ft = 288.789919\,ft^3$

$MB = I/Vd = 0.393\,ft$ $\quad$ $CoB_y + MB = 2.1609\,ft$

CoBy + MB > CoG, so confirmed stable!

D) $\beta = d/D = 0.5$ $\qquad C = 0.9975 - 6.53 \cdot \sqrt{\beta / Re}$

$$Re = \frac{\rho \cdot V \cdot D}{\eta}$$

$$\frac{Q_{pipe}}{A_{pipe}} = V_{pipe} = \frac{0.167038\ ft^3/s}{0.01413778\ ft^2} = 11.815009\ ft/s$$

$$A_{pipe} = \frac{\pi \cdot D^2}{4} = \frac{\pi \cdot (0.134167\ ft)^2}{4} = 0.01413778\ ft^2$$

$$Re = \frac{1.94\ \frac{lb \cdot s^2}{ft^4} \cdot 11.815009\ \frac{ft}{s} \cdot 0.134167\ ft}{2.35 \cdot 10^{-5}\ \frac{lb \cdot s}{ft^2}} = 1.3086 \cdot 10^5$$

$$C = 0.9975 - 6.53 \cdot \left(\frac{0.5}{1.3086 \cdot 10^5}\right)^{1/2} = 0.984736$$

from my own page 7 work.

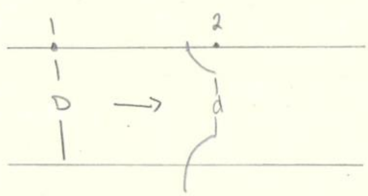
$$p_1 - p_2 = \frac{Q^2 \cdot \left[\left(\frac{A_1}{A_2}\right)^2 - 1\right] \cdot \gamma}{C_2 \cdot A_1^2 \cdot 2g}$$

$0.5 \cdot D = d = 0.0670835\ ft$

$A_1 = 0.01413778\ ft^2$

$A_2 = \frac{\pi \cdot d^2}{4} = 0.00353445\ ft^2$

$\left(\frac{A_1}{A_2}\right)^2 - 1 = 15.0004$



$$p_1 - p_2 = \frac{\left(0.167038\ \frac{ft^3}{s}\right)^2 \cdot 15.0004 \cdot 62.4\ lb/ft^3}{(0.984736)^2 \cdot (0.01413778\ ft^2)^2 \cdot 2 \cdot 32.2\ \frac{ft}{s^2}} = \frac{26.12295\ \frac{lb \cdot ft^3}{s^2}}{0.01224821\ \frac{ft^5}{s^2}}$$

$\frac{ft^6}{s^2} \cdot \frac{lb}{ft^3} \Rightarrow \frac{lb \cdot ft^3}{s^2}$ $\quad ft^4 \cdot \frac{ft}{s^2} \Rightarrow \frac{ft^5}{s^2}$ $\quad \frac{lb \cdot \cancel{ft^3}}{\cancel{s^2}} \cdot \frac{\cancel{s^2}}{ft^5} \Rightarrow \frac{lb}{ft^2}$ ✓

$$p_1 - p_2 = 2092.833 \frac{lb}{ft^2} \cdot \frac{1 ft^2}{144 in^2} = \boxed{14.5336 \text{ psi}}$$

E) $P_{max} = P_{operating} + \Delta p$ $\quad \Delta p = \rho \cdot V \cdot C$

$P_{operating}$: highest P in system

$$C = \frac{\left(\frac{E_o}{\rho}\right)^{1/2}}{\left(1 + \frac{E_o \cdot D}{E \cdot \delta}\right)^{1/2}}$$

$$E_o = 3.16 \cdot 10^5 \frac{lb}{in^2} \cdot \frac{144 in^2}{1 ft^2} = 45.504 \cdot 10^6 \frac{lb}{ft^2}$$

$$C = \frac{\left[\dfrac{45.504 \cdot 10^6 \frac{lb}{ft^2}}{1.94 \frac{lb \cdot s^2}{ft^4}}\right]^{1/2}}{\left[1 + \dfrac{45.506 \cdot 10^6 \frac{lb}{ft^2} \cdot 0.134167 ft}{4.177 \cdot 10^9 \frac{lb}{ft^2} \cdot 0.012083 ft}\right]^{1/2}} = \frac{4.843105 \cdot 10^3 ft/s}{1.05876}$$

$\left(\frac{\cancel{lb}}{\cancel{ft^2}} \cdot \frac{ft^{\cancel{4}\,2}}{\cancel{lb} \cdot s^2}\right)^{1/2}$

$\frac{\cancel{lb}}{\cancel{ft^2}} \cdot \cancel{ft} \cdot \frac{\cancel{ft}}{\cancel{lb}}$

$C = 4,574.318 \frac{ft}{s}$

$$\Delta P = \rho \cdot V \cdot C$$
$$= 1.94 \frac{lb \cdot s^2}{ft^4} \cdot 11.815009 \frac{ft}{\cancel{s}} \cdot 4,574.318 \frac{ft}{\cancel{s}}$$

$$\Delta P = 104,848.48 \frac{lb}{ft^2} \cdot \frac{1 ft^2}{144 in^2} = 728.1144 \text{ psi}$$

pressure increment.

Now, thinking it over.
Largest pressure is normally at a pump outlet, but we have no pump.

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so where is the Largest P?

→ think at the pipe entrance
- has experienced no losses yet
- has pressurized air $+ \gamma_{H_2O} \cdot 3ft$

Dr. Ayala specifies we should not need Bernoulli's on this one, but I fail to see how we can determine $P_{operating}$ w/o it

Like B, I'll have to return here after I figure of P_{air}.

F) max log — this steps log

$A = 16.67742\,ft^2$ — $A = 8.33871\,ft^2$
$B = 4.0838\,ft$ — $B = 2.88768\,ft$
$H = 4.0838\,ft$ — $H = 2.88768\,ft$

- er, ½ area? volume? just says ½ size.
- assuming ½ area
- keeping square

From Table 17.1, C_D is 1.16 as a/b in chart $= 1$

$$V_{dis} = \frac{Q_{discharge}}{A_{channel}} = \frac{87.647059\ \frac{ft^3}{s}}{1.73 \cdot y^2} = \frac{87.647059\ ft^3/s}{1.73\,(3.535794\,ft)^2}$$

$V_{discharge} = 4.05244\ ft/s$

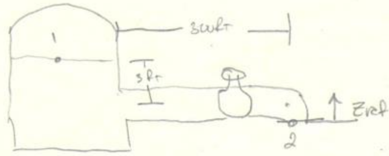
$$F_D = C_D \cdot \frac{\rho \cdot V_{discharge}^2}{2} \cdot A$$

$$= 1.16 \cdot \frac{1.94\,\frac{lb \cdot s^2}{ft^4} \cdot \left(4.05244\,\frac{ft}{s}\right)^2}{2} \cdot 8.33871\,ft^2$$

$$\boxed{F_D = 154.0855\ lb}$$

$$\frac{lb \cdot \cancel{s^2}}{\cancel{ft^4}} \cdot \frac{\cancel{ft^2}}{\cancel{s^2}} \cdot \cancel{ft^2} \checkmark$$

A look at the system



$$\frac{P_1}{\gamma} + \cancel{\frac{V_1^2}{2g}} + z_1 = \cancel{\frac{P_2}{\gamma}} + \frac{V_2^2}{2g} + \cancel{z_2} + h_{L_{ent}} + h_{L_{FR}} + h_{L_{valve}} + h_{L_{elbow}} + \cancel{h_{L_{exit}}} ?$$

answe if this included

- I would normally not include h_L exit because that is exiting into another reservoir, which this is not

$$h_{L\,ent} = K \cdot \frac{V^2}{2g} = 0.5 \cdot \frac{V^2}{2g}$$

$$h_{L\,valve} = K \cdot \frac{V^2}{2g} = 6.8 \cdot \frac{V^2}{2g}$$ assuming globe valve

$$K_{valve} = 340 \cdot f_T = 340 \cdot 0.020 = 6.8$$

$$f_T \text{ of pipe} = 0.020$$

$$h_{L\,elbow} = K \cdot \frac{V^2}{2g} = 0.6 \cdot \frac{V^2}{2g}$$

$$K_{elbow} = 30 \cdot f_T = 30 \cdot 0.020 = 0.600$$

$$h_{L\,FR} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \qquad f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\left(\frac{D}{\varepsilon}\right)} + \frac{5.74}{Re^{0.9}}\right)\right]^2}$$

$$Re = \frac{\rho \cdot V D}{\eta} \qquad \frac{D}{\varepsilon} \leftarrow \text{Table 8.2}$$

$$P_1 = \frac{h_{L\,ent} + h_{L_{FR}} + h_{L_{valve}} + h_{L_{elbow}} - z_1 + \frac{V_2^2}{2g}}{\gamma}$$

20

piece by piece

$D = 0.134167\,ft$ $\qquad \frac{D}{\varepsilon} = 894.44667$

$\varepsilon = 1.5\times10^{-4}\,ft$

$$Re = \frac{\rho \cdot V \cdot D}{\eta} = \frac{1.94\,\frac{lb\cdot s^2}{ft^4} \cdot 11.815009\,\frac{ft}{s} \cdot 0.134167\,ft}{2.35\times10^{-5}\,\frac{lb\cdot s}{ft^2}} = 1.30862\cdot10^5$$

$$f = \frac{0.25}{\left[\log\left(\frac{1}{3.7\cdot 894.44667} + \frac{5.74}{(1.30862\cdot10^5)^{0.9}}\right)\right]^2} = 0.02225$$

$$h_{L\,FR} = f\cdot\frac{L}{D}\cdot\frac{V^2}{2g} = 0.02225 \cdot \frac{300\,ft}{0.134167\,ft}\cdot\frac{\left(11.815009\,\frac{ft}{s}\right)^2}{2\cdot 32.2\,\frac{ft}{s^2}}$$

$h_{L\,FR} = 107.84197\,ft$

$$h_{L\,elbow} = 0.6\cdot\frac{\left(11.815009\,\frac{ft}{s}\right)^2}{2\cdot 32.2\,\frac{ft}{s^2}} = 1.300569\,ft$$

$$h_{L\,valve} = 6.8\cdot\frac{\left(11.815009\,\frac{ft}{s}\right)^2}{2\cdot 32.2\,\frac{ft}{s^2}} = 14.73979\,ft$$

$$h_{L\,ent} = 0.5\cdot\frac{\left(11.815009\,\frac{ft}{s}\right)^2}{2\cdot 32.2\,\frac{ft}{s^2}} = 1.08381\,ft$$

$$P_1 = \frac{1.0381\,ft + 107.84197\,ft + 1.300569\,ft + 14.73979\,ft - 3\,ft + \frac{\left(11.815009\,\frac{ft}{s}\right)^2}{2\cdot 32.2\,ft/s^2}}{\cancel{62.4\,\frac{lb}{ft^3}}}$$

$ft\cdot\frac{lb}{ft^3} = ✓$

$P_1 =$ something has gone wrong. these units are no good.

oh duh, $\cdot\gamma$, not $\div\gamma$.

$$P_1 = 7{,}743.094\,\frac{lb}{ft^2}\cdot\frac{1\,ft^2}{144\,in^2} = 53.77149\,psi$$

↑ air pressure

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$P_{entrance}$: $P_{air} + \gamma_{H_2O} \cdot 3ft = 7743{,}094 \frac{lb}{ft^2} + 62.4 \frac{lb}{ft^3} \cdot 3ft =$

$P_{pipe\ entrance} = 7{,}930.294 \frac{lb}{ft^2}$

now then ~

E) I believe $P_{pipe\ entrance}$ to be the largest P in the system.

$P_{max} = P_{operation} + \Delta P = 7{,}930.294 \frac{lb}{ft^2} + 104{,}848.48 \frac{lb}{ft^2} = 112{,}778.774 \frac{lb}{ft^2}$.

then, using equation 11-9, make sure t of pipe can hold against that.

$$t = \frac{p \cdot D}{2(S \cdot E + p \cdot Y)}$$

- p being P_{max}
- D here is outside diameter
- S is 16,700 lb/in²
- E is 1 for seamless steel
- Y is 0.40 for steel

$$t = \frac{112{,}778.774 \frac{lb}{ft^2} \cdot 1.9in \cdot \frac{1ft}{12in}}{2\left(16900 \frac{lb}{in^2} \cdot \frac{144 in^2}{1ft^2} \cdot 1 + 112{,}778.774 \frac{lb}{ft^2} \cdot 0.40\right)}$$

$t = 0.003644\ ft \cdot \frac{12in}{1ft} = 0.043in$ ⟵ so needed wall thickness

wall thickness of 1½in schedule 40 steel is

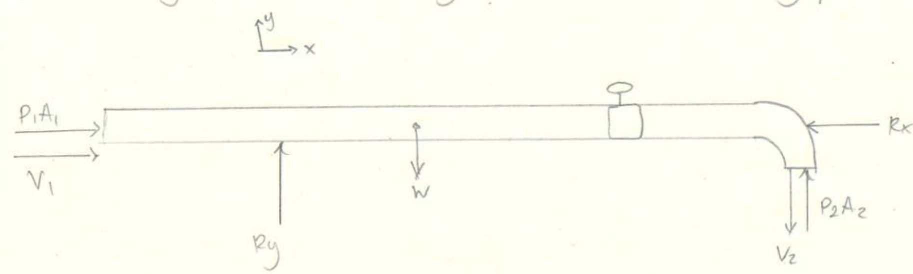
what we have! ⟶ 0.145 in , which can handle it! ^^

Now for cavitation:

- seems absolutely impossible w/o any form of suction to drop the pressure so dramatically

Given that the outlet is open to atmosphere and nothing drawing suction, I am willing to declare that cavitation can not happen in this system under normal operation

B) frustrated by B, so I want to try & sort it out & then email any questions.



$F = \rho \cdot Q \cdot \Delta V$ $\qquad A_1 = A_2 \qquad V_1 = V_2$

but $P_1 \neq P_2$ ...? ↳ correct, they are not equal.

ΣF_x:

$P_1A_1 - R_x = \rho \cdot Q \cdot (\cancel{V_{2x}} - V_{1x})$

$P_1 = P_{air} + \gamma_{H_2O} \cdot 3ft = 7{,}930.2914 \frac{lb}{ft^2}$

$A_1 = \frac{\pi \cdot D^2}{4} = 0.01413778 ft^2$

$-R_x = (\rho \cdot Q \cdot -V_1) - P_1 \cdot A_1$

$-R_x = \left(1.94 \frac{lb \cdot s^2}{ft^4} \cdot 0.1670388 \frac{ft^3}{s} \cdot -11.815009 \frac{ft}{s}\right) - 7930.2914 \frac{lb}{ft^2} \cdot 0.01413778 ft^2$

$R_x = 115.9454\ lb$

ΣF_y: $P_2 \cdot \cancel{A_2} + R_y - W = \rho \cdot Q \cdot V_{2y} - \cancel{V_{1y}}$

- so A_1 equals A_2, but I think $P_2 = \emptyset$ because exposed to atmosphere
- but now, I do not know Ry or W, or the relation between Ry and Rx

$\ddot{\sim}$

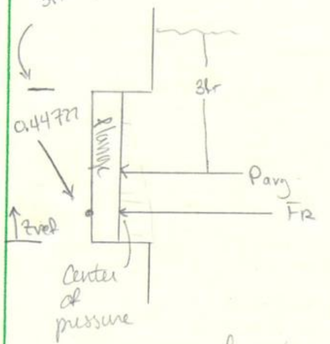
$\Rightarrow R_y - W = \left(1.94 \frac{lb \cdot s^2}{ft^4} \cdot 0.1670388 \frac{ft^3}{s} \cdot -11.815009 \frac{ft}{s}\right)$

$R_y - W = -3.8286981\ b$

- have 2 unknowns and don't see why.

→ sent off email to Dr. Ayala $\ddot{\frown}$

G) $3ft - \frac{1}{2} \cdot D = 2.9329 ft$



$D_{flange} = D_{pipe} = 0.134167 ft$

centroid of flange is where Pavg will be located

$F = P \cdot A$

$P_{pipe\ entrance} = P_{flange}$

from my own page 21

$$P = P_{air} + \gamma_{H_2O} \cdot 3ft = 7743.094 \frac{lb}{ft^2} + 62.4 \frac{lb}{ft^3} \cdot 3ft = 7{,}930.294 \frac{lb}{ft^2}$$

$$A_{circle} = \frac{\pi \cdot D^2}{4} = 0.01413778 ft^2$$

$$\boxed{F_R = P \cdot A = 112.11675 lb}$$

$h_c = 3ft$
$h_p =$ location of F_R.

$$h_p = h_c + \frac{I_c \cdot \sin^2\theta}{h_c \cdot A}$$

but there is no angle between them, so that is out.

F_R is located at the centroid of the pressure distribution triangle

oh my gosh that was a fact I was missing for so long.

centroid of triangle $= \frac{H}{3}$

H here is diameter of the flange,

so located at 0.044722 ft. from z ref.

or $3ft + \frac{2H}{3}$ from fluid surface, 3.08944 ft

After speaking via email to Dr Ayala, I have confirmed I should know the weight and am doing something wrong.

B) from page 22
$R_y - W = -3.8286981b.$

$\gamma = \frac{W}{\forall}$ $W = m \cdot g$ $m = \rho \cdot \forall$

thank you so much, Dr Ayala

$W = \rho \cdot \forall \cdot g$

$\forall_{pipe} = A \cdot L$
$= 0.01413778 ft^2 \cdot 300 ft$
$= 4.2413 ft^3$

$W = 1.94 \frac{lb \cdot s^2}{ft^4} \cdot 4.2413 ft^3 \cdot 32.2 \frac{ft}{s^2}$
$W = 264.94553 lb$

$R_y = -3.828698 lb + 264.94553 lb$
$R_y = 261.11683 lb$

$R = (R_x^2 + R_y^2)^{1/2} = 285.70148 lb.$

$\tan^{-1} \frac{R_y}{R_x} = \theta = 66.057°$

Lessons:
$P_1A_1 \neq P_2A_2$ $W = m \cdot g = \rho \cdot \forall \cdot g$

F_R is located at the centroid of a pressure triangle

Summary:

The channel is 3.536 ft deep. The length of the hickory log proved irrelevant. The log is proven to be stable. The pressure drop across the flow nozzle is 14.5336psi. The pressure increase due to water hammer is 728.114 psi. The drag force of a log ½ the area of the first is 154.055lb. The air in the tank is pressurized to 53.77psi. The highest pressure experienced in the system is at the pipe entrance. The thickness of standard 1 ½ in schedule 40 steel piping is more than sufficient for the water hammer experienced in this system. There is nothing in the system drawing suction (such as a pump) or creating any negative pressure, so there is no risk of cavitation in standard operation. The reactionary force is 115.95lb in the right-direction, and 285.7lb in the up-direction. Force felt by the flange should be 112.12lb, located 3.089ft from the water surface.

Materials:

300ft of 1 ½ inch schedule 40 steel pipe

1 water tank

1 blind flange

1 globe valve

1 pipe elbow

Analysis:

I remain unsure on the force location for the blind flange. I worry that the pressure distribution triangle starts at the water's height instead of the flange itself, which would put the centroid of said triangle 2ft into the water instead of 2/3 down the flange face.

Did not have to lean on thermal tables for cavitation pressure after thinking it out as class email suggested. No reason for a suction/vacuum effect to drop the pressure that dramatically and create cavitation. Circumstance would change with the inclusion of a pump and Bernoulli's would have to verify that pressure does not drop too low.

Water hammer creates an enormous amount of pressure (around 700psi here), but stainless steel is also exceptionally durable (can withstand and influx of pressure nearly triple what the system should experience). That said, the strength of the steel pipe can withstand up to 3x the pressure created in this valve-slamming scenario at standard thickness.

Came to finally understand that the location of the resultant force on a surface is placed at the centroid of a pressure distribution triangle. Had been intensely confused on that topic prior to this application.

Contact with Dr. Ayala during the exam helped me clarify that I could determine the weight of the water in the pipe system, and that while P_1A_1 cancelled out in our example problem during class with P_2A_2, this was not a guaranteed trend and was simply a coincidence on that problem. Eliminating that misconception helped clear up issues with forces.