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MET 330 Fluid Mechanics
Dr. Orlando Ayala
Fall 2022
Test 2

Take home – Due Tuesday November 1st, 2022, before midnight.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. <u>HINT:</u> THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)
2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments, and ten (10) other points are based on the basis of technical writing. The other eighty (80) points will come from the problem solutions. For the technical writing I will follow the attached rubric.
3. There is 1 problem with 7 different parts. Each part will be worth (80/7) points.
4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.
5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.
6. You have to turn in your test ON TIME and ONLY through BLACKBOARD. You must submit only one file and it has to be a pdf file. For the ePortfolio (which is optional) you are supposed to upload this artifact to your Google drive. I will provide more instructions later.
7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.
8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

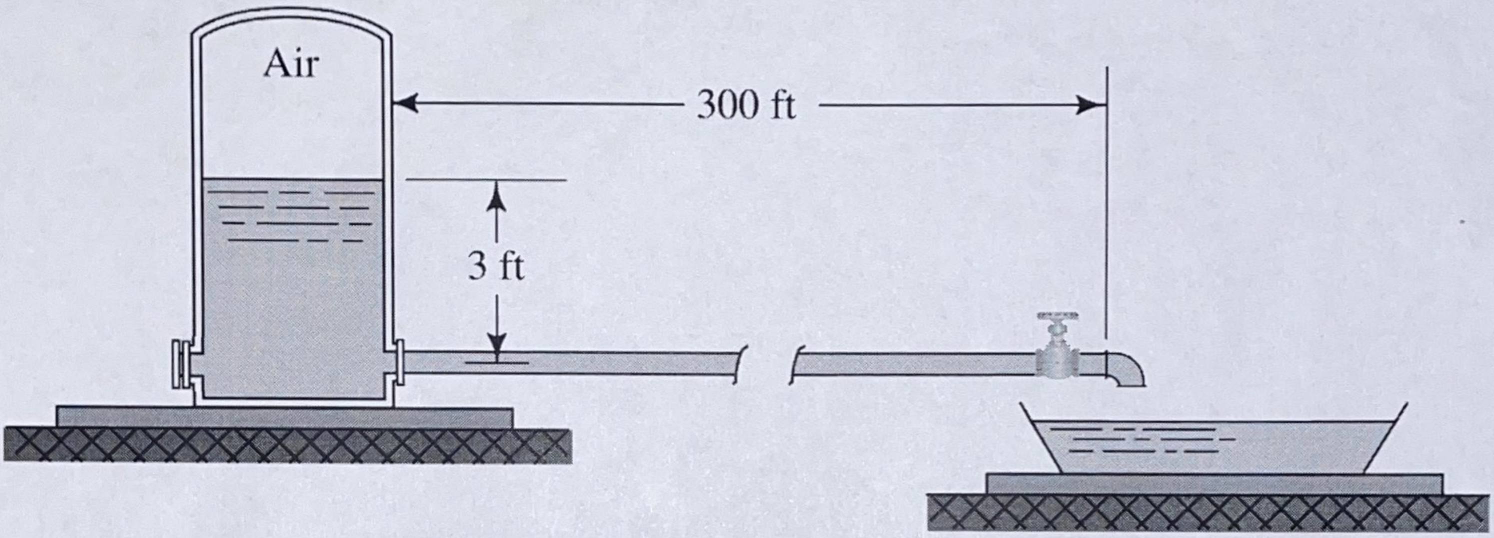
IX. PROHIBITED CONDUCT

A. Academic Integrity violations, including:

1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

A company hired an engineer to design the system below. However, the engineer quitted and now you are hired to finish the work. The system is supposed to deliver 60 °F water at a rate of 75 gpm from a pressurized storage tank to a trapezoidal open channel through 300 ft of 1 ½ in Schedule 40 steel pipe as shown in the figure. The modulus of elasticity of steel is 200 GPa. The purpose of the open channel is to carry hickory wood logs downstream (they will float). The density of hickory wood is 830 kg/m³



The company would like you to complete the following tasks.

a. What is the water depth (y) in the open channel? The angle of the lateral walls is 60°. The width at the top of the water (T) is T=2.309y (see table 14.3 in the book). The channel slope is 0.1 percent and is made of unfinished concrete.

b. The pipe needs to be supported. Your civil engineer colleague requires to know the relevant forces for the support design. Calculate the total horizontal and vertical forces in the whole system pipe-elbow.

c. What is the largest hickory wood log the open channel can carry? The log should barely float. The log has a square cross section. Is it stable? Prove the stability answer using the equations.

d. Your client also proposes to use a flow nozzle to measure the flow. For a nozzle diameter to pipe diameter ratio of 0.5, what is the pressure drop across the nozzle?

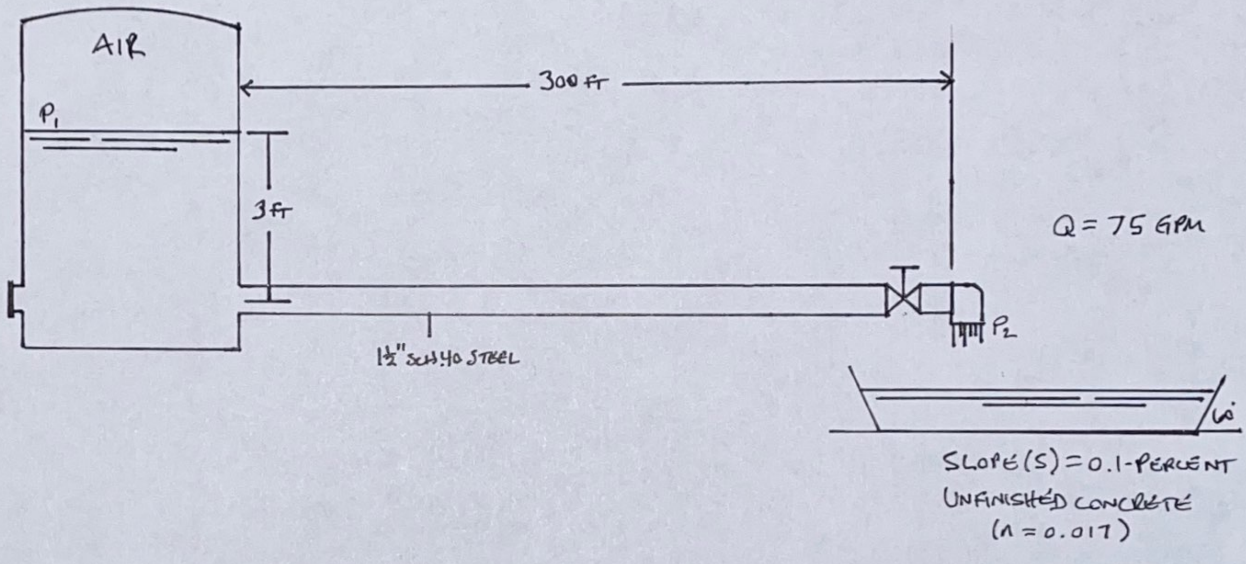
e. If the valve in the pipe closest suddenly, what is the pressure increment after the sudden closing? Is there any change of cavitation in your system? Why?

f. Assuming a log with half of the size of the largest log that can be carried in channel (the one computed in part c), what is the largest drag force it would experience if it got stuck at the bottom of the channel? Make any reasonable assumption.

g. Compute the force acting upon the blind flange at the left-hand-side of the tank. The diameter of the blind flange is the same as the pipe diameter. Where is the force location?

PURPOSE: TO DETERMINE (a) THE WATER DEPTH IN THE OPEN CHANNEL SYSTEM. (b) THE TOTAL RELEVANT HORIZONTAL AND VERTICAL FORCES IN THE PIPING SYSTEM. (c) THE LARGEST HICKORY WOOD LOG THAT THE OPEN CHANNEL CAN CARRY. (d) THE PRESSURE DROP ACROSS THE PROPOSED FLOW NOZZLE. (e) THE PRESSURE INCREMENT IF THE VALVE IS CLOSED SUDDENLY ALONG WITH CONSIDERATION FOR CAVITATION. (f) THE LARGEST DRAG FORCE THAT A LOG HALF THE SIZE CALCULATED IN (c) WOULD EXPERIENCE IF STUCK ON BOTTOM OF OPEN CHANNEL AND (g) THE FORCE ACTING ON THE BLIND FLANGE AT THE LEFT-HAND-SIDE OF TANK ALONG WITH LOCATION.

DIAGRAM:



SOURCES: MOTT AND UNTENER. APPLIED FLUID MECHANICS. 7TH EDITION. PEARSON. 2015

DESIGN CONSIDERATIONS:

1. INCOMPRESSIBLE FLUIDS
2. ISOTHERMAL SYSTEM
3. MINOR ENERGY LOSSES TO BE INCLUDED
4. TANK PRESSURIZED ABOVE ATMOSPHERIC

DATA AND VARIABLES:

$Q = 75$ GPM

$L_p = 300$ FT

$Z_1 = 3$ FT

$S = 0.001$

$n = 0.017$

$\beta = 0.5$

$E_s = 200$ GPa

$\rho_L = 830 \frac{kg}{m^3}$

$1\frac{1}{2}$" SCH.40 STEEL

$A = 0.0144$ FT^2

$D_i = 0.1342$ FT $= 40.9$ mm

$D_o = 1.9$ in $= 48.3$ mm

MATERIALS:

- WATER @ 60F
- STEEL PIPING
- UNFINISHED CONCRETE
- HICKORY WOOD LOG

PROCEDURE: (a) $n = 0.017$ (UNFINISHED CONCRETE) TRAPEZOIDAL CHANNEL, 60° WALLS

$$Q = 75\,\frac{GAL}{MIN} \cdot \frac{1\,FT^3/S}{449\,\frac{GAL}{MIN}} = 0.1671\,\frac{FT^3}{S}$$

$S = 0.001$

I WILL SOLVE FOR THE OPEN CHANNEL DEPTH (y) USING THE MANNING EQUATION:

$$A R^{2/3} = \frac{n\,Q}{1.49\,S^{1/2}}$$

USING TABLE 14.3 FROM THE TEXT, I FIND THAT,

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

I WILL THEN SUBSTITUTE THESE VALUES INTO THE MANNING EQUATION AND SOLVE FOR y:

$$(1.73y^2)\left(\frac{y^{2/3}}{2^{2/3}}\right) = \frac{(0.017 \cdot 0.1671)}{1.49\,(0.001)^{1/2}}$$

$$\rightarrow \frac{1.73y^{8/3}}{1.5874} = \frac{0.002841}{0.047118}$$

$$\rightarrow 1.73y^{8/3} = (0.060295)(1.5874)$$

$$\rightarrow y^{8/3} = \frac{0.095712}{1.73}$$

$$\rightarrow y = (0.055325)^{3/8}$$

$$y = 0.3378\ FT$$

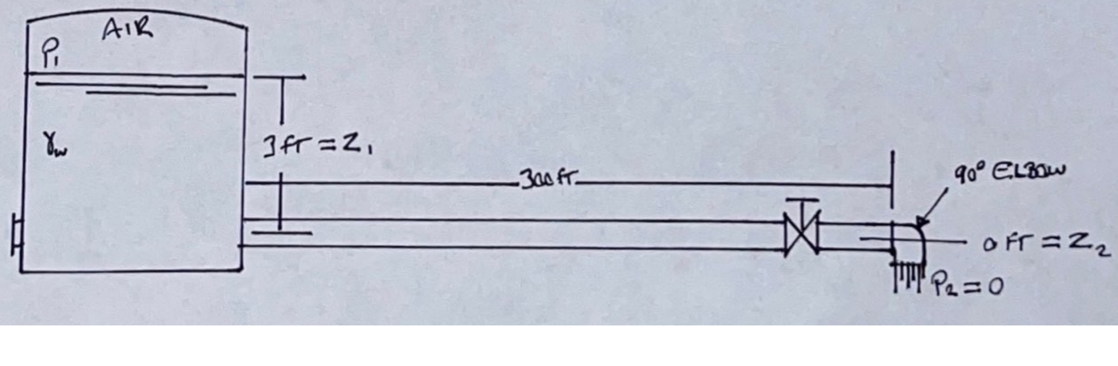
THEREFORE, THE DEPTH OF THE OPEN CHANNEL IS $y = 0.3378$ FT.

(b) NEXT, I WILL NEED TO COMPUTE RELEVANT FORCES DUE TO SYSTEM OPERATION. I WILL USE THE FOLLOWING INFORMATION,

$Q = 0.1671\,\frac{FT^3}{S}$ $\quad V = \frac{Q}{A} = \frac{0.1671}{0.01414} = 11.8175\,\frac{FT}{S}$ $\quad L = 300\,FT$

$A = 0.01414\,FT^2$ $\quad D_i = 0.1342\,FT$ $\quad \nu = 1.21 \times 10^{-5}\,\frac{FT^2}{S}$

$\gamma_w = 62.4\,\frac{lb}{FT^3}$ $\quad \varepsilon = 1.5 \times 10^{-4}$ (FROM TABLE 8.2)



(1b) CONT.

I WILL BEGIN BY EVALUATING THE SYSTEM USING BERNOULLI'S EQUATION, PRESSURE AT P_1 IS UNKNOWN SO I WILL HAVE TO SOLVE FOR IT. VELOCITY AT V_1 IS 0 AND THERE IS NO PUMP OR MECHANICAL DEVICE. PRESSURE AT P_2 IS ATMOSPHERIC.

$$\frac{P_1}{\gamma_w} + \cancel{\frac{V_1^2}{2g}}^{0} + z_1 + \cancel{h_A}^{0} - \cancel{h_R}^{0} - h_L = \cancel{\frac{P_2}{\gamma_w}}^{0} + \frac{V_2^2}{2g} + \cancel{z_2}^{0}$$

$$\longrightarrow \quad \frac{P_1}{\gamma_w} + z_1 - h_L = \frac{V_2^2}{2g}$$

$$\longrightarrow \quad P_1 = \left(\frac{V_2^2}{2g} - z_1 + h_L\right)\gamma_w$$

NOW THAT I REARRANGED MY EQUATION, I WILL NEED TO DETERMINE ENERGY LOSSES IN THE SYSTEM. THE ENERGY LOSSES IN CONSIDERATION ARE THE EXIT OF THE TANK (ASSUMED TO BE SQUARE-EDGED), THE PIPE, THE VALVE (VALVE ASSUMED TO BE GLOBE BASED ON DIAGRAM), AND THE ELBOW.

(TANK EXIT) $h_{L_1} = K\left(\frac{v^2}{2g}\right) \longrightarrow K = 0.5$ (SQUARE-EDGED), $h_{L_1} = 0.5\left(\frac{11.8175^2 \frac{ft}{s}}{2(32.2\frac{ft}{s^2})}\right)$

$= 1.084$ FT

THE OTHER LOSSES WILL REQUIRE CALCULATING THE FRICTION FACTOR (f), USING DARCY EQUATION FOR ENERGY LOSSES,

$$\frac{D}{\varepsilon} = \frac{0.1342 \text{ ft}}{1.5\times10^{-4} \text{ ft}} = 894.67 \quad , \quad N_R = \frac{vD}{\nu} = \frac{(11.8175\frac{ft}{s})(0.1342 \text{ ft})}{1.21\times10^{-5}}$$

$$= 131067$$

USING THESE TWO VALUES IN MOODY'S, I FIND,

$$f = 0.029$$

(PIPE LOSS) $h_{L_2} = f\frac{L}{D}\frac{v^2}{2g} = 0.029\left(\frac{300\text{ft}}{0.1342\text{ft}} \cdot \frac{11.8175^2\frac{ft}{s}}{2(32.2\frac{ft}{s^2})}\right) = 140.583$ ft

(GLOBE VALVE) $h_{L_3} = K\left(\frac{v^2}{2g}\right) \longrightarrow K = 0.029(340)$, $h_{L_3} = 9.86\left(\frac{11.8175^2\frac{ft}{s}}{2(32.2)}\right) = 21.382$ ft

(ELBOW) $h_{L_4} = K\left(\frac{v^2}{2g}\right) \longrightarrow K = 30(0.029)$, $h_{L_4} = 0.87\left(\frac{11.8175^2\frac{ft}{s}}{2(32.2\frac{ft}{s^2})}\right) = 1.887$ ft

NOW I CAN FIND TOTAL ENERGY LOSS,

$$h_L = h_{L_1} + h_{L_2} + h_{L_3} + h_{L_4} = (1.084 \text{ ft}) + (140.583 \text{ ft}) + (21.382 \text{ ft}) + (1.887 \text{ ft})$$

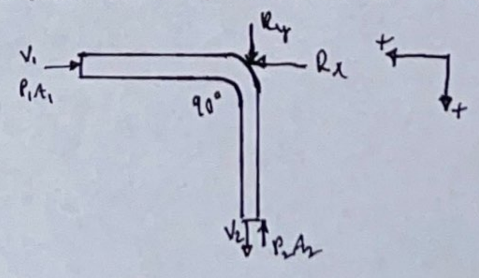
$$h_L = 164.936 \text{ ft}$$

I HAVE EVERYTHING REQUIRED TO SOLVE BERNOULLI'S EQUATION FOR P_1,

$$P_1 = \left(\frac{V_2^2}{2g} - z_1 + h_L\right)\gamma_w = \left(\frac{11.8175^2\frac{ft}{s}}{2(32.2\frac{ft}{s^2})} - 3\text{ft} + 164.936 \text{ ft}\right)\left(62.4\frac{lb}{ft^3}\right)$$

$$P_1 = 10240.1 \frac{lb}{ft^2} \cdot \frac{1 ft^2}{144 in^2} = 71.112 \text{ psi}$$

NOW I WILL FIND THE FORCES FOR SUPPORT DESIGN, EVALUATING THE PIPE ELBOW AT THE EXIT:



$$F_x = \rho Q(V_{2x} - V_{1x})$$
$$F_x = R_x - V_1 A_1$$
$$V_{2x} = 0$$
$$V_{1x} = -11.8175\frac{ft}{s}$$

(b) CONT.

$$R_x = P_1A_1 = \rho Q(0 - (-3.60197 \tfrac{m}{s})$$

$$R_x = \rho Q V_1 + P_1 A_1 = (490298.64 \tfrac{N}{m^2})(0.004732 \tfrac{m^3}{s})(3.60197 \tfrac{m}{s}) + (490298.64 \tfrac{N}{m^2} \times 0.001314\, m^2)$$

CONVERT TO METRIC FOR CLEAN CALC.

$$P = 10240.1 \tfrac{lb}{ft^2} \cdot \frac{47.88 \frac{N}{m^2}}{1 \frac{lb}{ft^2}} = 490298.64 \tfrac{N}{m^2}$$

$$Q = 0.004732 \tfrac{m^3}{s}$$

$$V = 11.8175 \tfrac{ft}{s} \cdot \frac{0.3048 \frac{m}{s}}{1 \frac{ft}{s}} = 3.60197 \tfrac{m}{s}$$

$$A_p = 0.001314\, m^2$$

$$R_x = 9001.16\, N$$

$$9001.16\, N \cdot \frac{0.224809\, lbf}{1 N} = 2023.541 lbf$$

$$R_x = 2023.541 lb \longleftarrow$$

$$F_y = \rho Q(V_{2y} - V_{1y})$$

$$F_y = R_y - P_2A_2$$

$$V_{2y} = V_2$$

$$V_{1y} = 0$$

$$R_y - P_2A_2 = \rho Q V_2$$

$$R_y = \rho Q V_2 + P_2A_2$$

$$= (490298.64 \tfrac{N}{m^2})(0.004732 \tfrac{m^3}{s})(3.60197 \tfrac{m}{s}) + (490298.64 \times 0.001314\, m^2)$$

$$= 9001.16 N$$

$$R_y = 2023.541 lb \downarrow$$

AT THE ELBOW, SUPPORTS WILL BE REQUIRED TO HANDLE HORIZONTAL FORCE OF 2023.541 lb AS WELL AS VERTICAL FORCE OF SAME VALUE.

(c) $\rho_w = 1000 \frac{kg}{m^3}$, $\rho_{H.W.} = 830 \frac{kg}{m^3}$ $\quad I_c = \frac{H^4}{12}$

FLOATING

SQUARE CROSS-SECTION

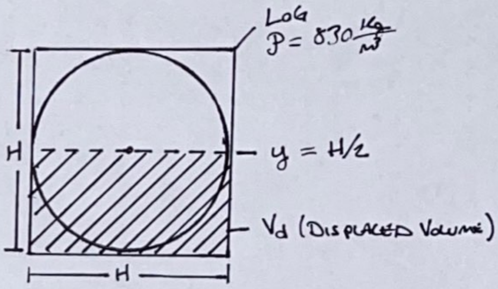
b = WIDTH OF BOTTOM OF CHANNEL $= 1.155y$

(y FROM (a)) $\quad = 1.155(0.103)$

$\quad = 0.119\ m$

$y = 0.3378\ ft \cdot \frac{3.281\ m}{1\ ft}$

$= 0.103\ m$



IN ORDER FOR THE LOG TO FLOAT, THE BOUYANCY FORCE ACTING ON THE LOG MUST BE EQUAL TO THE WEIGHT OF THE LOG. THE FOLLOWING EQUATIONS CAN BE USED:

$$F_b = \gamma_w \cdot V_d \qquad w_L = \gamma_L \cdot V_L$$

THE BOUYANCY FORCE IS EQUAL TO THE SPECIFIC WEIGHT OF WATER TIMES THE VOLUME OF WATER DISPLACED BY THE LOG. THE WEIGHT OF THE LOG IS EQUAL TO THE SPECIFIC WEIGHT OF THE LOG TIMES THE VOLUME OF THE LOG. I CAN BREAK THE FORMULAS DOWN FURTHER FOR EASIER SOLVING:

$$F_b = \rho_w \cdot g \cdot V_d \qquad w_L = \rho_L \cdot g \cdot V_L$$

BECAUSE I DON'T HAVE ANY DIMENSIONS FOR THE LOG, I WILL HAVE TO SOLVE FOR THE LARGEST LOG SIZE ALGEBRAICALLY BY SETTING THE FORMULAS EQUAL TO EACHOTHER.

$$\rho_w \cdot g \cdot V_d = \rho_L \cdot g \cdot V_L$$

$$\frac{\rho_w \cdot \cancel{g} \cdot (\cancel{H} \cdot y \cdot \cancel{L})}{\cancel{g} \cdot (\cancel{H} \cdot H \cdot \cancel{L})} = \rho_L \cdot g \cdot (H \cdot H \cdot L)$$

$$\rightarrow \frac{\rho_w \cdot y}{H} = \rho_L \rightarrow \frac{y}{H} = \frac{\rho_L}{\rho_w} \rightarrow y = \frac{\rho_L}{\rho_w} \cdot H$$

$$\rightarrow y = \frac{830 \frac{kg}{m^3}}{1000 \frac{kg}{m^3}} \cdot H \rightarrow y = 0.83H$$

CORRECTION
I WAS ORIGINALLY THINKING THAT I NEEDED TO USE BOTTOM WIDTH TO DETERMINE WIDTH. THIS IS WRONG BECAUSE THE BOTTOM CHANNEL WIDTH IS EQUAL TO 1.155y, SO IT IS A LARGER DIMENSION THAN THE HEIGHT OF THE OPEN CHANNEL.

NOW I WILL USE THE HEIGHT ~~WIDTH AT THE BOTTOM~~ OF THE CHANNEL (b) THAT I PREVIOUSLY FOUND TO DETERMINE THE LARGEST LOG SIZE POSSIBLE.

LET $H = y_d$ (DEPTH OF CHANNEL FROM (a))

$$y = 0.83 y_d \rightarrow y = 0.83(0.103\ m) = 0.0855\ m$$

THEREFORE, SUBMERGED PORTION IS 0.0855 m. TO FIND SIZE OF LOG, MULTIPLY BY 2:

$$y(2) \rightarrow 0.0855\ m(2) = 0.171\ m$$

THE LARGEST LOG SIZE IS 0.171 M IN CROSS-SECTIONAL LENGTH. NOW I WILL SOLVE FOR STABILITY OF THE LOG IN THE CHANNEL,

NOTE: STABILITY IS WHEN THE METACENTER OF AN OBJECT IS ABOVE THE CENTER OF GRAVITY OF THE OBJECT.

$y = 0.0855\ m \qquad M_c = \frac{I}{V_d} \qquad c_g = \frac{H}{2} \qquad y_{cb} = \frac{x}{2}$

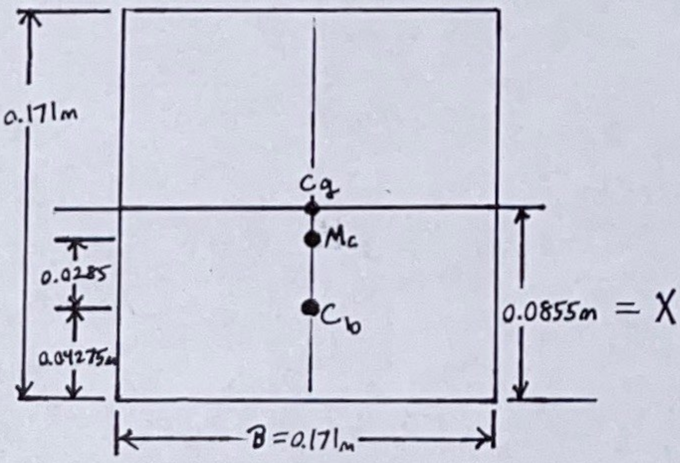
$H = 0.171\ m$

ASSUMING LOG IS OF UNIFORM SPECIFIC WEIGHT THROUGHOUT, I CAN CALCULATE CENTER OF GRAVITY AS FOLLOWS:

$$C_g = \frac{H}{2} = \frac{0.171\,m}{2}$$

$$= 0.0855\,m$$

(BASED ON LOG SIZE ABOVE)



TO FIND THE CENTER OF BOUYANCY,
LET $y = X$,

$$y_{cb} = \frac{X}{2} = \frac{0.0855\,m}{2}$$

$$= 0.04275\,m$$

BECAUSE THE CENTER OF GRAVITY APPEARS TO BE ABOVE THE CENTER OF BOUYANCY, I MUST LOCATE THE METACENTER OF THE LOG TO DETERMINE ITS STABILITY IN THE CHANNEL:

$$M_c = \frac{I}{V_d} \rightarrow \frac{\left(\frac{LB^3}{12}\right)}{LBX}$$

FOR CALCULATION PURPOSES, I WILL GUESS A LENGTH OF THE PROPOSED LOG, LET'S SAY 6 METERS = L. THIS WILL NOT HAVE AN EFFECT ON THE RESULT OF THE CALCULATION, I COULD USE 1 METER AND IT WOULD YIELD SAME RESULT.

$$M_c = \frac{\left(\frac{(6m)(0.171m)^3}{12}\right)}{(6m \times 0.171m \times 0.0855m)} = 0.0285\,m$$

THE DISTANCE FROM THE CENTER OF BOUYANCY TO THE METACENTER IS 0.0285m. NOW TO FIND THE POSITION OF METACENTER (y_{mc}) FROM THE BOTTOM FOR STABILITY,

$$y_{mc} = y_{cb} + M_c \rightarrow 0.04275\,m + 0.0285\,m$$

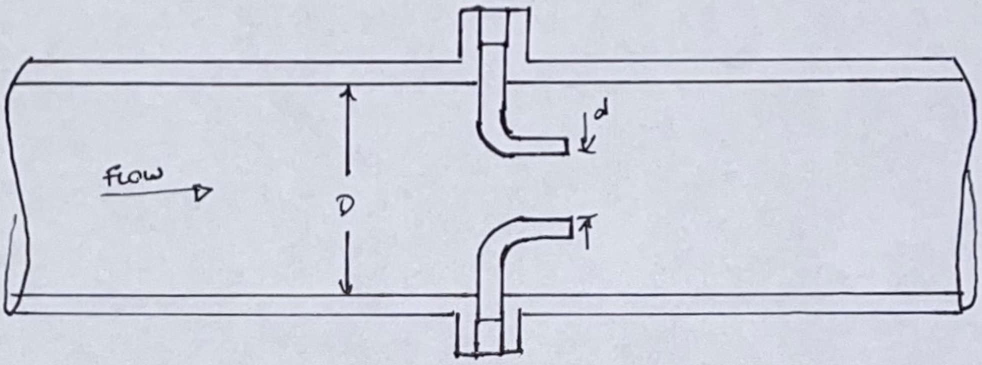
$$y_{mc} = 0.07125\,m \text{ FROM BOTTOM}$$

THEREFORE, THE LOG IS NOT STABLE BECAUSE THE METACENTER IS BELOW THE CENTER OF GRAVITY BY A DISTANCE OF 0.01425m.

(d) $\gamma_w = 62.4 \frac{lb}{ft^3}$ $\quad N_R = 131067$

$D_p = 0.1342\ ft$ $\quad V_1 = 11.8175 \frac{ft}{s}$

$\beta = \frac{d}{D} = 0.5 \rightarrow d = 0.5(0.1342 ft)$
$= 0.0671\ ft$



TO SOLVE FOR THE PRESSURE DROP ACROSS THE FLOW NOZZLE, I WILL USE THE FORMULA INTRODUCED IN THE CLASS LECTURE:

$$V_1 = C\sqrt{\frac{2g(P_1-P_2)/\gamma}{(A_1/A_2)^2-1}}$$

FIRST, I WILL SOLVE FOR MY UNKNOWNS, THEN REARRANGE THE EQUATION TO SOLVE FOR PRESSURE DROP.

$$C = 0.9975 - 6.53\sqrt{\beta/N_R}$$
$$= 0.9975 - 6.53\sqrt{0.5/131067}$$
$$= 0.9847$$

$$A_1 = \frac{\pi D^2}{4} = \frac{\pi(0.1342ft)^2}{4} = 0.01414\ ft$$

$$A_2 = \frac{\pi d^2}{4} = \frac{\pi(0.0671ft)^2}{4} = 0.003536\ ft$$

$$V_1 = C\sqrt{\frac{2g(P_1-P_2)/\gamma}{(A_1/A_2)^2-1}} \rightarrow \left(\frac{V_1}{C}\right)^2 = \frac{\left(\frac{2g(P_1-P_2)}{\gamma}\right)}{\left(\left(\frac{A_1}{A_2}\right)^2-1\right)} \rightarrow \left(\left(\frac{A_1}{A_2}\right)^2-1\right)\left(\frac{V_1}{C}\right)^2 = \frac{2g(P_1-P_2)}{\gamma}$$

$$\rightarrow (P_1-P_2) = \frac{\gamma\left(\left(\frac{A_1}{A_2}\right)^2-1\right)\left(\frac{V_1}{C}\right)^2}{2g}$$

$$= \frac{\left(62.4\frac{lb}{ft^3}\right)\left(\left(\frac{0.01414\ ft^2}{0.003536\ ft^2}\right)^2-1\right)\left(\frac{11.8175\ \frac{ft}{s}}{0.9847}\right)^2}{2\left(32.2\frac{ft}{s^2}\right)}$$

$$\Delta P = 2092.05\ \frac{lb}{ft^2}\cdot\frac{1ft^2}{144\ in^2} = 14.528\ psi$$

$$\Delta P = 14.528\ psi$$

THEREFORE, WITH THE FLOW NOZZLE HAVING A NOZZLE DIAMETER TO PIPE DIAMETER RATIO OF $\beta = 0.5$, THE PRESSURE DROP ACROSS THE FLOW NOZZLE WOULD BE 14.528 psi.

(e) $P = 10240.1 \frac{lb}{ft^2} \cdot \frac{47.88\ Pa}{1\ \frac{lb}{ft^2}} = 490296 \frac{N}{m^2}$

$V = 11.8175 \frac{ft}{s} \cdot \frac{1m}{3.281 ft} = 3.602 \frac{m}{s}$

$1\frac{1}{2}$" SCH. 40 STEEL $\rightarrow D_o = 0.0483m$

$D_i = 0.0409m$

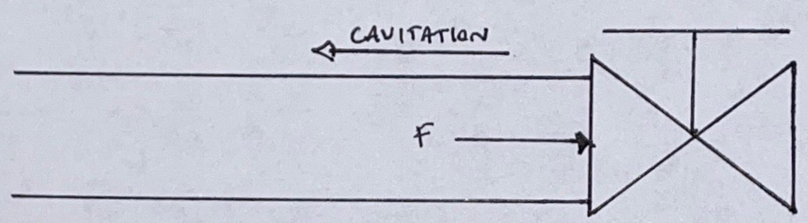
E_0 = BULK MODULUS OF FLUID $= 2.179 \frac{N}{m^2} (\times 10^9)$

$\rho_w = 1000 \frac{kg}{m^3}$ ~~$= 1.0 \times 10^6 \frac{g}{m^3}$~~

D = PIPE DIAMETER, INTERNAL

E_p = ELASTIC MODULUS OF PIPE $= 2 \times 10^{11} \frac{N}{m^2}$

t = PIPE THICKNESS (CALCULATED)



TO SOLVE FOR PRESSURE INCREMENT AFTER VALVE SUDDENLY CLOSING, I WILL USE THE FORMULAS DISCUSSED IN THE LECTURE AND IN THE TEXT,

$$P_{MAX} = P_{op} + \Delta P \qquad \Delta P = \rho_w V C \qquad C = \frac{\sqrt{E_o / \rho_w}}{\sqrt{1 + \frac{E_o D}{E_p t_{nom}}}} \qquad t = \frac{PD}{2(SE + PY)}$$

I WILL START BY SOLVING FOR THICKNESS OF THE PIPE (t) SINCE THIS IS UNKNOWN.

$t = \frac{P \cdot D}{2(SE + PY)} \longrightarrow$ FROM THE TEXT, (CH. 11, PAGE 285)

$S = 138000000$ Pa OR $\frac{N}{m^2}$ (STEEL PIPE)

$E = 1.0$ (SEAMLESS STEEL PIPE)

$Y = 0.4$ (STEEL LESS THAN 900F)

$$\longrightarrow \frac{(490296 \frac{N}{m^2} \times 0.0483 m)}{2((1.38 \times 10^8 \times 1) + (490296 \frac{N}{m^2} \times 0.4))} = 0.000086 m = t$$

$t_{MIN} = t + A$ (CORROSION ALLOWANCE = 2mm, CH. 11)

$= 0.000086m + 0.002m = 0.002086m = t_{MIN}$

$t_{NOM} = 1.143 t_{MIN} = 1.143(0.002086m) = 0.002384 m = t_{NOM} = 2.384 mm$

NOW I WILL BEGIN SOLVING FOR C, $Pa = \frac{N}{m^2} = \frac{kg}{m\,s^2}$

$$C = \sqrt{\frac{2.1787 \times 10^9\ Pa}{1000\frac{kg}{m^3}\left(1 + \left(\frac{40.9mm \times 2.1787 \times 10^9\ Pa}{2.384mm \times 2 \times 10^{11}\ Pa}\right)\right)}} = 1354.86\frac{m}{s}$$

SOLVING FOR PRESSURE CHANGE DUE TO SUDDEN VALVE SHUTTING,

$$\Delta P = \rho_w \cdot C \cdot V \rightarrow \left(1000\frac{kg}{m^3}\right)\left(1354.86\frac{m}{s}\right)\left(3.602\frac{m}{s}\right) = \cancel{4.88 \times 10^6\ Pa}$$
$$= 4880205\ Pa$$

(BEING EXACT)

THEN SOLVE FOR TOTAL PRESSURE, P_{max}:

$$P_{MAX} = P + \Delta P \rightarrow (490296\ Pa) + (4880205\ Pa) = 5370501\ Pa$$

$$5370501\ Pa \cdot \frac{1\ \frac{lb}{in^2}}{6895\ Pa} = 778.9\ psi$$

$$P_{MAX} = 778.9\ psi$$

THEREFORE, AFTER SHUTTING THE VALVE SUDDENLY, THE PRESSURE CAN REACH 778.9 psi IN THE PIPING.

THERE WOULD BE CHANGES OF CAVITATION IN THE SYSTEM BECAUSE WHEN THE VALVE IS SUDDENLY SHUT, THE FLUID PRESSURE INCREASES AND ~~FLOWS~~ IT WILL REVERSE TOWARDS TANK. THE TANK HAS PRESSURE ALSO SO WHEN THIS HAPPENS, PRESSURE WILL GO BACK AND FORTH, EXPANDING AND CONTRACTING PIPE BETWEEN VALVE AND TANK UNTIL ENERGY DISSIPATES IN FLUID.

(f) $\frac{1}{2}$ SIZE OF LOG $= \frac{0.171 m}{2} = 0.0855 m \cdot \frac{3.281 FT}{1 m} = 0.2805 ft = H$

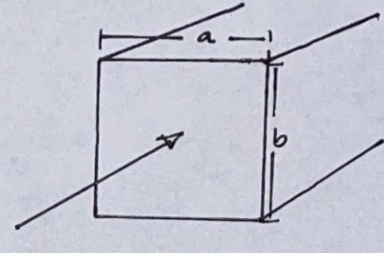
$A_L = H^2 = (0.2805 ft)^2 = 0.07868 ft^2$

$CD = 1.16$ (CH.17, DRAG + LIFT)

$S = 0.001$

$R = \frac{y}{2} = \frac{0.3378}{2} = 0.1689$

$n = 0.017$



$\frac{a}{b} = \frac{0.2805 FT}{0.2805 FT} = 1$

C_D w/ $1 = 1.16$

SOLVE FOR VELOCITY IN OPEN CHANNEL,

$$V = \frac{1.49}{n} R^{2/3} S^{1/2} \rightarrow \left(\frac{1.49}{0.017}\right)\left(\frac{0.3378 ft}{2}\right)^{2/3}(0.001)^{1/2} = 0.8469 \frac{FT}{S}$$

NOW SOLVE FOR DRAG FORCE ON LOG AT BOTTOM,

$$F_D = C_D\left(\frac{\rho_w V^2}{2}\right)A_L \rightarrow 1.16\left(\frac{1.94 \frac{lbs^2}{ft^4} \times 0.8469^2 \frac{FT}{S}}{2}\right)(0.07868 ft^2)$$

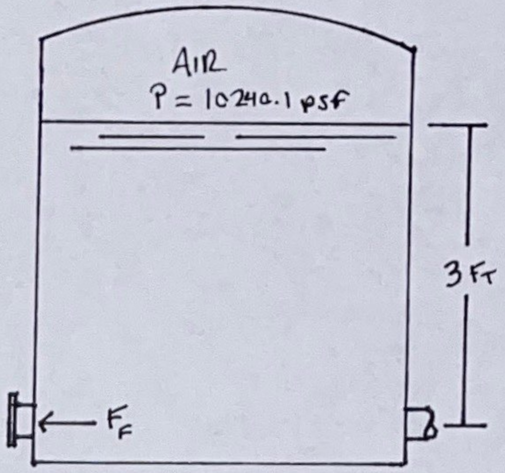
$$F_D = 0.0635 \text{ lb}$$

(g) $h_c = 3\text{ ft}$

$A_p = 0.01414\text{ ft}^2$

$\gamma_w = 62.4\ \frac{\text{lb}}{\text{ft}^3}$

$P_a = 10240.1\ \frac{\text{lb}}{\text{ft}^2}$



TO SOLVE FOR FORCE ACTING ON BLIND FLANGE ON LEFT-HAND SIDE OF TANK, I WILL START BY SOLVING FOR EQUIVALENT DEPTH OF FLUID USING EQUATION FOR PIEZOMETRIC HEAD, h_a:

$$h_a = \frac{P_a}{\gamma_w} \rightarrow \frac{10240.1\ \frac{\text{lb}}{\text{ft}^2}}{62.4\ \frac{\text{lb}}{\text{ft}^3}} = 164.104\text{ ft}$$

$$h_E = h_c + h_a \rightarrow 3\text{ ft} + 164.104\text{ ft} = 167.104\text{ ft}$$

NEXT, I WILL SOLVE FOR THE RESULTANT FORCE AT THE BLIND FLANGE:

$$F_R = \gamma_w \cdot h_E \cdot A_p \rightarrow \left(62.4\ \frac{\text{lb}}{\text{ft}^3}\right)(167.104\text{ ft})(0.01414\text{ ft}^2)$$

$$F_R = 147.442\text{ lb}$$

THE LOCATION OF THE RESULTANT FORCE ON THE BLIND FLANGE WOULD BE AT THE CENTER OF THE BLIND FLANGE.

Summary: THE DEPTH OF THE WATER FLOWING IN THE OPEN CHANNEL IS 0.3378 FT. THIS CHANNEL DEPTH WILL SUPPORT THE TRANSFER OF LOGS (HICKORY) THAT ARE 0.171 m IN HEIGHT AND WIDTH, OR SMALLER, AT A VELOCITY OF 0.8469 $\frac{FT}{S}$. HOWEVER, THE LOGS MAY NOT BE STABLE AND MAY ROLL. FOR THE SYSTEM SUPPLYING THE OPEN CHANNEL WITH WATER, THE VOLUME FLOW RATE WILL BE 75 GPM DUE TO THE TANK BEING PRESSURIZED AT 71.112 psi. IF THE FLOW CONTROL VALVE IS SUDDENLY SHUT, THE MAXIMUM PRESSURE THAT THE PIPING SYSTEM COULD EXPERIENCE IS 778.9 psi. THIS COULD DEFINITELY CAUSE CAVITATION IN THE SYSTEM DUE TO A TEN-FOLD INCREASE IN SYSTEM PRESSURE. THE PIPING SYSTEM SHOULD BE SUPPORTED DUE TO ITS EXCESSIVE LENGTH AND DUE TO REACTION FORCES EXPERIENCED AT THE ELBOW DURING NORMAL OPERATION, WHICH EQUATE TO 2023.54 lb IN BOTH THE VERTICAL AND HORIZONTAL DIRECTIONS. IF A FLOW NOZZLE WITH A NOZZLE-PIPE DIAMETER RATIO ~~IS~~ OF 0.5 IS IMPLEMENTED AS MENTIONED, THE PRESSURE DROP EXPERIENCED ACROSS THE NOZZLE DURING NORMAL SYSTEM OPERATION WOULD BE 14.528 psi. THE BLIND FLANGE LOCATED AT THE BOTTOM LEFT-HAND-SIDE OF THE TANK MUST BE ABLE TO WITHSTAND FORCE OF 147.442 lb ACTING AT ITS CENTER.

ANALYSIS: BASED ON THE CURRENT SYSTEM DESIGN THAT WAS DEVELOPED BY THE PREVIOUS ENGINEER, THE SYSTEM APPEARS TO WORK. ALL CHARACTERISTICS THAT WERE ANALYZED WERE PROVED TO BE SUFFICIENT FOR SYSTEM OPERATION. HOWEVER, SEVERAL CHANGES COULD BE MADE TO MAKE THE DESIGN MORE EFFICIENT. ALTHOUGH SLOW SHUTTING OF VALVE IS A GOOD PRACTICE, MEASURES COULD BE IMPLEMENTED FOR WORST CASE SCENARIO - A SUDDEN SHUTTING OF THE VALVE. TO HELP REDUCE THE EFFECTS OF WATER HAMMER AND CAVITATION IN THE SYSTEM, A WATER HAMMER ARRESTOR OR A SILENT CENTER-GUIDED CHECK VALVE SHOULD BE PLACED UPSTREAM OF THE VALVE. THIS WAY WHEN THERE IS A LOSS OF UPSTREAM FLOW OR A VALVE IS SUDDENLY SHUT, THE DEVICE WILL REDUCE THE EFFECT OF WATER HAMMER ON SYSTEM. ANOTHER IMPROVEMENT WOULD BE TO CHANGE THE OPEN CHANNEL GEOMETRY TO A SEMI-CIRCLE. SINCE CONVEYANCE OF A CHANNEL IS MAXIMUM WHEN THE WETTED PERIMETER IS LEAST FOR A GIVEN AREA, A SEMICIRCLE DESIGN WOULD BE IDEAL. THE MATERIAL THAT THE CHANNEL IS MADE OUT OF COULD ALSO BE CHANGED TO SOMETHING THAT PROVIDES LESS FRICTIONAL RESISTANCE TO FLOW, LIKE PLASTIC, STEEL, OR FINISHED CONCRETE. LASTLY, THE LENGTH OF THE PIPING SYSTEM LEADS TO A DECENT AMOUNT OF ENERGY LOSSES. IF THERE WAS A WAY TO REDUCE THE DISTANCE BETWEEN THE TANK AND THE CHANNEL, THERE WOULD BE LESS ENERGY LOSS. IF THIS IS NOT POSSIBLE, A PUMP COULD BE IMPLEMENTED TO INCREASE FLOW RATE AND OVERCOME. THERE COULD ALSO BE A LARGER CHANNEL TO SUPPLY A HIGHER FLOW RATE IF THIS WAS THE CASE. IF THESE CHANGES WERE TO BE MADE THEN CALCULATIONS WOULD HAVE TO BE RE-WORKED TO REFLECT NEW SYSTEM DESIGN, BUT I BELIEVE THAT EITHER INDIVIDUALLY OR COLLECTIVELY THE PROPOSED CHANGES WOULD BE IMPROVEMENTS TO THE CURRENT DESIGN.