Name: Dylan J Arnold.

MET 330 Fluid Mechanics
Dr. Orlando Ayala
Summer 2023
Test 3

Take home – Due Sunday July 16th 2023 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. HINT: 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.

3. There are 5 problems to solve, each worth (90/5) 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 CANVAS. You must submit only one file and it has to be a pdf file. For the ePortfolio you are also supposed to upload this artifact to your Google drive. When you are done solving the test, please go ahead and upload it now before you forget.

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).

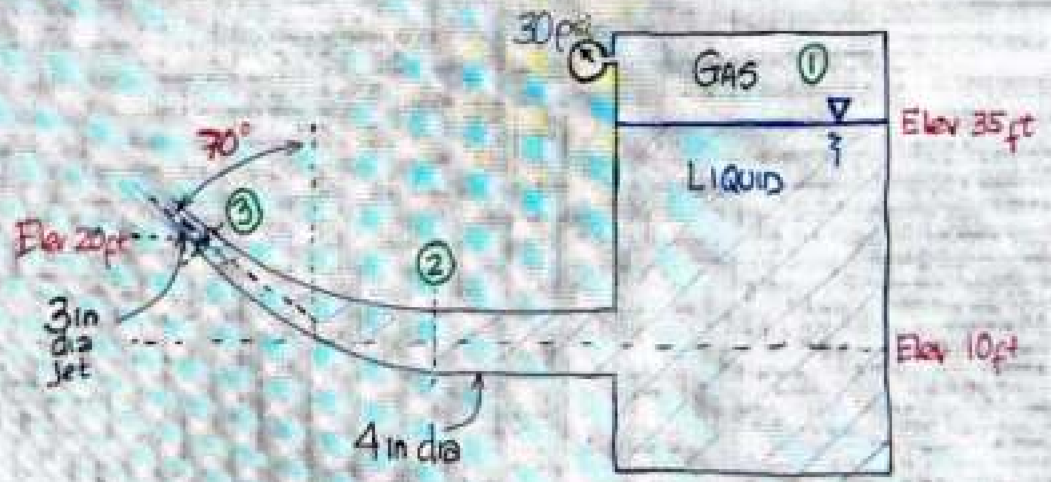
With that said, you are NOT authorized to use any online source of any type, unless it is ODU related.

1. On this problem you will compute the moment at the base of a vertical pole. The moment is due to a 80 mi/h wind. The pole is composed by two cylinders connected to each other end to end. The lowest cylinder is of 4 in nominal schedule 40 steel pipe with a length of L_{bottom}. The other cylinder is made of 3 ½ in nominal schedule 40 steel pipe with a length of L_{top}. The temperature of the air is 71 F. Use the table below to get the values for L_{bottom} and L_{top}. Use the 1st (from right to left) digit of your UIN to use the table.

2. On this problem you will compute the liquid height in an open channel with a slope of 0.001. The channel has a rectangular shape and it is made of cement. The width of the channel is W and water runs through it at a flow rate of Q. Is the flow supercritical or subcritical? Use the table below to get the values for W and Q. Use the 2nd (from right to left) digit of your UIN to use the table.

3. On this problem you will compute the reading of a mercury manometer when an orifice plate of β=0.5 is used to measure a water flow rate of Q running through a pipe with a diameter D nominal, schedule 40 pipe. Use the table below to get the values for Q and D. Use the 3rd (from right to left) digit of your UIN to use the table.

4. On this problem you will compute the force on the curved pipe section shown in the figure. The length of that section is L_{curved}. For the force you will provide its magnitude and direction. Neglect any energy losses. The specific weigth of the liquid is γ=55 lb/ft³. Use the table below to get the values for L_{curved}. Use the 4th (from right to left) digit of your UIN to use the table.



5. At the end of a steel pipe (E=2x10⁷ N/cm²) of internal diameter D, and thickness δ=10mm, there is a valve. The water velocity in the pipe is V. Calculate the pressure increment when the valve closes all of the sudden. Water compressibility module is E_0=2.03 x 10⁵ N/cm². Use the table below to get the values for D and V. Use the 5th (from right to left) digit of your UIN to use the table.

DIGIT	Problem 1	Problem 2	Problem 3	Problem 4	Problem 5
0	L_{bottom}=3ft L_{top}=6ft	W=18ft Q=150ft³/s	Q=12000gpm D=24"	L_{curved}=10ft	D=600mm V=2.5m/s
2	L_{bottom}=3ft L_{top}=3ft	W=18ft Q=350ft³/s	Q=12000gpm D=12"	L_{curved}=20ft	D=600mm V=1.0m/s
1	L_{bottom}=6ft L_{top}=6ft	W=9ft Q=150ft³/s	Q=6000gpm D=24"	L_{curved}=30ft	D=300mm V=2.5m/s
4	L_{bottom}=3ft L_{top}=6ft	W=9ft Q=350ft³/s	Q=6000gpm D=12"	L_{curved}=40ft	D=300mm V=1.0m/s
3	L_{bottom}=3ft L_{top}=3ft	W=18ft Q=150ft³/s	Q=12000gpm D=24"	L_{curved}=50ft	D=600mm V=2.5m/s
6	L_{bottom}=6ft L_{top}=6ft	W=18ft Q=350ft³/s	Q=12000gpm D=12"	L_{curved}=10ft	D=600mm V=1.0m/s
5	L_{bottom}=3ft L_{top}=6ft	W=9ft Q=150ft³/s	Q=6000gpm D=24"	L_{curved}=20ft	D=300mm V=2.5m/s
8	L_{bottom}=3ft L_{top}=3ft	W=9ft Q=350ft³/s	Q=6000gpm D=12"	L_{curved}=30ft	D=300mm V=1.0m/s
7	L_{bottom}=6ft L_{top}=6ft	W=18ft Q=150ft³/s	Q=12000gpm D=24"	L_{curved}=40ft	D=600mm V=2.5m/s
9	L_{bottom}=3ft L_{top}=6ft	W=18ft Q=350ft³/s	Q=12000gpm D=12"	L_{curved}=50ft	D=600mm V=1.0m/s

HONOR CODE

I pledge to follow the Honor Code and to obey all rules for taking exams and performing homework assignments as specified by the course instructor.

I understand that when asked to follow the Honor Code on exams or homework assignments I must follow the rules below.

1. When following the Honor Code a student must work entirely alone on exams.

2. When following the Honor Code a student may not share information about any aspect of the exam with other members of the class, other faculty members, or other people who has not already taken the exam this year, or its equivalent in future years.

3. When following the Honor Code a student must direct all questions concerning the exam or homework assignment to the course instructor or teaching assistant.

4. When following the Honor Code it is the student's responsibility to obtain clarification from the instructor if there are questions concerning the requirements of the Honor Code.

5. When following the Honor Code a student can only access websites related to ODU (such as Blackboard, etc.) while taking the test.

6. When following the Honor Code a student cannot access, neither ask for help, from websites such as coursehero, chegg, and any other similar website, while taking the test.

I understand that failure to follow this Honor Code imply that the professor will immediately report my case for academic dishonesty to the ODU Office of Student Conduct & Academic Integrity.

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UID: 01166349

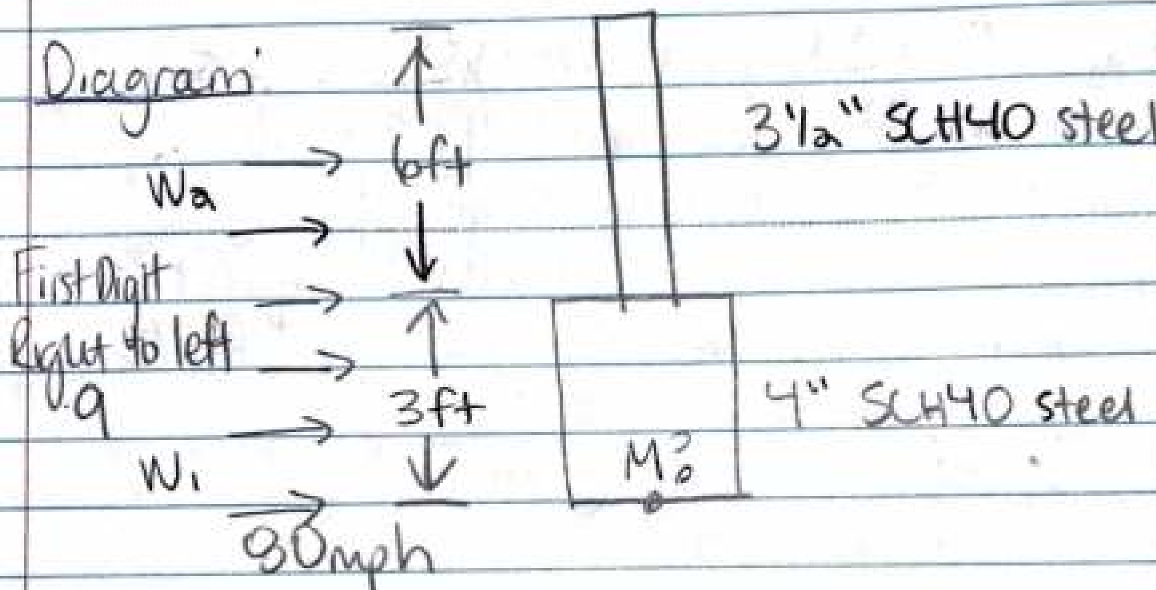
Student Signature: Dylan J Arnold

Date: 7/16/2023

Dylan Arnold Test 3 University ID: 01166349
MET330 Professor Ayala July 26th, 2023

1. Purpose: Compute the moment at the base of a vertical pole that's occurring due to 80mph wind.

Diagram:



Sources: Mott and Untener. Applied Fluid Mechanics. 7th Edition. Pearson. 2015.

Design Considerations:
1. Incompressible Fluid
2. Isothermal Process
3. Steady State

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Cont'd: Data and Variables:

$L_{top} = 6ft$
$L_{\phi_T} = 3\frac{1}{2}$" SCH40 Steel $D = 4.0" = 0.33ft$
$L_{bottom} = 3ft$
$L_{\phi_B} = 4$" SCH40 steel $D = 4.5" = 0.375ft$
Wind velocity = 80 mph = 117.33 ft/s
Air at 71°F = 21.6°C Table E.2
ρ for 20°C air = 2.57×10^{-3} slugs/ft^3
Kinematic viscosity $\nu = 1.37 \times 10^{-4}$ ft^2/s

Materials:
Air, SCH40 steel

Procedure and calculations:

$$F_d = C_d \left(\frac{\rho V^2}{2}\right) A$$

Cd findings...

$$N_{R_2} = \frac{vD}{\nu} = \frac{(117.33)(0.33)}{1.37 \times 10^{-4}} = 2.8 \times 10^5$$

$$N_{R_1} \frac{vD}{\nu} = \frac{(117.33)(0.375)}{1.37 \times 10^{-4}} = 3.2 \times 10^5$$

Cd approximately = 0.9-1 Figure 17.4

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1 Cont'd: A of 3½ SCH40 pipe

$A_2 = 2\pi r h + 2\pi r^2$

$A_2 = 2\pi\left(\frac{0.33}{2}\right)(6ft) + 2\pi\left(\frac{0.33}{2}\right)^2$

$A_2 = 6.39 ft^2$

$A_1 = 2\pi r h + 2\pi r^2$

$A_1 = 2\pi\left(\frac{0.375}{2}\right)(3ft) + 2\pi\left(\frac{0.375}{2}\right)^2$

$A_1 = 3.76 ft^2$

$2.57\times10^{-3}\ slugs/ft^3 = 2.57\times10^{-3}\ \frac{lb\cdot s^2}{ft^4}$

$Fd_2 = (1)\left(\frac{2.57\times10^{-3}\ \frac{lb\cdot s^2}{ft^4}(117.33\ ft/s)^2}{2}\right)(6.39ft^2)$

$Fd_2 = 113.04 lb$

$Fd_1 = (0.9)\left(\frac{(2.57\times10^{-3})(117.33)^2}{2}\right)(3.76)$

$Fd_1 = 59.9 lb$

Moment = FL

$= ((113.04 lb)(6+3 ft) + (59.9 lb)(3ft))$

M = 1197.06 lb·ft

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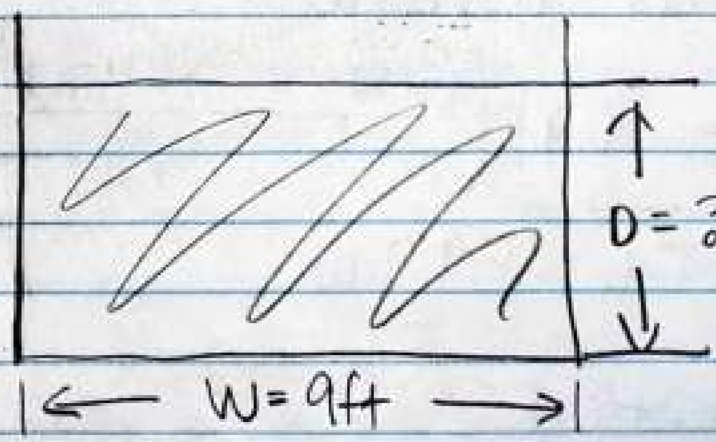
1 Contd: **Summary:**
The moment at the base of the flagpole is 1197.06 lb.ft.

Analysis:
Reynolds number was a little high so its possible that the diameter of both poles could be decreased.

2. **Purpose:** Compute the liquid height in an open channel flow with a slope of 0.001.

Diagram:

2nd Digit Right to left
4



$Q = 350\ ft^3/s$

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2 (cont'd) Sources: Mott and Untener. Applied Fluid Mechanics. 7th Edition. Pearson. 2015

Design Considerations:
1. Incompressible fluid
2. Isothermal process
3. Steady state

Data and Variables:

$Q = 350\ ft^3/s$ $\quad A_{rectangle} = WD = 2.0D^2$

$W = 9\ ft$

$D = ?\ ft$ $\quad WP_{rectangle} = W + 2D = 4D$

$n_{cement} = 0.013$ Table 14.1

$AR^{2/3} = \frac{nQ}{1.49S^{1/2}}$ $\quad$ Slope $= 0.001$

$\hookrightarrow \sin^{-1}(0.001) = 0.057°$

Materials:
Cement, water

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2 Cont'd: Procedure and Calculations:

$$AR^{2/3} = \frac{nQ}{1.49 S^{1/2}}$$

$$AR^{2/3} = \frac{(0.013)(350)}{1.49(0.001)^{1/2}}$$

$$AR^{2/3} = 96.57$$

$A = 9D$

$WP = 9 + 9D$

$$R = \frac{A}{WP} = \frac{9D}{9+9D}$$

$$96.57 = AR^{2/3} = 9D\left(\frac{9D}{9+9D}\right)^{2/3}$$

Trial and error

$D = 2.0$ FT, $AR^{2/3} = 13.74$

higher

$D = 6.0$ FT, $AR^{2/3} = 48.73$

higher

$D = 12.0$ FT, $AR^{2/3} = 102.39$

lower

$D = 11.375$ FT, $AR^{2/3} = 96.78$ close enough within +/- 0.5%

$D = 11.375$ FT

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2 cont'd $R = \frac{9(11.375)}{9+9(11.375)} = 0.919$

$Q = Av \quad v = \frac{Q}{A} \quad v = \frac{350 \frac{ft^3}{s}}{9 \cdot 11.375} \quad v = 3.42 \frac{ft}{s}$

$N_R = \frac{vR}{\nu}$ Assume Temperature of water 70°F
$\nu = 1.05 \times 10^{-5}$

$N_R = \frac{(3.42)(0.919)}{1.05 \times 10^{-5}} = 299331 > 2000$
so turbulent

$N_F = \frac{v}{\sqrt{g y_h}}$

$y_h = A/T$ T is width of free surface of fluid at top of channel

$y_h = \frac{9(11.375)}{9} = 11.375$

$N_F = \frac{3.42}{\sqrt{(32.174)(11.375)}} = 0.178 < 1$

Flow is Subcritical - turbulent

Summary: The liquid height in a rectangular open channel flow where width is 9ft and Q = 350 ft³/s is 11.375ft and the flow is subcritical-turbulent.

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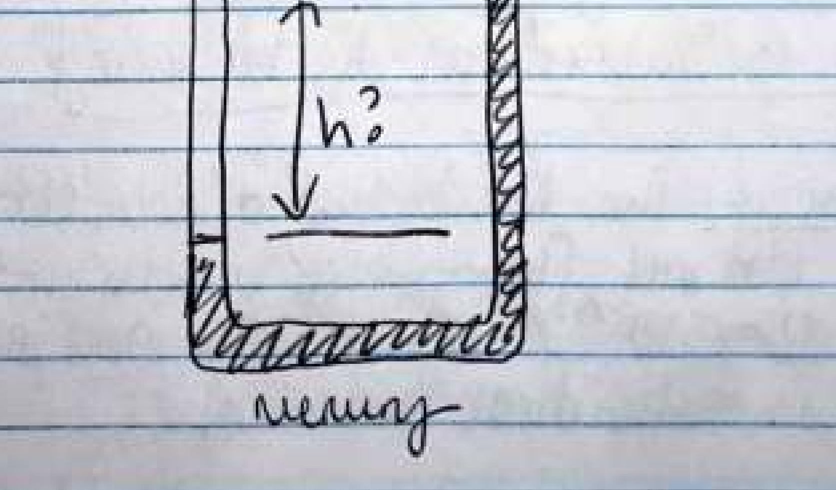
2 Cont'd: Analysis: Could make width larger in order to not have height be so high, but its understood that space may be of great need so there is no other choice but to dig deep

3. Purpose: Compute the reading of a mercury manometer when an orifice plate of $\beta = 0.5$ is used to measure a water flow rate of Q running through a pipe with a diameter D nominal, schedule 40 pipe.
D = 24" Q = 12000 gpm
Diagram:



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3(Cont'd) Sources: Mott and Untener. Applied Fluid Mechanics. 7th Edition. 2015. Pearson.

Design Considerations:
1. Incompressible fluid
2. Isothermal Process
3. Steady State

Data and variables:
$D = 24"$ SCH 40 pipe
$\beta = 0.5$, therefore $d = 12"$ ($d/D = 0.50$)
$Q = 12000 gpm = 26.73\ ft^3/s$
$\gamma_m = 844.9\ lb/ft^3$ $\gamma_w = 62.4\ lb/ft^3$
$A_D = 2.792 ft^2$ Table F.1
$A_d = 0.78 ft^2$ $\left(\frac{\pi d^2}{4}\right)$

Materials:
Water, mercury, SCH40 pipe

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3Cont'd: Procedure and Calculations

$Q = VA \quad V = \frac{Q}{A} \quad V = C\sqrt{\frac{2gh[(\gamma_m/\gamma_w)-1]}{(A_0/A_d)^2-1}}$

$V = \frac{26.73 \frac{ft^3}{s}}{2.792 ft^2} = 9.57 \, ft/s$

$\left(\frac{A_0}{A_d}\right)^2 = \left(\frac{2.792 ft^2}{0.78 ft^2}\right)^2 = 12.81 - 1 = 11.81$

$[(\gamma_m/\gamma_w)-1] = \frac{(844.9)}{(62.4)} - 1 = 12.54$

$N_R = \frac{vD\rho}{\eta}$

ρ assume 70°F = $1.94 \frac{slugs}{ft^3}$

η " " = $2.04 \times 10^{-5} \frac{lb \cdot s}{ft^2}$

$D = 1.886 ft$

$N_R = \frac{(9.57)(1.886)(1.94)}{2.04 \times 10^{-5}} = 1.7 \times 10^6$

C = 0.602 FIGURE 15.7

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3(cont'd) $9.57\,ft/s = 0.602\sqrt{\frac{2(32.174)(h)(12.54)}{11.81}}$

$(5.897)^2 = \left(\sqrt{\frac{806.9h}{11.81}}\right)^2$

$252.71 = \frac{806.9h}{11.81}$

$\frac{2984.56}{806.9} = \frac{806.9h}{806.9}$ $\boxed{h = 3.7ft}$

Summary: The reading of the mercury manometer is 3.7ft

Analysis: Almost 49 inches of reading seems a little high for a 24" pipe, however the large amount of flow is the reason for such reading.

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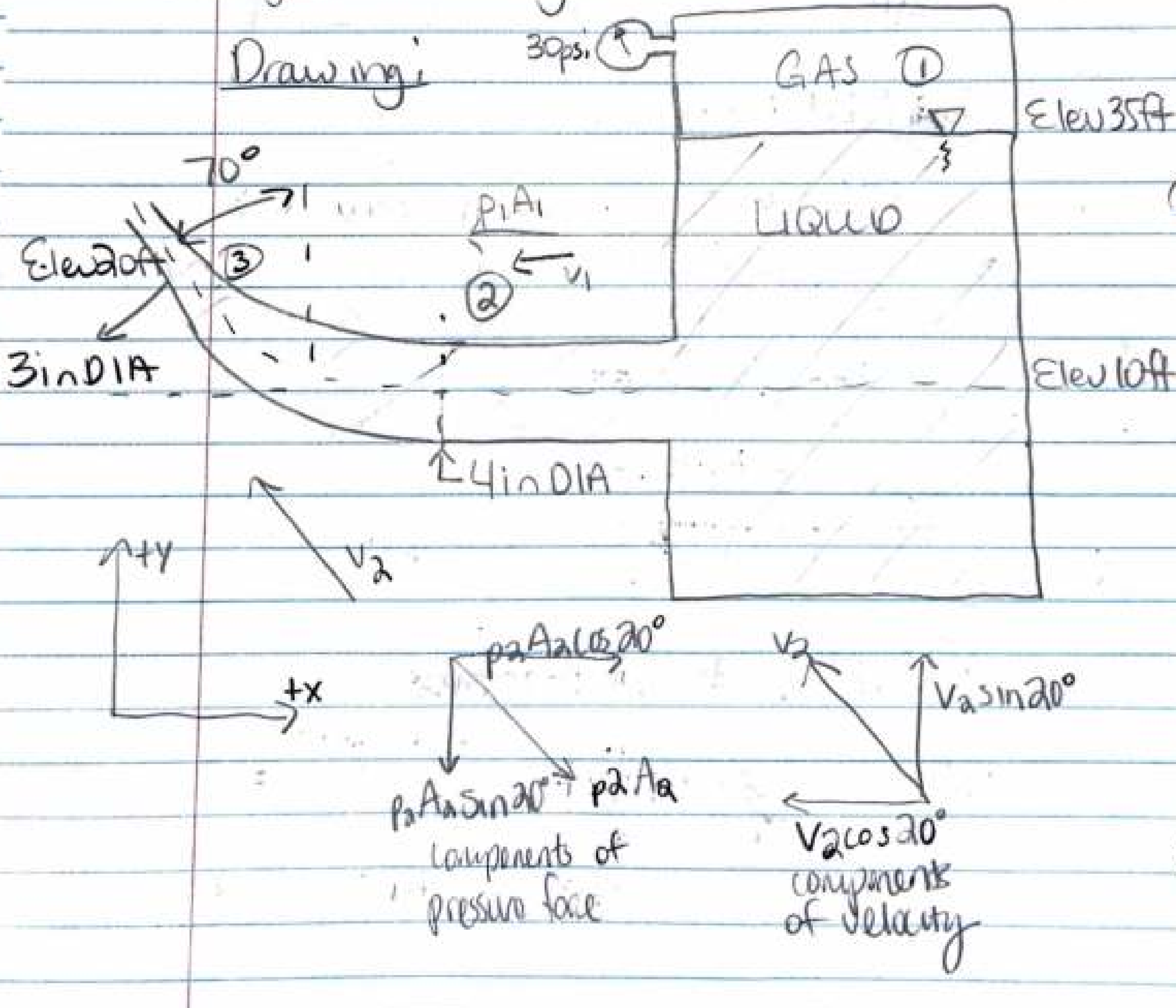
4. Purpose: Compute the force on the curved pipe section, when length is L_{curved}. Will provide magnitude and direction. Will neglect energy losses (all).
Digit 4th from right = 6 L_{curved} = 10ft

Drawing:



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4 (contd) Sources: Mott and Untener. Applied Fluid Mechanics. 7th Edition. 2015. Pearson.

Design Considerations:
1. Incompressible Fluid
2. Isothermal process
3. Steady State

Materials:
LIQUID, GAS, PIPE

Data and Variables:
$L_{curved} = 10 ft$ $P = 30 psi$ P_{T_1} Elev = 35 ft
$\gamma_{liquid} = 55\ lb/ft^3$ P_{T_3} Elev = 20 ft P_{T_2} Elev = 10 ft
P_{T_2} D = 4" P_{T_3} D = 3"

Procedure and Calculations:

$v_1 = \sqrt{2gh}$ where $h = z_1 - z_2$

$v_1 = \sqrt{2(32.174)(25 ft)} = 40.1\ ft/s$

$v_2 = v_1(A_1/A_2)$ b/c of continuity

$A_1 = 4"$ $r = 2"$ $r = 0.167 ft$, $\pi r^2 = 0.0873 ft^2$

$A_2 = 3"$ $r = 1.5"$ $r = 0.125 ft$ $\pi r^2 = 0.0491 ft^2$

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4 Cont'd: $v_2 = 40.1\,ft/s \left(\frac{0.0873\,ft^2}{0.0491\,ft^2}\right) = 71.3\,\frac{ft}{s}$

$R_y = p_2 A_2 \sin 20° + \rho Q v_2 \sin 20°$

$\gamma = \rho g \qquad \rho = \frac{\gamma}{g}$

$\rho = \frac{55\,lb/ft^3}{(32.174\,ft/s^2)} = 1.71\,slugs/ft^3 = \frac{lb \cdot s}{ft^4}$

$Q = A_1 v_1 = (0.0873\,ft^2)(40.1\,ft/s) = 3.5\,ft^3/s$

Bernoulli's Equation $\frac{P_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{P_3}{\gamma} + z_2 + \frac{v_2^2}{2g}$

$P_1 = 30\,psi = \frac{30\,lb}{in^2} \times \frac{144\,in^2}{ft^2} = 4320\,lb/ft^2$

$P_2 = P_1 + \gamma h = 4320\,lb/ft^2 + 55(25) = 5695\,lb/ft^2$

$$\frac{P_2}{\gamma} + z_2 + \frac{V_2^2}{2g} = \frac{P_3}{\gamma} + z_3 + \frac{V_3^2}{2g}$$

$$P_3 = P_2 + (\gamma)(z_2 - z_3) + (\gamma)\left(\frac{V_2^2 - V_3^2}{2g}\right)$$

$$= 5695 + (55)(10-20) + (55)\left(\frac{40.1^2 - 71.3^2}{2 \cdot 32.174}\right)$$

$P_3 = 2174.24\,lb/ft^2$

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4 (cont'd) $p_1 A_1 = (5695)(0.0873) = 497.17 lb$

$p_2 A_2 = (2174.24)(0.0491) = 106.76 lb$

$\rho Q v_1 = (1.71)(3.5)(40.1) = 240 lb$

$\rho Q v_2 = (1.71)(3.5)(71.3) = 426.73 lb$

$R_x = p_1 A_1 - p_2 A_2 \cos 20° - \rho Q v_2 \cos 20 + \rho Q v_1$

$R_y = p_2 A_2 \sin 20° + \rho Q v_2 \sin 20°$

$R_x = 497.17 lb - 106.76 lb(\cos 20°) - 426.73 lb(\cos 20°) + 240 lb$

$\boxed{R_x = 235.85 lb}$

$R_y = 106.76 lb(\sin 20°) + 426.73 lb(\sin 20°)$

$\boxed{R_y = 182.46 lb}$

$R = \sqrt{R_x^2 + R_y^2} = \sqrt{235.85^2 + 182.46^2} \boxed{= 298.19 lb}$

$\tan\theta = \frac{R_y}{R_x} = \frac{182.46}{235.85} = 0.774 = \tan^{-1}(0.774) \boxed{= 37.74°}$

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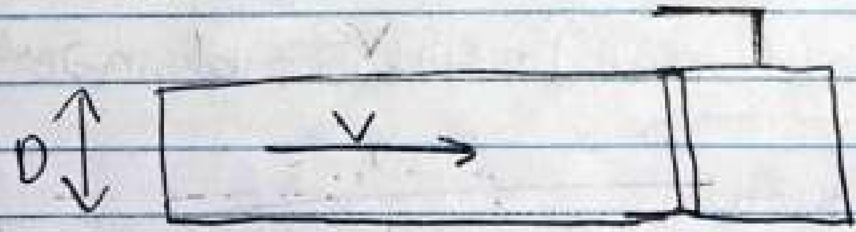
4 Cont'd: Summary: The magnitude (force) on the curved pipe section is $R_x = 235.85lb$, $R_y = 182.46lb$ for a resultant force of 298.19lb and a direction of 37.74°.

Analysis: With a tensile strength of 2,786lb, SCH40 PVC would be more than sufficient for the job.

5. Purpose: Calculate the pressure increment when a valve at the end of a steel pipe closes all of a sudden.

Drawing:



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5 Cont'd Sources: Mott and Untener. Applied Fluid Mechanics. Pearson. 7th Edition. 2015.

Design Considerations:
1) Incompressible Fluid
2) Isothermal Process
3) Steady State

Data and Variables:
5th digit UIN (right to left = 6)
D = 600mm = 0.6m (internal)
V = 1.0 m/s
$\rho_{water} = 997 \text{ kg/m}^3$ assume 25°C ?
E steel pipe = 2×10^7 N/cm²
thickness δ = 10mm = 0.01m
OD = 0.62m
$E_o = 2.03 \times 10^5$ N/cm²

$$\Delta P = \rho C V$$

$$C = \frac{\sqrt{\frac{E_o}{\rho}}}{\sqrt{1 + \frac{E_o D}{E \delta}}}$$

E_o = bulk Modulus of fluid (N/m²)
ρ = fluid density (kg/m³)
D = Pipe diameter (m)
E = elastic modulus of pipe (N/m²)
δ = pipe thickness

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5 Cont'd: <u>Procedure and Calculations:</u>

$2 \times 10^{7}\ N/cm^2 \rightarrow N/m^2 = 2 \times 10^{11}\ N/m^2$

$2.03 \times 10^{5}\ N/cm^2 \rightarrow N/m^2 = 2.03 \times 10^{9}\ N/m^2$

$D = 600mm \Rightarrow m = 0.6m$

$\delta = 10mm \Rightarrow m = 0.01m$

$P = \rho C V$

$$C = \frac{\sqrt{\dfrac{E_o\ (N/m^2)}{\rho\ (kg/m^3)}}}{\sqrt{1 + \dfrac{E_o D\ (N/m^2 \cdot m)}{E \delta\ (N/m^2 \cdot m)}}}$$

$$C = \frac{\sqrt{\dfrac{2.03 \times 10^{9}}{997}}}{\sqrt{1 + \dfrac{(2.03 \times 10^{9})(0.6)}{(2.0 \times 10^{11})(0.01)}}}$$

$$C = \frac{1426.92}{1.268} = 1124.92$$

$P = \rho C V$

$$P = (997)(1124.92)(1) = 1.12 \times 10^{6}\ N/m^2 = 1.12\ MPa$$

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5 (cont'd) Summary: The pressure increment when valve is closed all of a sudden (water hammer) is 1.12 MPa or 1.12×10^6 N/m².

Analysis: Remember that slowly turning the valve will mitigate the water hammer slightly. The large diameter pipe helps already with the low velocity.

Materials: Valve, water, pipe