1) Purpose: I am tasked with designing a new lazy river for a water park based on the number of stipulations listed in the problem.

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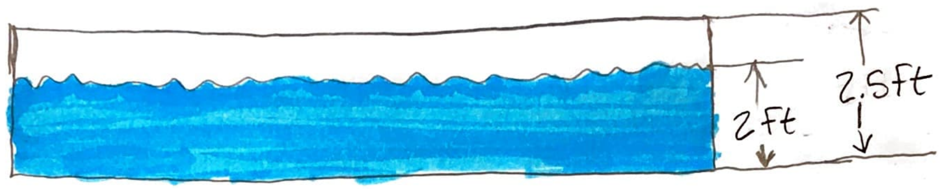
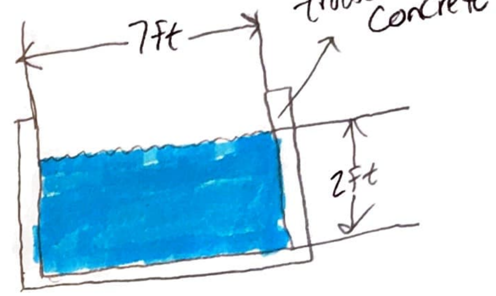
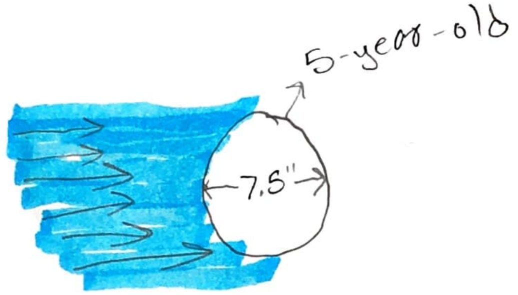
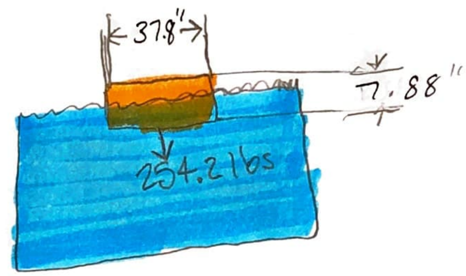
Drawings & Diagrams:









Sources: Mott & Untener, Applied Fluid Mechanics, 7th Edition, Pearson, 2015

Design Considerations:

- Slope = 0.057°
- 3-year-old girl (≈ 34.5") safe standing in water
- At least wide enough to fit 2 38" tubes
- Open channel flow (uniform steady flow)
- 5-year-old average chest diameter ≈ 7.5"

Data & Variables: $W = 7\,ft$ $d = 2\,ft$ $\gamma_w = 62.1\ lb/ft^3$ $n = 0.013$ (trowel-finished concrete)

$A = 14\,ft^2$ $W_{\text{tube and person}} = 254.2\ lbs$ Temp = 90°F

$\rho_{water} = 1.93\ slugs/ft^3$ $S = 0.001$ $\eta_{water} = 1.60 \times 10^{-5}\ lb\text{-}s/ft^2$

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Procedure: 1) Find water flow rate required. First find R

$$R = \frac{A}{WP} \qquad WP = w + 2d = 7 + 4 = 11$$

$$\therefore R = \frac{14}{11} = 1.27\text{ ft}$$

Once we have solved for R we can use

$$Q = \left(\frac{1.00}{n}\right) A R^{2/3} S^{1/2}$$

to find the required flow rate for our Open Channel lazy river.

$$\therefore Q = \left(\frac{1.00}{0.013}\right) 14\text{ ft} (1.27\text{ ft})^{2/3} (.001)^{1/2}$$

$$\therefore \boxed{Q = 39.94\ \text{ft}^3/\text{s}}$$

2) Find the drag force a 5-year-old will feel while Standing in the lazy river. First we need to find velocity according to Flow Rate.

$$V = \frac{Q}{A}$$

$$\therefore V = \frac{39.94}{14} = 2.85\ \text{ft}/\text{s}$$

Once we have the velocity we can find Reynolds Number

$$N_R = \frac{\rho V D}{\eta} = \frac{1.93\ \text{slug}/\text{ft}^3 (2.85\ \text{ft}/\text{s})(0.625\ \text{ft})}{1.60 \times 10^{-5}\ \text{lb-s}/\text{ft}^2}$$

$$\therefore N_R = 2.15 \times 10^5$$

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Procedure Cont': Once the Reynolds Number is found we can use it to go to figure 17.4 on page 435 of the textbook to find C_D.

$$C_D = 1 \quad \text{(for Cylinder)}$$

Now for the Lateral Surface Area of the cylinder

$$A = 2\pi r h$$
$$= 2\pi(0.3125\,ft)(2\,ft)$$
$$\therefore A = 3.927\,ft^2$$

Now that we have our Area we can use

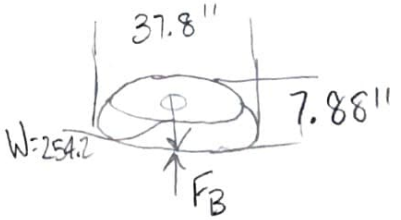
$$F_D = C_D\left(\frac{\rho v^2}{2}\right)A$$

to solve for the drag force.

$$F_D = 1\left(\frac{1.93\,slugs/ft^3\,(2.85\,ft/s)^2}{2}\right)(3.927\,ft^2)$$

$$\therefore \boxed{F_D = 30.781\,lbs}$$

3) Find the depth of immersion for the tube with a 250 lb person on top.



Start by finding the volume displaced by the weight of person and tube.

$$F_b = W = 254.2\,lbs$$

$$\therefore V_D = \frac{F_b}{\gamma_w} = \frac{254.2\,lbs}{62.1\,lb/ft^3} = 4.093\,ft^3$$

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Procedure Cont': Now that we have the volume displaced we can use the volume of the cylinder to find depth of immersion.

$$V_d = \pi r^2 h$$

$$\therefore h = \frac{V_d}{\pi r^2} = \frac{4.093\,ft^3}{\pi(1.575\,ft)^2}$$

$$\therefore \boxed{h = 0.525\,ft = 6.3\,in}$$

Once we have found h we can use that to find y_{cb}

$$y_{cb} = h/2 = .525/2 = 0.2625\,ft$$

Then we need to find I of a cylinder

$$I = \frac{\pi D^4}{64} = \frac{\pi(3.15)^4}{64} = 4.83\,ft^4$$

Using I and V_d we can now find the metacenter distance from the center of buoyancy with

$$MB = I/V_d$$

$$\therefore MB = \frac{4.83\,ft^4}{4.093\,ft^3} = 1.18\,ft$$

Then using MB and y_{cb} we can find y_{mc}.

$$y_{mc} = MB + y_{cb}$$

$$\therefore y_{mc} = 1.18\,ft + 0.2625\,ft = 1.4425\,ft$$

In conclusion $y_{cg} = .328\,ft$ and $y_{mc} = 1.4425\,ft$

Therefore $y_{cg} < y_{mc}$ so it is stable

Procedure Cont': 4) Find the forces on the floor and walls of the lazy river. For the floor we need to first find the pressure at the bottom of the lazy river.

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$$P_B = \gamma_w h$$

$$\therefore P_B = 62.1\ \text{lb/ft}^3\ (2\ \text{ft}) = 124.2\ \text{psfg}$$
$$= 0.86\ \text{psig}$$

With P_B we can now use

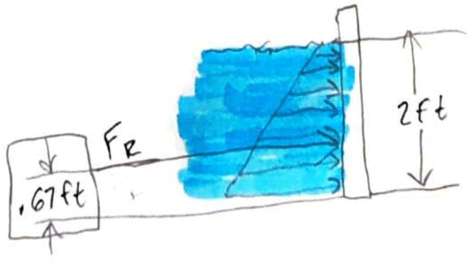
$$F = P_B A$$

to find the force on the floor in a 3.281 ft section of the lazy river.

$$F = 124.2\ \text{lb/ft}^2\ (3.281\ \text{ft} \times 7\ \text{ft})$$

$$\therefore F_{Bottom} = 2,852.50\ \text{lb}$$

Now to find the forces on the walls in a 3.281 ft section of the lazy river.



To find the F_R we can use

$$F_R = \gamma (h/2) A$$

$$\therefore F_R = 62.1\ \text{lb/ft}^3\ (2\text{ft}/2)(2\text{ft} \times 3.281\text{ft})$$

$F_R = 407.50$ lb at .67 ft from bottom of river

Robert Knypp
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Summary: 1) For part 1 I chose to make a rectangular bottom channel with a width of 7ft and a depth of water of 2ft. By using these dimensions I was able to find an R of 1.27ft and then solve for Q where I found the flow rate required to be 39.94 ft^3/s.

2) For part 2 I researched the average chest diameter of a 5-year-old to be roughly 7.5". I was able to use the Q from part 1 to find a v of 2.85 ft/s then use that to find a Reynolds Number of 2.15×10^5. I could then find the C_D in figure 17.4 of 1, I then computed the lateral surface area of the child (cylinder) to be able to find a Drag Force (F_D) of 30.781 lbs.

3) In part 3 Buoyancy Force (F_b) was equal to Weight which was a total of 254.2 lbs (250 (person) + 4.2 (tube)). With the F_b I was able to find a V_D of 4.093 ft^3 and use that to find a depth of immersion (h) of 0.525 ft. I then calculated to find y_{mc} of 1.4425 ft and found it was larger than y_{cg} (.328 ft) which meant the vessel was stable.

4) For part 4 I had to find the pressure at the bottom of the water (P_B) which was 124.2 psfg then used that to find F_{Bottom} of 2,852.50 lb for a 3.281 ft section. I found F_R for the sides using γ_{water}, h, and A which came out to 407.50 lb and divided height of water (2ft) by 3 to find a location of .67 ft from the bottom for the force.

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Analysis: From this problem I learned all of the steps it would take to design a lazy river to specs you would actually see in the industry. This problem showed exact application of the things we learned in class on: Flow rates for Open channels, drag force, buoyancy force and Stability, and Forces of liquid on surfaces. I believe that the lazy river I designed will be safe for kids 3 and up and be fun for the entire family.

Robert Knupp
MET 330
Test #2
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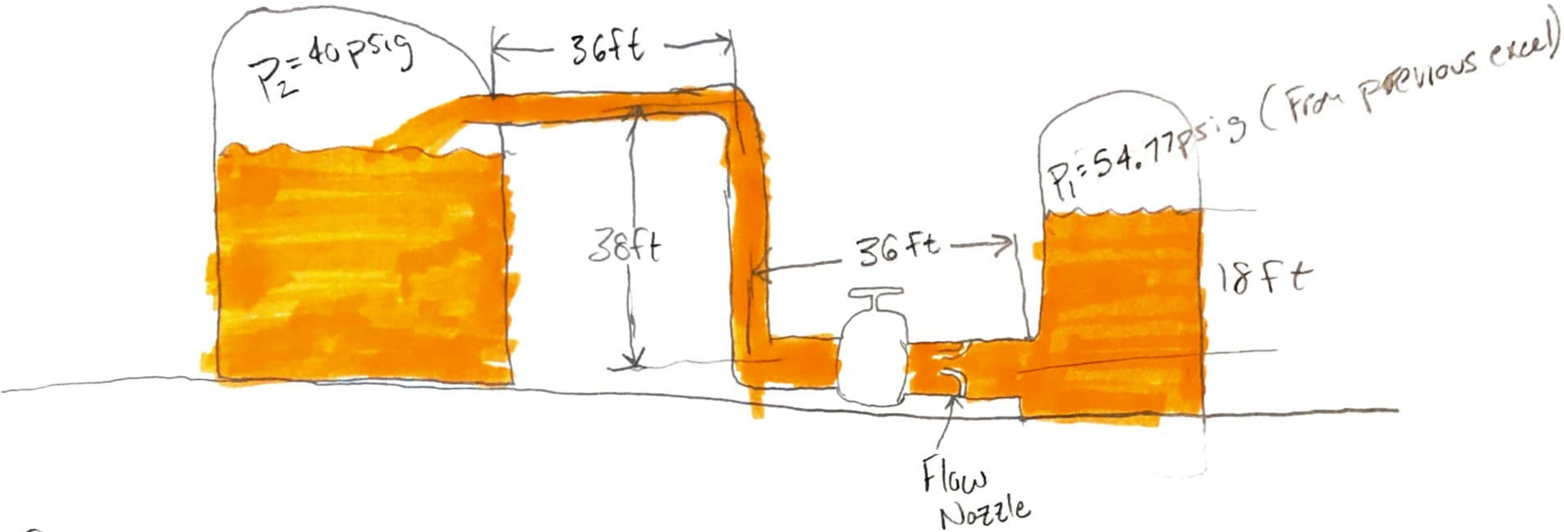
Purpose: Complete the overall design of the system that was used in test 1. With a new flow rate of 100 gpm.

Drawings & Diagrams:



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

Design Considerations:
- Incompressible Fluids
- Steady State
- Isothermal
- Constant Properties

Data & Variables: $V_1 = 0\ ft/s$ $V_2 = 0\ ft/s$ $Q = 100\ gpm$ Ø2in sched 40 = 2.067"

$\rho_{EA} = 1.53\ slugs/ft^3$ $\gamma_{EA} = 49.01\ lb/ft^3$ $\eta_{EA} = 2.10 \times 10^{-5}\ lb\cdot s/ft$

$P_1 = 54.77\ psig$ $P_2 = 40\ psig$ $Q = 0.2228\ ft^3/s$

$V = 1.293\ ft/s$ $A_{pipe} = 0.0233\ ft^2$ $g = 32.2\ ft/s^2$

$E_{o\,EA} = 130{,}000\ psi$ $\delta = 0.154"$ $E = 2.9 \times 10^7\ psi$

$E = 1.00$ $Y = 0.40$ $S = 20{,}000\ psi$

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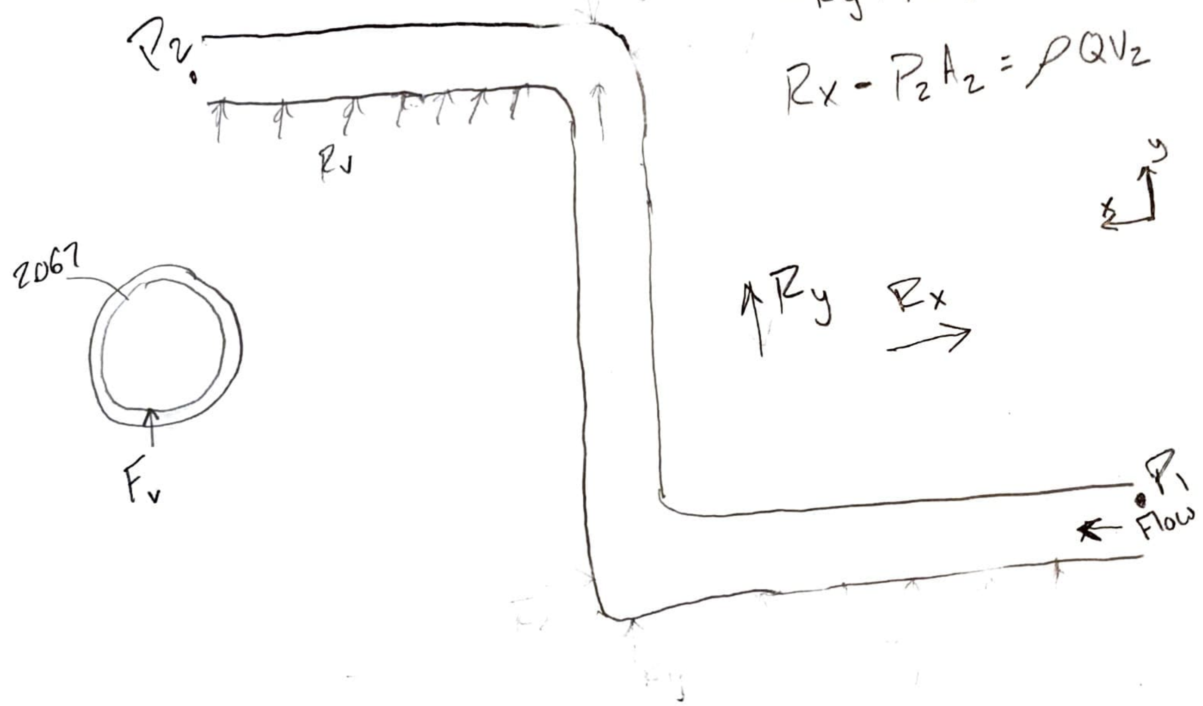
Procedure: 1) First we need to draw a FBD of the Complete piping sytem.

$-R_y + P_1 A_1 = \rho Q V_1$

$R_x - P_2 A_2 = \rho Q V_2$



In order to calculate forces on the pipe we need to add up all forces acting on all sections of pipe.

$$R_y = \gamma_{EA}(36ft \times 2 + 38ft)$$

$$R_x = \frac{P_1 - P_2}{A}$$

We need to find P_1 at the beginning of the pipe system with

$$P_1 - P_2 = \gamma h$$

$$\therefore P_1 - 7{,}886.88 = 49.01(18)$$

$$\therefore P_1 = 8{,}769.06 \text{ psf or } 60.89 \text{ psi}$$

Procedure Cont': Once we have P, we can solve for the Reaction forces in the x and y direction

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$$R_x = \frac{P_1 - P_2}{A}$$

$$\therefore R_x = \frac{60.89\ psig - 40\ psig}{0.0233\ ft^2}$$

$$\boxed{R_x = 896.57\ lbs}$$

$$R_y = \gamma_{EA}(36ft \times 2 + 38ft)$$

$$\therefore R_y = 49.01(36ft \times 2 + 38ft)$$

$$\boxed{R_y = 5{,}391.1\ lb}$$

2) For part 2 we need to calculate Reynold's Number for the new Flow Rate.

$$N_R = \frac{\rho v D}{\eta} = \frac{(1.53\ slugs/ft^3)(1.293\ ft/s)(.177225\ ft)}{2.10 \times 10^{-5}\ lbs/ft}$$

$$\therefore N_R = 16{,}695.355$$

Now that we have Reynold's Number we can Solve for the Discharge Coefficient (c) of a flow Nozzle.

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

$$\therefore C = 0.9975 - 6.53\sqrt{.9 / 16{,}695.355}$$

$$C = 0.96177$$

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Procedure Cont': After we solve for C we can solve for P_2 with

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

$$0.2228\ ft^3/s = 0.96177(.0233 ft^2)\sqrt{\frac{2(32.2)(8768.16 - P_2)/49.01\ lb/ft^3}{(2)^2 - 1}}$$

$\therefore P_2 = 8542.47$ psf or 59.32 psi

$\therefore \Delta P = 60.89 - 59.32 = \boxed{1.57\ psi}$

3) For part 3 we need to solve for water hammer if the valve closes suddenly. First we need to find C.

$$C = \frac{\sqrt{E_o/\rho}}{\sqrt{1 + \frac{E_o D}{E \delta}}} = \frac{\sqrt{\frac{18720000}{1.53}}}{\sqrt{1 + \frac{18720000(.17225)}{4176000000}}}$$

$\therefore C = 3,497.899$

Now we can use C to solve for ΔP

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

$\therefore \Delta P = 1.53(3,497.899)(1.293)$

$\Delta P = 6,919.859$ psf or 48.054 psi

$\therefore P_{max} = P_{op} + \Delta P = 60.89 + 48.054 =$

$\boxed{P_{max} = 108.945\ psi}$

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Procedure Cont'd: After finding the P_{max} of the suddenly Closed Valve we can put that in

$$t = \frac{pD}{2(SE + pY)}$$

$$\therefore t = \frac{108{,}945(2.067)}{2(20{,}000(1.00) + 108.945(0.40))}$$

$$t = 0.005''$$

After finding this thickness we can conclude that our thickness of 0.154" is plenty thick enough to handle the water hammer.

For cavitation the vapor pressure of Ethyl Alcohol at 77°F is 1.798 psi which will never exceed any pressure in the system since our lowest is at the exit of the pipe of 40 psi.

Robert Knupp
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Summary: 1) In part 1 we found that the force in the y direction was much larger than the x at 5,391.1lbs and 896.57 lbs respectively. We will be able to send these numbers to the civil engineer to get the correct supports needed

2) In part 2 we placed a flow nozzle in the system to help monitor the flow. We found that the flow nozzle only created a drop in pressure of 1.57psi.

3) In part 3 we had to solve for the max pressure the pipes would see if the valve was suddenly closed. We found that max pressure to be 108.945psi and used that in equation 11-9 to find a required pipe thickness of 0.005" which our 0.154" pipe greatly exceeds. There will be no cavitation in this system because the vapor pressure of Ethyl Alcohol is much lower than the pressure at any point in the system.

Robert Knapp
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Analysis: In this problem I believe I provided the civil engineer with the correct data that he needs to support the piping system as well as provided a very low pressure loss way to monitor the flow of the system. I also verified that my selected pipe thickness was appropriate to handle any water hammer that may happen and prove that there will be no areas of cavitation.