Problem A: Test 2

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Purpose

The purpose of this problem is design a lazy river. The flow rate must be found. I need to calculate the drag force that a 5-year-old kid might experience. The buoyancy & stability needs to be found for a 250lb person. As well as what the force will be in a certain location on the wall & floor.

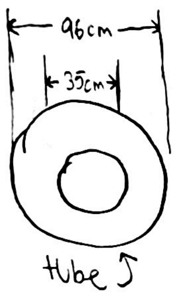
Sources

Mott, R., Untener, J.A., "Applied Fluid Mechanics," 7th edition, Pearson Education Inc.

Design considerations

- Water depth must be safe for 3-year-old girl
- Constant temperature
- Water is incompressible

Drawings & diagrams



Data & Variables

- Slope = 0.1%
- Outer diameter = 96cm = 3.15 ft
- Inner diameter = 35cm = 1.148 ft
- Width of channel must be → 3.15ft × 2 = 6.4 ft ≈ 7ft
- Avg height of 3-year-old = 35in = 2.1 ft → depth of water = 1.5 ft
- Pool water temp = 80°F
- Avg height of 5-year-old = 43in = 3.58ft ≈ 3.5ft
- Kinematic viscosity of water @ 80°F = 9.15×10^{-6} ft²/s
- Weight of tube = 4.189 lb
- $\gamma_{water} = 62.4$ lb/ft³

Procedure

First I need to find the flow rate of an open channel. I will use the normal discharge equation. I find the Area, Hydraulic radius, n, and slope. I plug these in and get the flow rate. Next I need to need calculate the drag force that a 5-year-old would feel. To use the drag force equation, I need to find the drag coefficient, density of the water, kinematic viscosity, velocity, and Area. Once they are found I plug them into the drag force equation. Next I need to find how deep into the water a 250 lb person will go. I need to find the buoyancy force, and manipulate the equation of equilibrium to work for this problem. Once I have all the needed variables, I solve for the depth of the person. I then need to find out if this person is stable. I find the metacenter by calculating MB and adding that to the center of buoyancy. Lastly, I have to find the force of a 1m-length section. I use the force equation and solve.

Calculations

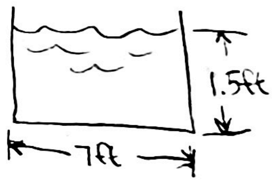
1. $Q = \left(\frac{1.49}{n}\right) A R^{2/3} S^{1/2}$

$A = WD = (7\text{ ft})(1.5\text{ ft}) = 10.5\text{ ft}^2$

$R = \frac{by}{b+2y} = \frac{10.5\text{ ft}^2}{7\text{ ft} + 2(1.5\text{ ft})} = 1.05\text{ ft}$

Slope = 0.1%

$n = 0.013$



$Q = \left(\frac{1.49}{0.013}\right)(10.5\text{ ft}^2)(1.05\text{ ft})^{2/3}(0.001)^{1/2} = \boxed{39.32\text{ ft}^3/\text{s}}$

2. $F_D = C_D(\rho v^2/2)A$

$A = (3.5\text{ ft})(1\text{ ft}) = 3.5\text{ ft}^2$ $\quad \nu = 9.15\times10^{-6}\text{ ft}^2/\text{s}$ $\quad \rho = 1.93\text{ slug/ft}^3$

$V = Q/A = (39.32\text{ ft}^3/\text{s})/(10.5\text{ ft}^2) = 3.74\text{ ft/s}$

$N_R = vD/\nu = \frac{(3.74\text{ ft/s})(1\text{ ft})}{9.15\times10^{-6}\text{ ft}^2/\text{s}} = 408{,}743.17 \rightarrow C_D = 1.22$

$F_D = 1.22\left(\frac{(1.93\text{ lb s}^2/\text{ft}^4)(3.74\text{ ft/s})^2}{2}\right)(3.5\text{ ft}^2) = \boxed{57.64\text{ lb}}$

3. $\Sigma F_v = 0 \rightarrow F_b - F_e - W = 0$ $\quad \gamma_w = 62.4\text{ lb/ft}^3$ $\quad F_e = 250\text{ lb}$

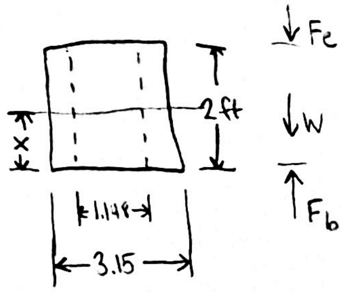
$W = 4.189\text{ lb}$

$F_b = \gamma_f V_d$

$V = \frac{\pi}{4}D^2 X = \frac{\pi}{4}(3.15\text{ ft})^2 X = 7.79\text{ ft}^3$

$\gamma_f V_d = F_e + W \rightarrow \gamma_f\left(\frac{\pi}{4}D^2 h\right)X = F_e + W$

$\hookrightarrow X = \frac{F_e + W}{\gamma_f\left(\frac{\pi}{4}D^2\right)} = \frac{250\text{ lb} + 4.189\text{ lb}}{(62.4\text{ lb/ft}^3)(7.79\text{ ft}^3)} = \boxed{0.523\text{ ft}}$



$y_{cb} = x/2 = 0.523\,ft/2 = 0.262\,ft$

$V_d = \frac{\pi}{4} D^2 x = \frac{\pi}{4}(3.15ft)^2(0.523ft) = 4.08\,ft^3$

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

$MB = I/V_d = \frac{4.83ft^4}{4.08ft^3} = 1.18\,ft$

$y_{mc} = y_{cb} + MB = 0.262\,ft + 1.18\,ft = 1.442$

$y_{cg} = \frac{2ft}{2} = 1\,ft \rightarrow y_{mc} > y_{cg} \rightarrow$ It is Stable

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4. $F = \rho Q V = (1.93\,lb \cdot s^2/ft^4)(39.32\,ft^3/s)(3.74\,ft/s)$

$F = 283.82\,lb$ on both the wall and floor

*Note: I was a bit confused with the wording of the question so I did the best I could.

Summary

The flow rate for the lazy river is 39.32 ft^3/s. The drag force on a 5-year-old kid is 57.64 lb. The tube will go 0.523 ft into the water with a 250lb person on top and it will be stable. The force on the floor and wall is 283.82 lb.

Materials

- Pool water temp = 80°F
- tube material = PVC

Analysis

Overall, this lazy river seems like it would be a safe and fun activity for people of all ages and sizes.

Problem B:

Purpose

The purpose of this problem is to calculate the total horizontal and vertical forces that there are in a tank system. I need to calculate the pressure drop from the nozzle that was added to the system. As well as calculate if the pipe would fail due to water hammer and check if there will be cavitation.

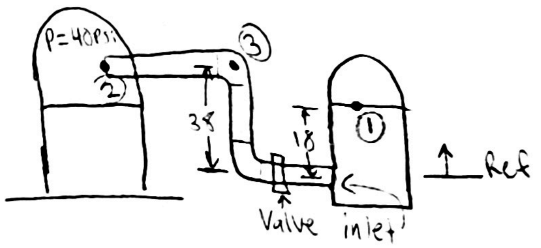
Sources

Mott, R., Utener, J.A., "Applied Fluid Mechanics," 7th edition, Pearson Education Inc.

Design Considerations

- Constant Properties
- Incompressible fluids

Drawings & diagrams



Data & Variables

- 100 gpm = 0.223 ft^3/s
- P_2 = 40 psi
- γ_{EA} = 49.01 lb/ft^3
- ρ = 1.53 $lb \cdot s^2/ft^4$
- A = 0.02333 ft^2
- β = 0.5
- ν = 1.37×10^{-5} ft^2/s
- D = 0.198 ft
- g = 32.2 ft/s^2
- Modulus of E = 200 MPa
- yield strength = 50763.2 Psi
- FOS = 2

- E = 1
- Y = 0.40

Procedure

To start I need to find the total horizontal & vertical forces in the pipe-elbow-valve system from tank to tank. I will be using the force equation, so I need to find density, flow rate, two velocities, pressure, and area. once each vertical & horizontal forces have been found, I add them up. Next I need to calculate the pressure difference across the nozzle. I take Bernoulli's equation and manipulate it to work for this problem, by making it solve for the difference in pressure. Lastly, I have to find out if water hammer will make the pipe fail. I do this by use the wall thickness equation and compare the two thicknesses. I will need to verify if there is cavitation in the system.

Calculations

5. $F_x = \rho Q (V_{2x} - V_{1x})$ $\quad V = 0.223 ft^3/s / 0.02333 ft^2 = 9.56 ft/s$

From P_1 to inlet:

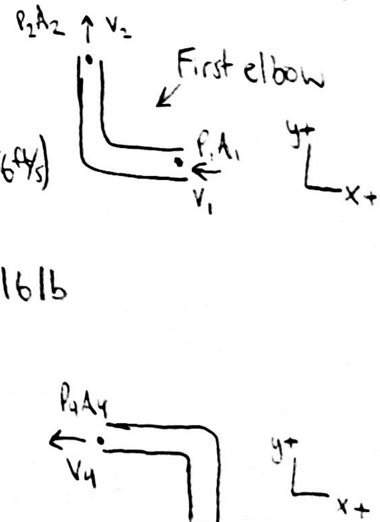
$P_{inlet} = (49.01 lb/ft^3)(18 ft) = 882.18 lb/ft^2$

From inlet to valve:

$$\frac{P_{inlet}}{\gamma} + z_1 + \frac{V_1^2}{2g} - h_L = \frac{P_{valve}}{\gamma} + z_2 + \frac{V_2^2}{2g} \rightarrow \frac{882.18 lb/ft^2}{49.01 lb/ft^3} + \frac{(9.56 ft/s)}{2(32.2 ft/s^2)} - 1.345 ft = \frac{P_2}{49.01 lb/ft^3} + \frac{9.56 ft/s}{2(32.2 ft/s^2)}$$

$P_{valve} = 816.26 lb/ft^2$

First elbow:



$R_x - P_1A_1 = \rho Q (V_{2x} - V_{1x}) \rightarrow R_x - (816.26 lb/ft^2)(0.02333 ft^2) = (1.93 lb \cdot s^2/ft^3)(0.223 ft^3/s)(9.56 ft/s)$

$R_x = 23.16 lb$

$R_y - (816.26 lb/ft^2)(0.02333 ft^2) = (1.93 lb \cdot s^2/ft^3)(0.223 ft^3/s)(9.56 ft/s) = 23.16 lb$

Second elbow:

$P_3 = 53.566 psi$

$R_x - (7713.5 lb/ft^2)(0.02333 ft^2) = (1.93)(0.223)(9.56) =$

$R_x = 184.07 lb$

$R_y - (7713.5)(0.02333) = (1.93)(0.223)(-9.56) = 175.84 lb$

$R_{x\,total} = 23.16 + 184.07 = 207.23 lb$

$R_{y\,total} = 23.16 + 175.84 = 199 lb$

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

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

$N_R = \frac{V_1 D}{\nu} \rightarrow V_1 = 0.223\,ft^3/s / 0.02333\,ft^2 = 9.56\ ft/s$

$N_R = \frac{(9.56\ ft/s)(0.189\ ft)}{1.37\times10^{-5}\ ft^2/s} = 131886.13$

$C = 0.9975 - 6.53\sqrt{0.5/131886.13} = 0.9848$

$\beta = d/D \rightarrow 0.5 = d/0.189\,ft \rightarrow d = 0.099\,ft \rightarrow A_2 = \frac{\pi}{4}(0.099\,ft)^2 = 0.0077\,ft^2$

$\Delta P = \left(\frac{9.56\ ft/s}{0.9848}\right)^2\left(\frac{(49.01\ lb/ft^3)((0.02333\,ft^2/0.0077\,ft^2)^2-1)}{2(32.2\ ft/s^2)}\right) = 656.90\ lb/ft^2 = \boxed{4.56\ Psi}$

7. Yield Strength for steel = 50763.2 psi

Allowable stress = 50763.2 Psi/2 = 25381.6 Psi = 3,654,950.4 lb/ft²

$P = \gamma h = (49.01\ lb/ft^3)(18\ ft) = 882.18\ lb/ft^2$

$E = 1$, $Y = 0.40$

$t = \frac{PD}{2(SE+PY)} = \frac{(882.18\ lb/ft^2)(0.198\ ft)}{2((3654950.4\ lb/ft^2)(1)+(882.18\ lb/ft^2)(0.40))} = 2.390\times10^{-5}\ ft = \boxed{2.867\times10^{-4}\ in}$

Schedule 40, 2in Steel Pipe thickness = 0.154in

No the pipe will not break. Cavitation could happen in the valve.

Materials

- Schedule 40, 2in Steel Pipe
- Ethyl Alcohol @ 77°F
- Air @ 77°F

Summary

The total horizontal forces are 207.23 lb, the total vertical forces are 199 lb. The pressure difference from the nozzle is 4.56 Psi. The pipe will not fail, but there could be cavitation.

Analysis

It is important to make sure the piping of a system can handle various situations thrown at it. It is always better to over build.