Test 2

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MET 330

Purpose:

To further improve the design of a system to deliver water from a lower open channel to an elevated open channel by,

a) making sure the lower open channel will not run dry

b) designing a support system for the discharge pipe

c) adding a flow nozzle

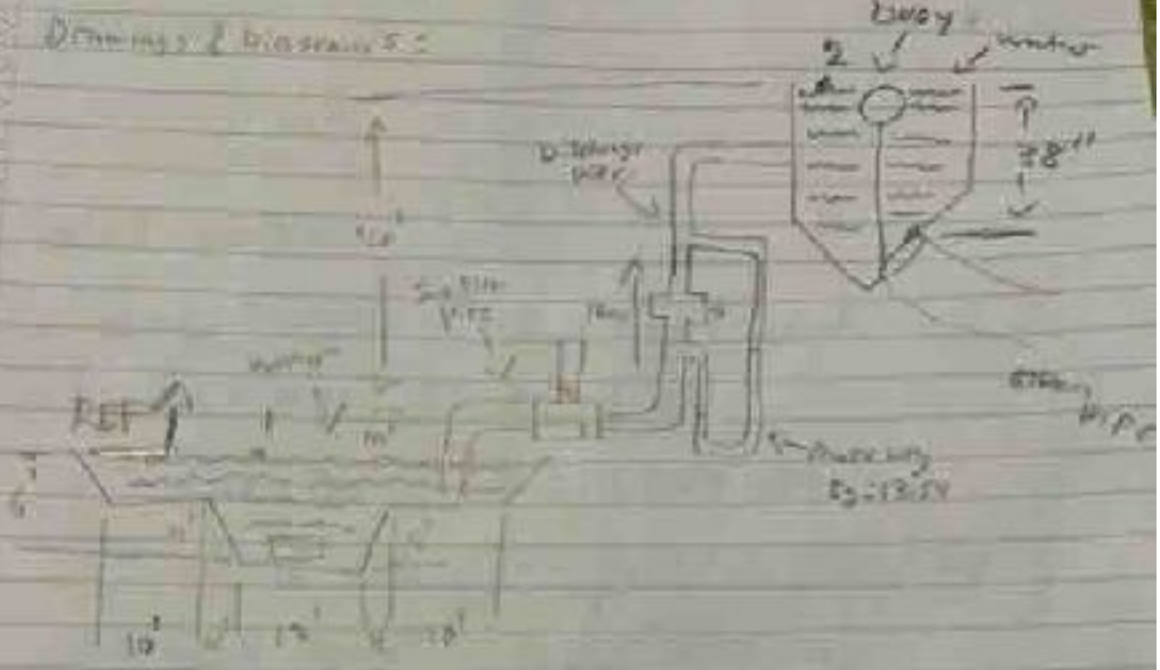
d) check for water hammer and/or cavitation

e) determine how large the buoy needs to be to properly function and if its stable

f) determine the maximum weight of an object in the lower open channel that will move

g) Create an excel sheet to run the calculations

Drawings & Diagrams:



Sources:

Mott, R., Untener, J.A., "Applied Fluid Mechanics" 7th edition, Pearson Education Inc. (2015)

Design Considerations:

- Constant properties
- Fluids are incompressible
- Isothermal conditions
- Steady state
- newtonian Fluid

Materials:

- Water @ 60°F
- Steel pipe

Data & Variables

$L_{discharge} = 8{,}500 ft$ $\quad$ $\gamma_{Hg} = 844.9 lb/ft^3$

$L_{suction} = 11 ft$ $\quad$ $\eta_{pump} = 0.6$

$\varepsilon = 1.5 \times 10^{-4} ft$ $\quad$ $Q = 3.337 ft^3/s$

$\nu = 1.21 \times 10^{-5} ft^2/s$ $\quad$ $S = 0.00015$ (from trusses)

$\gamma = 62.4 lb/ft^3$ $\quad$ $E_{steel} = 200 GPa$

Procedure:

For the 6 main parts I will,

a) Calculate flow rate of the lower open channel by using given parameters for it and compare to the flow rate of the system to determine if the amount pumped is negligible

b) Calculate forces in the discharge pipe system and determine relevant reaction forces

c) Calculate pressure drop over a flow nozzle then add the difference in sum of energy losses to power of water to get pump power increase since energy must be conserved

d) Check if our system will fail via water hammer or cavitation by comparing the failing thickness to our own pipes thickness

e) Solve for diameter by creating a FBD to determine forces by doing this I set buoyancy force equal to the force of water on the gate

F) by knowing the geometry water velocity and coefficient of friction I can solve for the maximum weight the channel can move

Calculations:

(a) Using the open channel flow equation

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

To find R I take $\frac{\text{Area}}{\text{wetted perimeter}}$

taken as $\Sigma A = A_1 + A_2$, $\Sigma WP = WP_1 + WP_2$

$A_1 = (b + zy)y = (12 + (1)(4))4 = 64\,ft^2$

$A_2 = (b + zy)y = (40 + (1)(2))2 = 84\,ft^2$

$A = 64\,ft^2 + 84\,ft^2 = 148\,ft^2$

$WP_1 = b + 2y\sqrt{1+z^2} = 12 + 2(4)\sqrt{1+1^2} = 23.31\,ft$

$WP_2 = b + 2y\sqrt{1+z^2} = 40 + (2)(2)\sqrt{1+1^2} = 45.66\,ft$

$WP = 68.97\,ft$

$$R = \frac{148}{68.97} = 2.146$$

Knowing that this is a natural channel with light brush and the slope is 0.00015 I can find the flow rate

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

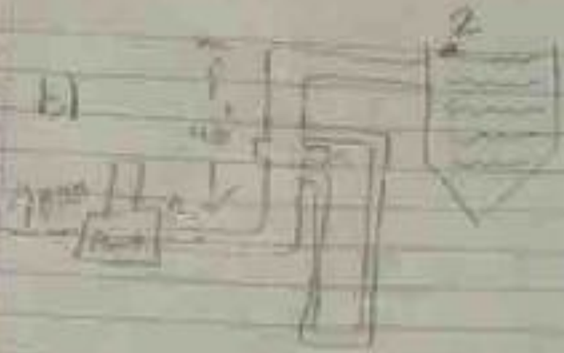
$$Q = \frac{1.49}{0.050} (148) (0.00015)^{1/2} (2.146)^{2/3} \approx 89.87 \frac{ft^3}{s}$$

Compared to the flow rate of the system

$$Q = 3.387 \frac{ft^3}{s}$$

$$\frac{3.387 \, ft^3/s}{89.87 \, ft^3/s} = 0.0377 \times 100 = 3.77\%$$

Yes, the amount of water pumped can be considered negligible as it is only 3.77% of the flow rate of the open channel b)



by using Bernoulli's equation between points 1 & 2 I can solve for pressure at point 1

$$\cancel{h_p} + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{\cancel{P_2}}{\gamma} + \cancel{\frac{V_2^2}{2g}} + z_2 + h_{L_{1-2}}$$

by placing 2 at surface $P_2, V_2 = 0$

adding the elevation, pipe, elbow losses

Isect

Pipe: $f\frac{L}{D}\frac{V^2}{2g}$

$$V = \frac{Q}{A} = \frac{3.387}{0.3472} = 9.755 \text{ ft/s}$$

$$Re = \frac{VD}{\nu} = \frac{9.7755 \times 0.6651}{1.21 \times 10^{-5}} = 5.36 \times 10^{5}$$

$$D/\varepsilon = \frac{0.6651}{1.5 \times 10^{-4}} = 4434$$

$$f \simeq 0.01537$$

$h_{pipe} = 0.0151 \times \frac{775 ft}{0.4431} \times \frac{(9.755)^2}{2\times32.2} = 86.48$ ft

Elbows:

$h_{elbows} = K_f \frac{V^2}{2g} \times 2$

$h_{elbows} = 30 f_T = 0.414 \times \frac{9.755^2}{2\times32.2} \times 2 = 1.25$ ft

Valve:

$h_{valve} = K \frac{V^2}{2g} = 5.3 \times \frac{9.755^2}{2\times32.2} = 7.83$ ft

Exit:

$h_{exit} = K \frac{V^2}{2g} = 1 \times \frac{9.755^2}{2\times32.2} = 1.48$ ft

$h_{L_{1-2}} = 97.04$ ft

Knowing $V_1 = 9.755$ ft/s

I can solve for pressure at pump exit (1)

$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = z_2 + h_{L_{1-2}}$$

$$P_1 = \left(z_2 - z_1 - \frac{V_1^2}{2g} + h_{L_{1-2}}\right)\gamma$$

$$P_1 = \left(40\,ft - \frac{(9.775\,ft/s)^2}{2(32.2\,ft/s^2)} + 97.04\,ft\right) 62.4\,\frac{lb}{ft^3}$$

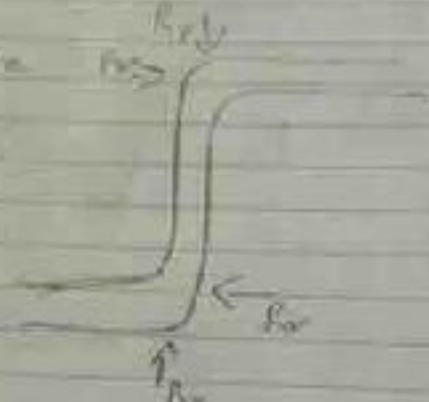
$$P_1 = 8458.7\,\frac{lb}{ft^2}\left(\frac{1}{12}\frac{ft}{in}\right)\left(\frac{1}{12}\frac{ft}{in}\right) =$$

$$P_1 = 58.74\,psi = 8458.7\,\frac{lb}{ft^2}$$

By using the force equation

$$\vec{F} = \rho a \Delta \vec{v}$$

Forces in the elbow are



$$F_x = \rho a \Delta v_x$$
$$F_y = \rho a \Delta v_y$$

$$R_x = \rho a v + P_1 A_1$$
$$R_y = \rho a_{v_2} + P_2 A_2$$

$$R_x = R_y$$

$$R_x = R_y = \rho a v + PA = \left(1.94\,\frac{slugs}{ft^3}\right)\left(3.387\,\frac{ft^3}{s}\right)\left(9.775\,\frac{ft}{s}\right)$$

$$+ \left(8458.7\,\frac{lb}{ft^2}\right)\left(0.3472\,ft^2\right)\left(\frac{1}{32.174}\frac{slug}{lb}\right)$$

$$R_x = R_y = 155.5\,\frac{slug \times ft}{s^2} = 155.5\,lbs$$

2) For this part I will calculate pressure drop from flow nozzle by :

From Previous Velocity in ex Sample

$V = 9.255$ ft/s

and applying the equation for a flow nozzle

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

Since $A_1 = \pi D^2/4 = \frac{\pi(0.667)^2}{4} = 0.3477\ ft^2$ From test 1

$$A_2 = \frac{\pi(0.5\times0.667)^2}{4} = 0.086$$

$$A_1/A_2 = 3.999$$

C is calculated from

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

$$C = 0.9973 - 6.53\sqrt{0.5/5.36\times10^5}$$

$$C = 0.99119$$

I need to solve for $\Delta P = P_1 - P_2$

$$9.281 = 0.9919\sqrt{\frac{64.4(\Delta P)/62.4}{15}}$$

$$9.155 = 0.9919\left(0.0688\,\Delta P\right)^{1/2}$$

$$9.242^2 = 0.0688\,\Delta P$$

$$96.86 = 0.0688\,\Delta P$$

$$1407.78\ lb/ft^2 = \Delta P$$

$$\Delta P = 9.78\ psi$$

I will add this to head loss since
Pressure drop is directly related to
energy loss

Pump power before Flow nozzle:

$$P = \frac{\gamma Q h_A}{\eta} = \frac{62.4 \times 3.387 \times 147.53}{0.6} = 51{,}967.147\ \frac{lb \cdot ft}{s}$$

after adding Flow nozzle

$$P = \frac{\gamma Q h_A}{\eta} = \frac{62.4 \times 3.387 \times 157.31}{0.6} = 55412.133\ \frac{lb \cdot ft}{s}$$

%: Pump Power increase

$$\frac{55412.133 - 51967.147}{51967.147} \times 100 = 6.63\%\ \text{increase}$$

d) I will check for water hammer & cavitation

by knowing the fluid type and temperature I know fluid density & bulk modulus

by knowing that the pipe is steel, thickness, and diameter is 0.662ft I know all the variables and

P_{max} can be compared to $P_{op} + \Delta P$

$$\Delta P = \rho c V$$

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

$$c = \frac{\sqrt{\frac{2.17\times10^9}{1660}}}{\sqrt{1 + \frac{2.17\times10^9\,(0.2)}{2\times10^{11}\,(0.00218)}}} = 1170\ m/s$$

$\Delta P = 1008 \frac{kN}{m^3} \times 1170 \frac{m}{s} \times 2.947 \, m/s = 3474900 \frac{kn}{m}$

$\Delta P = 503981 \, psi$

Pressure in system

Calculated in section b) $P = 58.74 \, psi$

most likely to occur at high pressure

$P_{max} = 503981 + 58.74 \, psi = 504050 \, psi$

From wall thickness calculation equation 11-9 to see if the wall is thick enough to withstand water hammer

$t = \frac{PD}{2(SE + PY)}$ 548 psig

E assumed = 1, for solid steel

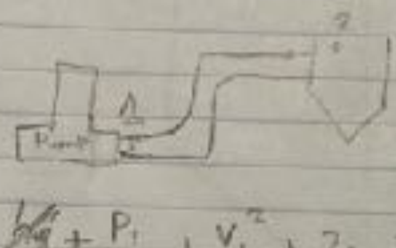
$t = \frac{504050(3.625)}{2(200000 \times 1 + 504050 \times .4)}$

$t = 5.4 \, in$

Our Pipe would not Fail from water hammer

Check for Cavitation.

From right after the pump were pressure will be the lowest at cavitation is most likely to occur



$$\cancel{\frac{P_p}{\gamma}} + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \cancel{\frac{P_2}{\gamma}} + \cancel{\frac{V_2^2}{2g}} + z_2 + h_{L,1-2}$$

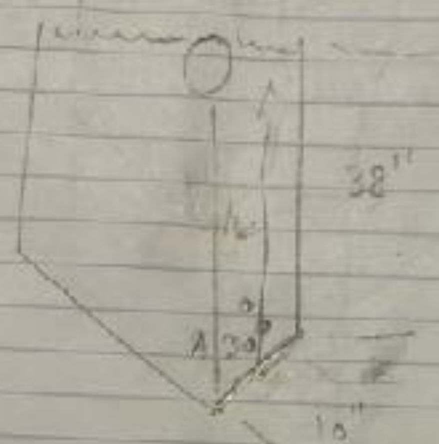
$$\frac{P_1}{\gamma} = z_2 - z_1 - \frac{V_1^2}{2g} + h_{L,1-2}$$

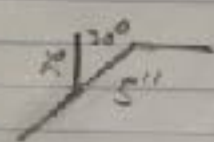
$$P_1 = \left(40\,ft - \frac{(9.753\,ft/s)^2}{2 \times 32.2\,ft/s^2} + 97.04\,ft\right) 62.4\,\frac{lb}{ft^3}$$

$$P_1 = 58.74\,psi < 0.256\,psi \text{ @ } 60\,°F \left\{ \text{From Thermo textbook} \right.$$

So there is no Cavitation since calculated pressure is larger than P_{sat}.

C) To determine the diameter of the buoy needed to open the gate





to keep the ratio equal and the system to work I will set the pressure of water on the gate equal to the buoyancy force to get the needed diameter

$F = \gamma h_c A$ - Force of water on latch

$\cos 30 = \frac{x}{5}$

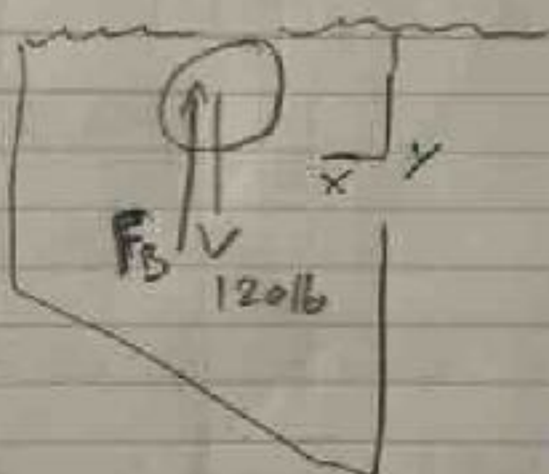
$x = 5\cos 30 = 4.33\text{ in}$

$h_c = 38 + 4.33'' = 42.33\text{ in} = 3.528\text{ ft}$

$A = \frac{\pi D^2}{4} = \frac{\pi (0.83)^2}{4} = 0.545\text{ ft}^2$

$$62.4\ \frac{lb}{ft^3} \times 3.528\ ft \times 0.545\ ft^2 = 120\ lb$$

FBD



$F_B = \gamma \times h_c \times A$

$\cancel{\gamma_b} V_b = 120\ lb$ $\qquad$ γ_w - is neglected

Since the buoy is submerged the entire volume is used

$V_b = 120/62.4$

Volume of a sphere $= \frac{4}{3}\pi r^3$

$\frac{4}{3}\pi r^3 = 1.92 \text{ ft}^3 \times \frac{3}{4}$

$\pi r^3 = \frac{1.44}{\pi}$

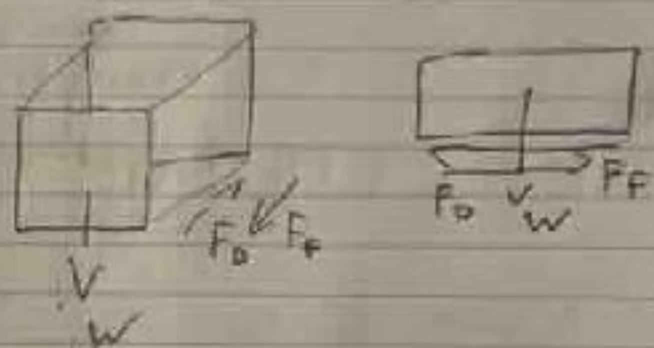
$r^3 = 0.458$

$r = 0.77$ ft

Diameter of buoy $=$ $\underline{1.54 \text{ ft} = 18.5 \text{in}}$

Yes, the buoy is stable when pulling the gate because the this will lower the Systems Center of gravity below the Center of buoyancy

F) I want to calculate maximum object weight in the lower open channel that can slide on the ground and fluid flows around it



$F_D > WF_F$

$F_D > WF_F$

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

$C_D = 1.6$ from tables

From taking flow rate from part a) and dividing it by area I get velocity of the lower open channel

$$V = \frac{89.87\,ft^3/s}{148\,ft^2} = 0.607\,ft/s$$

$$Area = 1 \times 1 = 1\,ft^2$$

$$F_D = 1.6\left(\frac{1.94\,slugs/ft^3\,(0.607\,ft/s)^2}{2}\right) 1\,ft^2$$

$$F_D = 0.572\,slug = 18.4\,lb$$

$$\frac{(18.4)}{0.6} > W$$

$$W < 30.67\,lb$$

Summary: In this test I improved the System by Solving for reaction forces to the Pipe can be supported and by Showing the results to the Client what happens when a Flow nozzle is added. I made sure the System was Safe by checking for Water hammer and Cavitation that could cause Failure. I also determined the buoy diameter to accurately keep the elevated open channel at 38''

Analysis: In this test the design was improved upon and information was given to the structural engineer about the reaction forces to design a support system. This is benificial as it will allow the system to last and not deform over time. In the excel portion I demonstrated what adjusting the Hp of the pump to half, what that will do and results if that happened. Calculations were given for the diameter of the buoy, if a smaller buoy would be used the system would overflow. In contrast if a larger than needed buoy was used It could cause the system to drain to quickly. From my calculations a properly sized buoy will maintain the balance and keep the system at 38"