

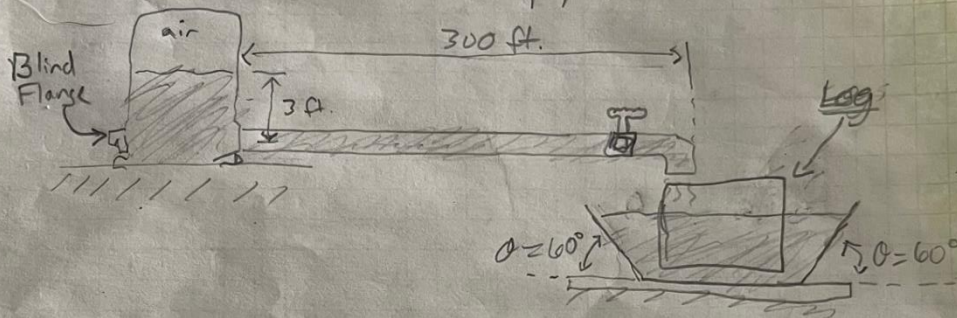
Test # 2

DAVIS TAPPA

MET 330

P5.1

Scenario: The system below is supposed to deliver water at 60°F and a flow rate, $Q = 75 \text{ cfm}$ from the storage tank to the trapezoidal open channel through a 300 ft., 1.5" schedule 40 steel pipe.



Purpose: The goal of this scenario is to provide the calculations for parameters regarding the safe and efficient flow of logs downstream of the trapezoidal shaped open channel trough.

Sources: MET330 fluid mechanics textbook

- Appendices for common fluid properties / Dimensions of steel pipes
- Table 14.2 / 14.3 (Geometries of open-channel systems)
- Appendix for efficiency of them)
- conversion factors
- Table 17.1, "Typical Drag Coefficients"

Design Considerations:

(Pg. 2)

- It is assumed that since the pressure at the top level of the water in the tank is equal to air pressure that we can set it to zero.
- Since the temperature of the water is not room temperature, we must adjust/interpolate for the appropriate density/viscosity w/ respect to 60°F.
- The book use T for width of water from table 14.3 but I will use W since there is a given Temp value (T_w)

Data & Variables: • Temp of Water, $T_w = 60^\circ\text{F}$

• $Q = 60 \text{ GPM}$

• $n_{\text{concrete}} = 0.017$

• $\rho_{\text{hickory wood}} = 830 \text{ kg/m}^3$

• $E_{\text{steel}} = 200 \text{ GPa}$

• Inner Diameter of 1.5" schedule 40 = 0.1342 ft
O.D = 1.9" • 0.15833 ft or

• Channel slope (Downstream) = 0.1% 40.9 mm
(Made of Concrete)

"Unfinished"

Procedure: I will first calculate the water depth, y of the open channel system by using the tables A.2 & 14.3 in the textbook to solve for dimensions of the system. I will then calculate the total forces acting on the pipe from the tank to the valve: (~ 300 ft). Then,

I will calculate the theoretical largest size of wood log it can carry using buoyancy eq'ns. I will also calculate the pressure drop across the flow nozzle in the system. I will then answer theoretical questions regarding pressure drops, cavitations and drag forces experienced within the system.

Lastly, I will calculate the force from the water pressure exerted on the blind flange shown in the figure and the orientation/location of the force.

Calculations: part a - water height of channel, y

first, convert Q from GPM to ft^3/s

$$Q = 75 \text{ GPM} \left(\frac{1 \text{ ft}^3/\text{s}}{449 \text{ GPM}} \right) = \underline{0.16704 \text{ ft}^3/\text{s}}$$

Equation for Normal discharge:

$$\frac{nQ}{\sqrt{s}} = A(R)^{2/3} \quad \text{where } s = 0.1\% \text{ or } \underline{0.001}$$

Plug-in Values:

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$$\frac{(0.017)(0.16704 \text{ ft}^3/\text{s})}{\sqrt{0.001}} = A \cdot R^{2/3}$$

$$0.089797 = A \cdot R^{2/3}$$

Width @ Top of channel, $W = b + 2 \cdot z \cdot y$, where $z = 0.577$

$$W = 2.309 y$$

$$\therefore b + 2(0.577)y = 2.309 y$$

$$\therefore b = 2(0.577)y$$

$$b = 1.155 y \rightarrow \text{eq \#1}$$

$$A_{\text{Trapz}} = (b + zy)y \rightarrow \text{plug-in eq \#1}$$

$$= (1.155y + 0.577y)y$$

$$A_{\text{Trapz}} = 1.732 y^2$$

$$R_{\text{Trap-z}} = \frac{(b + zy)y}{b + 2y\sqrt{1+y^2}} \rightarrow \text{plug-in eq \#1}$$

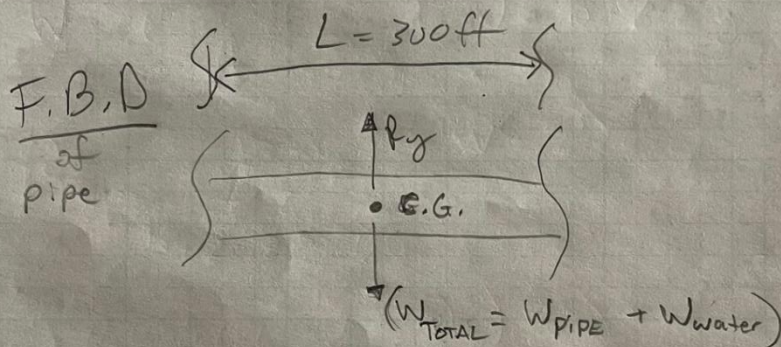
$$R_{\text{Trap-z}} = \frac{1.732 y^2}{1.155y + 2y\sqrt{1+y^2}} = \frac{1.732 y}{1.155 + 2\sqrt{1+y^2}}$$

$y \approx 0.387245$ ft. (solved using attached excel file)

Ps. 5

(a)

(b) Calculate total forces in x and y direction of pipe system.



$$W_{pipe} = \rho_{steel} \cdot V_{pipe}$$

$$\rho_{steel} = 490 \text{ lb/ft}^3$$

$$V_{pipe} = \frac{\pi H (0.1583^2 - 0.1342^2)}{4}$$

$$W_{pipe} = 490 \text{ lb/ft}^3 \left(\frac{\pi (300 \text{ ft}) (0.00706 \text{ ft}^2)}{4} \right)$$

$$\underline{W_{pipe} = 815.08 \text{ lbs}}$$

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$$W_{\text{water}} = \rho_{\text{water}} \cdot V_{\text{inner diameter}} \quad (\text{inside of pipe})$$

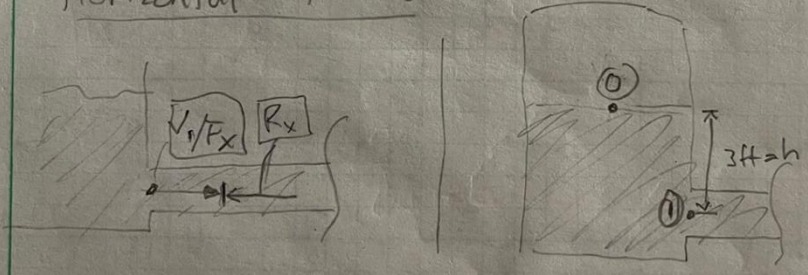
$$W_{\text{water}} = (62.41 \text{ lb/ft}^3) \left(\frac{\pi (0.1342 \text{ ft}^2) (300 \text{ ft})}{4} \right)$$

$$W_{\text{water}} = 1973.66 \text{ lbs.}$$

$$\therefore W_{\text{TOTAL}} = (815.08 \text{ lbs} + 1973.66 \text{ lbs})$$

$$W_{\text{TOTAL}} = 2788.74 \text{ lbs} (\downarrow) - \text{Vertical forces}$$

Horizontal Forces



First, find V_1 using bernoulli's eq'n:

$$\frac{P_0}{\rho} + z_0 + \frac{V_0^2}{2g} = \frac{P_1}{\rho} + z_1 + \frac{V_1^2}{2g} + h_L$$

$$(z_0 - z_1) = \frac{V_1^2}{2g} + K_{\text{inlet}} \left(\frac{V_1^2}{2g} \right)$$

Using $K=0.5$ for square edged inlet.

(Ps. 7)

$$\frac{V_1^2}{2g} + 0.5 \frac{V_1^2}{2g} = h$$

$$\sqrt{\left(\frac{1.5 V_1^2}{2g} = h\right) 2g}$$

$$V_1 = \sqrt{\frac{4}{3}gh}$$

$$V_1 = \sqrt{\frac{4}{3}(32.174 \text{ ft/s}^2)(3 \text{ ft})}$$

$$V_1 = 11.344 \text{ ft/s}$$

Now, Q @ exit of pipe = $0.16704 \text{ ft}^3/\text{s}$

$$Q_{\text{exit}} = A_{\text{pipe}} V_{\text{exit}}(2)$$

$$\therefore 0.16704 \text{ ft}^3/\text{s} = \pi \left(\frac{0.1342 \text{ ft}}{2}\right)^2 V_2$$

$$V_2 = 10.548 \text{ ft/s}$$

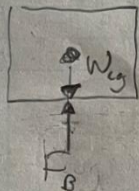
Forces in x-direction, $F_x = \rho_{\text{water}} Q (V_2 - V_1)$

$$F_x = (1.94 \text{ lb} \cdot \text{s}^2/\text{ft}^4)(0.16704 \text{ ft}^3/\text{s})(10.548 \text{ ft/s} - 11.344 \text{ ft/s})$$

$$F_x = -0.258 \text{ lbs (negative indicates opposite direction)}$$

c) Largest hickory wood log possible (P5.8)

FB D: Cross-section view
log



Assuming that the log will barely float,
then $W_{log} = F_B$

$$W_{log} = \gamma_{hickory} \cdot V_{log} \quad // \quad F_B = \gamma_{water} \cdot V_{displaced}$$

$$\therefore \gamma_{hickory} \cdot V_{log} = \gamma_{water} \cdot V_{displaced}$$

$$\gamma_{hickory} = \rho_{hickory} (g)$$

$$= 830 \text{ kg/m}^3 (9.81 \text{ m/s}^2)$$

$$\gamma_{hickory} = 8147.3 \text{ N/m}^3 \left(\frac{0.00636588 \text{ lb/ft}^3}{1 \text{ N/m}^3} \right)$$

$$\underline{\gamma_{hickory} = 51.833 \text{ lbf/ft}^3}$$

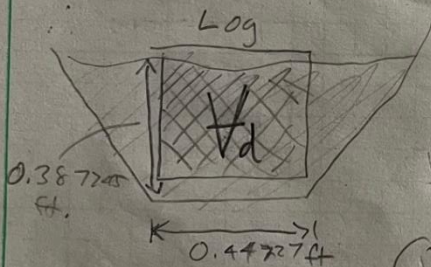
$$V_{log} = V_{displaced} \left(\frac{62.41 \text{ lb/ft}^3}{57.833 \text{ lb/ft}^3} \right)$$

PS-9

$$V_{log} = V_{displaced} (1.204)$$

So, the total volume of the log must be approx. 1.204 times the total volume displaced.

Now, we know that the water depth, y
 $= 0.387245$ ft and width at the
 bottom, $b = 1.155(y) = 0.44727$ ft



First, we will set the
 $h_{submerged} = 0.387245$ ft

$$(b \cdot h \cdot l)_{TOTAL (Log)} = (b \cdot h \cdot l)_{submerged} \times 1.204$$

$$\begin{aligned} b_{TOTAL} &= b_{sub} \\ l_{TOTAL} &= l_{sub} \\ h_{TOTAL} &\neq h_{sub} \end{aligned}$$

Pg 10

Plug in Values:

$$\cancel{b_T} \cdot \cancel{h_T} \cdot \cancel{A_T} = \cancel{b_S} \cdot h_S \cdot \cancel{A_S} \cdot 1.204$$

$$h_{TOTAL} = 1.204 (0.387245 \text{ ft})$$

$$\underline{h_{TOTAL} = 0.4662 \text{ ft}}$$

However, since cross-section is square
then $\underline{b_{TOTAL}}$ also = 0.4662 ft. since $b_{LOG} > b_{channel}$.

This is too large.

So, we instead will use $b = h = 0.44727 \text{ ft}$
and check to make sure that the total $h_{submerged} < 0.387 \text{ ft}$

$$(0.44727 \text{ ft})^2 = (0.44727 \text{ ft}) 1.204 \cdot h_S$$

$$\therefore \underline{h_S = 0.3715 \text{ ft}}$$

∴ the theoretical largest Cross-sectional Area
of log is $\underline{0.44727 \text{ ft} \times 0.44727 \text{ ft}}$

ds Pressure drop across flow nozzle

(Pg. 11)

Given: $\beta = 0.50 \left(\frac{d}{D} \right)_{ratio} = \left(0.50 = \frac{D_2}{D_1} \right)^{-1}$

$\therefore \frac{D_1}{D_2} = 2.0$

Using Table 10.3A for resistance coefficient, K ,

@ $\frac{D_1}{D_2} = 2$ and $v = 10.548 \text{ ft/s}$.

Interpolate for, K : $\frac{15 - 10}{10.548 - 10} = \frac{0.34 - 0.36}{K - 0.36}$

$h_{L_{flow \text{ nozzle}}} = K \left(\frac{v^2}{2g} \right)$

$9.1241(K - 0.36) = -0.02$

$9.1241K - 0.32847 = -0.02$
 $+0.32847$

$h_{L_{flow}} = 0.3578 \left(\frac{10.548^2}{2(32.174)} \right)$

$9.1241K = 3.2647$

9.1241

$h_{L(FN)} = 0.05865 \text{ ft}$

$K = 0.3578$

Now, $\Delta P_{(across \text{ nozzle})} = \gamma_{water} \cdot h_L$

$\Delta P = 62.41 \text{ lb/ft}^3 (0.05865 \text{ ft})$

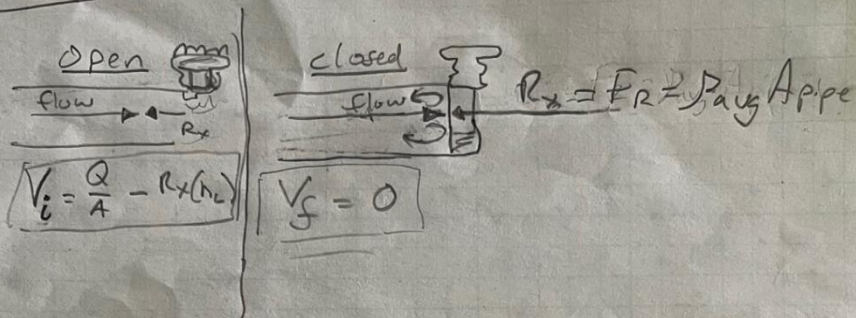
$\Delta P = 3.66 \text{ lb/ft}^2 \left(\frac{0.0069444 \text{ psi}}{1 \text{ lb/ft}^2} \right)$

$\Delta P = 0.02542 \text{ psi}$

e) Pressure change due to sudden closure of globe valve.

(pg. 12)

FRD's:



Calculate the forces felt against the globe valve after sudden closure:

$$F_x = \Delta P Q (V_f - V_i) = F_R = P_{avg} A_{pipe}$$

$$F_R = P_{avg} A_{pipe} = 62.41 \text{ lb/ft}^3 \cdot P_{avg} = P_{avg} \left(\frac{10 \text{ pipe}}{2} \right)$$

∴ Solve for change in ΔP

$$\Delta P = \frac{P_{avg} \cdot A_{pipe}}{Q(V_f - V_i)} = \frac{(1.94 \text{ slug/ft}^3) \left(\frac{0.1342 \text{ ft}}{2} \right) \left(\pi \left(\frac{0.1342 \text{ ft}}{2} \right)^2 \right)}{(0.16704 \text{ ft}^3/\text{s}) (10 - 10.548 \text{ ft/s})}$$

$$\Delta P = \frac{4.18771 \text{ slug/ft}^2 (0.0141447 \text{ ft}^2)}{-1.76194 \text{ ft}^3/\text{s}^2}$$

$$\Delta P = \left(\frac{0.00184 \text{ slug/ft}^2}{-1.76194 \text{ (lb/ft}^2\text{)}} \right)^{-1} = -956.91 \text{ lb/ft}^2 \left(\frac{0.0069444}{1 \text{ lb/ft}^2} \right)$$

$$\Delta P = -6.646 \text{ psi}$$

(Pg. 13)

Because there is a sudden decrease
in velocity of the fluid from
 V_c to $V_g = 0$, there must be a

Corresponding decrease to pressure felt immediately
at the valve to satisfy Bernoulli's equation.
This sudden drop in pressure leads to
a cavitation effect felt immediately in the
area of the valve.

(F) Drag force on half-sized hickory log

(pg. 14)

First, Determine the cross-sectional area of the largest possible log, A_{max} .

$$A_{max} = (0.44727 \text{ ft} \times 0.44727 \text{ ft}) = b \times h$$

$$A_{max} = 0.20005 \text{ ft}^2$$

Now, find $A_{\frac{1}{2}max}$:

$$\frac{A_{max}}{2} = \underline{\underline{0.100025 \text{ ft}^2}}$$

Using table 17.1, "Typical Drag Coefficients"

Rectangular plate with $\frac{a}{b} \text{ ratio} = \frac{b}{h} = \underline{\underline{1}}$

$$\boxed{C_D = 1.16}$$

Density of water, $\rho_{water} = \underline{\underline{1.94 \text{ slugs/ft}^3}}$

Eg'n for Drag force, $F_D = C_D \left(\frac{\rho_w \cdot v_{stream}^2}{2} \right) A_{\frac{1}{2}max}$

All that is left to determine is the velocity of the stream, $v_{stream(s)}$;

Using the given value for necessary flow rate, Q
 $Q = 75 \text{ GPM} // 0.16704 \text{ ft}^3/\text{s}$

There are multiple ways to find the velocity of the stream in the open-channel system. We can either use the slope (0.1%) and solve for change in KE over a set distance or we can use the slope, s , hydraulic Radius, R of open channel without the log and solve for v_s using $Q = Av_s$ manipulation — we'll use this method.

$Q = Av_s = \left(\frac{1.49}{n} \right) R^{2/3} s^{1/2}$

$\therefore v_{stream(s)} = \left(\frac{1.49}{n} \right) R^{2/3} s^{1/2}$ (Derivation of Manning's Eq'n)

$n = 0.017 \text{ (unfinishe concrete)}$

Pg. 16

$$R_{\text{open channel}} = \frac{(b + 0.577y)y}{b + 2y\sqrt{1 + 0.577^2}}$$

$$\begin{aligned} R_{\text{open channel}} &= \frac{(0.44727 \text{ ft} + 0.577(0.387245))0.387245}{0.44727 \text{ ft} + 2(0.387245)\sqrt{1 + 0.577^2}} \\ &= \frac{0.25973 \text{ ft}^2}{1.34144 \text{ ft}} \end{aligned}$$

$$R_{a.c.} = 0.19362 \text{ ft}$$

$$V_{\text{stream}} = \left(\frac{1.49}{0.017} \right) (0.19362)^{\frac{2}{3}} (0.001)^{\frac{1}{3}}$$

$$V_{\text{stream}} = (87.64706) / (0.0105836 \text{ ft/s})$$

$$V_{\text{stream}} = 0.92762 \text{ ft/s} \text{ (open-channel flow velocity)}$$

Now, calculate drag force, F_D :

$$F_D = C_D \left(\frac{\rho_{\text{water}} \cdot V_s^2}{2} \right) A_{\frac{\text{max}}{2}}$$

$$= (1.16) \left(\frac{1.94 \text{ slug/ft}^3 \cdot (0.92762 \text{ ft/s})^2}{2} \right) 0.100025 \text{ ft}^2$$

$$F_D = (1.16) \left(\frac{1.94 \text{ slug/ft}^3 \cdot 0.86048 \text{ ft}^2/\text{s}^2}{2} \right) 0.100025 \text{ ft}^2$$

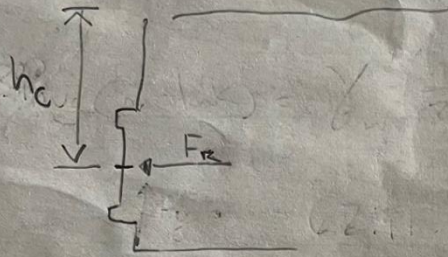
$$F_D = (1.16) (0.8346645 \text{ } \cancel{\text{lb}}/\cancel{\text{ft}^2}) (0.100025 \text{ ft}^2)$$

pg. 17

$$\boxed{F_D = 0.096845 \text{ lbs}} \quad \left(\begin{array}{l} \text{of force in drag resistance} \\ \text{on cross-section w/ Area} = \frac{1}{2} \text{ ft}^2_{\text{max}} \end{array} \right)$$

g) Compute forces acting on the blind flange. (Pg. 18)

$$\phi_{\text{flange}} \approx 1.61''$$



$$h_c = L_c \cdot \sin(90^\circ)$$

$$h_c = PL_c$$

$$h_c = \left(3\text{ft} - \frac{d}{2}\right) = 3\text{ft} - \frac{0.1342\text{ft}}{2} = 2.933\text{ft}$$

(below top surface)

$$F_{\text{resultant}}, F_R = \gamma \cdot h_c \cdot A_{\text{flange}}$$

$$F_R = (62.41 \text{ lb/ft}^3) \times (2.933\text{ft}) \times \left(\pi \left(\frac{0.1342\text{ft}}{2}\right)^2\right)$$

$$\underline{F_R = 2.589 \text{ lbs (acting on centroid of flange)}}$$