# CE 3372 Water Systems Design
## Fall 2016

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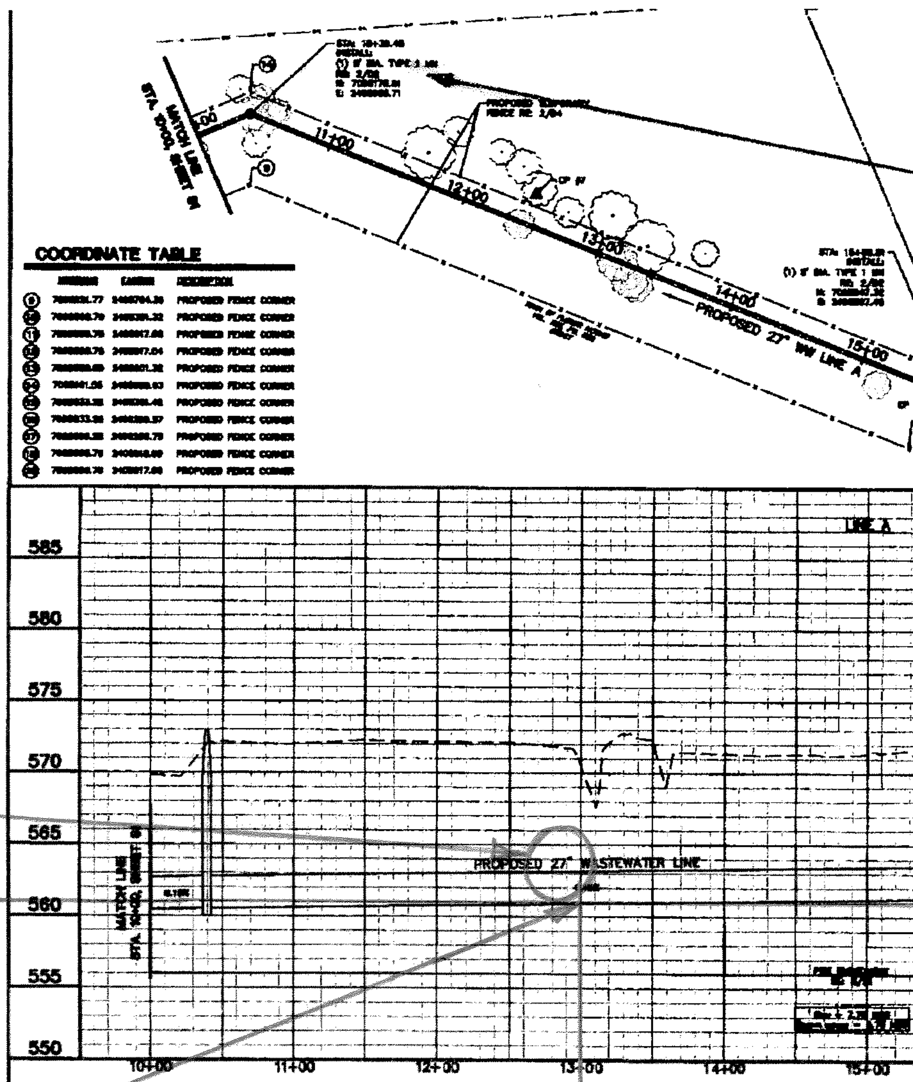
1. Figure 1 is a portion of an engineering drawing of a gravity-flow wastewater conduit.

561'




561'

Figure 1: Engineering drawing of sanitary sewer system

(a) What object is located at station 10+38.48? 5 Foot diameter, type 1 manhole (+1) (junction box also acceptable)

(b) What is the invert elevation of the pipe at station 13+00? 561 ft (+1)

(c) What is the diameter of the pipe in inches? 27 inches (+1)

(d) What direction is sewage intended to flow? RIGHT TO LEFT ← (+1)



5 PTS THIS PAGE

 Name: SOLUTION (+1)

2. Equation 1 is the Hazen-Williams discharge model for U.S. Customary units.

$$Q = 1.318\ A\ C_h\ R^{0.63}\ S^{0.54} \tag{1}$$

where;

$Q$ is the discharge in $ft^3/sec$;
$A$ is the cross section area of pipe in $ft^2$ ($A = \frac{\pi D^2}{4}$; $D$ is the pipe diameter.);
$C_h$ is the Hazen-Williams friction coefficient (depends on pipe roughness);
$R$ is the hydraulic radius in $ft$; and
$S$ is the slope of the energy grade line ($\frac{h_f}{L}$); $L$ is the length of pipe.

(a) Rearrange the equation in terms of head loss ($h_f = \ldots$).

$S = \frac{h_f}{L}$ (GIVEN) ; SUBSTITUTE INTO (1)

$$Q = 1.318\ A\ C_h\ R^{0.63} \left(\frac{h_f}{L}\right)^{0.54}$$ $\leftarrow$ EQN WITH SUBSTITUTION (+1)

$$\frac{Q\ L^{0.54}}{1.318\ A\ C_h\ R^{0.63}} = h_f^{0.54}$$ $\leftarrow$ EQN ISOLATING $h_f^{0.54}$ (+1)

$$\left(\frac{Q\ L^{0.54}}{1.318\ A\ C_h\ R^{0.63}}\right)^{\frac{1}{0.54}} = h_f$$ $\leftarrow$ EQN WITH $h_f = \ldots$ (+7)



10 pts this page

 Name: SOLUTION (+1)

(b) Estimate the head loss in a 12,000 foot length of 6-foot diameter, enamel coated steel pipe that carries carries 60$^o$F water at a discharge of 295 cubic-feet per second (cfs), using the Hazen-Williams head loss model. Use a Hazen-Williams loss coefficient of $C_h$ = 150. OK IF IMBED

$Q = 295 \ ft^3/s$ (+1) $\quad A = \frac{\pi (6)^2}{4} = 28.274 ft^2$ (+1) $\quad R = \frac{D}{4} = 1.5 ft$ (+1)

$$h_f = \left( \frac{Q \ L^{0.54}}{1.318 \ A \ C_h R^{0.63}} \right)^{\frac{1}{0.54}}$$

USE PRIOR RESULT (+1)
SUBSTITUTE IN VALUES

$$h_f = \left( \frac{295 (12,000)^{0.54}}{1.318(28.274)(150)(1.5)^{0.63}} \right)^{\frac{1}{0.54}} = \left( \frac{47052.195}{7216.579} \right)^{\frac{1}{0.54}}$$

ARITHMETIC (+3)

$$= (6.5200131)^{\frac{1}{0.54}} = 32.2 \ ft$$

(+2) # & UNITS

 10 pts this page 

 Name: SOLUTION (+1)

3. Equation 2 is an explicit formula (based on the Darcy-Weisbach head loss model and the Colebrook-White frictional loss equation)for estimating discharge from head loss and material properties.

$$Q = -2.22D^{5/2} \times \sqrt{gh_f/L} \times [log_{10}(\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{gh_f/L}})] \tag{2}$$

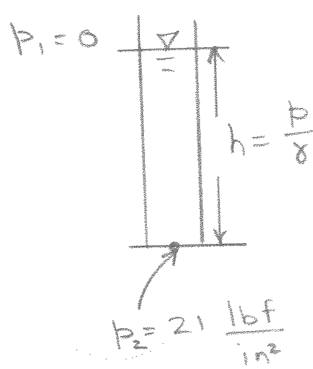
where;

$Q$ is the discharge in $L^3/T$;
$D$ is the pipe diameter;
$h_f$ is the head loss in the pipe;
$g$ is the gravitational acceleration constant;
$L$ is the length of pipe;
$k_s$ is the pipe roughness height;
$\nu$ is the kinematic viscosity of liquid in the pipe;

Water at 50$^o$F has kinematic viscosity of $1.45 \times 10^{-5}$ $ft^2/s$. The sand roughness of ductile iron is $8.5 \times 10^{-4}$ $ft$.

Determine:

(a) Depth of a column of water if the pressure at the bottom of the column is 21 psi?




(+1) Sketch

$\frac{\cancel{p_1}^{\,0}}{\gamma} + h = \frac{p_2}{\gamma}$

$\therefore h = \frac{p_2}{\gamma}$

NEED TO FIND h

$h = \frac{p}{\gamma}$ (+1) FORMULA

$p = \frac{21\ lbf}{in^2} \cdot \frac{144\ in^2}{1\ ft^2} = 3024\ lbf/ft^2$ (+1) PRESSURE CONVERT

$\gamma = 62.4\ lbf/ft^3$ (+1) SP. WEIGHT (OR $\rho g$)

(+1) UNITS

$\therefore h = \frac{3024\ lbf/ft^2}{62.4\ lbf/ft^3} = 48.46\ ft$ (+1) RESULT

(+1) ARITHMETIC



8pts. this page

(b) Estimate the discharge in the 3.2 mile long, 24-inch diameter, ductile iron pipeline connecting points A and B depicted in Figure 2. Point A is 28 feet higher in elevation than point B. The pressure at point B is 21 pounds per square-inch (psi) greater than the pressure at point A.

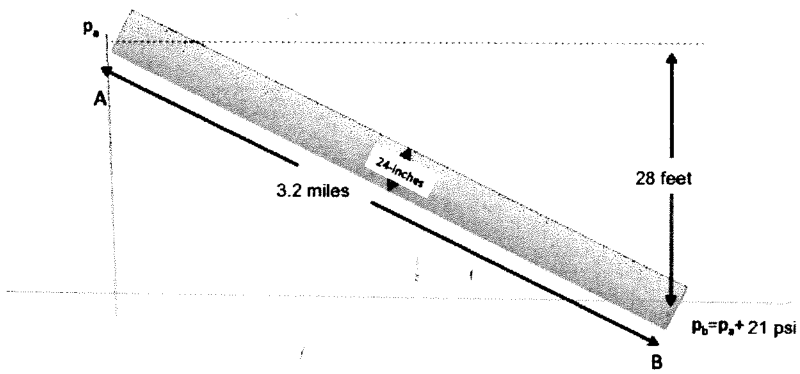



Figure 2: Pipeline Schematic

(+1) ENERGY

ENERGY

$$\frac{p_a}{\gamma} + \cancel{\frac{V_a^2}{2g}} + \underbrace{z_a}_{28\,ft} + \cancel{h_p} = \frac{p_b}{\gamma} + \cancel{\frac{V_b^2}{2g}} + \cancel{z_b} + \cancel{h_T} + h_L$$

$h_p$ = 0 No pump; $h_T$ = 0 No turbine; $z_b$ = 0 datum

$V_a = V_b$

(+1) CANCEL/NEGLECT TERMS WITH EXPLAIN

$$\frac{p_a}{\gamma} + z_a = \frac{p_b}{\gamma} + h_L$$

$$\frac{p_a - p_b}{\gamma} + z_a = h_L$$

BUT

$p_b = p_a + 21\,psi$ (+1) CANCEL $p_a$

$$\therefore \frac{\cancel{p_a} - (\cancel{p_a} + 21\,psi)}{\gamma} + z_a = h_L$$

$$z_a - \frac{21\,psi}{\gamma} = h_L$$

$$\frac{21\,psi}{\gamma} = 48.46\,ft$$

So $28\,ft - 48.46\,ft = -20.46\,ft = h_L$

→ MUST BE FLOWING FROM B → A

(+3) DIRECTION + VALUE

$\therefore h_L = 20.46\,ft$ (FLOWING UPHILL)

NOW APPLY JAIN EQUATION

$$Q = -2.22\, D^{5/2} \sqrt{g \frac{h_f}{L}} \left[\log_{10}\left(\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{g\frac{h_f}{L}}}\right)\right]$$

$D^{5/2} = (2)^{5/2} = 5.6568$  $D^{3/2} = (2)^{3/2} = 2.82843$

$\frac{k_s}{3.7D} = \frac{8.5 \cdot 10^{-4}}{3.7(2)} = 1.1486 \cdot 10^{-4}$  $1.78\nu = 1.78(1.45 \cdot 10^{-5}) = 2.581 \cdot 10^{-5}$

$$\sqrt{\frac{g h_f}{L}} = \sqrt{\frac{32.2(20.46)}{3.2(5280)}} = 0.1974644$$

$$\log_{10}\left(1.1486 \cdot 10^{-4} + 4.6212 \cdot 10^{-5}\right) = -3.793$$

$$Q = -2.22(5.6568)(0.1974644)(-3.793)$$ (+1) ARITHMETIC

$$= 9.4\,\frac{ft^3}{sec}$$ (+2) RESULT & UNITS



10 pts this page

 Name: SOLUTION (+1)

4. Figure 3 is an aerial image of a parallel pipeline system in California.

LEFT

$96in = 8ft$ ← JAIN EQN VALUES (+1)

USE JAIN EQN.

$D^{5/2} = (8)^{5/2} = 181.02$

$D^{3/2} = (8)^{3/2} = 22.62$

$\frac{k_s}{3.7D} = \frac{1.64 \cdot 10^{-4}}{3.7(8)} = 5.54 \cdot 10^{-6}$

$\frac{1.78\nu}{D^{3/2}} = \frac{1.78(1.45 \cdot 10^{-5})}{22.62} = 1.141 \cdot 10^{-6}$

$\frac{g h_f}{L} = \frac{32.2(100ft)}{5280} = 0.6098$

$\sqrt{0.6098} = 0.7809$

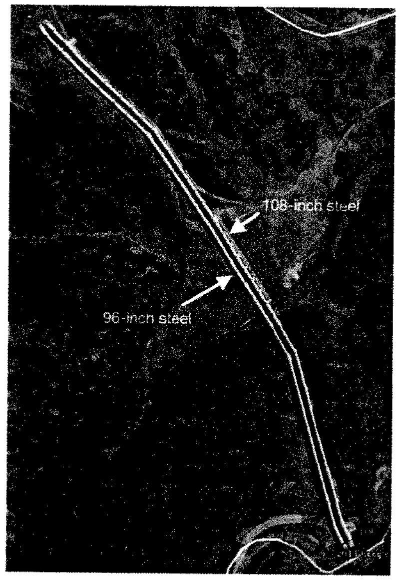



Figure 3: Parallel Pipeline System

RIGHT

$108in = 9ft.$ ← JAIN EQN VALUES (+1)

USE JAIN EQN.

$D^{5/2} = (9)^{5/2} = 243$

$D^{3/2} = (9)^{3/2} = 27$

$\frac{k_s}{3.7D} = \frac{1.64 \cdot 10^{-4}}{3.7(9)} = 4.9249 \cdot 10^{-6}$

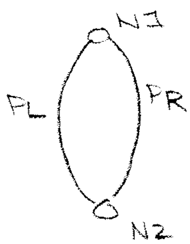
$\frac{1.78\nu}{D^{3/2}} = \frac{1.78(1.45 \cdot 10^{-5})}{27} = 9.559 \cdot 10^{-7}$

$\frac{g h_f}{L} = \frac{32.2(100ft)}{5280} = 0.6098$

$\sqrt{0.6098} = 0.7809$

The left pipeline is a 96-inch diameter steel pipe, whereas the right pipeline is a 108-inch diameter steel pipe. Water at 50$^o$F has kinematic viscosity of $1.45 \times 10^{-5}$ $ft^2/s$. The sand roughness of ductile iron is $1.64 \times 10^{-4}$ $ft$. If the head loss for the two one-mile long pipelines between the thrust blocks is 100 feet, determine the discharge in each pipe in cubic-feet-per-second.

PARALLEL PIPES ⇒ HEAD LOSS EITHER PATH IS SAME (100ft, GIVEN)




JAIN EQN: $Q = -2.22 D^{5/2} \sqrt{\frac{g h_f}{L}} \cdot \log_{10}\left[\frac{k_s}{3.7D} + \frac{1.78\nu}{D^{3/2}\sqrt{\frac{g h_f}{L}}}\right]$

(+1) EQUATION

LEFT:

ARITHMETIC + CONSTANTS (+3)

$Q_L = -2.22(181.02)(0.7809)\log_{10}\left(5.54 \cdot 10^{-6} + \frac{1.141 \cdot 10^{-6}}{(22.62)(0.7809)}\right)$

$= 1.6177 \cdot 10^3$

$= 1617.7$ cfs (+2) RESULT + UNITS

REVISION A

15 pts this problem (Pg 6 + 7)

Problem 3 (continued)

RIGHT

+3 ARITHMETIC + CONSTANTS

$$Q_R = -2.22(243)(0.7809)\log_{10}\left(4.9249\cdot 10^{-6} + \frac{9.5593\cdot 10^{-7}}{(27)(0.7809)}\right)$$

$$= 2.2108\cdot 10^{3}$$

$$= 2210.8 \text{ cfs}$$

+2 RESULT + UNITS

 Name: SOLUTION (+1)

Figure 4 is a pipe network with the following properties:

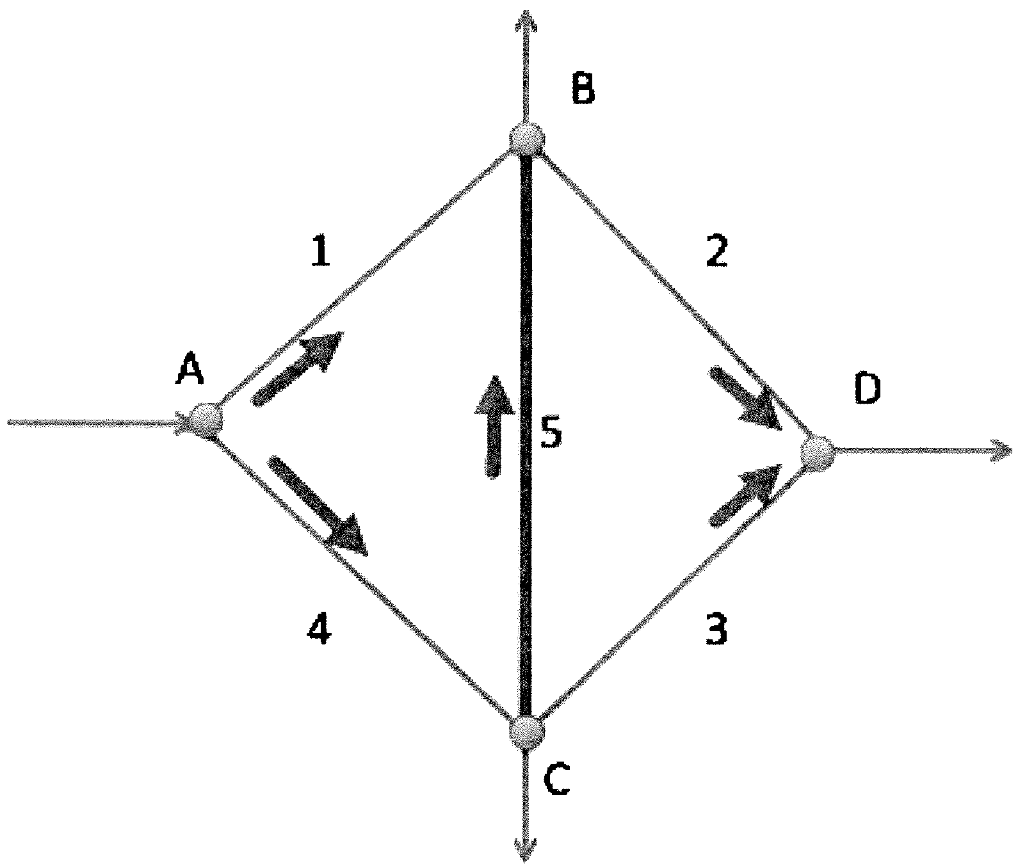



Figure 4: Pipe network

Table 1: Network properties for Figure 4

| Node | Demand (cfs) | Elevation(ft) |
|---|---|---|
| A | -0.60 | 0.00 |
| B | 0.15 | 0.00 |
| C | 0.15 | 0.00 |
| D | 0.30 | 0.00 |
| **Pipe** | **Length (ft)** | **Diameter (ft)** |
| 1 | 1000 | 3/12 |
| 2 | 1000 | 3/12 |
| 3 | 1000 | 3/12 |
| 4 | 1000 | 3/12 |
| 5 | 1400 | 3/12 |



1 PT. THIS PAGE

 Name: SOLUTION (+1)

5. Referring to Figure 4, the discharge in pipe 5 is closest to

   (A) 0.00 cfs, from Node B to Node C (+1)

   (B) 0.15 cfs, from Node C to Node B

   (C) 0.66 cfs, from Node C to Node B

   (D) 0.66 cfs, from Node B to Node C

6. Referring to Figure 4, if the demands at all nodes are those in Table 1, and pipe 2 is decreased to a diameter of 2/12, the discharge in pipe 5 is closest to

   (A) 0.00 cfs, from Node C to Node B

   (B) 0.15 cfs, from Node B to Node C (+2)

   (C) 0.30 cfs, from Node C to Node B

   (D) 0.60 cfs, from Node B to Node C

VISUALIZE PIPE 2 GONE.
THEN FLOW MUST BE DOWNWARD
SO HEAD LOSS $P_2 + P_3 = P_4$
(NODE A → C EITHER PATH)
FLOW MUST BE DOWN;
SO (A) & (C) NOT FEASIBLE
(D) HAS TOTAL FLOW INPUT WHICH
CANNOT BE TRUE
IF PIPE 4 ALIVE;
MUST BE (B)

7. Referring to Figure 4, assuming the average friction factor is 0.018, the head loss, in feet, from Node A to Node C (when all pipes are the same diameter) is closest to

   (A) 12 feet

   (B) 25 feet

   (C) 50 feet

   (D) 75 feet

$$h_L = \frac{8(0.018)(1000\,ft)(0.30\,cfs)^2}{\pi^2\,(32.2\,ft/s^2)\,(3/12\,ft)^5} = 41.75\,ft$$

(+2) (1 FOR SHOW WORK)

8. Referring to Figure 4, and Table 1 the flow distribution is:

   $Q_5 = 0$

   (A) $[Q_1,\ Q_2,\ Q_3,\ Q_4,\ Q_5\ ]$ =[0.30,0.15,0.15,0.30,0.00] CFS (+1)

   (B) $[Q_1,\ Q_2,\ Q_3,\ Q_4,\ Q_5\ ]$ =[0.30,0.15,0.15,0.30,0.30] CFS

   (C) $[Q_1,\ Q_2,\ Q_3,\ Q_4,\ Q_5\ ]$ =[0.30,0.15,0.15,0.00,0.50] CFS

   (D) $[Q_1,\ Q_2,\ Q_3,\ Q_4,\ Q_5\ ]$ =[0.30,-0.15,-0.15,0.30,-0.60] CFS

9. An EPANET model must have which of the following components to run

   (A) A pipe, a node, and a pump

   (B) A pipe, a node, and a valve

   (C) A pipe, a tank, and a pump

   (D) A pipe, a node, and a reservoir (+1)



8 PTS. THIS PAGE