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Analysis of water supply networks

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Water Supply Networks

- Urban water supply
- Water treatment plants
- Domestic pipe network

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Components of a water supply network

- Pipes
- Pumps
- Reservoirs and tanks
- Valves, bends, junctions etc.

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Water Supply System Analysis

- Continuity equation

  $A_1 V_1 = A_2 V_2$

- Energy equation

  $$z_1 + \frac{p_1}{\gamma} + \frac{V_1^2}{2g} + h_p = z_2 + \frac{p_2}{\gamma} + \frac{V_2^2}{2g} + h_L$$

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Roughness formulae

Darcy-Weisbach $h_L = f\frac{L}{D}\frac{V^2}{2g}$

Hazen-William $V = 0.85 C_H R^{0.63} S^{0.54}$

Manning $V = \frac{1}{n} R^{2/3} S^{1/2}$

Chezy $V = C\sqrt{RS}$

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Head Loss

$$h_L = KQ^x$$

Formula	***x* value**
Darcy-Weisbach	1.75-2.0
Hazen-William	1.85
Manning	2.0
Chezy	2.0

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Common methods to analyze pipe networks

- Hardy-Cross method

  Limitation: Pipe flows have to be assumed such that continuity requirement is met. Therefore suitable for small networks only.

- Linear method

  All the equations are solved simultaneously without requiring initial pipe flows. Therefore suitable for all types of networks.

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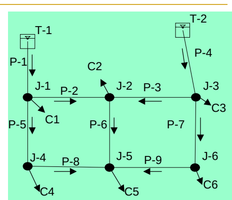
Pipe network

N_{eq}= Number of equations required
N_j= number of junction nodes
N_l= number of loops
N_f= number of Fixed Grade Nodes (e.g. elevated tanks)



$$N_{eq} = N_j + N_l + N_f - 1$$

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Hardy Cross Method

- The algebraic sum of the pressure drops around any closed loop must be zero
- The flow entering a junction must equal the flow leaving it.

$$Q = Q_a + \Delta$$

$Q =$ Actual flow rate
$Q_a =$ Assumed flow rate
$\Delta =$ Correction

$$\sum K(Q_a + \Delta)^x = 0$$

$$\sum KQ_a^x + \sum xK\Delta Q_a^{x-1} + \sum \frac{x-1}{2} xK\Delta^2 Q_a^{x-2} + \cdots = 0$$

$$\Delta = -\frac{\sum KQ_a^x}{\sum \left| xKQ_a^{x-1} \right|}$$

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Linear Method

- Continuity equations for all the nodes are written on the basis of assumed direction of flow
- Loop equations are written in the linear form

$$f(Q) = f(q) + \frac{\partial f}{\partial q}(Q - q)$$

q= flow rate from previous iteration
Q= unknown flow rate.

$$KQ^x = Kq^x + xKq^{x-1}(Q-q) = DQ + D'$$

$$D = xKq^{x-1} \qquad D' = (1-x)Kq^x$$

- Pump equation for the loops containing pumps

$$AQ^2 + BQ + H = Aq^2 + Bq + H + (2Aq + B)(Q - q) = EQ + E'$$
$$E = 2Aq + B \qquad E' = H - Aq^2$$

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Linear Method

- All the equations can be expressed in the form of matrices as follows:

$$[A][Q] = [C]$$

[A] is a coefficient matrix and [C] is a column matrix of constants. The unknown [Q] can be found as:

$$[Q] = [A]^{-1}[C]$$

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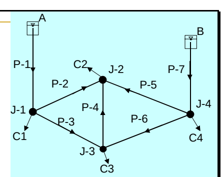
Example



$$Q_1 - Q_2 - Q_3 - C_1 = 0$$
$$Q_2 + Q_4 - Q_5 - C_2 = 0$$
$$Q_3 - Q_4 + Q_6 - C_3 = 0$$
$$-Q_5 - Q_6 + Q_7 - C_4 = 0$$

$$K_2Q_2^2 - K_3Q_3^2 - K_4Q_4^2 = 0$$
$$K_4Q_4^2 - K_5Q_5^2 + K_6Q_6^2 = 0$$
$$-K_1Q_1^2 - K_2Q_2^2 + K_5Q_5^2 + K_7Q_7^2 = z_B - z_A$$

$$D_2Q_2 - D_3Q_3 - D_4Q_4 = -D_2' + D_3' + D_4' = C_5$$
$$D_4Q_4 - D_5Q_5 + D_6Q_6 = -D_4' + D_5' - D_6' = C_6$$
$$-D_1Q_1 - D_2Q_2 + D_5Q_5 + D_7Q_7 = z_B - z_A + D_1' + D_2' - D_5' - D_7' = C_7$$

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Design of Water Supply System

- Pressure (240 to 410 kPa, Maximum: 650 kPa)
- Water demand (Based on population)
- Demand pattern (Due to usage variation)
- Fire demand (Based on type of construction)
- Storage facilities (For emergencies)

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Common software to analyze pipe networks

- **Public domain**
  - EPANET2 : www.epa.gov
- **Commercial**
  - WaterCAD : www.bentley.com
  - MIKE-NET : www.dhi.dk

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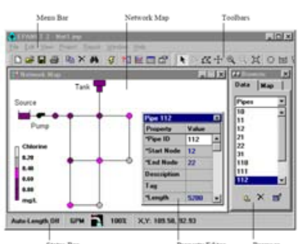
EPANET 2



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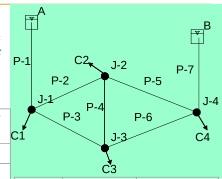
Example :

Determine the discharge in each line and the pressure at each junction for the pipe network shown. All the pipes are made of Galvanized iron.

Line	Nodes	Length (m)	Diameter (cm)
1	A-J1	300	30
2	J1-J2	250	20
3	J1-J3	200	20
4	J2-J3	220	15
5	J2-J4	180	20
6	J3-J4	250	20
7	J4-B	270	25



Node	Elevation(m)	Demand(L/s)
A	126	-
B	123	-
J1	96	56
J2	99	112
J3	93	28
J4	90	85

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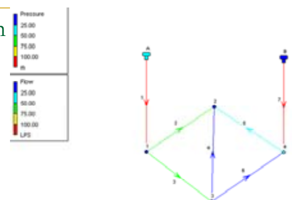
Solution



Network Table - Nodes

Node ID	Demand LPS	Head m
Junc 1	56.00	120.89
Junc 4	85.00	117.76
Junc 2	112.00	116.53
Junc 3	28.00	117.92
Tank A	-169.20	126.00
Tank B	-111.80	123.00

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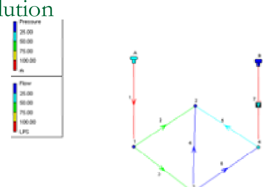
Solution



Network Table - Links

Link ID	Length m	Diameter mm	Roughness mm	Flow LPS	Velocity m/s	Unit Headloss m/km	Friction Factor
Pipe 1	300	300	0.15	169.20	2.39	17.04	0.018
Pipe 2	250	200	0.15	58.95	1.88	17.43	0.019
Pipe 3	200	200	0.15	54.25	1.73	14.82	0.020
Pipe 5	180	200	0.15	36.70	1.17	6.94	0.020
Pipe 6	250	200	0.15	9.90	0.32	0.56	0.023
Pipe 7	270	250	0.15	111.80	2.28	19.33	0.018
Pipe 4	220	150	0.15	16.35	0.93	6.33	0.022

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Design project

Given:

Elevations of all the nodes
Pipe properties
Population and per capita water use

Required:

Pipe flows
Pressure at all the nodes

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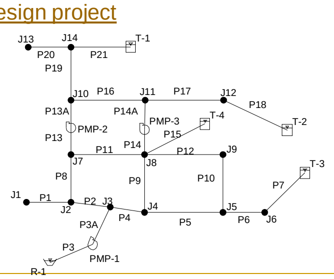
Design project



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Questions