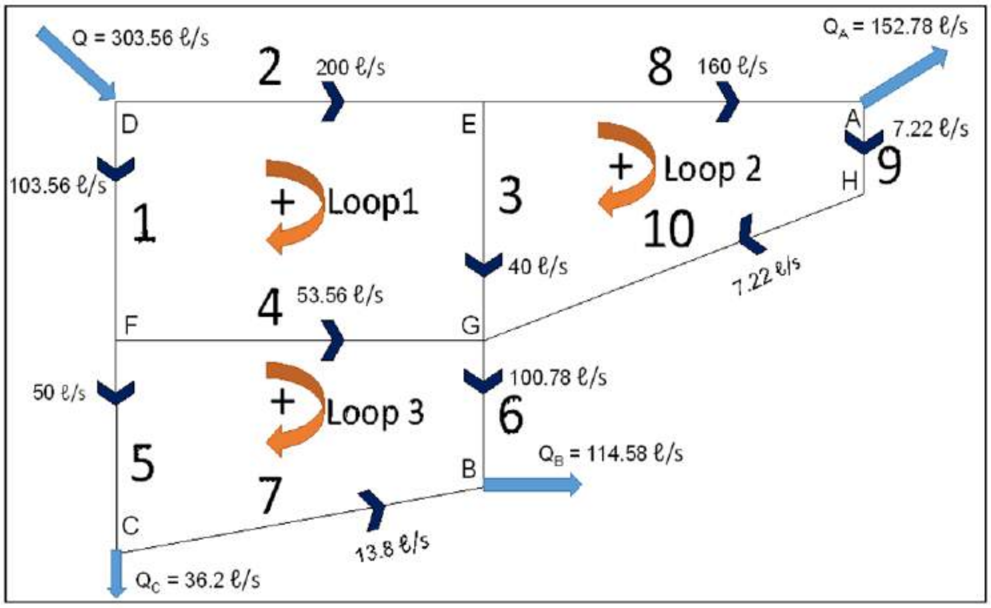
Example: Network Analysis by Hardy-Cross Method - With 3 LOOPS

appVersion(4) = "0.99.7739.40423" $t_0 := \text{time}(0)$

Assumed pipe flows also shown



Note:: Common Pipes
LOOP 1 has 2 coorections,
LOOP 2 has 1 correction.
LOOP 3 has 1 corrections

- LOOP1/P3 : with LOOP2 /P3 & LOOP1/P4 with LOOP3/P4.
- LOOP2//P3 with LOOP1/P3.
- LOOP3/P4 with LOOP1/P4.

$n_{13} = \Delta q2$ $n_{14} = \Delta q3$

$n_{21} = \Delta q1$

$n_{31} = \Delta q1$

Flows at Nodes

$$QJ := \begin{bmatrix} 303.56 \\ -152.78 \\ -114.58 \\ -36.2 \end{bmatrix} \frac{L}{s}$$

Continuity of the whole network. Sum of Nodal flows should be zero

$$\sum QJ = 0$$

Darcy-Weisbach 'n'

$n := 2$

Kinematic Viscosity of water

$$\nu := 1.13 \cdot 10^{-6} \frac{m^2}{s}$$

Flows in LOOPS should be balanced first to start with. Otherwise, will yield wrong answers

Assumed Flows for Continuity in LOOP 1

$$Q1 := \begin{bmatrix} -103.56 \\ 200 \\ 40 \\ -53.56 \end{bmatrix} \frac{L}{s} \quad \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \end{bmatrix}$$

Assumed Flows for Continuity in LOOP 2

$$Q2 := \begin{bmatrix} -40 \\ 160 \\ 7.22 \\ 7.22 \end{bmatrix} \frac{L}{s} \quad \begin{bmatrix} 3 \\ 8 \\ 9 \\ 10 \end{bmatrix}$$

Assumed Flows for Continuity in LOOP 3

$$Q3 := \begin{bmatrix} 53.56 \\ -50 \\ 100.78 \\ -13.8 \end{bmatrix} \frac{L}{s} \quad \begin{bmatrix} 4 \\ 5 \\ 6 \\ 7 \end{bmatrix}$$

Flows in LOOPS Sign Convention
1. Clockwise: +ve
2. Anticlockwise: -ve

Pipe no.	L(m)	D(m)	ks(m)
Bulk main	5000	0.65	0.00010
1	1000	0.40	0.00005
2	2000	0.45	0.00005
3	1000	0.30	0.00005
4	2000	0.30	0.00005
5	1000	0.40	0.00003
6	750	0.30	0.00003
7	2200	0.30	0.00003
8	2000	0.30	0.00003
9	500	0.25	0.00003
10	2200	0.25	0.00003

v= 1.13E-06 m^2/s

dq = -Σhf/(2Σ(hf/q))

Lengths LOOP 1 Dia. LOOP 1 Ks: LOOP 1

$$L1 := \begin{bmatrix} 1000 \\ 2000 \\ 1000 \\ 2000 \end{bmatrix} m \quad D1 := \begin{bmatrix} 0.4 \\ 0.45 \\ 0.30 \\ 0.30 \end{bmatrix} m \quad Ks1 := \begin{bmatrix} 0.00005 \\ 0.00005 \\ 0.00005 \\ 0.00005 \end{bmatrix} m$$

Lengths LOOP 2 Dia. LOOP 2 Ks: LOOP 2

$$L2 := \begin{bmatrix} 1000 \\ 2000 \\ 500 \\ 2200 \end{bmatrix} m \quad D2 := \begin{bmatrix} 0.3 \\ 0.3 \\ 0.25 \\ 0.25 \end{bmatrix} m \quad Ks2 := \begin{bmatrix} 0.00005 \\ 0.00003 \\ 0.00003 \\ 0.00003 \end{bmatrix} m$$

Lengths LOOP 3 Dia. LOOP 3 Ks: LOOP 3

$$L3 := \begin{bmatrix} 2000 \\ 1000 \\ 750 \\ 2200 \end{bmatrix} m \quad D3 := \begin{bmatrix} 0.3 \\ 0.4 \\ 0.3 \\ 0.3 \end{bmatrix} m \quad Ks3 := \begin{bmatrix} 0.00005 \\ 0.00003 \\ 0.00003 \\ 0.00003 \end{bmatrix} m$$

$$\lambda = 0.0055[1 + \left(\frac{20000ks}{D} + \frac{10^6}{Re}\right)^{\frac{1}{3}}]$$

$$h_f = \frac{8\lambda L Q^2}{\pi^2 g D^5}$$

Ks = Pipe's effective roughness height (m)
Ks/D = Relative roughness (number)

Calc_Param (q, L#, D#, ks#) :=

$$V\# := \overrightarrow{\left(\frac{q}{\frac{\pi}{4} \cdot D\#^2}\right)}$$ Pipe velocity

$$Re\# := \overrightarrow{\left|\left(\frac{V\# \cdot D\#}{\nu}\right)\right|}$$ Reynold number

$$\lambda := 0.0055 \cdot \overrightarrow{\left(1 + \left(2 \cdot 10^4 \cdot \frac{ks\#}{D\#} + \frac{10^6}{Re\#}\right)^{\frac{1}{3}}\right)}$$ Apprx. Colebrook Formula

$$h_f := \overrightarrow{\frac{8 \cdot \lambda \cdot L\# \cdot q \cdot |q|^{n-1}}{g_e \cdot (D\#)^5 \cdot \pi^2}}$$ Head loss

$$hf\_q := \overrightarrow{\left|\frac{h_f}{q}\right|}$$

$$dq := -\frac{\sum h_f}{n \cdot \left(\sum hf\_q\right)}$$ Correction to the LOOP

Loop 1 Correction: $Z1 := \overrightarrow{Calc\_Param([Q1],[L1],[D1],[Ks1])} = [-6.162]\ \frac{L}{s}$

Loop 2 Correction: $Z2 := \overrightarrow{Calc\_Param([Q2],[L2],[D2],[Ks2])} = [-55.3262]\ \frac{L}{s}$

Loop 3 Correction: $Z3 := \overrightarrow{Calc\_Param([Q3],[L3],[D3],[Ks3])} = [-25.3484]\ \frac{L}{s}$

PROGRAM 2: Calculates 'Corrected Flows' & 'Corrections' CALLS PROGRAM 1

Calc_All_Param (q1, q2, q3) :=

"Find first corrections for all 3 LOOPS"

$$\Delta q := \overrightarrow{Calc\_Param\left(\begin{bmatrix} q1 \\ q2 \\ q3 \end{bmatrix}, \begin{bmatrix} L1 \\ L2 \\ L3 \end{bmatrix}, \begin{bmatrix} D1 \\ D2 \\ D3 \end{bmatrix}, \begin{bmatrix} Ks1 \\ Ks2 \\ Ks3 \end{bmatrix}\right)}$$

"Apply first correction to all pipes in 3 LOOPS"

$$q1_{cor} := q1 + \Delta q_1$$

$$q2_{cor} := q2 + \Delta q_2$$

$$q3_{cor} := q3 + \Delta q_3$$

"LOOP1/Pipe3 gets 2nd correction from LOOP2 (Δq2)"

$$q1_{cor_3} := \left(q1_{cor_3} - \Delta q_2\right)$$

"LOOP1/Pipe4 gets 2nd correction from LOOP3 (Δq3)"

$$q1_{cor_4} := \left(q1_{cor_4} - \Delta q_3\right)$$

"LOOP2/Pipe1 gets 2nd correction from LOOP1 (Δq1)"

$$q2_{cor_1} := \left(q2_{cor_1} - \Delta q_1\right)$$

"LOOP3/Pipe1 gets 2nd correction from LOOP1 (Δq1)"

$$q3_{cor_1} := \left(q3_{cor_1} - \Delta q_1\right)$$

$$\begin{bmatrix} \begin{bmatrix} q1_{cor} \\ q2_{cor} \\ q3_{cor} \end{bmatrix} & \Delta q \end{bmatrix}$$

TRIAL 1

$Tr1 := Calc\_All\_Param(Q1, Q2, Q3)_1$

TRIAL 2

$Tr2 := Calc\_All\_Param\left(Tr1_1, Tr1_2, Tr1_3\right)_1$

TRIAL 3

$Tr3 := Calc\_All\_Param\left(Tr2_1, Tr2_2, Tr2_3\right)_1$

TRIAL 4

$Tr4 := Calc\_All\_Param\left(Tr3_1, Tr3_2, Tr3_3\right)_1$

$$Tr1 = \begin{bmatrix} \begin{bmatrix} -109.722 \\ 193.838 \\ 89.1643 \\ -34.3736 \end{bmatrix} \\ \begin{bmatrix} -89.1643 \\ 104.6738 \\ -48.1062 \\ -48.1062 \end{bmatrix} \\ \begin{bmatrix} 34.3736 \\ -75.3484 \\ 75.4316 \\ -39.1484 \end{bmatrix} \end{bmatrix} \frac{L}{s} \quad Tr2 = \begin{bmatrix} \begin{bmatrix} -133.903 \\ 169.657 \\ 62.201 \\ -54.7411 \end{bmatrix} \\ \begin{bmatrix} -62.201 \\ 107.456 \\ -45.324 \\ -45.324 \end{bmatrix} \\ \begin{bmatrix} 54.7411 \\ -79.1619 \\ 71.6181 \\ -42.9619 \end{bmatrix} \end{bmatrix} \frac{L}{s}$$

$$Tr3 = \begin{bmatrix} \begin{bmatrix} -135.2682 \\ 168.2918 \\ 63.5978 \\ -48.5462 \end{bmatrix} \\ \begin{bmatrix} -63.5978 \\ 104.694 \\ -48.086 \\ -48.086 \end{bmatrix} \\ \begin{bmatrix} 48.5462 \\ -86.7219 \\ 64.0581 \\ -50.5219 \end{bmatrix} \end{bmatrix} \frac{L}{s} \quad Tr4 = \begin{bmatrix} \begin{bmatrix} -139.2824 \\ 164.2776 \\ 59.8766 \\ -51.5065 \end{bmatrix} \\ \begin{bmatrix} -59.8766 \\ 104.401 \\ -48.379 \\ -48.379 \end{bmatrix} \\ \begin{bmatrix} 51.5065 \\ -87.7759 \\ 63.0041 \\ -51.5759 \end{bmatrix} \end{bmatrix} \frac{L}{s}$$

METHOD 2: Hardy Cross Method: For Any Given Number of Iterations

PROGRAM 3: Repeated Iteration Method. CALLS PROGRAM 2

```
Q(q1, q2, q3, iter) := | for j ∈ [1..iter]
                       |   | if j = 1
                       |   |   P_j := Calc_All_Param(q1, q2, q3)
                       |   | else
                       |   |   P_j := Calc_All_Param((P_{j-1})_1_1, (P_{j-1})_1_2, (P_{j-1})_1_3)
                       | P_iter
```

Using 10 iterations - PROGRAM 3

$Q_{10} := Q(Q1, Q2, Q3, 10)$

METHOD 3: Hardy Cross Method: Using While Loop

PROGRAM 4: Using 'While' loop :
CALLS PROHRAM 2

```
Z(q1, q2, q3) := | B := Calc_All_Param(q1, q2, q3)
                 | ΔQ := B_2
                 | qq1 := (B_1)_1
                 | qq2 := (B_1)_2
                 | qq3 := (B_1)_3
                 | Δ := 0.05 L/s
                 | while (|ΔQ_1| ≥ Δ) ∨ ((|ΔQ_2| ≥ Δ) ∨ (|ΔQ_3| ≥ Δ))
                 |   | B := Calc_All_Param(qq1, qq2, qq3)
                 |   | "---------------------------------"
```

Using "while" LOOP - PROGRAM 4
Accuracy 0.05 L/s

$Q_w := Z(Q1, Q2, Q3)$

```
"--------------------------------"
qq1 := B
        1
         1
qq2 := B
        1
         2
qq3 := B
        1
         3
ΔQ := B
        2
B
```

RESULTS

Using "while" LOOP - PROGRAM 4
Accuracy 0.05 L/s

$$Q_W = \left[\left[\begin{matrix} \begin{bmatrix} -141.2318 \\ 162.3282 \\ 58.5899 \\ -51.2061 \end{bmatrix} \\ \begin{bmatrix} -58.5899 \\ 103.7384 \\ -49.0416 \\ -49.0416 \end{bmatrix} \\ \begin{bmatrix} 51.2061 \\ -90.0257 \\ 60.7543 \\ -53.8257 \end{bmatrix} \end{matrix}\right] \begin{bmatrix} -0.0324 \\ -0.0066 \\ -0.0238 \end{bmatrix}\right] \frac{L}{s}$$

Compare

Using 10 iterations - PROGRAM 3

$$Q_{10} = \left[\left[\begin{matrix} \begin{bmatrix} -141.2318 \\ 162.3282 \\ 58.5899 \\ -51.2061 \end{bmatrix} \\ \begin{bmatrix} -58.5899 \\ 103.7384 \\ -49.0416 \\ -49.0416 \end{bmatrix} \\ \begin{bmatrix} 51.2061 \\ -90.0257 \\ 60.7543 \\ -53.8257 \end{bmatrix} \end{matrix}\right] \begin{bmatrix} -0.0324 \\ -0.0066 \\ -0.0238 \end{bmatrix}\right] \frac{L}{s}$$

$${Q_{10}}_1 = \left[\begin{matrix} \begin{bmatrix} -141.23 \\ 162.33 \\ 58.59 \\ -51.21 \end{bmatrix} \\ \begin{bmatrix} -58.59 \\ 103.74 \\ -49.04 \\ -49.04 \end{bmatrix} \\ \begin{bmatrix} 51.21 \\ -90.03 \\ 60.75 \\ -53.83 \end{bmatrix} \end{matrix}\right] \frac{L}{s}$$

Pipe numbers: [1, 2, 3, 4], [3, 8, 9, 10], [4, 5, 6, 7]

Note:: Common Pipes

LOOP 1 has 2 coorections.

LOOP 2 has 1 correction.,

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- LOOP1/P3 : with LOOP2 /P3 & LOOP1/P4 with LOOP3/P4.
- LOOP2//P3 with LOOP1/P3.
- LOOP3/P4 with LOOP1/P4.

$\mathrm{time}(0) - t_0 = 1.3\ s$

Link to Original Excel File

https://drive.google.com/file/d/0B29kBjmISsLMeEdCSVFHcHZBODQ/edit

Link to VIDEO Example

https://www.youtube.com/watch?app=desktop&v=M8f1FNgeq7o&ab_channel=TM%27sChannel