

# ANALYSIS OF HYDRAULIC NETWORK USING HARDY-CROSS METHOD AND EPANET

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## ABSTRACT

Water distribution network requires huge investments to be made and hence the network should serve its purpose. The analysis of complex hydraulic network is a time consuming and equally tedious task. Thus, analysis of illustrative four loop hydraulic network is carried out using Hardy Cross method using Hazen-William's equation. And then modelling the same hydraulic network in computer software EPANET. EPANET is a computer software that performs extended period simulation of hydraulic network and water quality behavior in pipes. The procedures developed for analysis in this paper have been explained and tested using a 2X2 illustrative four loop hydraulic network. It also compares between analytical solution by Hardy Cross method using Hazen-William's equation and analysis using computer software EPANET. This paper aims to develop a simple procedure for water distribution network analysis using Hardy Cross method. Analytical solution for four loop hydraulic network is obtained using electronic spreadsheets in MS-Excel.

**Keywords:** Analysis, EPANET, Hardy Cross method, Hazen-William equation, MS-Excel.

## I. INTRODUCTION

It is impossible to imagine life without water on earth. Humans require water for drinking, cooking, washing, sanitation, agriculture etc. Hence to provide these various uses, the supply of water should meet the demand of the user, and should be satisfactory in quality and adequate in quantity. Water should be readily available to users with adequate pressure and be relatively cheap. It is important to provide drinking or potable water to the end users; hence, implementation of effective water supply is important in designing a new hydraulic network or in expanding the existing one. Computation of flows and pressures in a complex network has been of great challenge and interest for people involved with design, construction and maintenance of public water distribution systems. Analysis and design of pipe networks create a relatively complex problem, especially if the network consists of range of pipes as frequently occurs in water distribution systems. The primary task for water utilities is to deliver water of the required quantity to individual customers under sufficient pressure through a distribution network. This paper aims to develop a simple procedure for analysis of water distribution network using hardy cross method with the help of electronic spreadsheets and EPANET.

## II. OBJECTIVE OF STUDY

Keeping in view the literature, following objectives is planned.

- i. To study the hydraulic network of four loops using hardy cross method.
- ii. To analyze hydraulic network of four loops by using EPANET software.
- iii. To check the discharge and pressure head in looped network

### 2.1 Hazen-Williams Formula

Hazen-Williams equation is the most widely used empirical equation that can be expressed as:

$$V = 0.85C_H R^{0.63} S^{0.54} \quad (2.1)$$

Where,  $C_H$  = Hazen-Williams coefficient of pipe  $S$  = slope of hydraulic gradient line (m/m), which is equal to the ratio of head loss to pipe length. The value of  $C_H$  for the cast iron pipe for design purposes is 100 (Manual, 1999).

Substituting,  $V = 4Q/(\pi D^2)$ ,  $C_H = 100$ ,  $R = D/4$  and  $S = hf/L$  in Eq. (2.20) and after some algebraic manipulations, one can obtain Equations.

$$h_f = \frac{10.68LQ^{1.852}}{C_H^{1.852}D^{4.87}} \quad (2.2)$$

$$h_f = K_i Q_i^{1.85} \quad (2.3)$$

Where,  $K$  = Resistance coefficient of a pipe and given by:

$$K = \frac{10.68L_i}{C_H^{1.852}D^{4.87}} \quad (2.4)$$

The Hazen Williams formula expressed in the forms of above equations can be used to compute the loss of head in a pipe flowing under pressure.

### 2.2 Methods of balancing heads

- i. Assume the clockwise flows as positive and counter clockwise flows as negative; and
- ii. Assign positive sign to the head losses for flows towards the junction and negative sign to those away from the junction.

The procedure, for the looped network analysis using hardy cross method of balancing head as follows:

1. Number all the nodes and pipe links. Also the number of loops. Adopt a sign convention that a pipe discharge is positive if it flows from a lower node number to a higher node number, otherwise negative. Apply nodal continuity equation at all nodes to obtain initial pipe discharges.
2. Obtain discharge in other pipes Repeat the procedure until all the pipe flows are known. Compute corresponding  $K$  using equation 2.4
3. Assume the loop pipe flow sign convention to apply loop discharges corrections;
4. Take the value of  $C_H$  from table 1;
5. Calculate  $\Delta Q$  for the existing pipe flows using equation and apply pipe corrections algebraically.

Apply the similar procedure in all the loops of a pipe network. Repeat step 5 until the discharge corrections in all the loops are relatively very small i.e. within allowable limits of  $\pm 2\%$  or the sum of the head losses in a closed loops relatively very small i.e. within allowable limit of  $\pm 0.150m$ . When the corrections are less than allowable limits, the assumed flows are correct, and iterations are terminated.

### 2.3 Steps for analysis using EPANET

1. Draw a network representation of your distribution system.
2. Edit the properties of the objects that make up the system.

3. Describe how the system is operated.
4. Select a set of analysis options.
5. Run a hydraulic/water quality analysis.
6. View the results of the analysis

2.4 Analysis of hydraulic network

The hydraulic network contains single source and Four loops is given in Fig. 1. In this network pipe 4 is common to loops I and II, pipe 6 is common to loops I and III, pipe 7 is common to loops II and IV, pipe 9 is common to loops III and IV. The corrections in discharges  $\Delta Q_1, \Delta Q_2, \Delta Q_3, \Delta Q_4$  are applied to find discharge in the pipe. Yje required data for the analysis of the hydraulic network containing flow and resistance for pipes are given in Table 1.

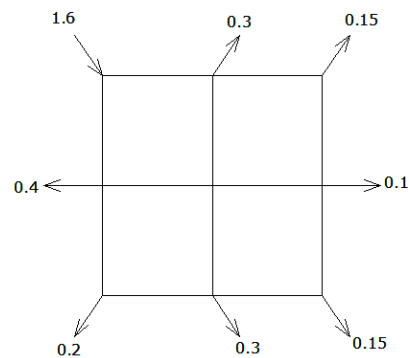
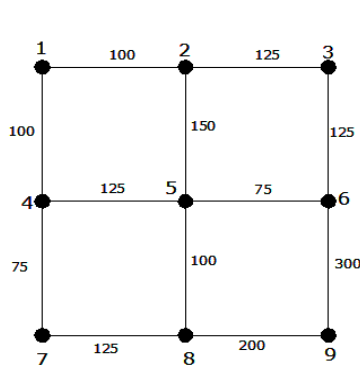


Fig 1: Four loop Example with Length in (m)      Fig 2: Four loop Example with demands in (m<sup>3</sup>/s)

2.5 Analysis of hydraulic Network using HCM

The step by step procedure for the analysis of hydraulic network using HCM is as follows:

- Step 1: Assume the flow and direction in all pipes such that continuity equation gets satisfied at all the junctions;
- Step 2: Use the sign convention for flow to apply the discharge correction;
- Step 3: Calculate the value of K; assume (d=0.4m)
- Step 4: Calculate hf for each pipe using the equation (2.3); and find  $\sum hf$  for loop I (for pipe 1)
- Step 5: Calculate the  $\Delta Q$  for network and apply correction algebraically using the equation for loop I
- Step 6: Apply the similar procedure for all the pipes in a loop and all the loop in a network. Repeat the Step 4 and Step 5 until the head corrections in all the loops are relatively very small (within the allowable limits of  $\pm 150$  m), and the assumed flows are correct. The relevant calculations required for iteration 1 for the hydraulic network 1 are given in Table 2.

Table 1. Flow and length of pipes for hydraulic network

| Node | Nodal flow (q) m <sup>3</sup> /s | Pipe | Length (m) | Flow Q m <sup>3</sup> /s |
|------|----------------------------------|------|------------|--------------------------|
| 1    | -1.60                            | 1-2  | 100        | 0.70                     |
| 2    | +0.3                             | 2-3  | 125        | 0.20                     |
| 3    | +0.15                            | 1-4  | 100        | 0.90                     |
| 4    | +0.4                             | 2-5  | 150        | 0.20                     |
| 5    | 0                                | 3-6  | 125        | 0.05                     |
| 6    | +0.10                            | 4-5  | 125        | 0.25                     |
| 7    | +0.20                            | 5-6  | 75         | 0.10                     |
| 8    | +0.30                            | 4-7  | 75         | 0.25                     |
| 9    | +0.15                            | 5-8  | 100        | 0.35                     |
| 10   | -                                | 6-9  | 300        | 0.05                     |
| 11   | -                                | 7-8  | 125        | 0.05                     |
| 12   | -                                | 8-9  | 200        | 0.10                     |

$${}_1\Delta Q = \frac{\sum K * Q^{1.852}}{1.85 \sum K * Q^{0.852}}$$

$${}_1\Delta Q = 0.0729$$

For common pipe, corrected flow in loop I, is:

$${}_1Q_2 = \text{Assumed flow} + {}_1\Delta Q - {}_1\Delta Q_2$$

### III. RESULTS AND DISCUSSIONS

Table 2 shows the results of analysis of four loop hydraulic network analysed using Hardy Cross Method. In this method, the permissible results were obtained in 4 th iteration fulfilling the criteria  $\sum H_L \leq 0.150\text{m}$ ; the acceptable results were obtained in 10th iteration fulfilling the criteria  $\sum H_L \leq 0.0001\text{m}$ . The variations in head loss with iterations loops 1 to 4 are shown in the figures 3 to figure 6 which indicates that the sum of head loss varies from negative values to positive values and finally arrives at acceptable limits after 10th iteration

#### 3.1 Junction Report

Four loop hydraulic network consists of nine junctions. The results for four loop illustrative problem is obtained using EPANET software. The pressure is determined using Hazen-Williams approach. For elevation of Tank equals to 15 meters no junctions out of nine junctions show negative pressure-head. The negative pressure head means that hydraulic gradient line lies below the supply level. This problem can be overcome by increasing the diameter of supply pipes or by providing booster pumps. Other junctions show fluctuation in the pressure head.

#### 3.2 Pipe Report

Four loop hydraulic network consists of 12 pipes. Following are some of the findings of the study. The error between the actual flow and flow computed using EPANET software is compared. The actual flow is nearly equal to flow obtained using EPANET. Head loss computed using EPANET is nearly equal to actual head loss.

Table 2. Showing relevant calculations required for iteration 1

| Iteration 1 |      |      |      |                      |       |                    |                         |         |         |              |
|-------------|------|------|------|----------------------|-------|--------------------|-------------------------|---------|---------|--------------|
| Loop        | Pipe | D(m) | L(m) | Q(m <sup>3</sup> /s) | K     | KQ <sup>1.85</sup> | 1.85KQ <sup>0.852</sup> | ΔQ      | Qc      | %EQ          |
| 1           | 1-2  | 0.4  | 100  | 0.7                  | 18.30 | 9.454              | 24.988                  | 0.0729  | 0.7729  | -10.416      |
|             | 2-5  | 0.4  | 150  | 0.2                  | 27.45 | 1.393              | 12.890                  | 0.0618  | 0.2618  | -30.945      |
|             | 5-4  | 0.4  | 125  | -0.25                | 22.87 | -1.755             | 12.991                  | 0.1581  | -0.0918 | 63.253       |
|             | 4-1  | 0.4  | 100  | -0.9                 | 18.30 | -15.05             | 30.954                  | 0.0729  | -0.8270 | 8.101        |
|             |      |      |      |                      |       | -5.966             | 81.825                  | 0.0729  |         |              |
| Loop        | Pipe | D(m) | L(m) | Q(m <sup>3</sup> /s) | K     | KQ <sup>1.85</sup> | 1.85KQ <sup>0.852</sup> | ΔQ      | Qc      | %EQ          |
| 2           | 2-3  | 0.4  | 125  | 0.2                  | 22.87 | 1.161              | 10.742                  | 0.011   | 0.211   | -5.510       |
|             | 3-6  | 0.4  | 125  | 0.05                 | 22.87 | 0.089              | 3.297                   | 0.011   | 0.061   | -22.043      |
|             | 6-5  | 0.4  | 75   | -0.1                 | 13.72 | -0.193             | 3.570                   | -0.067  | -0.167  | -67.225      |
|             | 5-2  | 0.4  | 150  | -0.2                 | 27.45 | -1.393             | 12.890                  | 0.096   | -0.103  | 48.121       |
|             |      |      |      |                      |       | -0.336             | 30.501                  | 0.011   |         |              |
| Loop        | Pipe | D(m) | L(m) | Q(m <sup>3</sup> /s) | K     | KQ <sup>1.85</sup> | 1.85KQ <sup>0.852</sup> | ΔQ      | Qc      | %EQ          |
| 3           | 4-5  | 0.4  | 125  | 0.25                 | 22.87 | 1.755              | 12.991                  | -0.1581 | 0.091   | 63.25        |
|             | 5-8  | 0.4  | 100  | 0.35                 | 18.30 | 2.619              | 13.843                  | -0.1634 | 0.186   | 46.70        |
|             | 8-7  | 0.4  | 125  | -0.05                | 22.87 | -0.089             | 3.297                   | -0.0852 | -0.135  | -170.44      |
|             | 7-4  | 0.4  | 75   | -0.25                | 13.72 | -1.053             | 7.795                   | -0.0852 | -0.335  | -34.088      |
|             |      |      |      |                      |       | 3.232              | 37.927                  | -0.085  |         |              |
| Loop        | Pipe | D(m) | L(m) | Q(m <sup>3</sup> /s) | K     | KQ <sup>1.85</sup> | 1.85KQ <sup>0.852</sup> | ΔQ      | Qc      | %EQ          |
| 4           | 5-6  | 0.4  | 75   | 0.1                  | 13.72 | 0.193              | 3.570                   | 0.0672  | 0.167   | -67.225      |
|             | 6-9  | 0.4  | 300  | 0.05                 | 54.91 | 0.213              | 7.913                   | 0.0782  | 0.128   | -<br>156.494 |
|             | 9-8  | 0.4  | 200  | -0.1                 | 36.60 | -0.514             | 9.522                   | 0.0782  | -0.021  | 78.247       |
|             | 8-5  | 0.4  | 100  | -0.35                | 18.30 | -2.619             | 13.843                  | 0.1634  | -0.186  | 46.705       |
|             |      |      |      |                      |       | -2.726             | 34.850                  | 0.07821 |         |              |

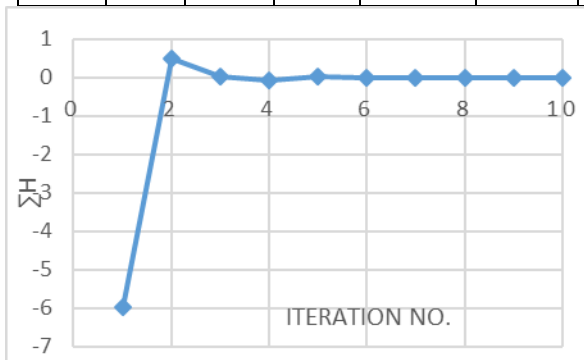


Fig. 3: Variation in Head Loss with Iteration in Loop I

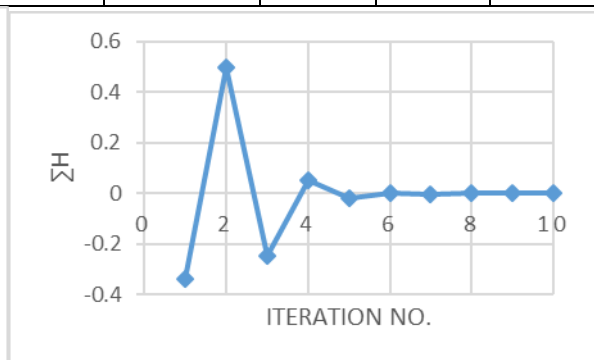


Fig. 3: Variation in Head Loss with Iteration in Loop II

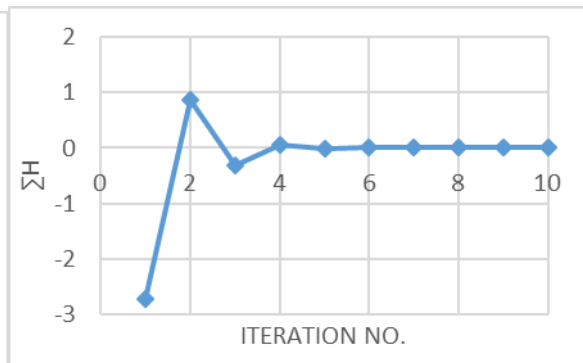
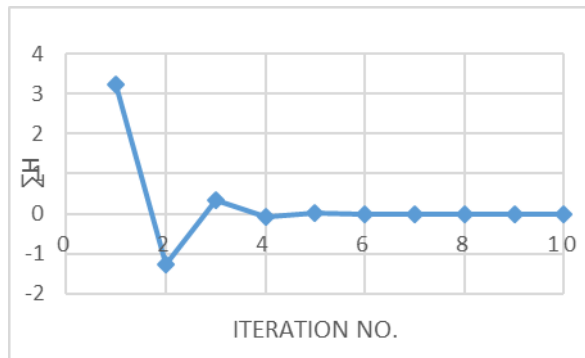


Fig. 5: Variation in Head Loss with Iteration in Loop III

Fig. 6: Variation in Head Loss with Iteration in Loop IV

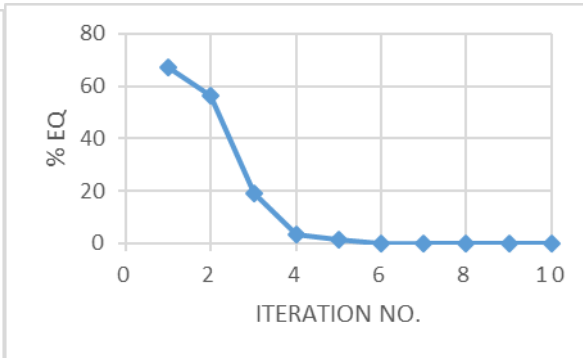
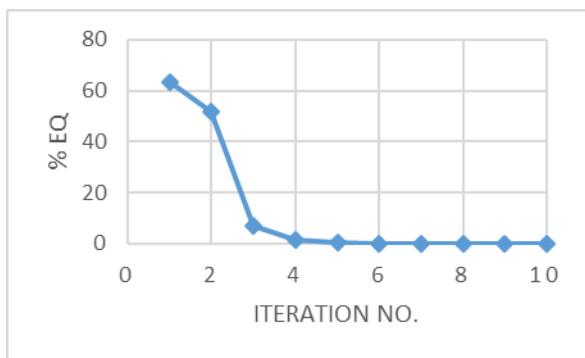


Fig. 7: Variation in Error with Iteration in Loop I

Fig. 8: Variation in Error with Iteration in Loop II

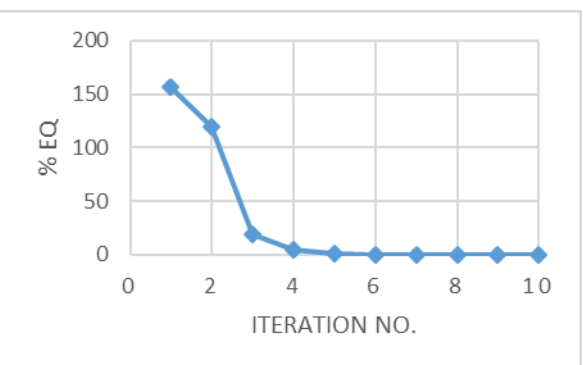
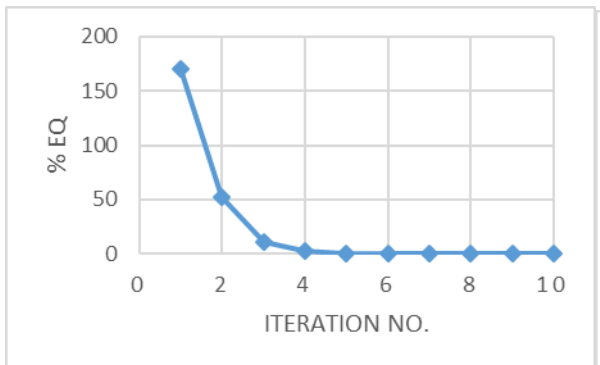


Fig. 9: Variation in Error with Iteration in Loop III

Fig. 10: Variation in Error with Iteration in Loop IV

## VII. CONCLUSIONS

From above study it was concluded that;

1. Hardy Cross method is easy but, it requires more number of iterations and takes time for obtaining final result and it cannot be used for large networks easily.
2. EPANET software is time saving and has no limitation for number of nodes, number of pipes or pumps to be modelled and analyzed in it so complex networks can be easily solved.
3. As the number of iterations increase, the value of head loss becomes closer to zero and to verify the obtained answers, balancing of flows at each point is done.
4. For each loop graphs are plotted between total head loss versus number of iteration, which shows that after multiple iterations head loss in a loop becomes constant (zero).

5. The results obtained using Hardy Cross method and EPANET software are nearly equal.

The present study on analysis of water distribution network using hardy-cross method gives better emphasis on effective design and distribution of network pipes using EPANET tool.

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