2025 Virginias Symposium – Environmental & Water Resources Competition

Background

ASCE member Hardy Cross was a structural engineer and Professor at the University of Illinois Champaign-Urbana in 1930 when he developed the moment distribution method, which revolutionized structural analysis. In 1936 Professor Cross adapted the method to solve pipe network flow distribution problems, again changing engineering practice and giving designers a critically important computational tool. In the 2025 Virginias Symposium Environmental & Water Resources Competition, participants will honor Professor Cross' legacy and achievements by competing to see who can apply his method most quickly to solve for the flows in a pipe network of given characteristics.

Rules

1. Teams may consist of any number of participants.
2. Each team may use only one computer.
3. Each team may use as many calculators as they wish, but only NCEES-approved calculators may be utilized.
    a. Casio: All fx-115 and fx-991 models (Any Casio calculator must have "fx-115" or "fx-991" in its model name.)
    b. Hewlett Packard: The HP 33s and HP 35s models, but no others
    c. Texas Instruments: All TI-30X and TI-36X models (Any Texas Instruments calculator must have "TI-30X" or "TI-36X" in its model name.)
4. Microsoft Excel may be utilized for calculations, but teams must start with a blank file (i.e., they may not utilize any previously-completed problems as a starting point).
5. No Excel ad-ins or macros may be used during the competition.
6. The Darcy-Weisbach method should be used to calculate energy loss due to pipe friction.
7. The Jain equation should be used to estimate the Darcy-Weisbach friction factor f.
8. Local losses (i.e., due to pipe bends, fittings, valves, etc.) should be neglected.
9. Pipe network layout, pipe diameter, pipe length, and pipe material equivalent sand roughness values will be provided. SI units will be utilized, and the answer should be provided in SI units.
10. All competing teams will be given the same pipe network problem statement at the same time.
11. The first team to determine the correct flow rate through each pipe in the network to within +/- 1% will be the winner.
12. After calculating the pipe flow rates, teams should fill in the provided worksheet and hand the worksheet to the competition judge, who will determine if the flow rates are correct.
13. If the flow rates are not correct to within +/1 1% then the team must wait at least 2 minutes before submitting a revised answer.

Resources

To help participants prepare for the competition, several supporting resources are available, including a method guide, example problems, and explanatory videos.

Hardy Cross Method Guide

$$h_L = rQ^n$$

$$r = \frac{fL}{2gA^2 D}$$

SI units, Darcy Weisbach friction

$$r = \frac{10.44L}{d^{4.8655} C^{1.85}}$$

Traditional units (gpm, feet, inches), Hazen-Williams friction

h_L = head loss in each pipe

r = proportionality constant, based on losses in pipe: neglecting local losses,
Q = flow rate
n = power based on friction loss formula power coefficient (Darcy-Weisbach n = 2; Hazen-Williams, n = 1.85)

Flow Correction Factor

$$\Delta Q_i = -\frac{\sum_{j=1}^{NP(i)} r_{ij} Q_j \left|Q_j\right|^{n-1}}{\sum_{j=1}^{NP(i)} n r_{ij} \left|Q_j\right|^{n-1}}$$

i = loop number
j = some pipe in loop i
ΔQi = flow correction
NP(i) = the number of pipes in loop i

Step 1: Determine the value of n.

Step 2: Select a positive flow direction (such as clockwise)

Step 3: Label all the pipes and loops in the network

Step 4: Define your loops: make sure each pipe is included in at least one loop.

Step 5: Assign "guess" flow rates, Q, and directions for each pipe in the network: satisfy continuity.

Step 6: Calculate r for each pipe in the network.

Step 7: For the flow rate Q, calculate rQ|Q| and nr|Q| for each pipe in the first loop.

Step 8: Sum the rQ|Q| and nr|Q| for all pipes in the first loop.

Step 9: Find the flow correction factor, ΔQ, for the first loop using the equation above.

Step 10: Apply the correction factor, ΔQ, to each pipe in the first loop, this is the corrected flow, Q, to be used in the next iteration of the first loop.

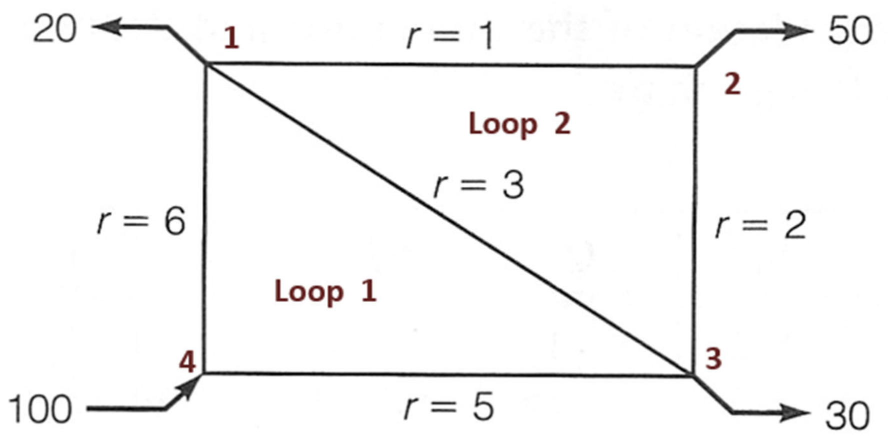
Step 11: For pipes from the first loop that are common to other loops, use the corrected flow rate that was found in the first iteration for the initial guess in other loops. (For each new loop, use the most recent corrected Q as the flow rate.)

Constructing a table, using the pattern below, may be helpful for organizing your calculations:

Iteration	Loop	Pipe	n	r	Q	rQ|Q|	nr|Q|	ΔQ	Corrected Q

Example Problem #1

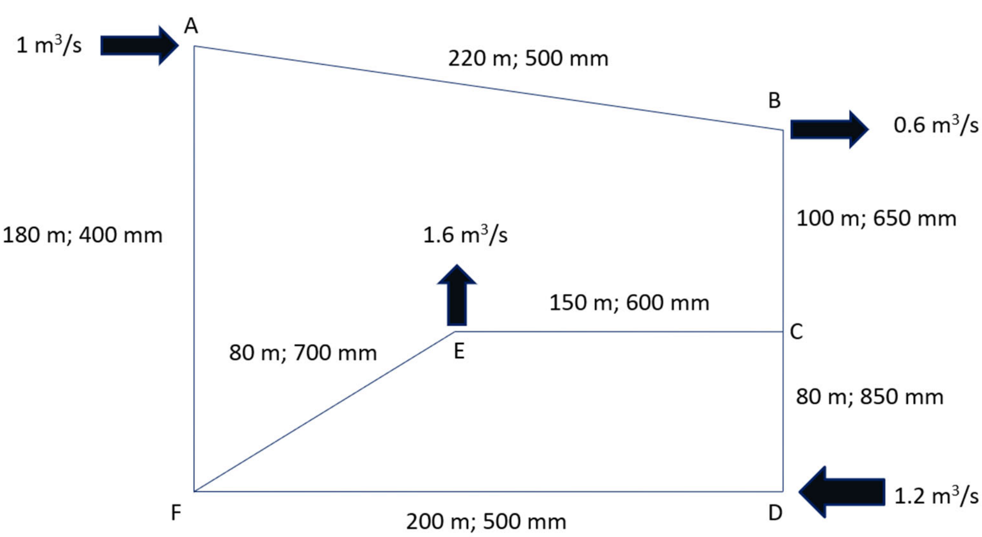
Determine the flow rate through each pipe where the "r" values are given directly, and do not change between iterations.



Note: this example problem is simpler than the problem that will be given on the day of the competition. It is offered as an opportunity to practice initial flow balance, and how to set up the Hardy Cross method in a spreadsheet.

The solution to this problem is included in the spreadsheet provided. A video showing the setup of the spreadsheet is available at: https://youtu.be/D0UZTdSvkGc?t=1911

Example Problem #2



ε = 0.3 mm for all pipes

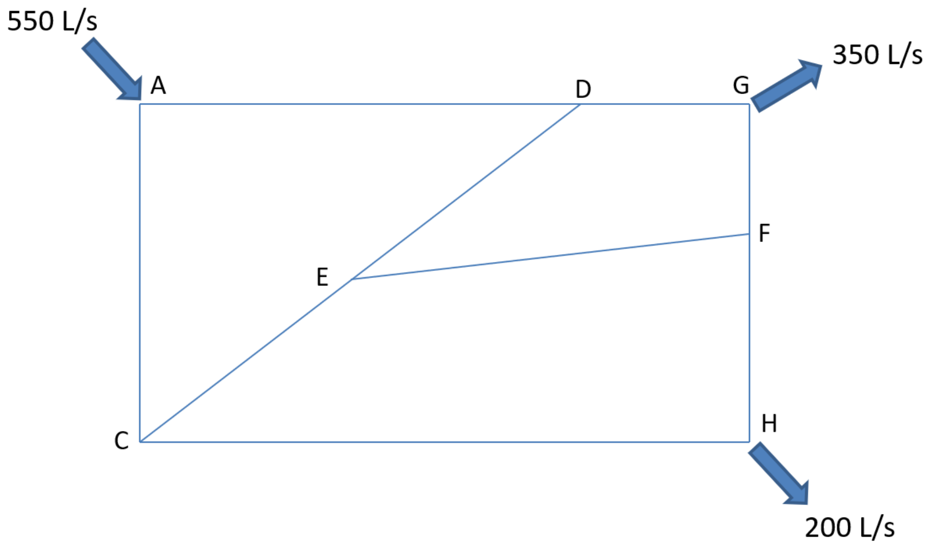
$\nu = 1 \times 10^{-6}$ m^2/s

Note: this example problem includes the use of the Darcy-Weisbach friction factor for determining energy loss due to pipe friction.

The solution to this problem is included in the spreadsheet provided. A video showing the setup of the spreadsheet is available at: https://youtu.be/X7PEwjYqFfE?t=339

Example Problem #3

Determine the flow rate (L/s) through each pipe using the Hardy Cross method.



Pipe	Length (m)	Diameter (mm)	Material & ε (mm)
AD	850	175	Cast Iron (0.26)
DG	400	200	Galv. Iron (0.15)
GF	400	250	Wrought iron (0.046)
FH	550	200	Cast Iron (0.26)
HC	1100	150	Galv. Iron (0.15)
CE	600	225	Wrought iron (0.046)
EF	200	300	Copper (0.00015)
ED	650	225	Concrete (0.3)
AC	950	150	Cast Iron (0.26)

The solution to this problem is included in the spreadsheet provided.