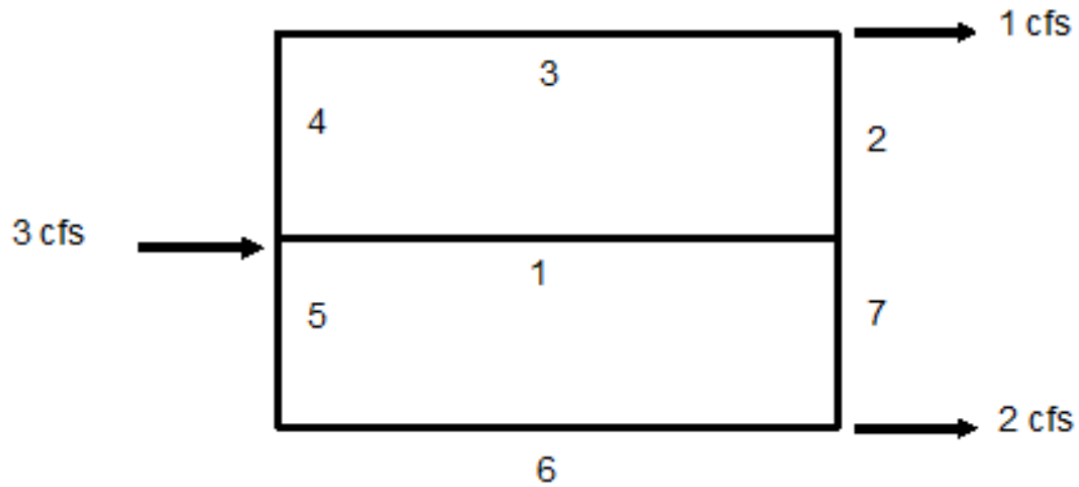


Hardy Cross

February 12, 2022

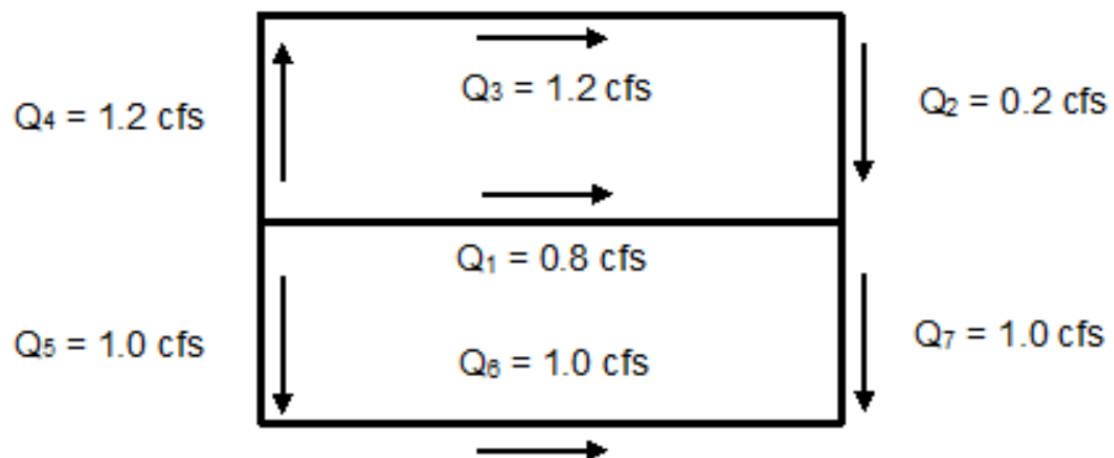
```
[1]: from msu_esd import Pipe, hardy_cross  
import numpy as np
```

1 Example 1.11



Pipe	L (ft)	D (in)	K	C	ϵ (ft)
1	2000	12	0	0	0.00015
2	2000	8	0	0	0.00015
3	3000	6	0	0	0.00015
4	4000	6	0	0	0.00015
5	1000	8	0	0	0.00015
6	3000	8	0	0	0.00015
7	2000	8	0	0	0.00015

The guess values are,



Define pipe objects first.

```
[2]: epsilon = 0.00015
      rho = 1.94
      mu = 3.104e-5

      pipe1 = Pipe(1, 2000, epsilon, rho, mu)
      pipe2 = Pipe(8/12, 2000, epsilon, rho, mu)
      pipe3 = Pipe(6/12, 3000, epsilon, rho, mu)
      pipe4 = Pipe(6/12, 4000, epsilon, rho, mu)
      pipe5 = Pipe(8/12, 1000, epsilon, rho, mu)
      pipe6 = Pipe(8/12, 3000, epsilon, rho, mu)
      pipe7 = Pipe(8/12, 2000, epsilon, rho, mu)
```

Define the connection matrix and flow rates like so,

```
[3]: Q_guess = np.array([0.8, 0.2, 1.2, 1.2, 1, 1, 1])
      N = np.transpose([
          [1, -1, -1, -1, 0, 0, 0],
          [-1, 0, 0, 0, 1, 1, -1]
      ])
      N
```

```
[3]: array([[ 1, -1],
            [-1,  0],
            [-1,  0],
            [-1,  0],
            [ 0,  1],
            [ 0,  1],
            [ 0, -1]])
```

1.1 No Additional Devices

Utilize the hardy cross function.

```
[4]: Q = hardy_cross([pipe1, pipe2, pipe3, pipe4, pipe5, pipe6, pipe7],
                    Q_guess, N)
      Q
```

```
[4]: array([ 1.8661928 , -0.76214598,  0.23785402,  0.23785402,  0.89595318,
            0.89595318,  1.10404682])
```

1.2 Heat Exchanger in Line 1

A list of functions needs to be inputting in for h and dh . If the device loss has a value of $50Q_1^2$,

```
[5]: h = [
        lambda Q_: 50*Q_*abs(Q_), # Positive because loss is considered positive
        ↪(e.g. turbine)
        lambda Q_: 0,
        lambda Q_: 0,
```

```

        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0
    ]

    dh = [
        lambda Q_: 100*abs(Q_),
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0,
        lambda Q_: 0
    ]

    Q = hardy_cross([pipe1, pipe2, pipe3, pipe4, pipe5, pipe6, pipe7],
                    Q_guess, N, h=h, dh=dh)
    Q

```

```

[5]: array([ 0.80979017, -0.43632714,  0.56367286,  0.56367286,  1.62653696,
            1.62653696,  0.37346304])

```

1.3 Adding a Pump to Line 1

If we add a pump with a head of 203.5 ft,

```

[6]: # Only need to change the function in the first index
    h[0] = lambda Q_: 50*Q_*abs(Q_) - 203.5 # Subtract because pump means the
    ↪system is doing work
    Q = hardy_cross([pipe1, pipe2, pipe3, pipe4, pipe5, pipe6, pipe7],
                    Q_guess, N, h=h, dh=dh)
    Q

```

```

[6]: array([ 2.0000145 , -0.81268625,  0.18731375,  0.18731375,  0.81267175,
            0.81267175,  1.18732825])

```