Design of Water Transmission System With Pumping

Nandini Shirbhate and Rampravesh Rai

February 26, 2020

Design of Water Transmission System With Pumping

N. S. Shirbhate[1]; R. K. Rai[2]

[1]*Post Graduate Student, (Government College of Engineering, Amravati, Civil Engineering Department, India) E-mail: nandini.shirbhate15@gmail.com*

[2]*Associate Professor, (Government College of Engineering, Amravati, Civil Engineering Department, India) E-mail: rairampravesh@yahoo.co.in*

Abstract:

As population increases, city grows extensively which leads to increase in demand of water for domestic, irrigation and industries. Also as the lifestyle of society is changing, they are getting more concerned about hygiene. So, it is duty of authorities to find nearest source of water, treat, store and use it optimally. This requires well designed water transmission and distribution system for providing treated water to consumers. Present study is related to the water transmission network *i.e.* flow of water from water treatment plant to elevated service reservoir. Main objective of this study was to determine optimum cost of the network. Here, the four reservoir system was considered with low head of source reservoir and higher heads of receiving reservoirs. Dynamic program was used for optimal design of water transmission network involving pumping using the Hazen-Williams equation. Here, the diameter equation was used for assuming initial value of diameter for pipes. Various values of diameter (on higher and lower side of calculated diameter) at an interval of 25 mm were considered and its effect on overall cost of network was analyzed. By using dynamic programming, the set of diameters which gave minimum cost of the network was considered as the optimal solution. Design process helps to identify head of service reservoir and diameters of pipes. The necessary cost data was taken from Maharashtra Jeevan Pradhikaran, Amravati for the year 2019-20.

Keywords: Dynamic programming, Hazen-Williams equation, Optimum cost, Optimal design, Four reservoir system, Transmission network.

1. Introduction:

As population is increasing demand of water for domestic, irrigation and industrial purpose has been increased. Also due to education and up gradation in lifestyle of society, they are getting more concerned about hygiene so, its duty of authorities to provide treated water to consumers. For this, they have to search nearby source of water, treat it and supply it according to the necessity. Water sources like lakes or rivers are not able to fulfill current water demand of society it may be due to various reasons like increase in population, global warming, variation in rainfall, climatic changes etc. so optimal utilization of it is on the upmost priority list. Every year Water Resource Department (WRD) spends ample of money on water distribution project, but some minute saving of cost by improving design results in acceptable saving in total cost of project. Also improvement in design helps in optimal utilization of water.

Water, air and food are the basic needs of human for survival. Water supply network (WSN) is the most important part in urbanization and every WSN has its unique design depending upon environmental, geological and economical factors. Following are the components for WSN:

1) Water source and intake well;
2) Water treatment plant and storage tank;
3) Water transmission network; and
4) Water distribution network.

Water from the source is transferred to water treatment plant (WTP). At WTP, required treatment is given to the water depending upon quality of water. Then treated water is stored in storage tank also called as main balance reservoir (MBR). From MBR, water is transferred to elevated service reservoir (ESR) this is called as water transmission network and from ESR water is proceed to consumer this is called as water distribution network.

Depending upon the level of the source and that of the city, topography of the area and other local considerations, the water may flow into the transmission network in the following three ways:

1) By gravitational system;
2) By pumping system; and
3) Combination of both gravity and pumping system.

This paper emphasizes on combination of both gravity and pumping system. Flow path algorithm and Hazen-Williams equation was developed for optimal design of three reservoir system.

2. Hydraulic Modeling Equations and Equations Used for Designing:

2.1 Economical diameter for pumping main:

For optimal conditions, we must choose such a diameter, which together with the pumping cost, will make the total annual expenses, the minimum. The diameter which provides such optimal conditions is known as the economical diameter of the pipe (Garg, 2014).

$$D = (0.97\ to 1.22)\sqrt{Q} \qquad (1)$$

2.2 Pumping main diameter equation:

While pumping water from low head to higher head in pipe it creates pressure head difference by the use of pump which is also known as rising main and for this the diameter can be calculated by using following equation.

$$D = \left(\frac{51.98\gamma L Q^{1.852}}{m {C_H}^{1.852}} \frac{K_t}{K_m}\right)^{\frac{1}{m+4.870}} \qquad (2)$$

2.3 Hazen Williams formula:

Hazen-Williams equation is empirically and dimensionally non-homogeneous equation and was originally introduced in 1902. It is the most widely used for design of pressure main. This formula is applicable for smooth turbulent flow.

$$V = 0.849 C_H R^{0.63} S^{0.54} \qquad (3)$$

$$h_f = \frac{10.674 L Q^{1.852}}{C_H^{1.852} D^{4.870}} \qquad (4)$$

3. Cost Function:

For computing cost of transmission network it is important to identify all the components which are involved in it and whose slight change in property shows considerable change in the cost of network. Major components of transmission network which affect the cost of network are as follows:

1. Cost of Pipe;
2. Cost of Pump; and
3. Cost of Energy.

3.1 Cost of Pipe:

Generally, various pipes are used for conveying water from source to its destination. Cast iron or ductile iron pipes are most popular in all as they give resistance to corrosion and are more durable.

$$C_m = K_m L_i D_i^m \quad (5)$$

Where,

K_m and m = Cost parameter for pipes;

L_i = Length of pipe, m; and

D_i = Diameter of pipe, m.

CI pipe was considered for water transmission from source to elevated service reservoirs (ESR). To determine cost of pipe, schedule rate of pipe per meter length was taken from Maharashtra Jeevan Pradhikaran (MJP), Amravati. Total Capitalized Cost of Pipe v/s Diameter of Pipe is shown in Fig. 1. According to Fig. 1 cost parameters for CI pipe are K_m = 35242, m = 1.403 and R^2 = 0.995.

3.2 Cost of Pump:

Pumping is involved to transfer water from low head source; it can be lake or river to the high head ESR. Pumping plant and pumping house cost is included in pumping system. The cost function for pumping calculates the power of pump which is proportional to cost of pump house.

$$C_p = (1 + S) K_p P \quad (6)$$

Where,

K_p = Cost parameter of pump; and

P = Power of pump, KW; and

S = Standby Pump.

$$P = \frac{\gamma Q h_0}{1000\eta} \quad (7)$$

Where,

η = Efficiency of pump;

γ = Mass density of fluid;

Q = Discharge, m^3/s; and

h_0 = Pumping head, m.

To determine cost of pump, schedule data was taken from MJP, Amravati. Cost of Pump v/s Diameter of Pipe is shown in Fig. 2. Cost parameter for pump from Fig. 2 are K_p = 17695 and R^2 = 0.978

3.3 Cost of Energy:

Unlike cost of pipe and pump it is not one time investment, rather it is an annual expenditure and with huge considerable cost. This cost is proportional to the power consume, indirectly it is proportional to discharge and pumping head, h_0.

$$C_e = \frac{8760 P F_A F_D R_E}{r} \quad (8)$$

Where,

D = Diameter of pipe, m;

F_A = Annual averaging factor;

F_D = Daily averaging factor for the discharge;

R_e = Electricity rate; and

R = Rate of interest.

4. Design Example:

Fig. 3 shows basic example of WTN which consists of four reservoirs 3, 3’, 2’, 1 and two junctions *J1*and *J2*. Corresponding data of reservoirs and pipe is as follows:

Table 1: Data of Three Reservoir System

Pipe/Reservoir	***H***	***L***	***Q***
S	20	300	0.6
3		5000	0.6
3’	85	3000	0.2
2		4000	0.4
2’	75	2000	0.15
1	60	4500	0.25

5. Procedure of Dynamic Programming and Cost Calculation:

Trial 1

Stage 1:

1. Diameter of pipe *3* (D_3), *3'* ($D_{3'}$) and *2'* ($D_{2'}$) was calculated by using eq. 1 and diameter of pipe *1* (D_1) and *2* (D_2) was calculated by eq. 4. D_S was calculated by raising main equation i.e. eq. 2.
2. Diameter D_3 and $D_{3'}$ was kept fix and $D_{2'}$ was varied in the interval of 25mm on higher and lower side of calculated values. D_1 and D_2 value was changing with variation in $D_{2'}$ values and it was rounded up to the next higher value.

Stage 2:

1. From stage 1, diameter $D_{2'}$ and D_1 was selected for which total cost of network was minimum. Selected diameter $D_{2'}$ and D_1 also D_3 was kept fix while $D_{3'}$ was varied in the interval of 25mm on higher and lower side of calculated values. D_2 value was changing with variation in $D_{3'}$ values and it was rounded up to the next higher value.

Stage 3:

1. From stage 2, diameter $D_{3'}$ was selected which shows global minimum value of total cost of network. Selected diameters of $D_{3'}$, $D_{2'}$ and D_1 was kept fix while D_3 was varied in the interval of 25mm on higher and lower side of calculated value.

Trial 2

Stage 1:

1. Selected diameters of D_3 and $D_{3'}$ from trial 1 was kept fix and $D_{2'}$ was varied with the interval of 25mm on higher and lower side of selected value from previous trial. D_1 and D_2 value was changing with variation in $D_{2'}$ values and it was rounded up to the next higher value.

Stage 2:

1. From previous stage, diameter $D_{2'}$ and D_1 was selected for which total cost of network was minimum. Selected diameter $D_{2'}$, D_1 and D_3 was kept fix while $D_{3'}$ was varied with the interval of 25mm on higher and lower side of selected value from previous trial. D_2 value was changing with variation in $D_{3'}$ values and it was rounded up to the next higher value.

Stage 3:

1. From stage 2, diameter $D_{3'}$ was selected which have global minimum value of total cost of network. Selected diameter $D_{3'}$, $D_{2'}$ and D_1 was kept fix while D_3 was varied with the interval of 25mm on higher and lower side of selected value from previous trial.
2. In this stage same set of diameters were giving global minimum value of total cost of network. So, no further iterations required. If there is change in diameter set and minimum cost value same steps are followed in further trials.

Results and Discussion:

Trial 1:

Stage 1:

From Table 3 and Fig. 4 it was concluded that 775mm dia. of D_3, 450mm dia. of $D_{3'}$, 575mm dia. of D_2, 425mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network. In stage 2 above values of $D_{2'}$ and D_1 was kept fix.

Stage 2:

From Table 4 and Fig. 5 it was concluded that 775mm dia. of D_3, 525mm dia. of $D_{3'}$, 625mm dia. of D_2, 425mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network. In stage 3, above value of $D_{3'}$, $D_{2'}$ and D_1 was kept fix.

Stage 3:

From Table 5and Fig. 6 it was concluded that 800mm dia. of D_3, 525mm dia. of $D_{3'}$, 625mm dia. of D_2, 425mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network.

Trial 2:

Stage 1:

In this stage D_3 and $D_{3'}$ selected from trial 1 was kept fix. From Table 6 and Fig. 7 it was concluded that 800mm dia. of D_3, 525mm dia. of $D_{3'}$, 600mm dia. of D_2, 475mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network. In stage 2 above values of $D_{2'}$ and D_1 was kept fix.

Stage 2:

From Table 7 and Fig. 8 it was concluded that 800mm dia. of D_3, 525mm dia. of $D_{3'}$, 600mm dia. of D_2, 475mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network. In stage 3, above value of $D_{3'}$, $D_{2'}$ and D_1 was kept fix.

Stage 3:

From Table 8 and Fig. 9 it was concluded that 800mm dia. of D_3, 525mm dia. of $D_{3'}$, 600mm dia. of D_2, 475mm dia. of $D_{2'}$ and 475mm dia. of D_1 gave global minimum value of total cost of network.

As in this stage with the variation in dia. of pipe 3 there is no change in minimum cost so no further trials required for analysis.

5. Conclusions

This dynamic program was developed to analyse water transmission network using pumping. In this dynamic programme analysis starts from end node and it minimizes total cost of network by varying diameters of pipe in various trials. Here minimum cost was obtained in stage 3 of trial 2 with no change in set of diameters, so no need of further analysis. It was also useful for predicting pumping head from source to service reservoir. This approach can be utilized in future for complex transmission network.

References

[1] P. K. Swamee, Design of multistage pumping main, *Journal of Transportation Engineering, Vol. 22, No. 1,* 1996.

[2] P. K. Swamee, and A. K. Sharma, Design of water supply pipe network, *John Wiley & Sons, Inc., Hoboken, New Jersey,* 2008.

[3] N. Sonaje, and M. Joshi, A review of modeling and application of water distribution network software, *International Journal of Technical Research and Applications, Vol. 3, No. 5,* 2015, 174-178.

[4] B. A. Konnur, and R. K. Rai, Optimal Design of Water Transmission Networks, *International Journal of Engineering Research, Vol. 5,* 2016, 250-256.

[5] R. S. Tetu, R. K. Rai, Optimal Design of Water Transmission System With Pumping, *International Journal of Engineering Research, Vol. 5,* 2016, 172-174.

[6] P. R. Patil and R. K. Rai, Optimal design of water transmission system with pumping, *International Conference on Energy and Environment: Global Challenges, NIT Calicut, Kerala, India,* March 9-10, 2018

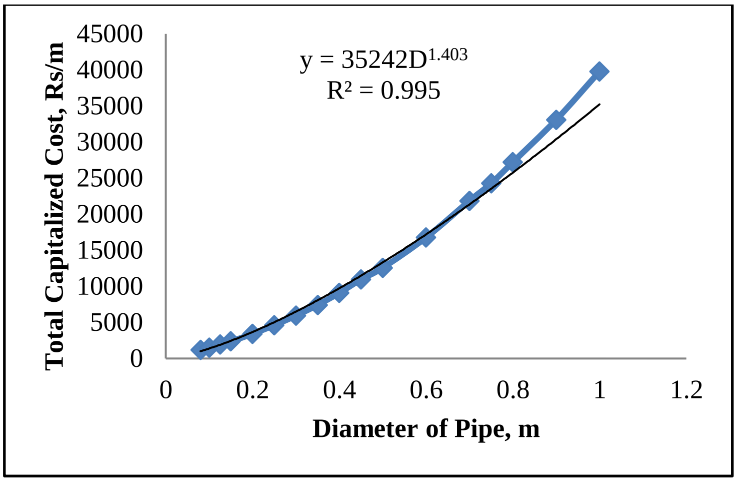

Fig. 1: Total Capitalized Cost v/s Diameter of Pipe

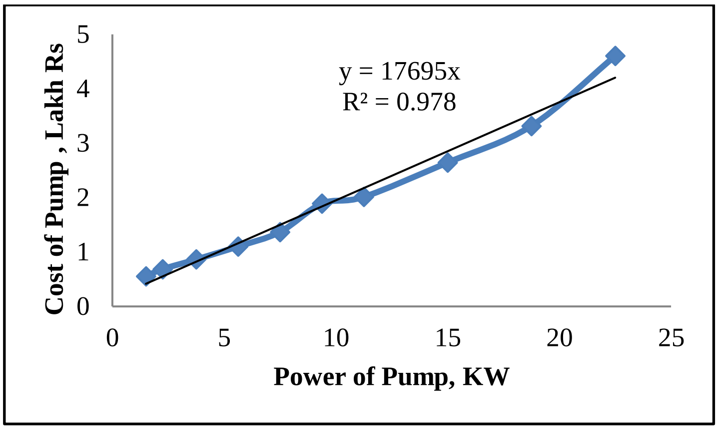

Fig. 2: Capitalized Cost of Pump v/s Power of Pump

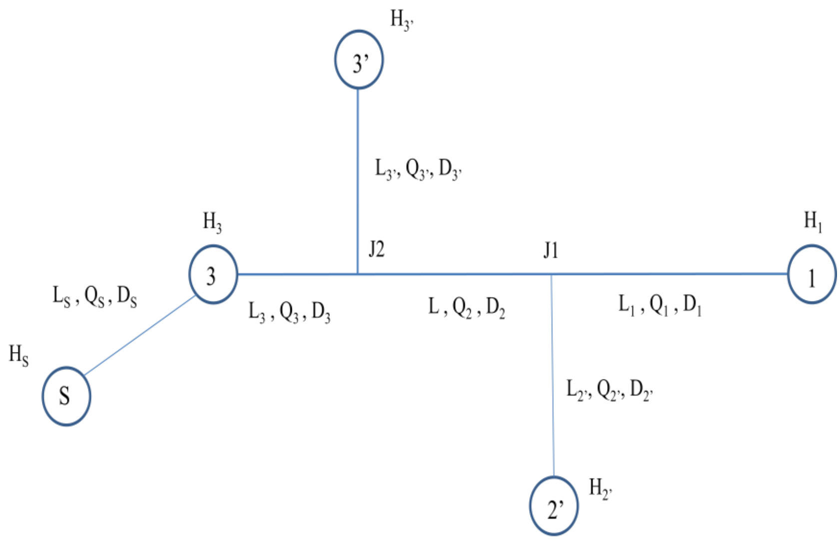

Fig. 3: Four Reservoir System using Pumping

Table 2: Initially Assumed Diameter Values

D₃ **(mm)**	***D₃'*** **(mm)**	***D₂*** **(mm)**	***D₂'*** **(mm)**	***D₁*** **(mm)**	**Total cost of network (Lakh, Rs)**
775	450	600	400	475	7519.128

Table 3: Results Analysis of Trial 1-Stage 1

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	775	450	675	350	450	825	103.376	7568.772
2	775	450	625	375	450	825	103.376	7502.701
3	775	450	600	400	475	825	103.376	7519.128
4	775	450	575	425	475	825	103.376	7496.525
5	775	450	575	450	475	825	103.376	7514.242
6	775	450	575	475	475	825	103.376	7532.360
7	775	450	575	500	475	825	103.376	7550.867

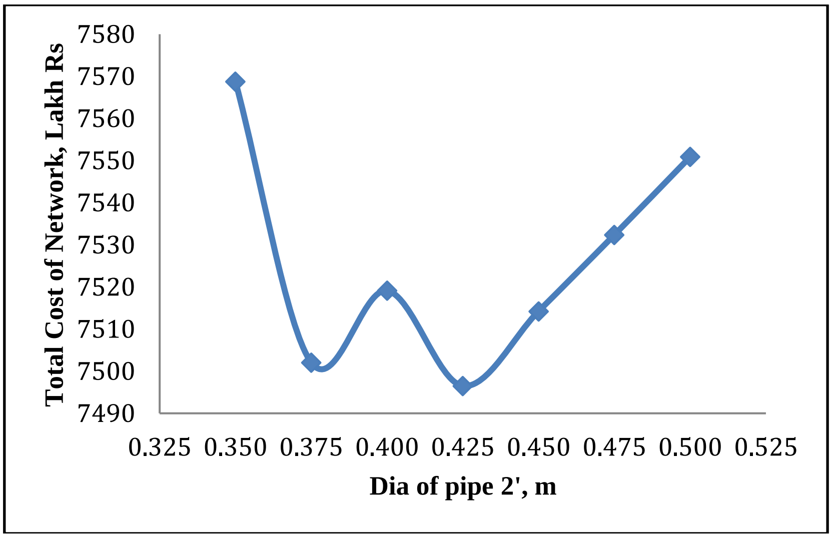

Fig. 4: Total Cost of Network v/s Dia. of Pipe 2’

Table 4: Results Analysis of Trial 1-Stage 2

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	775	400	525	425	475	825	110.856	7747.334
2	775	425	550	425	475	825	106.475	7588.620
3	775	450	575	425	475	825	103.376	7496.525
4	775	475	600	425	475	825	101.140	7449.736
5	775	500	625	425	475	825	99.5	7434.517
6	775	525	625	425	475	825	98.278	7400.566
7	775	550	650	425	475	825	97.354	7423.611
8	775	575	650	425	475	825	96.646	7416.985
9	775	600	675	425	475	825	96.099	7460.889

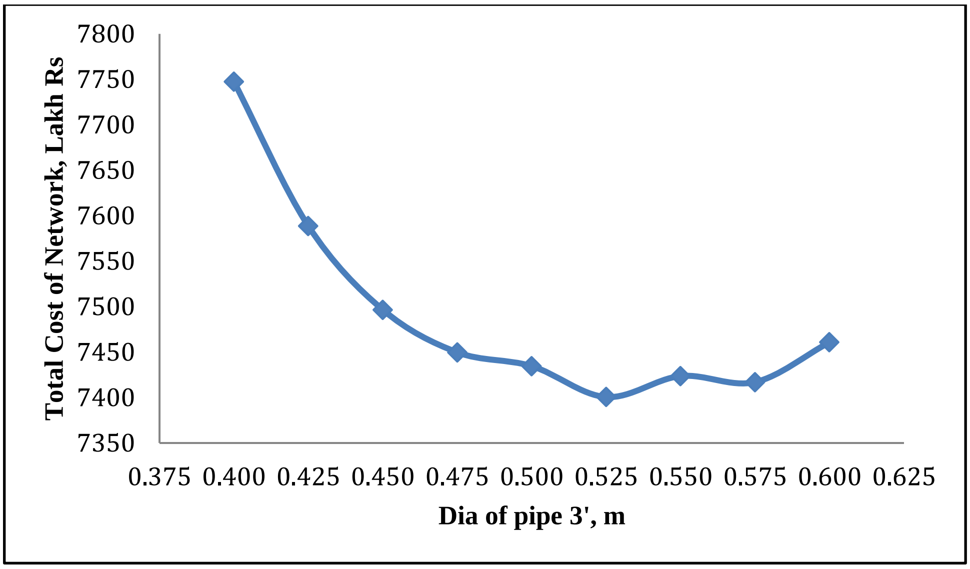

Fig. 5: Total Cost of Network v/s Dia. of Pipe 3’

Table 5: Results Analysis of Trial 1-Stage 3

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	725	525	625	425	475	825	101.624	7460.952
2	750	525	625	425	475	825	99.788	7422.072
3	775	525	625	425	475	825	98.278	7400.566
4	800	525	625	425	475	825	97.029	7393.062
5	825	525	625	425	475	825	95.989	7396.941
6	850	525	625	425	475	825	95.119	7410.154
7	875	525	625	425	475	825	94.387	7431.086

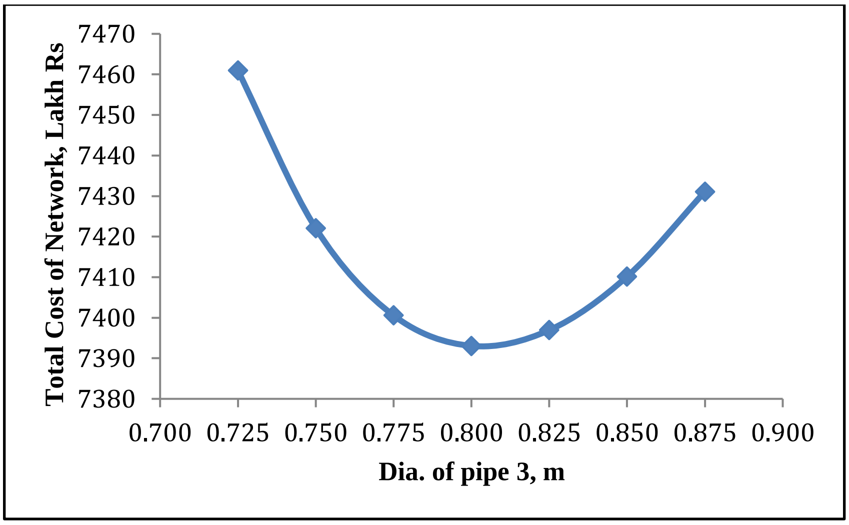

Fig. 6: Total Cost of Network v/s Dia. of Pipe 3

Table 6: Results Analysis of Trial 2-Stage 1

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	800	525	725	375	450	825	97.029	7486.892
2	800	525	650	400	475	825	97.029	7417.001
3	800	525	625	425	475	825	97.029	7393.062
4	800	525	625	450	475	825	97.029	7410.779
5	800	525	600	475	475	825	97.029	7388.317
6	800	525	600	500	475	825	97.029	7406.824
7	800	525	600	525	475	825	97.029	7425.708

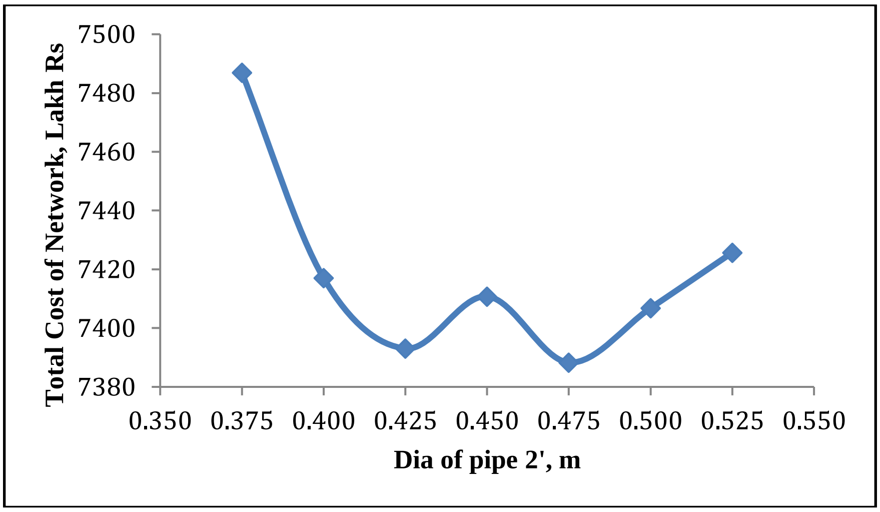

Fig. 7: Total Cost of Network v/s Dia. of Pipe 2’

Table 7: Results Analysis of Trial 2-Stage 2

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	800	475	575	475	475	825	99.891	7438.163
2	800	500	600	475	475	825	98.251	7422.268
3	800	525	600	475	475	825	97.029	7388.317
4	800	550	625	475	475	825	96.105	7410.702
5	800	575	625	475	475	825	95.397	7404.076
6	800	600	625	475	475	825	94.849	7406.096

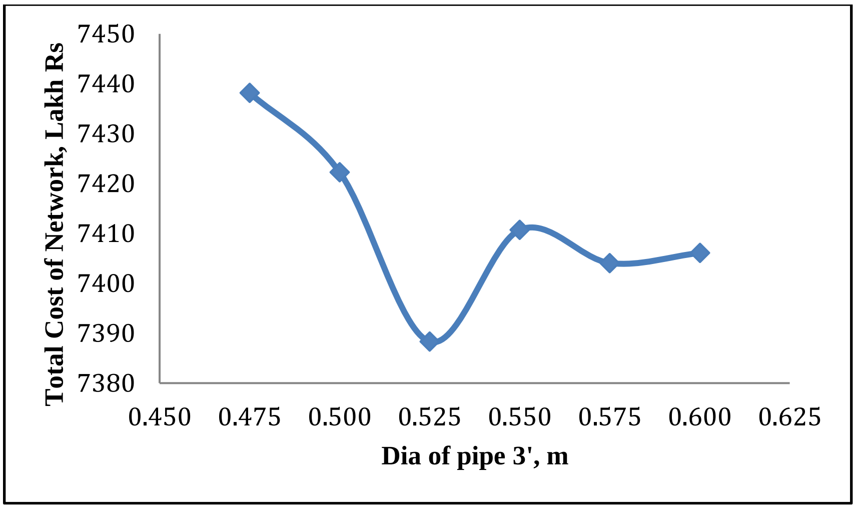

Fig. 8: Total Cost of Network v/s Dia. of Pipe 3’

Table 8: Results Analysis of Trial 2-Stage 3

Sr. No.	D_3 (mm)	$D_{3'}$ (mm)	D_2 (mm)	$D_{2'}$ (mm)	D_1 (mm)	D_S (mm)	H_3 (m)	Total cost of network (Lakh, Rs)
1	750	525	600	475	475	825	99.788	7417.327
2	775	525	600	475	475	825	98.278	7395.821
3	800	525	600	475	475	825	97.029	7388.317
4	825	525	600	475	475	825	95.989	7392.196
5	850	525	600	475	475	825	95.119	7405.409
6	875	525	600	475	475	825	94.387	7426.341

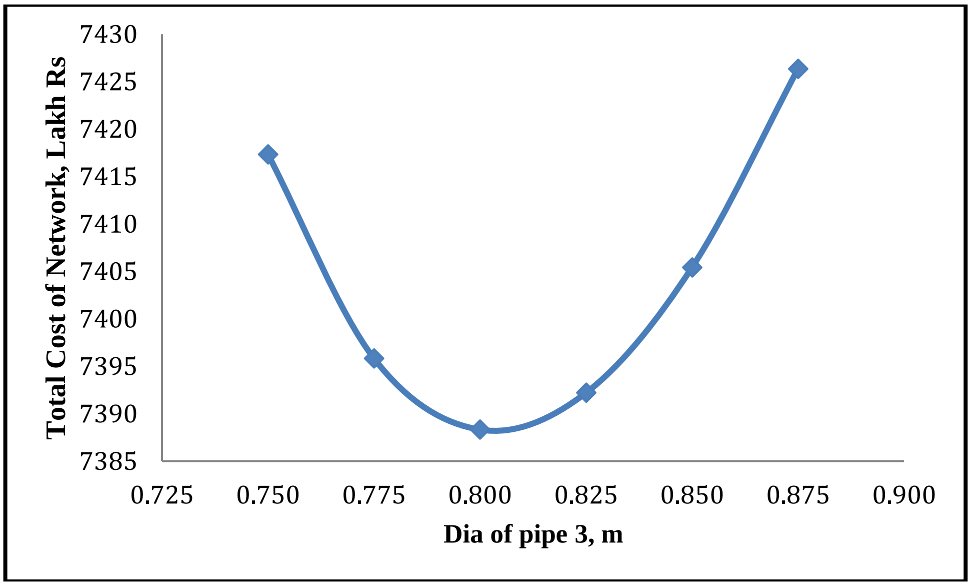

Fig. 9: Total Cost of Network v/s Dia. of Pipe 3