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Optimization of Integrated Sewerage System by using Simplex Method

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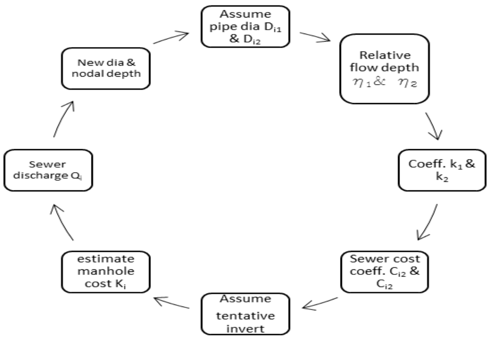
GRAPHICAL ABSTRACT



ABSTRACT

Sanitary sewer systems are the fundamental and expensive facilities for controlling water pollution. Optimising of sewer design is a tough task due to its complex hydraulic. Most of the designs are based on the Hazen William equations or Manning's equations. But due to their empirical nature, its range of applicability is limited to a certain level. In the design of sewerage system, the sewer line is the vital unit which occurs repeatedly in the design process. This paper encourages the use of Darcy-Weisbach equation for the designing of sewerage system by making a comparison between the results of SewerGEMs v8i software and a Function developed by using Darcy-Weisbach equation. The network consists of 5 links and 6 nodes, which is around 200m long. In linear programming a cost function has been used which contains the cost of manholes, trenches, and pipes. Each link consists of 3 decision variables and 4 constraints equations. By keeping all the design constraints into considerations, equations have been made and solved by using Microsoft excel. Same network designed by using SewerGEMs V8i software. The results by the both the algorithms have been made and conclusion is drawn.

***Index Terms*—Darcy-Weisbach, Linear Programming, Sewer Network, SewerGEMs V8i.**

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I. INTRODUCTION

Wastewater is collected from the residential and commercial or somewhere industrial areas and transported through the sewerage system to wastewater treatment plant. Though, the sewerage system has a very high responsibility of keeping the solids in suspension by maintaining the minimum and maximum velocities as per CPHEEO Manual in each link. The construction of the sewerage system is an expensive task. However, the cost associates with the sewerage system can be significantly reduced if the system configuration e.g., sewer dia, pipe slopes, pipe invert levels, etc. can be optimised effectively. Several optimisation techniques have been proposed till date. But the optimisation of the sewerage system is not an easy task. Various alternative solutions have been developed for the optimisation of the network. But we cannot stick to a optimisation technique, because it involves many complex hydraulics and engineering constraints. Most of the design based on Manning's equation and Hazen William equations. But the Manning's equation has discouraged because of its dimensionless nature and use Darcy-Weisbach equation for the design of sewer [1]. A lot of work has been done in the construction and management part of these systems. Various types of optimisation techniques have been introduced. A method for the hydraulics design of the sewer networks had been developed and which mainly highlighted the two main functions of the sewerage systems to carry the maximum discharge, for which it is designed to transport SS [2]. Since then many researchers have contributed to the design of the sewer network. Genetic Algorithm becomes the most popular and most acceptable method. This method has been applied to optimisation of sewer networks, which results in the good performance and more reliable results [3], [4]. But as the number of decision variable and equality constrains increases the GA becomes slow. To overcome this problem researchers hybridised the Genetic Algorithms with Linear Programming and Integer Linear Programming [5], [6]. An ant colony optimisation algorithm for the combined sewer design has also been applied. In this approach elevations are used as decision variables [7], [8]. Particle Swarm Optimisation are some famous metaheuristics applied to water and sewer problems.

II. MATERIALS AND METHODOLOGY

Design of sewerage system incorporates lots of money to serve better quality of services for the next 25-30 years. There is a huge responsibility of design engineers to optimise the sewer networks, where they can minimise the overall cost. It is totally depending upon their technical knowledge and their past experiences. It is hard to decide which methodology is to be adopted.

Although, using of Linear Programming method has been applied to the optimal design of sewerage networks. In this approach, the whole system is designed as single entity and not as individual pipe link. The termination point or LP cycles depends on the number of commercially available pipe sizes taken into consideration. By using pipe diameters directly into the algorithm, the problem of rounding off the diameter to the nearest commercially available pipe sizes can be avoided.

In this paper, LP optimisation technique has been used for the estimation of pipe diameters and invert depths, by using the Darcy–Weisbach equation and commercially available pipe sizes directly into the problem [10].

A. Constraints Equations

The invert slope S_0 by the Darcy-Weisbach: -

$$S_0 = \frac{f\,Q^2}{8gRA^2} \qquad (1)$$

here f = friction factor; Q = discharge; g = gravitational acceleration; and R = hydraulic radius defined as the ratio of the wetted area to perimeter,

As per Colebrook equation:

$$f = 1.325\{\ln(\frac{s}{12R} + \frac{0.625v}{VR\sqrt{f}})\}^{-2} \qquad (2)$$

Since this equation is implicit in f, by using equation (1), (2) can be converted into explicit function as written below [9]: -

$$f = \frac{4}{3}\{\ln(\frac{s}{12R} + 1.63(\frac{vP}{Q})^{0.9})\}^{-2} \qquad (3)$$

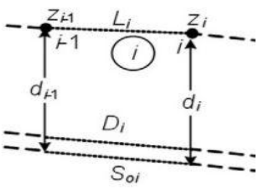

Fig. 1 Longitudinal profile for the i[th] Sewer Link

L_i = Length of pipe i^{th} link, D_i = Diameter of pipe , d_i = Invert depth of pipe, z_i = Ground level at Node i, S_{oi}= slope of pipe i^{th} link.

The invert slope of the ith link S_{oi} is given by: -

$$S_{oi} = \frac{d_i - d_{i-1} - z_i + z_{i-1}}{L_i} \qquad (4)$$

By putting equ (3) into (1), the value of S_{oi} can be written as: -

$$S_{oi} = \frac{Q_i^2}{6gA_i^2R_i}\{ln(\frac{s_i}{12R_i} + 1.63(\frac{vP_i}{Q_i})^{0.9})\}^{-2} \qquad (5)$$

Considering all the equations, (5) can be modified as [10]:

$$S_{oi} = \frac{k_1 Q_i^2}{g D_i^5}\{ln(\frac{s_i}{12R_i} + k_3(\frac{vD_i}{Q_i})^{0.9})\}^{-2} \qquad (6)$$

Where

$$K_1 = \frac{32\cos^{-1}(1-2\eta)}{3\{\cos^{-1}(1-2\eta) - 2(1-2\eta)\sqrt{\eta(1-\eta)}\}^3} \qquad (7)$$

$$K_2 = \frac{3\{\cos^{-1}(1-2\eta) - 2(1-2\eta)\sqrt{\eta(1-\eta)}\}}{\cos^{-1}(1-2\eta)} \qquad (8)$$

$$K_3 = 1.63\{\cos^{-1}(1-2\eta)\}^{0.9} \qquad (9)$$

Where, η= relative flow depth

On comparing equation (4) and (6), will get: -

$$d_i - d_{i-1} - z_i + z_{i-1} = \frac{k_1 L_i Q_i^2}{g D_i^5}\{ln\left(\frac{s_i}{K_2 D_i}\right)\}^{-2} \qquad (10)$$

Term which contains value of v can be neglected, because of its small value.

Another constraints equation can be developed based on the minimum and maximum slope. As per the CPHEEO Manual min slope of .1% is needed to avoid the silting of the solids into the sewer and max. slope of .5% can considered to avoid the scouring of the pipe material [11]. By keeping these points in mind two more constraints equations can be developed.

$$-z_i + z_{i-1} > .001(L_i) - d_i + d_{i-1} \qquad (11)$$

$$-z_i + z_{i-1} < .005(L_i) - d_i + d_{i-1} \qquad (12)$$

B. Objective Function

Since this function is considered for the trenchless technology, the earth excavation has been neglected. Sewer line consists of the link cost and nodal cost. Link cost consist the cost of the pipes which includes the laying out cost. Nodal cost consists the cost of the manhole required as per the CPHEEO Manual. The following internal sizes of the circular manholes for varying depths have been adopted for costing [11]: -

Depths b/w 0.90 m - 1.65 m – manhole 0.90 m diameter
Depths b/w 1.65 m - 2.30 m – manhole 1.20 m diameter
Depths b/w 2.30 m - 9.00 m – manhole 1.50 m diameter

Based on the above discussion, a cost function can be written as: -

$$F = \sum_{i=1}^{i=l}(k_i d_i + C_i L_i) \qquad (13)$$

Here, d_i= nodal depth (m), L_i= length of the link (m), C_i= cost of the pipe per unit meter, k_i= depth of manhole per unit meter.

C. Algorithm Description and Optimisation

A function has been made which contains the values of the depth as d_i and the length of the pipes as L_i. Here the length of the pipe of each link is disintegrated into two parts x_{i1} and x_{i2}, in such a manner that the sum of the two parts is equal to the length of the link. x_{i1} and x_{i2} corresponds to the respective diameters, D_{I1} and D_{i2}. So, the equation (10) can be rewrite as: -

$$d_i - d_{i-1} - \frac{k_1 x_{i1} Q_i^2}{g D_{i1}^5}\{ln\left(\frac{s_i}{K_2 D_{i1}}\right)\}^{-2} - \frac{k_1 x_{i2} Q_i^2}{g D_{i2}^5}\{ln\left(\frac{s_i}{K_2 D_{i2}}\right)\}^{-2} = z_i - z_{i-1} \qquad (14)$$

Values of the cost of the pipes C_{i1} and C_{i2} corresponds the respective diameters. Here k_i is the cost the manholes per unit depth. Since this function deals with trenchless technologies the cost of excavation has not been included and cost of the manholes has been taken from the standard rates of the manholes. Finally, the cost function can be written as follows: -

$$F=\sum_{i=1}^{i=l}(k_i d_i + C_{i1}x_{i1} + C_{i2}x_{i2}) \quad (15)$$

where,

$$x_{i1} + x_{i2} = L_i \quad (16)$$

To initiate this LP problem, the upper and lower diameters of commercially available pipes viz D_{i1} and D_{I2} are included. Now select the cost of the corresponding pipes as C_{I1} and C_{i2} as per the mentioned schedule of rates. Then tentatively assume the initial depth of the pipe as per the CPHEEO Manual and estimate all the invert level based on minimum or maximum slopes. Then estimate the cost of the manhole per unit depth viz k_i. By using continuity conditions Q_i can be estimated. Now this function can be optimised by using linear programming which can be solved in Microsoft Excel. The results or LP solutions indicates the preference for the one diameter over another in each pipe link. By knowing such preferences, the sewer pipe diameter not preferred by LP is rejected and next available diameter replacing it is introduced as D_{I1} and D_{i2}. With all the new diameters and invert depth, functions and all four constraint equations are revised. The process of LP cycle is continued until D_{i1} and D_{i2} are the two-consecutive commercially available sewer diameters. After one more LP cycle, optimised pipe diameters and invert levels can be obtained. This is prescribed in the flow chart Fig 2.

The application of a linear programming requires linearisation of objective function and constraints. In this LP, there is one objective function which is depicted in equation (15).

This optimisation incorporates with 4 constraints equations. Two are inequality constraints, which has described in equations (11), (12) and other two are equality constraints (14), (16). By making use of these equations networks can be optimised.

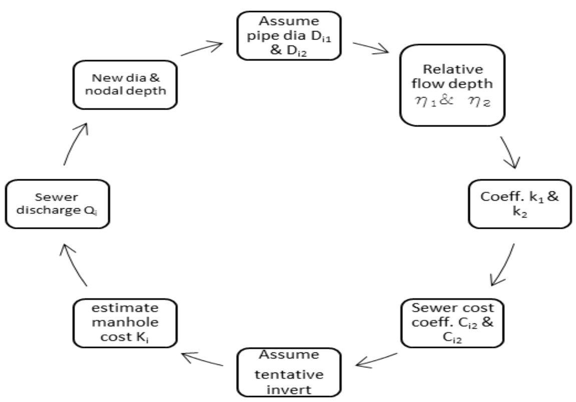

Fig 2. Flow chart of Simplex Method

III. PROBLEM AND ITS RESULTS

A. Problem

To understand more about this algorithm a simple hypothetical network is taken as an example shown in Fig 3. A comparison has been made between the algorithm and the software (SewerGEMs v8i).

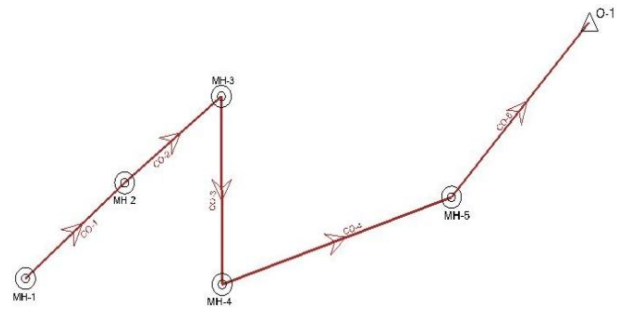

Fig 3. Plan of the Sewer Line

This problem contains five links and six nodes. Discharges, diameters, and length of the links are depicted in the Table 1. Table 2 represents the schedule of rates for the PVC pipes which includes the cost of laying [10]. A single pipe material is considered for the design viz PVC. This problem has 15 decision variables and 20 constraint equations which can be optimised in Microsoft Excel. The results are then compared with the Software (SewerGEMs V8i). Analysis of the results has also been done in the software to check out the efficiency of the network which is designed by using linear programming.

TABLE 1. Sewer Line Data

Pipe link	Start node	End node	Length of link (m)	Elevation of start node(m)	Discharge at node(m^3/s)
1	MH-1	MH-2	30	100	0.01
2	MH-2	MH-3	30	101	0.03
3	MH-3	MH-4	30	101.5	0.05
4	MH-4	MH-5	30	102	0.08
5	MH-5	O-1	30	103	0.1
	O-1			102	

Where, MH = Manhole, O-1= Outfall

TABLE 2. Cost of Various commercial sizes including the cost of laying

Sl. No.	Pipe Dia(mm)	Cost per meter(Rs)	Sl. No.	Pipe Dia(mm)	Cost per meter(Rs)
1	200	452	6	700	2580
2	300	710	7	800	3485
3	400	1289	8	900	3981
4	500	1640	9	1000	4450
5	600	2126	10	1100	5103

B. Results and Discussions

The variation of system cost with LP cycles is shown in Fig 4. In this Fig 4 the optimal solution is drawn in the 9th iteration and it is around Rs. *810015*.

Further the values of invert levels and diameters obtained by the linear programming and the computer algorithm are compared respectively in the Fig 5 and Fig 6. Fig 7 depicts the final cost of the projects by both the algorithms.

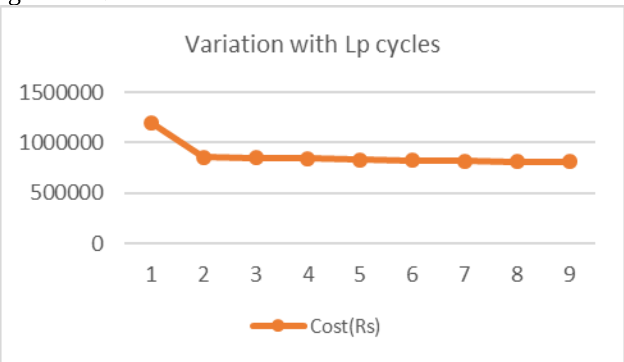

Fig 4. Variation of sewer line cost with LP cycles (Rs)

Total cost (excluding earth excavation cost) calculated by different algorithms clearly shows that the results shown by the linear programming are more acceptable in terms of cost. But to check the hydraulics of the system, both method's hydraulic profiles have been made. By seeing in Fig 8 conclusion can be drawn that the system will run full efficiently.

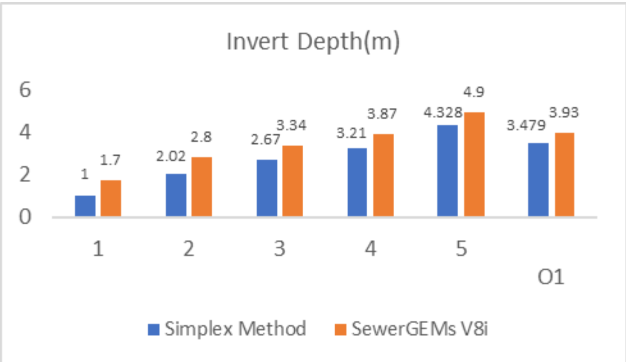

Fig 5. Comparison of Invert Levels (m)

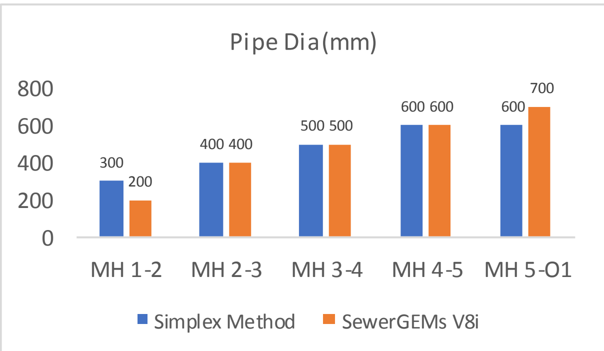

Fig 6. Comparison of the pipe diameters (mm)

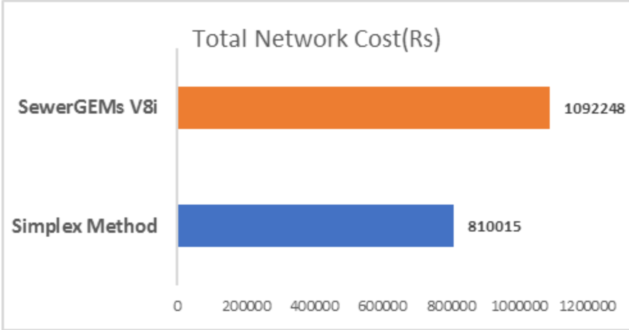

Fig 7. Overall Cost (Rs)

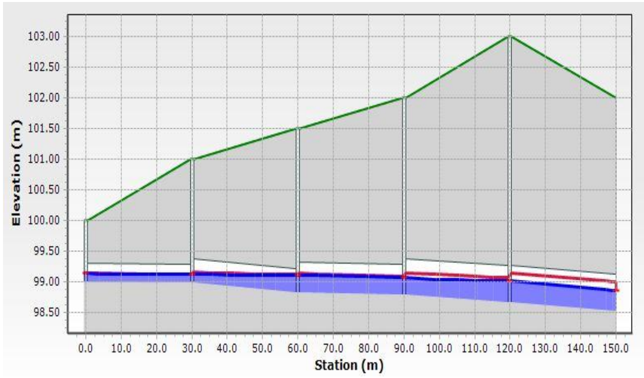

Fig 8. The Engineering Profile of the System Designed by the Simplex Method

C. Abbreviations and Acronyms

Dept.	Department	Dia	Diameter
CE	Civil Engineering	GA	*Genetic Algorithm*
LP	Linear Programming	SS	Suspended Solids

IV. CONCLUSION

25% reduction in the overall cost of the network has achieved by using linear programming. Problem of rounding off the estimated diameters of pipes to the nearest commercially available sizes has been eliminated. This algorithm doesn't get slow as the number of constraints increases unlike GA. Hence, this can be used for the bigger networks also. This algorithm doesn't deal with Manning's equation which has been discouraged by ASCE. This algorithm contains the concept of relative flow depth which maintains the flow in the sewer. It reduces the chances of overflow in the pipes with the given discharge values. This algorithm works with the slope ranges from .1% to .5%. This can be altered as per our requirement.

REFERENCES

[1] ASCE Task Force, Friction factors in Open Channels: Progress report of task force on friction factors in Open channels, Journal of Hydraulics Engineering Division, ASCE 89(2) (1963), pp-97-143.

[2] P.K. Swamee,"Design of Sewer Line", Journal of Environment Engineering, (2001), pp- 776-781.

[3] M. H. Afshar, “Rebirthing Genetic Algorithm for Strom Sewer Network design”, Scientia Iranica,19(1), (2012), pp-11-19.

[4] A. Haghighi, A. E. Bakhshipour, “Optimization of Sewer Network design using an Adaptive Genetic Algorithm”, Water Resource Management, (2012), http://dx.doi.org/10.1007/s11269-012-0084-3.

[5] M. Cisty, “Hybrid Genetic Algorithm and Linear Programming “Method for Least Count Design of the Water Distribution System”, Water Resource Management, 24(1), (2010), pp-1-24.

[6] H. Haghighi, M. V. Samani,“GA-ILP Method for Optimization of Water Distribution Network”, Water Resource Management, 25(7), (2011), pp-1791-1808.

[7] M. H. Afshar, “A Parameter Free Continuous Ant Colony Optimization Algorithm for the Optimal Design of Storm Sewer Network”, Advanced Engineering Software, 41(2), (2010), pp-188-195.

[8] R. Moeini, M. H. Afshar,“Layout and Size Optimization of Sanitary Sewer Network using Intelligent Ants”, Advanced Engineering Software, 51(2012), pp-49-62.

[9] P. K. Swamee, “Critical Slope Equations for Open Channels”, ISH Journal of hydraulic Engineering, 8(2), (2002), pp- 44-49.

[10] P. K. Swamee, A. K. Sharma, “Optimal Design of a Sewer Line using Linear Programming”, Journal of Applied Mathematics, 37(2013), pp-4430-4439.

[11] Manual on Sewerage and Sewage Treatment (1993), Second Edition, Central Public Health, and Environmental Engineering Organisation.