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Design of Sewer Network using Dynamic Programing

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ABSTRACT: The sewers carrying waste water are the significant infrastructural component of the waste water conveyance system. The water, which is used for various purposes, is safely conveyed through it to the desired place for disposal. The sewers must be of adequate size, shape and also must be laid at a desired slope so as to avoid the clogging, overflow and subsequent damage to the nearby property causing health hazards and severe environmental problems. Sewage networks are optimally designed so as to reduce its construction and maintenance cost while providing required capacity. In this paper, the technique is developed by analyzing the physical and hydraulic parameters to achieve a pipe network that has least cost. It is necessary to determine and maintain minimum flow velocity to avoid deposition and also heavy excavation and high lift for pumping should be avoided. Considering the depth, slope, minimum velocity and the capacity constraints, the overall cost of sewage network should be minimum. The sewage network design is an iterative process, it provides a large number of alternative options for sewer line, resulting in complexity of selecting the most appropriate network design; thus, it is essential to devise an approach which will enable the optimized sewerage network. A dynamic programming model is designed so as to substantially reduce the number of options for the sewer line and select an appropriate design.

KEYWORDS: Sewage, cost of network, sewage network, Dynamic programming approach

I. INTRODUCTION

A sewerage network consists of sewer pipes and several sewer appurtenances such as manholes, street inlets, inverted siphons, sewage pumping stations etc. which makes a sewer system strong enough to serve in a best possible way. A sewer line consists of a number of sewer links or pipes connected in series to form a network. The manholes are provided at the junction of two sewer links or pipes. The main sewer line ends at the outfall, while the large sewer lines come to end at junctions. Thus, a sewer network collects discharge from all sewer lines at their junction and discharges into other sewers. The general layout of sewer network consists of trunk line, sub-main line and main line. The waste water finally drops into the trunk line; the trunk line gets waste water from the main lines, all main lines collect water from the sub-main lines and the sub-main line collects wastewater from various sources. A great deal of research work has been carried out on developing methods to select a plan and the optimal dimensions from the number of viable options.

Camp et al. [1] was the first to emphasize the need for hydraulic design of sewers, which was neglected in the technical literature at that time as well as by the sewage works engineers. Since then a large number of research workers contributed to this subject. These approaches employed heuristic methodologies, which can be adapted on a microcomputer by Dasher and Davis et al. [2]; Charalambous and Elimam et al. [3]. Using piecewise linearization, the problem was solved by linear programming by [3]. On the other hand, Jain [4] used a sequential linear programming method to find the sewer diameters and Gupta et al. [5] used Powell's method of conjugate directions to search the optima of the cost function.

The design should satisfy the minimum and maximum velocity constraints and the procedure adopted is essentially one of trial and error. In a method, for obtaining diameter D, average velocity *V,* hydraulic radius *R,* and flow area A of a circular section, the researchers used a dimensionally consistent resistance equation given by Swamee et al. [6]. In another study the sewer line design problem is formulated as a minimization of the cost function subjected to tight and loose constraints. The problem is solved by iterative application of the Lagrange-multiplier method giving the detailed design of various appurtenances and cost estimation for each of the pipe of sewerage founded by Balaji et al. [7]. The study of Swarna and Modak et al. [8] developed the graphs based on the concept of feasible diameter set for the rapid design of sanitary sewers which are used for quick and improved designs, thereby eliminating need for trial-and-error procedures. Identifying the need for intermediate and end pumping in real life wastewater collection systems, optimization algorithm is developed for the design of gravity-cum-pumped systems using dynamic programming by

Kulkarni and Khanna et al. [9]. The problem of dimensionality is minimized through cost effective feasible groupings at junction manholes. The problem consists of minimization of a nonlinear cost function subjected to nonlinear constraints.

All these approaches use the Manning equation or Hazen- Williams's equation for resistance description. The Manning equation is applicable for a limited bandwidth, 0.004–0.04, of the relative roughness concluded by Christensen et al. [11]. The ASCE has disapproved the Manning equation and recommended the utilization of the Darcy-Weisbach equation for open-channel resistance. On the other hand, in a detailed study Liou strongly discouraged the use of the Hazen-Williams equation. This deficiency of Manning formula was also pointed out [10], to eliminate such shortcomings in the computational problems, it was recommended to use the modified Hazen-Williams formula [3]. The Manning equation is applicable for rough turbulent flow and the Hazen-Williams equation for smooth turbulent flow, whereas the Darcy-Weisbach equation is applicable for laminar as well as turbulent flow, also this equation is a accurate pipe flow resistance equation. From all the studies and the review of literature, it is concluded that for the design of sewer networks, various parameters such as hydraulic equations, constraints, design formulae and materials of sewer are required to be considered. Further, there is a need to study various design constraints, cost functions, designs and optimization technique for the optimal design of sewer network. Considering the complexity of the problem, in this study another technique is proposed to obtain the optimal design of small-sized sewer network by using dynamic programming.

II. METHODOLOGY AND DISCUSSION

An algorithm for the optimal design of a sewerage network and design procedure is developed in such a way, that, it determines the optimal diameter, invert slope, minimum and maximum velocities, depth of flow for each link, invert depths at upstream as well as downstream of the manhole, the total cost of the sewer line and the total cost of sewer network. The analytical modelling can be used for the design of sewer network by the following the design procedures as given below.

1. Design Procedure 1: The feasible diameters are obtained for a given flow using design relative depth, and maximum and minimum velocities. Assuming that the sewer pipes are available in diameters which are with an increment of 100 mm, the set of feasible diameters is obtained for each sewer link of sewer network. If the number of options is insufficient, a few more options can be obtained by relaxing relative depth, on the lower side. Further the central angle, for different values, the discharge and velocity at full flowing condition using flow and velocity with partially full flowing condition is determined. The slope of each option of a link and thereby head loss using Manning equation is calculated. The upstream invert of first sewer depends on minimum soil cover and link diameter; its downstream invert depends on head loss and ground levels. Thus, the inverts for each link for each option are determined. Finally, the cost of sewer pipe, cost of excavation and cost of manhole which added together gives total cost of a sewer link is calculated. Thus, the total cost of network with optimal design is obtained.Closed edges in the binary edge image are grouped by dilation using eight- connected structuring elements. Then small connected components in the dilated image are filtered using erosion. The output is a binary image that contains text candidate regions.

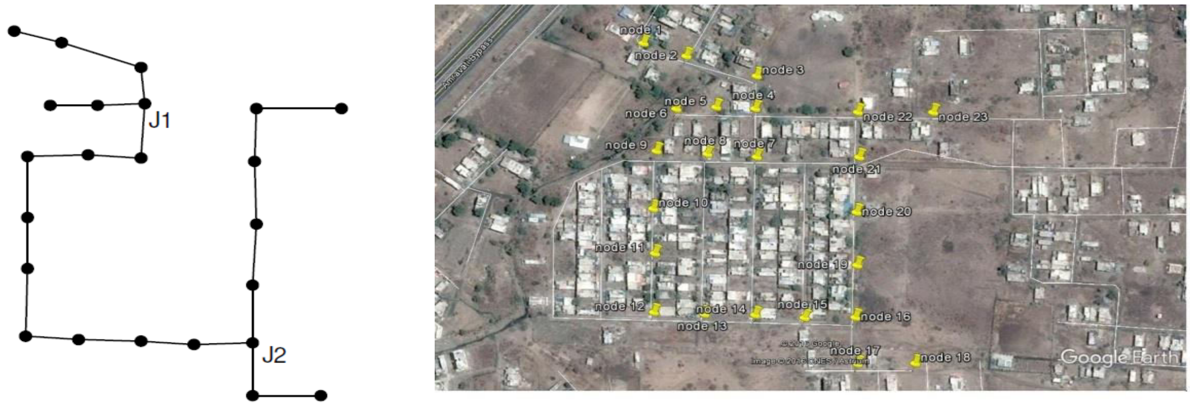
2. Design Procedure 2: The determination of set of feasible diameters for each link and the head loss and slope for each diameter are the same as that of design procedure I. All the sewer links that form the main line of the sewer network are designed, such that the invert of outgoing link at the junction manhole is greater than or equal to the invert of the incoming links at the junction manhole. The cost of each sewer link forming the main line is then determined. After the cost effective grouping of the first branch line and main line, the options with lesser cost is selected and the procedure of designing and grouping is repeated for the next branch line at the next junction of the main line. The procedure is then repeated for the entire network

III. PERFORMANCE ANALYSIS

The study presented here pertains to the Moti Nagar area, Amravati, Maharashtra. The field data for the underground drainage scheme is collected for the design of sewer network and some data is also obtained from the Google earth.. The optimal solution for the sewer network consisting of 22 links and 2 junctions and the other 25 links and 4 junctions is obtained by using sewer line design algorithm and Epanet.

A. **Case study I :**

The data for the Professor colony (lat. 20.91° long. 77.77°) having the 22-Link sewer network consisting of 3 sewer lines is shown in Fig.1 The data adopted for L_i, Q_i and Z_i to design the sewer network. In this case, the minimum velocity is adopted. The Manning's co-efficient of roughness for the RCC pipe in fair condition is taken as 0.015. The cost parameters adopted for sewerage network are, k_m = 7894.0 ₹/m, m = 1.394, c_e = 31.7 ₹/m^3, c_r = 62.994 ₹/m^3/m, c_s = 220.48 ₹/m^2, c_{rs} = 14.133 ₹/m^2/m, k_h = 13663 ₹/m



(a) (b)

Fig.1. Images for case study 1: (a) Image of network (b) Google Earth image of Sewer Network

Table 1. Design Data

Pipe	Discharge (m3/s)	Ground levels at upstream node z1(m)	Ground levels at upstream node z2 (m)	Length(m)
1 – 1	0.08	7.15	6.868	35
1 – 2	0.111	6.862	6.66	35
1 – 3	0.106	6.66	6	30
1 – 4	0.156	6.995	6.835	30
1 – 5	0.18	6.835	6.865	35
1 – 6	0.183	6.865	7.115	30
1 – 7	0.169	7.115	6.925	26
1 – 8	0.312	6.925	6.885	26
1 – 9	0.322	6.885	6.465	30
1 – 10	0.303	6.465	6.335	35
1 – 11	0.075	6.335	6	30
1 – 12	0.034	6	6.655	35
1 – 13	0.117	6.655	5.395	35
1 – 14	0.036	5.395	5.405	35
1 – 15	0.173	5.405	5.3	36
1 – 16	0.044	7.155	6.935	40
1 – 17	0.063	6.935	6.995	35
1 – 18	0.115	6.145	6.035	39
3 – 1	0.075	6.035	6.075	40
3 – 2	0.069	6.075	6.335	40

3 – 3	0.115	5.545	5.515	39
2 – 1	0.03	5.515	6.035	35
2 – 2	0.1	5.395	5.375	36

Results and Discussion for Case study I:

The set of feasible diameters and the corresponding head loss for each link of the sewer network are obtained and are as given in Table 2.

Table 2. Feasible Diameters and Head Loss for 22-Link Sewer Network

Set of feasible diameter (mm)	200	300	400	500
Pipe	Head Loss			
1 – 1	0.081	0.009	0.0019	0.0006
1 – 2	0.156	0.017	0.0037	0.0015
1 – 3	0.143	0.016	0.0033	0.001
1 – 4	0.309	0.034	0.0073	0.0022
1 – 5	0.411	0.046	0.0097	0.003
1 – 6	0.426	0.047	0.01	0.003
1 – 7	0.363	0.04	0.0085	0.0026
1 – 8	1.206	0.137	0.029	0.009
1 – 9	1.284	0.146	0.031	0.009
1 – 10	0.135	0.129	0.028	0.008
1 – 11	0.069	0.0079	0.0016	0.001
1 – 12	1.432	0.163	0.035	0.0005
1 – 13	0.169	0.019	0.004	0.0012
1 – 14	0.016	0.0018	0.001	0.0001
1 – 15	0.38	0.042	0.009	0.0028
1 – 16	0.025	0.0027	0.0005	0.0001
1 – 17	0.05	0.0056	0.0011	0.0003
1 – 18	0.168	0.005	0.003	0.001
3 – 1	0.071	0.016	0.0016	0.0005
3 – 2	0.061	0.006	0.0014	0.0004
3 – 3	0.168	0.018	0.004	0.0016
2 – 1	0.011	0.001	0.0002	0.0001
2 – 2	0.127	0.014	0.003	0.001

Considering main line with initial node of link 1-1 as a starting point and considering the head loss for each diameter of all the links in main line; invert depths for each option are calculated, such that invert depth of outgoing link at the junction is greater than or equal to the invert depth of the incoming link at the junction. Similarly, the branch lines and the sub-branch line are designed. The capitalized cost of manhole is then calculated.

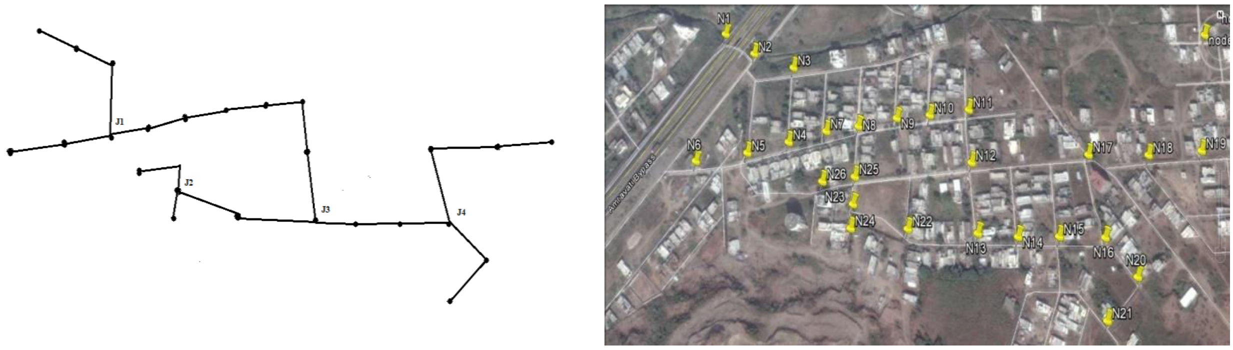
Table 3. Cost Estimation of each link

Pipe	Capitalized cost C_m , ₹	Capital cost of earthwork C_{ew} ,₹	Capital cost of sheeting and shoring C_{es} ,₹	Total cost of excavation C_e ,₹	Cost of manhole C_h ,₹	Final cost C_t, ₹
1 – 1	29286.7	1329.6	18835.6	20165.2	232224	281676
1 – 2	29286.7	1375.66	19499.7	20875.4	23224.4	73386.5

1 - 3	25102.9	953.995	13479.1	14433.1	23224.4	62760.4
1 - 4	25102.9	788.22	11115.5	11903.8	23224.4	60231.1
1 – 5	29286.7	919.59	12968.1	13887.7	23224.4	66398.8
1 – 6	25102.9	1403.39	19964.2	21367.6	23224.4	69694.9
1 - 7	21755.9	1027.05	14559.7	15586.7	23224.4	60567
1 - 8	21755.9	1091.37	15489.4	16580.7	23224.4	61561
1 - 9	25102.9	1071.71	15166.9	16238.7	23224.4	64566
1 – 10	29286.7	1417.17	20099.3	21516.4	23224.4	74027.6
1 – 11	25102.9	1113.54	15768.6	16882.1	23224.4	65209.4
1 - 12	29286.7	1873.74	26745.8	28619.5	23224.4	81130.6
1 – 13	29286.7	772.605	10884.9	11657.5	23224.4	64168.7
1 – 14	29286.7	1498.07	21269.9	22768	23224.4	75279.1
1 – 15	30123.5	1472.51	20888.1	22360.6	23224.4	75708.5
1 – 16	33470.6	1560.33	22114.4	23674.7	23224.4	80369.7
1 – 17	29286.7	1527.02	21689.5	23216.5	23224.4	75727.7
1 – 18	32633.8	1592	22582.2	24174.2	23224.4	80032.4
3 – 1	33470.6	1731.93	24596.1	26328	23224.4	83023
3 - 2	33470.6	1877.83	26715.7	28593.5	23224.4	85288.4
3 – 3	32633.8	1643.5	23327.3	24970.8	23224.4	80829
2 – 1	29286.7	1794.71	25588.4	27383.1	23224.4	79894.2
2 – 2	30123.5	1523.02	21619	23142.1	23224.4	76489.9

B. **Case study II :**

The study II pertains to the Mangaldham colony having (lat 20.906° and lon. 77.77°) including 25-Link sewer network consisting of 5 sewer lines as shown in Fig. 2. The data used for *Li*, *Qi* and *Zi* to design the sewerage network is given in Table 5. The Manning's coefficient of roughness for the RCC pipe in fair condition was taken as 0.015. The cost parameters adopted for sewerage network are, *km* = 7894.0 ₹/m, *m* = 1.394, *ce* = 31.7 ₹/m3, *cr* = 62.994 ₹/m3/m, *cs* = 220.48 ₹/m2, *crs* = 14.133 ₹/m2/m, *kh* = 13663 ₹/m and *bh*=-6356.



(a) (b)

Fig.2. (a) Image of network (b) Google Earth image of Sewerage Network

Table 4. Design Data

Pipe	Discharge (m^3/s)	Ground levels at upstream node z1(m)	Ground levels at upstream node z1(m)	Length (m)
1 – 1	0.09	6.95	6.852	32
1 – 2	0.103	6.852	6.826	35
1 - 3	0.116	6.826	6.664	29
1 - 4	0.158	6.664	6.561	34
1 – 5	0.164	6.561	6.451	30
1 – 6	0.17	6.451	6.329	39
1 - 7	0.176	6.329	6.254	37
1 - 8	0.182	6.254	5.94	26
1 - 9	0.188	5.94	5.751	34
1 – 10	0.194	5.751	5.562	28
1 – 11	0.316	5.562	5.451	28
1 - 12	0.322	5.451	5.326	38
1 – 13	0.329	5.326	5.241	35
1 – 14	0.379	5.241	5.015	30
1 – 15	0.384	5.015	4.921	34
2 – 1	0.024	7.155	6.935	40
2 – 2	0.037	6.935	6.82	35
3 – 1	0.062	6.852	6.72	39
3 – 2	0.111	6.72	6.523	35
3 – 3	0.115	6.532	6.41	40
4 – 1	0.033	6.82	6.235	29
4 – 2	0.043	6.235	6.035	35
5 – 1	0.028	5.395	5.375	37
5 – 2	0.037	5.375	5.029	29
5 – 3	0.046	5.029	5	36

Results and Discussion for Case study II:

The set of feasible diameters and the corresponding head loss for each link of the sewerage network is determined as given in Table 5

Table 5. Feasible Diameters and Head Loss for 22-Link Sewerage Network

Set of feasible diameter	200	300	400	500
Pipe	Head loss			
1 - 1	0.081	0.009	0.0019	0.0006
1 - 2	0.156	0.017	0.0037	0.0015
1 - 3	0.143	0.016	0.0033	0.001
1 - 4	0.309	0.034	0.0073	0.0022
1 - 5	0.411	0.046	0.0097	0.003
1 - 6	0.426	0.047	0.01	0.003
1 - 7	0.363	0.04	0.0085	0.0026
1 - 8	1.206	0.137	0.029	0.009
1 - 9	1.284	0.146	0.031	0.009
1 – 10	0.135	0.129	0.028	0.008

1 – 11	0.069	0.0079	0.0016	0.001
1 - 12	1.432	0.163	0.035	0.0005
1 – 13	0.169	0.019	0.004	0.0012
1 – 14	0.016	0.0018	0.001	0.0001
1 – 15	0.38	0.042	0.009	0.0028
2 – 1	0.025	0.0027	0.0005	0.0001
2 – 2	0.05	0.0056	0.0011	0.0003
3 – 1	0.168	0.005	0.003	0.001
3 – 2	0.071	0.016	0.0016	0.0005
3 – 3	0.061	0.006	0.0014	0.0004
4 – 1	0.168	0.018	0.004	0.0016
4 – 2	0.011	0.001	0.0002	0.0001
5 – 1	0.127	0.014	0.003	0.001
5 – 2	0.13	0.002	0.0005	0.009
5 – 3	0.126	0.0012	0.003	0.009

The line 1 is considered as a main line; lines 2, 3 and 5 as branch lines and Line 4 as sub-branch line. Considering the main line with initial node of link 1-1 as a starting point, and considering the head loss for each diameter of all the links in main line; invert depths for each option is calculated such that invert depth of outgoing link at the junction is greater than or equal to the invert depth of the incoming link at the junction. Similarly, the branch lines and the sub-branch line are designed.

Table 6. Cost Estimation of each link

Pipe	Capitalized cost C_m ,₹	Capital cost of earthwork C_{ew} ,₹	Capital cost of sheeting and shoring C_{es} ,₹	Total cost of excavation C_e ,₹	Cost of manhole C_h , ₹	Final cost C_t , ₹
1 – 1	26776.448	1312.5884	18620.593	19933.181	232224.39	278934.02
1 – 2	29286.74	1477.2462	20968.261	22445.507	23224.39	74956.637
1 – 3	24266.156	1158.9348	16432.721	17591.656	23224.39	65082.202
1 – 4	28449.976	893.31616	12597.608	13490.924	23224.39	65165.29
1 - 5	25102.92	788.22014	11115.536	11903.756	23224.39	60231.066
1 – 6	32633.796	1584.2798	22470.672	24054.951	23224.39	79913.137
1 – 7	30960.268	1531.7226	21733.156	23264.879	23224.39	77449.537
1 – 8	21755.864	974.03377	13795.204	14769.238	23224.39	59749.492
1 – 9	28449.976	1343.6307	19047.626	20391.257	23224.39	72065.623
1 - 10	23429.392	1106.5194	15686.28	16792.8	23224.39	63446.582
1 - 11	23429.392	1142.5108	16206.21	17348.72	23224.39	64002.502
1 - 12	31797.032	1541.7775	21867.333	23409.111	23224.39	78430.533
1 - 13	29286.74	1443.1507	20474.841	21917.991	23224.39	74429.121
1 - 14	25102.92	1167.2854	16543.074	17710.36	23224.39	66037.67
1 - 15	28449.976	1396.8689	19816.825	21213.694	23224.39	72888.06
2 - 1	33470.56	1560.3298	22114.404	23674.734	23224.39	80369.684
2 - 2	29286.74	1425.8296	20224.385	21650.214	23224.39	74161.344
3 - 1	32633.796	1577.8497	22377.743	23955.593	23224.39	79813.779
3 - 2	29286.74	1378.5389	19541.305	20919.844	23224.39	73430.974
3 - 3	33470.56	1624.9023	23046.843	24671.745	23224.39	81366.695
4 - 1	24266.156	957.69535	13537.978	14495.673	23224.39	61986.219
4 - 2	29286.74	1376.8103	19516.356	20893.166	23224.39	73404.296
5 - 1	30960.268	1565.3282	22219.56	23784.888	23224.39	77969.546
5 - 2	24266.15	1071.185	15167.594	16238.779	23224.39	39463.169

5 - 3	30123.504	1517.6691	21541.52	23059.189	23224.39	46283.579

IV. CONCLUSION

Optimal design of a sewer network involves determination of the combination of slope and diameter, so as to obtain the least cost design satisfying various design constraints such as invert depth, minimum velocity *etc*. In this study, the analytical design procedure is developed to obtain optimal design of sewer network. From the study of optimal design of sewer network the dynamic programming is carried out. The optimal design of a small sewer network can be obtained easily using dynamic programming, if the number of options for sewer pipes is more, the number of options for the sewer network obtained using the dynamic programming becomes too large. The number of options for the sewer diameter can be increased by relaxing the relative depth. The set of feasible diameters obtained after relaxing the relative depth is complete. The net decrease in head loss is very helpful in reducing the number of options of diameters for a link. The number of options of diameters can further be reduced by designing each link individually and neglecting the options having more invert depths than the optimal option. Thus, computational efforts for finding the optimal solution for a network can further be reduced.

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