Optimization and Design of Sewage Carrying System Network

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Abstract— This paper develops optimization based approaches addressing Sewage carrying system planning and design at area level. Area Sewage carrying system is required for the collection from individual houses/societies and the treatment of the wastewater that is generated in an area before being discharged into a water body. Sewage carrying system solutions are costly and very difficult to reverse, it is important that they are planned &designed efficiently so that to give a cost-effective solution that minimizes capital investment at the same time as ensuring a good system performance under specific design criteria and achieving a better environmental performance. Two main costs of Sewage carrying system are excavation and pipe cost, which often create differing objectives in the planning & design of Sewage carrying system. Any reduction in pipe size is liable to result in an increase in slope of Sewage carrying system that will increase excavation costs. On the other hand, reducing excavation costs requires milder slopes for Sewage carrying system, leading to larger pipe sizes for carrying the design discharge. Giving milder slopes will not be always possible on steep sloping ground surface, in that case invert drops required to be provided. Reduction in the length of main sewer line also reduces the cost of pipes and excavation cost. Therefore, finding an economical design for sewerage networks requires an optimal trade-off between length of main sewer line, diameter of pipes and excavation costs, which cannot be easily achieved by engineering judgment. This paper pertains to the application of dynamic programming for optimizing the network of Sewage carrying system and accordingly design of a Sewage carrying system as per hydraulic laws and regulations given in the Manual on Sewer and Sewerage System by CPHEEO.

Keywords — Sewage carrying system, Networks, Optimization, Dynamic programming, Design.

I. INTRODUCTION
Sanitation and wastewater collection systems were developed to protect public health from disease. Sewerage systems are required for the collection and the treatment of the wastewater that is generated in a region before being discharged into a water body. The investment in wastewater treatment facilities is one of the important parts of a nation’s total public expenditure. Because of this, and also because Sewage carrying systems and entire sewerage systems solutions are costly and very difficult to reverse, it is important that they should planned and designed efficiently. Many cities and industries are faced with the problem of planning Sewage collection system and treatment to collected sewage for a growing Society. Poor planning can result in the construction of an unnecessarily expensive, non-optimal, system. The day to day increasing costs of construction, increasing difficulty of the treatment processes and the limited availability of capital for investment has focused attention on the need for better planning of improvement of capacity of Sewage carrying systems.

The purpose of this study will to develop an economic decision model to be used as a management and planning tool by regional and local planners for the sequential expansion, designing, upgrading, and regionalization of sewage collection system at a minimum total discounted future cost. The analysis will include the projected populations, wastewater quantity, interest rates, inflation rates, construction costs etc. For this case study of Eranjada village in Badlapur city, Maharashtra is taken.

II. DYNAMIC PROGRAMMING
Dynamic programming was developed for dealing with sequential decision processes. It is based on Bellman’s Principle of Optimality (Bellman and Dryfus, 1962), which states that “an optimal policy has the property that, whatever the initial state and initial decision are, the remaining decisions must constitute an optimal policy with respect to the state resulting from the first decision.” Mathematically, this can be written as

\[ f_s(x) = \max \left\{ r(d_n) + f_{N-1}(T(x,d_n)) \right\} \\
\text{d}_n \in \mathcal{X} \]

Where
\( f_N(x) = \) the optimal return from an N-stage process when initial stage is x
\( r(d_n) = \) immediate return due to decision \( d_n \)
\( T(x,d_n) = \) the transfer function which gives the resulting state
\( \mathcal{X} = \) set of admissible decision

Dynamic programming is a method used for solving complex problems by breaking them down into simpler sub problems. It is applicable to problems exhibiting the properties of overlapping
sub problems which are only slightly smaller and optimal substructure. When applicable, the method takes far less time than other methods. The method behind dynamic programming is quite simple. In general, to solve a given problem, we need to solve different parts of the problem (sub problems), then combine the solutions of the sub problems to reach an overall solution. Many times, most of these sub problems are really the same. The dynamic programming approach seeks to solve each sub problem only once, thus reducing the number of computations. This is especially useful when the number of repeating sub problems is exponentially large.

Dynamic Programming method can be used for finding Shortest routes/paths for water pipe line, sewer line from complicated network etc., for obtaining an exact solution to solve complex reservoir operational problems ([Ilaboya I.R et al. (2011)])[3], to develop an approach of objectively selecting and prioritizing sewerage projects within available funds and system capacity (Md. M. Rashid et al., (2011)) [6], for solving regional wastewater treatment system capacity expansion problems. (S.L.Ong et al. (1990)) [8]. Application of dynamic programming is very useful for obtaining the optimal design of sewer line. The cost was determined by various equations used for finding cost of manholes, cost of excavations, and cost of sewer pipes. Sewer line was designed by using Manning’s equation and Continuity equation and using dynamic programming. (Nagoshe S.R et al. (2014)) [5].

III. GENERAL DETAILS ABOUT THE DESIGN OF SEWER

For the hydraulic design of the pipe, Manning’s equation is used, which is given as

\[ V = \left(\frac{1}{n}\right) R^{2/3} S^{1/2} \]  

(2)

Where,

- \( V \) = Design velocity in m/s
- \( n \) = Manning’s roughness coefficient
- \( R \) = Hydraulic radius in m
- \( S \) = Hydraulic slope

Program is made using Microsoft Excel to design of sewer network thereby limiting design constraints like maximum and minimum velocity, maximum and minimum cover, depth and slopes. The design process includes numbering of the nodes and likes, assignment of flows based on population at different nodes, selecting a set of feasible diameters out of the set of specified commercially available diameter for each pipe subject to the condition that the velocity requirement and slope requirement are satisfied (maximum and minimum slopes). This begins with the maximum permissible ratio of depth of flow in pipe (d) to the diameter of pipe (D), calculation of actual pipes slopes and their elevations, determination of velocities and depths of flows in the line, checking of the minimum cover depth. The result includes the peak flows, water depths, pipe slopes for each line. Also the U/S and D/S ground elevations, invert elevations/levels calculated and accordingly excavation depth for each line is calculated. In respect of nodes the total excavation depth and the difference in elevation of the highest invert entering the node and that of leaving the node is calculated. The more complicated and larger the network, it will take more time to design.

IV. CASE STUDY - ERANJAD VILLAGE, BADLAPUR, MAHARASHTRA

A. General Information about Badlapur City

Badlapur is a city in Thane District, Maharashtra state, India. It is a part of the Mumbai Metropolitan Region. Due to population growth in nearby cities, people working in Mumbai have been moving to Badlapur for a number of socio-economic reasons, including close proximity to Mumbai via rail. Badlapur city encompasses the old villages of Badlapur, Kulgaon, Manjarli, Belavali, Katrap, Eranjad and many other small villages. In this case study Eranjad Village is taken for design of Sewage carrying system, which is 2.5 Km from Badlapur railway station. Badlapur was recognised as a town in 1971, as a municipal town in then Ulhasnagar tehsil. The city has seen massive growth since the 1980s, with a rapid increase in population, due in part its proximity to Mumbai by rail.

B. Existing system: (Source: World Bank Financing strategy and Advisory services for cities in Maharashtra, 2011)

The source of water supply to Kulgaon Badlapur is Ulhas river. Present supply is about 145 lpcd, with an estimated supply at consumer end of 127 lpcd.

Waste water generated from the town is 19.17 MLD. It is disposed off at household level through septic tanks. Kulgaon Badlapur has no centralized sewerage system and no means for safe wastewater
treatment and disposal. The existing individual septic tanks and absorption pits are a source of odour and filth. Effluent from the septic tanks finds its way into the river, resulting in gross pollution of the river and ground water. It also causes contamination of the drinking water due to ingress of waste water in the leaking empty water lines. The flooding in rainy season poses a serious possible threat to public health. The need for a sewerage system is therefore felt urgently. The sewerage project is therefore proposed as one of the most important infrastructure projects for Kulgaon Badlapur and accordingly the DPR has been prepared and sewerage system project work funded under JNNURM (Jawaharlal Nehru Urban Renewal Mission) costing Rs. 2827 Million is in progress since 2010-11.

C. Design proposal for proposed sewer network at Eranjad Village, Badlapur

The preliminary work for a design engineer is to carry out field investigation and further to study carefully the characteristics of the study area pertaining to the road network pattern, projected population, land topography, natural barrier, existing and proposed land use, tentatively proposed site for pumping station and sewage treatment plant and the outfalls etc. The location plan. shows various housing unit, street orientation for the study area( Fig.1).

D. Data Collection

For design a Sewer network of Eranjad village in Badlapur, the following data were obtained from Kulgaon Badlapur Municipal Council’s (KBMC) office.
1) Collection of the population as per census 2011.
2) Road map of Badlapur City.
3) Data of undergoing Sewer network.

E. Population forecast

Geometrical Increase method will be most suitable to forecast the population of Badlapur City as it is growing city having vast scope of expansion. On similar concepts Population of Eranjad village is calculated is shown in Table I. For designing the sewage carrying system forecasted population of 2041 is used. Population at each node is also forecasted to calculate the discharge coming at each node.

F. Selection of routes/path from network using Dynamic Programming

Sn - Node in stage n
Xn - Node in stage n-1 from which Sn is reached
d(Xn,Sn) - Distance between nodes Xn and Sn
fn*(Sn) - Minimum distance from source node 1 to node Sn
fn*(Sn) = - mid(d(Xn,Sn)+fn-1*(Xn))

<table>
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<th>Stage (n)</th>
<th>Sn</th>
<th>Xn</th>
<th>d(Xn,Sn)</th>
<th>fn-1*(Xn)</th>
<th>d(Xn,Sn)+ fn-1*(Xn)</th>
<th>fn* (Sn)</th>
<th>Xn*</th>
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1) Shortest route is shown as M-H-G-D-C-B having shortest distance as 624.5 mtr and eliminated nodes are A, N, E, F, I, J, K. (Fig. 2)
2) Again applying Dynamic programming for eliminated nodes.

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<th>2031</th>
<th>2041</th>
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From table -

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<td>775.5</td>
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</table>

Shortest Route is H-J-I-F-E-N and eliminated node is K and shortest distance is 775.5 mtr. (Fig. 3)

Loopholes found in the Existing sewage carrying System design, taken for ongoing project work is as below.

- Manhole spacing is more i.e, even up to 40 to 50 mtr at few locations instead of 30 mtr.
- Main sewer line size is kept small i.e 150 mm, thus it will create frequent choke/overflow problem.
- Minimum cover of 1 mtr above top of sewer line is not maintained and sewer line to be laid shown at shallow depth.
- Invert drops are not provided even after having steep ground surface.

**G. Design of sewage carrying system (Sewer line)**

- Design Period - 30 years up to 2041
- Type of pipe - Circular R.C. NP3 class and NP4 class
- Water supply rate - 135 LPCD
- Sewage generated - 80% i.e. 108 LPCD
- Manning’s Constant (n) - 0.013
- Peak factor - 3 (as population is less than 20000)
- Infiltration - 10%
- The minimum diameter of sewer adopted is 200 mm instead of 150 mm to avoid frequent choke up problem.(Source: NCRPB)
- Circular manholes in Brick masonry
- Scraper manholes after each 5 manholes
- Ventilation arrangement by providing ventshaft @ 150 mtr interval or at every 5th manhole.
- Design is carried out before 2011 census, thus population of 2041 is taken as 7,82,464 instead of 10,65,122 calculated based on census 2011.

Results obtained can be tabulated below in table IV.

**V. Conclusion**

By using Dynamic programming method we can optimize and select appropriate pipe network. Existing design of ongoing project needs to be changed otherwise there will be needs of capacity expansion in future. Changes to be made are as follows.

- Sewer line of 150 mm dia should be replaced with minimum 200 mm dia. Pipe sewer line.

**H. Result and discussion**
Extra manholes need to be constructed, where spacing between two manholes are more than 30 mtr.

NOTE: Line LK is kept side while solving above sewer network for finding shortest route by using Dynamic Programming because it is a compulsory route. Shortest route is shown as M-H-G-D-C-B having shortest distance as 624.5 mtr and eliminated nodes are A, N, E, F, I, J, K.

To find shortest route for eliminated nodes J, K, I, F, E, N only, because it seems that line L-K and A-C are compulsory routes towards Node K and C. Shortest route is shown as H-J-I-F-E-N and eliminated Node K will be connected to Node J as length of line JK is less than line IK.

- Extra manholes need to be constructed, where spacing between two manholes are more than 30 mtr.
### TABLE IV
### RESULTS OBTAINED

<table>
<thead>
<tr>
<th>Line from Manhole to Manhole</th>
<th>From Node</th>
<th>To Node</th>
<th>Peak flow in cum/sec</th>
<th>Length in mtr</th>
<th>Diameter in mtr</th>
<th>Slope 1 in</th>
<th>No. Of Manholes in Line</th>
<th>Average Excavation depth of line up to Invert level in mtr</th>
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<td>1-25</td>
<td>A</td>
<td>C</td>
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<td>0.20</td>
<td>80</td>
<td>27</td>
<td>1.441</td>
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<td>C</td>
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<td>0.20</td>
<td>152</td>
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REFERENCES


