DESIGN OF WASTEWATER COLLECTION SYSTEM WITH LEAST COST USING DYNAMIC PROGRAMMING

Kouji Ogawa, Winai Liengcharernsit, Hiroyuki Araki, and Kenichi Koga
Saga University, Saga.

Introduction

In the design of a wastewater collection system, an engineer must decide whether he will use a large sewer with mild slope or a smaller sewer with steeper slope. The decision on one sewer section will affect the design of all the downstream sections, and of cource, will affect the installation cost as well as the operation and maintenace (O&M) costs of the whole sewerage system. Selection of the most suitable sizes and slopes of sewers which satisfy the hydraulic requirements at the cheapest cost is needed.

In this study, a computer program is developed to help design of the wastewater collection system. The dynamic programming optimization algorithm is applied to select the design alternatives with result in the lowest cost, taking into account both installation cost and O&M costs. The design is made to meet the specified criteria, including maximum and mimimum flow velocities, minimum cover, maximum allowable depth, etc. A number of intermediate pumping stations are also allowed. The O&M costs are taken into account in terms of the present values of annual costs which are added to the installation cost of the system.

Model Development

From the map of the project area which shows various types of land uses including residential, commercial and industrial areas, exising roads, canals, rivers, and other infrastructures, as well as data on topography and possible locations of the wastewater treatment facility, a number of preliminary layouts of the sewerage system can be made. For each layout, wastewater flow rate in each sewer is estimated taking into consideration the population density, types of commercial establishments and industries connected to the sewers, available water use data, infiltration rate, etc. From these preliminary layouts, the dynamic programming algorithm will be applied to determine the most suitables sizes and slopes of all sewer lines.

On each alternative of sewer layout, a number of manholes are located. The manholes are normally placed at some different intervals depending on the local circumstances such as the location of road intersections, and the sewer size (which must be roughly estimated at the beginning). Numbers are then given to all manholes and connecting sewers for the referring purpose. The computation will start at the upstream end of each sewer line and end at the last manhole located at the treatment plant.

At each manhole, some different crown levels of the outflowing sewer are considered. The highest level should be at a proper depth below the ground surface which satisfies the minimum sewer cover requirement, whereas the lowest level should be placed at a suitable depth which is practical for the existing geological condition and local installation techniques. The interval between each level can be in the range of 0.10–1.00 m depending on the required accuracy and capacity of the available computer facility. The crown levels of the outflowing sewer at each manhole are the decision variables to be determined in the dynamic programming model.

Starting from the upstream manhole, the minimum and maximum slopes of the outflowing sewer are determined based on the estimated wastewater flow rate, so that all the hydraulic requirements, which normally include minimum and maximum flow velocities and ratio between depth of flow and sewer diameter, are satisfied. The slope of a sewer connected between two adjacent manholes is computed from the difference in elevations of the connecting points divided by the distance between manholes. Only those connections with slopes within the favorable limits are considered feasible. It should be noted that installation of a pumping facility is also allowed and the crown level of the outflowing sewer will be set at the highest possible level if a pumping unit is installed at that manhole. Figure 1 illustrates sewer connections between a number of manholes starting from the most upstream end.

For each feasible connection, the required sewer size is determined and then cost estimation is made. This cost includes excavation cost, sheet-pile cost, sewer cost, refill cost, manhole cost, and installation cost and present values of annual O&M costs of the installed pumping facility.

For each level of sewer crown in the adjacent downstream manhole, the cumulative costs of various feasible connections are computed by adding the cost of this sewer section, which connects to that sewer crown level from some different levels of sewer crown at the adjacent upstream manhole, to the minimum cumulative cost to the corresponding upstream sewer crown level. The connection which results in minimum cumulative cost is selected and recorded. This connection will be considered in the next downstream sewer section while other connections with higher costs will be eliminated. The recursive relationship can be written as:

$$f_n^*(s) = \min\{c_{xn} + f^*_{n-1}(x_n)\}$$

where $f_n^*(s)$ is the minimum cumulative cost to level s at the manhole n,

$f^*_{n-1}(x_n)$ is the minimum cumulative cost to level x_n at the manhole $n-1$,

c_{xn} is the installation cost between the crown level s at the manhole n and the level x_n at the manhole $n-1$.

Note that if a pumping unit is installed at the manhole $n-1$, its cost will be included in c_{xn}. Using this recursive relationship, the solution procedure moves downstream stage by stage – each time finding the optimal crown level of the outflowing sewer at each manhole – until it reaches the last manhole located at the treatment plant. The optimal crown levels at the manholes and the sewer diameters required for those connections obtained from this solution procedure will result in the lowest cost for this sewer layout pattern. This solution procedure is then applied to another layout patterns. The layout which results in the overall minimum cost is considered most suitable in the economical viewpoint.

Model Testing

A computer program is written based on the above mentioned solution procedure. The developed computer program is tested by applying to a number of layouts with some different values of cost items, wastewater flow rates, topography, and complexity of the sewer network.

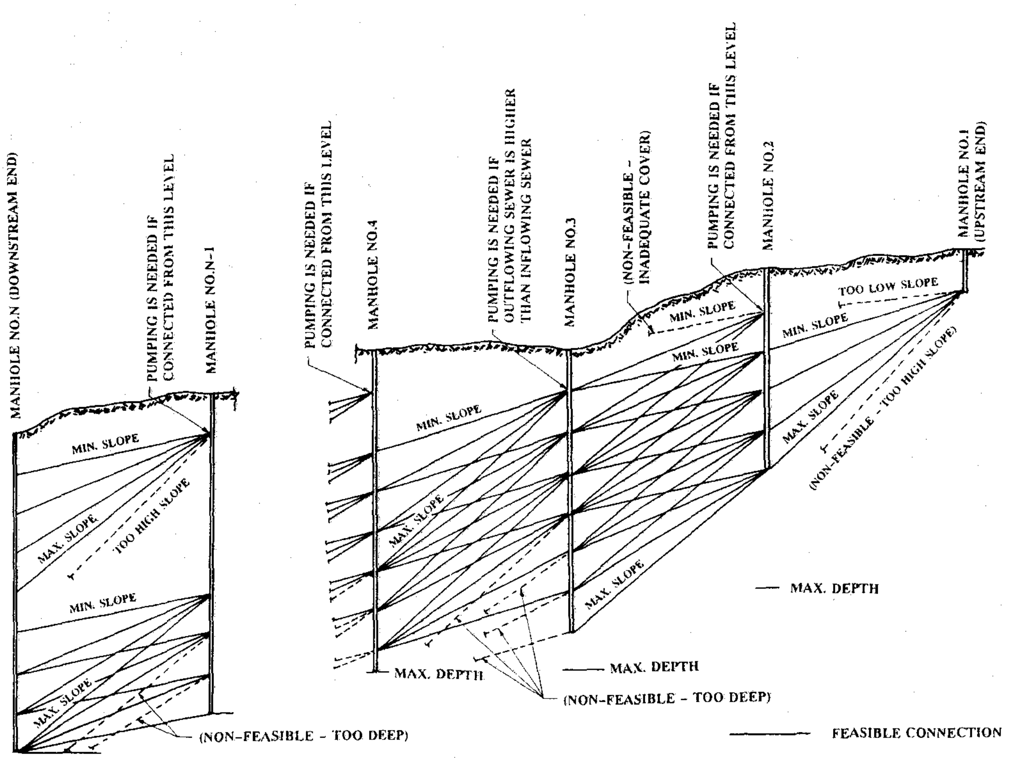

Figure 1. Various alternatives of sewer connections.