MODULE - 8 LECTURE NOTES – 6

URBAN STORMWATER MANAGEMENT

INTRODUCTION

Urban stormwater management systems are meant to guide, control and modify the quantity and quality of surface runoff. There are basically five subsystems which characterizes the urban drainage system: (i) surface runoff subsystem (2) storm sewer subsystem (3) detention subsystem (4) open channel transport subsystem and (5) receivers such as rivers, lakes or oceans. In this lecture we will discuss about the various subsystems and the design of storm sewers using various methods.

SUBSYSTEMS

The surface runoff subsystem transforms the rainfall input into surface water runoff. The outputs runoff hydrograph from surface runoff subsystem is the input to the storm sewer subsystem. Storm sewer subsystem transports runoff to either a detention subsystem or an open channel transport subsystem or a receiver subsystem. Output releases from a detention subsystem can be the input to an open channel subsystem or a receiver subsystem. Output releases from open channel subsystem can be the input to a detention subsystem or a receiver subsystem.

In urban stromwater management, the determination of runoff yield and the optimal design of storm sewer networks are very important. Strom water runoff alleviation is a major task.

STORM SEWERS

Strom sewers play an important role in urban stromwater management.A storm sewer system may consist of a number of sewers, junctions, manholes and inlets in addition to regulating and operating devices. The design of storm sewer includes determining the diameter, slopes and crown elevations of each pipe in the network. The design models can be divided as hydraulic design models and optimization design models. The hydraulic design models determine the sewer diameters by considering only the hydraulic parameters. In optimization design models, the minimum sewer size that is able to carry the design discharge under full pipe gravity conditions is determined. In these design models, the sewer system layout is predetermined and the sewer slope is assumed to be same as that of ground slope. The assumptions and constraints commonly used in storm sewer design are:

(i) Sewer is usually designed for gravity flow, No need of pumping stations or pressurized sewers.

(ii) The pipes used are commercially available circular ones with a minimum diameter of 20 cm.

(iii) The design diameter should the smallest available pipe with flow capacity equal or greater than the design discharge and satisfies all constraints.

(iv) The storm sewers must be placed well below the ground level to prevent frost, drain basements and also to allow sufficient cushioning against breakage due to ground surface loading. Therefore, minimum cover depths should be specified.

(v) At junctions, the crown elevation of the upstream sewer should not be lower than that of the downstream sewer.

(vi) A minimum permissible flow velocity at design discharge or at barely full pipe gravity flow should be specified to prevent excessive deposition of solids in the sewers.

(vii) A maximum permissible flow velocity should be specified to prevent scouring effects.

(viii) The downstream sewer should not be smaller than any of the upstream sewers at any junction.

(ix) The sewer system is a dendritic network converging towards downstream without any closed loops.

DESIGN OF STORM SEWERS

(1) Rational method:

This is the most popular method for the design of storm sewers. The surface runoff peak is estimated using the rational formula:

$$Q = C\,i\,A$$

where Q is the peak runoff, C is the runoff coefficient, i is the average rainfall intensity and A is the drainage area. If there are m subcatchments, then

$$Q = i\sum_{j=1}^{m} C_j A_j$$

The rainfall intensity i is the average rainfall intensity over a particular basin or sub-basin. The time of concentration, t_c is the time at which the peak runoff reaches the point of interest. The t_c to any point in a storm sewer system is the sum of the inlet time t_0 and the flow time in the upstream sewers t_f. i.e., $t_c = t_0 + t_f$, where t_0 is the longest time of overland flow to reach the storm sewer inlet and $t_f = \sum_{j=1}^{n} \frac{L_j}{V_j}$ is the flow time required within a pipe of length L_j and average flow velocity V_j.

(2) Hydrograph method:

In this method, the input design hydrograph at the upstream end of the sewer is propagated to the downstream end of the sewer through some routing methods. This sum of the routed hydrographs from all the upstream sewers is added to the surface runoff hydrograph at the downstream junction. This represents the design inflow hydrograph to the downstream sewer pipe. Now, based on the commercially available pipes, those pipes which can handle the peak discharge of the inflow hydrograph and maintain a gravity flow are selected.

A simple hydrograph design method is the hydrograph time lag method. which is a hydrologic routing method. In this method, the inflow hydrographs of each sewer are shifted by a sewer flow time without distortion t_f to generate the outflow hydrographs. These outflow hydrographs are added at a manhole with the direct inflow hydrograph of the manhole to generate the inflow hydrograph of the downstream sewer. This can be expressed as

$$\sum Q_{ij} + Q_j - Q_0 = \frac{dS}{dt}$$

where Q_{ij} is the inflow from the i^{th} upstream sewer into junction j, Q_j is the direct inflow into the junction, Q_0 is the outflow from the junction to the downstream sewer and S is the water stored at the junction.

(3) Minimum cost design:

In this method, the minimum cost of sewer system is achieved by a trade-off between the pipe cost and the excavation cost. A specific amount of discharge can be carried using a steeper pipe, if one wants to reduce the pipe cost. This may in turn increase the excavation cost (for increased slope). The design variables in this problem are the pipe diameters, u/s and d/s crown elevations of sewers and the depth of manholes. Often, dynamic programming (DP) is used to solve the least cost design of storm sewer systems. The stage, state, decision, return and transformation of DP are explained below:

Stage: the entire sewer network is divided into several stages by drawing imaginary isonodal lines. These lines pass through manholes which are separated from the system outlet. A stage i includes the pipes connecting u/s manholes on line i to d/s manholes on line i+1. Hence, if there are *I* isonodal lines, there will be *I - 1* stages. The manholes on any line *i* are connected to the outlet by *I-I* pipe sections. The isonodal lines are constructed starting from the outlet and proceeding u/s. The numbering is done reversely starting from u/s and proceeding to d/s. A simple network with isonodal lines is shown in figure 1.

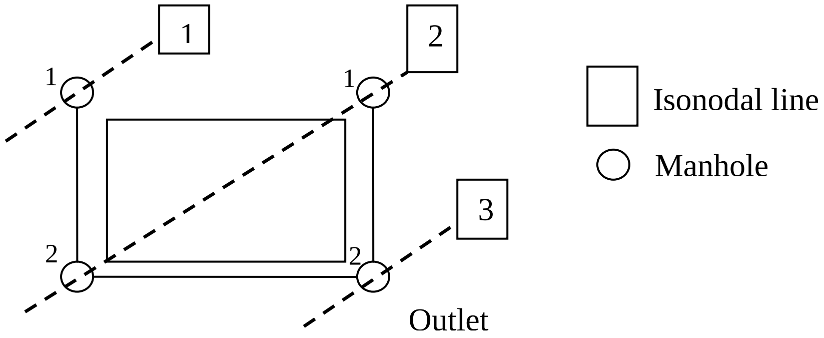

Fig. 1 Isonodal lines of a simple network

States: At each stage *i*, the states are the crown elevations of the pipes. Let $S_{mi,\ mi+1}$ be the input states i.e., crown elevation at the u/s end of the pipe connecting manholes m_i and m_{i+1} and $\hat{S}_{mi,\ mi+1}$ be the output states i.e, crown elevation at the d/s manholes m_{i+1}.

Decision: The decision $D_{mi,\ mi+1}$ is the drops in the crown elevations of the pipes across the stage. The drop in elevation represents the slope. Now, by using Mannings eqn. the pipe diameter can be determined for design flow rate, assuming full pipe flow.

Return: The cost of each pipe and the respective u/s manhole. Each manhole on u/s isonodal line is drained to the d/s isonodal line. Therefore if there are M_i pipes connecting across stage *i*, then the total return at each stage *i* can be expressed as $r_i = \sum_{m_i}^{M_i} r_{m_i,m_{i+1}}\left(S_{m_i,m_{i+1}}, D_{m_i,m_{i+1}}\right)$.

Transformation: This defines the transformation of input states i.e., crown elevations $S_{mi,\ mi+1}$ into output crown elevations $\hat{S}_{mi,\ mi+1}$, through the decision variables $D_{mi,\ mi+1}$. This can be expressed as

$$\hat{S}_{mi,\ mi+1} = S_{mi,\ mi+1} - D_{mi,\ mi+1}$$

The recursive equation for each pipe at each stage is

$$f_i\left(S_{m_i,m_{i+1}}\right) = \min_{D_{m_i,m_{i+1}}} \left[r_{m_i,m_{i+1}}\left(S_{m_i,m_{i+1}}, D_{m_i,m_{i+1}}\right) + f_{i-1}\left(S_{m_i,m_{i+1}}\right) \right] \qquad i = 1,2,\ldots I-1$$

where $f_i(\hat{S}_{mi,\ mi+1})$ is the minimum cost of the system that is connected to manhole m_{i+1} through manhole m_i. Hence, the recursive equation for all pipes in the state can be expressed as

$$\sum_{T_{m_i,m_{i+1}}} f_i\left(T_{m_i,m_{i+1}}\right) = \sum_{T_{m_i,m_{i+1}}} \min_{D_{m_i,m_{i+1}}} \left[C_{m_i,m_{i+1}}\left(T_{m_i,m_{i+1}}, D_{m_i,m_{i+1}}\right) + f_{i-1}\left(T_{m_i,m_{i+1}}\right) \right] \qquad i = 1,2,\ldots I-1$$

where $T_{mi,\, mi+1}$ is the combinations of pipes m_i from isonodal lines i to i+1.

DETENTION SUBSYSTEM

The runoff volume increases due to urbanization. Detention is meant to reduce the peak runoff rates by holding the runoff for a short period of time. The water is then released to natural water course as shown in figure 2. The detention structures can be a road culvert or even a reservoir with control devices. Retention is the storage of water for a long period of time. The water may never be released to a natural water course. The water in retention may be consumed by plants, evaporation or even infiltration.

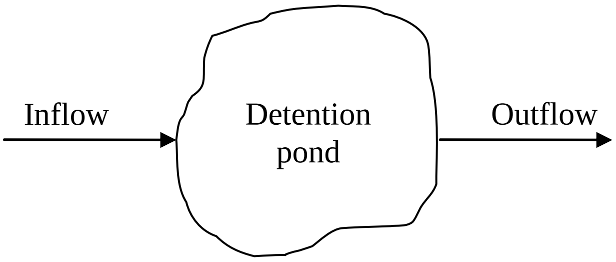

Fig. 2 Detention Structure

Detention storage can be near the precipitation site or in the storm sewers or in d/s impoundments. Detention may not significantly reduce the total runoff; but it reduces the peak runoff by redistributing the runoff over time as shown in figure 3.

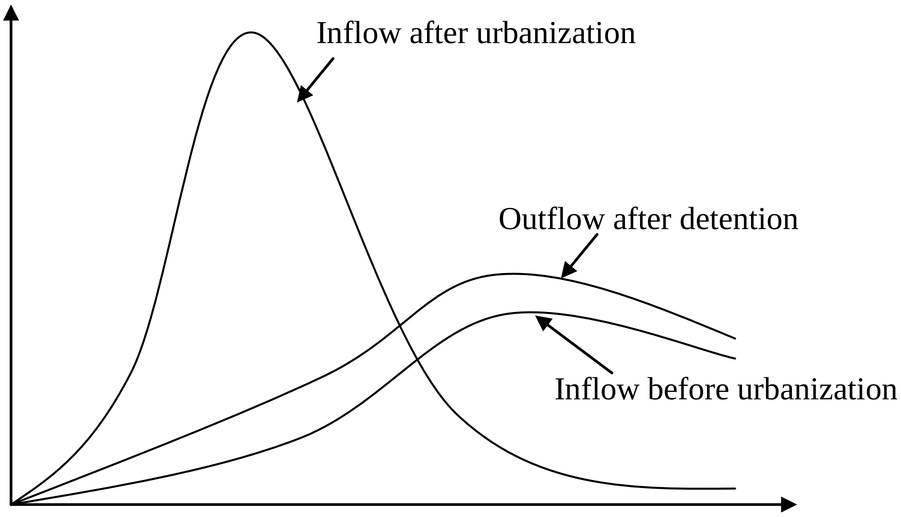

Fig. 3 Inflow and Outflow hydrographs

BIBLIOGRAPHY / FURTHER READING

1. Jain, S.K. and V.P. Singh, Water Resources Systems Planning and Management, Vol. 51, Elsevier Science, 2003.
2. Loucks D.P. and van Beek E., ‘Water Resources Systems Planning and Management’, UNESCO Publishing, The Netherlands, 2005.
3. Loucks, D.P., J.R. Stedinger, and D.A. Haith, *Water Resources Systems Planning and Analysis*, Prentice-Hall, N.J., 1981.
4. Mays, L.W. and K. Tung, *Hydrosystems Engineering and Management*, Water Resources Publication, 2002.
5. Vedula S., and P.P. Mujumdar, *Water Resources Systems: Modelling Techniques and Analysis*, Tata McGraw Hill, New Delhi, 2005.