ROLE OF DETENTION AND RETENTION STORAGE IN CONTROLLING URBAN FLOODING

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Abstract

Urbanization increases peak flood that adversely affects downstream floodplains. People want urban development without rise in flood peak in post development period. Computation of peak flood in an urban catchment is necessary for the planning and design of storm water drainage system. Peak inflow flood to be adopted for the design depends on the frequency of occurrence or return period which in turn is decided by cost and funds available for development. Storage of excess floodwater in detention and retention basins is widely used to control the increased run-off due to urbanization of undeveloped areas e.g. smart cities. Such basins in the catchment area offers excellent water quality benefits since pollutants are removed through sedimentation, degradation and other mechanisms. Run-off temporarily stored in the basin are helpful in conservation of flood water and artificial recharge of ground water and consequent rise in water table. Apart from water conservation, they help in fish culture and offer excellent recreational facilities for urban population. The paper is intended to discuss the various aspects of hydraulic and hydrologic design of detention and retention basins.

Key words: Peak flood, detention basin, flood routing

1.0 INTRODUCTION

Urban storm water drainage in India is becoming increasingly important over years due to rising population in the cities. Most of the metropolitan cities in India e.g. Delhi, Kolkata, Mumbai, Chennai are facing acute problem of communication due to water-logging during rainy seasons when life comes to a standstill. Generally, the cities are built by the side of rivers which are in spate during monsoon. Urbanization leads to higher run-off as most of the open spaces are being covered and the existing water bodies are being filled in to meet the increasing need for human habitations, roads, industries etc. Majority of the people, migrating to cities and encroaching on flood plains for their livelihood, are poor and most affected by the floods. Safe disposal of storm water without causing water-logging and flooding should be given priority in any urban development program. People curse God when floods damage localities in the pre-development stage. Same people ask for compensation from project authorities when flood damage occurs in post-development period.

Urbanization of rural areas and development of smart cities, conceived recently by the Govt. of India, will result in rise in flood peak that will adversely affect downstream floodplains. Many local government are enacting ordinances which require that the post- development flood peaks do not exceed pre-development peaks i.e. zero excess runoff for defined storm frequency.

The detention and retention basins are most effective means to control peak flood. Size of the basin can be adjusted to generate outflow peak flood discharge same as the pre-development flood peak. Rise in flood level causes congestion of flow and sometimes backflow into the storm sewers due to rise in flood level and consequent submergence. To ensure free fall of the storm sewer, it is important to ensure that the submergence do not exceed a critical value (Mazumder and Joshi(1981), Mazumder & Debroy(1998) .This paper deals with different hydrologic and hydraulic aspects of design of detention and retention basins used to control flooding.

1.0 ESTIMATION OF PEAK FLOOD

Peak inflow flood from an urban/semi urban catchment can be determined by a number of methods, namely, empirical formulae, rational formula, SCS-method, unit hydrograph method etc. Peak flood/HFL data are not available in many catchments, especially for small streams in remote and inaccessible areas. However, rainfall data collected by Indian Meteorological Department (IMD) are usually available for years. Depending on the size of catchment areas, a number of reliable methods of flood estimation based on observed rainfall data are briefly discussed underneath.

2.1 Use of Empirical Formula For Flood Estimation

One of the most popular empirical formula which is used in various part of India for the estimation of flood peak, is the Dickens Formula. This formula gives direct relation between flood peak (Q)and the drainage area(A) as follows:

$$Q = C\,A^{3/4} \qquad (1)$$

Where, Q = Peak Flood discharge in Cumec

A = Catchment Area in Km^2

C = Dickens constant with values varying between 6 to 30 as mentioned underneath.

North – Indian Plain- C=6

North – Indian Hilly Regions - C varies from11 to14

Central India - C varies from 14 to 28

Coastal Andhra and Orissa- C varies from 22 to 28

Such empirical formula should be avoided as it is independent of rainfall.

2.2 Rational Formula

The rational formula for estimating peak flood is based on the concept that the critical rainfall intensity continues indefinitely and uniformly all over the catchment. The runoff at the outlet of a catchment will increase until the time of concentration T_C, when the whole catchment starts contributing flows to the outlet. The peak flood is given by the following expression:

$$Q_p = 0.028\, f\, P\, A\, I_c \qquad (1)$$

where,
Q_p = peak flood in cumec
A = Catchment area in hectares
I_c = Critical intensity of rainfall in cm/hr for the selected frequency and duration equal to the time of concentration, t_c given by the relation

$$I_c = F/T[(T+1)/(t_c+1)] \quad (2)$$

P = Coefficient of run-off for the given catchment. Since the run-off coefficients are different for different types of surfaces (e.g. concrete roof top, metalled roads, lawns etc.), equation (1) can be written as

$$Q = \sum Q_n = 0.028 f\, I_c \sum (P_n A_n) \ldots.. n = 1.2.3\ldots. \quad (3)$$

where,
Q_n i.e. Q_1, Q_2, Q_3…. Etc. are the peak discharges from different areas A_n i.e.A_1, A_2, A_3…etc. having different run-off coefficients P_n i.e.P_1, P_2, P_3…respectively.
f = Spread factor for converting point rainfall into areal mean rainfall.
F = total rainfall in cm in a duration of T hours depending on storm duration and design return period
tc= Time of concentration in hours

Further details of computation of peak flood by Rational method may be found in IRC: SP:42(2014).Rational formula is not applicable for catchment areas greater than 25 sq.km.

2.3 SCS Method (Run Off Curve Number Method)

The SCS (Soil Conservation Services) method or Runoff Curve Number(CN) method of estimating direct runoff from storm rainfall is developed by U.S Soil Conservation Services. Relation between rainfall, runoff, initial abstraction and potential maximum retention can be expressed as;

$$Q = (P-I_a)^2 / [(P-I_a) + S] \quad (4)$$

Where,
Q = storm runoff in mm
P = storm rainfall in mm
Ia = initial abstraction in mm = 0.2S
S = potential maximum retention in mm =(25,400/CN) – 254
CN= Curve number applicable for the given surface and antecedent soil moisture condition
Further details of computation of peak flood by SCS method by use of SCS curve numbers are available in IRC: SP:42(2014)

2.4 Synthetic Unit Hydrograph Method
Unit hydrograph can be prepared synthetically (Subramanya, 2013, CWC Flood Estimation Reports) by using physiographic data like area of catchments, length of stream, longitudinal bed slope, soil and cover conditions etc. Daily rainfall corresponding to design flood return period is

found from iso-hyetal curves for the catchment. Hourly distribution of rainfall and rainfall excess-values corresponding to design storm are found. By using the unit hydrograph and rainfall excesses, flood hydrograph is prepared and the peak flood is determined. Details of computing peak flood by using synthetic unit hydrograph are available in "Flood Estimation Reports" prepared jointly by CWC, RDSO,IMD &MORTH, Govt. of India and published by Hydrology Directorate, Central Water Commission (CWC), for 26 hydro-meteorologically similar sub-zones in India. Unlike other methods, unit hydrograph is useful for generating flood hydrograph for a given storm of required frequency/return period. Such flood hydrographs give the volume of flood flow (area under flood hydrograph gives the flood volume) which is needed for design of detention storage capacity discussed under clause-3.1 below. Unit hydrograph method of flood estimation is applicable for catchment area varying from 30 to 3,000 sq. km.

2.5 Use of Manning's Equation

When stream cross-section is available, Manning's equation can be used to determine mean flow velocity (V) from the equation

$$V = (1/n)\, R^{2/3}\, S^{1/2} \qquad (5)$$

and flood discharge (Q) corresponding to measured high flood level (HFL)

$$`Q = A.V \qquad (6)$$

where,V is mean velocity of flow in m/s, n is Manning's roughness coefficient, R is hydraulic mean depth in m given by R= A/P and S is the energy slope, A is area of cross section normal to flow in m^2 and Q is flow in m^3/s. Manning's n-values can be obtained from standard textbook of hydraulics (Chow,1970 ; French,1986).

Assuming different stages (water levels), Q-values corresponding to the different stages can be found from Manning's equation for the given stream section. Stage-discharge curve can be obtained by plotting discharges against corresponding stages/water levels. Peak flood can be obtained from the stage – discharge curve corresponding to measured HFL during flood.

3.0 DESIGN PEAK FLOOD

Design peak flood is the peak flood discharge for which the storm sewer is to be designed to safely dispose the flood water without causing water logging and other problems. Cost is one of the prime concern. Too high a peak will require large size conduits/channels requiring high investment, although it will ensure instant clearance of flood water. Apart from cost, such large size conduits/channels will run partially full with low velocity when flow of lower magnitude will occur during low flow season or during floods lower than design peak flood in other years. This will result in silting and accumulation of debris thereby increasing annual maintenance cost.The following range of design period is commonly used in storm sewer design. (ASCE-1992, HEC:22-2013)

(i) 2 to15 years for storm sewers in residential areas, most commonly 10 years
(ii) 10 to 50 years for sewers in commercial and high-value areas
(iii) 25 years for drainage culverts
(iv) 50 years for flood- protection works
(v) 5 years for District Roads
(vi) 10 years for district roads at valley points

Guidelines for Urban Drainage (IRC:SP:50-2013) prescribes rational formula for determination of design flood discharge based on design rainfall intensity. Current practice being followed in some of the metropolitan cities in India is given below:

Delhi:(i) Internal Drains- 1cusec/acre, (ii) Intercepting Drains-0.75 cusec/acre and
(iii) Main Drains-0.5 cusec/Acre
Mumbai: Critical intensity of rainfall- 50 mm/hour (Frequency of storms:2times a year)
Chennai: Critical intensity of rainfall-25mm/hour(corresponding to a duration of 1 hour with 1.25 year return period

3.0Detention and Retention Basins

Detention and retention basins are widely used to control flooding due to urbanization of undeveloped areas. Both are used for storing flood water for routing of incoming flood. While detention basins detain the storm water for a specific period of time and evacuated for absorption of following flood, the retention basin is not fully evacuated and retain flood water up to a certain minimum level/pond level so that a pool is created for use e.g. river pollution control, fish culture, percolation for building ground water etc. Water stored temporarily in the space above pond level help in flood routing and reduction of flood peak. These basins offer excellent water quality since pollutants are removed from incoming flood run-off through sedimentation, degradation and other mechanisms. Detention basins are also called dry ponds since they store run-off only during wet weather. Outlet structures are designed to completely evacuate the water so that the basin is dry and ready for moderation of following flood during subsequent storms. Retention basins are called wet pool since they retain a permanent water pool space above which is used for flood routing. Fig.1 illustrates typical L-section of a detention/retention basin. Emergency spillways are provided to take care of extra-ordinary flood higher than design peak flood.

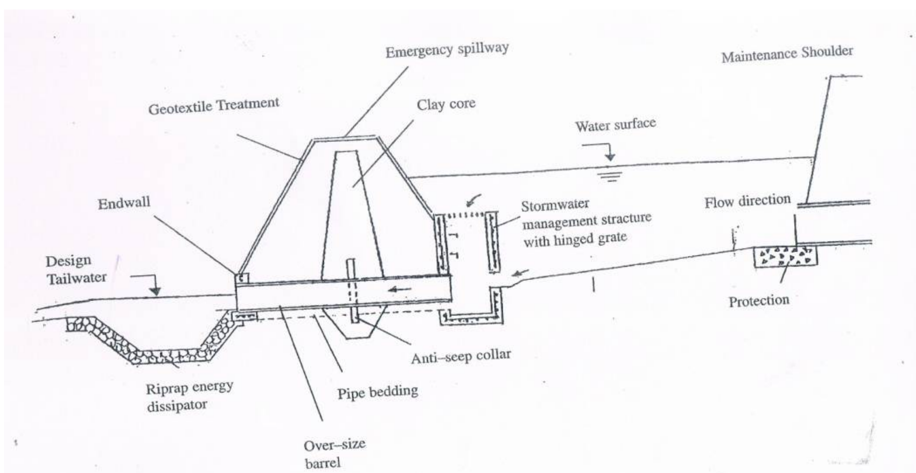

Fig.1 Sectional View of Detention Basin (Source:Hydraulic Structures -Design and Construction Hand book-By Mays, Mc.Graw Hill,1999)

3.1 Design Guidelines For Detention/Retention Basin

Specific design criteria for the basins vary under different local conditions. Some general guidelines as given by Mays (1999) and ASCE(1992), FHWA (1996) are given below.

(i)Main objective of providing the basin is to reduce the post development (without basin)peak flood to the pre-development peak as shown in Fig.2

(ii)The outfall structure should be designed to limit the peak outflow rates to allowable rates

(iii) Detention basin must have sufficient capacity for temporary storage of incoming run-off

(iv) The inlet, outlet and side slopes should be stabilized where needed to prevent erosion

(v) The side slopes (Fig.1) should be 3(H):1(V) or flatter

(vi) The channel bottom should be sloped not less than 2% toward the outlet

(vii)Detention basin length to width ratio should be no less than 3

(viii)Outlet should be provided with trash rack

(viii)An emergency spillway should be provided with adequate energy dissipation to take care of extra ordinary flood of 100 year return period

3.2 Hydrologic and Hydraulic Design of Detention/retention Basin

Denoting I as inflow rate, O as outflow rate and S as storage, The basic principle of flood routing in a detention basin can be expressed as

$$\Delta S = S_2 - S_1 = [1/2(I_1+I_2) - 1/2(O_1+O_2)]\Delta t \qquad (7a)$$

In differential form, eq. (7a) may be expressed as

$$dS/dt = dI/dt - dO/dt \qquad (7b)$$

Where,

S_1 and S_2 are the storage volumes in the basin before and after a time interval Δt, ΔS is the storage in time interval Δt, I_1 and I_2 are the inflow rates in to the basin, O_1 and O_2 are the outflow rates from the basin before and after the time interval Δt. Inflow rates can be found from inflow flood hydrograph without detention basin as discussed under sections 2& 3. Outflow rates are governed by the head (H) at control point at the outlet. For weir type control at the outlet, outflow 'O' can be expresses as

$$O = C_d . L_{eff.} H^{3/2} \qquad (8)$$

Here, L_{eff} is the effective waterway of outlet(in case of weir type control, it is the weir length), C_d is the coefficient of discharge depending upon free fall weir or submerged weir (Mazumder,2007). For orifice type outlet, Outlet discharge O can be found by using orifice flow equation

$$O = KA_0 \, (2gH_0)^{0.5} \qquad (9)$$

Where

K is orifice flow coefficient, H_0 is the orifice head and A_0 is the area of orifice

From eq.(7b), storage is maximum when I=O and the pond level is the maximum. Storage capacity of a detention pond for routing of a given peak inflow flood (without detention basin) to a desired peak outflow flood (with detention basin) can be found in a tabular form by incremental time (Δt) step method (USBR,1968). Fig.2 ilustrates the inflow (Q_{in}=I) and outflow (Q_{out}=O) hydrographs obtained by routing procedure as discussed above. Detention storage volume required V_s (=$\sum\Delta S$) is indicated by the shaded area between inflow and outflow hydrographs as shown in Fig.2.Further details about design of detention storage is given in the textbook Ground and Surface Water Hydrology by Mays (2012).It may be noted from Fig.2 that the peak value of inflow flood (inflow hydrograph 'Q_{in}' without basin) is substantially reduced to peak value of outflow flood (outflow hydrograph'Q_{out}'with basin) due to provision of detention basin.

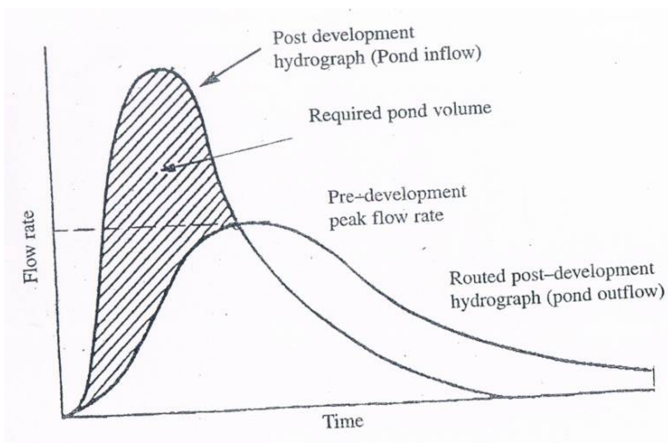

Fig.2 Routing of Inflow Flood (High Peak) by Storage in Detention Basin

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