ESTIMATION OF PEAK FLOOD AND FLOOD LEVEL FOR DESIGN OF HYDRAULIC STRUCTURES

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ABSTRACT

Estimation of peak flood and high flood level (HFL) is essentially needed for safe and economic design of hydraulic structures e.g. dams & barrages, bridges, hydro power plants, roads, flood embankments, cross-drainage structures etc. Most reliable method of estimating peak flood of any given frequency/return period, depending on importance of the structure, is to collect past peak flood data and make frequency analysis of extreme value distribution e.g. Gumbel, Log normal, Pearson type-III etc. However, such chronologic and continuous data of long duration are usually not available in many of the catchments in India. For ungauged catchments, Indian codes like IRC, RDSO and BIS recommend several empirical formulae of Dickens, Ryves, Khosla etc. for determining peak flood. Synthetic unit hydrograph method, developed jointly by CWC, IMD, RDSO & MORTH, has been included in recent revision of the codes since rainfall records are usually available for longer periods. In this paper, authors have discussed briefly the methodologies used to estimate peak flood and HFL for design of several hydraulic structures.

Keywords: Peak Flood, Design Flood, High Flood Level, Design Flood Hydraulic structures

1. INTRODUCTION

Determination of peak flood and high flood level (HFL) is essential for safe and economic design of hydraulic structures e.g. dams & barrages, bridges, hydro power plants, roads, flood embankments, cross-drainage structures etc. Over estimation of peak flood and HFL results in escalation of costs whereas underestimation of the same may lead to failure of the structures resulting in severe damages. Estimation of Peak flood and HFL are needed for the design of hydraulic structures, computation of waterway, spillway capacity, flood plain submergence, sediment flushing and many other purposes. Magnitude of flood peaks and high flood levels are usually expressed in terms of return period which is given by the inverse of flood frequency. In a gauged catchment, peak floods and flood levels are to be measured every year by use of gauges in the river. Central Water Commission (CWC:2013-14) has 954 river gauge stations in major interstate rivers. State Govts. also have installed large numbers of gauges in medium and minor within the state. The hydrological data collected from sites are scrutinized, validated and published in the form of water year book, water quality year book and sediment year book, by CWC hydro-meteorological data directorate. Water level recorders e.g. gauging staff, floats, transducers etc. are used to measure only stages i.e. flood levels as floods of different intensities flow in the river. For measurement of discharges corresponding to different flood levels, either floats or current meters are employed to find mean velocity of flow. There are other methods of discharge measurement e.g. flow meters, salt solution method, electro-magnetic method etc. (Mazumder, 2007). More sophisticated means of stream gauging e.g. ADV, ADCP, particle
image velocity-metry (EWRI/IAHR, 2007) etc. may be used depending on river size, slope and velocity of flow. The observed flow data in gauged catchments form the basis of flood-frequency analysis for estimating peak flood and corresponding high flood level (HFL). For ungauged catchments where no flow data are available, peak floods and HFL are estimated from observed rainfall data and their analysis. Various empirical methods e.g. Dickens, Ryves, Khosla (CBIP-1989; IRC:SP:89-1997; IS: 2912-1999) are prescribed in Indian codes. Such empirical formulae, however, should be avoided as they do not consider different other parameters (excepting rainfall and area of catchment) governing flood. Rational formula (IRC:SP:42, 2014) for determining peak flood is dependable for small catchments. For medium and large catchments, unit hydrograph method of peak flood estimation is quite dependable. HEC-RAS (1964) method based on Saint Venant equation (Chow,1970) is popular for estimation of Flood and HFL in rivers/channels having non-prismatic geometry.

The peak flood and HFL for which hydrologic and hydraulic design of structures are carried out are designated as design flood which vary from structure to structure, depending upon their size, importance and safety. Relative economy by cost analysis is also an important factor in the choice of design flood. As illustrated in Fig.1, optimum cost of a drainage scheme was found to be a flood of return period 25 years and hence the design flood was chosen as peak flood of 25 years return period. Tables 1 and 2 give the return periods of design floods to be considered for hydraulic design of dams, roads, cross-drainage works and flood embankments. Objective of writing this paper is to emphasise the methodology adopted in practice to find the peak flood and HFL for design of different hydraulic structures.

2.0 DESIGN FLOOD FOR DIFFERENT HYDRAULIC STRUCTURES

As already stated, design flood to be adopted for design of hydraulic hydraulic depends upon type of structures, their importance, safety requirement and costs. Failure of dams, barrages, flood embankments may result in unprecedented damages and unimaginable sufferings of people which can not be measured in terms of money. Photographs-1 and 2 illustrate flood havoc due to breach in flood embankments in rivers Ganga and Kosi.

2.1 DESIGN FLOOD FOR DAMS

Guidelines for Safety inspection of dams, compiled by Dam Safety Organization of CWC, has classified dams according to size by using the hydraulic head (from normal or annual average flood level on the downstream to the maximum water level) and the gross storage behind the dam. Indian Standard (IS : 1122-1985) gives the criteria for inflow design flood. Table-1 gives the design floods for determining spillway capacity and freeboard (above MRL) based on overall size of the dams. The relevant parameters to be considered in judging the hazard in addition to the size would be: (i) distance to and location of the human habitations on the downstream after considering the likely future developments. (ii) Maximum hydraulic capacity of the downstream channel at a level at which catastrophic damage is not expected. For more important projects, dam break studies may be done as an aid to the judgment in deciding whether probable maximum flood (PMF) needs to be used. Where the studies or judgment indicate an
danger to settlements, the PMF should be used. Any departure from the general criteria as above on account of larger or smaller hazard should be clearly brought out. It should be remembered that when floods occur in a river without a dam/barrage, people blame God. The same people will blame the project authorities and ask for compensation when floods occur in the river when dams and barrages are constructed.

2.2 **Design Flood for Roads, Cross-Drainage Works and Flood Embankments**

Construction of a road unavoidably obstructs and interferes with the natural overland flow and flow through the natural channels e.g. rivers, nallas, canals, drains etc. Suitable cross –drainage works like bridges and culverts under the road must be provided across these channels with a
### Table-1 Design Floods for Spillway Capacity and Freeboard in Dams

<table>
<thead>
<tr>
<th>S. No</th>
<th>Classification</th>
<th>Hydraulic Head (m)</th>
<th>Design Flood for Items Other Than Freeboard</th>
<th>Design Flood for Freeboard</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(Storage in Mm³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Small</td>
<td>7.5 m to 12 m</td>
<td>100 years</td>
<td>500 years/SPF, whichever is higher</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.5-10 Mm³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Intermediate</td>
<td>12 m to 30 m</td>
<td>SPF</td>
<td>1 in 1000 year flood</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(10-60 Mm³)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Large</td>
<td>Greater than 30 m</td>
<td>PMF</td>
<td>PMF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&gt; 60 Mm³)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: SPF - Standard Project Flood; PMF - Probable Maximum Flood*

view to pass the peak discharge through the channels without causing harmful afflux, flooding and disturbing the natural flow regime. Submergence and overtopping of road not only causes damage to the road and road structures, it results in disruption of traffic, loss of travel time and miseries to many of the poor people who take shelter on roads during floods in many parts of our country. Road level is to be decided keeping in view the design flood and corresponding high flood levels as mentioned in Table-2.

Culverts and underpasses are often used by local people and livestock to cross the busy roads like national and state highways in high embankments. Bridges and culverts also act as passage for up and down movement of fish and other aquatic animals. Sediments and debris carried by the streams must freely move downstream through these openings to avoid aggradations and other interrelated problems. Cross-drainage works e.g. Bridges, and culverts of adequate numbers and capacities are to be provided across the road to pass design floods as mentioned in Table-2 and IRC guidelines (IRC:5-1998, IRC:SP:13-2004, IRC:SP:42-2014).

Major causes of failure of flood embankments is overtopping and breaching of embankments during floods (Mazumder, 2007). According to its height (h) above natural surface level (NSL), an embankment is designated as low (h<3 m), medium (3 m<h<10 m) or major (h>10 m) as per IS: 12094 - 2000. Design floods for fixing top level of flood embankments are given in table-2.

**3.0 ESTIMATION OF PEAK FLOOD**

As stated earlier, peak floods can be estimated for both gauged and ungauged catchments by using different methods as mentioned under sections 3.1 and 3.2 below.
### Table-2 Design Floods for Roads, Cross-drainage Works & Flood Embankments

<table>
<thead>
<tr>
<th>CATEGORY OF ROAD/BRIDGES/CULVERTS</th>
<th>DESIGN FLOODS (Return Period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Roads</td>
<td></td>
</tr>
<tr>
<td>National &amp; State Highways</td>
<td>10 year</td>
</tr>
<tr>
<td>Do (at valley Points)</td>
<td>25 year</td>
</tr>
<tr>
<td>District Roads</td>
<td>5 year</td>
</tr>
<tr>
<td>District Roads at valley Point</td>
<td>10 year</td>
</tr>
<tr>
<td>(b) Cross-Drainage Works</td>
<td></td>
</tr>
<tr>
<td>Major Bridges of Importance (Span&gt;30m)</td>
<td>100 year</td>
</tr>
<tr>
<td>Minor Bridges (Span&lt;30m)</td>
<td>50 year</td>
</tr>
<tr>
<td>Culverts for National &amp; State Highways Up to 2 m span</td>
<td>25 year</td>
</tr>
<tr>
<td>Culverts for National &amp; State Highways For 2 to 6 m Span</td>
<td>50 year</td>
</tr>
<tr>
<td>Culverts for District &amp; village Roads Up to 2 m span</td>
<td>10 year</td>
</tr>
<tr>
<td>Culverts for District &amp; village For 2 to 6 m Span</td>
<td>25 year</td>
</tr>
<tr>
<td>(c) Flood Embankments</td>
<td></td>
</tr>
<tr>
<td>Predominantly agricultural areas</td>
<td>25 year</td>
</tr>
<tr>
<td>Urban areas having industries</td>
<td>100 year</td>
</tr>
<tr>
<td>Urban areas where anti erosion Measures are adopted</td>
<td>50 year</td>
</tr>
</tbody>
</table>

### 3.1 For Gauged Catchments

Most reliable method of peak flood estimation is to collect past annual flood series for 15 to 20 consecutive years depending upon the return period of design flood. Higher the return period, more is the period/years of peak flood data required for reliable estimation of flood. Frequency analysis is performed by tabulating the recorded peak floods and the high flood levels according to their magnitudes with the highest value on top and lowest at the bottom. There are several methods of computing design flood of any given frequency/return period e.g. Gumbel method,
Log normal method, Pearson type-III etc. All of them are essentially probabilistic methods of best curve fitting of extreme value distributions. Details of these methods are given in standard hydrology text books (Raghunath, 1985 ; CBIP, 1989). Peak floods of design return periods (Tables-I and II) can be determined by these methods for design purposes.

3.2 For Ungauged Catchments

Peak flood/HFL data are not available in many catchments, especially for 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.

3.2.1 Dickens Formula

One of the most popular empirical formula which is very popular 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:

\[ Q = C A^{3/4} \]

Where, 
Q = Peak Flood discharge in Cumecs
A = Catchment Area in Km²
C = Dickens constant with value varying between 6 to 30 as mentioned underneath.
North – Indian Plain- C=6
North – Indian Hilly Regions C varies from 11 to 14
Central India C varies from 14 to 28
Coastal Andhra and Orissa C varies from 22 to 28

3.2.2 Rational Method

The rational method is appropriate for estimating peak discharges for small drainage areas of up to about 25 sq. km. The idea behind the Rational Method is uniform 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 Tc, when the whole catchment is contributing flows to the outlet. The peak runoff is given by the following expression:

\[ Q = 0.028 P f A I \]

Where, 
Q = Maximum runoff in cumecs
A = Catchment area in hectares
I = Design Rainfall intensity in cm/ hr for the selected frequency and duration equal to the time of concentration
P = Coefficient of run-off for the given catchment
f = Spread factor for converting point rainfall into areal mean rainfall.
Further details of computation of peak flood by Rational method may be found in IRC:SP:42(2014)
3.2.3 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:

\[ Q = \frac{(P-I_a)^2}{(P-I_a+S)} \]  

Where, 
- \( Q \) = storm runoff in mm 
- \( P \) = storm rainfall in mm 
- \( I_a \) = initial abstraction in mm = 0.2S 
- \( S \) = potential maximum retention in mm = \((25,400/CN) - 254\)

Further details of computation of peak flood by SCS method by use of SCS curve numbers are available in IRC:SP:42(2014).

3.2.4 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 isohyetal curves for the catchment. Hourly distribution of rainfall and rainfall excess-values corresponding to design storm are found. By using the unitgraph 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, CWC, for 26 hydro-meteorologically similar subzone areas in India.

3.2.5 From Hydraulic Structures

Peak floods can be estimated by recording HFL upstream and downstream of existing hydraulic structures in the river e.g. dams and barrages, bridges, culverts and other cross-drainage structures. General equation for measuring flow past such hydraulic structures may be written as

\[ Q = C_d L_{eff} H^{3/2} \]  

where,
- \( Q \) is flow rate in cumec, \( L_{eff} \) is the effective waterway in m, \( H \) is the head above crest in m and \( C_d \) is the coefficient of discharge in m\(^{1.2}\)/s. \( C_d \)-value varies from structure to structure depending upon whether the flow is free or submerged, geometry of the structure etc. \( C_d \)-values for dam spillways under free and submerged conditions may be obtained from USBR (1968), IRC:-SP:13 (2004), Rangaraju (1993), French (1986) King (1954). Defining submergence as \( S = h_2/h_1 \), flow is free when \( S < S_{cr} \) and submerged when \( S > S_{cr} \). Here \( h_1 \) and \( h_2 \) are flow depths u/s and d/s of flow meter and \( S_{cr} \) is critical submergence of flow meter. \( S_{cr} \)-values for different types of flow meters were found experimentally by Mazumder (2007), Mazumder and Joshi (1981), Mazumder and Debroy (1997, 1999).

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

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

(4)

\[
Q = A \cdot V
\]

(5)

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 \(R = \frac{A}{P}\) 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. Design peak flood can be obtained from the stage – discharge curve corresponding to measured HFL or vice versa.

Usually, the stream section is measured during low flow season. Stream bed may be scoured during passage of high flood. As such scoured bed profile should be obtained to estimate design peak flood and HFL. Several methods for obtaining scoured bed profile are given by Melville and Coleman (2000).

### 4.0 ESTIMATION OF DESIGN HFL

As discussed under clause-3.1, design HFL corresponding to design peak flood can be found from stage-discharge curve where flow records are available. Stage – discharge curve can also be prepared by Manning’s equation discussed under 3.2.6. These are normal HFL assuming that the low water bed level (usually surveyed during low flow period) remains unaltered during flood. Actually, there is always some change in bed level due to scouring of bed during passage of high floods. River bed usually undergoes retrogression (especially downstream of hydraulic structures like dams and barrages) resulting in lowering of HFL. Sometimes, there is aggradations too, especially in those rivers where heavy sediment load comes from landslides. Photograph no.3 illustrate heavy sediment deposition due to landslides in Uttarakhand in 2012. River bed level rose from……m to……m due to land slides. Obviously such aggradations will cause rise in HFL also. HFL can be estimated by using softwares e.g. HEC-RAS (1964) or MIKE—11 (2013). HFL upstream of structures can be found by adding afflux (Mazumder,1998; Mazumder and Dhiman,2003) normal HFL downstream.

### 5.0 CONCLUSIONS

Design floods and HFLs are the peak floods and corresponding HFL of a given return period which are used for the design of different hydraulic structures e.g dams and barrages, roads, cross drainage structures, flood embankments etc. They are to be very carefully selected for safe and economic design of hydraulic structures. Different methods of estimation of peak floods and HFLs are discussed in the paper with the objective of guiding designers of hydraulic structures.
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