Training Course

On

Hydrological Processes in an Ungauged Catchment

[July 25 – 29, 2011]

CHAPTER-10

Risk & Reliability in Flood Estimation

By

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Organized under Hydrology Project - II

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CHAPTER 10

RISK & RELIABILITY IN FLOOD ESTIMATION

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10.0 INTRODUCTION

While designing any hydraulic structure some of the questions which may come in the mind of any designer are:

1. Why should we do risk analysis?
2. What should be the return period for which the structure should be designed?
3. What is the risk involved when we design a structure having a design life of n years for a T year return period flood?
4. How much risk is permissible?

Since design and planning are concerned with future events which are stochastic in nature, concepts of probability or frequency are used to define them. The risk acceptable, depends upon economic and policy considerations. The hydraulic structure can be designed for the worst possible event but the cost involved will be very high. So risk is calculated for a given frequency and based on risk acceptable, the structures are designed. Risk analysis concepts are explained in subsequent sections.

10.1 RISK ANLAYSIS

The most important question facing the designer of any hydraulic structure is: what is the risk of failure? In a recent study of over 300 dams disasters (Biswas and Chatterjee, 1971) it was found that about 35% of the failures were due to inadequate spillway design.

The simplest procedure in the frequency analysis estimation of design flood is to select a return period and use either graphical technique or a mathematical distribution to derive the corresponding event magnitude. The return period for which a structure should be designed is calculated based on the risk acceptable. Risk is nothing but the probability of occurrence of a flood at least once during successive years of design life. Risk acceptable depends upon economic and policy considerations. The general formula for risk calculation is: If for a time invariant hydrologic system the probability of occurrence of an event, x, greater than the design

$$p=\frac{1}{T} \tag{10.1}$$

event, x, during a period of n years is P, then the probability of non-occurrence, Q is 1-P.

If this design event has a return period to T years and a corresponding annual probability of exceedance of p then:

The probability of non-occurrence in any one year is:

$$q = 1 - \frac{1}{T} \qquad (10.2)$$

The probability of non-occurrence in n years is:

$$Q = \left(1 - \frac{1}{T}\right)^n \qquad (10.3)$$

Hence the probability that X will occur at least once in the n years i.e. the risk of failure, T is:

$$R = P = 1 - \left(1 - \frac{1}{T}\right)^n \qquad (10.4)$$

$$R = 1 - \left(1 - \frac{1}{T}\right)^n \qquad (10.5)$$

i.e.

where,

R is the risk
T is the return period for which the structure should be designed, and
n is the design life of the structure.

Example 10.1

For a hydraulic structure having a design life of 100 years, what will be the risk involved if it is designed for (i) 50 years return period flood, (ii) 1000 years return period flood.

Solution:

(i) In the first case n = 100 years, T = 50 years and the risk (R)involved may be computed by substituting the values of n & T in equation (5) as given below:

$$R = 1 - \left(1 - \frac{1}{50}\right)^{100} \qquad (10.5)$$

= 0.867
= 86.7%

(ii) In the second case, n = 100 years, T = 100 years and the risk involved is:

$$R = 1 - \left(1 - \frac{1}{1000}\right)^{100} \qquad (10.5)$$

= 0.095 = 9.5%

Table 10.1 Return Periods Associated with Various Degrees of Risk and Expected Design Life

Risk %	Expected Design Life							
	2	5	10	15	20	25	50	100
75	2.00	4.02	6.69	11.0	14.9	18.0	35.6	72.7
50	3.43	7.74	11.9	22.1	29.4	36.6	72.6	144.8
40	4.44	10.3	20.1	29.9	39.7	49.5	98.4	196.3
30	6.12	14.5	28.5	42.6	56.5	70.6	140.7	281.0
25	7.46	17.9	35.3	52.6	70.0	87.4	174.3	348.0
20	9.47	22.9	45.3	67.7	90.1	112.5	224.6	449.0
15	12.8	31.3	62.0	90.8	123.6	154.3	308.0	616.0
10	19.5	48.1	95.4	142.9	190.3	238.0	475.0	950.0
5	39.5	98.0	195.5	292.9	390.0	488.0	976.0	1949.0
2	99.5	248.0	496.0	743.0	990.0	1238.0	2475.0	4950.0
1	198.4	498.0	996.0	1492.0	1992.0	2488.0	4975.0	9953.0

Based on the risk acceptable the return period for which the structure should be designed can be ascertained.

Table 1 gives return period associated with various degrees of risk and expected design life using equation (6). Fig. provides solution of equation (6).

Example 10.2

What return period must a highway engineer use in his design of a critical underpass drain if he is willing to accept: (i) only 10% risk that flooding will occur in the next five years? (ii) 20% risk that flooding will occur in next 2 years?

Solution:

In (i), the risk involved (R) is 0.10, n = 2 years, substituting these values in the following equation:

$$R = 1 - \left(1 - \frac{1}{T}\right)^{n} \qquad (10.5)$$

$$0.10 = 1 - \left(1 - \frac{1}{T}\right)^{5}$$

or

or T = 48.1 years.

This means that there are 10% chances that a 48.1 years flood will occur once or more in next five years.

In (ii), the risk involved (R) is 0.20, n = 2 years, T = ?

$$0.20 = 1 - \left(1 - \frac{1}{T}\right)^2$$

or

or

T = 9.47 years.

It shows that there are 20% chance that a flood corresponding to a return period of 9.47 years will occur in the next 2 years. These values may also be read from the Table 1. If one is interested in knowing exactly once, twice or thrice occurrences of a flood then concepts of Binomial distribution or Poisson distribution should be used.

10.2 BINOMIAL DISTRIBUTION

The Binomial distribution is a discrete distribution and is based on Binomial theorem which states that probability of exactly x successes in n trials is:

$$P(x) = \binom{n}{x} p^x q^{n-x} \tag{10.6}$$

where,

$$\binom{n}{x} = \frac{n!}{x!(n-x)!} \tag{10.7}$$

q = 1-p
p = probability of exceedance/success,
q = probability of nonexceedance/failure,
x = number of exceedance/successes,
n = total number of events.

The assumptions for Binomial distribution are same as for Bernoulli trials. Tossing a coin or drawing a card from a pack are examples of Bernoulli trials which operates under the following three conditions:

(i) Any trial can have either success or failure, true or false, rain or no rain.
(ii) Successive trials are independent
(iii)Probabilities are stable

Binomial distribution is valid under above three conditions.

Example 10.3

If a dam is having project life of 50 years then what is the probability that flood with return period of 100 years will occur (i) once, (ii) twice during the life of the dam.

Solution:

(i) Here, n = 50 years, T = 100 years, the Probability of exceedance = p

here $p = \frac{1}{T} = \frac{1}{100} = 0.01$

$q = 1 - p$
$= 1 - 0.01 = 0.99$
$x = 1$
$n\text{-}x = 50 - 1 = 49$

$$P(1) = \binom{50}{1} .0.01^{1}.0.99^{49} \qquad (10.6)$$

$$\frac{50!}{1!(49)!}(0.01)^{1}(0.99)^{49}$$

$= 0.306$
$= 30.6\%$

(ii) Here, n = 50 years, T = 100 years,
$x = 2$,
$n - x = 50\text{-}2 = 48$

$$P(2) = \binom{50}{2} .0.01^{2}.0.99^{48} \qquad (10.6)$$

$$= \frac{50!}{2!(48)!}(0.01)^{2}(0.99)^{48}$$
$= 0.0755 = 7.55\%$

This means that there are 30.6% chances that 100 years return period flood will occur once during the project life and there are 7.56% chances of its two time occurrence.

10.3 POISSON DISTRIBUTION

The terms of a Binomial expansion are little inconvenient to compute in any large number. If n is large (> 30) and p is small (< 0.1) then Binomial distribution tends to Poisson distribution.

$$P\,(x) = \frac{\lambda^{x} \cdot e^{-\lambda}}{x!} \tag{10.8}$$

where, $\lambda = np$

The conditions for this approximation are:

- (i) The number of events is discrete
- (ii) Two events can not coincide
- (iii) The mean number of events in unit time is constant
- (iv) Events are independent.

The above Example-3 can be solved with Poisson distribution also. The results are:

$$P(1) = \frac{\left(50 \,.\, \frac{1}{100}\right)^{1} esup\text{-}(50/100)}{1!} = 0.303 = 30.3\% \tag{10.8}$$

$$P(2) = \frac{\left(50 \,.\, \frac{1}{100}\right)^{2} esup\text{-}(50/100)}{2!} = 0.0758 = 7.58\% \tag{10.8}$$

The results obtained by Binomial distribution and Poisson distribution are almost same.

10.4 DESIGN FREQUENCIES

The designer is generally concerned with the return period for which the structure should be designed. The design frequencies shown in Table 2 are typical of levels generally encountered in minor structure design (Viessman et al, 1977).

(a) Probable Maximum Flood

Probable maximum flood is the flood caused by probable maximum precipitation. Probable maximum flood is generally obtained by using unit hydrograph and rainfall estimates of PMP. The probable maximum storm is defined as the most severe storm considered reasonably possible to occur. The ASCE Hydraulics Division Committee on Hydrometeorology (1973) has suggested that the probable maximum flood is perhaps equivalent to a design return period of 10,000 years.

(b) Standard Project Floods

SPF is the flood caused by standard project storm which is generally obtained from a survey of severe storms in the general vicinity of the drainage basin or severe storms experienced in meteorologically similar areas.

In India, the present practice (BIS code) is to specify the design flood for various structures in terms of frequency of return period as indicated below:

Table 10.2 Minor Structure Design Frequencies

Type of Minor Structures	Return Period (in T years)	Frequency $\left(P = \frac{1}{T}\right)$
Highway cross road drainage		
0-400 ADT*	10	0.1
400-1700 ADT	10-25	0.1-0.04
1700-5000 ADT	25	0.04
5000 ADT	50	0.02
Airfields	5	0.2
Storm drainage	2-10	0.5 to 0.1
Levees	2-5	05-0.02
Drainage ditches	5-50	0.20-0.02

**ADT - Average Daily Traffic.*

Selection criteria given by Snyder (1964) for spillway design of dams are given in Table 10.3.

Table 10.3 Spillway Design Flood for Dams

Category	Impoundment danger potential		Failure damage		
	Storage (Acre-feet)	Height (ft.)	Potential		Spillway design flood
			Loss of life	Damage	
Major	50,000	60	Considerable	Excessive or as a matter of policy	Probable maximum flood (a)
Intermediate	1000-50,000	40-100	Possible but small	-	Standard project flood (b)
Minor	1000	50	None	Of same magnitude	50-100 years occurrence

				as cost of dam	interval

Table 10.4 : Frequency of return period advocated by IBS code

Sl. No.	Structure	Return Period of design flood (Yrs)
1.	Major dams with storage more than 6000 ha.m. (50,000 ac. ft.)	1000
2.	Minor dams with storage less than 6000 ha.m.	100*
3.	Barrages and pick up weirs (a) Free board (b) Items other than free board	 500+ 50-100
4.	River Training Works (Calculation of Scour)	50-100@
5.	Water way of bridges	50

* IS 5477 - Method of fixing capacities of reservoirs-Part IV
+ IS 6966 - Criteria for hydraulic design of barrages and weirs
@ IS 3408 - Criteria for river training works for barrages and weirs in alluvium.

In case of spillways for major and medium reservoirs with storages more than 6000 ha.m. design is generally done for probable maximum flood which is the physical upper limit of the flood in the catchment.

Table 10.5 :CWC (1969) recommends the following design frequencies:

Sl. No.	Structure	Return period
(i)	Major dam with storage more than 50,000 acre feet	Probable maximum flood or frequency not less than once in 100 years
(ii)	Permanent barrages and minor dams with storage less than 50,000 acre feet	Standard project flood or 100 year flood whichever is higher
(iii)	Pick up weirs	50-100 years

(iv)	Canal aqueducts:	
	(a) Waterways	50-100 years
	(b) Foundations and freeboard	50-500 years

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