RE-PRINTS

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Various Methods of Designing Spillway Capacity of Dams and Estimating Flood Discharges
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SYMPOSIUM ON "VARIOUS METHODS OF DESIGNING SPILL WAY CAPACITY OF DAMS AND ESTIMATING FLOOD DISCHARGES"

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The subject of the Symposium has to be considered in two parts, the latter part being considered first.

VARIOUS METHODS OF ESTIMATING FLOOD DISCHARGES:

(1) Method to be adopted in estimating flood discharges must necessarily depend on the following factors:

(a) The purpose, size and importance of the hydraulic structure to be built and the degree of hazard created by its failure. In Mysore, flood discharges for small reservoirs called tanks are calculated by empirical formula which have been evolved by collection of field data. Unless the tanks are in series, that is one above the other covering an entire valley, this method has proved generally satisfactory. For bigger reservoirs, detailed studies of flood flow are made.

(b) Availability of data recording stream gaugings, climatological, meteorological and hydrological data of heavy storms, topographical, geological and soil survey maps of the catchment. For bigger streams data regarding stream gaugings are generally available for periods extend to a maximum of 45 years in Mysore State. There is hardly any systematic study made of the various factors causing a heavy storm or its effects after it has precipitated. Rain-fall data extending over nearly a century in some cases are available. Unfortunately, the rain gauges are not always located in places which can give representative values of rain-fall in the area covered by them. Hardly any data exists of climatological and meteorological data of heavy storms that have occurred from time to time over the Mysore territory. It is fortunate hydrological data of the heaviest flood that has occurred on the river Cauvery at Krishnarajasagara in Mysore State have however been recorded. Considerable amount of work is still necessary to complete collection of systematic data regarding soils, and crops. Topo sheets of the Trigonometrical survey of India have however been prepared for the entire state;

(c) On the characteristics of the catchment basin size, lattitude, topography, drainage pattern, soils, vegetal cover, etc., and lastly;

(d) On the availability of data regarding intervals between two periods of intense rain-fall, depth and area relationships of heavy storms and proposed regulation of reservoirs to be built. Very little data on these are available.

(2) The various methods adopted for estimating flood discharges are the following.
- (a) By empirical formulae
- (b) By analysis of stream flow records and frequency studies.
- (c) By determination of design storms by meteorological considerations.
- (d) By analysis of actual heavy storms, and
- (e) By study of an envelope curve.

(a) Empirical Formulae: (i) Single Formula Methods:

Most of the flood estimates are based on a single formula establishing correlation directly and/or indirectly with the following factors which affect the intensity of a flood.

(i) Intensity, distribution and duration of rain-fall.
(ii) Area, shape, and slope of catchment.
(iii) Initial state of wetness of the catchment and
(iv) Other factors depending on the Geology of the catchment, vegetal cover, wind intensity and direction, temperature and humidity.

It has been the experience that it has not still been possible to device any formula applicable to all catchments on account of the large number of variables involved in a flood run off. Every formula gives fairly reliable values for the territory over which the data was gathered for generalising them into a formula. In Mysore for small catchments in which tanks are constructed, the Ryve's formula $Q=CM^{273}$ has been used with a large measure of realiability. Q is the flood discharge, C a coefficient and M is the catchment in square miles. The value of C for various sizes of catchment in both the hilly and plain tracts of Mysore have been tabulated. Since the value of C assumed has to cover all the variables, this formula can have only a limited field of application.

(b) Flood estimation by "rationalised formulae"

A few attempts have also been made to estimate the maximum flood discharges by having a series of formulae to correlate the many variable factors. The most noteworthy of them is by Richards[1]. His theory of flood estimation rests on the principle "that the average intensity of rain-fall is an inverse function of both the catchment area and of the duration of the storm. The assumptions are then made that the storm fully covers the catchment and that its duration is equal to the period of concentration of the flood. The rain-fall is uniform and constant over the catchment. The coefficient of runoff is constant and uniform over the catchment. The slope of the catchment is uniform. These have been called "standard conditions."

His equations are:

$$\mathrm{i} = \frac{\mathrm{R} + f(\mathrm{a})}{\mathrm{t} + 1} \quad \ldots.(2)$$

$$\frac{\mathrm{t}^3}{\mathrm{t} + 1} = \frac{\mathrm{C.L}^2}{\mathrm{K.\$.R.}f(\mathrm{a})} \quad \ldots.(3)$$

$$\mathrm{Q_m} = 1000\mathrm{KI} \quad \ldots.(4)$$

$$\mathrm{R_0} = 3600\mathrm{Q_m^t} \quad \ldots.(5)$$

Where	i	is the average intensity of rain-fall in inches per hour.
	K	is a coefficient of run off.
	$	is the slope of the catchment.
	t	is the period of concentration.
	T	is the total duration of the storm.

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[1] Flood Estimation and Control by B.D.Richards.

R is a rain-fall coefficient.

(a) is a function of the area for the adjustment of the average intensity of rain-fall.

If I and i denote the maximum and average intensities of rain fall;

Then i =If(a). Where a is the area of the catchment in units of 1000 acres.

$c = \frac{9}{4c^2}$ Where C is the coefficient in Chezy formula $v = C\sqrt{i\$}$

L is the furtherst length of the catchment in miles from point of concentration.

R_o is run off in cft per 1000 acres.

Q_m is the maximum intensity of flood in usecs per 1000 acres.

The effect of variation from his "standard conditions" have been examined. The variations may be in respect of any of the following.

(1) Duration of storm T may be greater or lesser than period of concentration t.

(2) Area of storm may be less than that of the catchment.

(3) Intensity of rain fall may vary over the catchment area.

(4) Intensity of storm may vary during the period of strom.

(5) Moving storms.

(6) Variations in the slope of the catchment and in the coefficient of run off.

He estimates that an addition of about 25 per cent to the estimate of the flood intensity based on standard conditions can cover all these deviations. While these formulae are no doubt more rational than the single formula type, its usefulness for estimating floods over large catchments covering hundreds of square miles can only be limited.

(b) Analysis of stream flow records and frequency studies:

There are two types of methods: (1) Mathematical methods (2) Graphical methods.

Flood frequency studies based on records available at a single gauging station have to be made with great care, specially if it includes data of a near record or record flood. Short periods of records may not be representative of long time flood flow distribution characteristic of the river. Therefore rigorous adherence to probabilities indicated by such short term records for the purpose of producing probabilities to cover long periods of time will be misleading. With short term records it may not be possible to estimate the coefficient of skew with a fair degree of realiability. To ensure statistical significance in the coefficient of skew the number of years of record required for its determination is placed by J.J.Seade Jr. at 140 as a minimum[2]. As the period of record available is much less than

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[2] Water supply paper 771, page. 426.

this, the usual practice is to study the flood behaviour in adjoining areas for developing areas for developing the probability curve. Both Hazen[3] and Foster[4] have developed methods of accounting for regional flood potentiolities in determining probabilities for a particular stream developed out of observations regarding the coefficient of skew.[5] Both the authors employ the usual parameters - mean, coefficient of variation (CV) and coefficient of skew (C.S). Factual data indicate that (a) one extreme storm and the resulting flood occurring within a period of record ordinarily available, materially affect the coefficient of skew (C.S) increasing the expectancy of larger floods. (b) The magnitude of the C.S. is a function of the climate, varying from one climatic region to another (c) Variation in C.S. is independent of the size of the drainage basin.[5] The value of C.S. has been calculated in the United States for most of the catchments. In India these studies are still to be made. Determination of the coefficient of variation and the mean require a minimum of 30 years and 20 years of record respectively.[5] Tables of "Logarthmic skew factors" by Hazen and of "skew factors" by Foster have been published. These factors are used in determining the frequencies of floods of various magnitudes in asymmetric districution. Hazen has employed only one table while Foster has given out two tables. Foster's type III curve factors are usually applicable to flood flow data. The type which best fits the series may be selected by trial. Coefficients of skew even when adjusted do not in many cases yield curves of best fit. Hazen has suggested the use of "graphic skew" in such cases. This is formed by trying values C.S. until one is found that produces a curve which fits the plotted points of recorded data.

The difficulty in this method is since the probability curve continues to rise with time, a limit should be determined at which the maximum or near maximum should be reached. This frequency should have some correlation with the number of floods or of years of observed data.

There are also other methods of determining flood frequencies. Mention may be made of Greyer, Slade, Gumbel, Sawkins, and California Methods.[5]

Determination of design storms:

The design storm is that rain fall which is used for designing the spill way of a hydraulic project. The most common method adopted involves transposition to the catchment selected major storms and their adjustments to maximum there. Several observed storms are considered. The criteria in determining whether a particular storm may be transposed to the catchment is whether dynamically similar storms do or can occur in the area. The estimate of the maximum possible storm is obtained by plotting each of the transposed and adjusted storms as a depth duration curve for the drainage area size and smoothly enveloping all of the curves. This curve gives the maximum

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[3] "Flood Flows" by Allen Hazen 1930.
[4] Foster in Transactions ASCE of 1924.
[5] Bureau of Reclamation, Vol. IV, Water studies.

rain-fall depth for the drainage area. This method assumes that the volume of maximum run off thus determined when worked out in terms of discharge per sec taking into consideration the flood absorption capacity of the reservoir, time of concentration etc., will give the peak discharge. But in some cases when the reservoir capacity is small and the catchment is long and narrow the peak discharge resulting from a maximum storm in the lower part of the catchment may be more than that worked out by the maximum volume of run off over the entire catchment area method.

In making an estimate of the maximum storm by this method, the following simplifying assumptions are made:

(a) That the peak discharge is from among the great storms observed in the catchment basin,

(b) that the sea level dew point is representative of the moisture in the entire column of air,

(c) that the annual variation of average wind speeds is representative of the annual variation of inflow winds to maximum storms, and

(d) that the same adjustment is appropriate to all periods in the same storm.

This method can be very usefully adopted where there is close collaboration between a hydro meteorologist and a hydrologist. Collection of considerable meteorological data is also necessary. At present this method has not been used on any of our projects.

(d) Analysis of actual storms - The unit hydrograph method:

This method involves the following steps:[5]

(a) Division of drainage area into sub-areas if necessary. When it is divided into sub-areas floods from each of them have to be routed separately.

(b) Derivation of unit hydrographs. This may be done either for sub-areas separately or for the total catchment area. This may be derived either directly from observed hydrographs or by synthesis.

(c) Derivation of design storm and its apportionment to sub-areas. The design storm is derived by hydro meteorological conditions. If a single unit hydrograph is developed for the entire catchment, then the depth duration value used will also be for the entire area. If it is divided into sub-areas the depth duration area for each sub-area will be different. For drainage areas where orographic rain fall predominates, the depth duration curve for each sub-area is determined by assuming the curve to be proportional to the depth duration curve for the whole catchment. In other cases, the area of highest precipitation can be assumed to be anywhere in the catchment. It is generally assumed to be at the down stream end of the catchment. The apportionment of rain-fall to each of the sub-areas are such that their depth duration curves conform to the design storm.

(d) Determination of minimum retention rate and calculation of rain-fall excess of design storm, are then made.

(e) Next step is the arrangement of design storm. The arrangement of increments of rain-fall excess should be such as to give the most critical conditions of run off. This is done by pairing off values of the largest rain fall excess increment with the largest run off coefficient from the distribution graph and then pairing the next two highest values and so on. Obviously this arrangement gives the highest possible value for run off. If the total drainage area has been sub-divided into several units, the maximum possible flood in each area is first determined and then the sub-area flood is routed down the river to the section of the day at which site the value of the maximum flood is desired.

(e)Envelope curve method:

In this method the values of known peak floods and area of drainage are plotted for a number of rivers in a particular region. The peak floods at a few sections along the same river if it is very lengthy are also plotted against the drainage area covered by them. Then a curve enveloping all the points are drawn. This gives an approximate idea of the maximum possible value of the flood that can occur for a particular drainage area in the region. The value of such curves is enhanced by the period covered and the reliability of the data. Such a curve has been drawn for Indian Catchments.[6]

Design Spillway Capacity

After the value of the peak flood is fixed by many or all of the methods described above, the spill way capacity will have to be fixed. The factors coming into consideration are the following:

(1)Fixing storage capacity
(2) Determining the inflow hydrograph of the worst flood.
(3) Effect of flood routing on downstream of dam.
(4) Type of spillway proposed.

(1)Fixing storage capacity:

This in turn depends upon the following :(a) Purpose for which the reservoir is to be built. If the reservoir is for flood control, then the spillway capacity may be a minimum. The economics raising the height of a dam to give greater flood absorption capacity against the cost of providing longer length and/or greater depth of discharge over spillway will have to be worked out for each case. If the purpose is for irrigation power, navigation or for multipurpose, apart from the economies mentioned above other factors like the over all returns to be expected from the project, the method of operation of the reservoir, the effect of sediment on the life of the reservoir, climatic factors etc., will also have to be considered. (b) operation of the reservoir: Regular working tables on a weekly or monthly basis showing the inflow during the past twenty or more years prior to the construction of the project, the outflow due to requirements of irrigation, power, losses due to evaporation and seepage etc., should be worked out and the probable level of the reservoir at the beginning of each flood determined. The economies of raising the dam to give a greater flood absorption capacity against cost of providing greater spill way capacity should then be worked out.(c) Proportion of total run off to storage capacity: Reservoirs may be designed and operated in such a manner that all the run off occurring in a normal year of

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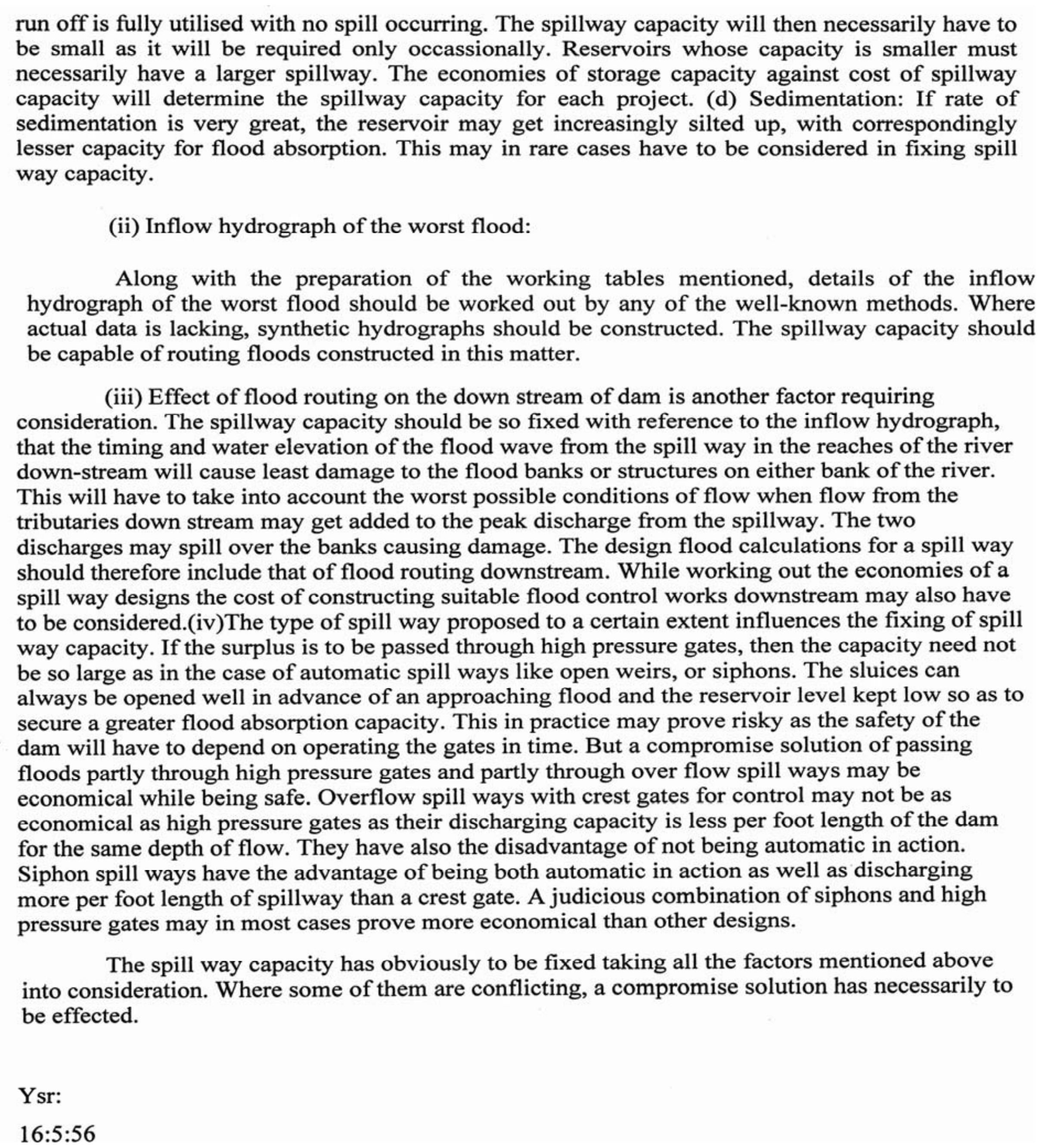
6. Envelope Curve by Kanwar Sain and
 - C.B.I.Journal.



run off is fully utilised with no spill occurring. The spillway capacity will then necessarily have to be small as it will be required only occassionally. Reservoirs whose capacity is smaller must necessarily have a larger spillway. The economies of storage capacity against cost of spillway capacity will determine the spillway capacity for each project. (d) Sedimentation: If rate of sedimentation is very great, the reservoir may get increasingly silted up, with correspondingly lesser capacity for flood absorption. This may in rare cases have to be considered in fixing spill way capacity.

(ii) Inflow hydrograph of the worst flood:

Along with the preparation of the working tables mentioned, details of the inflow hydrograph of the worst flood should be worked out by any of the well-known methods. Where actual data is lacking, synthetic hydrographs should be constructed. The spillway capacity should be capable of routing floods constructed in this matter.

(iii) Effect of flood routing on the down stream of dam is another factor requiring consideration. The spillway capacity should be so fixed with reference to the inflow hydrograph, that the timing and water elevation of the flood wave from the spill way in the reaches of the river down-stream will cause least damage to the flood banks or structures on either bank of the river. This will have to take into account the worst possible conditions of flow when flow from the tributaries down stream may get added to the peak discharge from the spillway. The two discharges may spill over the banks causing damage. The design flood calculations for a spill way should therefore include that of flood routing downstream. While working out the economies of a spill way designs the cost of constructing suitable flood control works downstream may also have to be considered.(iv)The type of spill way proposed to a certain extent influences the fixing of spill way capacity. If the surplus is to be passed through high pressure gates, then the capacity need not be so large as in the case of automatic spill ways like open weirs, or siphons. The sluices can always be opened well in advance of an approaching flood and the reservoir level kept low so as to secure a greater flood absorption capacity. This in practice may prove risky as the safety of the dam will have to depend on operating the gates in time. But a compromise solution of passing floods partly through high pressure gates and partly through over flow spill ways may be economical while being safe. Overflow spill ways with crest gates for control may not be as economical as high pressure gates as their discharging capacity is less per foot length of the dam for the same depth of flow. They have also the disadvantage of not being automatic in action. Siphon spill ways have the advantage of being both automatic in action as well as discharging more per foot length of spillway than a crest gate. A judicious combination of siphons and high pressure gates may in most cases prove more economical than other designs.

The spill way capacity has obviously to be fixed taking all the factors mentioned above into consideration. Where some of them are conflicting, a compromise solution has necessarily to be effected.

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