HYDROLOGIC SAFETY OF DAMS IN INDIA

SH N. K. Mathur
Chief Engineer, Hso, Cwc
Bhopal Singh
Director , Hydrology(S), Cwc

1.0 INTRODUCTION

India has a geographical area of 3.29 million sq. km. and receives an average annual rainfall of 1170 mm which results in a surface run-off of approximately 1869 km^3. However, there is a huge seasonal and spatial disparity in the rainfall and run-off with about 90% of the average annual run-off of peninsular rivers and about 80% of that in the Himalayan rivers flowing during the monsoon season, i.e. from June to September. Therefore, for meeting the round the year needs of irrigation, domestic and industrial and hydro-power in the country, creation of storages across rivers and streams is vital. Water resources exploitation, in India, dates back to prehistoric times. Small tanks for irrigation and earlier bunds for spill protection had been in vogue from the dawn of history. By 18th century, aided by advancement in technology, larger structures were being constructed on various rivers in India and significant development has come up during the last 50 to 60 years.

India has so far constructed about 4700 large dams which have provided about 225 km^3 of storage. Another 390 projects with storages of about 63.9 BCM are construction. Thus, while there is an obvious need to construct storage dams as they play an important role in the water resources development of the nation, there is also the need of ensuring the safety and long life of the dams already constructed and taking due safety care of dams under construction or being planned.

As per failure data on large dams collected by ICOLD, globally nearly 35% of dams have failed due to causes related to inadequate spillway capacity and therefore, this becomes a major concern in Dam Safety Programme.

Old dams were designed based on whatever information/data was available at that time and using the method prevalent at that time. About 70 percent of dams are more than two decade old. Over the year, significant amount hydro-meteorological data have been collected and also a lot of technological development has taken place in the field. Thus, there is a need to review hydrologic safety of old dams based on scientific data collected in situ and on the basis of procedures that have evolved during the period. The likely effect of climate change on the extreme events may also require thinking on the hydrologic safety of old dams.

2.0 DESIGN FLOOD ESTIMATION

2.1 Design Flood Criteria

The hydrologic design criteria for fixing the spillway capacity as prevalent in India are indicated in IS: 11223:1985. " Guidelines for fixing Spillway Capacity". According to these guidelines, the criteria for classification of dams is based on gross storage behind the dam and the hydraulic head (MWL – minimum tail water level). The classification for the dam is greater of the two indicated parameters:

Classification	Gross storage(S) in Mm^3	Hydraulic Head (H) in m.
Small	Between 0.5 and 10.0	Between 7.5m and 12.0
Intermediate	Between 10.0 and 60.0	Between 12.0m and 30.0
Large	Greater than 60.0	Greater than 30.0

The inflow design flood for safety of the dam would be as follows:

Classification as above	Inflow design flood for safety of dam
Small	100 year flood
Intermediate	SPF
Large	PMF

Floods of larger or smaller magnitudes may be used if the hazards involved is high or low. 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 the 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 PMF needs to be used. Where the studies or judgment indicate an imminent danger to present or future human settlements, the PMF should be used. Any departure from the general criteria as above on account of larger or smaller hazards should be clearly brought out and recorded.

2.2 Various Approaches to Design Flood Estimation

Various methods commonly employed for design flood estimation are:

(i) Empirical flood formulae

(ii) Enveloping curves

(iii) Flood frequency analysis

(iv) Hydro-meteorological approach

Previously, design flood estimation was mostly based on empirical flood formulae since large series of observed discharge data became available only much later. The methods (i) and (ii) above are not suggested for the estimation of design flood for the design of dams and they may at the most be used for getting a first hand estimate of design flood peak. Frequency analysis method was commonly used where hydro-meteorological method could not be applied for want of required meteorological and hydrological data. Similarly for the design of barrages and small dams, design flood of certain frequencies are adopted.

Hydro-meteorological approach preferably based on site specific information is suggested for the estimation of design flood of intermediate and large dams, especially when the storage has a significant effect on modifying the design flood hydrograph as it flows through the reservoir.

2.2.1 Hydro-meteorological Approach

In the hydro-meteorological method, attempt is made to analyse the causative factors responsible for the production of severe floods. Thus in this method, the hydrograph of runoff is assumed to consist of a base flow component and direct runoff component. The direct runoff component is obtained by convoluting the excess rainfall hyetograph with basin response function. The excess rainfall is that part of total storm rainfall which contributes to the direct runoff. Even though many of these components elude precise physical definition, the method is found to be very convenient and sufficiently accurate for practical purposes.

Thus, in hydro-meteorological method, design flood computation involves estimation of design storm hyetograph, derivation of catchment response function and convolution. The catchment response function usually used can be either a lumped system model or a distributed lumped system model. In distributed system model, the catchment is divided into smaller sub regions and the unit hydrographs of the sub-regions along with the channel and /or reservoir routing functions will define the catchment response function.

3.0 DAM SAFETY PROGRAM IN INDIA

Dam safety is now considered an inherent feature in the planning, design, construction, maintenance and operation of dams. It has been recognized world-wide for the past some time that dam safety aspects, particularly of the existing dams, are not receiving as much attention as they should be, especially in view of the fact that a number of these old/existing dams are aging, leading to gradual natural degeneration. Another aspect in respect of these dams is that they were constructed using the technology, standards and criteria prevalent at that time which have changed vastly over the years due to experiences gained and advancement in technology. These old dams may either not be safe under today's technology and know-how or may not be acceptable to the present society which has become more aware of its rights and needs and demands absolute safety in terms of life and property. With the ever-increasing number of dams, Government of India realized the importance of dam safety way back in the mid seventies and took a number of steps to highlight its concern for creating general awareness among the engineering community.

In India, a " Report on Dam Safety Procedures" was brought out by Central Water Commission in 1986. These procedures form the basis of the dam Safety programme in the country which is being overseen and monitored by National Committee on Dam Safety chaired by Chairman, CWC. As per existing procedure, checking and upgrading the hydrologic capability is a key technical issue in the National Dam safety programme.

3.1 Guidelines for Determining Hydrological Safety of existing Dams

The guidelines for determining hydrological safety of existing dams have been included in the "Report on Dam Safety Procedures" 1986 published by Central Water Commission. A brief extract of the guidelines is given in the following paragraphs

- **Need for separate guidelines**

The question of whether guidelines for fixing spillway capacity consistent with the safety of dams should be of general nature covering both new and existing structures or whether these should be separate for the two types of structures is debatable.

At present in India, the hydrologic safety for both old and new dams is provided using the same criteria though there may be some marginal difference in regard to free board, clearance and safety factors.

- **Review of adequacy of spillway and allied provisions in existing dams**

The guidelines for ensuring hydrologic safety for existing dams are the same as the guidelines for new dams which have been reflected in the latest Indian standards IS: 11223: 1985. However, while reviewing adequacy of spillway capacity, relaxation of the following ambient conditions is considered on merit of each case.

a. For existing dams, impingement level to be considered can be lower than for new dams, after taking into account a practicable schedule of filling
b. For existing dams, where a flood forecasting possibilities exist and have been proved in the field, a reasonable pre-depletion may also be allowed, although this is not allowable for new dams
c. For existing dams, where gate maintenance is very satisfactory, and after making sure of standby arrangements, the design conditions one of the gate failure may not be considered.
d. Relaxation of free board and clearance

   For existing dams, these could be relaxed on case to case basis. A properly designed solid parapet wall may be considered for the free board.

- **Prioritisation for modification of existing dams for greater safety**

Since resources available for undertaking rehabilitation projects may be limited, it is necessary to have guidelines for deciding the priorities in tackling existing dams for greater safety under floods. These guidelines may be based on the safety status of each dam after assessing the revised inflow design flood. The extent of inadequacy of the spillway capacity may be classified according to the following:-

i) The maximum inflow flood that can be passed through the dam with the relaxed ambient conditions, expressed as a proportion of the inflow design flood.
ii) The likely effect of the inflow design flood on the safety of the dam, i.e. whether the dam has reasonable chance of not failing under such a flood.
iii) The risk associated with the failure of dam

3.2 Dam Safety Assurance and Rehabilitation Programme

Dam Safety Assurance and Rehabilitation Project was taken up for implementation with the World Bank assistance in 1991 and was completed in 1999. About 55 dams were reviewed under the dam safety programme, Hirakud (Orissa) and Ghandhi Sagar Project (MP) being two main dams whose hydrologic capabilities were thoroughly examined. Formulation and use of a number of guidelines on Dam Safety, preparation of Probable Maximum Precipitation (PMP) Atlases by CWC for a number of basins were unique achievements of the project.

3.3 Dam Rehabilitation and Improvement Project

As follow up of Dam Safety Assurance and Rehabilitation Project (DSARP), a new project titled “Dam Rehabilitation and Improvement Project” (DRIP) has been initiated with the help of World Bank in four states viz. Kerala, Madhya Pradesh, Orissa and Tamil Nadu, based on their readiness for project implementation. Out of a total of 1231 large dams in these five participating states, the DRIP covers 223 dams. The broad objectives of DRIP are to strengthen and further consolidate the institutional framework of Dam Safety Assurance in CWC and the participating States, to carry out detailed safety review of identified dams and take up measures for improving their safety. The guidelines for safety of dams including hydrologic safety shall also be reviewed. The hydrological review are to be carried out for all the identified dams. This task of has already been initiated and design flood review of a number of projects have been carried out.

4.0 REVIEW OF DESIGN FLOOD CRITERIA

4.1 Design Flood Criteria Followed In other Countries

Design flood criteria being followed in various countries are given below:

ICOLD Recommended Approach

The ICOLD categorization of a Large Dam is any dam over 15m high or between 5 m and 15 m high and with a capacity of impounded water of over 3,000,000 m^3 stored volume (Asmal, 2000). In general the PMF should be taken as the design standard for a Large Dam.

Australia

Australia has a highly developed infrastructure for water resources, leading to one of the largest amounts of storage per capita (4717 m^3 in 2003). The approach to flood design for dams in Australia is based upon the PMF and the PMP. The PMP-DF (Probable Maximum Precipitation Design Flood) has been proposed to be the design flood for which the probability of the flood is the same as the probability of the rainfall (Nathan et al. 2001).

China

The Chinese design standards are set according to the purpose and design of the structure and the potential consequences of failure. The water conservancy and hydropower projects in China are classified into five different ranks in accordance with their scales, benefits and importance in national economy.

Classification of Water Conservancy and Hydropower Projects in China

Class of project	Storage capacity of reservoir (10^6 m^3)	Flood Prevention		Water Logging Control	Irrigation	Water Supply	Water Power
		Cities & industrial regions	Farmland (10^3 ha)	Draining Water logged area (10^3 ha)	Irrigation area (10^3 ha)	Cities & Mines	Installed capacity (MW)
I	> 1,000	Very important	> 333	> 133.3	> 100	Very important	> 750
II	1,000 – 100	Important	333 – 67	133.3 – 40	100 – 33.3	Important	750 – 250
III	100 – 10	Moderately important	67 – 20	40 – 10	33.3 – 3.3	Moderately important	250 – 25
IV	10 – 1.0	Less important	< 3.3	< 2.0	< 0.3		< 0.5
V	< 1.0		< 3.3	< 2.0	< 0.3		< 0.5

Check design flood criteria for permanent structures in China

Class	1	2	3	4	5	
Embankment Dams	10,000 or PMF	2,000	1,000	500	200	Return period in years
Concrete Dams, etc	5,000	1,000	500	200	100	

France

In France all dams over 20 m are regulated for public safety, together with lower ones whose failure could cause hazard to public safety or communication (Radzicki et al. 2005). The design flood standard is set according to the factor $H^2\sqrt{V}$ where H (m) is the height of the dam and V (hm^3) is its storage capacity. The parameter $H^2\sqrt{V}$ does not appear to have any particular theoretical basis but expresses the need to consider store volume as well as impounded water depth as a contributor to the overall hazard posed by the dam.

French dam safety assessment criteria

$H^2\sqrt{V}$	<5	5 to 30	30 to 100	100 to 700	>700
Probability of the design flood %	1	0.5	0.1	0.05	0.01
Flood return period in years	100	200	1,000	2,000	10,000

Japan

In Japan, the inflow design floods for dams are stipulated in the Structural Standards for River Protective Facilities (Cabinet Order), which was drawn up on the basis of River Law. According to the standards, when the dam is constructed or reconstructed, the inflow design floods for a concrete dam must be taken on the largest value among the following three discharges:

- 200-year flood at the dam site;
- Maximum experienced flood discharge at the dam site and
- Maximum flood discharge that can be expected at the dam site based on the maximum experienced flood discharge in the basins with similar hydrological conditions or climate.
- For an embankment dam, the design flood should be specified to be 1.2 times of the relevant values for a concrete dam (JICE, 2000). The return period of the design flood for an embankment dam is actually equivalent to 1000 years or more.

In case PMP estimation is required, it is estimated using the DAD analysis. However, in some areas where the rain gauge network is not adequate, rainfall estimates from radar are used for DAD analysis.

UK

All dams with normal impounded volume exceeding 25,000 m^3 are regulated under the 1975 Reservoirs Act, although there are proposals to reduce this limit before Parliament in the Floods and Water Bill of 2009.
Dams are classified into one of four categories A, B, C or D according to the potential consequences in the event of a failure (A high hazard to D no hazard). The design conditions vary according to the dam category as tabulated :

UK dam safety assessment criteria

Category	Consequence of dam breach	Normal design standard	Minimum standard if overtopping tolerable	Initial Reservoir condition	Wind speed and minimum wave surcharge
A	Endangers lives in a community	PMF	10000 year flood	Spilling long-term average inflow	• Mean annual maximum wind speed • Minimum 0.6 m wave surcharge
B	• Endangers lives of individuals or • Causes extensive damage	10000 year flood	1000 year flood	Full to spillway crest	As Category A

C	Negligible risk to life and limited damage	1000 year flood	150 year flood	Full to spillway crest	• Mean annual maximum wind speed • Minimum 0.4 m wave surcharge
D	No risk to life and very limited additional flood damage	150 year flood	150 year flood	Spilling long-term average inflow	• Average annual maximum wind speed • Minimum 0.3 m wave surcharge

USA

FEMA (the Federal Emergency Management Agency) republished four documents on the federal guidelines for dam safety in 2004.

The Federal design code 7509.11_0_code for dam spillways provides the following design floods :

US Federal recommended spillway design floods

Hazard potential	Size class	Spillway design flood
High • Loss of life probable • Environmental, economic and lifeline losses expected	A	PMF
	B	PMF
	C	1/2 PMF to PMF
	D	100 yr. to 1/2 PMF
Moderate • No loss of life expected • Environmental, economic and lifeline losses expected	A	PMF
	B	1/2 PMF to PMF
	C	100 yr. to 1/2 PMF
Low • No loss of life expected • Low or limited environmental, economic and lifeline losses	A	1/2 PMF to PMF
	B	100 yr. to 1/2 PMF
	C	50 yr. to 100 yr.

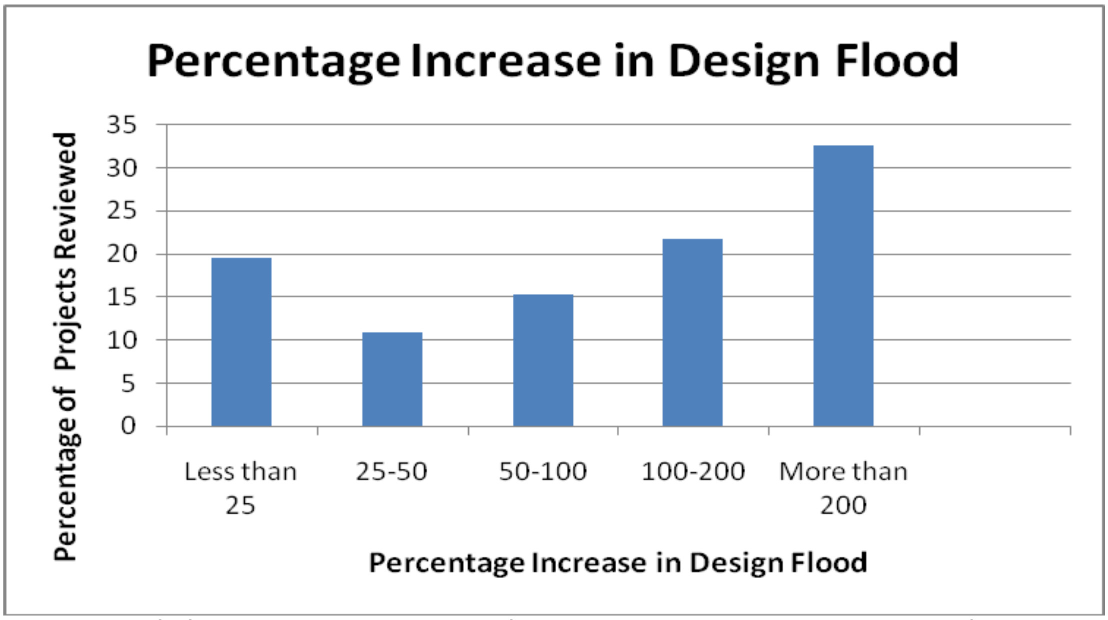
4.2 Need for Review of Design Criteria

The widespread practice internationally as discussed above is to associate the design inflow for dam safety assessment with the potential consequences downstream of the structure in the event of its failure. The classification may also depend upon the height of the dam and the stored volume. In most countries, the design inflow for a safety assessment which should be passed without failure of the dam is related to the probable maximum flood (PMF), but the spillway capacity may be set for a lower inflow.

The classification and criteria laid down in the Indian standards are based on highest safety standards and are comparable to the safety standards adopted worldwide. However the Indian Standard for fixing the criteria for design flood for safety of dams has not directly incorporated the concept of hazard in selecting the design flood for dams. It has left the choice to the designer to modify the guidelines taking into account the possible hazard posed by the dam without giving any quantitative measures for hazard involved. This freedom given to the designer has been found to be seldom exercised, resulting in a blind usage of the table referred in the para 2.1. Thus there is a need to take up the task of hazard assessment seriously and modifying the design criteria accordingly. Inclusion of quantitative hazard assessment in hydrologic design criteria explicitly may also be desirable. However, it may not be used as a prelude to lower the applicable design flood based on height and storage criteria as hazard perception keep on changing. This aspect needs to be discussed/debated.

5.0 GENERAL OUTCOME OF DESIGN FLOOD REVIEW STUDIES

Review design flood studies of a number of projects have been carried out by Central Water Commission in association with states. The revised inflow design floods is generally found to be higher than original design flood for most of the old dams. The median increase in review design floods of various projects is found to be order 107 percent. The percentage of projects with different range of increase is given below:



More than half of the projects show increase of more than 100 percent in review design flood. About one third of projects show increase of more than 200 percent. Most of the projects with high increase in review design flood are small dam which were designed using empirical formulae.

The main reason for such a significant increase in design flood of old dams can be attributed to the fact that design floods for old dams were mainly based on empirical formulae without much support of hydro meteorological data available at that time. The concept of hydro meteorological approach for estimating design flood picked up in late seventies only. Even the design flood studies for major dams were based on flood frequency analysis (1000 year flood etc).The problem of increased design flood is found to be more acute in case of small/medium dams with smaller catchments where hardly any observed data was available at that time. The upward revision of design storm value on availability of additional data /information about severe most storms from hydro-meteorologically homogeneous regions was found to be another main reason for upward revision of design floods.

Once the review design flood is found to be significantly higher, adequacy of spillway capacity needs to be thoroughly reviewed. The relaxation of the ambient conditions as given in para 3.2 above may be considered on merit of each case.

When it is found that the revised design flood hydrograph, even with relaxation of the ambient conditions as given in para 3.2, cannot still be routed through the spillway without encroaching into the free board, then various structural and non structural measures may be used to make the dam hydrologically safe. The appropriate solution to be adopted will vary from case to case and following list of alternatives is not exhaustive and are only for example.

i. Augmenting the existing spillway capacity through addition of more spillway bays of the same type as existing.
ii. Provision of breaching sections or fuse plugs. If suitable sites are available it is preferable to locate such breaching sections on a saddle rather than on the main dam section. However, it is required to investigate the alignment of the surplus channel till it meets the main channel to assess the likely damages in the surrounding valley in the event of design flood at dam causing a breaching of the section.
iii. Increasing the free board above FRL of the dam by provision of parapets including strengthening of sections where necessary so that the flood cushion available will be increased.
iv. Establishing early flood warning system: An early warning system involving flood forecasting by utilizing real time data of rainfall, stage and discharge at upstream stations will greatly help in evacuating the reservoir in anticipation of severe flood inflows into the reservoir so that the moderation in peak obtained will be higher.

v. Increasing the flood storage by lowering the conservation storage level, so that flood moderation will be enhanced. However, this may also result in some reduction in benefits and on the positive sides it will involve little investment required for modifications.

A suitable alternative is to be chosen by considering the various options that are feasible and working out the relative benefit cost scenario.

6.0 EFFECT OF GLOF

There have been number of glacier lake outburst floods in the recent times. The impact of climate change on glacial lakes is likely to further accentuate the associated risk with GLOF. The GLOF is caused when glacier lake burst their banks and caused wide spread flood and havoc to life, flora and fauna of the downstream area, apart from heavy damage to infrastructure. The effect of GLOF is to be considered on the inflow design flood to be adopted for a dam. In view of above it has now been practice to consider GLOF in many countries including India, while planning designing and constructing any infrastructures special water resources projects. The process involves identification of potentially dangerous glacial lakes based on records of past events, field observation, geo-morphological and geotechnical characteristics of lakes. Recently Central Water Commission in association with NRSC has taken up mapping of glacier lakes in Himalayan region. The project includes preparation of inventory of glacial lakes/water bodies with spatial extent greater than 50 ha, their vulnerability rating and their monitoring on monthly basis during June to October months for 5 years. The inventory of lakes have already been prepared. The same can be used for identifying the vulnerable glacial lakes associated with any project and carry out GLOF analysis. Other issue which requires attention is the guideline for combining the GLOF with conventional design flood. At present, the GLOF, appropriately routed to dam location, is simply added to the conventional design flood. This aspect needs to be carefully analyzed and appropriate guidelines be framed

7.0 PREPARATION OF PMP ATLASES

Assessment of design storm hyetograph forms the key component in the design flood study of any project. The storm studies require not only professional expertise but also large amount of storm data base in and around the catchment/basin. IMD is the main source of storm data /other meteorological data and authority for finalizing the design storm values for any project. However, IMD is not in a position to take up the storm studies of such large number of projects due manpower and other constraints. The PMP atlases have been quite useful in this regard. PMP Atlases for the following regions were prepared under the Dam Safety and Rehabilitation Project (DSARP) in early nineties.

- Region covering Cauvery and adjoining East flowing rivers.
- Region covering Godavari Basin
- Region covering Mahanadi and adjoining river basins
- Region covering Sone, Betwa, Chambal and Mahi river basins
- Region covering Narmada, Tapi, Sabarmati and Luni river systems and small rivers/ streams of Gujarat flowing into Arabian Sea.
- Region covering West flowing rivers of Western Ghat.

The following PMP Atlases were prepared during the Xth Plan through IITM Pune.

- Krishna
- Indus

Now the work of preparation of the PMP Atlases for the following remaining basins namely Ganga Basin and Brahmaputra Basin has been taken up in XIth plan by CWC. In addition to the above two basins, the work of updation of PMP Atlases for the river basins prepared in under DSARP-I (Six river basins) in nineties has also been taken up. The work of preparation of PMP atlases as above is being carried out through consultant and is scheduled to be completed by October, 2013. The PMP atlases not only help in quick initial estimate of design storm(PMP/SPS) but also are useful source of information on storm data base for detailed storm studies of any project.

8.0 OTHER RELEVANT ISSUES

8.1 Need for Public Awareness

The international practices, especially in the United States aim at a programme of assessing the risk to public safety and corrective action to reduce or eliminate such risks from time to time under the Dam Safety Programme. Thus, the effort is to eliminate unacceptable risks but not to provide a risk free environment. Probable Maximum Flood is a theoretical flood value/magnitude that is possible at the dam location as per the data/methodologies available and can occur as a natural flood even if the structure does not exist.

Even though floods of the order of PMF have only very low exceedence probabilities, their possibility cannot be ruled out and we need to well prepared for any such eventuality through well laid out emergency preparedness plan for each major dam. We also need to take up rehabilitation process (corrective action packages) in the case of the dams perceived to be in distress.

Hydrology is a data based science and therefore, with improvement in data base, results of studies are bound to differ. Further with improved knowledge of hydrologic processes and better tools of analysis, more reliable estimation of SPF/PMF have been made possible. Therefore, revised values of SPF/PMF are not comparable with values used in original design. Restraint needs to be exercised before classifying a dam unsafe merely on the basis of the fact that the revised design flood peak is more than that used in original study. Even in developed countries like USA, it has been observed that 93% of existing dams do not conform to the current safety standards. Public administrators should be more responsible before setting alarm bells on.

8.2 Considering the Impact of Climate Change on Design Flood

An important concern in hydrological prediction is that the likely climate change , will lead to changes in flood frequency and magnitude. Current information on the effects of climate change contains considerable complexity and uncertainty which precludes making firm assessment of the changes in flood magnitude and frequency. Studies in regard to climate changes scenarios predict that the frequencies of floods may increase and floods of same magnitude become more frequent. In National Water Mission Document, 2008 of MOWR, it is mentioned that it would be difficult to judge , at present, how the estimation of the PMP/SPS would change with climate change and it is suggested to continue with the present practice in case of major and medium dams. However, for new small dams, which are currently designed for 100 year return period flood, it is suggesting to start these for 150 year flood, on adhoc basis. It is also felt that PMP and in turn PMF forms relatively a sound basis for assessing the design flood for any structure depending upon the risk involved in its failure. Also PMP values, it assessed rationally, are likely to be less impacted by likely climate change unlike return period flood based on flood/rainfall peaks observed. It may be appropriate to make PMP/PMF and its appropriate fractions as basis of the design flood for a dam. For example, for a small dam, the design flood could be 0.5 PMF or 100 return periods flood whichever is more. All these issues needs to be researched and thoroughly debated/discussed before affecting any change in design criteria.

8.3 Strengthening Data Collection Network

The design floods of a large number of projects have been reviewed, however the efforts on data collection is commonly found lacking. Even after 30-40 years functioning of a project, the requisite data such as short interval concurrent rainfall and runoff data , instantaneous flood peaks, SRRG data etc are hardly available for any project. As quantity and quality of requisite hydro-meteorological data form the very basis of any hydrological review, it is extremely important to establish adequate data collection network for every project and regularly collect and maintain the data properly. The existing meteorological & hydrological observations network is inadequate particularly in Himalayan region. At higher altitudes (above 3000 msl), the data availability is very poor. The collection of snow data/information is extremely poor. There is a need of strengthening the data collection network and efforts not only by central agencies such as CWC, IMD etc. but also by project authorities. The Planning Commission is giving a lot of stress on improving the data collection network and database management and a lot thrust is proposed to be given for strengthening the hydro-meteorological data collection network significantly during 12th plan. It is planned to increase the HO network of CWC from present 878 stations to about 2800 stations.

9.0 CONCLUSIONS

The task of hydrologic safety of dams needs to be taken very seriously and professionally by dam authorities. In the case of dams with inadequate spillways, certain relaxations in assumptions/ambient conditions, to be selected on a case-to-case basis, may be considered. In case, the dam is still unable to handle the revised inflow design flood hydrograph, various structural/non-structural alternative solutions need to evaluated for arriving at a remedial action giving due considerations to local conditions as also the associated risk and cost considerations. In the case of all large dams, the implementation of a flood forecasting system, leading to lower flood impingement levels, greatly improves the capacity of the system to handle larger floods. This needs to be examined before committing huge investments that may be required for spillway modification.

Further, since floods of the order of PMF are rare events, it may suffice to provide emergency type spillways to handle higher order flood events.

In any case, it is essential that an emergency preparedness plan is planned, well documented and put in place, for all large dams, to meet the eventuality of the unexpected rare event actually materializing.

There is a need of strengthening the data collection network and creating database. The impact of climate change on design flood aspects and design criteria need to be researched and thoroughly debated/discussed.

REFERENCES:-

1. Manual on " Estimation of Design Flood" CWC, March, 2001
2. Report on Dam Safety Procedures – CWC 1987
3. Guidelines for fixing spillway capacity of dam, BIS – 11223, 1985
4. "Manual or Estimation of Probable Maximum Precipitation", WMO Operational Hydrology Report No. 1, WMO-332, 1986,
5. Staff Appraisal Report (India) Dam Safety Project World Bank 1991
6. State of Art Report on HAD-SW, November, 2010
7. National Water Mission document, MOWR, December, 2008