Adaptions to climate change induced uncertainties for safeguarding existing dams – case study of Banas basin, Gujarat, India

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ABSTRACT:

Climate change has posed many threats including extreme floods that may cause huge damages to the existing dams. There are many old dams which were designed on the basis of empirical formulas in absence of reliable rain gauge and river gauge data as in those days the limitations of instruments for observation of hydrological behavior of rivers were ample. Frequent extreme events with severity have proven the limitations of the then applied empirical formulas for designing the spillover capacities of the dams and hence has become urgent to review the hydrology for such dams. This paper discusses this issue with the help of a case study of Gujarat, India in which has been the discussion on one river basin having two river courses meeting somewhere on the approach of the plane land. The said river courses have a dam on each. This basin called Banas is an interstate basin shared by Gujarat and Rajasthan states of India. It received heavy flood after construction of a dam on one course for which the design flood was computed as per an empirical formula but the actual flood with much higher discharge occurred soon after its construction and hence the review of hydrology was made as per which additional spillway was subsequently provided to ensure the safety of the dam. Another dam was constructed on the other course of the same basin with the revised historical flood as the basis for computation of spillover capacity; however, the recent flood proved that the scientific approach for the latter case and that, too, with the revised fold data fell short in estimating the safe design flood. Albeit, the previously constructed dam with added spillover capacity not only performed well but also helped modulate the flood peak effectively. Thus, this paper puts forth an interesting case study as to how the flood estimation methodologies are required to be modified in the present times of unexpected extreme floods in order to ensure effective flood control and safety of the dams. It also underlines the importance of retrofitting of the existing old dams in light of the recent flood data by reviewing the hydrology.

1. BANAS BASIN AND ITS TOPOGRAPHIC AND CLIMATIC FEATURES

Banas basin sprawls from peak of Aravali mountain range to the desert of Banaskantha district of Gujarat state of India. The said desert neighbors the desert of Katchchh. Entire region including neighboring part of Rajasthan state i.e. Thar desert is arid from agroclimatic zonation point of view.

Figure 1. Agroclimatic zones of India and location of Banas basin

Western India normally receives monsoon due to southwestern wind as shown in Figure 2 which loses its strength by the time it reaches the northern part of Gujarat and Rajasthan and therefore they are arid. Main reason for location of deserts of Kachchh and Thar is the scanty rainfall in the normal monsoon.

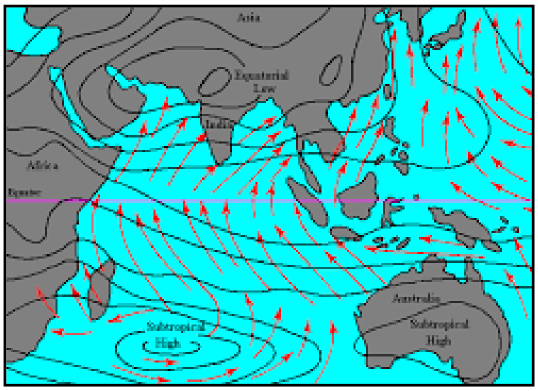

Figure 2. Normal monsoon pattern for western India i.e. southwestern wind induced rain

Figure 3. Arvalli and Vindhyas mountain ranges

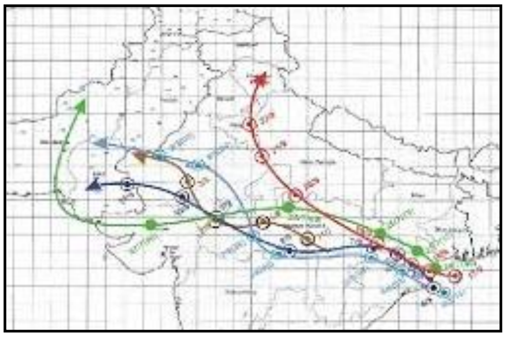

Figure 4. Exceptional monsoon pattern for western India

Exceptional monsoon passing between the Aravalli and Vindyas mountain ranges occurs when low pressure is formed in Arabian sea. Such monsoon brings heavy rains in the Banskantha district and desert of Kachchh.

2 DANTIWADA DAM: LIMITED HYDROLOGICAL DATA AND ITS CONSEQUENCES

As shown in Figure 5, a tributary name by Sipu meets Banas in the upstream of Deesa town. Banas main course and Sipu, both have their upper catchment in Abu hills of the Aravali mountain range. There is a dam on each of the two river courses – Dantiwada on Banas and Sipu on the Sipu river course. Both the dams are located on the foothills of Aravalli mountain range. Catchment area of Banas river at Dantiwada dam site is of 1130 square miles (2862 Km^2) of which 432 square miles (1093 Km^2) in Rajasthan state and the rest in the Gujarat state. Catchment of Sipu Dam is 1221 Km^2. Free catchment in the downstream of both the dams is 2090 Km^2.

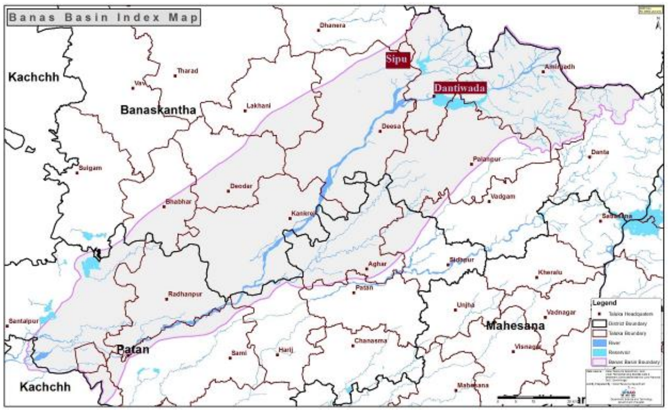

Figure 5. Index map of Banas basin

Dantiwa dam is constructed across river Banas near village Dantiwada of Banaskantha district of Gujarat state in India. It was envisaged in 1950s and surveying and geological investigations were carried out in 1955 onward. Its design was completed in 1960 and construction in 1965. Its gross storage is 464.381 Million Cubic Meter. Its Full Reservoir Level is R.L. 184.15 m. Its command area is 45,823 hectare. Earthen flanks are on both the sides of the river gorge and in the middle portion is the masonry spillway with 11 radial gates each of size12.50 m X 8.23 m. Length of the masonry dam is 601 m. Only seven times in its history the dam has received water up to its Full Reservoir Level. The geology of the dam site is characterized by penultimate granite outcrop of river Banas.

When the hydrology for the Dantiwada dam was worked out in 1955, the rainfall and river flow data were scanty. Rainfall data for 19 years was available for Abu Road station in the upstream of the dam site and for only 5 years it was available for Amirgadh station. Therefore, data for a short period that was available from the stations in the neighboring basin – Saraswati was also considered. It was found that the rainfall was concentrated – in July it was 45% and in August 30% as average. River gauging data was available only for 6 years at Dantiwada site and for 4 years at Kamalpur site which was 40 miles further downstream. Maximum flood discharges were computed by using various formulas. The figures were varying between 1,13,000 cusec (3290 m^3/ sec) to 4,45,000 cusec (12955 m^3/ sec). For the design of spillway, flood as per Inglis formula was considered which was 2,35,000 cusec (6841 m^3/ sec). Dantiwada dam including its components was completed in 1965.


Figure 6. Dantiwada Dam

Design flood at the Dantiwada dam site was computed as 2,35,000 cusec i.e. 6,650.5 m^3/ sec for the catchment area of 2,862 Km^2 against which a flood arrived of the size of 11,942 m^3/ sec on 31st August, 1973 at 20.00 hours. On 1st September, 1973 at 8.00 hours another peak of flood arrived of the size of 12,112 m^3/ sec. The former was due to heavy rainfall in the catchment of Banas river whereas the latter was due to breach in Swarupganj tank which was in upstream of the Dantiwada dam in Rajasthan state. Very soon from the completion of the construction of dam, the event of facing a severe flood - more than the design flood, posed a question on safety of the dam. The gates and apron were badly damaged and erosion in the river bed in the downstream of the apron was severe. Because the inflow peak was much higher than the spillover capacity, the radial gates which were open had to take a great thrust and the water level went higher to surmount the top of the gates. The office building adjacent to the spillover section was having through openings in the forms of doors and windows which were also used by the flood water as additional waterway as shown in Figure 7 and 8.

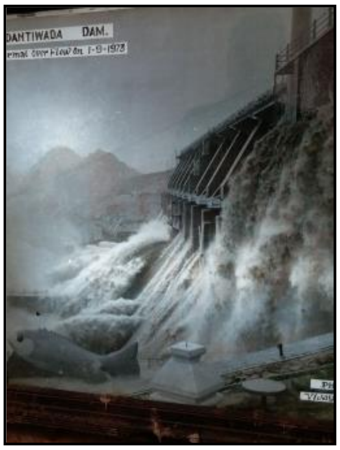

Figure 7. Dantiwada Dam – actual flood much more than the design flood


Figure 8. Dantiwada Dam – endangered due to heavy flood

3 DANTIWADA DAM: REVISION OF HYDROLOGY

In case of Dantiwada dam, the data available was so scanty that the data for adjoining basins was taken and still the required data was not possible to be obtained and hence the Inglis formula was resorted to. The actual flood in 1973 proved the insufficiency of design flood and that is how the revision of design flood and follow up actions were required to ensure hassle free performance of the dam for long years. The biggest limitation of the empirical formulas used in earlier days was that they considered only one value of bed gradient for the river course. When the dam is located at the foothill, obviously the topography of the catchment would result in to a complex gradient phenomenon which could not be represented by a single value and in case it is done so, it would give a misguiding value of discharge. Moreover, different empirical formulas lead to large variations in the estimated discharge and hence it becomes very difficult to arrive at a particular value of discharge as the design flood.

As the flood of 31st August and 1st September, 1973 proved that the design flood of 6650.5 m^3/sec was not sufficient, the Central Water Commission took up the review of it. Even in 1973 the rain gauge and river gauge data were not sufficient and therefore the fabricated hydrograph from the actual flood data was the only wayout. The flood hydrograph of 4,22,000 cusec with a peaking time of 3 hours suggested the need of a unit hydrograph with 1 hour duration. With trial and error, the unit hydrograph that was in unison with the flood data was prepared and was converted in to 6 hour hydrograph to obtain the flood hydrograph. It was compared with the actual flood data and was found satisfactory. With 70% of run off factor and 23 hours as the base period the Probable Maximum Flood (PMF) was worked out as 6,40,000 cusec (18653 m3/ sec). Total flood volume was estimated as 1450 Million Cubic Meter. Considering the said results, additional spillway with 14 vertical gates each of the size 18.29 m X 4.88 m with approach and tail channels was constructed on the right flank of the damLength of the additional spillway was designed as 308.5 meter and its crest level as R.L. 179.22 m. Its spilling capacity was worked out as 6792 m^3/ sec. The construction of the additional spillway was completed in 1985.

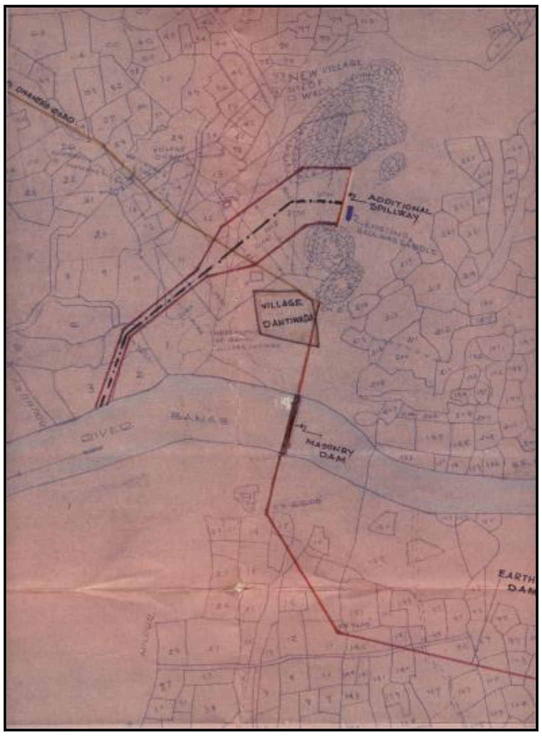

Figure 9. Alignment of Dantiwada Dam and Additional Spillway

4 SIPU DAM: ENOUGH HYDROLOGICAL DATA BUT STILL FACED CHALLENGE

Figure 10. Storm intensity at different rain gauge stations

Sipu dam was envisaged to be constructed across river Sipu which is a tributary of river Banas. It was constructed in 1990s. Length of the dam is 8200 m. Its gross storage capacity is 177.78 Million Cubic Meter. The river has a total catchment of 1221 Km^2 out of which 970 Km^2 is in Rajasthan state. The geology of the Sipu river at the Sipu dam site was found very similar to that of the Banas river at the Dantiwada dam site. The spillway is in the gorge portion and has 12 radial gates of size 12.5 m X 8.23 m each. The design flood peak is 7080 m^3/ sec at H.F.L./ F.R.L. at R.L. 186.43 m. As per the Central Water Commission, Government of India, projects having storage capacity of more than 61.53 Million Cubic Meter should be designed as per Probable Maximum Flood (PMF). The two day catchment storm depth of 398 mm as per the observed isohyetal pattern of the storm of

1st and 2nd September, 1973 was taken as the basis. It was further maximized by 20% to get the PMF depth of 478 mm. From the short hourly distribution of rainfall the PMF peak was worked out as 8601 m^3/ sec. Length of the spillover section has been provided as 180 m with the crest level of R.L. 178.157 m. As Sipu dam was constructed long after Dantiwada dam, data availability was not a big issue and the flood of 1973 also became a source of reliable information to work out the PMF. Therefore, Sipu was designed not with empirical formula for hydrology but on actual data and with scientific method and was believed to be reliable.

Rainfall in monsoon of 2015 which was of exceptional type instead of southwestern type, was concentrated for a short period in the Banas basin. It was 250 mm in 12 hours. But the rainfall in monsoon of 2017 which was again of exceptional type was unprecedented. Total rainfall occurred till end of |July, 2017 was 960 mm. On 23rd and 24th July the rainfall intensity was at its peak. Only in 2 hours there was 250 mm rainfall recorded at Datiwada. During the same period there was heavy rainfall in Rajasthan also. Mount Abu recorded 750 mm rainfall in only 24 hours. All the water suddenly came to Sipu and Datiwada dams as the topography of the catchment is hilly and the gradient is steep. Observations of rain gauge stations were studied to understand the storm. Fortunately, sufficient rain gauge stations have been provided which became very useful in understanding the situation. Various parts of the catchment areas of the Banas basin had received the storm of identical characteristics and that, too, almost simultaneously which could be appreciated from Figure 11 i.e. the chart prepared from the rainfall data of some rain gauge stations located sparsely. Actually the entire basin somehow was clouded evenly and hence the precipitation pattern was identical which happens rarely.

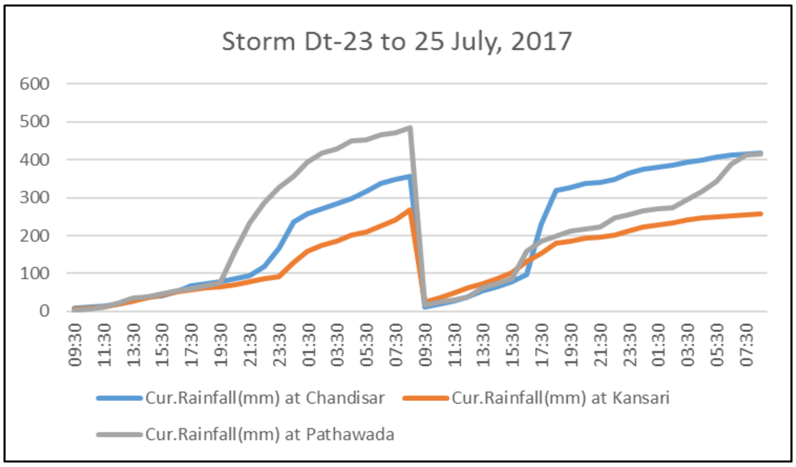

Figure 11. Storm intensity at different rain gauge stations

The precipitation was so widespread and intense that the entire drainage system of the basin got inundated and the topographic surface could not dispose the runoff which resulted in to sheet-flow on a large area which devastated several villages and towns. This was in spite of two dams to modulate the flood peaks in the foothills of the mountain range. This scenario not only indicate the need of review of the hydrology for the dams but also the urgency of reviewing the drainage plan of the entire basin in order to avoid the devastation of human habitation and public property.

Because the hydrology of the Sipu dam has been worked out with the flood data of 1973 as narrated above with quite a reliable data of long years, Sipu was expected not to face any need of revision in hydrology. Maximum outflow recorded in history till date was only 582 m^3/ sec till 2015. In the flood of 2015, the net inflow was 4200 m^3/ sec against the designed spillover capacity of 8601 m^3/ sec and hence was easily managed. But on 23rd July, 2017 the peak inflow of 10860 m^3/ sec was recorded. As the raingauge stations in the upstream of the dam supplied alarming data, the outflow was gradually increased from 1456 m^3/ sec to 10860 m^3/ sec and hence thanks to timely release that the dam survived. Devastation in the downstream due to dambreak could be avoided in spite of so high intensity of the flood. However, the left side guide wall was damaged seriously because of the hydraulic behaviour owing to the downstream topography of the river gorge. However, the actual flood though was greater than the design flood did not hit the open gates on the spillover section and hence the devastation was not large. Moreover, the apron could also sustain the effects of the flood as the hydraulics was worked out very well at the design stage and the bottom rock was also strong enough to sustain the impact. For the Sipu Dam, the flood of 2017 was more severe than the 1973 and hence even with 20% of room provided in the computation of the Probable Maximum Flood which was worked out on the basis of the flood data of 1973, the actual flood was greater than the design flood. Thus, nature has put forth the fact that the present hydrology is not sufficient.

5 CHALLENGE OF 2017 FLOOD TESTED THE RETROFITTED DANTIWADA DAM

Dantiwada has the spillover capacity of is 13633 m^3/ sec including additional spillway. The peak flood to be managed on 30th July, 2015 was 3581 m^3/ sec which was after modulation using the actual spillover capacity. Thus, it could be said that the increased capacity helped in modulation and the peak of the inflow was effectively controlled. But the real test was the 2017 flood. Peak flood to be managed was 7016 m^3/ sec on 24th July, 2017 and that too, with sufficient spillover capacity and rain gauge stations in the upstream. Because of greater spillover capacity due to reviewed hydrology and additional spillway, the flood was effectively modulated by operating both the spillways for a short duration and advanced release was made and hence the peak could be controlled. Compared with the 1973 situation, the flood peaks were perhaps not more severe but without additional spillway the Dantiwada dam could not have been safely operated is a crucial fact. Actually, the real benefit of revision of hydrology and spillover capacity in context of any large flood subsequent to construction of any dam is the revision in capacity of modulation of the flood peak and that is the strength of the dam during the crisis management.

6 SIPU DAM: REVISION OF HYDROLOGY AND SPILLOVER CAPACITY

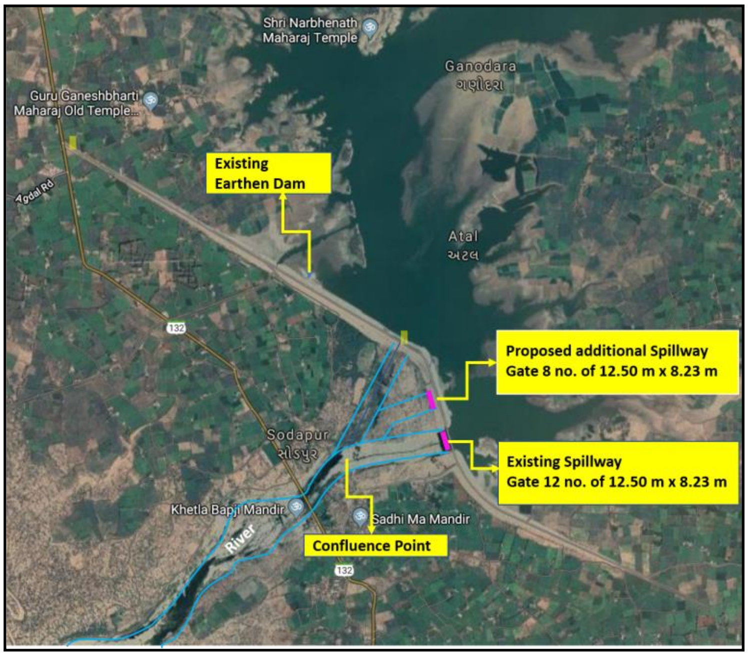

Figure 12. Proposed additional spillway

Just as flood of 31st August and 1st September 1973 provided an opportunity to review the hydrology and to provide additional spillway, the flood of 24th July, 2017 did for the Sipu dam. The hourly distribution of rainfall of each bell of 12 Hour bell distribution of rainfall was carried out taking the normalized distribution coefficients. Critical sequencing of hourly effective PMP rainfall of each bell was considered. The reverse of critically sequenced effective rainfall has been used for convolution with ordinates of unit hydrograph to get Probable Maximum Flood Hydrograph. Revision of design flood was carried out in consultation with the Central Water Commission, Government of India. The reverse sequence of hourly effective rainfall was convoluted with ordinates of unit hydrograph to get PMF direct runoff hydrograph. The base flow contribution was added to get the PMF hydrograph at Sipu Reservoir Project. The peak of PMF was worked out in order of 12694 m3/sec. The estimated PMF for Sipu Reservoir Project lies between lower envelope (3551 m^3/ sec) and upper envelope (19288 m^3/ sec) of envelope curves.

With the revised hydrology, additional spillover section with 8 gates of 12.50 m X 8.23 m each is being provided. Additional spillways would have the designed spillover capacity of 5078 m^3/ sec. Thereafter the total spillover capacity of the Sipu dam would be 12158 m^3/ sec.

7 CONCLUSION

Climate change has now become really a serious problem for all the aspects of human lives. But the existing dams with design flood values worked out using empirical formulas are under a great threat because the recent floods are of much higher intensities than what it was estimated using empirical formulas. In past the problem was of the rain gauge and river gauge data and therefore the designers had to depend on the empirical formulas. They generally used only one value of the river bed gradient and hence the complex topographical variations were simply averaged out which became the biggest limitation with them. Variations in results of different formulas being very large, arriving at a particular value as design flood was also very difficult. On the other hand, in some cases, recently it has been found that even scientifically worked out design flood values are not sufficient against the actual floods and hence the modern approach is required to be relooked in to. The risk to the existing dams in the given situation requires serious thought as there could be a bigger risk by dams themselves if the issue remains unaddressed in the light of the fact that the in case of dam failure, the actual flood peak could be drastically severe as compared to the natural flood peak. Keeping in mind this aspect of the dam safety that the hydrology of the existing dams is required to be reviewed rationally and necessary steps for retrofitting if required be taken urgently. In addition to it, the recent floods have also suggested the urgency of reviewing the drainage plan at the basin level in order to avoid the devastation of human habitation and public property. This entire process is actually adaptive learning in the dam engineering which has become very essential.