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INCOLD

INCOLD JOURNAL

A Half Yearly Technical Journal of Indian Committee on Large Dams

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Mr. Gajendra Singh Shekhawat, Hon'ble Minister, Ministry of Jal Shakti, Government of India, and dignitaries during inaugural session of ICOLD Symposium on Sustainable Development of Dams and River Basins & APG Symposium on Water and Dams on 24th February 2021, New Delhi

INDIAN COMMITTEE ON LARGE DAMS
CBIP Building, Malcha Marg, Chanakyapuri, New Delhi - 110 021
Ph. : 91-11-2611 5984/2611 6567, Fax : 91-11-2611 6347
E-mail : sunil@cbip.org; cbip@cbip.org; Web: http//www.cbip.org

AIMS & SCOPE

INCOLD Journal is a half yearly journal of Indian Committee on Large Dams (INCOLD) which is involved in dissemination of the latest technological development taking place in the field of dam engineering and its related activities all over the world to the Indian dam/hydropower professionals.

The aim of the journal is to encourage exchange of ideas and latest technological developments in the field among the dam engineering Professionals. The journal is for fully-reviewed qualitative articles on planning, design, construction and maintenance of reservoirs, dams and barrages and their foundations. The articles cover scientific aspects of the design, analysis and modelling of dams and associated structures including foundations and also provides information relating to latest know how in the field of construction technology for the related works. In addition to the information on the research work on the relevant subjects, the journal provides information on the related technical events in India and abroad such as conferences/ training programmes/ exhibitions etc. Information related to ICOLD (International Commission on Large Dams) activities such as ICOLD Congresses, its technical symposia, workshops, technical lectures, technical bulletins are also highlighted for the benefit of INCOLD members.

The original unpublished manuscripts that enhance the level of expertise and research in the various disciplines covered in the Journal are encouraged. The articles/technical papers are peer reviewed by editorial Board consisting of renowned experts before publication. The Journal has both print and online versions. There are no publication charges on the author.

A.K. Dinkar
Secretary General
Indian Committee on Large Dams

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ABOUT JOURNAL

INCOLD Journal is a half yearly journal for fully-reviewed qualitative articles on aspects of the planning, design, construction and maintenance of reservoirs, dams and barrages, foundation and scientific aspects of the design, analysis and modelling of dams and associated structures.

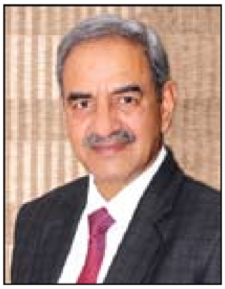
In addition to the information on the research work on the relevant subjects, the journal shall provide information on the related technical events in India and abroad such as conferences/training programmes/exhibitions etc. Information related to ICOLD activities shall also be highlighted.

All communications to be addressed to :

Secretary General

Indian Committee on Large Dams, CBIP Building, Malcha Marg, Chanakyapuri, New Delhi – 110 021

From the President Desk



Dear INCOLD Members, Colleagues, Ladies and Gentleman,

Greetings from the Indian National Committee on Large Dams (INCOLD), New Delhi.

The global spread of COVID-19 coronavirus has infected millions of people around the world and is continuing at faster pace. At the moment, it's a challenge to contain the pathogen due to its different variants. Vaccination of the large population across the globe to achieve herd immunity is taking considerable time. Availability of vaccination for entire global population is another challenge. This crisis calls for greater cooperation across the borders to turn the tide. On behalf of ICOLD fraternity, we would like to offer our heartfelt condolences to the families of the COVID-19 victims around the world. It is hoped that soon we will be able to overcome this deadly virus.

On behalf of the INCOLD and on my personal behalf, I wish to express our solidarity with the INCOLD and ICOLD 'Family Members' during this hour of crisis. Our prayers and thoughts are with the families currently dealing with COVID-19.

We are happy to inform that ICOLD Board has agreed to organize the 92nd Annual Meeting of ICOLD and Symposium in the year 2024 at New Delhi. ICOLD-2024 International Symposium will provide an excellent platform for researchers, scientists, engineers, policy makers and young professionals working in the field of energy and water resources management around the world. This event will definitely act as confluence of brilliant minds and provide an interactive platform to share path breaking ideas on the theme "Dams for People, Water, Environment and Development" besides Special Workshops on the different aspects of dam engineering to be organized by ICOLD experts.

In view of the challenge to develop new dams and reservoirs worldwide and combating the effects of climate change, I invite dam professionals from all over the Globe to join us for the ICOLD- 2024 Symposium, to discuss and deliberate on emerging professional issues. This would be an excellent opportunity to meet the National and International dam experts.

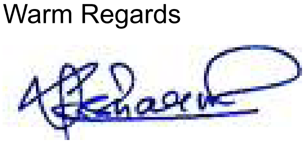
The Symposium would see convergence of renowned dam experts in academia, industry, utilities & research institutions and in other related disciplines from across the world. These experts and participants would brainstorm and deliberate on various aspects of Dams for People, Water, Environment and Development i.e. meeting the needs of the present without compromising the ability of future generations to meet their own water needs.

The deliberations of the Symposium would include presentations by national and international experts who are involved in the planning, design, construction and operation & maintenance of dams and associated structures and would share their experiences to tackle various issues connected with the sustainable development of dams and river basins.

INCOLD also offers heartfelt condolences to the families of the victims who lost their lives, to those untraced and to all those who have been impacted in the recent tragedies due to floods in Maharashtra; in Macleod Ganj in Kangra district and landslides in Kinnaur and Sirmour districts in Himachal Pradesh during the months of July and August, 2021.

I am looking forward to welcoming the ICOLD and INCOLD family, old members as well as newcomers to the ICOLD event in the year 2024 at New Delhi.

Warm Regards



Devendra Kumar Sharma
President
Indian National Committee on Large Dams
and
Vice President
International Commission of Large Dams (ICOLD)

Editorial

Greetings from INCOLD, New Delhi.

A dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10,000 years, i.e. having a one percent chance of being exceeded in 100 years. It is very difficult to predict what can happen during such a rare event as very few earthquakes of this size have actually affected dams. Therefore, it is important to refer to the few such observations that are available. The main lessons learnt from the large Wenchuan and Chile earthquakes will have an impact on the seismic safety assessment of existing dams and the design of new dams in the future.

There is a basic difference between the load bearing behaviour of buildings and bridges on the one side, and dams on the other side. Under normal conditions buildings and bridges have to carry mainly vertical loads due to the dead load of the structures and some secondary live loads. In the case of dams the main load is the water load, which in the case of concrete dams with a vertical upstream face acts in the horizontal direction. In the case of embankment dams the water load acts normal to the impervious core or the upstream facing. Earthquake damage of buildings and bridges is mainly due to the horizontal earthquake component. Concrete and embankment dams are much better suited to carry horizontal loads than buildings and bridges. Large dams are required to be able to withstand an earthquake with a return period of about 10,000 years, whereas buildings and bridges are usually designed for an earthquake with a return period of 475 years. This is the typical building code requirement, which means the event has a 10% chance of being exceeded in 50 years. Depending on the risk category of buildings and bridges, importance factors are specified in earthquake codes, which translate into longer return periods, but they do not reach those used for large dams.

Moreover, most of the existing buildings and bridges have not been designed against earthquakes using modern concepts, whereas dams have been designed to resist against earthquakes since the 1930s. Although the design criteria and analyses concepts used in the design of dams built before the 1990s are considered as obsolete today, the reassessment of the earthquake safety of conservatively designed dams shows that in general these dams comply with today's design and performance criteria and are safe. In many parts of the world the earthquake safety of existing dams is reassessed based on recommendations and guidelines documented in bulletins of the International Commission on Large Dams (ICOLD).

There is a need to create awareness amongst engineers, scientists, dam professionals, and contractors etc. about the procedures in working out appropriate seismic design parameters, different seismic hazards affecting storage dams, such as fault movement in the footprints of dams and dam safety, utilizing the State-of-the technology/practices followed globally. In this effort, Indian Committee on Large Dams (INCOLD) and the Central Board of Irrigation & Power will to organize Virtual Workshops for two days durations on the subjects relevant to different aspects of dam safety engineering development on the following topics:

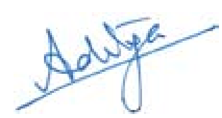
1. Reservoirs and Seismicity: September 23-24, 2021 (Thursday and Friday)
2. Earthquake and Dam Safety: October 21-22, 2021 (Thursday and Friday)
3. Seismic safety of Existing Dams: November 18-19, 2021 (Thursday and Friday)
4. Seismic Aspect of Dam Design: December 16-17, 2021 (Thursday and Friday)
5. Multiple Hazards Caused by Strong Earthquakes to Dams and Appurtenant Structures: January 20-21, 2022 (Thursday and Friday)

The Virtual Workshops gives an overview on the possible effects of Reservoir-Triggered Seismicity (RTS) on the safety of large dam projects; different seismic hazards affecting storage dams such as fault movements in the footprint of dams and reservoir triggered seismicity, seismic design criteria and multiple hazards caused by strong earthquakes to dams and appurtenant structures. These virtual workshops will offer a good scope for interchange of experiences, to facilitate exposure of state of art technology in all aspects of seismic design, dam safety and earthquake, especially considering participation of eminent dam expert Dr. Wieland Martin, Chairman, ICOLD Committee on Seismic Aspects of Dam Designs from Switzerland as expert faculty.

We thank all the authors for their contributions. I also take this opportunity to thank all the members of the Editorial Board for helping us in our endeavour and providing us with their valuable suggestions in bringing out this journal.

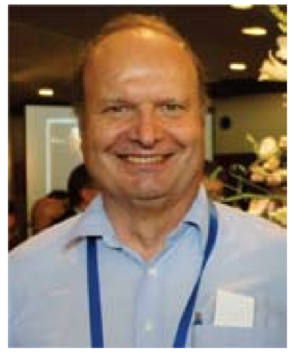
We request all the water and dam professionals' readers to contribute technical papers/articles news etc. which would be of interest for publishing in the subsequent issues of the journal.

We also request for the comments /suggestions of the readers so as to improve the utility of the journal.



A.K. Dinkar
Secretary General
Indian National Committee on Large Dams

Changes to Expect in Seismic Safety Assessment of Large Storage Dams in Future



M. Wieland

Poyry Switzerland Ltd., Zurich, Switzerland

ABSTRACT

Since the 1930s, when the pseudostatic seismic analysis methods for concrete and embankment dams were introduced, the following changes have taken place: (i) from pseudostatic to dynamic seismic analysis of dams, (ii) from the representation of the earthquake ground shaking by a seismic coefficient to safety evaluation earthquake ground motion parameters, (iii) from consideration of single hazard to multiple seismic hazards including ground shaking, mass movements, and faulting, and (iv) from safety factors to rational seismic performance criteria, characterized by dam deformations. There are still considerable uncertainties about the behaviour of a dam under very strong ground shaking. The following topics are discussed that need further attention: inelastic earthquake behaviour of dams under strong ground shaking; seismic strengthening of existing dams; short-term behaviour of mass concrete, RCC and rockfill materials; seismic design of hydro-mechanical equipment; abutment stability of arch dams during earth-quakes, seismic behaviour of asphalt core rockfill dams and other new types of dams; seismic safety of tailings dams during operation and long-time storage phase, and seismic design and performance criteria.

1. INTRODUCTION

The first modern dams that experienced strong ground shaking were those affected by the 1906 San Francisco earthquake. At that time no seismic loads were considered in the analysis and safety checks of dams. Rational seismic analysis concepts for concrete dams were used in the 1930s for the construction of Hoover dam in the USA (Westergaard, 1936). At the same time a method for the seismic slope stability analysis was proposed by Mononobe et al. (1936). For both types of dams the seismic hazard (ground shaking) was represented by a seismic coefficient. Typically a value of 0.1 was used, almost irrespective of the seismic hazard at the dam site. For concrete dams the horizontal inertia force of the mass concrete was taken as the product of the seismic coefficient times the dead load of the dam and the hydrodynamic pressure from the reservoir was taken into account assuming incompressible behavior of water. For embankment dams the earthquake load was represented by the horizontal inertia load acting in the most unfavorable direction in the center of gravity of the sliding mass. All seismic loads were considered as static loads and, therefore, they could be analyzed in the same way as the other static loads, which made this analysis that is called pseudostatic analysis, quite simple. This was the international state-of-practice until 1989, when ICOLD published its first modern guideline on “Selecting Seismic Parameters for Large Dams” (ICOLD, 1989). However, already in 1971, when several dams were damaged during the San Fernando Earthquake in California, it became obvious that the pseudostatic method of analysis is no longer appropriate (Wieland, 2018a).

Why is the pseudostatic method obsolete? To answer this question we only have to look into the dams, which experienced cracks and inelastic deformations during strong earthquakes. If these dams have been designed according to the pseudostatic method with stresses within the allowable stresses and the sliding safety factors exceeding the required values, then these dams should not have been damaged at all. This is not only a result of the underestimate of the seismic coefficient but also due to the neglect of the dynamic response of the dams.

Different research works on the seismic analysis and behavior of dams started already before the San Fernando earthquake, but these dynamic methods were only used in special cases.

Since the 1930s considerable developments in the seismic analysis and design of large storage dams have taken place. The main developments, documented in several ICOLD Bulletins, may be described as follows:

(i) from pseudostatic analysis to dynamic seismic analysis of dams,
(ii) from the representation of the earthquake ground shaking by a seismic coefficient to safety evaluation earthquake ground motion parameters,
(iii) from consideration of single hazard to multiple seismic hazards including ground shaking, mass movements, and faulting, and
(iv) from stability safety factors and allowable stresses to rational seismic performance criteria, characterized by dam deformations and seismic failure modes of dams.

In several countries and organizations, the old seismic analysis concepts are still used although they have been considered as obsolete and even wrong since the time of the San Fernando Earthquake in 1971. Because the pseudostatic analysis method is that simple, and since it is used in seismic codes for buildings, many dam engineers are using and defending this outdated method, even in areas of high seismicity, where these deficiencies are most obvious.

Moreover, there are many dams that have been built without taking into account earthquakes or which were designed against earthquakes using the pseudostatic analysis method. Therefore, it is not known if these existing dams satisfy today‘s seismic design and safety criteria.

Based on this brief overview it may be concluded that for the seismic analysis and design of new dams modern seismic design and safety criteria are used, and that for all existing dams, it must be checked, if they comply with today‘s seismic design and safety criteria, which are the same for old and new dams (Wieland, 2016).

As earthquake engineering is still a relatively young discipline and since large dams have to be able to withstand the strongest ground motion at a dam site, there is a need for periodic review and updating of the seismic design and safety criteria for dams. Still, there are major uncertainties in the estimated seismic ground motion parameters and none or very little information exists on the seismic performance of new types of dams during strong earthquakes as, for example, asphalt core rockfill dams, concrete-face rockfill dams and others, which are popular today among dam engineers. Therefore, it is important to look beyond the current state-of-practice. It should also be pointed out that the criteria given in ICOLD guidelines are minimum requirements and that for special problems engineers have to use more advanced seismic safety concepts or even new ones.

Moreover, if we talk about the future, we think about a time frame of 10 to 20 years, which corresponds to the intervals new seismic guidelines should be prepared. This seems to be a long period, but as mentioned before, it takes still a long time until new safety concepts are introduced in all countries. For example, the check of the seismic safety of existing dams, which was recommended by the author, when he was appointed Chairman of the ICOLD Committee on Seismic Aspects of Dam Design in 1999, has only been done in a few countries. It must also be pointed out that seismicity does hardly change at dam sites, but it is the knowledge on the seismic hazard that changes and new information becomes available. The safety checks are delayed because of economic constraints rather than lack of manpower or knowledge.

2. SEISMIC HAZARD EVALUATION OF DAM SITE

For large storage dam projects, the earthquake hazard includes (i) ground shaking, which is the main hazard considered in seismic design codes and guidelines, (ii) displacements along potentially active faults in the dam foundation and/or the reservoir, (iii), landslides and rockfalls, which may cause impulse waves in the reservoir, block intakes of low level outlets and spillways or may damage important equipment and installations at or close to the dam site or block access roads to the dam, and (iv) other site-specific and project-specific hazards.

Moreover, as strong earthquakes a rare events, the earthquake hazard is one of the least known hazards. In particular, the estimate of the ground motion at the dam site for the strongest earthquakes with a very low probability of occurrence is difficult and associated with major uncertainties. Therefore, a thorough investigation of the geologic and seismotectonic setting of the dam and reservoir region and, the seismic hazard assessment based on different earthquake scenarios and probabilistic analyses is required.

At this time the seismic hazard studies focus only on ground shaking. This is important, but the other seismic hazards must be analyzed to the same extent in future. The methods of seismic hazard analyses have made great process within the last 20 to 30 years and the models used are getting more and more complex. A lot of research is done in this field and changes are expected in the future. However, large uncertainties may remain.

The main future developments in the ground shaking hazard relevant for large dams are as follows:

(i) ground motion parameters of strong near-field earthquakes,
(ii) site-specific geological and topographic effects on ground motion parameters,
(iii) directivity effects of ground motion at dam sites,

(iv) duration of strong ground shaking of different design earthquakes,

(v) development of site-specific (spectrum-matched) acceleration time histories, and

(vi) development of non-uniform ground motion models for dams.

There are other factors that are important for seismologists but of lesser importance for dam engineers. It is essential that seismologists provide the ground motions required by dam engineers and that they make the dam engineers aware of new developments in ground motion prediction that may have a negative effect on dam safety.

From the above items, item (v) is the most important one for dam engineers, as for their seismic analyses, they need acceleration time histories as input. As the inelastic deformations in dams, the build-up of pore pressure in soils and other damage mechanisms depend on the duration of strong ground shaking; therefore records with long duration of strong ground shaking are needed for a conservative design and safety assessment of dam projects. By using extended durations of strong ground shaking, the effects of aftershocks can be included, without requiring extra analyses.

Non-uniform ground motion models (item vi above) are still in the early research stage and there is a lack of simple models that could be used by dam engineers for their large dam projects. Of course, one could include the geologic and seismotectonic conditions and the earthquake mechanism in a dam-reservoir-foundation model, but such models are not yet used for dam design, as due to the many uncertainties numerous sensitivity analyses would be necessary and the finite element models of the dam would be too coarse in such analyses. Moreover, the cost of such analyses would also exceed any budget for dam analysis.

The design ground motions required by dam engineers that allow them to design safe dams may be quite different from recorded earthquake ground motions as discussed by Wieland (2018b). Seismologists, who want to provide "exact" ground motions, may not be aware of the fact that for the seismic design and safety checks, so-called ground motion models are used rather than exact ground motions. The concept of ground motion models is equivalent to that of load models used in the design of buildings and bridges for over 100 years by engineers and this concept has proven to be very powerful in practice. Here a better understanding among seismologists and dam engineers is necessary in future. This aspect is important as it creates much misunderstanding. Also, the seismic design and earthquake safety assessment of dams is the core competence of dam engineers.

For seismic hazard characterization the following developments have taken place or may be anticipated in the future:

(i) Seismic coefficient: This is the first ground motion model used in which the earthquake ground motion (acceleration time history) is characterized by a seismic coefficient that represents the peak ground acceleration (PGA). However, there is no sound scientific basis between the seismic coefficient and the PGA and it is not clear what level of design ground motion it represents. The seismic coefficient model is still used for the design of large dams, although this is an outdated model.

(ii) Ground motion parameters determined from probabilistic and/or deterministic seismic hazard analyses: Typically, the acceleration response spectra are calculated for different return periods and confidence levels. Spectrum-matched acceleration time histories are determined, as they are required as input for the seismic analysis of dams. The acceleration time histories are not real earthquake ground motions and have to be considered as ground motion models. This represents the present stage in the seismic analysis of dams. The seismic hazard analyses (ground shaking hazard) have become very sophisticated as compared to (i).

(iii) Future ground motion models: For future ground motion models used in the dam industry, the probabilistic seismic hazard analysis approach will be suitable for determining the ground motion parameters for usual" design earthquakes. However, for the SEE ground motion, we can see the following approaches: (a) use of present methods discussed in (ii), taking into account new developments, or (b) an upper bound magnitude and focal depth are specified as area source. To some extent, this would correspond to the seismic coefficient approach listed above. No recurrence period would be assigned to such "floating" earthquakes, which as a worst case could occur directly beneath the dam. Floating earthquake scenarios are nothing new. They are assumed, for example, in the Zagros Mountain Range in Iran, where at a depth of 10 km a rock salt layer exist where earthquakes (reverse faulting mechanism) with moment magnitudes of 5.8-6.5 were specified, considering the magnitude of past earthquake in the project region. The advantage of (b) is that the seismic hazard analysis would be much simpler than that used today (ii), which is becoming more and more advanced without actually contributing to the improvement of the seismic safety of dams.

3. SEISMIC DESIGN CRITERIA

The seismic design criteria as recommended in ICOLD Bulletin 148 (ICOLD, 2016) will remain for quite some time. However, the requirement that a large storage dam has to withstand the worst ground motion at the dam site will initiate further discussions as this concept is basically in contradiction with any risk-based design concepts. This discussion has been going on for quite many years and will hardly be resolved as this design philosophy has proven to be very successful and powerful, especially when the seismic safety has to be explained to the public. The following statement is still valid for the designers of any structure or project: We sell safety and not risk.

As far as dam safety of existing older dams is concerned and this includes seismic safety, there shall be no difference in safety for people living downstream of an old or new dam. This implies that all dams must satisfy today‘s safety criteria. This is still not the case in many parts of the world. Therefore, this is a long-term task for the future, but there is nothing new with this. It must be done.

The main issue related to the seismic design criteria, which are specified for three types of dams (ICOLD, 2016), i.e. extreme or high consequence dams, moderate consequence dams, and low consequence dams, is the risk classification of dams. There are significant differences in the risk classification used in different countries and organizations. If the same dam is, for example, classified as a high risk dam in one country which must resist the ground motion of an earthquake with a recurrence period of 10,000 years (ICOLD, 2016) and in another country, it is classified as a moderate consequence dam, the recurrence period is reduced to 3000 years or even 1000 years for low consequence dams. Future developments must address this issue. Risk-based approaches may be used, but for densely populated countries in Europe, where the failure of any large dam has high consequences, this approach is not feasible.

Although ICOLD recommends a recurrence period of the safety evaluation earthquake (SEE) of 10,000 years for high consequence dams, other recurrence periods are specified in some countries, i.e. 2475 years, similar to the reference return period used in seismic building codes in North America. More flexible criteria for the return period may be provided in future for dams located in areas of different seismicity.

An important aspect of the seismic design criteria is the definition of the seismic load combinations, which form the basis of any seismic analyses (Wieland, 2019), which may have to be updated based on future safety requirements and due to new knowledge about possible seismic failure modes of dams. There is also the question of higher safety standards for dams forming dam cascades along rivers and other projects with extreme consequences.

4. SEISMIC PERFORMANCE CRITERIA

If we use modern seismic design criteria for large dams (ICOLD, 2016), the following, very general, performance criteria apply for the effects of the strongest ground motion at a dam site:

(i) Retain the reservoir and to protect people from the catastrophic release of water from the reservoir,

(ii) Control the reservoir level after an earthquake as a dam could be overtopped and destroyed if the inflowing water into the reservoir cannot be released through damaged spillways or low-level outlets, and

(iii) Lower the reservoir level after an earthquake (i) for repair works or (ii) for increasing the safety of a damaged dam or when there are doubts about the safety of a dam.

These seismic performance criteria are different from those used in the past, when a dam was declared safe, when for different load combinations including static and seismic loads, the stresses were within the allowable stresses, the deformations were within allowable deformations and the safety factors against sliding, overturning and others were larger than the safety factors specified in design guidelines. This concept has been used in the past and is still being used by some engineers today.

These new seismic performance criteria have far-reaching consequences, which go beyond the tasks of dam engineers – mainly civil engineers -, because functionality of gates of spillways and low-level outlets is the main task of hydro-mechanical and electro-mechanical engineers, who may not be aware of these new requirements. Therefore, in future, there is a need to have a broader look at the seismic safety of dams and to include the functionality of safety-critical hydro-mechanical and electro-mechanical components. There is a need to adjust the design guidelines for hydro-mechanical and electro-mechanical components of spillways and low-level outlets. These components must be designed for the SEE ground motions at the support of these components.

The seismic safety of the existing gated spillways must be checked taking into the account the ground motion transverse to the river flow direction. The spillway piers have not been designed against such seismic actions. Also, low-level outlets are not provided in many dams. They are needed to cope with the possible effects of strong earthquakes. Hopefully, in future, we will see more dams with low-level outlets.

5. METHODS OF SEISMIC ANALYSES OF DAMS

5.1 Nonlinear dynamic analysis of dams

At the moment, most seismic analyses carried out by dam analysts are linear-elastic analyses (ICOLD, 1986), assuming that the foundation is massless and the water in the reservoir is incompressible. The advantage of such analyses is that they are quite simple and if the same material parameters are used, dam analysts would obtain the same results if different software is used. However, in view of today‘s seismic design and performance criteria, where inelastic deformations are accepted when a dam is subjected to the SEE ground motions, nonlinear analysis models have to be used, as, for example, it would not be possible to economically design a concrete dam, where the dynamic tensile stresses do not exceed the dynamic tensile strength of concrete in all parts of the dam.

The simplest nonlinear analysis models are of the dynamic stability analysis type, originally proposed by Newmark for the sliding block analysis of embankment dams. In concrete dams, block joints are modelled as well as cracks along the dam-foundation contact. In general, a so-called post-cracking analyses is carried out in concrete dams, in which it is assumed that cracks have fully developed, i.e. that they have propagated along lift or construction joints from the upstream to the downstream dam face etc. (Malla & Wieland, 2003). These discrete crack models are the simplest ones for the nonlinear seismic analysis of concrete dams.

The methods for nonlinear dynamic analysis of dams are, however, still under development. Nonlinear seismic analyses need substantial engineering judgment. Relatively simple models should be preferred to complex models employing nonlinear constitutive laws using parameters that are either not available or very hard to determine. These developments have been going on for several decades already and a dramatic change in the models used by dam engineers is not expected in the near future, except for special cases. Again, the main problem are the high cost of such analyses, which due to uncertainties in the parameters of the nonlinear constitutive models will require extensive sensitivity analyses. However, changes are expected in line with the implementation of the new seismic design and performance criteria discussed in the previous sections.

Dynamic stability analyse methods are also needed for the safety check of abutment wedges. This is of main concern for arch dams, which are vulnerable to foundation movements.

5.2 Concrete dams

There are several commercial general purpose computer programs, which can be used for the nonlinear dynamic analysis of dam-reservoir-foundation systems. They are mainly applicable to concrete dams. There are other geotechnical programs that are suitable for embankment dams.

An important, still not properly resolved issue is the effect of dynamic dam-foundation interaction. In linear-elastic stress analyses, the maximum dynamic stresses of an idealized homogeneous massed foundation may be 40 to 65% smaller than those obtained from a massless foundation model. Therefore, some analysts prefer massed foundation models. However, massed foundation models need more sophisticated analysis models, which are not provided in general purpose analysis software. The main problems come from the geology and material properties of the foundation rock. Jointed rock masses and rock anisotropy and other factors may limit wave radiation in the foundation. Therefore, to cope with the seismic input variability and the uncertainties in dynamic dam-foundation interaction effects, massless foundation models are normally used. Such kinematic interaction analyses, whose results are assumed to be on the safe side, are also much cheaper. Some future developments are expected, but in general, only models, which can be implemented in standard software, will be successful on a worldwide basis.

Another issue for concrete dams is the damping ratio. The values proposed in some guidelines vary from 5% to more than 12% for strong ground shaking. With the increased number of dams equipped with strong motion instruments, records will eventually become available, which allow the determination of better damping ratios. It must be kept in mind that the damping ratio is the most important material property that governs the dynamic response of concrete dams.

5.3 Embankment dams

For the seismic analysis of embankment dams the linear-equivalent method with shear strain dependent shear modulus and damping ratio is still used by most dam consultants, although this method is already more than 50 years old. This method, in combination with the Newmark sliding block analysis of critical wedges in embankment dams, does not provide reliable information on the inelastic seismic deformations of the dam. For earth and rockfill dams, and dams with a flexible upstream geomembrane or asphalt facing, the results from this simplified method allow a conservative assessment of the safety against overtopping and internal erosion (dams with filter).

However, for new types of dams like concrete-face rockfill dams, asphalt core rockfill dams, and dams with core walls made of (plastic) concrete, where the waterproofing elements are very thin compared to the thickness of the core of an earth core rockfill dam, are vulnerable to dam deformations, which may be of the same order or even larger than the thickness of the waterproofing elements. In CFRDs it is the great difference in stiffness between concrete and rockfill, which creates high membrane stresses in a concrete face and in asphalt core dam, sliding movements of wedges may damage the thin asphalt core, although it is very flexible in bending but not necessarily in shear. Similar problems are encountered in concrete core walls.

Therefore, computer programs are needed, which allow the reliable prediction of the inelastic seismic deformations of these new types of dams, which are already built even in highly seismic regions; therefore, such software is urgently needed.

6. DYNAMIC MATERIAL PROPERTIES

Dynamic material properties and constitutive models for concrete, soils and rock is basically a long-term research field. Most available information is related to the dynamic material properties of concrete and rock, the shear strength of joints, and the shear strain dependent shear moduli and damping ratios of soils, which are required in the different types of dynamic analyses of dams. The uncertainties in material properties or even lack of them require extensive sensitivity analyses. New results for mass concrete, RCC and soils are expected. This is a long-term issue. For concrete dams, as pointed out earlier, the main interest is in the damping ratio, which controls the dynamic response.

7. SEISMIC INSTRUMENTATION OF DAMS

In the seismic instrumentation of large dams we have to note the following (Wieland, 2009):

(i) The seismologists and some dam analysts want to have most stations located in the free-field and in the abutments so they can reanalyze the dam with the recorded ground motions.

(ii) The dam engineers want to understand the seismic behavior of the dam under strong earthquakes; therefore, they need instruments in the dam body and not in the dam foundation. However, for the calibration of finite element models as many stations as possible are needed in the dam body and the dam foundation.

The absolute minimum number of instruments is two, i.e. at the base of the dam and the other on the crest. This is the concept used in Japan.

The main questions to be answered by strong motion instruments are as follows:

(i) What is the damping in concrete dams under strong ground shaking (in many dynamic analyses a value is assumed which may have no relation with reality, i.e. by selecting high damping ratios the dynamic response can be reduced substantially)?

(ii) What is the amplification of the ground acceleration with respect to the crest of the dam?

(iii) What is the variation of the ground motion along the abutments (mainly of arch dams) in steep and narrow valleys?

Besides accelerometers other instruments can be used to monitor inelastic deformations (pendulums, joint meters, geodetic measurements, tiltmeters, etc.) and for changes in the ground water regime (piezometers, pressure cells, seepage measurements, etc.).

In the case of large reservoirs it is recommended to install a microseismic network in the dam and reservoir region, which should be in operation at least two years prior to the start of dam construction to measure the background seismicity, during construction, the first filling of the reservoir and the subsequent years of reservoir operation.

Strong motion instrumentation of large dams has other benefits as well as such instruments can also be used (i) for health monitoring of the dam (monitoring of changes of eigenfrequencies with time), (ii) for alarm purposes, and (iii) for the verification and improvement of the seismic design criteria.

The benefits of seismic instruments in dams have not yet been exploited fully. We strongly recommend the installation of such instruments in all large dams. The priority should be given to dams located in highly seismic regions, very large dams with large reservoirs, dams, which have shown some unusual behavior, dams that have experienced strong ground shaking, dams that are vulnerable to ground shaking, and new types of dams like CFRDs, RCC dams, asphalt core rockfill dams and others. Therefore, we expect that more dams will be equipped with strong motion instruments in future. These instruments need proper maintenance and the records must be properly evaluated. We have to keep in mind that engineers in charge of dam safety are only interested in strong ground shaking.

8. FUNCTIONAL RECOVERY AND OTHER ASPECTS

8.1 Functional Recovery

Functional recovery is basically a performance criteria issue of the hydro-mechanical and electro-mechanical equipment. This is an important matter for hydropower dams, ship locks used for navigation, and water supply systems. But the top priority remains the earthquake safety of the dam body and the safety of the people living downstream of large storage dams.

Functional recovery is gaining increasing importance. In the case of safety-critical equipment for gated spillways and low-level outlets, functionality is required for the strongest ground shaking (Wieland, 2017), which includes functional recovery. Thus, functional recovery is mainly a matter of the non-safety-critical elements. Functional recovery of the pressure waterways, powerhouse, switchyard and transmission lines may contribute to the management of the post-earthquake control of the reservoir level. However, this is not considered at present. As hydropower projects are subjected to different hazards from the natural and man-made environment, functionality is not only a concern for the earthquake hazard, which may not be the critical one.

8.2 Cut-off walls

In cut-off walls, plastic concrete is used, which, due to creep effects has similar long-term static stiffness characteristics like the surrounding soil. However, there is a need to study the stiffness of plastic concrete under seismic strain rates as creep effects will be greatly reduced, causing stiffening of the plastic concrete and changes in the dynamic behavior.

8.3 Risk analysis

Although seismic risk-based studies of large dam projects have been a hot topic for quite some time, but not much has been achieved except for the probabilistic description of the ground shaking hazard, which is standard practice today. However, as pointed out earlier, the seismic hazard is a multi-hazard, and other seismic hazards must be included in such analyses to be meaningful.

Further developments are expected in the future, which include the analysis of the seismic vulnerability of dams up to failure. The corresponding nonlinear dynamic analyses are still a great challenge. Shaking table tests would be an alternative, but they are only done for very few important dams, mainly in China. The use of theoretically derived fragility curves to describe the seismic vulnerability of dams is too simplistic. One of the terms of reference of the ICOLD Committee on Seismic Aspects of Dam Design some 20 years ago, was related to the seismic risk of dams. But due to the difficulties in defining the seismic vulnerability of different types of dams, which ultimately depends on the quality of the design and construction works, no real progress could be achieved and this subject had to be postponed. It has not yet been solved, but future developments are expected.

The present seismic risk analyses are mainly concerned with ground shaking and need further improvement. However, the seismic design of dams and the analysis of the earthquake safety of dams will still be based on deterministic concepts. Due to the limitations of risk-based analyses, stress tests are required, in industries, which rely on these concepts. These stress tests are done, e.g., for nuclear power plants, and include earthquake scenarios.

9. CONCLUSIONS

The seismic safety assessment of a dam includes the following main subjects: seismic hazard analysis, selection of seismic design criteria, modelling of dam-reservoir-foundation systems, determination of material models and dynamic material properties, methods of nonlinear seismic analysis, and definition of seismic performance criteria. All of them vary with time. Therefore, it is necessary to review the seismic safety assessment periodically. It is obvious that in a comprehensive safety review all other hazards must be included as well. This is the main task for the future. This periodic review concept is not new, but it is very useful and should be implemented by all dam owners and dam safety authorities. By this concept, effects of the widely discussed climate change on dam safety can also be assessed. If the safety criteria are not satisfied, then remedial actions have to be taken. Such detailed review should be done every 5 years, as for example in Switzerland. In practice, a reanalysis of the seismic safety may only be needed when the bases of the analysis have changed significantly, which may be in the time frame of 20 to 40 years – not every five years.

In future new developments may be expected in different areas that will affect the seismic analysis and design of new dams and the safety assessment of existing dams. In the assessment of future developments, the current ICOLD guidelines documented in several bulletins serve as benchmark. As these guidelines, which represent the state-of-the-practice have not yet been implemented by all dam owners or dam safety authorities, the first steps in the future will be to follow the recommendations made in the current ICOLD guidelines. Moreover, the seismic safety standards used in some countries may be ahead of that of ICOLD and what is considered as new or future development may not be the case for everybody. It is also important to note that the future development does not mean new research results but new methods and guidelines that are suitable for practical application. Accordingly, the following developments may be expected in the future:

1. Seismic hazard evaluation of dam site: There are four aspects: (i) besides ground shaking the earthquake hazard includes faulting, mass movements and others; (ii) the dam engineer does not need real earthquake records as analysis input but models of the earthquake ground motion, (iii) for the safety check of dams spectrum-matched acceleration time histories of the safety evaluation earthquake are required, and improvements in ground motion prediction models, especially for ground motion parameters with very long return periods.
2. Seismic design criteria: Changes are related to (i) the seismic design of hydro-mechanical end electro-

mechanical components of spillways and low-level outlets, (ii) the seismic load combinations, and (iii) the design criteria for dam cascades along rivers and very large reservoirs.

3. Seismic performance criteria: The general criteria may remain, but there is a need for low-level outlets.
4. Dynamic material properties: New material models are expected for embankment dam materials, estimates of the deformational characteristics of rockfill is required as input for advanced deformation analyses of embankment dams.
5. Methods of seismic analyses of dams: Nonlinear seismic analysis methods need further development. New types of embankment dams need reliable estimates of inelastic seismic deformations, e.g. asphalt core rockfill dams.
6. Seismic instrumentation of dams: Seismic instrumentation should be installed in all large dams.

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Life is more precious than gold, but not as precious as freshwater

Anthony T.Hincks

Adaptions to Climate Change Induced Uncertainties for Safeguarding Existing Dams – Case Study of Banas Basin, Gujarat, India

Vivek P. Kapadia
Water Resources Department, Government of Gujarat, Gandhinagar, India

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. (Fig. 1)

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. (Fig. 2&3)

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.

Fig. 1 : Agroclimatic zones of India and location of Banas basin

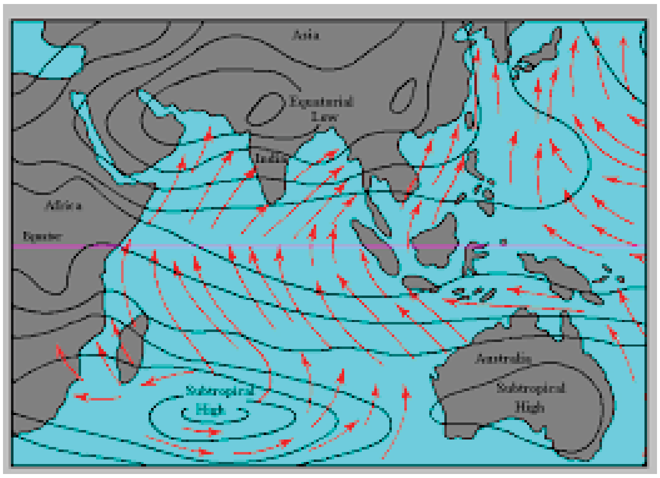


Fig. 2 : Normal monsoon pattern for western India i.e. southwestern wind induced rain

Fig. 3 : Arvalli and Vindhyas mountain ranges

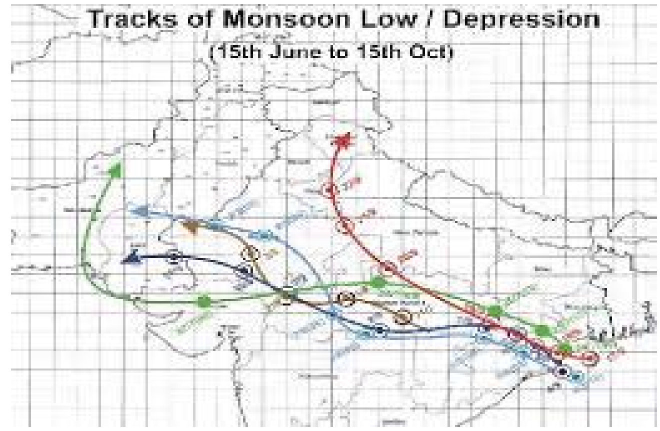


Fig. 4 : Exceptional monsoon pattern for western India

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.

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

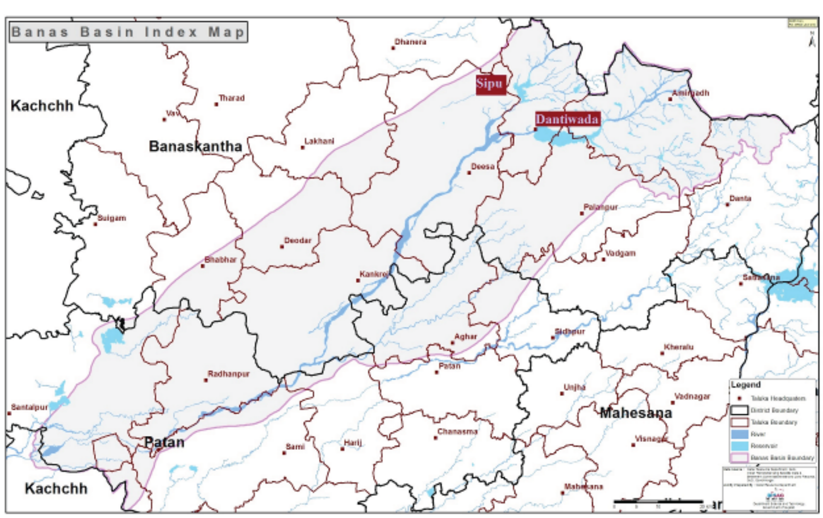


Fig. 5 : Index map of Banas basin

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)

Fig. 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 Figures 7 and 8.

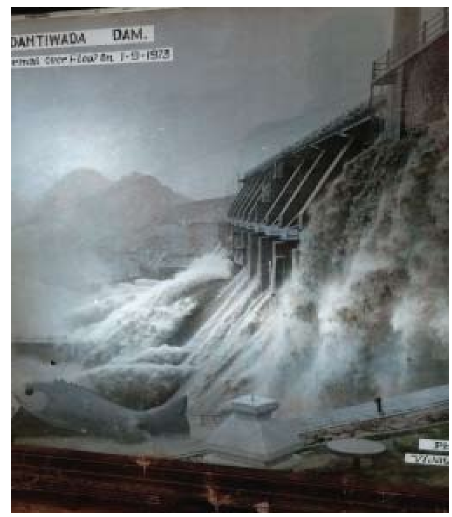


Fig. 7 : Dantiwada Dam – actual flood much more than the design flood

Fig. 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 m^3/ 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.

Fig. 9 : Alignment of Dantiwada Dam and Additional Spillway

4. SIPU DAM: ENOUGH HYDROLOGICAL DATA BUT STILL FACED CHALLENGE

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. (Figure 10)

Fig. 10 : Storm intensity at different rain gauge stations

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.

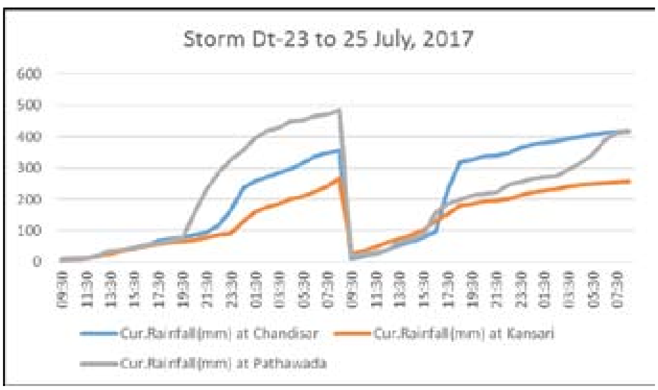


Fig. 11 : Storm intensity at different rain gauge stations

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

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. (Figure 12)

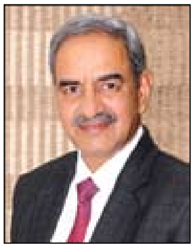
With the revised hydrology, additional spillover section with 8 gates of 12.50 m X 8.23 m each is being provided. Additional spillways would have the designed spillover capacity of 5078 m^3/ sec. Thereafter the total spillover capacity of the Sipu dam would be 12158 m^3/ sec.

Fig. 12 : Proposed additional spillway

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.

Challenges Posed by Climate Change and Sedimentation of Reservoirs for Flood Mitigation and Sustained Water Supply



Devendra Kumar Sharma[1], Anil Vyas[2], Tarun Agarwal[3] and Sukhdeep Singh[4]

ABSTRACT

The global climate crisis increases variability in the water cycle, reduces the predictability of water availability, affects water quality and aggravates water scarcity. These are compounded by number of contributing factors, including population increase, unmanaged migration, land use changes, reduced soil health, accelerated groundwater extraction, widespread ecological degradation and biodiversity loss. While all regions of the globe are affected, the impacts of climate change are highly variable. Some regions are experiencing drought while others are facing frequent-intensified floods and storms. In the past three years Bhakra Beas Management Board (BBMB) has tackled the problems posed due to climate change including drought, floods, historical minimum and maximum snow deposition, one of the highest inflows and witnessed maximum rainfall in sub-catchments in the century. It is often said that climate change impacts are observed more straight forward through water resources. Transboundary cooperation as well as cooperation between different states/provinces is needed to address climate impacts that cross national boundaries, to minimize adverse consequences from a basin perspective and also to harness the potential co-benefits of improved regional cooperation, such as reduced uncertainty due to exchange of data, enlarged planning space and shared costs and benefits.

Bhakra Beas Management Board operates two major reservoirs formed by Bhakra and Pong Dam, comprising varying inflows from 19-35 billion cubic meter (BCM) in a water year with average inflow of 27 BCM for both the reservoirs. The designed capacity of Bhakra and Pong Dam is 9.87 BCM and 8.58 BCM respectively from which the average water of 27 BCM from both reservoirs is supplied to the partner states. These reservoirs provide food and energy security and great immunity in case of droughts and floods in the North-West India. Due to sedimentation storage capacity of Bhakra and Pong reservoir reduced by 23% and12% respectively. Area downstream of the dams face danger especially in case of floods. The rivers beds are silted up and rivulets having catchment area downstream of the dams are carrying high inflows flood large areas.

To encapsulate the climate change, Bhakra Beas Management Board has taken various initiatives such as climate change studies, soil erosion hot spot identification, sediment transfer, both agriculture and non-agriculture productive use of sediments in the reservoir. The climatic studies show that by 2070 precipitation in Satluj and Beas basins would increase by 94 mm and 79 mm respectively compared to long term average of the year 1960-90 and temperature in these basins is likely to increase by 2.22 and 2.24 degree Celsius respectively. Systematic database and analysis of snow position, seasonal forecasting along with modern mathematical models is being done to minimize water scarcity conditions as well as to tackle the extreme floods. The paper brings out case study of the Beas and Satluj river basins.

1. Chairman, Bhakra Beas Management Board, Chandigarh

2. Asstt. Design Engr., Bhakra Beas Management Board, Chandigarh

3. Secretary, Bhakra Beas Management Board, Chandigarh

4. Sukhdeep Singh, Bhakra Beas Management Board, Chandigarh

1. INTRODUCTON

Water is considered as second most important thing to survive. Only 3% of the total water across the globe rest is saline water in oceans. Out of this fresh water Icecap, glaciers contains around 68.7% and 30.1% is available as ground water so only a small amount i.e. 0.9% is available on the surface in the form of rivers, swamps and lakes. If we talk in volumetric terms the (useable) water available in World are 10,633,450 BCM and most of it is deep in the ground and unavailable for humans. Only 93,113 BCM is available to humans through lakes, reservoirs and snow. The estimated volumes available in India 4,000 BCM and we are able to use only 688 BCM. The present storage capacity of India is 253 BCM. This storage capacity has, however, been reduced due to sedimentation. The per capita available fresh water in India 1.545 MCM whereas in World 5.9 MCM. For distribution of freshwater in Eastern and Western rivers, India and Pakistan signed Indus Water Treaty (IWT) in September 1960. IWT controls boundary river waters flowing from India into Pakistan. Indus water basin has 170 million acre feet (MAF) water out of which 34 MAF used to come from eastern rivers and 136 MAF from western rivers. Table 1 shows storage capacities permitted for India on Western rivers under IWT, 1960

The Indus river basin area 1.12×106 km^2 and 170 MAF water is distributed among Pakistan (47%), India (39%), China (8%) and Afghanistan (6%). Pakistan uses 95 MAF water for irrigation and stores 13.86 MAF in Tarbela, Mangla and Chashma. The annual water flow varies from 97 to 186 MAF (average 137 MAF) out of which 80% water flows in 100 days from June to September every year. Figure 1 shows location map of important dams and barrages on Indus System.

Table 1 : Storage capacities permitted on western rivers under Indus Water Treaty, 1960

Western River systems (Names)	Conservation storage capacity (As per IWT, 1960), in Million Acre Feet (MAF)		
	General storage capacity	**Power storage capacity**	**Flood storage Capacity**
The Indus	0.25 MAF	0.15 MAF	Nil
Jhelum (Tributary)	0.5 MAF	0.25 MAF	0.75 MAF
The Jhelum (main)	Nil	Nil	Not divert/hold
Chenab (Tributary)	0.50 MAF	0.60 MAF	Nil
The Chenab (main)	Nil	0.60 MAF	Nil
Ravi/Beas/Satluj	33MAF	33MAF	
Total storage	1.25 MAF	1.60 MAF	0.75 MAF

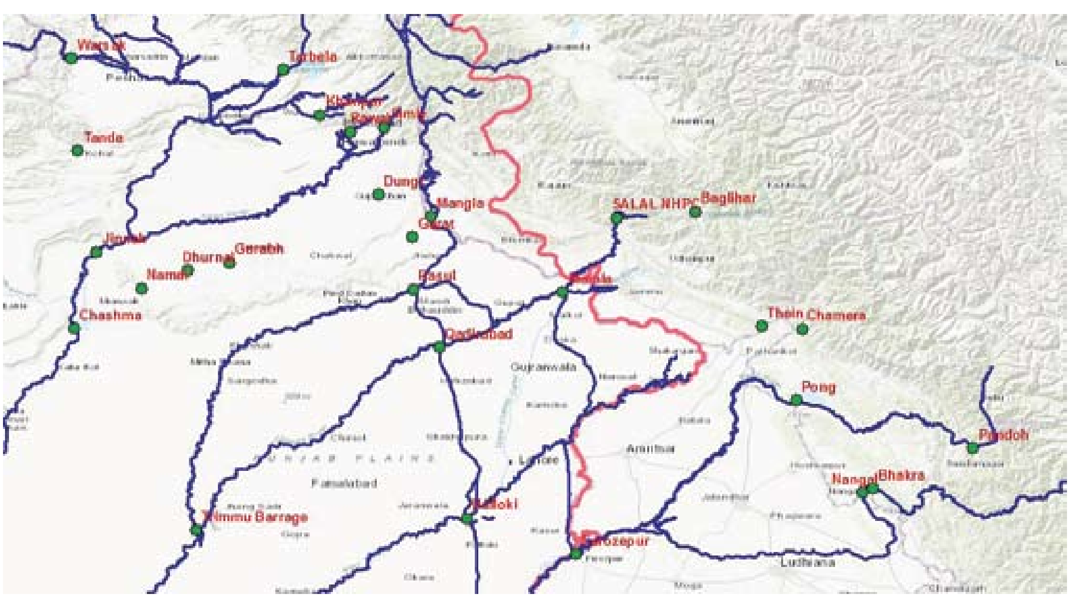


Fig. 1 : The location map showing important dams and barrages on Indus System

1.1 Western Rivers Water Run-off and Storage Dams.

The Indus system of Rivers carry nearly 170 MAF out of which India can utilize nearly 33 MAF (19 %) from the assigned three eastern rivers while Pakistan uses the balance 135 MAF(81%). In addition, India is entitled to use western river's waters for limited agricultural uses and unlimited domestic, non-consumptive, hydro power generation, etc. Even out of the assigned 19% share, a part of it flows down to Pakistan during monsoon and from Ujh river throughout the year.

Present situation around the world with increasing water and energy demand on one hand, while catchment degradation and sediment-induced problems in rivers and reservoirs on the other hand may diminish the safety of dams and shorten the reservoir life. Almost all reservoirs worldwide share this sedimentation problem in common, to a differing degree depending upon the characteristics connected to the hydrological, geo-morphological, socio-economic and ecological behaviors of its river basin. Reservoir sedimentation is a significant concern faced across the globe and the assessment of sediment deposition in reservoirs and its decisive management can be considered as one of the key factors in achieving the sustainable benefits from dams and reservoirs.

Bhakra Beas Management Board (BBMB) manages two storage Bhakra & Pong Dam and one diversion reservoir Pandoh Dam. Bhakra and Pong Dam has varying inflows from 14-22 BCM and 5-13 BCM respectively in a water year with average inflow of 18 BCM for Bhakra dam and 9 BCM for Pong Dam. The designed capacity of Bhakra and Pong Dam is 9.87 BCM and 8.58 BCM respectively from which the average demands 18.23 BCM and 8.97 BCM from Bhakra and Pong Dam are met of partner states. The current depleted storage volume of Bhakra and Dams due to sedimentation and flood control are of 7.04 and 6.79 billion cubic meter respectively.

The study area comprises of the Satluj and Beas River basins which have a total geographical area of 56,860 km^2 and 12,560 km^2 respectively as shown in Figure 2. The Satluj River rises to the west of Mt. Kailash in Tibet at an altitude of 5250 m and has a catchment area of 37,160 km^2 in Tibet and 19,820 km^2 in India at Bhakra dam site. The Satluj River flows through the Himalayas up to Bhakra Dam having elevation of 512 m above sea level. Two power houses are located at toe of the dam on left and right banks of the river have a total capacity of 1379 MW. The reservoir provides irrigation water to an area of 40,000 km^2 in the states of Punjab, Haryana and Rajasthan.

The Beas river rises from the southern face of Rohtang Pass in the Kullu district at an altitude of 3,400 m upstream of Manali and flows 116 km downstream to Pandoh Dam where water is diverted to the Satluj River through Beas Satluj Link Project. From Pandoh Dam, it is a further 130 km downstream to Pong Dam. The total catchment area at Pong Dam is 12,560 km^2 of which 777 km^2 is snowbound. Further downstream, the Beas River joins the Satluj River at Harike after traversing a distance of over a 400 km.

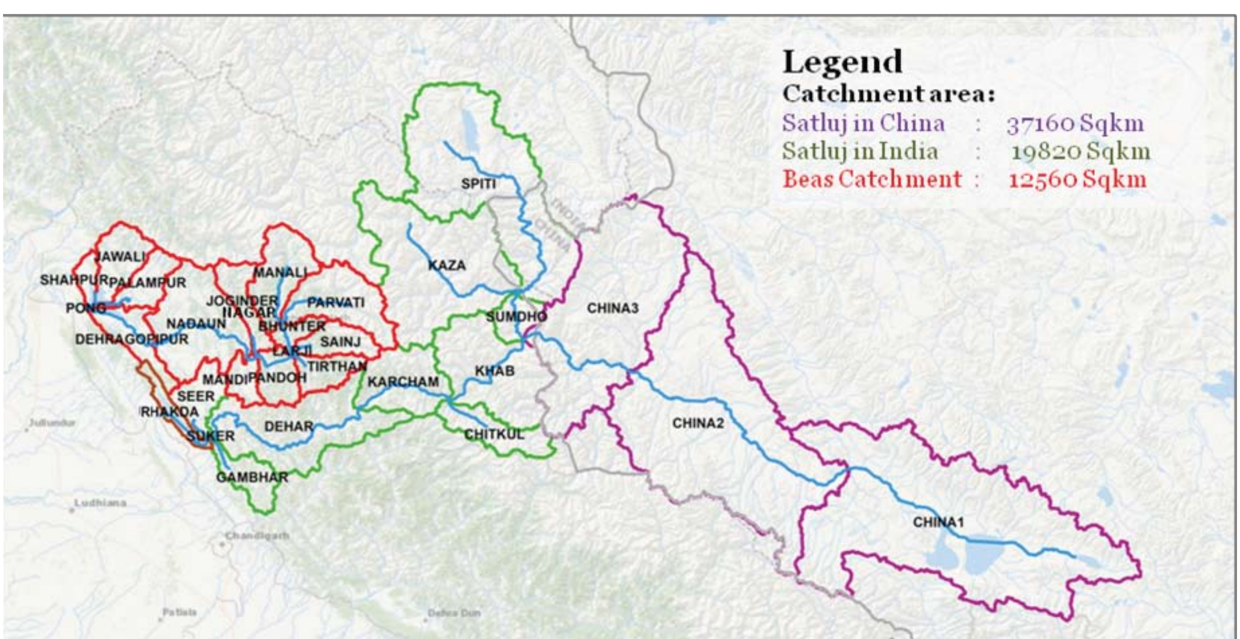


Fig. 2 : Satluj and Beas basins shapefile

2. CLIMATE CHANGE IMPACTS ON RIVER DYNAMICS

The Intergovernmental Panel on Climate Change (IPCC) report (2017) informs that the climate change is happening in distinguished ways and global warming is effecting our environment. As per observations, six river catchments showed an increase in rainfall whereas 15 river catchments had shown decrease in rainfall. Further, four river basins experienced increasing patterns in rainy days and 15 river basins had the decreasing patterns. Temperature data showed a monotonous rising pattern. Many studies have used the combination of climatic models and hydrological models to determine the climate change effects on river hydrology.

3. DATA SOURCEFOR CLIMATE CHANGE STUDY - GCM & RCP

General Circulation Models (GCMs) are highly complex mathematical models which use various atmospheric and oceanic variables to generate future temperature & precipitation data. A number of GCMs developed by the modeling groups of various countries have been used by pioneer organization like IPCC (Inter-governmental Panel on Climate Change) for different climate change scenarios with different emission standard. Community Earth System Model (CESM) is one of them. CESM is a fully-coupled, community, global climate model that provides state-of-the-art computer simulations of the Earth's past, present, and future climate states. CESM is sponsored by the National Science Foundation (NSF) and the U.S. Department of Energy (DOE). Administration of the CESM is maintained by the Climate and Global Dynamics Laboratory (CGD) at the National Center for Atmospheric Research (NCAR). The CESM project addresses important areas of climate system research. In particular, it is aimed at understanding and predicting the climate system.

Community Earth System Model, version 1 – Biogeochemistry CESM1 (BGC) characterize the fidelity of the Community Earth System Model (CESM1) carbon cycle with terrestrial carbon–nitrogen dynamics and an ocean biogeochemical model. Two sets of pre-industrial control and 20th century experiments were initialized and forced with prescribed CO_2 emissions (PROG) and CO_2 mole fractions (PRES). The Representative Concentration Pathway, RCP 4.5 scenario assumes that green housegas emissions stabilize by the middle of the twenty-first century with an anthropogenic radiative forcing of 4.5 W/m^2 at year 2100 (Thomson et al. 2011). The CESM1 (BGC) RCP4.5 simulation was run with prescribed atmospheric CO_2 levels.

4. GCM DATA ANALYSIS

Preliminary results have shown a consistent temperature & precipitation increase across the Satluj and Beas catchments i.e. 0.5-0.6 degree rise per decade for temperature and increase in annual precipitation per decade by 15-20 mm. Analysis for each decade for both these basins till 2090 has been carried out.

4.1 Precipitation Variation

The cumulative increase of annual mean precipitation in mm for the Satluj and Beas basins in 2070 (as per GCM CESM1_BGC AND RCP 4.5) with respect to observed mean precipitation from 1960-1990 for Satluj and Beas Catchment as shown in Figure 3. Table 2 shows decadal precipitation increase w.r.t. long term average 1960-90.Graphical representation of decadal precipitation increase in the river Satluj and the river Beas Sub-Catchments w.r.t. long term average is shown in Figure 4 & 5 respectively.

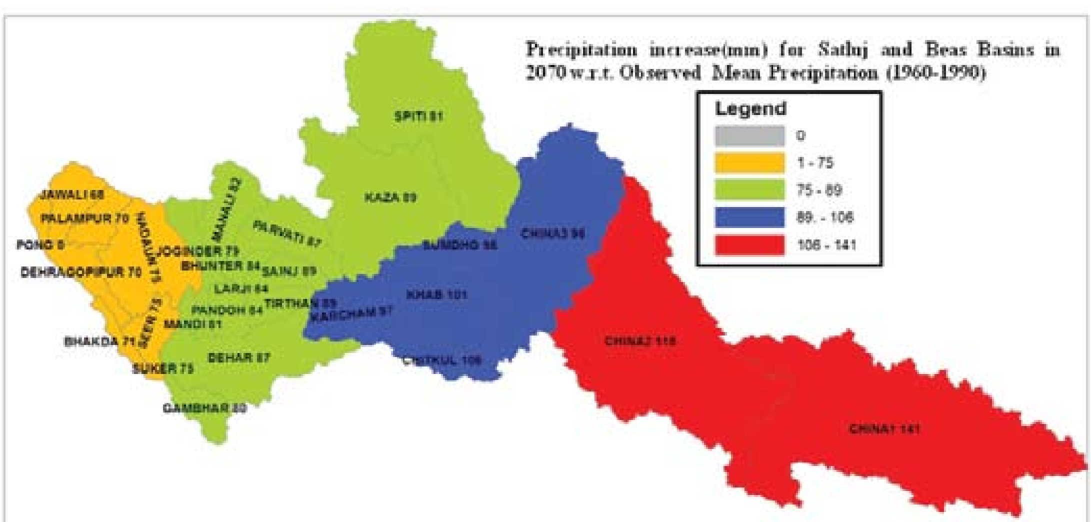


Fig. 3 : Cumulative increase of annual mean precipitation in "mm" for the river Satluj and Beas Basins in 2070 with respect to Observed Mean Precipitation from 1960-1990.

Table 2 : Decadal precipitation increase w.r.t. long term average

S. No.	Basin	Long term average(1960-90) in mm	Increase from average in 2020 in mm	Increase from average in 2030 in mm	Increase from average in 2050 in mm	Increase from average in 2070 in mm
1	Satluj	863	29	52	69	94
2	Beas	1551	31	44	57	79

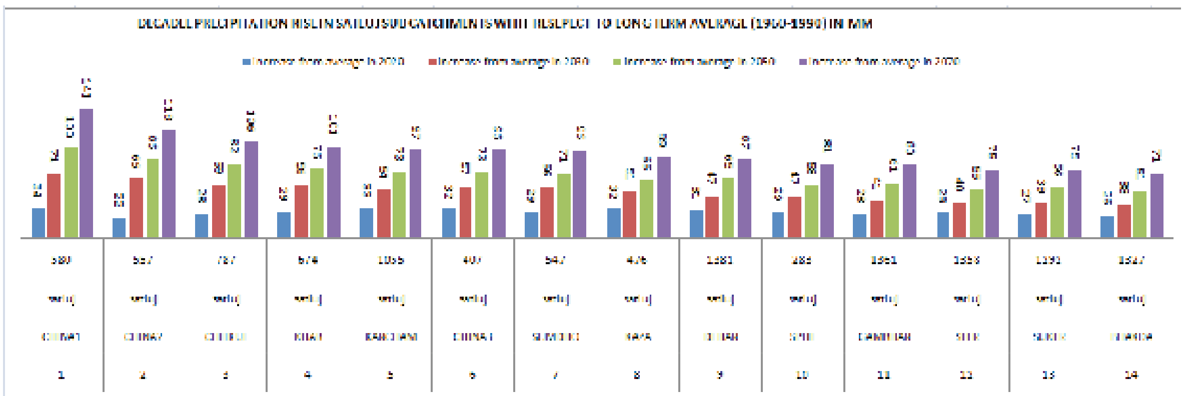


Fig. 4 : Graphical representation of decadal precipitation increase in Satluj Sub-Catchments w.r.t. long term average

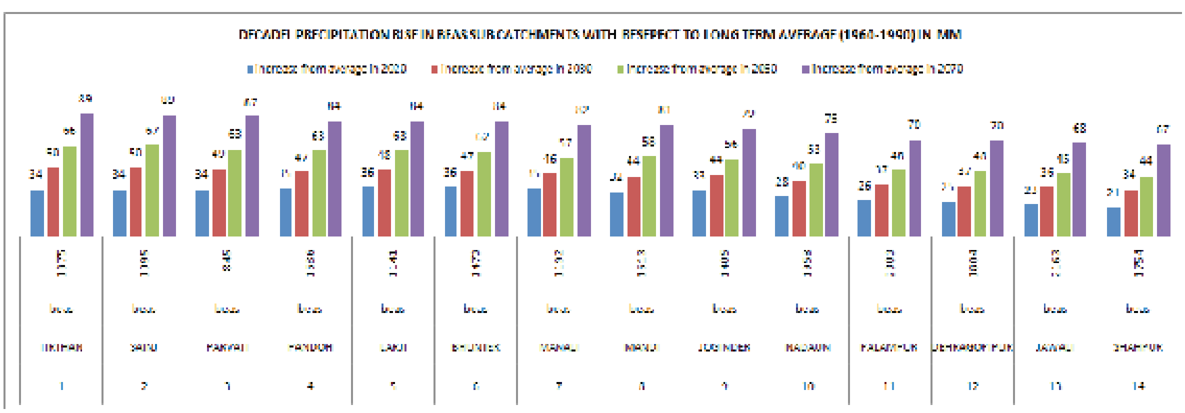


Fig. 5 : Graphical representation of decadal precipitation increase in Beas Sub-Catchments w.r.t. long term average

The maximum increase of annual precipitation approx. 100-140 mm by 2070 has been noticed in the Satluj in Tibet region, and approx. 80-100 mm by 2070 for Khab-Chitkul-Rampur region against an average annual increase of 94 mm rainfall for Satluj catchment in 2070. Similarly, for the Beas catchment the maximum increase of annual precipitation approx. 90 mm by 2070 against an annual average increase of 80 mm by 2070 has been observed in the snow bound sub basins above the Pandoh dam namely Tirthan, Sainj, Parvati and Manali.

4.2 Temperature Variation

Decadal Temperature Increase w.r.t Long Term Average for the River Satluj and Beas Catchments

The decadal rise in the Satluj and Beas catchment is 0.4 to 0.5 degree Celsius w.r.t. long term average temperature 1960-90.Summary of decadal temperature increase w.r.t long term average for Satluj and Beas Catchment is shown in Table 3. Spatial distribution shows comparatively more increase in temperature in snowbound region of the study area as depicted in Figure 6. Graphical representation of decadal temperature increase in the river Satluj and the river Beas sub-catchments w.r.t. long term average is shown below in Figure 7 & 8 respectively.

Table 3 : Summary of decadal temperature increase w.r.t long term average for Satluj and Beas Catchments

S.No.	Basin	Long term average (1960-90)	Increase from average in 2020	Increase from average in 2030	Increase from average in 2050	Increase from average in 2070
1	Satluj	6.93	0.48	1.27	1.91	2.22
2	Beas	14.87	0.48	1.30	1.87	2.24

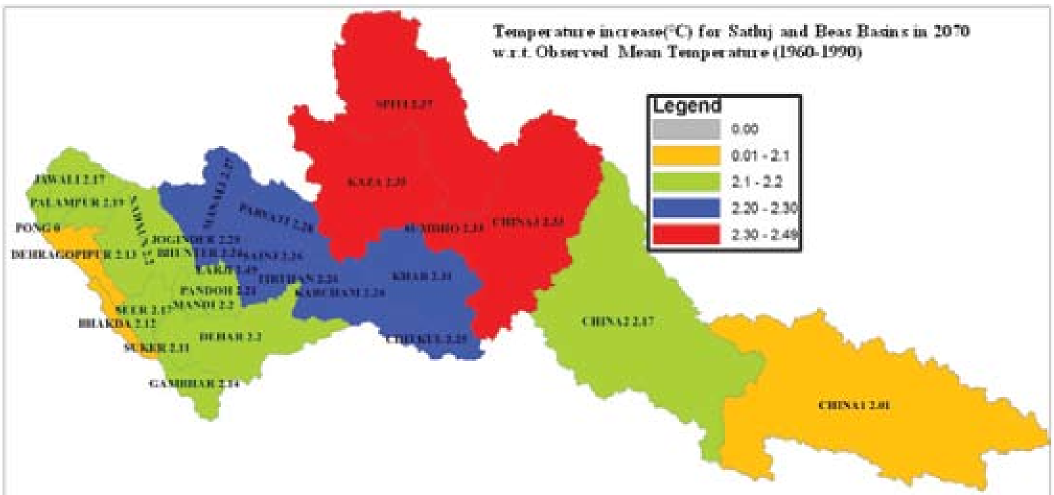


Figure 6 : The Increase of Annual Mean Temperature in Degree Celsius for the Satluj and Beas Basins in 2070 as per GCM Prediction (As per GCM CESM1_BGC and RCP 4.5) with respect to observed mean temperature from 1960-1990

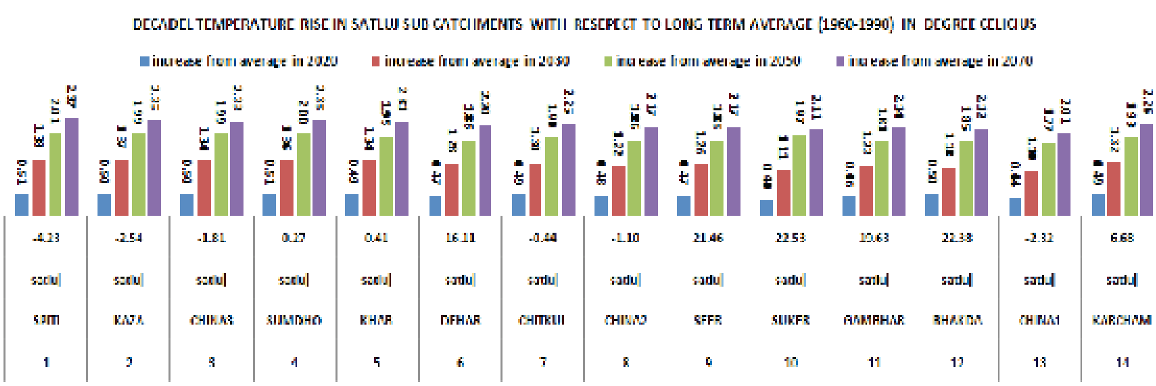


Figure 7 : Graphical representation of decadal temperature increase in Satluj Sub Catchments w.r.t. long term average

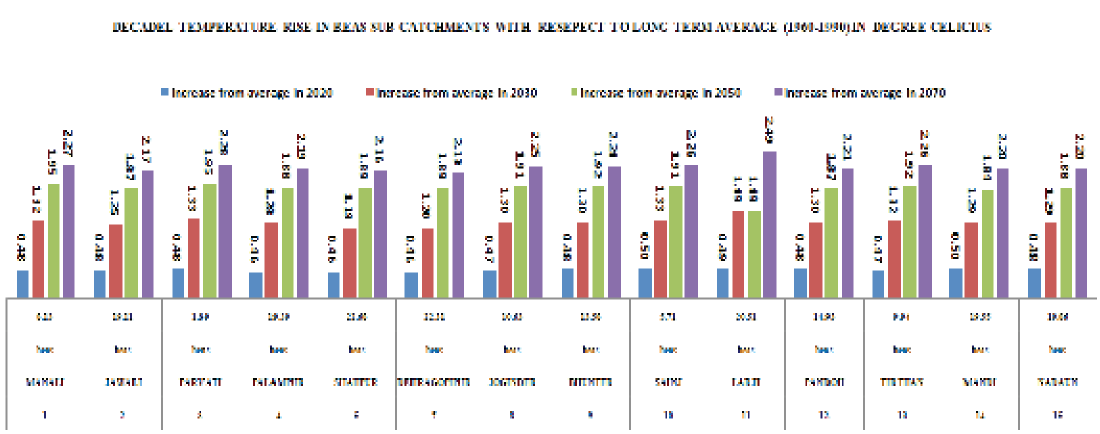


Figure 8 : Graphical representation of decadal temperature increase in Beas Sub Catchments w.r.t. long term average

The major catchment area of Satluj basin falls in snow bound sub basins region ranging from Rampur to source Mansarovar, Spiti and Kaza region. The mean annual temperature of the Satluj basin shows the variation from a minimum of -12 degree Celsius annual average in Tibet to a maximum of 23 degree Celsius annual average for region near Bhakra Dam. Similarly, the mean annual temperature of Beas basin shows the variation of minimum of 1.89 degree Celsius annual average in Parvati region to maximum of 22.68 degree Celsius annual average for Shahpur region.

An increase of temperature by 2-2.5 degree Celsius by 2070 would lead to major change in snow accumulation pattern affecting the snowmelt inflow to reservoirs. These increases in temperature is likely to change the hydrological behaviors of some of the sub basins which in turn would affect the inflows received from these sub basins into the system. Further studies require establishing the impact of these climatic change parameters on hydrological behavior of the basin.

5. SEDIMENTATION OF RESERVOIRS

A. BHAKRA DAM

Length of Bhakra reservoir is 96.56 km and area of reservoir is 168.35 square km. The curculios reach from Kasol to Bilaspur i.e. from 83,210 m to 48,463m follows a narrow and circuitous course which fans out near Bilaspur to a width of about 914 m. It again narrows down from 42,976.8m to 25,298m after which it opens into a wide expanse leading to a width of 6.44 km at full reservoir level just upstream of the dam. River reaches, where width of the reservoir increases act as silt traps. With the decrease in velocity due to the increased width, the heavy sediment settles down at the start of the wide reaches. This settled silt again gets eroded from the upper reaches due to the heavy inflows of water which carry this heavy charge to unload at the point where the still reservoir level meets, thus, giving way to the formation of delta at that point. Deposition of sediments over the years has created a hump from 12,497m to 27,737 m. The movement of crest of the hump towards the dam has not taken place beyond 12,497m during 2013-16 due to operation of reservoir at higher water level than the level of tip of hump. The average trap efficiency so far is 99.2%. Due to high trap efficiency, sediments have deposited over the years in the reservoir and are not discharging downstream of the dam. L-Section of reservoir of Gobind Sagar reservoir of Bhakra Dam before and after sedimentation is shown in Figure 9.

The silt deposited during the year 2016-2018 is 54.01 Mm^3 as compared to 119.98 Mm^3 observed during the year 2013-2016. The average annual rate of siltation has come down during last two years. This may be in view of construction of Kol Dam Project upstream of Govind Sagar Reservoir. This dam is acting as check dam and is definitely resulting in decrease of silt inflow and will increase the useful life of Gobind Sagar reservoir. The average annual rate of siltation has been worked out as 38.51 Mm^3 for the year from 1959 to 2018 against a designed figure of 33.61 Mm^3. The rate of sedimentation has shown a higher trend after the year 1990. Rate of sedimentation has increased noticeably after 2005, probably due to increased construction activities in the catchment area amongst other influencing factors. The average trap efficiency of the reservoir for the last 53 years is 99.2 %. Bed load carried by the river and its tributaries has been taken as 15% of the total suspended sediment load. Silt erosion index from Rampur to Kasol varies from 0.771 to 18.97 which indicates that erosion in this reach mainly cause contribution of silt into Bhakra Reservoir. Approximately 43% of the total sediment contribution is from Spiti and Satluj catchments above Khab (Namgia), located downstream of the place (Shipki-La) where the river Satluj enters India.

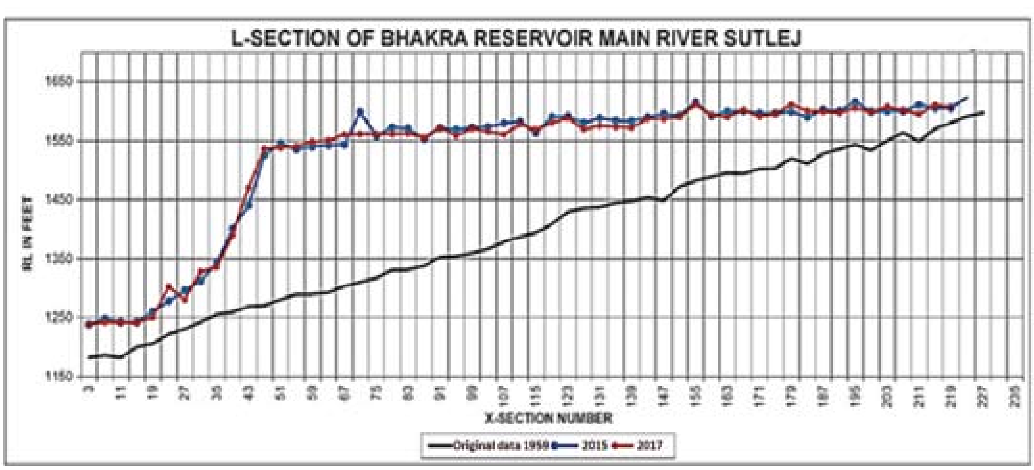


Fig. 9 : L-Section of Gobind Sagar Reservoir

Loss of Storage Capacity in Gobind Sagar Reservoir

The reservoir storage capacity loss consequent upon sedimentation deposition in Gobind Sagar reservoir is given in Table 4. The dead storage is reducing by an alarming rate of 0.73% annually and this number is going to increase. Live and Gross storage are also decreasing by 0.28% and 0.39% per year and these values increase every year.

The above table depicts that the sediments deposited up to year 2018 is 2272.73million cubic meters. Average sedimentation rate of 38.41 million cubic meters (31141acre feet) per year which is more than the designed figure of 33.61 million m^3 (27250 acre feet) per year.

B. MAHARANA PRATAP SAGAR RESERVOIR OF BEAS DAM

The storage dam on River Beas was a vital necessity to provide perennial irrigation supplies to the Thar Desert of Rajasthan and areas of Punjab & Haryana besides generating sizable hydroelectric power, flood control, though incidental is an added advantage. The Beas Dam, located at Pong in District Kangra of Himachal Pradesh in the Himalayan foot hills, across Beas River, is an earth core-gravel shell dam, 132.6 m (435 ft) high from the deepest foundation level. The Pong Power Plant has generating capacity of 6 x 66 MW i.e. 396 MW. Pong reservoir has a water spread areas of 260 square kilometer at full reservoir level at EL. 426.72 m (elevation 1400 feet.) to impound 8579 MCM of water and its extreme point extends to a distance of about 42 km.

River Beas and its tributaries carry large quantities of sediments, gravel and boulders etc. along with its flow. With the construction of the dam and creation of the vast reservoir behind it, the silt, gravel and boulders have hardly any exit from it; rather only a small fraction of suspended sediment is passed down through the penstock tunnels and other discharging facilities under operation. The rest of the sediment load gets deposited in the reservoir.

Annual suspended silt load of about 43 million tones (29260 acre feet) at average density of 1.24gm per cc (77.5 lbs per cubic ft) has been assumed on the basis of actual silt observations. The bed load carried by the river could not be assessed and has been taken as 15% of total suspended silt load. For working out the volume of deposits, an estimate of the probable density of the deposit was made. Available data indicates large amount of variation in the densities observed at various reservoir places and the lower and upper values as about 1.04 gm per cc (65lbs per cubic ft) and 1.44 gm per cc (90 lbs per cft) respectively were assumed for the preliminary studies. The rate of loss of storage capacity is worked out for these extreme values. The actual density of deposits may be somewhere between these limits. Figure 10 shows original and modified L-section of river after sedimentation of reservoir.

Table 4 : The reservoir storage capacity loss consequent upon sedimentation deposition in Gobind Sagar Reservoir

Capacity	Original designed capacity in million m^3at 1690 feet	Balance capacity of reservoir in million m^3 ending 2018	% capacity loss ending 2018	Balance capacity of reservoir in million m^3ending 2050	% capacity loss ending 2050
Dead storage	2431.81	1388.07	42.92%	821.78	66.21%
Live storage	7436.03	6208.34	16.51%	5542.19	25.47%
Gross storage	9867.84	7596.26	23.02%	6363.65	35.51%

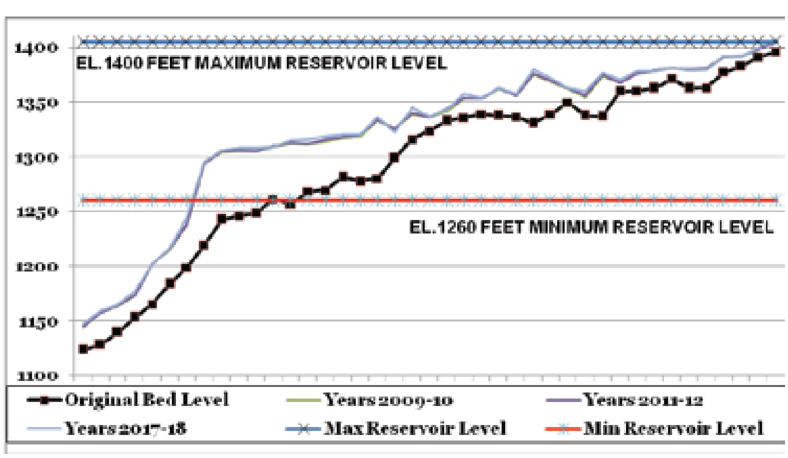


Fig. 10 : L-Section of Maharana Pratap Sagar Reservoir

The sediment observation data observed at the different stations for the period 1974-2018 has revealed that during pre-construction period of Pandoh Dam, the river had contributed about 72 % of the total sediment load brought into the reservoir, whereas the remaining 28 % was the combined contribution of streams. With the construction of Pandoh Dam, the sediment contribution of river reduced to about 64% as a part of sediment load in the river upto Pandoh gets deposited in the Pandoh reservoir and also passes through Pandoh Baggi tunnel of the Beas Satluj link Project. With the sedimentation of Pandoh reservoir, the sediment contribution by the river has now risen to about 77% of the total sediment load brought into the reservoir up to the end of 2017-18. It is also evident from soil erosion index that the sub catchment areas entrapped by Baner stream, Gaj stream and Dehar stream yield huge quantity of sediment, which necessitates immediate soil conservation measures in the sub catchment area of these streams. The sediment concentration and discharge relationship at sediment measuring station provides a measure of the sediment load carried out by the river/ streams. It is revealed that sediment load normally increases with the increase in discharge which generally happens during monsoon period. Average sediment yield per annum during the period from 1974 to 2018 per thousand hectares of catchment area is worked out to be 19338m^3 as compared to sediment yield of 19368 m3 during the year from 1959 to 2016 which depicts decrease in rate of sedimentation.

Loss of Storage Capacity Maharana Pratap Sagar Reservoir

The reservoir storage capacity loss consequent upon sedimentation deposition in Maharana Pratap Sagar reservoir is given in Table 5. The dead storage is reducing by an alarming rate of 0.50% annually and this number is likely to increase. Live and Gross storage are also decreasing by 0.25% and 0.28% per year and these values increase every year.

The reservoir storage capacity loss consequent upon sedimentation deposition in Maharana Pratap Reservoir is shown in Table 5.

The above table depicts that the Silt deposited up to year 2018 is 2495 million cubic meters.Average sedimentation rate of 24.29 million m^3 (19695 acre feet) per year which is nearby to the designed figure of 25.29 million m^3 (20500 acre feet) per year.

6. STUDY OF HYDROLOGICAL CYCLE FOR WATER YEAR

Inflow into Bhakra Dam during a water year starting from 01stOctober to 30th September, last two and current water year inflows are shown below in Figure 11. In the starting of a water year the inflow remains in the range of 11000 cusecs to 6500 cusecs so there is no much variation in the inflow pattern. During the water year, inflow remains almost straight line with downward gradient from 01st

Table 5 : The reservoir storage capacity loss consequent upon sedimentation deposition in Maharana Pratap Sagar Reservoir

Capacity	Original designed capacity in million m^{3}at 1400 ft.	Balance capacity of reservoir in million m^{3}ending 2018	% capacity loss ending 2018	Balance capacity of reservoirin million m^3 ending 2050*	% capacity loss ending 2050
Dead storage	1287.7	1005.31	21.93%	842.25	34.59%
Live storage	7291.2	6504.48	10.79%	6023.37	17.39%
Gross storage	8578.9	7509.97	12.46%	6865.62	19.97%

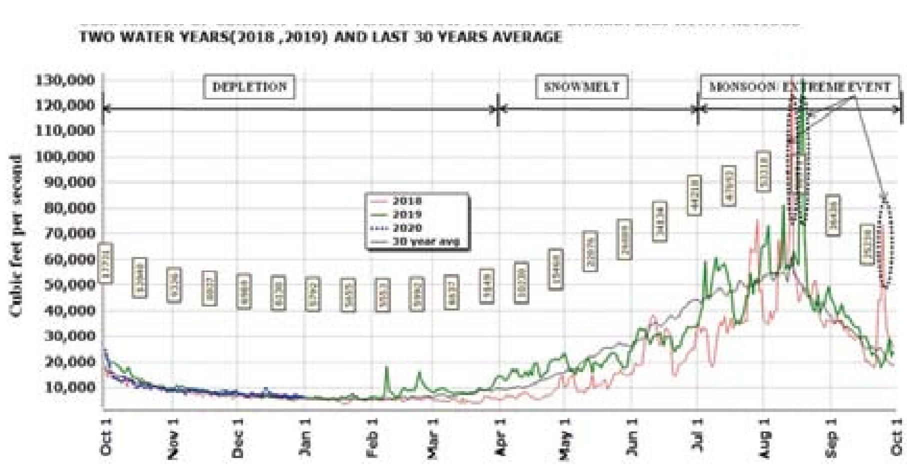


Fig. 11 : Comparison of current water year inflow pattern of Bhakra Dam during the last two water years (2018 & 2019)

October to 31st March. The inflow forecasting for this period, BBMB uses statistical methods like matching year pattern, percentage exceedance method. Normally, the inflow pattern remain between 40 and 60% limit, in average year and in dry and wet year may sometime goes upto 30% and 70% range but not much fluctuations has been observed.

Inflow into Pong Dam during a water year starting from 01st October to 30th September, last two and current water year inflows are shown below in Figure 12. Inflow remains constant averaging 6500 cusecs to 3000 cusecs in the starting of a water year the so there is no much variation in the inflow pattern. The inflow remains straight line with gradient in downward side upto the 15th of May. The inflow forecasting for this period, BBMB uses statistical methods like matching year pattern, percentage exceedance method. Normally, the inflow pattern remain between 40 and 60% limit, in average year and in dry and wet year this may sometime goes upto 30% and 70% range but not much fluctuations has been observed.

7. SEASONAL FORECASTING

Snow accumulation due to winter precipitation from October to March and melting during summer from April to June plays a vital role in the inflow of BBMB reservoirs. The 50% of total volume received in water year is due to snowmelt. Last three year witnessed, historically minimum inflow 3.2 billion cubic meter (BCM) in water year 2018 (due to average SWE 120 mm) and historically maximum 6.5 BCM (due to average SWE 200mm).The air temperature alongwith precipitation during accumulation and melting plays an important role. Snow water equivalent of deposited snow fall in the catchment vis a vis run-off is shown below in Table 6. Comparison of average depth of snow water equivalent available in snow bound sub basins in the catchment area of rivers Beas and Satluj and temperature in snow bound sub-basins of the river Satluj is shown in Figure 13 & 14 respectively.

Table 6 : Snow Accumulation in last three years in the Satluj and Beas Catchments

S. No.	Volume in BCM during 2017	Volume in BCM during 2018	Volume in BCM during 2019	Volume in BCM during 2020 (till December 2019)
Snow accumulation in BCM	8.65	4.58	10.21	11
Runoff in BCM	5.1	3.2	6.5	Expected more than 6.5 BCM

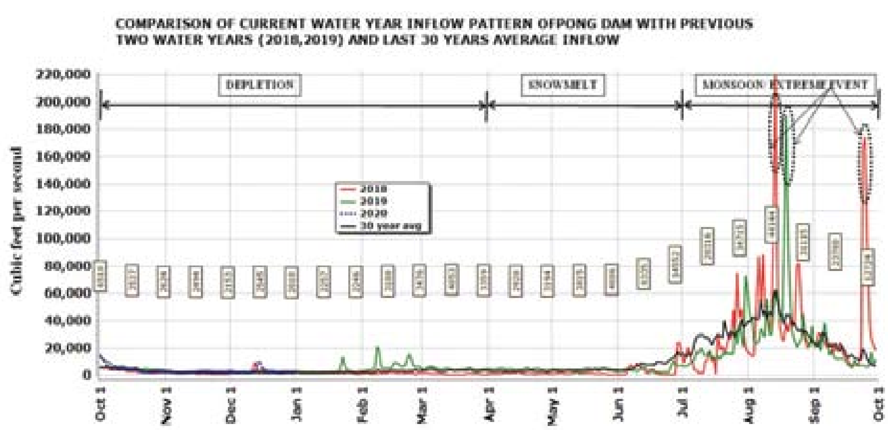


Fig. 12 : Comparison of current water year inflow pattern of Pong Dam with Last two water years (2018 & 2019)

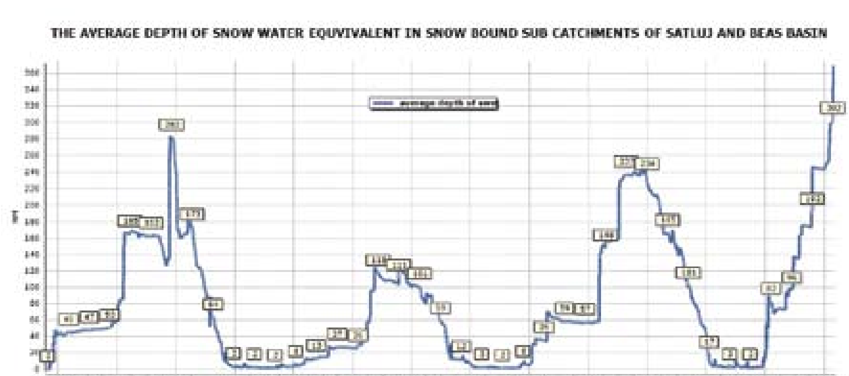


Fig. 13 : Comparison of average depth of snow water equivalent available in snow bound sub basins of the Satluj basin

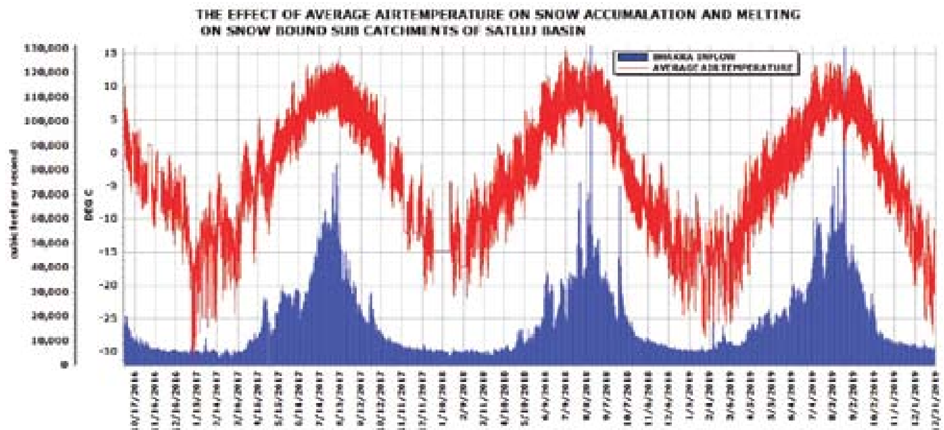


Fig. 14 : Comparison The effect of average temperature of snow bound sub basins of the Satluj catchment on inflow of Bhakra Dam

8. EXTREME EVENT ANALYSIS

On 16th of August, 2019, a forecast of heavy rain fall event was received and it was anticipated that as per model forecast the level of 1684 ft. would be reaching by 24th of August, 2019.On evening of 17th August, 2019, a fresh forecast with very heavy rainfall event in next 9 to 12 hours in the periphery of Bhakra reservoir and just downstream area of Bhakra Dam was received.

An unprecedented hydrological event occurred in the intervening night of 17/18 August, 2019, which generated around 3,11,134 cusecs of inflows into Bhakra Dam. This water inflow was more than 1988 considering that inflows of 8400 cusec into the river Satluj from the river Beas through Beas Satluj Link Project were stopped completely. Comparison of real time and forecasted rainfall during an hydrological event of 17th – 18th August 2019 is shown in Figure 15. Operation of Bhakra reservoir during this event is shown in Figure 16.

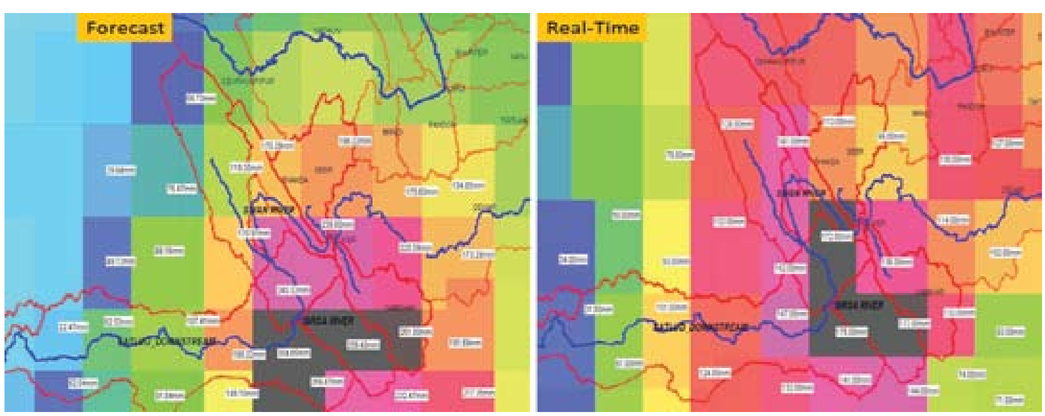


Fig. 15 : Comparison of Real time and forecasted rainfall during an hydrological event of 17th – 18th August 2019 in Govind Sagar reservoir.

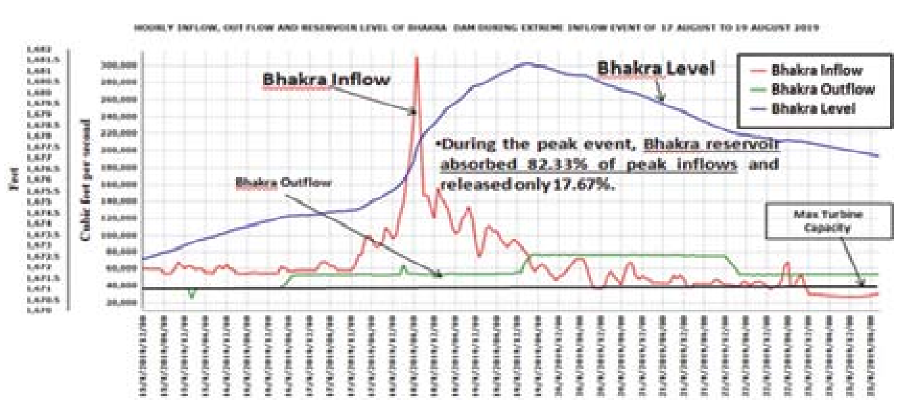


Fig. 16 : Operation of Govind Sagar Reservoir of Bhakra during the event of 17th – 18th August 2019

Inflows of 8400 cusec into the river Satluj from the river Beas through Beas Satluj Link Project were stopped completely to control the rise of water level in Bhakra Dam. These inflows along with flood discharge from the catchment entered into Pong reservoir. Comparison of Real time and forecasted rainfall alongwith hourly inflow, outflow and level of Pong Dam showing operation of Pong Reservoir during the hydrological event of 17th – 18th August 2019 is shown in Figures 17 & 18 respectively.

Further, during the event, the deflection of Bhakra Dam was observed to be all time high i.e. 1.1467 inches which was 22% more than the highest observed so far. The total seepage in the dam body also increased from 169 liter per minute on 17.08.2019 to 825 liter per minute on 18.08.2019.The rain fall event in the intervening night of 17/18th August, 2019 was historically high for the last 70 years.

High flood inflows were absorbed in the reservoir by allowing the level to rise even beyond the permissible storage level of 1680 feet and release of excess water in a controlled manner. This has been possible due to forecast of inflows and precipitation in the catchment area.

The extreme events were well forecasted prior to their arrival by the system accurately. The western disturbances, monsoon clash were forecasted in advance by the real time decision support system. Quantitative analysis of snow cover and temperature position in the catchment area were a great advantage in deducing the reduced inflows in months of April-May. The generated multiple scenarios act as guidelines for management in reservoir operation.

9. CONCLUSION

Due to climate change, the occurrence of extreme rainfall events having high intensity and high frequency is being witnessed over the years. Forecast of these extreme hydrological events due to climate change is becoming a challenge. These extreme events resulted in sudden increase in reservoir level causing floods (2019) and droughts (2018) as witnessed during the last two water years. Reduction of storage capacity of Bhakra (23%) and Pong reservoirs (12%) due to sedimentation is diminishing flood retention capacity and has led to adverse impact on areas downstream in eventuality of occurrence of such events. Filling of natural drainage

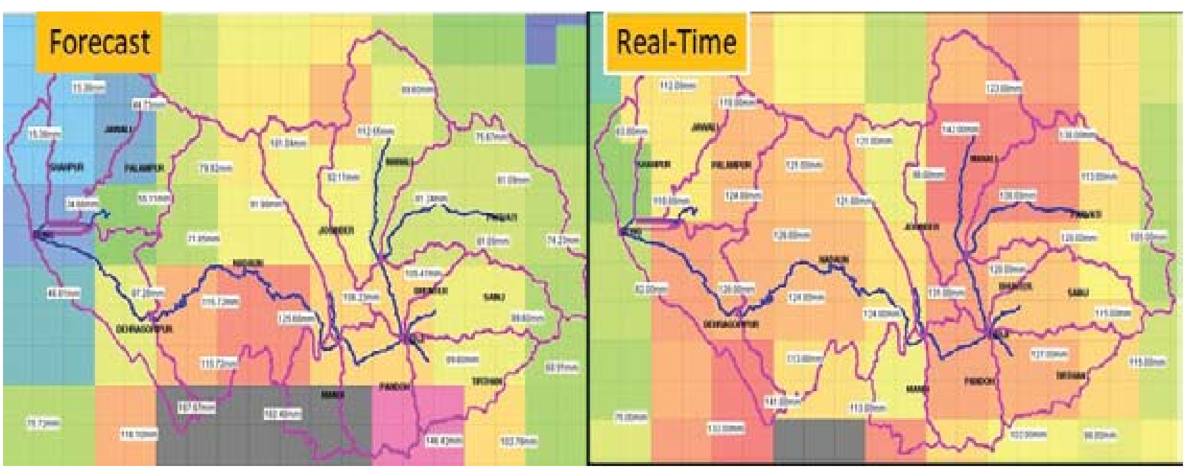


Fig. 17 : Comparison of Real time and forecasted rainfall during an hydrological event of 17th – 18th August 2019 in Maharana Pratap Sagar reservoir

Fig. 18 : Operation of Maharana Pratap Sagar Reservoir during the event17th – 18th August 2019

system for human usage, encroachment of flood plains of main rivers/streams has resulted in reduction in water carrying capacity of the rivers downstream of these dams has aggravated the problem of tackling floods in such like extreme hydrological events.

Keeping in view the climatic change scenario, sedimentation of both Bhakra and Pong dams and increase in PMF (Probable maximum flood) of these dams, water carrying capacity of the rivers and streams in the areas downstream of the dams need to be restored. Removal of encroachments in natural drainage system requires immediate attention. Complete Hydro-dynamic Model with 2D flood mapping of downstream areas with precise elevations need to be done on urgent basis so that vulnerable areas be identified and emergency disaster plan could be implemented. Embankment and Levees need to be strengthened/ repaired to sustain the designed floods along with river training works. Hydrological modelling (forecasting and real time monitoring) of downstream catchment areas is required so that flash floods in sub-basins are identified. Small storage dams are required to be constructed and also channelization of main rivulets/streams like Sirsa and Swan is required to be done. Desilting and restoration of storage capacity of barrages Ropar and Harike downstream of Bhakra dam, need to be taken up immediately.

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Dam Safety Rehabilitation - Indian Experience and Lessons Learnt

Pramod Narayan, Hadush Seged and Yogesh N Bhise
DRIP Project, New Delhi, India

ABSTRACT

Economic sustainability of a country heavily depends on the dams in the country and with over 5700 dams, India ranks 3rd in the world in total number of large dams next to the two world's largest economies China and USA. Dams are not only a source of water for drinking, for industry and for agriculture but also save people from flooding and provide cheap source of producing electricity. A substantial proportion of Indian dams have become old. About 4180 large dams are more than 25 years old, out of which 1200 are more than 50 years old. Aging and absence of maintenance play a critical role in the safety and sustainability of the dams. Several of these ageing dams have various deficiencies as per the present structural and hydrological design standards requiring critical rehabilitation. In line with this, the Dam Rehabilitation, and Improvement Project (DRIP) is among the major initiatives taken up by the government of India to effectively rehabilitate 223 existing dams in 7 States. Rehabilitation measures implemented under DRIP program have helped to improve conditions of these dams. The dams have been strengthened, ability to cater increase in design flood improved, initially observed structural defects rectified, leakages minimized, hydro-mechanical equipment renovated, access roads constructed or upgraded, surveillance systems installed, EAPs and O&M manuals prepared as per guidelines published by DRIP. As a result, the health of dams is enhanced, and risks reduced. Technology transfer and capacity building of the dam owners' engineers are also in place. This paper discusses Indian experience in dam safety rehabilitation and lessons learnt. The first phase of DRIP that successfully rehabilitated 223 dams in 7 states is planned to be closed by June 2021 and is to be followed by a new 10-year DRIP Phases II and III in 19 States with more than 700 dams.

1. INTRODUCTION

1.1 Background

Since rainfall occurs in India only for three months in a few spells, storage by dams is imperative to utilize available water resources. India has thus built and is still building several large dams for agriculture, power generation, domestic and industrial water supply as well as flood protection. As per the Indian National Registry of Large Dams (NLRD, 2020), there are 5745 large dams in India out of which 4180 dams are more than 25 years old with 1200 dams more than 50 years old (Figure 1 (b)).

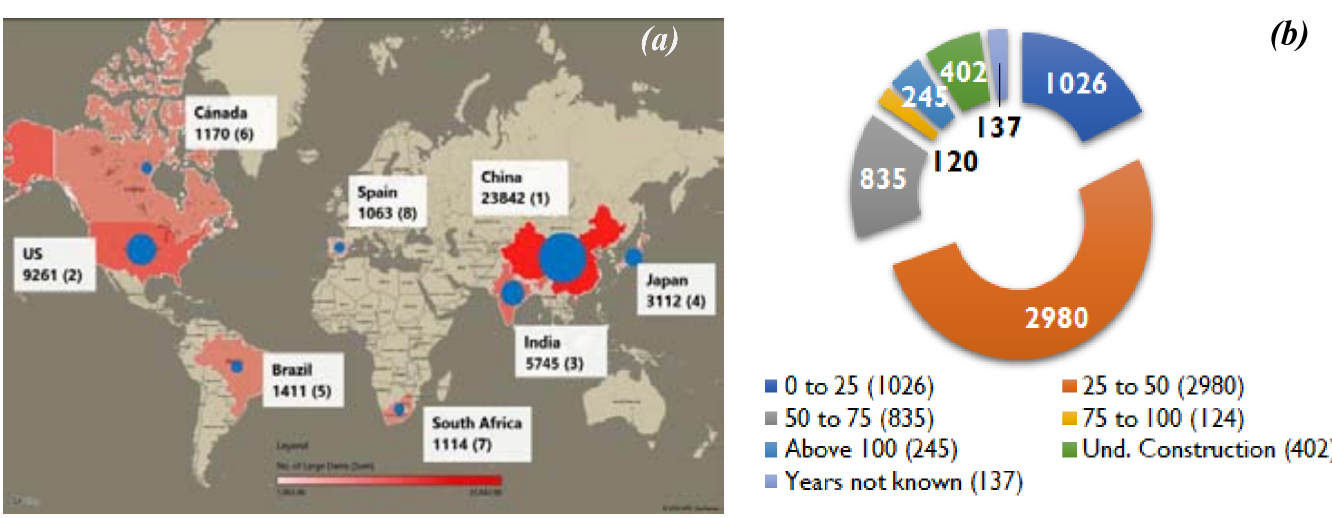

Fig. 1 : (a) Worldwide distribution of large dams and (b) Year wise age of Indian dams.

1.2 DRIP Initial and Revised Projects/ Costs

In April 2012, the Ministry of Water Resources, River Development and Ganga Rejuvenation with assistance from the World Bank, embarked upon a six-year Dam Rehabilitation and Improvement Project (DRIP) at a preliminarily estimated initial cost of Rs. 2100 Crore targeting rehabilitation and improvement of about 250 dams initially in four, later in seven states - namely: Karnataka, Kerala, Madhya Pradesh, Odisha, Tamil Nadu, Jharkhand, and Uttarakhand. In June 2018, the project was extended by two years, until June 2020 with a revised project cost of Rs. 3466 Crores including a 370-crore construction of additional spillway project in Odisha, whose Contract commenced in October

2018 but was terminated in January 2020 due to poor progress of works. DRIP was later again extended twice until December 2020 and June 2021. The current revised cost for DRIP is Rs.2642 Crores, out of which Rs. 2285 Crore (87%) is allocated for Component 1 (Rehabilitation and Improvement of Dams and Associated Appurtenances), Rs. 133 Crore (5%) is allocated for Component 2 (Dam Safety Institutional Strengthening) and Rs. 224 Crore (8%) is allocated for Component 3 (Project Management). The total number of dams under DRIP stands at 223 under 198 dam projects. Figure 2 shows the original and revised dam projects and costs agency wise.

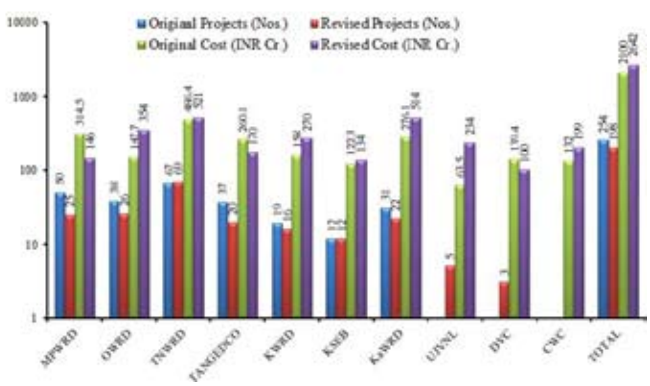

Fig. 2 : Agency-wise original and current dam projects/costs under DRIP

As can be seen from the above data, there has been major variations in the original projects and costs and revised project and costs. As shown in Figure 3, revised costs increased significantly in some IAs (UJVNL, OWRD, KSEB, KaWRD, KWRD), reduced other IAs (MPWRD, TANGEDCO, DVC).

UJVNL joined DRIP in 2015 and started with a limited budget that was available in the initially planned pool at the time. Later, the agency took up more necessary dam safety works and revised the budget with significant increase. Similarly, in some other implementing agencies costs increased due to additional works as well as variations in works Contracts that were unforeseen in

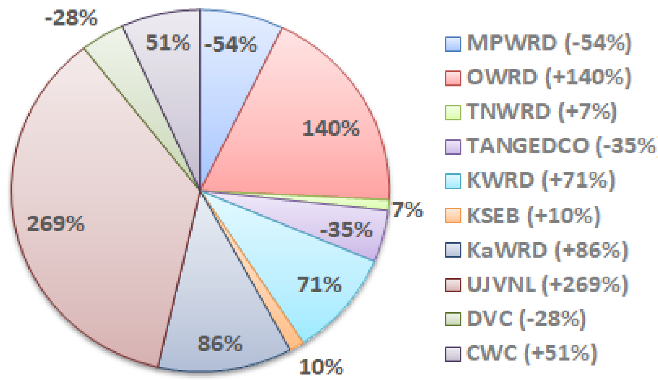

Fig. 3 : Agency-wise cost variations between original and revised costs.

the initial planning and design. To minimize/ avoid such significant cost variations all necessary studies and investigations including underwater investigations shall be carried out thoroughly at the initial stage of the project. In DVC, the DRIP project was closed in June 2020 with some of the initially planned works not fully completed, hence, there was a reduction in the revised project cost as compared to the original cost. DVC is currently completing the remaining works with State own budget. As the DRIP project was extended from the initial planned closure in June 2020 to June 2021, the CWC project management cost also increased by over 50%.

2. PREPARATORY ACTIVITIES

2.1 Dam Safety Inspections

Before taking up any rehabilitation measures under DRIP, dam specific inspections are carried out by a group of experts comprising dam designers, hydrologists, geologists, and dam safety engineers known as the Dam Safety Review Panel (DSRP). The DSRP examine each dam, identify deficiencies, and provide recommendations for rectifying the observed defects. In line with this, inspections of 260 dam projects were carried out and DSRP reports prepared that were handed over to the corresponding implementing agencies. In parallel, revision of dam specific design flood as per latest design practices were carried out, which were reviewed and approved by CWC. Based on the DSRP and revised design flood reports, the IAs prepared 250 dam specific Project Screening Template (PST) incorporating proposed rehabilitations measures and associated cost estimates. The PST is the main reference document for each dam and were reviewed and approved by CWC and the World Bank.

2.2 Revised Design Floods

In DRIP, out of the 223 dams under 198 projects, 203 dams have independent spillways, and the rest 20 dams are either saddle dams or have a common reservoir and spillway with another dam. Hence, assessment of revised design flood is carried out for the 203 dams.

Out of the 203 dams, design floods increased by more than 14% for a total of 167 dams or about 82.3% of the dams (Figure 4). It can also be seen that for 116 dams (57% of the 203 dams), the revised design flood increased by more than 50% and for 69 dams (34% of the 203 dams), it increased by more than 100% of the original design flood. This clearly shows that most of existing/ aged dams in India are designed for lesser design floods as per current practices. Hence, assessing and ensuring hydrological safety of existing dams is so paramount in a dam rehabilitation project.

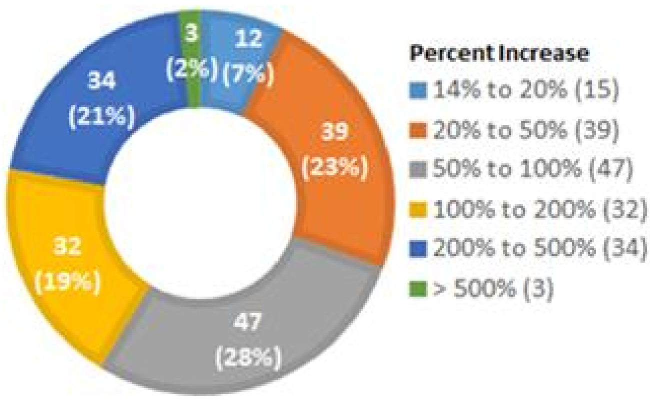

Fig. 4 : Dams with increase in revised design flood.

2.3 Flood Routing Study

Once the revised design floods were determined using current standards, for the dams with increased revised design flood, dam specific flood routing study was carried out to assess the capacity of the existing spillway, check the revised MWL (Maximum Water Level), and available freeboard above the MWL. These results were used to determine whether the dam specific existing spillway is sufficient or there is a need to take up a measure to ensure hydrologic safety of the dam. Flood routing study reports reveal that over 51% of the 167 dams with increased design do not have sufficient freeboard as per IS Code 10635 for embankment dams and IS Code 6512 for masonry/concrete dams and hence required structural and non-structural measures to ensure hydrologic safety.

3. REHABILITATION MEASURES

3.1 Hydraulic Safety Measures

Out of the 198 dam projects under DRIP, a total of 171 dams have taken up various rehabilitation measures to improve and ensure the hydraulic safety of the dams. The measures include provision of additional spillway, dam height raising, extension of spillway, repair and provision of parapet wall as part of freeboard, as well as critical repair/ strengthening of deteriorated spillway structures and repair or replacement of gates and hoists (Figure 5).

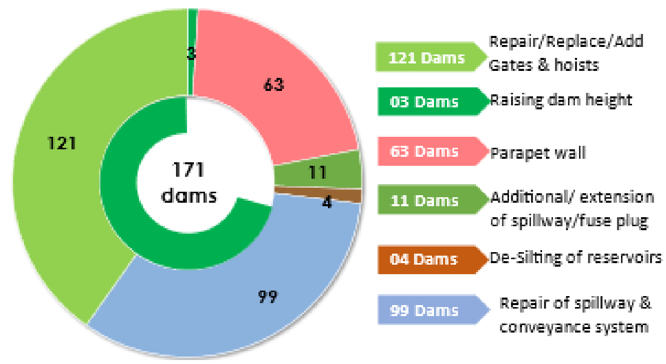

Fig. 5 : Hydraulic safety measures under DRIP.

Among the major hydraulic safety measures taken up in DRIP project, highlights of very few examples are discussed below.

At Manimukthanadi dam, Tamil Nadu, the original design flood was 926 m^3/s and is revised under DRIP to 3,356 m^3/s which is 3.26 times bigger. To ensure hydrologic safety of dam, additional spillway on left bank (4 no. bays with radial gates of size 10 m x 6.1 m each), 1 m high upstream solid parapet wall, and fuse plug of 250 m long on left abutment are provided (see Figure 6). With these measures, the dam is safe for the revised design flood.

Fig. 6 : Manimukthanadi dam additional spillway

At Sarathi dam, Madhya Pradesh, the design flood is revised from 251 m^3/s to 1651 m^3/s, which is 6.58 times bigger. The hydrological safety of dam is ensured by re-sectioning & raising of earth dam by 1.50 m with top width increased from 2.4 m to 4.5 m. Existing spillway weir is also modified to ogee shape to increase discharge capacity (Figure 7).

Fig. 7 : Sarathi dam raised and weir modified to ogee

At Narayanpur Dam, Karnataka repair of spillway radial gates and provision of new gantry crane & one set spillway stop logs was done. Measures included replacement of corroded horizontal stiffeners, zinc metallizing and repair of rubber seals. New 84 Ton capacity gantry crane with one set of stoplog elements (7 nos.) was also provided. Pier and pier grooves were also repaired. (Figure 8)

Fig. 8 : Narayanpur dam new gantry crane and set of stop logs

At Krishina Raja Sagar (KRS) dam, Karantaka replacemnt of 136 gates and 2 ganntry cranes is currently ongoing. The KRS dam is over 100 years old dam with many gates/ hoists not-working or have structural defects & suffer heavy leakages. Replacement of 136 gates and 2 gantry cranes currently ongoing including provision of automatic control of gates through SACADA. This activity is critical for hydrologic ensuring safety of the dam. (Figure 9)

Fig. 9 : Replacement of 136 gates at KRS dam

3.2 Structural Safety Measures

Out of the 198 dam projects under DRIP, a total of 164 dams have taken up various rehabilitation measures to improve and ensure the structural safety of the dams. The main measures include embankment dam rese-sectioning, repair of embankment upstream and downstream slope protection, masonry/concrete dam reaming of porous and foundation drains, masonry/concrete dam backing concrete, repair of abutments, etc. (Figure 10).

Among the major structural safety measures taken up in DRIP project, highlights of very few examples are discussed below.

At Pechiparai dam a backing concrete was constructed to ensure strutural safety. The Pechiperai dam is one of the oldest dams built during 1895–1906. The existing dam

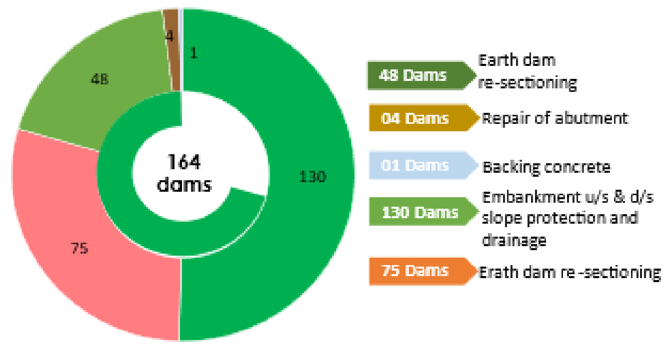

Fig. 10 : Structural safety measures under DRIP.

was found unsafe under seismic loading conditions and a backing concrete was provided. The backing concrete was designed and constructed considering appropriate bonding level between the existing dam and backing concrete. With this measures that dam is safe against seismic loading as per current practice. (Figure 11)

Fig. 11 : Pechiparai dam backing concrete.

Mallaghata dam is one of the very old dams in Karanataka which was constructed in 1907. To ensure structural safety, the embankment dam was re-sectioned by changing the downstream slope below RL 95.5 m from 1V:2H to 1V:2.5H plus a 3.0 m wide berm at. RL 95.5 m. To safely drain any possible seepage through the dam, a rock toe was provided. The upstream slope was also re-sectioned from 1V:1.5H to 1V:2H by providing additional rockfill/riprap over the existing riprap. (Figure 12)

Fig. 12 : Mallaghata dam re-sectioning.

3.3 Seepage Control Measures

Out of the 198 dam projects under DRIP, a total of 71 dams have taken up various rehabilitation measures to control seepage through the dams and foundation. The main measures include masonry dam raking and pointing of u/s face with UV resistant high strength mortar; dam body grouting of masonry/concrete dams and u/s face geomembrane; grouting of embankment dam dam/ foundation and provision of cut-off, etc. (Figure 13).

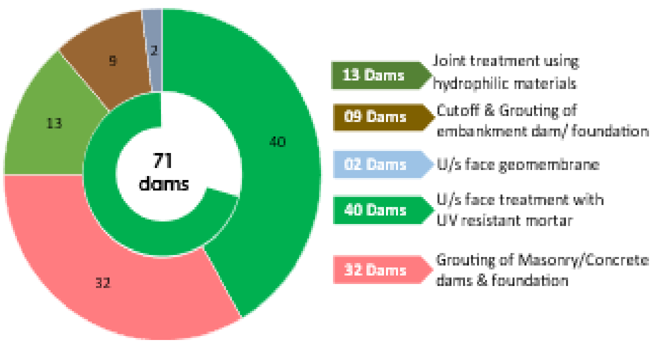

Fig. 13 : Seepage control measures under DRIP.

To reduce initially observed seepage at Porthimund dam, Tamilnadu, the masonry dam upstream face racking and pointing of upstream face of the masonry dam was carried out using UV resistant, high strength, non-shrink Polymer cementitious. Moreover, failed contraction joint water-stops were repaired using hydrophilic sealants. The downstream face of the dam was also raked and repointing with 1:3 ratio cement mortar. (Figure 14)

Fig. 14 : Porthimund dam u/s face treatment

At Servalar dam, Tamilnadu, to reduce initially observed seepage, left flank and overflow section upstream face of the masonry dam was treated using geomembrane water- proofing. On the right flank non-overflow section racking and pointing as well as contraction joint water-stop treatment was carried out. These measures stopped leakage of water on downstream face and gallery leakage reduced from 742.65 L/min to 28.96 L/min at reservoir level near FRL. (Figure 15)

Fig. 15 : Servalar dam geomembrane treatment

3.4 Dam Safety Basic Facilities

In addition to structural deficiencies, dam safety basic facilities were also absent in many dams. Out of the 198 dam projects under DRIP, a total of 178 dams have taken up various dam safety basic facilities. These include repair and construction of all-weather access roads and roads for access to sections of the dams; critical equipment for O&M and for emergency situations; provision of low-voltage electrical supplies in inspection and drainage galleries, improved lighting and security for external areas, standby generators for emergency operation of spillway gates, and inspection launches.

4. NON-STRUCTURAL MEASURES

In addition to the structural measures discussed above, several non-structural measures have also been undertaken under DRIP that are also critically important for ensuring safety of the dams. The different non-structural measures are implemented under DRIP are discussed below.

4.1 Technical Guidelines and Manuals

As the practices of dam safety is varying from State to State and from organization to organization in absence of any legislation, the CWC is making all out possible efforts for evolving unified practices of dam safety across the Country to maintain uniform standards by pooling the expertise available across the world. In regard, six guidelines and manuals were published during the 2018 International Dam safety Conference (IDSC) in Trivandrum, Kerala. five more guidelines and manuals were published in 2019 and four more are currently at advanced stage of preparation, which will make the total 14 manuals & guidelines. (Figure 16)

4.2 Emergency Action Plans (EAP)

Under DRIP, safety encompasses all aspects of the health of the dam; from structural repairs or modification to development of Emergency Action Plans (EAPs); all working to reduce risks to downstream population,

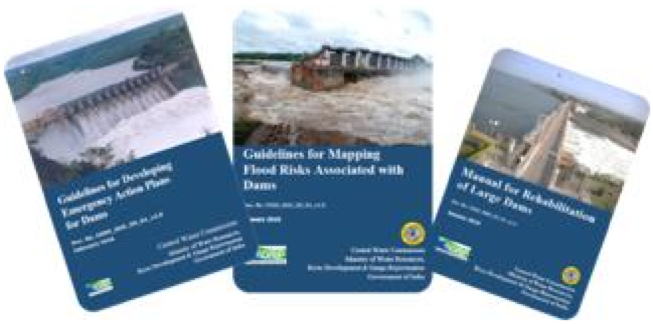

Fig. 16 : DRIP Guidelines and Manuals

minimize economic damages and ensure sustainable performance and efficiency of the dams. To date 222 dam breach analysis (DBA) are carried out, 195 EAPs prepared and out of which 185 published. Following preparation of EAPs, stakeholders' consultations are being conducted and 85 consultations have so far been conducted. (Figure 17)

Fig. 17 : Emergency Action Plan (Hirakud Dam)

4.3 O&M Manuals

Operation and Maintenance (O&M) manuals have been prepared as per the latest guideline published under DRIP. O&M manuals for Almatti dam, KaWRD with 26 spillway gates, hydraulic hoisting systems; for Maithon dam, DVC with 12 spillway gates, rope-drum hoisting system and no stop logs; and Ashoknal dam, OWRD with ungated spillway were first prepared as pilot O&M manual to be used as references by dam projects. The O&M manuals is a detailed set of written descriptions with step-by-step procedures for ensuring that the dam is safely operated, frequently inspected and properly maintained. It also includes O&M manual budget that needs to be updated annually. To date 203 O&M manuals have been prepared out of which 200 were reviewed and 146 were finalized and published. (Figure 18)

Fig. 18 : Pilot O&M Manuals

4.4 DHARMA (Dam Health and Rehabilitation Monitoring Application))

DHARMA is a web-based asset management software to support the effective collection and management of asset and health data for all large dams in India. Activities completed to date include development and launch of 7 modules and 2 analysis tools; capture of dam inspection, O&M, instrumentation, investigations and EAP data in Asset Health Module. Overall progress in Data entry is approximately 75% for DRIP dams. In addition, training of over 1000 users in the 9 DRIP Agencies and 4 non-DRIP Agencies has been conducted. (Figure 19)

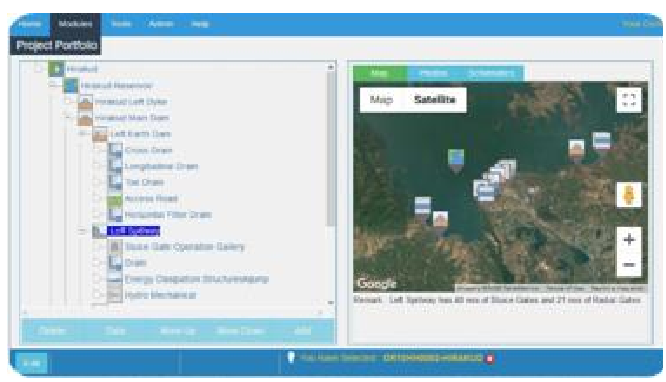

Fig. 19 : DHARMA Data Entry Platform

4.5 Dam Safety Conferences

Dam Safety Conferences provide a forum for exchange of expertise, experience among dam professionals around the world to address the dam safety concerns and provide an opportunity to learn about the international development in the technology of dam safety management. In the regard, DRIP project successfully conducted two International Dam Safety Conferences (IDSC) in 2018 Trivandrum, Kerala and in 2019 in Bhubaneswar, Odisha as well as three National Dam Safety Conferences (NDSC) in 2015 in Chennai, Tamil Nadu; in 2016 in Bengaluru, Karnataka; and in 2018 in Roorkee, Uttarakhand. (Figure 20)

Fig. 20 : Dam Safety Conferences

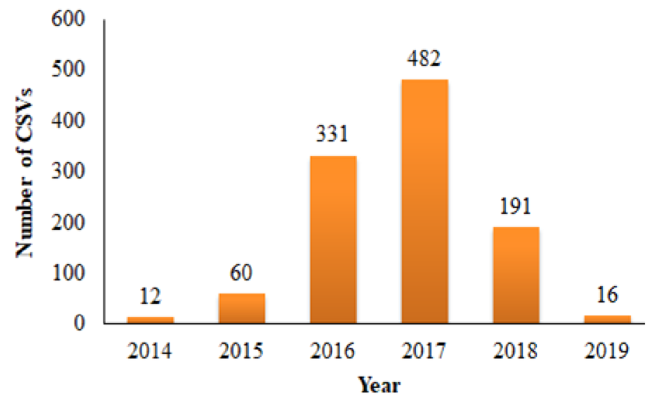

Fig. 21 : Construction Site Visits (CSVs)

5. THIRD-PARTY QUALITY CONTROL

Establishing an effective Construction Supervision and Quality Assurance (CS&QA) system in a Construction Project is most important to ensure that Works are executed with a high level of quality and comply with agreed Contract requirements. In DRIP Project, a three-tier mechanism was used to take care of CS&QA, which is very important for any rehabilitation work. In this case, the Contractor as 1st party is responsible for execution of the Works pursuant to Contract conditions; the Implementing Agency (IA) as 2nd party is responsible for day-to-day CS&QA issues and contract management; and, CPMU has been assigned as 3rd party for CS&QA activities.

In line with this, CPMU conducts regular 3rd party construction site visits (CSV) and quality control tests that play a key role in the successful implementation of the works. To date, a total of 1,092 construction site visits have been conducted to all projects under the 9 IAs. A total of 605 different third-party quality control tests have also been carried out during these site visits with 86% successful results and 14% failed results that were recommended for rectification. Third-party tests include looking at the engineering properties of materials (soil, aggregate, cement, steel, GI wire, etc.), embankment degree of compaction, and concrete tests. The tests on concrete include cube, core and non-destructive tests (NDT). (Figure 21)

6. LESSONS LEARNT

Over the course of the DRIP the following important lessons have been learnt that will be very useful input for the upcoming 10-year DRIP phase II and III projects.

Preparatory Stage : It needs standardized formats in advance for preliminary proposal submission by States, DSRP Inspection Report, DSRP composition, Design Flood Review, Project Screening Template and Standard Procurement Document, Empaneled Pool of Experts, continuous training and support by CWC.

Adequate Delegation of Financial Powers: It needs adequate delegation of financial powers up to working levels and field levels to minimize the approval stages and payment stages for fast and feasible execution of rehabilitation activities. The concerned Procurement Committees shall meet minimum once in a month for the approval.

Advance Planning and Approval for High-Risk Rehabilitation Activities : Advance planning is required to take up important rehabilitation activities like de-silting of reservoir, construction of additional spillway. The all investigations, feasibility report, rate analysis to firm up cost, bid document, EIA and EMP approval, R&R activities etc. shall be handled meticulously with rational timelines and desired outcomes.

Resource Identification and Assignment : High end technical activities like dam break analysis, inundation mapping, integrated reservoirs operations, numerical modelling, preparation of EAPs, O&M manuals etc. a technical competent group of officials shall be identified and may be assigned all these activities with appropriate technical trainings to execute these soft activities.

Bankable Tender Preparation : The tender document for any proposed rehabilitation work shall be drafted rationally based on required investigations to minimize cost variation along with feasible Qualification Criteria, Technical Specifications and BQS, payment milestones, completion time etc. to ensure timely completion with minimum litigation matters.

Contract Management Experience : The officials dealing with contract management shall have adequate experience of contract management otherwise it will invite matters related to undue delay in technical and financial evaluation up to contract award, matters related to time extension, cost variation, unreasonable claims by contractor, court cases and arbitrations, etc.

CS and QA Mechanism : In order to ensure that all important rehabilitation works shall be executed as per given technical specifications and bill of quantities to meet the end objectives, very effective Construction Supervision and Quality Assurance (CS&QA) team shall be at three level i.e. contractor, dam owner and CWC to carry out this assignment timely and advise for corrective actions as and when required.

Appropriate Capacity Building : All agencies must give due weightage to various kind of trainings for their staff and officials and it shall be ensured that right kind of training and at appropriate time shall be given to have long term sustainability of their intended objectives for optimum benefits from existing assets.

Monitoring Mechanism : Each Agency must have right kind of monitoring mechanism so that activities can be monitored, and corrective actions can be taken. It is desired that Scheme review shall be done by Principal Secretaries/ CMD monthly to ensure successful implementation of Scheme.

Quality Human Resources in SPMU : SPMU is the single window arrangement at State Level to steer the Scheme. It shall be explored that competent officials shall be posted with good service period alongwith minimum transfer, as these carry the institutional memory to ensure successful implementation of Scheme.

Mid-course Corrections in Significant Project Parameters due to Extreme Event of Flash Flood in Vishnugad Pipalkoti Hydro Electric Project (444MW), Uttarakhand, India

R.K. Vishnoi, Gajendra Singh, Ajay Kumar, N. K.Ojha and P. Vishwakarma

THDC India Limited, Rishikesh, Uttarakhand, India

ABSTRACT

Vishnugad Pipalkoti Hydro Electric Project (VPHEP) is a run of the river scheme, located on river Alaknanda, spanning between Helong and Birahi Villages in Chamoli district of Uttarakhand, India. The Project envisages construction of 65m high Concrete Gravity Dam, three nos. underground Desilting Chambers of 390m length each, 13.4 km long Head Race Tunnel of 8.8m diameter, 3 km long Tail Race Tunnel of 8.8 m diameter etc.

During June 15 to 17, 2013, cloud bursts and heavy to very heavy rainfall hit higher reaches near to project. This unprecedented rainfall resulted in a sudden increase in water levels giving rise to flash flood in Alaknanda river basin, caused extensive river bed and toe erosion, landslides at various locations and huge transportation/deposition of sediments in downstream area. Flash flood had eroded the river bed profile significantly in dam area, affected the designed diversion arrangements - tackled by lowering of Inlet and Outlet levels & discharge capacity of Diversion Tunnel. Parallelly, this event led to some deposition at Power House area and caused steep rise in bed level. Immense quantum of silt got deposited in power house exploratory drift, huge deposits of silt and muck was left by river at Tail Race Tunnel outlet area also. All of this was tackled by reviewing the layout and design of structures elaborately. This paper describes the impact of furious extreme flood event on the project planning and how in the middle of construction, this was tackled.

1. INTRODUCTION

VPHEP is a run of river scheme under construction, across the river Alaknanda utilizing a gross head of 237m to generate 444 MW of power envisaging above mentioned structures. During detailed project report (DPR) stage power intake, desilting chamber, head race tunnel and power house are planned on right bank of the Alaknanda river while diversion of the river was planned through left bank (Figure 1).

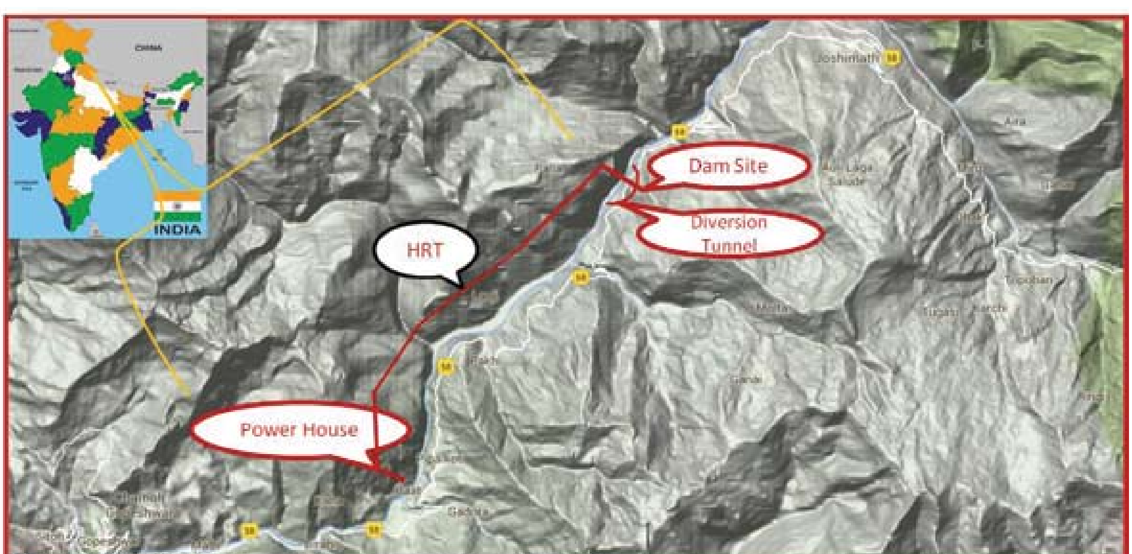

Figure 1 : Location Map of Vishnugad Pipalkoti HEP.

The river diversion arrangements for the project envisages to divert the river through a 10 m diameter circular shape diversion tunnel of 497m length plus open cut portion of 65m which also includes the length of cut and cover duct on left bank of river Alaknanda, with two coffer dams oneat the upstream side of main Damwith top at EL.1242m while riverbed level of EL. 1228m and other on downstream side with top at EL. 1229m while river bed level of EL. 1224m. In this case, overtopping of cofferdams vis-à-vis over the constructed structure is considered permissible to the extent that at least 8 months construction period in a year must be available for construction of the proposed dam structure. With this in view, the river diversion system has been approved by Central Water Commission (CWC) for 725 cumecs which corresponds to 1 in 25 year non monsoon flood. The location of the inlet & exit portals and the alignment of the diversion tunnel have been proposed in the tender documents based on the geological investigations which were carried out initially for project. Gradient of river Alaknanda at VPHEP Dam & Power house is shown in Figure 2.

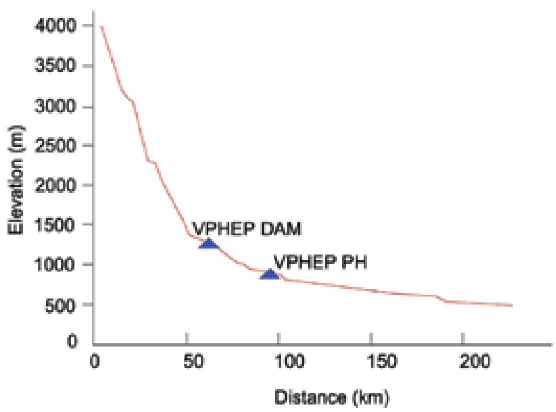

Figure 2 : L Section of river Alaknanda along with location of Dam & Power House of VPHEP

To access the underground powerhouse complex, invert level of Main Access Tunnel (MAT) and Cable cum Ventilation Tunnel (CVT) portal at EL 1066m and EL 1054m respectively were finalized during DPR stage.

2. GEOLOGICAL SETUP OF THE PROJECT AREA

The project is located in the tectonic window known as Pipalkoti Window (Carbonate suite of Chamoli) exposing Lesser Himalayan meta-sedimentary rocks enveloped by low to medium grade metamorphic rocks of Higher Himalaya. The Higher Himalayan crystalline rocks thrust over the Lesser Himalayan rocks along a major tectonic shear known as the Main Central Thrust (MCT) Zone, about 2 km upstream of Dam (Figure 3).The rocks of window zone are grouped under the Garhwal Group represented by low-grade quartzitic sandstone, dolomitic limestone and slates with metabasic sills and dykes. The rocks of the project area are folded in a wide open regional domal structure known as the Pipalkoti Anticline, which is intersected by a number of faults complicating the structural setup.

At Dam site, the left bank on which river diversion planned, comprises of quartzite rockmass with bands of amphibolite overlain by river borne material along with slope wash material in diversion tunnel area (Figure 4). The upstream cofferdam is located on alluvial materials more than 20m in depth. Diversion tunnel has been driven through quartzite with bands of amphibolite, characterised with moderately steep foliation and three other set of discontinuities. The rockmass condition along the diversion tunnel varies between Class II (193m) and Class III (255m) of RMR with a very small patch of Class IV. Power House complex has encountered mainly the Pipalkoti Formation of Garhwal Group consisting of slates,

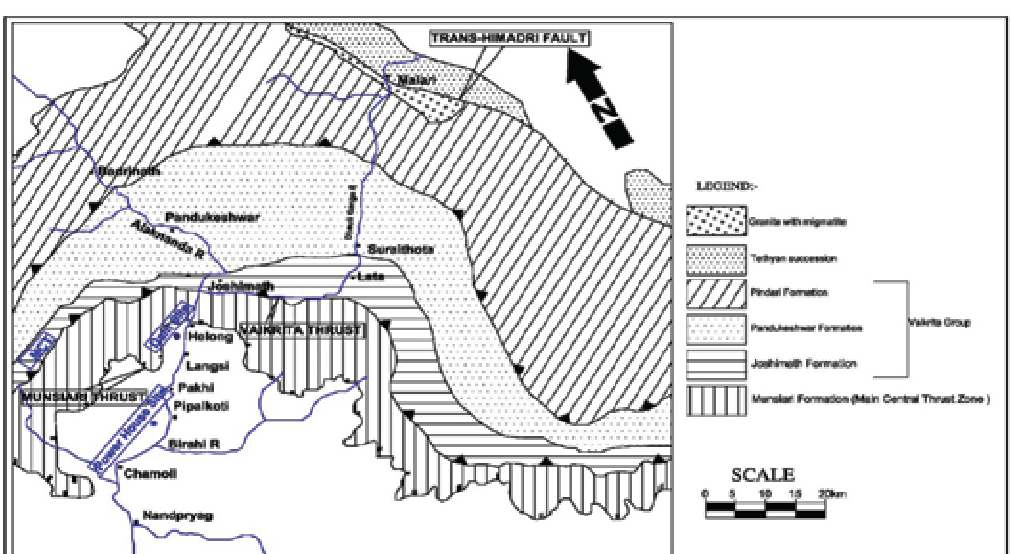

Figure 3 . Regional geological map of VPHEP area (after Valdiya).

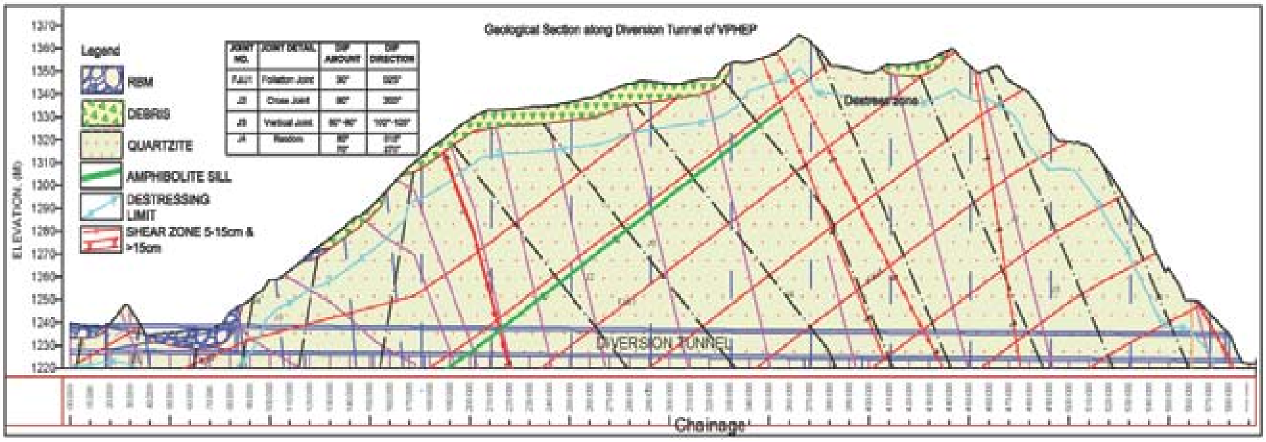

Figure 4 : Geological section along Diversion Tunnel

alternate bands of slate & dolomite with different set of discontinuities and folding within the Pipalkoti Formation. There is a narrow gorge section just downstream of power house exploratory drift / MAT & CVT portal which leads to ponding of the river in the vicinity during rainy season.

3. IMPACT OF EXTREME FLOOD EVENT ON DIFFERENT STRUCTURES DURING EXECUTION

In June 2013, a multi-day cloudburst and heavy to very heavy rainfall hit several parts of the higher reaches within the State. This unprecedented rainfall resulted in a sudden increase in water levels giving rise to flash floods in the Alaknanda and other river basins and also caused extensive river bed and toe erosion, landslides at various locations and huge transportation/deposition of sediments in downstream area. This extreme flood event caused deposition of debris at various locations (Power House area) of project resulted rise in river bed level and at places caused erosion which eventually lowered the river bed level in dam area.

3.1 Dam site

After June'2013 extreme flood event, revised cross-sections were taken to assess the latest river bed profile. A review of fresh cross sections indicated that there is a substantial level difference in the river bed levels at the inlet and the outlet of the diversion tunnel. The levels of river bed after flood event are EL.1222magainst EL.1228 m at inlet and EL.1214 m against EL.1224 m at outlet (Figures 5 and 6).

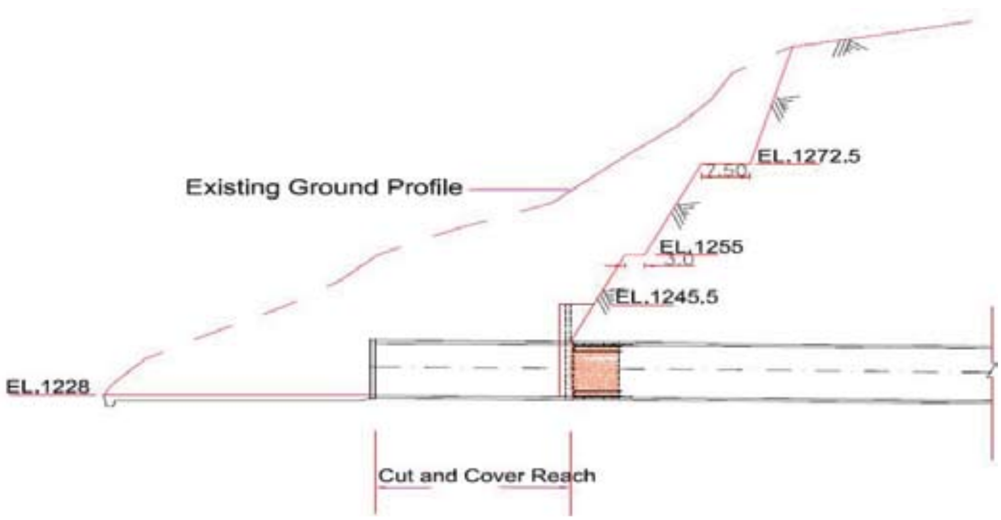

Figure 5 : Section at DT Inlet during Tender stage before flood.

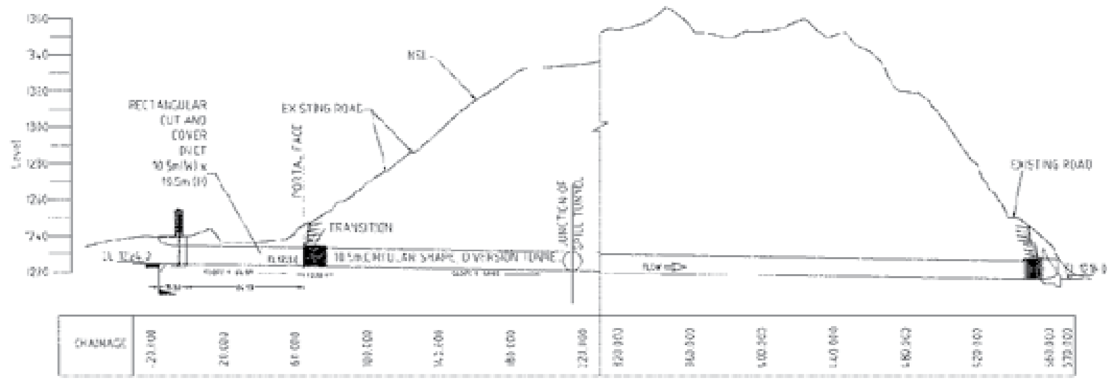

Figure 6 : Section along DT after flood.

As per the Techno Economic Clearance (TEC), approved DPR/ Tender documents, the top of the upstream coffer dam was proposed at EL.1242.0m with a diversion tunnel diameter of 10m. As per the studies, the hydraulic capacity of the proposed system is inadequate due to lower level of river bed after flash flood. The capacity of the system had to be enhanced by either increasing the diameter/ shape of the diversion tunnel or inlet level etc.

Proposed coffer dam was a semi-permanent gravity structure resting on the overburden hence it will not be desirable to place a gravity structure (temporary) of more than 15-16m high on this type of material.

It was evident to raise the height of U/s Coffer dam, if not the invert levels of Intake & Outlet structures are reviewed, which had been located on alluvial materials more than 20m in depth. Having further more height of coffer dam over such alluvial material was not at all suitable. This event compelled to review the diversion scheme thoughrolly in totality. Revision was required to release the required discharge.

With these considerations in view and to limit the heading up of water at upstream coffer dam, it was evolved to increase diameter of circular diversion tunnel upto 10.5m with supercritical flow conditions and impounding water level at upstream and downstream of coffer dams at El. 1238.23m and EL.1219.6m respectively. The top of the U/s and the D/s coffer dams have accordingly been adopted at EL 1239.0 and EL 1220.50m respectively indicating a height of 17m for the U/s coffer dam and 6.5m for the D/s coffer dam. Consequently, the invert of diversion tunnel was also lowered to El. 1224.0 M against El. 1228.0 M and El.1216m against El. 1224.0 M at inlet and outlet respectively.

3.2 Power House site

After June'2013 extreme flood event, revised cross-sections at Power House area were taken to assess the latest river bed profile.

During extreme flood event, the level of river Alaknanda went above the exploratory drift in the vicinity of power house area. Immense quantum of silt got deposited in power house exploratory drift for a stretch of more than 400m. Intensity of flood was so high that trolleys, exhaust fans and jack hammers etc. were washed away with the flood water. The drift had been inspected after lowering of flood water and observed that fine silt & sand is filled up to a height of 1m (Figure 7).

Figure 7 : Silt deposited in exploratory drift of Power House during flood event of 2013

The crate walls along with the drift muck have also been washed away with the water. During detailed engineering, probable maximum water level (level corresponding to PMF of 10840 cumecs) in river Alaknanda at location of MAT and VT is recalculated to ensure that invert level of MAT and VT are at a safe elevation. After detailed deliberations and reported discussion as well as taking into cognizance on the recorded data, it was decided that it would be appropriate to consider the invert level of 1075m as safe level for MAT and VT against portal at El 1066m and El 1054m respectively considered at tender stage.

Further, due to heavy river borne material accumulation along the right bank of the Alaknanda river near Tail Rail

Tunnel(TRT) outlet, river channel drifted its course towards the left bank. At Gauge& Discharge site, cable way system and gauges etc. got washed away due to heavy flood and drifting of river towards left bank. The water level near TRT outlet touched ±1031m. This change in river bed profile also changed the morphometry of junction of Alaknanda and Birahi. Such changes in river bed profile compelled to review the flood protection arrangement and accordingly flood protection arrangements modified considering the existing river bed morphology after flood event of 2013.

4. CONCLUSION

Extreme flood event of June 2013 changes the river bed profile significantly in dam area as well as Power House area of project which affected the designed levels of various portals/inlets at DPR stage. The changes in river bed profile accommodated, by limiting the height of coffer dam as earlier, by lowering of Inlet and Outlet levels of Diversion Tunnel and increasing the size of Diversion Tunnel (finished diameter revised from 10 m to 10.5 m) to accommodate the water levels behind coffer dam. Gradient of tunnel has also been increased to ensure super critical flow (free flow conditions). Similarly, invert of MAT and CVT were relocated at higher elevation to protect from the events like of 2013. These changes due to extreme flood event also influenced the time and cost of the tunnel from what was planned in DPR/Tender stage.

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Even though this generation still believes in the miracle working power of God, they must no longer wait for God to bring water from the rocks, but rather construct dams, water systems, subdue the power of the ocean thereby give glory to God almighty”

Sunday Adelaja

Flood Management at Kamala Dam

A. Mehta[1], D.V. Thareja[1] and V. Batta2

ABSTRACT

Kamala dam is a 216m high concrete gravity structure planned to be constructed across Kamla river in Arunachal Pradesh, India. It is one of the three large dams envisaged in Subansiri sub-basin of the Brahmaputra river. In addition to power generation, these dams would also provide flood relief in the Brahmaputra valley through integrated operation. The reservoir created by the Kamala dam will have a gross storage of 2.4 billion m^3 and will spread over a length of 67 km. A surcharge storage zone of 15m is provided above the full reservoir level (FRL) for storage of 438 million m^3 of water, exclusively for flood moderation. A part of the conservation storage for power generation is also utilized for flood moderation and a permanent flood control zone of 652 million m^3 is defined to be available during the monsoon months (rainy season). Additionally, 410 million m^3 of active storage for power generation that extends upto the minimum operating level is also available thus providing flexibility in reservoir operation. The spillway is configured 100m below the maximum water level (MWL) to provide the required capacity considering the reservoir size, its operation, sediment inflow and deposition. This provides storage of 2 billion m^3 above the spillway crest ensuring abundant buffer for sustainable use of the reservoir for flood mitigation. Reservoir routing studies have been carried out for moderation of floods and to define the reservoir operation rule curve. Rules of operation provide restriction on the outflow for floods upto 100-year return period. As competing objectives of power generation and flood moderation are to be achieved, an appropriate portion of the cost of the dam is assigned to flood moderation so that the generation cost and tariff are not impacted negatively. This paper discusses the flood management aspects and spillway configuration to ensure acceptable performance under design conditions.

1. INTRODUCTION

1.1 Overview of Kamala dam

Kamala hydroelectric project is conceived to serve twin objectives of power generation and flood moderation and features a 216m high concrete gravity dam planned to be constructed across river Kamla in Arunachal Pradesh state of India. In addition to providing flood relief in the Subansiri and Brahmaputra basins, Kamala dam would enable generation of 1800 MW of hydroelectric power providing a sizeable source of renewable energy. The dam comprises a 112m long central spillway, flanked by non-overflow sections - 236m on the left bank and 280m on the right bank. The spillway is configured 100m below the maximum water level (MWL) and comprises seven deep seated sluice openings, 6m x 10.5m, each and an upper bay, 6m x 13m (Figures 1-2). The spillway is designed for a Probable Maximum Flood (PMF) with peak of 17,416 m^3/s. The reservoir created by the dam will have a gross storage of 2.4 billion m^3 spreading over a length of 67 km at MWL.

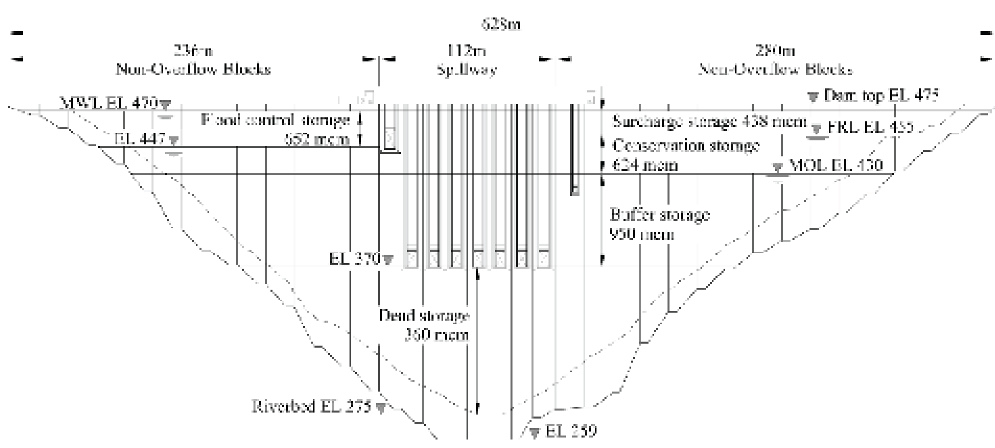

Fig. 1 : Kamala dam upstream view.

1. SNC Lavalin Engineering India Pvt. Ltd., Gurugram, India
2. SNC Lavalin Inc., Vancouver, British Columbia, Canada

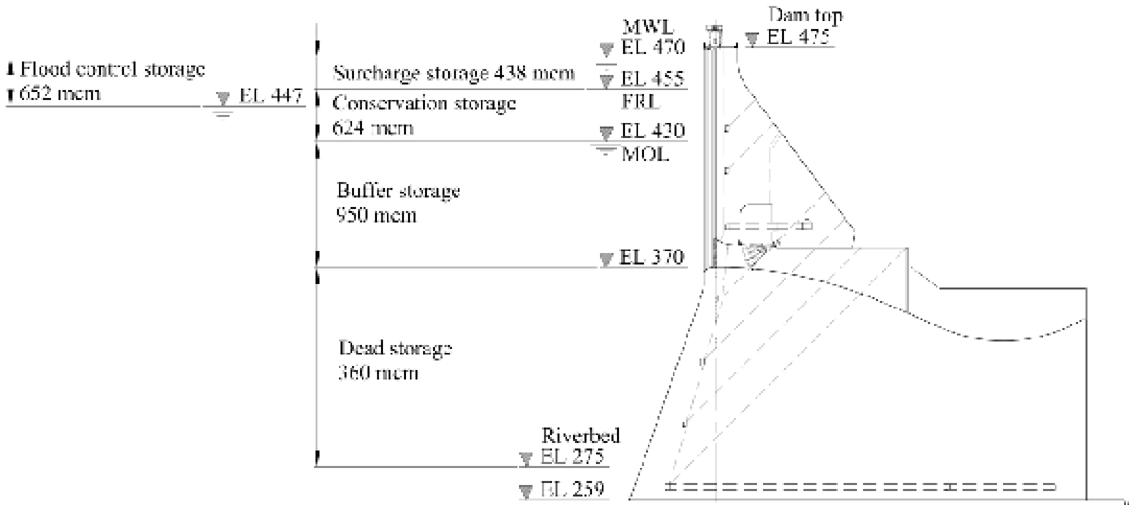

Fig. 2 : Kamala dam spillway section.

1.2 Background

Two large storage dam projects were originally conceived in the master plan of Brahmaputra basin, one each in its sub-basins of Subansiri and Siang for flood control benefits as well as to exploit the available power potential. However, after the feasibility studies, the projects could not be taken up for execution as they involved huge submergence including few main cities and consequent displacement of inhabitants. In order to address these concerns, the projects in the two sub-basins were split into cascade developments with three dams in each sub-basin (Fig. 3).

In Subansiri basin, three projects were planned, namely Subansiri Upper, Kamala (formerly Subansiri Middle) and Subansiri Lower. While the Subansiri Lower and Subansiri Upper dams lie on the Subansiri river, Kamala dam was envisaged on Kamla river, a tributary of river Subansiri. Subansiri Lower, the downstream-most project, was planned predominantly as a power generation project whereas the other two upstream projects were planned to ensure moderation of floods along with power generation. The reservoirs of significantly large dams at the two upper projects were envisaged to have dedicated storage for flood moderation.

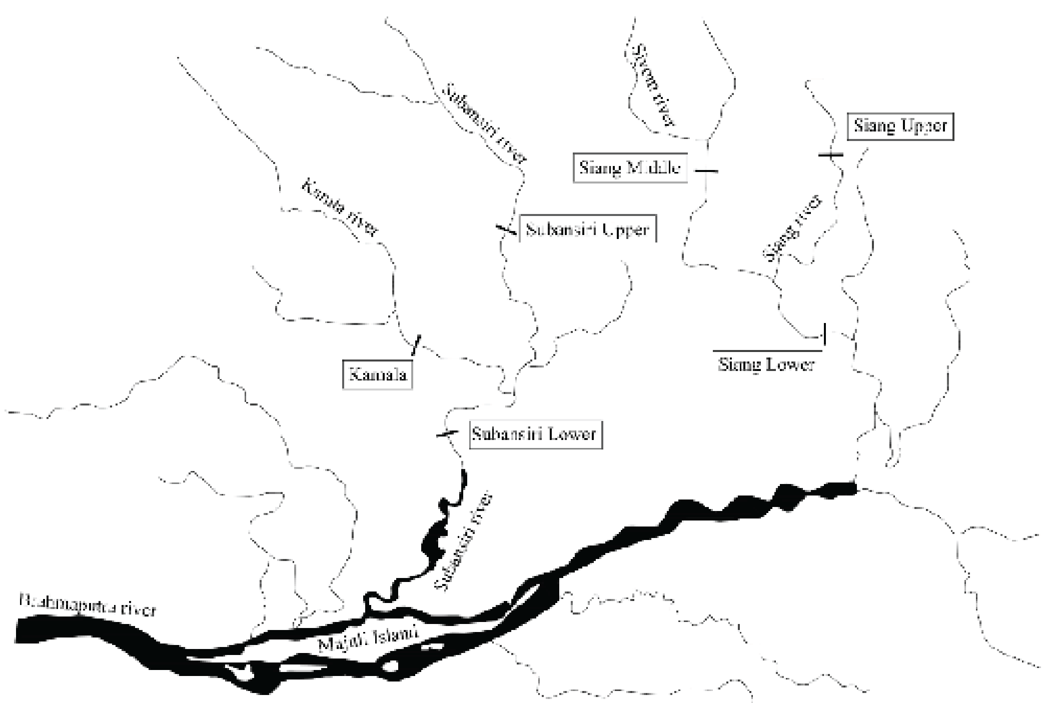

Figure 3 : Flood moderation dams in Subansiri and Siang basins

Development rights of all three projects were originally with a government power utility but later Kamala and Subansiri Upper were transferred to private developers on build, own, operate and transfer basis. The three projects are thus being developed by different parties and a proper coordination would be required for routing of floods. Presently, the Subansiri Lower project is under construction, Kamala is in advanced stage of approval of its Detailed Project Report (Feasibility report) and Subansiri Upper is in feasibility stage.

2. FLOOD MODERATION IN SUBANSIRI BASIN

2.1 Previous studies

An integrated plan of operation of the upper dams would moderate the flows reaching the lower dam that controls the flow to river Brahmaputra. Since, at one stage the projects belonged to the same government agency, integrated reservoir studies for flood moderation were performed for moderation of floods of 10-year, 25-year and 100-year return periods (NHPC, 2005). Flood cushions of 10m for Subansiri Upper and 15m for Kamala and rule curves for reservoir operation during monsoons for the three dams were defined (Table 1).

Table 1 : Reservoir operation rule curve during monsoon for Subansiri basin dams in previous studies.

Period			Reservoir level, m		
			Subansiri Upper	Kamala	Subansiri Lower
		FRL:	460	460*	205
Jun	I-III		435	431	190
Jul	I-III		435	431	190
Aug	I		447	443	190
	II		447	448	190
	III		451	454	195
Sep	I		453	454	195
	II		453	456	198
	III		455	456	205
Oct	I		455	458	205
	II		458	458	205
	III		460	460	205

*Full reservoir level (FRL) was subsequently reduced by 5m.

2.2 Flood moderation criteria

After the transfer of Kamala to its present developer, designers of the project faced some challenges in planning and firming up the key project parameters. To start with, different statutory government authorities for project approvals had different objectives: while the Ministry of Environment and Forest required FRL of the dam to be lowered in view of reducing the submergence of forest land, government's Standing Committee on Storage required the gross storage of the dam to be enhanced for sustainable reservoir development. After a few deliberations, it was agreed to lower FRL by 5m from El 460m to El 455m.

Another challenge was to integrate flood moderation studies for the two upper dams and finalize the release criterion for each dam during flood events. The Technical Group constituted by the government on flood moderation aspects in the Brahmaputra basin had commented on the previous integrated studies (conducted by the government agency) and required the following two basic criteria to be fulfilled for moderation of floods in the Subansiri basin:

(i) Same flood moderation should be available throughout the monsoon period; and

(ii) Release downstream of the Subansiri Lower dam should not exceed 7000 m^3/s based on the safe discharge capacity of river Subansiri.

The first criterion guides that the reservoirs be operated at such levels during the months of September-October (end of monsoon season) so as to achieve the same moderation benefits as during June-July (beginning of monsoon season). The second criterion puts a restriction on the release from the upper dams so that the combined flow, including that from the intermediate catchment, does not result in outflow from Subansiri Lower to exceed the permissible release (7000 m^3/s).

Reservoirs, generally, are not designed to provide complete protection against extremely large floods due to techno-economic, social and environmental limitations. Most dams designed for flood moderation are capable to absorb part of the flood and mitigate flood damages downstream rather than completely preventing the damage in case of large floods. Based on worldwide experience, typical flood protection has been provided for return periods between 20 and 200 years (ICOLD Bulletin 125, 2003). Accordingly, Subansiri basin dams are intended to provide protection against floods with return period of 1 in 100-years or lower to ensure reduction of downstream flows to non-damaging levels. The effect of moderation would be less for the larger floods.

3. FLOOD ROUTING STUDIES FOR KAMALA DAM

Releases from the two upper dams depend on the physiographic characteristics of their catchments as well as the provided flood cushions. In the previous studies, an equal and constant release was contemplated from the upper dams. Mandate of the present developer was not to perform the integrated studies of the entire basin rather follow the defined guidelines set by the authorities. Equal and constant release from the upper dams was, however, maintained.

3.1 Studies using previous rule curve

Since the reservoir rule curve developed from the earlier studies was for a different FRL, as a first step, parametric flood routing studies for the Kamala dam were performed considering the same parameters as in the earlier integrated studies. These parameters comprised: flood cushion of 15m, initial reservoir levels during flood as per the earlier defined rule curve and different constant releases. The updated and approved inflow hydrographs at the time of studies were, however, used. The objective of these studies was to assess if the earlier rule curve met the now defined flood moderation criteria. Summary of results for the 1 in 25-year and 1 in 100-year return period floods are given below in Table 2 and Table 3, respectively.

As observed from the above tables (highlighted), the maximum water level exceeds the 15m flood cushion mark i.e. El 475m, originally. For the 100-year flood, the reservoir attains a maximum elevation varying from El 489.44m to El 477.12m corresponding to constant downstream release of 1000 m^3/s to 3000 m^3/s. Similarly, for the 25-year flood the reservoir maximum water level reaches upto El 483.15m to 471.11m. It is evident that the original reservoir rule curve did not meet the flood moderation criteria. As per this rule curve, the reservoir level was being gradually raised from August and brought to FRL in October. Same flood moderation benefits would thus not be available from June to October if this rule curve was to be followed. Moreover, raising the water level close to FRL in September was not rational from

Table 2 : Flood routing results at Kamala dam for 1 in 25-year return period flood.

Period		**Initial reservoir level, m**	**Maximum reservoir level attained (m) corresponding to release (m^3/s)**					
			1000	1250	1500	2000	2500	3000
Jun	I-III	431.00	459.25	457.26	453.33	451.66	448.18	444.86
Jul	I-III	431.00	459.25	457.26	453.33	451.66	448.18	444.86
Aug	I	443.00	468.91	467.04	465.25	461.84	458.63	455.58
	II	448.00	473.03	471.22	469.48	466.16	463.05	460.10
	III	454.00	**478.06**	**476.31**	474.63	471.43	468.42	465.59
Sep	I	454.00	**478.06**	**476.31**	474.63	471.43	468.42	465.59
	II	456.00	**479.76**	**478.03**	**476.36**	473.20	470.23	467.43
	III	456.00	**479.76**	**478.03**	**476.36**	473.20	470.23	467.43
Oct	I	458.00	**481.46**	**479.75**	**478.11**	474.98	472.05	469.28
	II	458.00	**481.46**	**479.75**	**478.11**	474.98	472.05	469.28
	III	460.00	**483.15**	**481.46**	**479.84**	**476.75**	473.85	471.11

Table 3 : Flood routing results at Kamala dam for 1 in 100-year return period flood.

Period		**Initial reservoir level, m**	**Maximum reservoir level attained (m) corresponding to release (m^3/s)**					
			1000	1250	1500	2000	2500	3000
Jun	I-III	431.00	466.57	464.60	462.68	458.99	455.48	452.10
Jul	I-III	431.00	466.57	464.60	462.68	458.99	455.48	452.10
Aug	I	443.00	**475.77**	473.92	472.12	468.66	465.38	462.25
	II	448.00	**479.71**	**477.91**	**476.16**	472.80	469.61	466.57
	III	454.00	**484.53**	**482.78**	**481.08**	**477.83**	474.75	471.82
Sep	I	454.00	**484.53**	**482.78**	**481.08**	**477.83**	474.75	471.82
	II	456.00	**486.16**	**484.42**	**482.74**	**479.53**	**476.49**	473.58
	III	456.00	**486.16**	**484.42**	**482.74**	**479.53**	**476.49**	473.58
Oct	I	**458.00**	**487.80**	**486.08**	**484.42**	**481.24**	**478.23**	**475.36**
	II	**458.00**	**487.80**	**486.08**	**484.42**	**481.24**	**478.23**	**475.36**
	III	**460.00**	**489.44**	**487.73**	**486.08**	**482.93**	**479.96**	**477.12**

flood management view point as probability of 100-year flood occurring during these months could not be ruled out, particularly in the North-Eastern part of India that witness's heavy rainfall even during late September and early October. Clearly, a new reservoir operation philosophy was to be developed conforming to the requirements set out by the flood moderation criteria.

3.2 Flood routing with revised FRL

Further studies were performed with the revised FRL (reduced by 5m from the original value) to determine the reservoir operation level during monsoon for different releases from the upper dams for the 100-year flood. The studies also considered the likely coincident flood hydrographs of the uncontrolled drainage area of the intermediate catchment and travel time of flow released from the upper dams reaching the Subansiri Lower dam. The objective was to estimate the reservoir levels during monsoon for different constant releases (Table 4) and the index levels that define the reservoir levels when the inflow exceeding the power discharge is to be released from the reservoir. Inflows in-excess of the power discharge of the projects are held in the upper reservoirs and are envisaged to be released in such a way that these outflows when combined with the intermediate catchment hydrograph on its recession limb do not result in outflow from Subansiri Lower to exceed the permissible limits. Typical routing of the 100-year flood hydrograph at Kamala dam is shown in Figure 4.

Table 4 : Kamala reservoir levels during monsoon.

Release	Reservoir level
m^3/s	m
1500	440.00
2000	443.00
2500	445.50
3000	447.00

Flood moderation at Subansiri Lower dam for the maximum regulated outflows from upper dams during the 100-year flood event is shown in Figure 5. It is assessed that storage of about 75 million m^3 is required at the Subansiri Lower reservoir for restricting the downstream release to the prescribed limit of 7000 m^3/s. The available reservoir storage upto MWL is, however, higher. Although, Subansiri Lower was conceived mainly as a power generation project, its reservoir has additional storage that would contribute significantly to moderation of flood events.

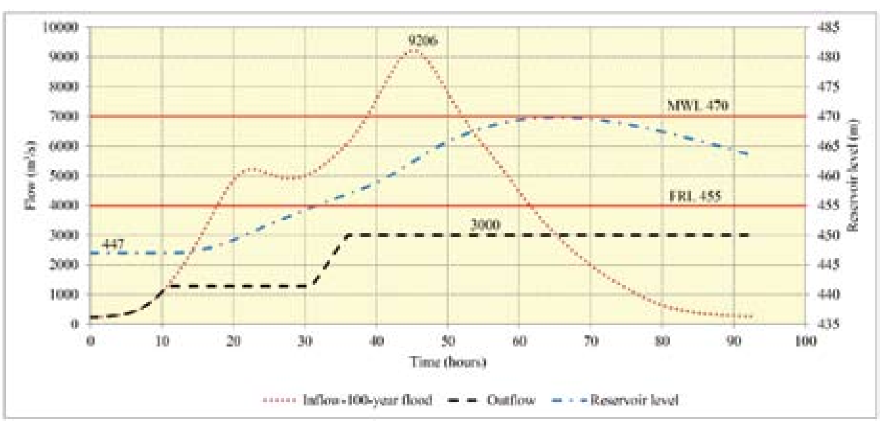

Fig. 4 : Routing of 100-year flood hydrograph at Kamala dam

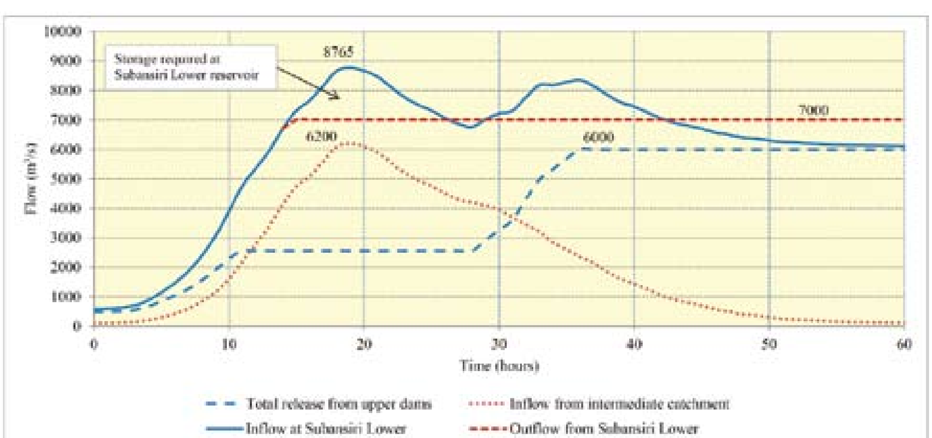

Fig. 5 : Flood moderation at Subansiri Lower dam for the regulated outflows from upper dams.

3.3 Rule curve for Kamala reservoir

The two demands from the reservoir i.e. power generation and flood moderation are competing and conflicting. While flood moderation requires low reservoir levels, power generation interests require as high a level as attainable. The rule curve should provide a balance between the two objectives. In multi-purpose reservoirs like Kamala, some part of the conservation storage space for power generation is sacrificed for flood moderation during the early stages of the monsoon. This space is filled up progressively towards the receding monsoon months. Discussions with Central Water Commission led to finalization of the reservoir level and release criteria for the Kamala dam during monsoons. It was decided to keep the reservoir level of Kamala dam at El 447m from 1st June to 10th October and thereafter raise it to El 455m (the FRL). Thus, a permanent flood control zone of 652 million m^3 is defined to be available during the monsoon months. This includes the surcharge storage zone of 15m height above FRL with storage capacity of 438 million m^3 and a part of the conservation storage. The maximum release was fixed at 3000 m^3/s once the index level is reached, which was worked out as El 456.50m.

The regulation plan so developed is able to attenuate a 100-year peak inflow of 9200 m^3/s to 3000 m^3/s downstream of the Kamala dam. For the control point downstream of the Subansiri Lower dam, the 100-year flood peak of 19,600 m^3/s gets reduced to 7000 m^3/s, thus respecting the criterion. The dams therefore would provide attenuation of about 65% of the 100-year flood peak.

4. ROUTING OF INFLOW DESIGN FLOOD

Operation of reservoirs based on historical data and fixed operation rule curves often poses difficulty in making appropriate reservoir release decisions due to uncertainty in the probability of occurrence of the flood event and also occurrence of flood event similar to the designed. Reservoir operation is an operation in real time in which water release decisions are to be taken at each instant of time with reliable inputs from flood forecasting system and rainfall-runoff models. A regulation plan to cover all the complex situations may be difficult to evolve but, generally, it should be possible by following the principle that lower portion of the flood reserve is used effectively to achieve the maximum moderation benefits by controlling the earlier part of the flood. Thereafter, releases are increased as scheduled to utilize the full storage capacity. For Kamala dam, rules of operation, as developed in these studies, provide the stipulated restriction on the outflow for floods upto 100-year return period. For larger floods, the outflow could be increased but at a controlled rate.

4.1 Spillway Configuration

Design flood for the safety of Kamala dam is the PMF, which has been assessed with peak as 17,416 m^3/s. The dam lies in a region of high rainfall intensity where the possibility of floods occurring in succession cannot be ruled out. To assess this possibility, the design condition also includes extreme flood events which is the occurrence of PMF preceded, or followed, by a 25-year flood.

The spillway capacity and its performance during a flood is governed by factors such as rules of operation of the reservoir, inflow design flood, initial level of reservoir at the beginning of flood, storage characteristics of the reservoir, functioning of spillway including consideration of non-availability of a portion of the spillway, and freeboard. Initial reservoir level (before the spillway design flood impinges) has been considered as higher of the FRL or the level at which 50% of the flood storage space is occupied i.e. El 459.25m. Even though the contemplated plan of operation is such that a portion of the storage capacity below the FRL probably would be available at the beginning of the design flood, the possibility of improper operation of gates as a result of incorrect flood prediction and mechanical difficulties justifies the above assumption. For the extreme flood scenarios, the initial level is considered as the rule curve level during monsoon.

The Kamala dam spillway has seven deep seated sluice openings (6m x 10.5m, each) configured 100m below MWL i.e. at El 370m and an upper bay, 6m x 13m, at El 446m. The spillway system is designed for the following conditions (Table 5).

Table 5 : Design conditions for safety of the Kamala dam

Design condition	Inflow design flood	Initial reservoir level, m	Free board corresponding to
Design flood	PMF	459.25	2/3 of maximum wind
Design flood + gate malfunction	PMF	459.25	1/2 of maximum wind
Extreme flood	25-year + PMF	447	1/2 of maximum wind
Extreme flood + gate malfunction	25-year + PMF	447	minimum 1m freeboard

Studies have been performed with varied outflow rates and rate of increase in outflow. Principle of effective use of available flood control storage space by restricted release is followed for deciding the spillway capacity. For the gate malfunction condition, 10% of the gates with minimum one gate with the largest capacity is considered inoperative. A reduced freeboard is acceptable under this condition as probability of simultaneous occurrence of extreme flood, gate malfunctioning and extreme wind is not significant. At MWL, the spillway has a discharge capacity of 16,800 m^3/s with all gates operative and 14,500 m^3/s with one gate inoperative.

Reservoir routing in the scenario with 25-year flood and PMF occurring in succession along with malfunctioning of gate is shown in Figure 6. Obviously, the effect of moderation is less pronounced than that for the 100-year flood.

5. COST APPORTIONMENT

As competing objectives of power generation and flood moderation are to be achieved at Kamala, the project cost therefore is apportioned among the two. The costs allocated to flood moderation include the cost of 15m additional height of the dam and appurtenances for providing surcharge storage; cost related to additional time required to construct a higher dam; and cost towards loss of annual energy generation attributable to reservoir operation at lower level in monsoons.

With the increasing role of private entities in developing hydropower plants and dams in India, projects with multipurpose benefits have to be supported by the government. Costs related to providing benefits other than power should be shared by the government so that the hydro tariff remains competitive. A policy framework must be put in place for such projects for aiding the decision making process. It is understood that the government has taken some steps in this direction.

6. SUSTAINABLE USE OF RESERVOIR

For integrated operation of the Subansiri reservoirs, a regulating mechanism and a detailed coordination plan of operation would require to be developed, and followed, to ensure optimum benefits of flood mitigation. The initial reservoir regulation strategies developed to meet the objectives established during planning studies would need to be continually reviewed and adjusted to reflect the changing conditions and priorities.

The minimum operating level of the Kamala reservoir has been set at El 430m that provides storage of about 1.1 billion m^3 above this level. Storage of 410 million m^3 below the operating level during monsoons i.e. El 447m provides sufficient flexibility in operation of the reservoir. The spillway configured at El 370m provides storage of 2 billion m^3 ensuring abundant buffer for sustainable use of the reservoir for flood mitigation. With reliable real time flood forecasting systems, the reservoir level can be lowered than the licensing conditions to make room for unexpected extreme events. With provision of the deep seated spillway, the reservoir regulation rule curve and release criteria could be adjusted to meet the future demands, if required, to take care of the climate changes, changes in design floods based on new hydrological information available since the initial design of dam, changes in analysis methods and new safety concepts, new risks like development of the flood plains and reservoir sedimentation etc. Cost apportionment for the change of reservoir use would have to be judiciously reworked and managed accordingly.

7. CONCLUSION

Once constructed, the upper dams in Subansiri basin, Kamala and Subansiri Upper, along with the under construction Subansiri Lower dam would provide flood

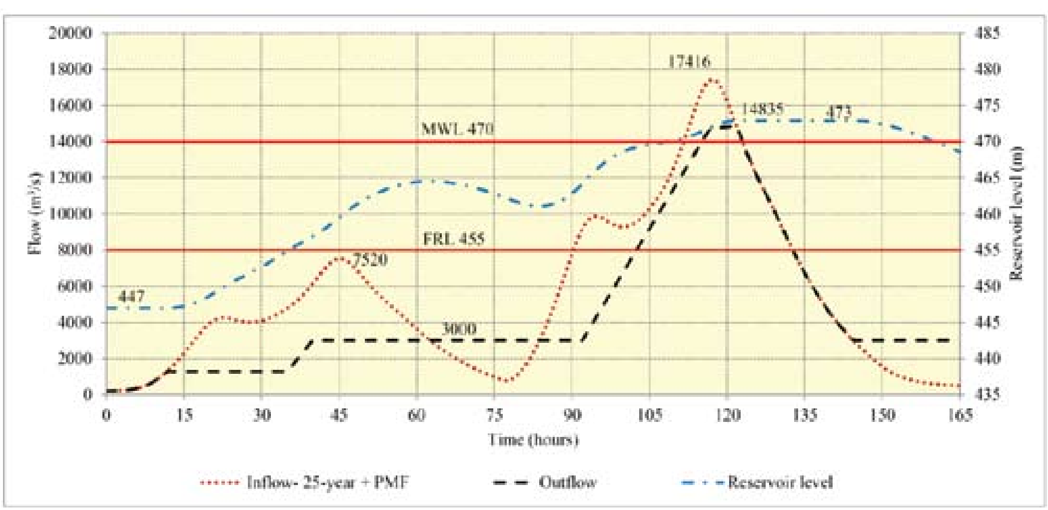

Fig. 6 : Routing of extreme flood hydrograph with one gate inoperative at Kamala dam

relief in the Brahmaputra basin through integrated operation of their reservoirs. It is anticipated that integrated operation of these reservoirs would provide a reduction of about 65% in the flood peak for the 100-year return period flood. A regulating mechanism and a detailed coordination plan of operation together with emergency release plans, reliable flood warning systems, emergency action and evacuation plans would require to be developed and followed to ensure that optimum benefits of flood mitigation are realized. Ideally, a common regulation entity should be constituted to take appropriate reservoir control decisions to ensure apportionment of releases from the three reservoirs for equitable distribution of water within the system for optimum flood control benefits.

Kamala dam is provided with large capacity deep seated sluice spillway to service the objectives of controlled depletion and preserve significant part of storage above the spillway crest through efficient sediment management. Subansiri Upper and Subansiri Lower are also designed with similar provisions. The Subansiri basin dams would ensure abundant allowances and flexibility to take care of future changing requirements and address hydrological changes including the impact of climate change to ensure sustainable use of the reservoirs for flood mitigation.

Extent of flood damages in recent years indicate that in future it would be imperative to increase measures to prevent and reduce damages that include construction of dams with dedicated flood storage provisions together with improvements in flood forecasting system for increased reliability. For multi-purpose dams with flood mitigation as one of the core objectives, the government should develop an equitable cost sharing framework and provide relevant financial support to the developer.

ACKNOWLEDGEMENT

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Rivers, ponds, lakes and streams -
They all have different names, but they all contain water.
Just as religions do - They all contain truths.

An Innovative Approach for Construction of Large Adit through River Borne Material at Vishnugad Pipalkoti Hydro Electric Project (444MW), Uttarakhand, India

D.V. Singh, R.K. Vishnoi, Gajendra Singh, Ajay Kumar, N.K.Ojha and P. Vishwakarma

THDC India Limited, Rishikesh, Uttarakhand, India

ABSTRACT

Vishnugad Pipalkoti Hydro Electric Project (VPHEP) is a run of the river scheme, located on river Alaknanda, spanning between Helong and Birahi Villages in Chamoli district of Uttarakhand, India. The Project envisages construction of 65m high Concrete Gravity Dam, three nos. underground Desilting Chambers of 390m length each, 13.4 km long circular Head Race Tunnel (HRT) of 8.8 m finished diameter (12 km by double shield Tunnel Boring Machine-TBM) etc.

In order to facilitate the start of excavation of HRT through TBM, an entry adit of diameter 9.95m and a chamber of diameter 12 m for launching the TBM are being constructed through huge deposits of River Borne Material (RBM) and slope wash material (debris). Construction of this large adit and large launching chamber by non-blasting, pre-strengthening and multiple drifting methods etc. through RBM is a unique example of engineering in the Himalayan region. Challenges during execution intensified in monsoon season due to massive water seepage laden with silt (being the RBM as tunnelling media) in entry adit to TBM.

This paper briefs about the art of engineering for designing, construction and tackling of complex geological circumstances encountered during construction of such a large adit. The adit 55 m in length, part of which will act as launching chamber (17.5 m length) for TBM has been constructed successfully.

1. INTRODUCTION

THDC India Limited (THDCIL), a joint venture of Govt. of India & Govt of U.P., have taken up the implementation of VPHEP with an installed capacity of 444MW (4x111 MW) on river Alaknanda in the state of Uttarakhand, India (Figure 1) with World Bank financial assistance. The purpose of the VPHEP is to harness the energy of the Alaknanda river for Hydro Electric Power generation as a part of Integrated and efficient development of Hydro resources of Bhagirathi and Alaknanda rivers and their tributaries. The project utilizes a gross head of 237m to generate 444 MW of power. The water conductor system consist of three intakes and sedimentation chambers and then a 13.4 km long HRT of 8.8m diameter of circular

Fig. 1 : Location Map of TBM launching platform of VPHEP

shape. The excavation of 12km long HRT shall be done with TBM method and 1.4 km length of HRT is being excavated by Drilling and Blasting Method (DBM). TBM is planned to enter from upstream side of the powerhouse complex towards the Intakes (i.e. from the Pipalkoti dolomites to the Gulabkoti quartzites) through an entry Adit of 632m length.

2. GEOLOGICAL SETUP OF PROJECT AREA

The project is located in the tectonic window known as Pipalkoti Window (Carbonate suite of Chamoli) exposing Lesser Himalayan metasedimentary rocks enveloped by low to medium grade metamorphic rocks of Higher Himalaya. The Higher Himalayan crystalline rocks thrust over the Lesser Himalayan rocks along a major tectonic shear known as the Main Central Thrust (MCT) Zone. The rocks of window zone are grouped under the Garhwal Group represented by low-grade quartzitic sandstone, dolomitic limestone and slates with metabasic sills and dykes. The rocks of the project area are folded in a wide open regional domal structure known as the Pipalkoti Anticline, which is intersected by a number of faults complicating the structural setup. The most important thrust/ faults are those that dissect the rocks of Pipalkoti Formation lying in the core of the structure: namely the Tapon Thrust, Bemru and Hat Faults. Towards the Intake, the Gulabkoti Formation has thrust over the Pipalkoti Formation along the Gulabkoti Thrust. On the south-western side, this formation has a faulted contact with an overriding crystalline thrust sheet locally known as Jaisal Fault.

Although, Power House area is situated in Pipalkoti Formation of Garhwal Group consisting of slates, alternate bands of slate & dolomite with different set of discontinuities and folding within the Pipalkoti Formation. However, TBM Adit to HRT is located on a river terrace at the right bank of Alaknanda river (upstream of Harsari Nala) at El. 1152.5 m. TBM platform and the slope above the TBM platform are covered by huge deposits of RBM and slope wash material (debris). The RBM is generally showing graded material consisting silt to boulders of up to 2 m. Most of the upper surface of the slope wash material had hardened due to calcareous solution activity. The calcareous leaching from upper reaches of dolomitic limestone solidifies the upper surface of the debris/RBM and it shows pseudo-rock behavior, and it is termed as 'Consolidated RBM' (Figure 2). It is worth to mention here that, on the back slopes above the TBM platform (El. 1152.5 m) there is 1.5 to 2 m thick layer of silt/ mud, sloping in the downstream direction. This layer was wet during summer also. In u/s slope end of TBM platform (± 165 m from TBM Adit) it is at EL 1164 m, while at TBM entry adit it levelled at EL 1157 m. There is no rockmass exposed in the TBM platform area (± 350 m length). Rocks are exposed in the adjacent nalas area which is ± 200 m away from TBM adit.

In order to assess the subsurface condition along TBM Adit, Geophysical exploration by Seismic Refraction method was performed by National Institute of Rock Mechanics (NIRM). Resistivity Imagine survey had been done by Geophysical team of NHPC to explore the rockmass condition up to 200m along the entry Adit of TBM. An Exploratory Drill Hole of 104m depth had also been done from surface at RD 217m of Adit to ascertaining the rockmass conditions along Adit.

During construction of Adit, RBM has been encountered at the beginning of excavation in heading portion. Sandy silt layer was encountered at the invert level after RD 10m and this sandy silt layer was gradually increased towards the crown portion and it reached crown portion at RD 41m. Afterwards, the face is completely covered by sandy silt layer. This sandy silt layer is damp to saturated in ground water condition. During monsoon the seepage of water has been measured upto ~200 litre / minute from the right side of the Adit.

632m long TBM entry Adit to HRT shall be driven through RBM/Slope wash material uo to RD 200m followed by Slate, interbedded sequence of slate and dolomitic limestone. Considering the huge extent of RBM / debris, it is planned to excavate remaining length of Adit (beyond RD 55) by TBM itself.

3. DESIGN OF SUPPORT SYSTEM

Construction of larger dia. tunnel is always a challenging task in the Himalayan region. Here at VPHEP, Adit of 12.75m diameter which is initial part of entry of TBM and launching chamber have been constructed through RBM / Slope Wash Material. This construction was possible due to steady rock support system analyzed and installed during construction of Adit. The densification of the strata indicates that the strength and deformation parameters may be more but for conservative design, the analysis and design for the TBM adit had been carried out on the parameters mentioned in Table 1.

Table 1 : Geotechnical Parameters for design

Parameters	**Unit**	**Values**
Saturated Unit Weight	[kN/m^3]	20
Friction Angle	[phi°]	27
Cohesion	[MPa]	0.075
Deformation modulus	[MPa]	250

To simulate the tunnel advance excavation or for softening of tunnel, the Modulus value of 75 MPa (30% of Original modulus) had been used in analyses. For the stability analysis, vertical load corresponding to the maximum vertical cover above the tunnel (50 m) is considered in the analysis. The analyses have been carried out for K=0.54 (Based on Jacky Formula) for estimation of horizontal stresses around the tunnel. Since, the river

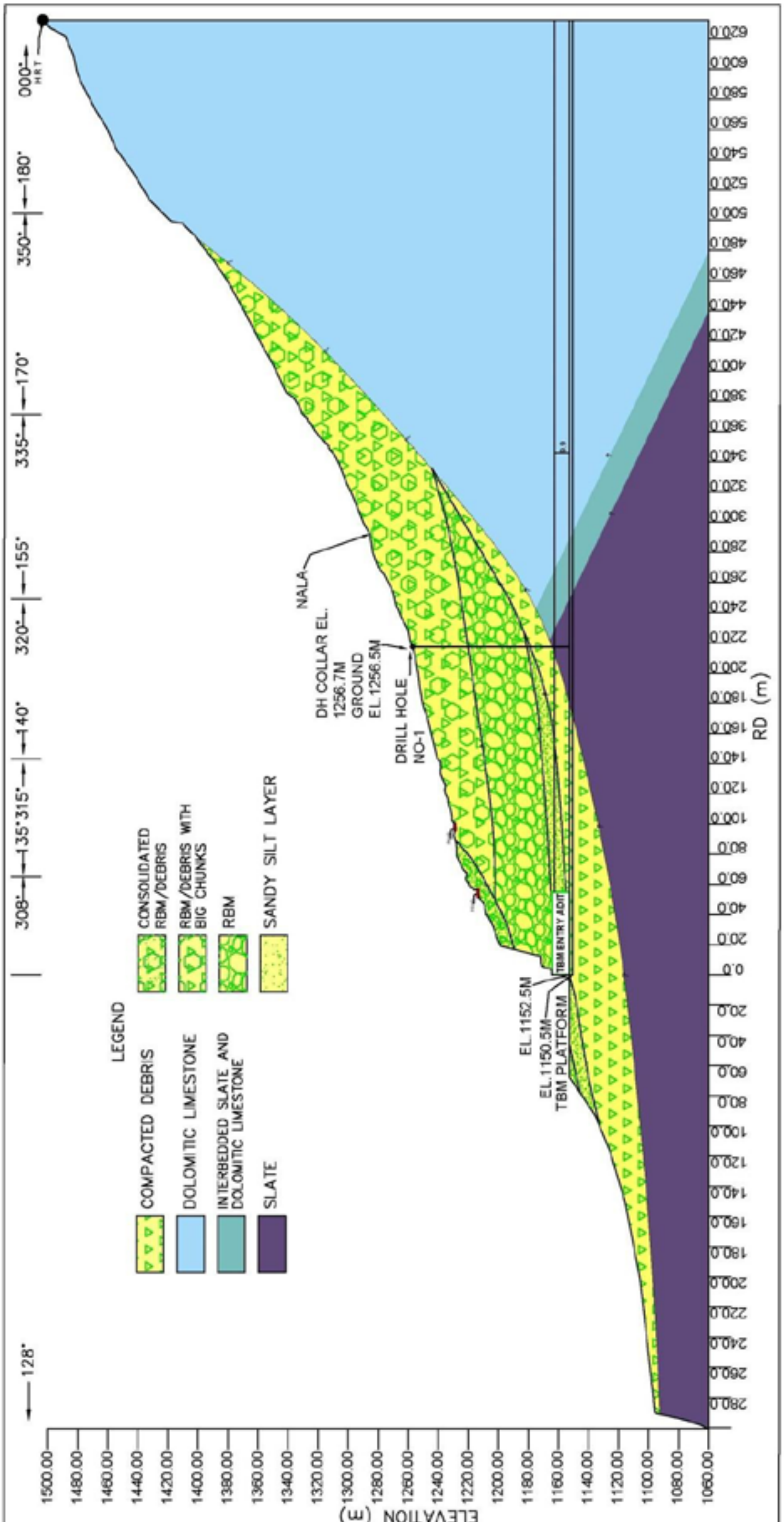

Fig. 2 : Geological Section along TBM Entry Adit

bed level is more than 80 m below the level of TBM platform, hence the effect of water table is not considered directly. However, the unit weight of overburden material is considered as saturated unit weight rather than the dry unit weight, to account for additional loading due to partial saturation during monsoon.

The stability analysis of the TBM Adit had been carried out using Finite Element Programme PHASE2 (Rocscience) by AF Consult, as a continuum model using Mohr-Coulomb yield criteria and stresses and deformations around the tunnel are estimated to check the stability of the tunnel. Following (Table 2) were considered in the analysis,

Table 2 : Consideration of rock support properties in design & analysis

Shotcrete Concrete strength = 25 MPa Modulus of Elasticity = 25 GPa Residual Compressive Strength = 5 MPa Tensile Strength = 3.5 MPa
Pipe roof Diameter= 114 mm Spacing @ 250 mm c/c Length= 12 m with overlap of 4 m and at an angle of 40 upward
Self drilling anchor (SDA) Diameter D = 32 mm Length L = 8 m Modulus of Elasticity E = 200 GPa Yield Capacity Fy = 28 t Design Tensile Capacity T = 16 t

In analyses the excavation is carried out in heading and stages of benching. Analyses indicate that the maximum total displacement values are 52 mm at crown, 29 mm at left wall, 29 mm at right wall and 62 mm at invert after complete excavation (Figure 3). The tunnel convergences (vertical and horizontal) after complete excavation are lower than that of 1% and the axial forces in the bolts are well within its design capacity. Hence the provided support system is adequate.

Hence, based on the analyses, the support systems adopted for TBM Adit are Pipe roof umbrella of 114 mm dia. (perforated pipes), 10 mm thick, 12 m long with overlap of 4 m with next pipe roof umbrella @ 250 mm centre to centre at an angle of 4º upward. The lattice girder 130x32x25 mm @ 1 m c/c along with 350mm shotcrete with fibres (Figure 4). The face confinement with 40 mm dia., fully grouted Fibre Glass Reinforcement, 6 m long @ 1.5 m c/c with 3 m overlap with next set of reinforcement.

32 mm dia., 8 m long fully grouted self drilling anchors (SDA) @ 1 m c/c in crown and walls after 7 m away from the portal location. For the tunnel stretch between portal and 7 m away, the length of the anchors kept as 4 m. The excavation cycle of 750 mm -1000 mm length had been considered as per site conditions for excavation and support system and only after supporting the stretch, the next cycle of excavation was undertaken.

4. CONSTRUCTION OF TBM ADIT

Before start of excavation of TBM entry Adit, it was necessary to stabilize the slope above and surrounding the Adit portal. This slope consists mainly of RBM and slope wash material. Slope surrounding the portal was treated by 100mm thick Shotcrete with one layer of wiremesh along with 12m long SDA of 32mm dia. @ 1.5m c/c. 8m long drainage hole of 76mm dia @ 4m c/c was also provided.

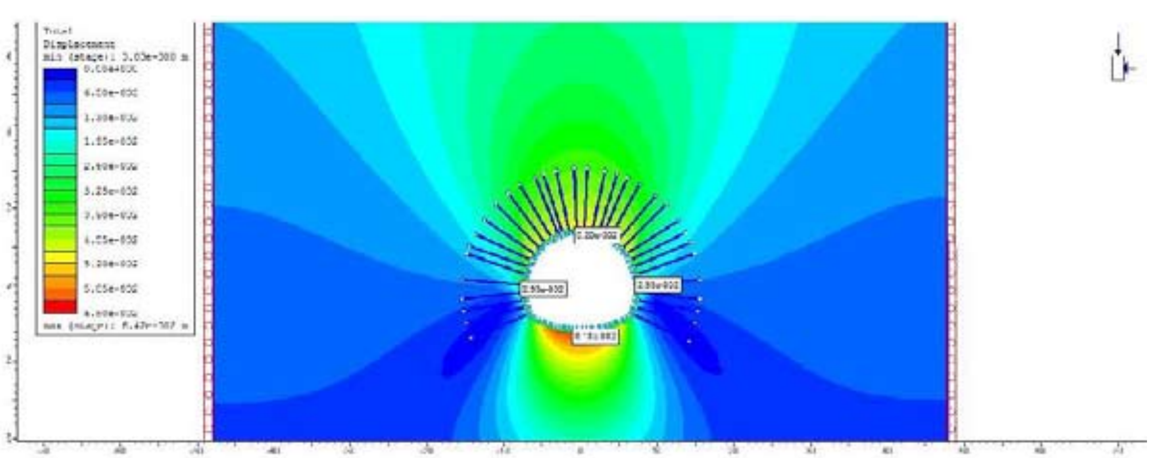

Figure 3 : Total displacement after complete excavation of TBM Adit.

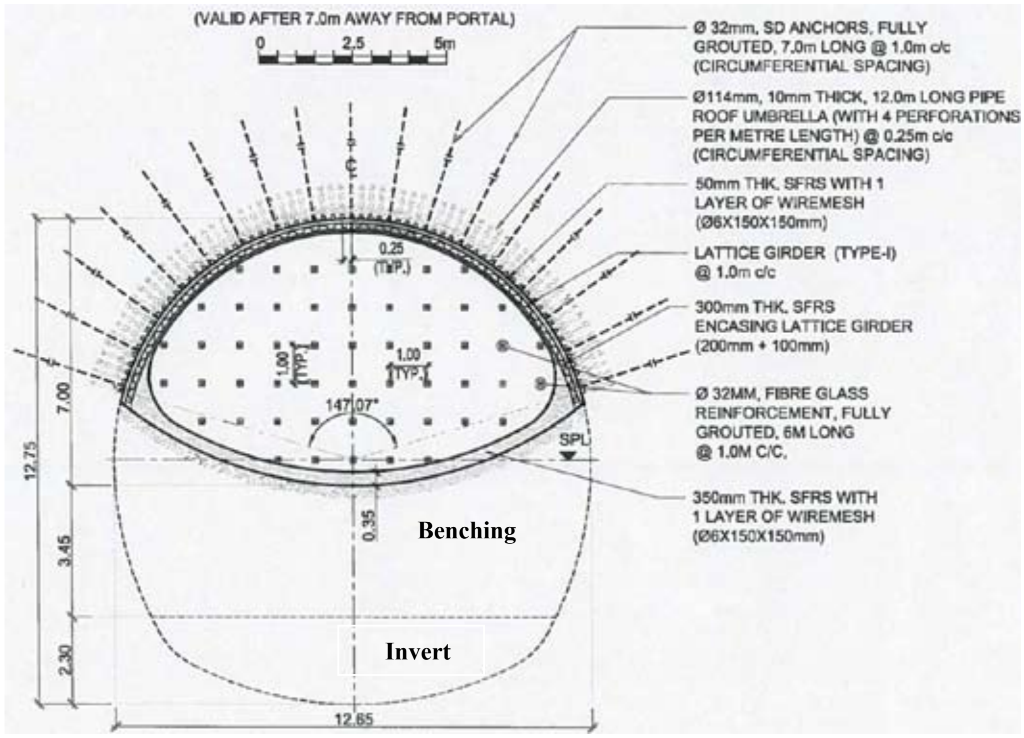

Fig. 4 : Support system for TBM entry Adit

Excavation of TBM Adit (up to 55m) was done in sequence of different stages i.e. Heading at Stage I, Benching at Stage II and Invert at Stage III.

After stabilization of slope and portal area with pipe roofing for 12m length @ 0.25m c/c, mechanical excavation of Adit was started by excavator. Pipe roofing was repeated after every 8m excavation uo to SPL so that there would be always overlap of 4m for additional support. Face excavation of heading was done for 0.75m - 1m, followed by 50mm thick SFRS and installation of lattice girder along with different layers of SFRS (300 mm) and SDA (4m long for initial 7m reach then length of SDA was adopted as 7m). Existing face was strengthen by SDA and shotcrete in addition to pipe roofing. Strengthening of invert was also planned by 350mm SFRS with one layer of wiremesh. After advancement of heading up to 16 m, benching was started.

RBM had encountered at the beginning of excavation of TBM entry Adit in heading portion. Sandy silt layer was encountered at the invert level after RD 10m and this sandy silt layer was gradually increased towards the crown portion and it reached crown portion at RD 41m. Afterwards, the face is completely covered by sandy silt layer. This sandy silt layer is damp to saturated in ground water condition. During monsoon the seepage of water has been measured upto ~200 litre / minute (Figure 5) from the right side of the Adit along with immense quantity of Silt. In the upstream of TBM Adit, the higher slopes are highly water charged during monsoon and the water bearing layer is having downward gradient. At chainage 38m, sand lens embedded in RBM together with approx. 3 l/s of water probably created above the crown and in front cavity of approx. 5 m height which affected the Adit up to RD 26m. The cavity area treated by installation of steel ribs of ISMB 300 @ 0.5m. Entry TBM Adit has been constructed up to 55m including the launching chamber of 17.5m (Figure 6).

Fig. 5 : Gushing of water with silt from right side at RD 41.5m of TBM entry Adit

Fig. 6 : TBM Entry Adit with Launching Chamber

5. CONCLUSION

There is no rock exposure in the TBM launching platform area and the slope above the platform are covered by huge deposits of RBM and slope wash material or debris. TBM will be driven through RBM/Slope wash material followed by slate, interbedded sequence of slate and dolomitic limestone. 12m large entry TBM Adit has been excavated up to 55m for launching of TBM. This large Adit has been constructed to facilitate HRT excavation in stages with the help of various kind of support system and tackling of extreme condition during Monsoon which is a unique example of engineering in the Himalayan region.

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Cascading Hydropower Projects on Teesta River Basin

Mrs. S. R. Patnaik, Mrs. V.P. Gadhe, B.S. Sundarlal,
Dr. M.R. Bhajantri and Dr. (Mrs.) V.V. Bhosekar
MoJS, DoWR, RD & GR, Central Water and Power Research Station, Pune, India

ABSTRACT

In Teesta River Basin construction of a series of cascade dams for hydropower generation is the most significant development activity in the state of Sikkim and West Bengal. Hydraulic model studies play a vital role in finalizing the design of spillway and energy dissipator of the hydro-power projects. The paper describes the hydraulic model studies of the cascading hydropower projects on Teesta River Basin namely, Teesta-IV, TLDP-IV and TLDP-III conducted at Central Water and Power Research station, Pune, India for evolving the optimum design of spillways, energy dissipators and layout of power intake structures.

1. INTRODUCTION

Teesta River originates from the Pahunri glacier and flows southward through deep and narrow gorges and rapids in the Sikkim. Throughout its course the river is turbulent and flows with high velocity with a steep gradient of the order of 1:125. The rapid descent of the river from high elevations makes it ideally suited for hydropower development. The most significant development activity on the Teesta is the construction of a series of cascade dams for hydropower generation in the state of Sikkim. Some of the major hydropower projects in West Bengal and Sikkim includes TLDP-III (132 MW), TLDP-IV (160 MW), Teesta -II (330 MW), Teesta -III (1200 MW), Teesta -IV (520 MW), Teesta-V (510 MW), Teesta-VI (500 MW). Figure 1 shows the Cascade Development of Hydropower Projects of Teesta River Basin. Hydraulic model studies of many of the above completed and proposed hydro-projects are conducted at Central Water and Power Research Station (CWPRS), Pune, India

The paper describes the hydraulic model studies of the cascading hydropower projects on Teesta River Basin namely, Teesta-IV, Teesta Low Dam Project (TLDP), Stage-IV and Teesta Low Dam Project (TLDP), Stage-III conducted at CWPRS for evolving the optimum design of spillways, energy dissipators and layout of power intake structures and shows how physical model studies play an important role in enhancing the overall performance of spillway and energy dissipator arrangement which ultimately helped the projects in optimizing a techno-economic design of spillway and associated appurtenant structures of dam complex.

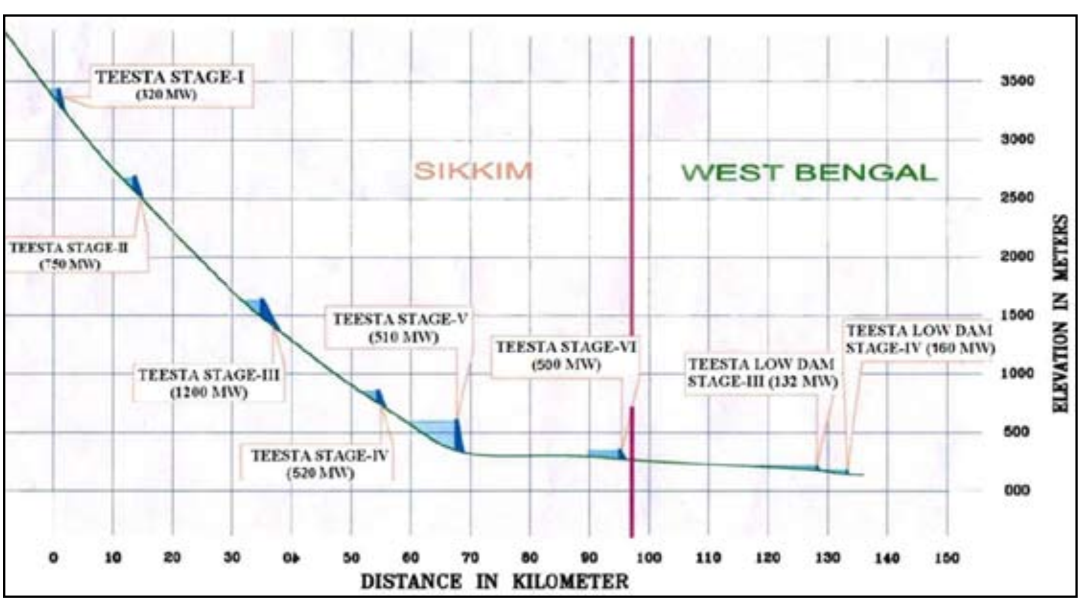

Fig. 1 : Cascade development of Teesta River Basin

2. TEESTA-IV DAM SPILLWAY, SIKKIM

Teesta H. E. Project, Stage-IV is a run-of-the-river scheme located on River Teesta after its confluence with tributary Runchu in Sikkim. The project envisages construction of 65 m high and 197.2 m long concrete gravity dam with top at El. 760 m. The breast wall spillway has been provided to pass the design flood of 13,000 m^3/s through 6 orifice openings of size 9 m wide x 14.5 m high with crest level at El. 716 m. The ski-jump bucket with 35 m radius and 350 lip angle and its invert at El. 697 m is provided for energy dissipation. An underground powerhouse has been provided on the right bank, with an installed capacity of 520 MW (4x130 MW) with design discharge of 480 m^3/s.

Hydraulic model studies were conducted on 1: 60 scale geometrically similar 3D comprehensive model for assessing the discharging capacity of spillway for ungated and gated operation, water surface profiles for entire range of discharges, pressures on the spillway surface and bottom of breast wall profile, performance of the spillway and energy dissipator for entire range of discharges and flow conditions in the vicinity of power intake. Photos 1 and 2 show the downstream and upstream view of the model respectively.

Photo 1 : Downstream View of Model

Photo 2 : Upstream View of Model

2.1 Studies for the Original Design of Spillway and Energy Dissipator

Studies were conducted for discharging capacity of spillway for all the spans operating with full gate opening for entire range of discharges for ungated operation of spillway. It was observed that with one span inoperative, the design discharge of 13,000 m^3/s could be passed at RWL El. 755.91 m as against FRL El. 755.0 m. Thus, the encroachment on the free board is only by 0.91 m as against the available free board of 6 m. At FRL El. 755.0 m, a discharge of 12,800 m^3/s could be passed for one gate inoperative, which is 1.5% less than the design discharge of 13000 m^3/s. As simultaneous occurrence of one gate inoperative and PMF in the river would be a very rare event, this small deficiency of discharging capacity can be accepted. As such, discharging capacity of the spillway is considered to be adequate. It was observed that submerged ski-action was taking place for the discharges higher than 3250 m^3/s with gated and ungated operation of spillway. It was also seen that the flow was concentrated towards the right bank in the plunge pool and the jet issuing from span no. 6 was also hitting the right bank. In order to avoid uncontrolled erosion of the right bank, it was suggested to provide curved dam axis and tilt the dam axis anti-clockwise by about 3^0 to improve the performance of ski-jump bucket, uniform flow distribution across the river valley downstream of spillway and would also economize to great extent the excavation of steep right bank required for providing pre-formed plunge pool. It was also revealed that the upper nappe of the jet was not following the breast wall bottom profile for entire range of reservoir water levels with orifice flow. Therefore, it was suggested to modify the bottom profile of the breast wall so as to make it effective as there is a scope for further improvement in the discharging capacity of spillway. Mild vortices were observed in front of all the 4 units of power intake for the entire range of discharges with and without operation of ungated and gated operation of spillway at MDDL El. 740 m. Therefore, it was recommended that the design of the intake needs to be revised. Photo 3 shows the performance of energy dissipator for the discharge of 13000 m^3/s.

Photo 3 : Performance of energy dissipator for the discharge of 13000 m^3/s

2.2 Studies for the Revised Design of Spillway and Energy Dissipator

Taking the due cognizance of the result of the model studies, the modification which includes the tapering of the pillway span, curvature in the dam axis and tilting by 3^0, revision in the design of intake and modification in breast wall bottom profile were incorporated in the existing 1:60 scale 3-D comprehensive model. It was observed that the discharging capacity was improved with C_d increasing from 0.78 to 0.84. Submerged ski-action was observed for the discharges higher than 3250 m^3/s with gated and ungated operation of spillway. Photo 4 shows the performance of energy dissipator for the discharge of 13000 m^3/s. No vortices were observed in front of all the 4 units of power intake for the entire range of discharges with and without operation of ungated and gated operation of spillway at MDDL El. 740 m as the centerline elevation was lowered by 1 m. S/D ratio increased from 1.65 m to 2.61m eliminating the possibility of formation of vortices ensuring adequate submergence. Figure 2 shows the plot of non-dimensional submergence versus Froude number. It was also observed that the ski-jump jet is impinging in the pre-formed plunge pool which was earlier hitting the right bank but it was recommended that the dam axis should be tilted to 5^0 instead of 3^0 so that the flow concentrated towards the right bank is further reduced.

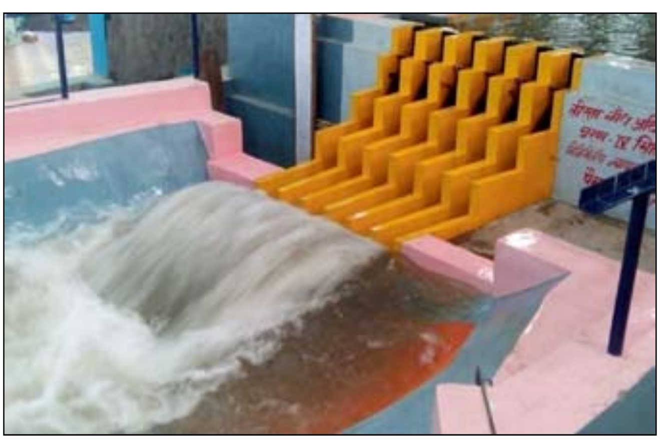

Photo 3 : Performance of energy dissipator for the discharge of 13000 m^3/s

2.3 Scour Studies for the Revised Design of Spillway and Energy Dissipator

Hydraulic model studies were conducted for assessing the maximum depth of scour and scour pattern downstream of spillway for various discharges up to design maximum discharge of 13000 m^3/s. The river portion downstream of spillway up to chainage 420 m downstream of dam axis was reproduced with cohesionless erodible material

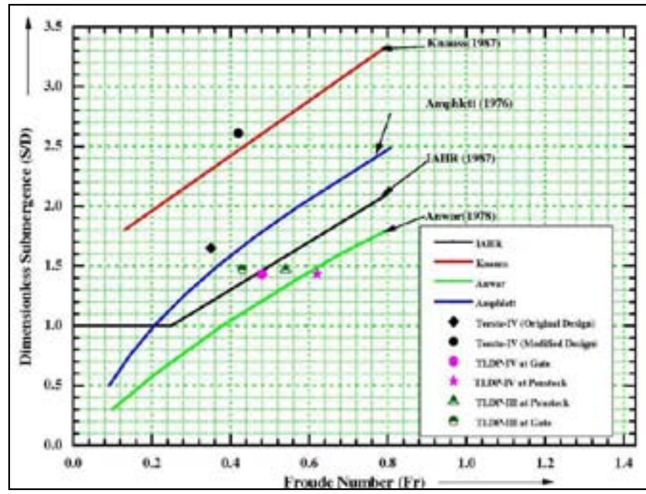

Fig. 2 : Plot of Non-Dimensional Submergence Versus Froude Number

(sand) of mean size (d_{50}) of about 1 mm and the river banks beyond chainage 420 m were reproduced. River banks beyond maximum tail water level of El. 715.26 m were reproduced rigid in the model which was not the actual site condition. The scour profiles in the river portion are indicative of depth of scour and location of deepest scour hole. It was observed from the model studies that the flow was concentrated towards the right bank due to the obliquity of the river course downstream of spillway, due to which the scour towards the right bank was maximum as compared to the left bank. Figure 3 shows the water and scour profile for gated operation of the spillway. Return flow was also observed which was taking the bed material towards the left bank thereby creating deposition in front of four spans. Photos 5 to 7 show the view of the scour pit, river bed with erodible bed material in the model and scour pattern for gated operation of the spillway for the discharge of 13000 m^3/s at FRL El. 755 m.

It was suggested to tilt the dam axis anti-clockwise by another 2^0 (Overall tilting by 5^0 in comparison to original layout) which would further improve the flow conditions in containing and guiding the ski-jump jet after the point of impingement towards the river course which was taking a left turn downstream of pre-formed plunge pool. It was also suggested to shift spillway layout towards left side by one span so as to improve the performance of ski-jump bucket and uniform flow distribution across the river width. This would also economize to great extent the excavation of steep right bank required for providing pre-formed plunge pool. The model studies for the revised design after incorporating shifting of dam complex towards left bank by one span and tilting of dam axis by 5^0 are in progress.

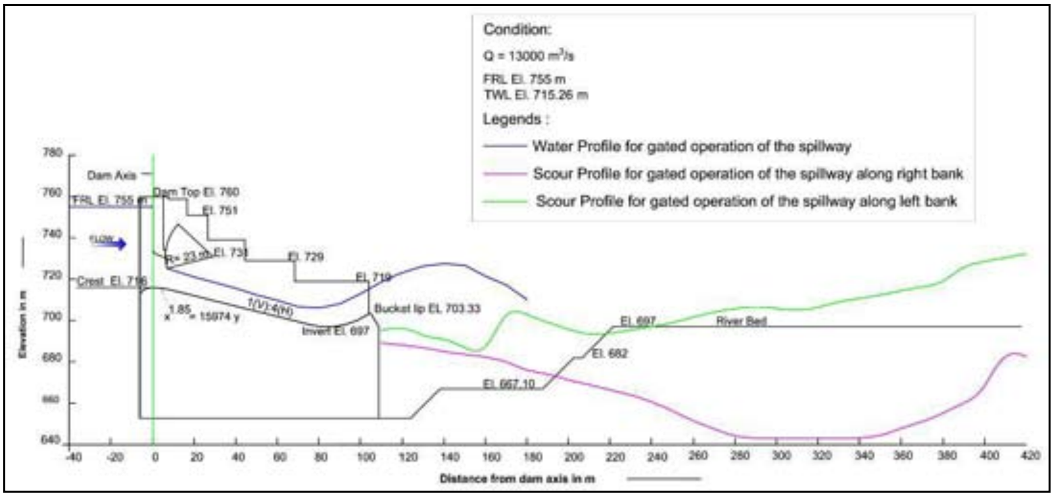

Fig. 3 : Water and scour profile for gated operation of the spillway

Photo 5 : View of scour pit in model

Photo 6 : River bed (scour pit) with erodible bed material in model

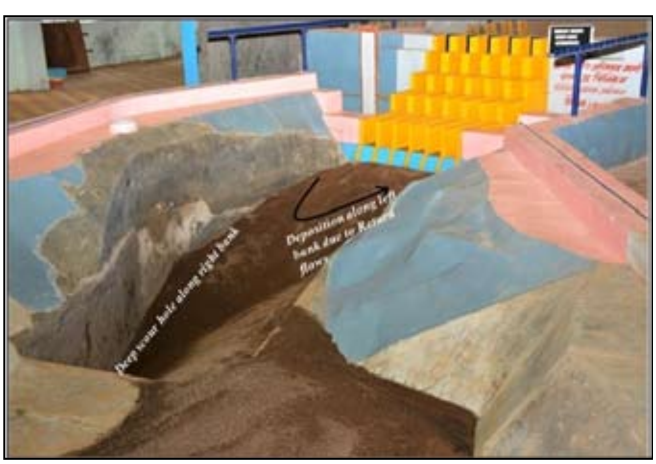

Photo 7 : Scour pattern for gated operation of spillway for the discharge of 13000 m^3/s at FRL El. 755 m

The model studies for the revised design after incorporating shifting of dam complex towards left bank by one span and tilting of dam axis by 5^0 are in progress. Figures 4 and 5 show the superimposed layout plan provided by Project Authorities & Recommended by CWPRS and General layout Plan provided by Project Authorities. Photos 8 to 11 show the downstream, upstream view of the model and performance of energy dissipator for the discharge of 6500 m^3/s and 13000 m^3/s respectively.

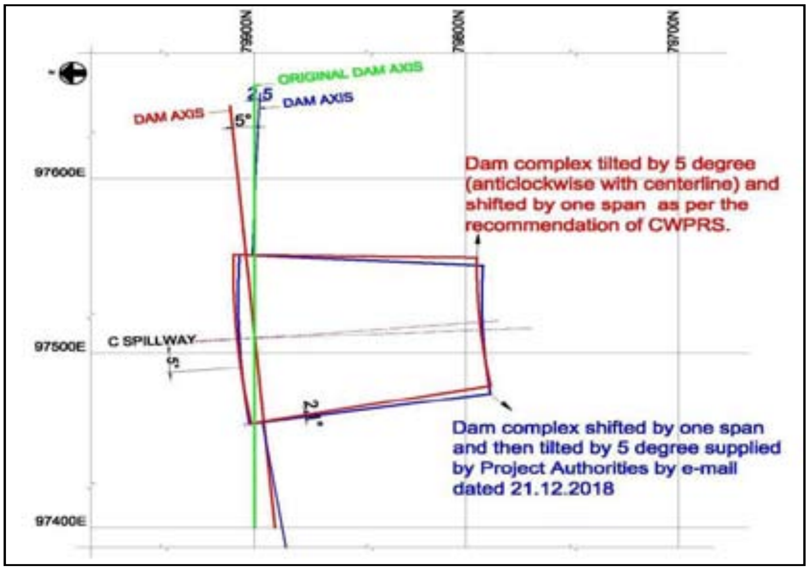

Fig. 4 : Superimposed Layout Plan Provided by Project Authorities & Recommended by CWPRS

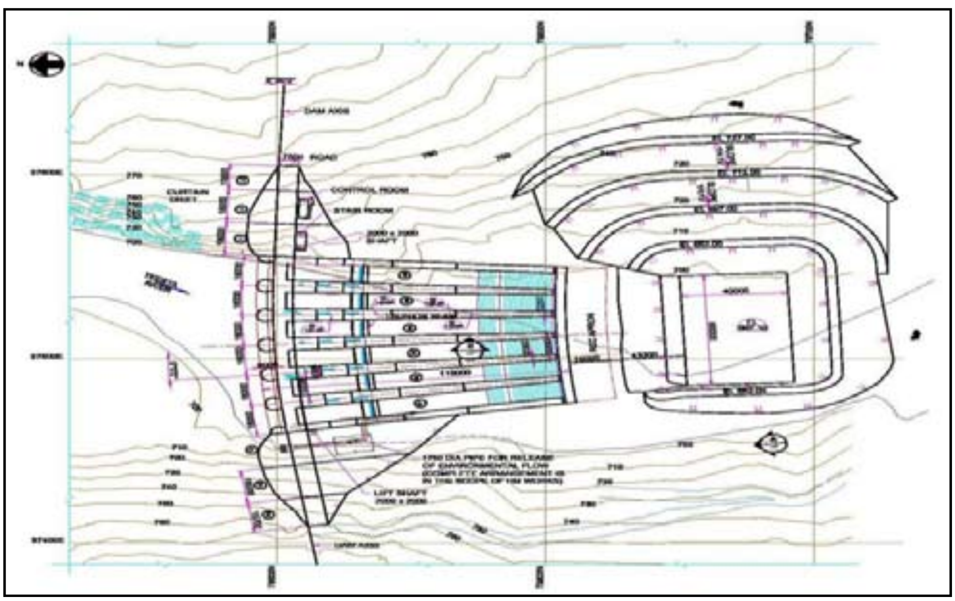

Fig. 5 : General layout Plan provided by Project Authorities

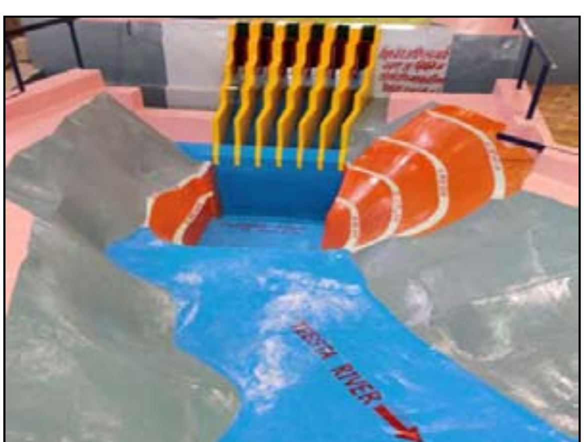

Photo 8 : Downstream View of the Model

Photo 9 : Upstream View of the Model

Photo 10 : Performance of energy dissipator for the discharge of 6500 m^3/s

Photo 11 : Performance of energy dissipator for the discharge of 13000 m^3/s

3. TEESTA LOW DAM PROJECT (TLDP) STAGE – IV, WEST BENGAL

Teesta Low Dam Project, Stage – IV is located on River Teesta in West Bengal, India. The project envisages construction of 30 m high concrete gravity dam above river bed level, 350 m upstream of the confluence of Kalikhola and River Teesta. The spillway consists of 7 spans of 11 m (W) x 17 m (H) with breast walls with the design discharge of 5,400 m^3/s at FRL El. 182.25 m. A surface powerhouse has been provided on the left bank, with an installed capacity of 160 MW, 4 units of 40 MW each with the design discharge of 787.60 m^3/s.

3.1 Selection of Energy Dissipator (Original Design)

As the tail water level of the dam was quite high, solid roller bucket type of energy dissipator was provided for energy dissipation. As the solid roller bucket was prone to damage due to accumulation of sediment lifted by the ground roller and its subsequent churning by the surface roller. It was, therefore, essential that the ground roller doesn't erode the river bed in the vicinity of the bucket. This was taken care by providing 15 m apron downstream of the bucket, 1m below the lip. The invert of the solid roller bucket in the original design was kept at El. 145.0 m, with a radius of 15 m and lip angle of 40 degree. The lip elevation was at El. 148.5 m. Figure 6 shows the original and alternative designs of solid roller buckets. Hydraulic model studies were conducted for finalizing the dimensions of the bucket based on its performance.

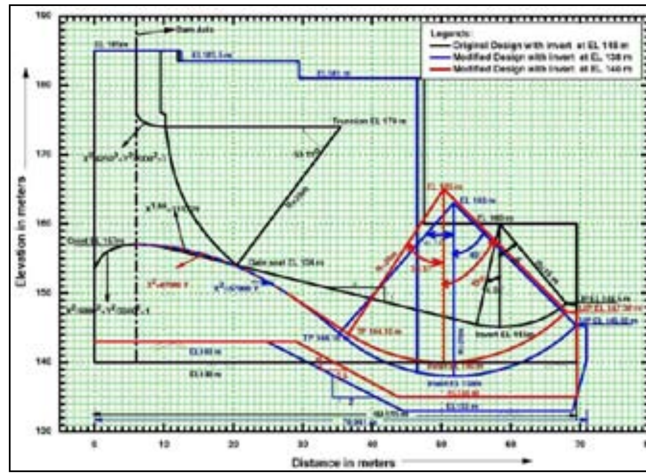

Fig. 6 : Original and alternative designs of solid roller buckets

3.2 Studies for the Original Design of Spillway and Energy Dissipator

Hydraulic model studies were conducted for the original design on a 1:70 scale geometrically similar 3-D comprehensive model. Studies revealed that the performance of the solid roller bucket was not satisfactory for the entire range of discharges as the surface and ground rollers were not forming properly. A drowned ski-action was seen with back up of flow like a hydraulic jump in the bucket. The thickness of jet entering into the bucket for 50% of design maximum discharge i.e. 7850 m^3/s was of the order of 4 m, for which the energy dissipator was designed. The discharge intensity was of the order of 100 m^3/s /m and the incoming Froude number was 4.5. Due to these hydraulic parameters the incoming jet does not turn to form the roller. Therefore, it was felt that the design of the bucket could be revised by lowering the bucket by about 5 m, increasing the radius of bucket from 15 m to 25 m and increasing the exit angle from 40^o to 45^o. Accordingly, a design of roller bucket (Alt –1) was suggested as shown in Figure 6. A crest profile conforming to equation $x^2 = 67\,y$ was suggested in place of the original equation $x^{1.85} = 11132\,y$. This alternative was incorporated in the model and it was observed that further lowering of the bucket by 2 m was necessary. Another alternative design of bucket with invert at El. 138 m (Alt-2) was studied on a 1: 45 scale 2D Sectional model.

Studies indicated that for 40% of design discharge i.e. 6,160 m^3/s and below, the performance of the bucket was found to be satisfactory as roller action could be seen. The performance of the solid roller bucket was not satisfactory for the discharges above 6,160 m^3/s i.e. 40%

of the PMF as no roller action could be seen due to high tail water level and weak submerged hydraulic jump was seen in the bucket. In view of the above observations and theoretical calculations, it was felt that improvement in the performance of the solid roller bucket could not be achieved due to high discharge intensity upto 200 m^3/s/m and incoming velocities of the order of 20-25 m/s which did not ensure proper roller action for energy dissipation. Thus, the performance of the solid roller bucket was not acceptable. Also it was considered that excessive excavation was required for the roller bucket with invert at El. 138.0 m and churning of material in the roller bucket might cause abrasion damage. Photos 12 and 13 show the performance of solid roller bucket for the discharge of 15400 m^3/s and 3850 m^3/s respectively.

Photo 12 : Performance of solid roller bucket for gated operation of spillway for the discharge of 15400 m^3/s

Photo 13 : Performance of solid roller bucket for gated operation of spillway for the discharge of 3850 m^3/s

3.3 Studies with Stilling Basin as Energy Dissipator

In view of the observations on the 2D model and the jump height analysis carried out with stilling basin floor level at El 144 m, the stilling basin type energy dissipator was considered to be more suitable as energy dissiaptor. After incorporation of stilling basin as energy dissipator with its floor at El 144 m in 1: 70 scale 3-D comprehensive model, the studies indicated that the performance of the spillway and energy dissipator was satisfactory as energy dissipation was taking place in the form of hydraulic jump for entire range of discharges. Photos 14 and 15 show the performance of stilling basin for the discharge of 7700 m^3/s and 3850 m^3/s for gated and ungated operation of spillway respectively.

Photo 14 : Performance of stilling basin for gated operation of spillway for the discharge of 7700 m^3/s

Photo 15 : Performance of stilling basin for ungated operation of spillway for the discharge of 7700 m^3/s

3.4 Raising of Power Intake

The submergence provided for the intakes was adequate, therefore, it was suggested that the intake could be raised so as to optimize the design of the intake. The MDDL was lowered by 1 m in the model and studies revealed that the flow conditions upstream of power intake were tranquil and no vortices were observed in front of intake for the entire range of discharges upto the design discharge of 787.6 m^3/s. Thus, the studies indicated that the intake level could be raised by 1 m. The Froude numbers at gate and penstock were 0.48 and 0.62 respectively which fall in the vicinity of IAHR curve as shown in Figure 2. In view of the model studies and theoretical analysis, raising of the intake level by 1.0 m was recommended as the submergence provided for the intake was found to be acceptable.

4. TEESTA LOW DAM PROJECT (TLDP) STAGE – III, WEST BENGAL

Teesta Low Dam Project Stage – III is the last but one at the fag end of the Teesta River. The project envisages construction of 32 m high barrage with total length of 140 m comprising of 7 bays each made up of about 200 m long RCC raft. The spillway consists of seven spans each with an opening size of 14 m (W) x 14 m (H) with breast walls and separated by a double pier each 3.5 m thick with design maximum discharge of 10430 m^3/s. The energy dissipator was provided in the form of a stilling basin. A surface powerhouse on the right bank has an installed capacity of 132 MW (four units of 33 MW each) with a design discharge of 693.6 m^3/s and water head of 21.34 m.

The original design of spillway consisted of a flat crest for a distance of 3.4 m on the upstream and downstream profile in the form of a slope of 1:3 up to stilling basin EL 178.0 m like a barrage. Since the head over the crest (30 m) is much more than that on the barrage, resulting in high velocity flow leading to separation, it was suggested that a crest profile conforming to the equation $x^2 = 72$ y downstream of barrage axis and an upstream profile in the form of an ellipse having an equation $X^2/3.4^2+Y^2/1.0^2=1$ may be provided. This design was accepted by the project authorities and adopted for the model studies.

4.1 Hydraulic Model Studies

Hydraulic model studies were conducted on 1:60 scale 3-D comprehensive model incorporating spillway, energy disssipator, power intake and river reach up to 725 m upstream and 675 m downstream of the dam axis. The Railey Khola nallah which meets the Teesta River just downstream of spillway was also reproduced in the model. Photos 16 and 17 show the upstream and downstream view of the model respectively. Studies revealed that the flow was free flow for the entire range of discharges with a low coefficient of discharge due to large orifice opening. The design maximum discharge of 10430 m^3/s could be passed through seven spans fully open with an upstream water level of EL 197.6 m as against the FRL EL 208 m. As such the discharging capacity of the spillway was found to be adequate. It was also suggested that the elevation of the trunnion may be raised by about 2 m and the height of left and right training walls (cellular wall) may also be raised considering bulking due to air entrainment and minimum free board required as the water profile was touching the trunnion of the radial gate and cellular walls for gated and ungated operation of the spillway. Photos 16 to 19 show the upstream and downstream view of the modeland performance of stilling basin for the discharge of 7822.5 m^3/s and 5215 m^3/s for gated operation of spillway respectively.

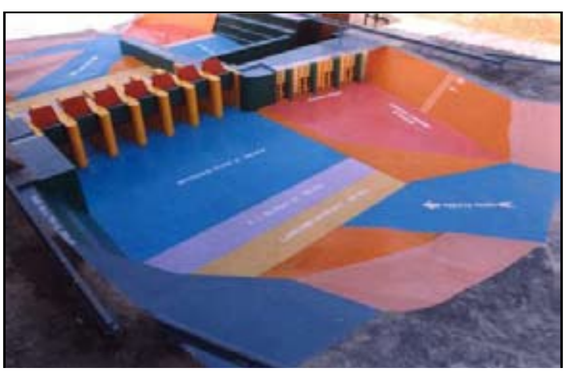

Photo 16 : Upstream View of the Model

Photo 17 : Downstream View of the Model

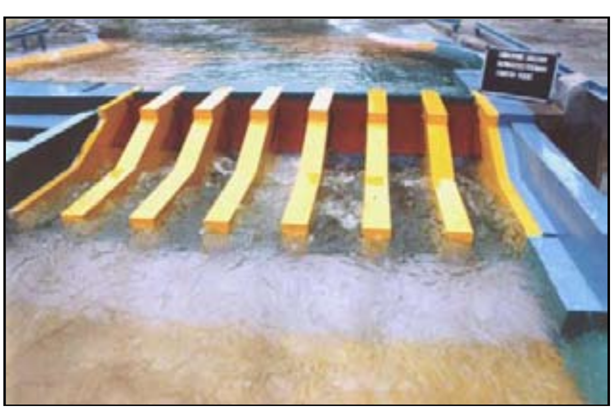

Photo 18 : Performance of stilling basin for the discharge of 7822.5 m^3/s for gated operation of spillway

Photo 19 : Performance of stilling basin for the dis-charge of 5215 m^3/s for gated operation of spillway

4.2 Tail Water and Jump Height Analysis

It was also observed that the tail water levels in front of the spillway are higher by about 2 to 3 m than those supplied by the project authorities when both the spillway and power house were operating. This rise in the tail water level was due to the deposited material brought by the Railley Khola and the subsequent high grounds in front of the spillway. The high ground in front of the spillway formed due to deposited material was dressed down varying from El. 186 m to El. 182 m resulting in reduction of about 0.5 m to 1.0 m in the tail water levels. The tail water level was also controlled by a rapid formed due to bend and constriction in the downstream. However, the water levels in the tail race channel were lower than the water levels in front of the spillway by about 2-3 m for the condition of both spillway and power house operating as the spillway and power house are separated by a divide wall. Figure 7 shows the tail water rating curves at 225 m downstream of barrage axis.

4.3 Upstream Protection Works and Flow Condition in Tail Race Channel

As the structure was being constructed on alluvial reaches, therefore, heavy protection works were required to be provided on the upstream of the spillway as in the case of barrages. Velocities of the order of 1 m/s to 4 m/s were observed along the left bank upstream of spillway with ungated operation of spillway for the entire range of discharges. It was suggested that the protection works on the left bank beyond the left training wall may be designed for these velocities.

The right bank portion in front of the tail race channel with bed at EL 179.0 m was having a sharp curve and return velocities of the order of 0.5 m/s were prevailing at Ch. 210 m with both spillway and power house operating. This sharp curve was modified and a mild curvature with a radius of 330 m was incorporated in the model. With this modification the return velocities vanished and forward velocities of the order of 0.8 m/s were observed. Hence, it was recommended that the modified curvature of the right bank downstream of tail race channel may be adopted.

4.4 Flow Condition in the Vicinity of Power Intake

Studies conducted to optimize the design of intake indicated that the intake level may be raised by 0.5 m as there was no formation of vortices. Tranquil and satisfactorily flow conditions were observed upstream of spillway and power intakes for any combinations of intakes operating with corresponding discharges and with four units operating with a design discharge of 693.6 m^3/s. Theoretical analysis was also carried out for assessing the submergence over the centre line of intake considering the areas at the penstock and gate for calculation of Froude number. It was found that the Froude number varied from 0.43 to 0.54 with corresponding S/D ratios of about 1.5 which falls in the vicinity of IAHR curve (IAHR 1987) as shown in Figure 2. Therefore, it was recommended that the intake level may be raised by 0.5 m.

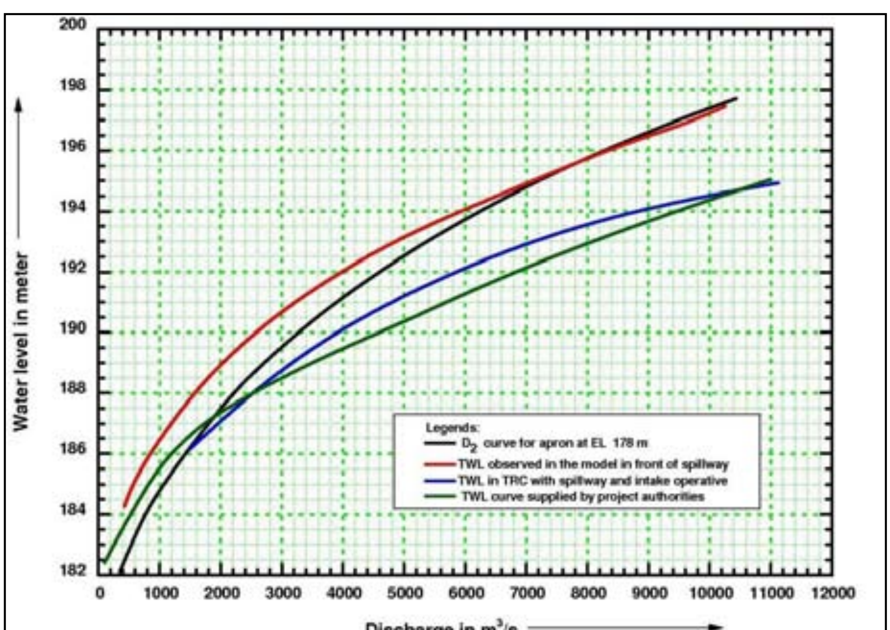

Fig. 7 : Tail Water Rating Curves at 225 m downstream of barrage axis

5. CONCLUSIONS

Hydraulic model studies are important for optimizing the efficient design of spillway and energy dissipator. The case studies of Teesta-IV, TLDP-IV and TLDP-III Projects indicated that the several modification were recommended for the original design of the spillway and energy disispator. All these modifications improved the overall performance of the spillway and energy dissipator and were very efficient and economical. Thus, the model studies played a crucial role in enhancing the overall performance of spillway, energy dissipator and other appurtenant structures based on techno-economic feasibility.

ACKNOWLEDGEMENT

The authors are thankful to the project and design engineers from NHPC Ltd. for constant interaction during the course of studies. The help of all the staff in conducting the studies and compiling the data is gratefully acknowledged.

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INCOLD Symposium on Sustainable Development of Dams and River Basins

24- 27 February, 2021, New Delhi

The key issue for ICOLD, and for the global dam engineering profession, is safety, and this was the major focus of discussions at the symposium, held both in person in Delhi, and virtually for international participants, from 24 to 27 February. It was entitled Sustainable Development of Dams and River Basins, and along with sessions on the safety, monitoring and upgrading of dams, were others on engineering challenges, climate, river basin development, and optimization of reservoir operation. Innovative technology featured strongly in the discussions, including smart monitoring systems and new developments in construction techniques. In this report we present summaries of some of the talks from selected sessions.

This international symposium would have been part of ICOLD's Annual Meeting in 2020 which had to be postponed as a result of the global pandemic. It was instead organized in hybrid format by the Indian National Committee (INCOLD) with ICOLD's Asia-Pacific Group, under the auspices of ICOLD. and in collaboration with India's Central Water Commission, die Dam Rehabilitation and Imp¬rovement Project (DRIP), and the National Hydrology Project (NHP). The major supporting organisations were the Ministry of Jal Shakli and the Ministry of Power.

1. OPENING PLENARY SESSIONS

1.1 Opening addresses

After the traditional lighting of the ceremonial candle, ICOLD Vice-President D.K. Sharma welcomed participants. and referred to INCOLD's long wait to hosl an ICOLD meeting, since the invitation had been accepted in Johannesburg, in 2016, to host the 2020 Annual Meeting. He mentioned that INCOLD would host a full Annual Meeting in 2023, but meanwhile the hybrid symposium would include around 150 presentations on a wide range of topics.

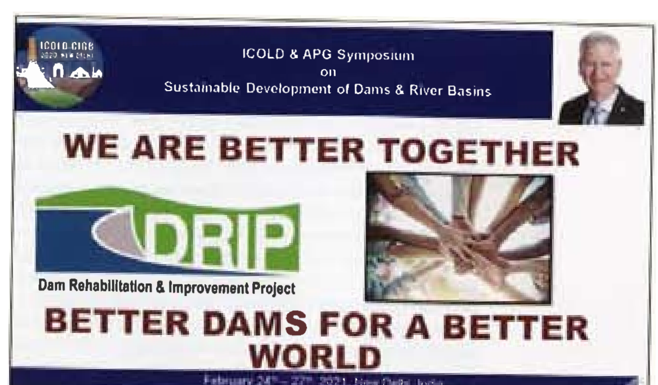
He briefly described India's portfolio of dams and hydro plants, noting that there was 50 GW of hydro capacity in operation, with a further 100 GW to be developed. He also emphasized the importance of refurbishing and upgrading ageing water infrastructure.

Hon'ble Minister for Jal Shakti.ShriShekawat (left), and D.K. Sharma, during the ceremonial lighting of the candle prior to the opening session

The inaugural address was then given by the Hon'ble Minister for Jal Shakti.Shri Gajendra Singh Shekawat, who paid tribute to INCOLD for fullfilling the challenging task of organising the symposium at such a challenging lime.

He referred to the critical importance of dams to meet needs for clean energy, waler and food security: he noted that India had the third largest number of large dams in the world, fulfilling the needs of its dense population. He quoted the government's mission to "make water everyone's business". led by Hon'ble Prime Minister Modi, and to adopt a holistic and consistent approach to water management. This was the reason that the Ministry for Jal Shakii had been formed in 2019 to bring together the former Ministry of Water Resources, River Development & Gauga Rejuvenation with the Ministry of Drinking Water and Sanitation.

He summed up the current major challenges as: limited funds being available for maintenance; climate issues; and. the need for capacity building.



During his opening address, ICOLD President Michael Rogers drew attention to India's DRIP programme for enhancing the safety of dams, which was in line with ICOLD's mission, to encourage better dams for a better world

Chairman of the Central Water Commission, S.K. Haldar. who called for a holistic approach to water resources management, to avoid conflict between water users, and deal with the challenges of climate change

Minister Shekawat said that the sustainable management of safely issues was a major priority for India, wiih the country emerging as a global leader, and he added that the recent disaster in Uttarakhand was a reminder of the kind of hazards to be faced, especially in view of the impacts of climate change. He called upon ICOLD to form a Technical Committee on Dam Emergency Action Plans.

ICOLD President, Michael Rogers, congratulated INCOLD on its perseverance in planning the meeting, during a difficult year, which had brought dramatic challenges to everyone's lives, throughout the pan-demic, INCOLD had remained strong, Rogers said, and had continued its valuable work, including the excellent DRIP (Dam Rehabilitation and Improvement Project). He noted that the water infrastructure built over decades now needed an infusion of investment to ensure safety, and he commended Indian engineers for taking responsibility for the safety of its people and its critical infrastructure, through initiatives such as the DRIP project.

ICOLD Secretaiy-General Michel de Vivo commended INCOLD, and Vice President D.K. Sharma in particular for achieving the organization of the symposium so efficiently, especially with an 'in person' element. After a brief overview of the history and activities of ICOLD (today with 104 member countries), he drew attention to the contribution of India, which had hosted Congresses in 1951 and 1979, as well as an Annual Meeting in 1998. He also made reference to the presidency of Mr C.V.J. Varma, between 2000 and 2003. India, he said, had rich engineering experience, and in recent years had accomplished much in the field of upgrading dams, as part of the DRIP initiative supported by the World Bank.

S.K. Haider, Chairman of the Central Water Commission, pointed out that the sustainable management and development of water resources was key to water security and economic growth. But he added that this economic development, involving more industrialization, population growth and increased urbanization, also led to conflict among water users; climate change was also beginning to have adverse impacts on the water sector, and so a holistic approach was needed. He briefly reviewed water resources development in India, stressing the importance of having a complete picture of the available resources within the country. He referred to the country's 5700 large dams, which were fulfilling a number of functions, and he also mentioned groundwater extraction, which had become excessive.

A. Sharma, Secretary at the Ministry of Energy, spoke of India's aims in the context of energy transition, noting that there were two big challenges: to meet the growing needs of citizens and industry, when per capita availability of electricity of the country was relatively low, and also the high dependence on fossil fuel-based generation. Sharma noted that the ambitious national target was to produce 450 GW from renewable energy sources by 2030, and he stressed that a major role would be played by hydropower, especially valuable as a balancing power, in synergy with other renewables. He also drew attention to the importance of storage schemes, noting that India had 18 per cent of the world population, but only 4 per cent of the water resources; and only about 6 per cent of rainfall was stored at present.

R.K. Singh, Minister of State for Power and Renewable Energy, commented in his address that har-nessing water resources had always been central to human lives and livelihoods. Looking back to ancient civilizations, he said, communities had settled, and life had flourished, beside rivers. The earliest dams on the Nile, thousands of years ago, he continued, had improved the lives of the people. He referred to the issue of those opposing dams, and stressed the need to devote more effort to public acceptance. While there was a need to accelerate the development of water resources, Singh stressed the Government's commitment also to environmental protection.

ICOLD Vice President Dr Ali Noorzad, of Iran, who chairs ICOLD's Asia-Pacific Group (APG), outlined to delegates the motivation, development and objectives of the Group. He noted that the Asia-Pacific countries had almost half of all the large dams in the world; developers of dams in the region shared many common challenges and issues, and so in 2002 the APG had been formed, to encourage collaboration and exchange knowledge and experience. Today there were 28 member countries, Dr Noorzad said, Activities of the Group, including the organization of meetings, training and information exchange, con-tributed to capacity building relating to the sustainable management of dams, he added.

1.2 Innovation and sustainability

The second plenary session was chaired by S.K. Haider, Chairman of the Central Water Commission, and co-chaired by D. Mukherjee, Additional Secretary, Ministry of Jal Shakti; it featured six talks by Indian and international experts on various aspects of innovation and sustainability.

A.B. Pandya, Secretary-General of ICID, began his talk by drawing attention to the uneven distribution of water resources in the country, and the insufficient storage capacity in some of the big river basins. This caused problems for food security and hydropower production. He added that while dams may be aging (a large number of Indian dams being more than 40 years old), no dam had outlived its purpose, and so new measures were urgent to restore their safety standards.

Summarizing measures to ensure sustainability, Pandya noted that India had more than 100 standards covering all aspects of planning and design, and consolidating the experience of the dam building community; engineering practices had developed over time. However, new techniques for investigation and analysis were necessary. He added that a dynamic dam safety programme should be set up, in particular to ensure continued surveillance and maintenance. It was furthermore necessary to back up techno-managerial initiatives with legislation.

Junaid A. Kamal, World Bank Country Director for India, commented that the current pandemic had shown that the world needed to be able to manage economic, health and climate shocks. Water storage, he felt, was central in managing such shocks, and thus strong commitments should be made to the value of storing water,

He felt the pandemic had been a 'wake-up call' regarding climate issues, and in this world of risks, the way in which water was managed was key to resilience of economies and the protection of communities during the recovery period. When talking of water storage, it was important to recognize that this meant a series of interventions: there was groundwater, the world's largest form of storage, watersheds, and then water infrastructure. Therefore managing storage involved figuring out how to manage all three in a continuum, and not in isolation .Management of water infrastructure, Kamal said, involved:

- the direct management of dams;
- financing of dams; and,
- investing in communities to take advantage of the dams.

ICOLD Hon. President, Dr Jia Jinsheng of China, pointed out that almost all dams could be considered safe for the traditional cases for which they had been designed, so emphasis needed to be placed on non-design load cases, such as extreme floods, earthquakes, and so on; in parallel, efforts needed to be made to decrease or limit disasters. New solutions were important to ensure intrinsic safety. He spoke of the vulnerability to extreme floods of traditional embankment dams, and then spoke of the development of the CMD dam type, which was resistant to overtopping. and was also a less expensive dam type than concrete structures. He drew attention to the design features. On the topic of mix design, he mentioned that digital mixing processes were now being introduced to ensure an optimal result.

Hon. President Prof Anton Schleiss of Switzerland, gave a talk on hydropower and dams as a catalyst for energy transition in Europe. He pointed out that a 'European Green Deal' would achieve a low-carbon, climate-resilient future in a safe and cost-effective way, serving as a worldwide example.

Phasing out nuclear and coal generation had begun, he said, with a transition to new renewable sources, mainly solar and wind, for electricity generation. However, he pointed out that as these were variable sources, they could not be expected to align with demand. This underlined the value of hydropower, in supporting the integration of the other renewables in the grid, by providing flexibility in generation, and the potential to provide storage capacity. Thus, hydropow¬er had all the characteristics to serve as an excellent catalyst for a successful energy transition.

He summarized some challenges for Europe, such as production capacity being too high, and the cost of COj certificates being rather low; and economic distortions being caused by subsidies for solar and wind power. making hydropower struggle to be competitive. Looking to the future, he predicted a strong contribution by pumped-storage schemes, and he highlighted the possibilites for installing them at existing infrastructure.

ICOLD Vice-President, Dr D.K. Sharma of India, spoke about the impact of climate change on the sustainable developments of dams and river basins. He outlined India's mission on strategic knowledge for climate change, which had heen developed by the Ministry of Science and Technology, and had the following objectives:

- the formation of knowledge networks among existing institutions engaged in R&D relating to climate science. to facilitate data sharing and information exchange;
- establishment of global technology watch groups with institutional capacities to carry out research on low risk technology selection for development choices;
- development of national capacity for modelling the regional impact of climate change on different ecological zones within Die country for different seasons and living standards;
- establishing research networks and encouraging

research in the areas of climate change impacts on important socio-economic sectors, such as agriculture, health, biodiversity, coastal /.ones, and so on;

- provision of improved understanding and awareness of the key climate processes and resulting risks and consequences; and,
- building alliances and partnerships through global collaboration in research and development.

Sharma also stressed the value of storage to combat drought and floods, and highlighted the dangers of glacial takes silting up.

Dr R.K. Gupta, Vice-President of INCOLD and Member (D&R) of the Central Water Commission, presented an overview of dam safety in India. He reported that the number of dams in India represented 10 per cent of the world's total (although only 3 to 4 per cent of global storage). There had only been 36 reported failures in the country. Most dams were relatively young, with an average age of 40 to 42 years, but he stressed that most dam failures did not relate to aging issues, but to incidents during first filling. Overtopping of embankment dams was another major cause of failure. Gupta then outlined achievements of the DRIP initiative.

He particularly commended risk-informed dam safety management, adding that the concept of rapid risk indexing had been adopted in India, to decide on priorities for rehabilitation. He also discussed the Dam Safety Bill which had been enacted in 2019, and which emphasizes the need for uniform dam safety procedures (including surveillance and O&M) throughout the country.

Another important aspect of this is that it ensures dam owners take responsibility for the upkeep of their structures, and that information on floods is shared with upstream and downstream owners, even if in different states.

Key challenges outlined by Dr Gupta in his conclusions were: reservoir siltation, the need for 'capacity building, aging water infrastructure, and the fact that many dams were not adequately instrumented, or were equipped with instruments which were not working.

1.3 Innovative financing of dams

Satoru Ueda, Lead Dam Specialist at the World Bank, welcomed delegates to the third plenary session and reported that the discussion would help to share good practice for financing new and maintaining existing dams, "We need to help develop resilient and sustainable dams and develop innovative financing mechanisms that adequately cover operation and maintenance during the life time of a scheme", Ueda said. He told delegates that the World Bank group had invested US$ 58 billion over the past 20 years for more than 430 dam projects across 90 countries. After giving some examples of these schemes in different regions. Ueda spoke of the significant resources published by the World Bank relating to dam safety and maintenance. These resources are available on the Bank's's website, he added.

Marcus Wishart, Lead Water Resources Management Specialist, World Bank, then spoke on innovative financing specifically. "There are a number of mechanisms used by the World Bank", he said, "which all start with some common fundamentals for financing to provide projects with a solid foundation". These include governance, regulatory oversight, and technical and financial performance, he added. Wishart emphasized the importance of full life-cycle cost analysis for a project, beyond construction and commissioning and including operation and maintenance stages.

He noted that until the 1990s, investments were focused to a greater extent on newly constructed schemes, but more recently funding had shifted to aging infrastructure and rehabilitation works, he said. Scheme usage had also become more multipurpose, he said, with irrigation, water supply, flood control and hydropower being the main functions. Reflecting on the multipurpose nature of projects, Wishart identified three revenue sources for funding schemes:

- tariffs (for example, from hydropower, irrigation, navigation etc.);
- taxes (subsidies, funds and grants) and;
- transfers (for example, budget payments, external grants, etc).

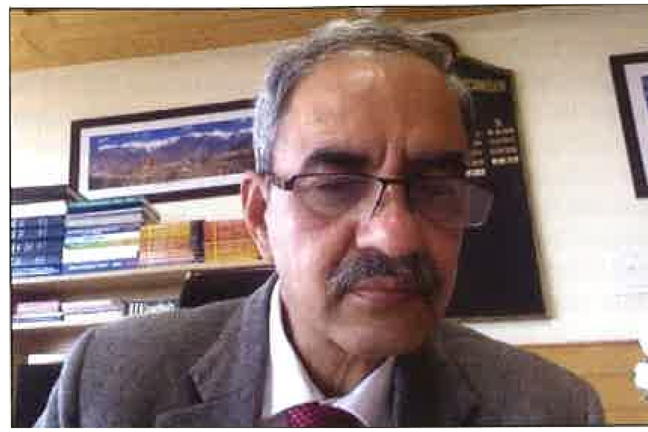
These three sources "constitute a cash flow which can be used to leverage repayable sources such as bank loans, equity investments and bond purchases", he explained. Alongside this, the World Bank may help provide credit enhancement, grants, advisory services and risk insurance to support projects, Wishart concluded.

Case study presentations were given by speakers from the USA and Australia, and regional projects from India were also described. In a presentation by Darren Protulipac (Project Manager, Regional Rusumo Falls Hydropower Project), he explained his project is a multipurpose scheme benefiting Burundi, Rwanda and Tanzania, currently 76 per cent complete. Protulipac explained the various FIDIC contract types used for civil works, electro-mechanical works and the owner's engineer. He reported that approximately 10 per cent of generation revenue was to be spent on operation and maintenance.

2. IMPACTS OF CLIMATE CHANGE: SUSTAINABLE DAMS AND HYDRO DEVELOPMENT

This session was chaired by ICOLD Vice-President, Dr. D.K.Sharma.

Dr Saeid Yousefl, of Iran Water and Power Resources, who felt that climate change adaptation represents an opportunity for hydropower in Iran



ICOLD Vice-President D.K. Sharma, chairing the session on climate change

C.R. Donnelly, Hatch, Canada, reported on the importance of glacial water for global hydropower production. As much as 69 per cent of the world's fresh water is stored in glaciers, he said. Donnelly pointed out that climate change would create significant changes to this frozen resource, including thawing of glaciers and permafrost, and potential increased natural hazards. "Typically, glaciers provide a battery type function, as water that becomes frozen during winter is released during summer", Donnelly said. He identified case studies of hydropower schemes in Europe, Asia and Latin America which rely on glacial runoff and noted that in the long term, three quarters of glacial sites may be ice-free by 2050; he said this loss could be mitigated by constructing dams to expand lakes. "Constructing engineered dams at 1000 of the approximately 1K5000 glaciated sites could provide up to 31 per cent of the total energy that is theoretically available from the entire portfolio", he added.

Daniel Kerres of Bjoernsen Consulting Engineers. Germany, described the legal frameworks for flood control in Europe, most notably the Water Framework Directive and the Habitats Directive. These Directives aim to ensure a project does not adversely affect river basin management and that any impact to a protected area be functionally restored. The significant legal burden presented by these directives have, Kerres said, created long delays in the planning process and caused considerable project risk.

A. Joshy of KWRD, India, discussed the role of flood control dams in managing extreme climatic events in southern India. He reported on the severe flood events in 2018 which had affected 1.2 million people, and killed 400, in the state of Kerala. In response, a programme of dam building and rehabilitation had been undertaken (in part through the DRIP scheme), Joshy said. This work has, he added, led to reduced flood depths during later events in the Periyar basin of up to 3.26 m.

Dr Saied Yousefi, of Iran Water and Power Resources Development Company, gave a talk in which he described climate change adaptation as a unique opportunity to define a new vision for hydropower development in his country. There would be a greater focus on renewable energy, and particularly on hydropower in view of its role in flood control, with reservoirs providing a vital buffer to help absorb runoff variability caused by unexpected flows.

3. MODERN TECHNOLOGIES IN SURVEY AND INVESTIGATION

Dr Sanjay Rana of Parsan, India, introduced the session on modern technologies in survey and investigation for sustainable dam development. He spoke of the fact modern and new technologies were often faced with resistance from staff. "There is resistance to adopting technologies because of uncertainty and fear of failure", he said. Driving this hesitancy is often a concern for job safety and a preference for lower risk, familiar technologies. When considering technologies for geophysical monitoring and site investigations, Rana identified three main issues. First, the adequacy of investigation of underground projects in terms of quantity, quality and budget. Second, the time available for investigations prior to construction, and third, the technological improvements required by new specifications and standards.

Mateja Klun, University of Ljbljana, Slovenia, reported on a vibration monitoring investigation at the Brezicc dam in Slovenia. Klun noted that the dam community in Slovenia had largely transitioned from the phase of building and designing dams to a phase of maintaining and extending their use. Reflecting this transition, dynamic monitoring of hydromechanical equipment, using laser doppler vibrometry and accelerometer instruments, had been undertaken to test the effect of various operational regimes on the Brezice dam structure. The results had revealed that additional accelerometers should be fitted

Maleja Kiwi, University of Ljbljana, Slovenia, discussing vibration monitoring investigation at the Brezice dam

in the powerhouse and additional measurements taken for temperature, humidity and joint openings.

Yukako Mogami, West Japan Engineering Consultants, Japan, presented an overview of the 'Follow-up System for Management of Dams' (FUSMOD) and its achievements. The scheme, first tested in 1996 before wider adoption in 2002 by the Ministry of Land, Infrastructure, Transport and Tourism, aims to provide post-construction assessments of dam projects, in part using environmental impact assessments. Mogami noted that achievements of FUSMOD to date included improved operating and survey methods, appropriate countermeasures to invasive species and providing insights to help assess the contribution of various schemes to local and regional economies.

Juan Vargas of AECOM, Mexico, reported on subsur-face investigations at a dam located on the Mexico-USA border which is founded on Karstic terrain. He said the concrete embankment dam has been constructed between 1963 and 1969 and fitted with 16 tainter gates. An integrated geological and geophysical approach has been adopted to investigate under seepage and through seepage at the site. Vargas reported that techniques including dye tracing, exploratory boreholes, water pressure tests and 3D geological foundation modelling had been used. "Sequencing investigations are key to optimize the use of the various techniques, as some are more valuable from a broad perspective such as for general seepage conditions, while others are more valuable when targeting very specific information, such as borings", Vargas said.

P.S. Kunjeer, CWPRS, India, stressed the importance of sedimentation when assessing reservoir capacity. He spoke of periodic assessments undertaken at the Indira Sagar project using advanced hydrographic survey techniques, including bathymetric surveys as a direct method for assessing sediment deposition and distribution. Single-beam and multi-beam bathymetric surveys had revealed that the reservoir (first commissioned in 2005) had already lost between 6 and 7 per cent of its original 12.21 x 1012 m^3 capacity.

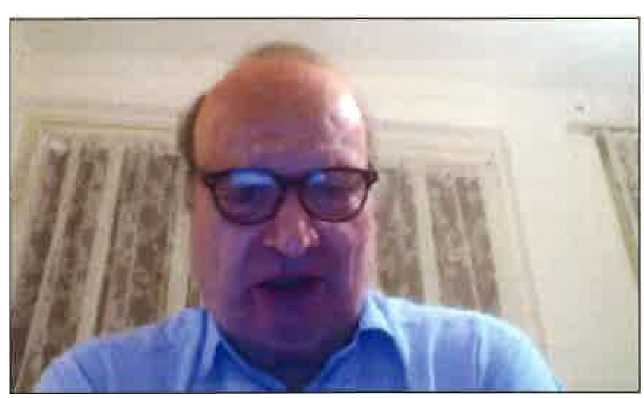
Masayuki Kashiwayanagi of EPDC, Japan, described earthquake monitoring at dams in Japan. He noted that this monitoring provides validation data for the design of dams and proposed that understanding of the dynamic behaviour of dams during earthquakes be used to analyse the safety of existing dams. "The deformation behaviour of dams is largely unknown during earthquake events", he said. To address this, Kashiwayanagi had used GPS positioning with a resolution of 2-5 mm to monitor changes. "While concrete gravity dams behave selectively in the upstream-downstream direction as 2D structures, as a result of the stiffness of the dam concrete and rock foundations, the behaviour of embankment dams is 3D attributing to dilatancy characteristics and the relatively low stiffness of materials and rock foundation", Kashiwayanagi concluded.

4. DAM SAFETY AND RISK

4.1 Advances in dam safety, risk assessment and management of seismic hazard

Dr. Martin Wieland, AFRY, Switzerland, chaired the first session on this topic, and also presented a paper on advances in dam safety, risk assessment and management of seismic hazard. Wieland reported that for dam safety to be credible, a comprehensive dam safety concept must be used and this should include structural safety, dam safety monitoring, operational safety and maintenance and emergency planning. "Each of these four elements is equally important", Wieland said. In a separate paper with greater focus on seismic safety, Wieland said that three key functions that a dam must serve during and after seismic event included:

- retaining the reservoir (to protect against a catastrophic release);



Dr Martin Wieland of Switzerland, who chaired the first session on dam safety and risk, and also gave a talk on seismic safety

- controlling the reservoir (such that spillways and outlets can still be operated following the event); and,
- lowering the reservoir (for repair works or to increase safety if the structure is damaged).

Mohan Acharya of Environment and Parks, Canada, underlined the need for a dam safety management programme in Nepal. A key driving force for this, he said, was the rapidly changing climate in the Himalayan region. Potential risks included: increased, intense rainfall; more frequent and extreme floods; increased risk of overtopping; and, increased landslides. Owners needed to have a comprehensive understanding of regulatory requirements he said. "An effective emergency management plan is a low-cost management tool for dam owners. Developing and testing an emergency management plan is a key requirement of an effective dam safety management programme", Acharya said. He added that the level of effort required for dam safety management depended on the consequence classification of dams.

Lijun Xue, of PowerChina, presented a stability analysis for the left abutment of the 305 m-high Jinping I concrete parabolic double-curvature arch dam. He reported that complicated geological conditions had been encountered during excavations that had started in 2005 and were completed in 2009. Since first impoundment in 2014. the reservoir had been filled seven times, and slope stability was reported to be good. The left bank slope deformation was predicted to last until 2034, Xue noted "The long-term deformation will have litlle effect on the arch dam and the slope is stable. However, the effect of long-term deformation of the slope is complex and still requires further study taking into account concrete creep, dam temperature rise, visco deformation and other factors", he said.

4.2 Safety and risk -2

The chairman for the second session on die topic, was Gulshan Raj, CDSO, CWC, India, who presented an overview of hydro-mechanical rehabilitation under the DRIP initiative. Several factors were presented as the cause of equipment being in a poor condition. These included general aging, gate leakage, lack of maintenance, and inadequate design and planning. To address this, remedial works. Raj said, included the replacement of electrical control equipment, the repair or replacement of seals and wheel components, the over-hauling of gate and hoists as well as surface preparation and painting. In total, more than 100 dams have been upgraded, including the spillways of four schemes, access to hydro-median teal equipment at 10 schemes and the replacement of hydro-mechanical equipment at a further 47 schemes. Raj concluded.

K. Sudhakar, National Institute of Rock Mechanics, India, reported on geodetic structural monitoring of concrete gravity dams using a case study of the 163 m-high. 1210 m long. Sardar Sarovar scheme in India. He noted that geodetic techniques had traditionally determined the absolute displacements of selected points on the surface of an object using triangulation or trilateration methods. However, newer technologies, including OPS, Lidar and optical systems were now replacing these. Sudhakar noted that DGPS (differential global positioning system) technology was used to evaluate the Sardar Sarovar scheme. Results of this investigation revealed that deformation at the dam varied from +10.44 mm to -14.13 mm. These variations were largely responses to changing reservoir levels, he noted. Sudhakar recommended the use of advanced geodetic technology (such as DGPS). especially when measuring large distances.

Bob Leitchol Woolpert. US A, described some of the key similarities between asset management and dam safety. Thc practice of ISO 55000-aligned asset management and the modern practice of dam safety are more aligned than they are different", lie said. "There are potentially significant benefits of considering the two practices in an integrated fashion", Lilch added. He presented examples of past incidents in the USA and UK that had helped shape

Darren Mukwanason, UEGCL, Uganda, presented the steps taken to evaluate dams in his country.

Veer Raja Malyala, AECOM, India, described remedial works at a scheme in the USA.

both disciplines, and obseived that both approaches sought to understand and document underlying causes of failure; both aimed to bring objectivity, repeatability, consistency rigor, and discipline. "Dam safety", Leitch commented, ''tends to have a greater focus on life safety and eco-nomics, while asset management tries to articulate all forms of benefits that are of value to an organisation". In conclusion, he proposed that it could be argued that dam safety is a specific case of applied asset management. "There is a growing awareness of synergistic possibilities and a number of potential benefits from better coordination and integration between the two practices", he said.

4.3 Safety and risk-3

The third session on this topic was chaired by D. Biju of IDRB, Kerala state, India, who also gave the first talk. He discussed the major floods which had occurred in his state in 2018, and a risk assessment study which had been carried out as a result, and had indicated the need for more flood control dams.

Stefan Hoppe of Ofiteco, Spain, then described a dam monitoring and data management system which could be used by mobile devices; such as tablets. He first gave some general observations about monitoring systems, for example, that if a system was not working properly, it was completely useless. Care should be taken to take readings in the right way, he pointed out, and to analyse data periodically, for use in a dam safely management system for decision making.

Typically, problems could occur when technicians were unsure what to read, and how often. Or there could be confusion about whether units were decimal or imperial, or confusion about the direction in which the sensor was placed. He also drew attention to problems with data processing, such as using an incorrect formula, transposing digits or making mistakes when transferring hand-written notes to a database. Hoppe also stressed the importance of maintaining instruments in a good and clean condition, and of sensor calibration. He advocated managing and sharing data on a monitoring platform which allowed for collaboration, and could encompass all tasks, such as data acquisition and storage, evaluation, and then making optimum use of findings.

Hoppe pointed out that mobile devices could help to organize workflows and improve data quality. By making updated data available on site, sensor calibration and data reading were improved. He added that a centralized monitoring platform would help to manage nil information, and optimize the evaluation process. It would combine monitoring data with results from sensor calibration.

P.V. Timbadya, of the Sardar Vallabhbhai National Institute of Technology in Gnjural, India, described a dam break flood wave analysis conducted for the Ukai dam on the Lower Tapi river, India. A ID HD MIKE 11 model had been created and calibrated, to analyse the dam break scenarios, and then a 2D HD model in MIKE 21 had been used to simulate flood wave propagation. The depth of flood water which would reach Surat city had been calculated.

Hussein Roshanomid of AFRY, Switzerland, presented a paper co-written with Dr Martin Wieland on safety aspects of the 156 m-high Rudbar Lores tan rockfilt dam. located in a narrow gorge in Iran. He described the construction of the dam, which had included a 5 m-wide fine sand filler tit both dam faces, widening to 10 m close to the abutments, which had been provided to protect the structure against internal erosion. The possibility of arching effects in the core, and the formation of cavities at the core-abutment contact zone had been minimized by a 5 m-wide plastic contact clay zone. Rock surface treatment had been carried out, and the abutment slope had been limited to 70°. Standard instrumentation with an automatic data acquisition system had been provided, and a microseismic network had been provided to monitor reservoir-triggered seismicity. He reported that no unusual seismic activity had been recorded since impounding in 2016.

5. REHABILITATION TECHNOLOGIES TO ENHANCE SAFETY

5.1 Innovations and Adaptations in Intakes, Spillways and Gates

Darren Mukwanason. UEGCL, Uganda, presented a risk-based stability evaluation of the upper spillway middle pier at the Isimba hydro scheme. The scheme is equipped with four units wiih a total installed capacity of 183 MW. Following visual inspections, analysis of instrumentation readings and a focused dam safety risk workshop, two polenlial failure modes had been identified. These were, pier flexural failure and uplift of the stilling basin. To help mitigate these risks, interim vibration reduction measures had been established and these include limiting the opening of upper spillway radial gates to less than 70 per cent of their maximum and, during flood conditions, discharging from both upper spillway outlets. As ongoing and future measures, Mukwanason recommended that regular visual inspections of the spillway be undertaken and additional instrumentation should be considered. Further, a stability analysis should be carried out, he added.

Santhosh Puthenpurayil, Irrigation Department of Kerala, India, presented a paper on the control of seepage at the Pathazhakkundu earth dam in Kerala, India. The project was commissioned in 1978 but is not now functioning because of excessive seepage. Puthenpurayil noted that at full reservoir level, whirlpools were visible. He explained remedial works recently completed included extension of the upstream blankets, curtain wall and scarification of the upstream earth portion, as well as refilling and compacting with riprap. Following successful completion of all remedial works, Puthenpurayil reported mat for the first time since 1980, the reservoir had been filled without seepage occurring, in late 2019.

Another paper focusing on seepage control, by Vigneswaran Ramaraj of CWPRS, India, presented a case study of the 705 m-long Domihira dam, where grouting of the masonry blocks had been undertaken following extensive laboratory testing. About 1532 tonnes of grout had been applied, in three stages, to the spillway and this had successfully reduced seepage from pre-application rate of 300 l/s to a post-treatment rate of 60 l/s, Ramaraj said.

Veerraja Malyala of AECOM, India, described the remedial design of a Barrel arch dam in California following a structural integrity evaluation undertaken by US ACE/EPA. Malyala described the geotechnical investigations which had included six borings down to a depth of 22 ft (6.7 m) and had revealed very loose upstream tailings with low shear strength, potentially liquefiable. Furthermore, they had contained arsenic, cyanide and other heavy metals. The recommended solution, adopted in mid-2018, had included the provision of an earth embankment consisting of downstream buttress cellular concrete with a stormwater drainage system. This solution had selected against three alternatives and the project had been successfully completed in December 2018, Malyala said.

5.2 Cause of damages and structural performance evaluation of dams

Alan Warren of Mott MacDonald, UK, discussed the Toddbrook reservoir spillway incident and emergency response, following a flood at the English scheme in late July 2019. The 310 m-long, clay core embankment dam had been constructed in 1831, with a 41 m-long primary spillway and 76 m-long secondary spillway. Warren said it is thought that crack injection caused uplift of slabs and ultimately spillway failure after a period of significant rainfall. He noted that 1500 people had been instructed to leave their homes temporarily, while 1.1 x 106 m^3 of water was pumped from the reservoir over a period of four days; within six days the reservoir level had been reduced by 12 m. Interim safety measures were reported to include a replacement auxiliary weir keyed into the core and a temporary lining of the central spillway chute. For further information of this event, see H&D Issue 1, 2021.

Mikhail Goncharov, National Research University, Russia, presented evaluation methodologies for the permitted risk level of aged dams. The method proposed by Goncharov adopts an ordinal scale for expert assessment of the dam condition based on a proposed condition index, such as that given in a descriptive database. Using this methodology, 14 'old' dams were assessed to establish acceptable risk.

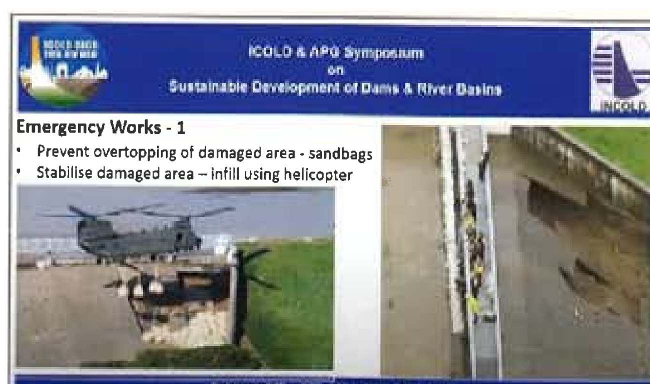
5.3 Modernization and optimization of ageing dams

This session was chaired by S.P. Bansal, Director -Civil, at SJVNL, India.

Among the speakers was Cyril Guidoux of GeophyConsult, France, who presented a paper co-authored with colleagues from EDF on the use of a fibre-optic leak and seepage detection system below a geomembrane at the Upper Bhavani dam, India. His talk demonstrated that fibreoptics, equipped with heating units, were accurate and cost-effective systems for detecting, locating and quantifying leakage and seepage below membranes.

Dr Georgette Hlepas of the US Army Corps of Engineers (USACE), USA, took a retrospective look at the success of the project three years ago to restore the safety of Mosul dam in Iraq, following the damage caused by

Alan Warren of Moll MacDonald, UK, who described the incident at the Toddbrook reservoir in 2019



A view of the emergency measures taken to stabilise the site, and to prevent failure of the dam, which he described in his presentation armed conflict in the region, when the dam had been showing signs of distress, with sinkholes forming, and one of the two bottom outlets out of operation. USACE had overseen a major grouting project, undertaken by Trevi of Italy, which had involved 4850 drilled holes, and about 39 227 m^3 of grout.

Three years after the emergency project, Hlepas said, there was a better understanding of the foundation conditions. It could be concluded that Mosul dam had been exceptionally well designed to withstand its problematic geological foundation problems. Key points had been the zoning of the embankment, filters, extensive foundation treatment and an aggressive initial grouting programme. The historical information had been a key factor in influencing the latest risk assessment.

R. Haselsteiner of Bjoernsen Consulting, Germany, gave a talk on the hazards associated with trees being located close to dykes, and drew attention to some major floods and hurricanes in Germany where trees had exacerbated damage. He pointed out that problems could be caused as a result of root penetration, the trees limiting access to the dykes, or the likelihood for animals such as foxes to dig holes close to the trees. He stressed the need to take this into account in risk assessments of levees. Haselsteiner also spoke of codes and guidelines which were being developed for levees with trees either on them or nearby, which set out criteria for the design of the levees and cases when trees should be removed from the area.

5.4 Modernization and optimization of ageing dams - 2

In another session on refurbishment which focused on the modernization and optimization of aging dams, chaired by K. Vohra, Member, CWC, India, a talk was presented on behalf of Nitya Nand Rai, Director of CWC, giving details of storm analysis and hydrological model studies which had been carried out for a review of the design flood of the Ukai dam in Gujarat. The point was stressed that for estimating PMP depths for such a large area as this case, it was essential to have a very good estimate of the PMP for each sub-catchment; for this, the influencing factors of storm centering and re-orientation should be decided carefully and confirmed to a reasonable level.

K. Vohra, of the Central Water Commission, invites discussion during the session he chaired on the modernization and optimization of ageing dams.

M.S. Hannumanthappa of CWPRS, Pune, India, spoke of studies on interpretation of monitoring data to ensure the long-term reliability of gravity days, taking as an example the Indira Sagar dam in his country. He stressed the importance of instrumentation for monitoring, noting that most dams in India were not adequately instrumented, or had instruments installed which were not in good working order; therefore, analysis and interpretation could not be done properly. He called for a centralized dam monitoring cell, to improve the situation. Turning to the case of a dam which was well instrumented, he referred to the 92 m-high Indira Sagar dam on the Narmada river in Madhya Pradesh, which has a storage capacity of 12.22 x 109m^3. Dam monitoring had begun in 2003, and as well as regular processing of the data, regular site visits were made to check on the instruments. Any missing data were obtained by interpolation or experience, arid as a result, there were clear indications of the dam's performance from 2003 to the present.

Dr Pavel Zvanut, of the Slovenian National Building and Civil Engineering Institute, described an extraordinary event at the 33 m-high Mariborski otok dam, part of a cascade development of run-of-river schemes on the Drava river. In December 2017, the steering system of the upper spillway gate management device had malfunctioned, causing an overflow of 230 m^3/s between the gates, and severely damaging the upper spillway gate and the concrete beam of the crane rail on the dam crest. Instrumentation to measure deformation and groundwater was able to provide valuable information on the incident. Zvanut then described a €2 million repair project, which he described as technical demanding. Auxiliary spillway gates had been installed, to enable the required lowering of the reservoir level, and then damaged concrete had been restored and repairs carried out to the gateworks. The work had extended the service life of the spillway for 30 to 40 years, vanut said.

5.5 Underwater inspections and maintenance

Chairman Dr George Darbre of Switzerland, in his introductory presentation, stressed the importance of inspecting underwater structures which tended to be overlooked as they were not visible. He stressed that underwater inspections should be carried out at regular intervals as part of a regulatory framework, so that components which had aged or been damaged by sediment, for example, could be repaired or replaced.

He advised on things to watch out for particularly, for various types of dam, as follows:

The Mariborski otok dam on the Drava river in Slovenia; Dr Pavel Zvanul described an incident in 2017 when the gateworks failed, necessitating a €2 million repair project

- Concrete and masonry dams: general condition of the material: occurrence of cracks; and. damage along joints (between blocks and at points of contact with the abutments).
- Embankment dams: condition of riprap or facing (asphalt of concrete): settlement or inception of sinkholes; and. cracks and openings at contacts with intakes, inlets, conduits, and so on.
- Run-of-river dams: displacements and deformations of dams and foundations; water infiltration in concrete or masonry; and, damage or ageing of steel or electromechanical components.
- In general: Sedimentation in front of intakes or inlets; and, the condition of intakes and inlets (corrosion, clogging, and so on).

While he acknowledged that it was a "more comfortable approach" to conduct inspections after drawing down the reservoir, he pointed out that this was not always practical, and disadvantages included the release of sediments downstream, the time involved, and the loss of production in the case of a hydra scheme. Darbre added that there should be particular caution if drawing down a reservoir at a high arch dam, and that its stability at low water levels would need to be verified.

Turning to the underwater inspection methods, Darbre pointed out that the use of divers would limit the depth of the inspection; water turbidity could impair vision, and the process was also time-intensive, as the duration of each dive had to be limited. When using remotely operated underwater vehicles, on the other hand, inspections at large depths would be possible. turbidity would not be a problem, there would be no impact on hydro production, and the process would be less costly than drawdown.

Several case studies followed on underwater inspections, maintenance and repairs. P. Sasikala of the Tamil Nadu Water Resources Department discussed non destructive testing for leakage at the Shola dam in Tamil Nadu, India, which is part of the Parambikulam Aliya projeci. She discussed the use of ground penetration radar, electrical resistivity imaging, and sonic tomography, and also the use of remotely operated vehicles for underwater scanning,

S. Uchida of the Japan Water Agency described the use of a remotely operated vehicle to inspect Ihe discharge facilities at the Takayama and Hiyoshi dams in his country. Tian Jiugjie, of the China Yangtze Power Co, spoke about underwater maintenance of the 'water cushion pool', a form of stilling basin at the Xiluodu dam, and the materials used to repair minor damage, such as abrasion and cracking. Another speaker from China, Xie Huaidong, discussed the underwater inspections of the lailraee area of some Chinese dams, including Gezhouba and Three Gorges. He described the use of a multi-beam sonar system, and he added that this was the first lime a detailed underwater inspection had been carried out at Three Gorges since the initial operation of the scheme.

K. Palaninppa. from the company IROV Technologies Pvt Ltd. in India, introduced some developments in ROVs developed by his company, including high density cameras, and high intensity illumination. In particular he described applications of an innovative system called EyeRov.

A. Scuera of Carpi. Switzerland, described the process of underwater repairs using flexible geomeimbranes. and presented some case studies of installations around the world, at projects with a large range of characteristic.

5.6 Surveillance and monitoring

The final session on aspects of rehabilitation was chaired by Sanjay Srivastava, Chairman of BBMB, India.

Jonathan Chambers of the British Geological Survey, UK, presented a paper, co-authored by colleagues at HR Walliugford and SOCOTEC Monitoring, UK, on a newly developed long-term monitoring system to detect change in earth embankment dams. He explained that it is based

Chairman of the Bhakra Beas Management Board, Sanjay Srivastava, introducing the session he chaired on surveillance and monitoring of dams on electrical resistivity imaging (the resistance of the ground to passing electrical current), whereby electrodes are connected to an imaging box. The system, which can be remotely operated, is sensitive to geological variations, changes in groundwater saturation and quality and temperature, Chambers said. He described the process of taking field measurements, using the case study of the Llangynid canal embankment in Wales, where it had been used for leakage detection. He said that there were not yet case studies relating to dams, but for the future, he foresaw the use of the system for monitoring the internal conditions of large embankment dams.

Godfrey Rwakafunjo, of UEGCL, Uganda, discussed improving dam surveillance and monitoring with particular reference to countries with no legal or regulatory dam safety frameworks. He said that in his country, the monitoring and surveillance programme for dams was benchmarked on that of Switzerland (the guidelines of the Swiss Federal Office of Energy) and on ICOLD guidelines. His talk focused on the case study of the 26.5 m-high, 1.6 km-long, Isimba composite dam, which had been commissioned in 2018 in his country. Global statistics showed, Rwakafunjo continued, that the highest percentage of dam failures occurred within the first five years of operation, so the two-year old Isimba scheme was considered to be at this critical stage. He then outlined the surveillance and monitoring programme for the scheme, which involved visual inspections daily, weekly, and at some other times as prescribed in the dam safety manual. These would include inspections by a panel of experts. There would also be regular functionality tests, for example monthly checks on the spillway gates. Two diesel generators were available on standby for emergency monitoring of the gates, and these would be operated for 30 minutes each month. The spillway gates would be opened once a year. Rwakafunjo gave details of the extensive instrumentation system installed at Isimba, which had 293 monitoring points. Rwakafunjo said that in countries where no legal framework existed for dam safety, best practice should be customized from a country with strong regulations.

6. DAM ANALYSIS AND DESIGN

Chairperson Ms Neeta Arora of SMEC, India, spoke of the advantages and disadvantages of computational fluid dynamic modelling. CFD modelling offers good understanding of root causes and possible solutions for flow problems at hydraulic structures she said. She added: "Once a baseline model environment has been established, different flow events and geometric arrangements can be tested rapidly to gain a comprehensive understanding under different operating scenarios". However, limitations of CFD modelling included long run times for even ID multi-year reservoir sedimentation models. Furthermore, Arora continued, "simulation of bed load and its movement in flood conditions is not accurate and provides indicative results only".

Ronald Haselsteiner of Bjoernsen Consulting Engineers, Germany, spoke about unsteady seepage flow through levees in the lower Rhine region. He presented the results from modelling saturated and unsaturated soils and had found that unsteady seepage modelling provided more realistic porewater pressure conditions for levees with zones and materials of low permeability. More generally, Haselsteiner also reported that unsteady seepage modelling shows more realistic seepage conditions than if using steady state modelling.

7. INNOVATIVE CONSTRUCTION METHODOLOGY AND CONTRACTING PRACTICES

R.K. Vishnoi of THDC, India, described a flood event during the construction of the World Bank-funded 444 MW Vishnugad Pipalkoti scheme in Uttarakhand, India. Following a period of very heavy rain in June 2013, there had been a sudden increase in water levels in the

T. Miyazaki of the Japan Water Agency, speaking of the use ofCIM modelling during the construction phase of the Koishiwaragawa dam in Japan

Alberto Scuero of Carpi, Switzerland, who gave examples of applications of geosynthetic membranes at dams

Alkaknanda river basin which had led to extensive river bed and toe erosion, landslides at various locations, and transportation and deposition of sediments downstream. To address the possibility of future events and to avoid further site damage, the upstream cofferdam had been modified to include a larger diameter (10.5 m) diversion tunnel and the heights of both upstream and downstream cofferdams were increased to 17 m and 6.5 m, respectively, with diversion tunnels also lowered.

Tomoya Miyazaki, Japan Water Agency, Japan, gave a talk on the construction information model (CIM) used during the construction phase of the Koishiwaragawa dam, to convert design drawings into 3D annotated models. "By creating a 3D model of the design drawing, it was possible to understand easily the relationships between structures", he said. "By saving the attribute information into the 3D design as externally linked references, the consultation of this data was more efficient". Miyazaki concluded by noting that as the history of the dam and slope measurements were recorded in the model, it would make future maintenance works easier.

8. THE USE OF GEOSYNTHETIC MATERIAL FOR DAM REPAIR AND REHABILITATION

Kelvin Legge, of the Department of Water Affairs and Forestry, South Africa, spoke of repair works incorporating geosynthetic materials at an embankment dam in South Africa. During the rehabilitation works, Legge noted that a range of geosynthetic materials, including geotextile, geogrids, geomembranes, geo-cells and geo-pipes were considered.

Alberto M. Scuero of Carpi, Switzerland, gave an overview of dam applications for geosynthetic materials. He noted that the technology was suitable for a range of applications, including for the prevention of seepage in newly constructed RCC and embankment dams, and for rehabilitation works to waterproof leaking cracks or joints. He reported that the selected geomembrane material must be flexible, and resistant to puncture, tearing and impact. In addition, the anchorage system should be adequately dimensioned, he said.

9. RIVER BASIN DEVELOPMENT AND MANAGEMENT

9.1 Extreme flood events

Three technical sessions were held on this topic, which also covered the optimization of reservoir operation. The first was chaired by A.B. Pandya, Secretary-General of ICID. India.

Among the presentations was one by D. Bellamo of AECOM, USA. He reviewed the economic losses from flood events in the USA, and drew attention to the need to improve the identification of flood risks and to quantify the risks. As part of the effort to reduce economic losses, there were attempts to encourage new industrial and domestic developments to be outside areas identified to be prone to floods, and then to make those already inside the areas resistant. Significant investments were being made in levees and dams for this purpose. The US Army Corps of Engineers (USACE) kept a database of levees, and was responsible for regulation of lhe structures. Bellamo pointed out that USACE was working together with FEMA, based on a probabilistic approach to study the behaviour of levees in different scenarios. In parallel efforts were being made to inform the public better about flood risk.

Christian Ingenhoff, of Bjoernsen Consulting, Germany, gave details of flood control measures on the Lower Rhine in his country, and a study which had been done to analyse risk. He pointed out the 1249 km-long Rhine had the third largest catchment area in Europe, with sub-basins in nine countries. The area of the study described (Lower Rhine) was a major industrial centre, and also contained five very large cities, Groundwater in the area had been affected by long-term pumping, and subsidence had also occurred because of former mining activities. He explained that levees were the backbone of flood protection measures, and added that these required continuous monitoring and rehabilitation. The Government had established a 'roadmap' for the rehabilitation programme, with the aim of completing necessary work on all the structures by 2025.

Maki Iwamoto of Kyoto University, Japan, discussed extreme flood events in the Katsura river basin, and a rainfall-runoff-inundation analysis which had been carried out to optimise reservoir operation. The study had followed a severe flood event in July 2018 which had filled eight reservoirs to their full capacity, and emergency gate operation had led to a risk to downstream areas. She described the user of a single model to identify optimal operation of the reservoirs. Future work would include: a statistical analysis for extreme flood events based on rainfall scenario datasets; and, the development of damage function model which would represent severe damage in extreme events, including a risk of human loss.

9.2 River basin management and sedimentation

The second session continuing on the topic of river and reservoir management, was chaired by Gabriel Troncoso of Geko Ingenieria, Chile. He also gave a keynote talk, addressing the issue of stakeholder involvement in risk management and planning. He stressed the importance of early involvement of the public, and that there should be good representation of all relevant stakeholders.

The majority of papers in the session dealt with sedimentation issues.

Dr Neena Isaac of the Central Water Research Station at Pune spoke of a study to investigate the concept of reservoirs functioning as settling basins, based on ID and 3D models. Her findings were that flushing could take placed during periods of low velocity flow, to restore storage capacity. The 3D physical scale model study had shown that most suspended sediment settles in a reservoir, and only a small amount would enter a water conveyance system. One of her conclusions was that an integrated approach, with numerical and physical modelling, was most effective to investigate the sediment deposition pattern and sediment distribution at run-of-river schemes.

Vaishali P. Gadhe of the Central Water and Power Research Station (CWPRS), Pune, India, discussed the cascade of hydro projects in the Teesta river basin. She gave details of the projects already completed, and then described model studies carried out for Teesta IV (in particular (or ihe spillway, energy dissipator) and modifications to the project design recommended by CWPRS as a result of the studies. Li particular, it was suggested to tilt the dam axis anti-clockwise hy about 3", which would be beneficial in conlaining and guiding the ski-jump jet after the point of impingement towards the river course; modifications were also suggested for the bottom profile of the breast wall, and to the design of the power intake.

9.3 Upstream and downstream issues

Joop Stoutjesdyke, Lead Water Resources Manage¬ment Specialist at the World Bank, chaired the third session on river basin development and management. He commented that speakers were covering a wide range of topics on upstream and downstream issue.

Ronald Haselsteiner, Bjoernsen Consulting Engi¬neers, Germany, spoke about flood retention dams to control flashfloods in Oman. As background, he pointed out that the average temperature there was 41-44°C, and most of the country was arid desert. When flooding occurred, he said, often as a result of cyclones from the Indian Ocean,

Joop Souljesdyke of the World Bank, chairing one of the three sessions on river basin development.

Ronald Haselsteiner of Bjoernsen Consulting Engineers, Germany, discussing Ihe challenges of constructing dams in Oman, for protection from flash floods

the events would be very strong and of short duration. Peak discharge per area was highest in world.

In 2017, cyclone Gonu had not been predicted, and had led to the death of 50 people; there had also been two major cyclones in 2010, and the frequency was clearly increasing. Therefore, large dams and spill-ways were required with large-capacity reservoirs, as the only way to control such extreme floodwaters. Heavy sedimentation was another challenge.

Generally, RCC or asphaltic core dams are implemented, Haselsteiner said, but the hot climate could present placement challenges; RCC had to be placed during the night, for example.

Manoj Verma of CWPRS, India, discussed dealing with suspended sediment, to ensure the optimal operation of hydro plants in the Himalayan region, where he explained the region was characterized by steep slopes and fragile geological conditions. Heavy sedimentation would occur during the monsoon seasons, with bedload settling in reservoirs, and as a result, turbines would sustain severe damage. He described some examples where desilting chambers had been designed for some large schemes in northern India, and some others in Bhutan and Nepal. One case study he outlined related to model studies for the 3097 MW Etalin hydro scheme in Arunachal Pradesh, India.

Suveer Pandey described a project at the Salal dam in India where flap-type radial gates had been installed, to deal with a problem of floating trash. A new 2 m-high flap gate had been installed, and the radial arms had been optimized so that they could be accommodated within the existing trunnion assembly. The new gate was operated by a double acting hydraulic hoist, Pandey said. It had been successfully commissioned in mid-2019.

Viraj Loliyana of Mechatronics, India, described an integrated river basin management system for the Upper Wardha scheme in India. He pointed out that despite major investments in dams and reservoirs across India, most hydraulic structures were being operated on the basis of experience, 'rule of thumb', or static rules which had been established at the time of construction. Manual calculations would be used for flood forecasting, and manual operations for spillway gates. He then presented his company's approach in developing systems based on artificial intelligence, ICT, IoT and digital technology, to encourage a new style of management, characterized by real time data-driven decision making, and automated field operations. He described smart systems for inflow forecasting, and for weather, water level, rainfall and flow measurement. He then referred to systems installed at the Wardha scheme, which included a smart gate operating system.

10. ICOLD YOUNG PROFESSIONALS

Michel de Vivo, Secretary-General of ICOLD, welcomed participants to this session and expressed his pleasure at the growth of the Young Engineers Forum. "This century will be the century of energy and water", he said. "There will be many challenges for young engineers, not least climate change, energy and water, ageing dams and sedimentation", de Vivo added. He proposed that the YEF was the place for people of the future to work together, and exchange ideas with experienced members'of the ICOLD family. "We must work together and share together, to face the future with hope and success", he said.

Dr D.K.Sharma, Vice President of ICOLD and President of INCOLD, also expressed his pleasure with the growth of the YEF and he encouraged all young members of ICOLD "to come forward and raise questions with mentors". Sharma noted that to help with the development of young engineers, INCOLD would make available all conference materials to young professionals, including the proceedings.

ICOLD President Michel Rogers began by expressing sympathy for those who had died in the recent landslide in Uttarkarand, India, before thanking INCOLD and YEF for their work. Rogers encouraged young engineers to engage with the programme speakers and to raise questions and voice opinions. "Changes are being made to support the role of young engineers", he said. One activity being undertaken by Central Office is to facilitate a Vice Chair position in each Technical Committee, he noted.

"February 21 to 27 is National Engineers Week in the USA. This week-long celebration was founded in 1951 by the National Society of Professional Engineers to promote diversity and education among engineers. If you are an engineer; please take a moment to reflect on what inspired you to become one. Then, share that inspirational story with a student or younger engineer. By sharing our stories we will inspire future generations to do the same! I encourage us all to work hard and stay humble", Rogers said. "By telling our stories of working on projects we bring our work to as many people as we can and encourage them to the profession and advance the important work of ICOLD. I am still learning, and today I learn about dams in Moambitjue and Slovenia", Rogers continued. He reported that the industry faces very similar challenges across different countries, including climate change and aging infrastructure. "We can and must share solutions to these. The DRIP programme is exceptional and many countries can learn from that", he added.

As well as the professional benefits and opportunities generated from the work of ICOLD, Rogers said "the main thing I have taken from ICOLD is that I can have fun and feel pari of a community and family. (cannot wait to travel again to share our stories, personal, family and professional", he concluded.

An early warning system developed by Mechatronics. described by Viraj Loliyana.

ICOLD Secretary-Genet al, Michel de Vivo, who welcomed participants to the Young Engineers' session. He also spoke in the plenary opening of the symposium, commending India for its contributions to the work of ICOLD.

Elias Baplista, Chairman of the Young Engineers' Forum. He presented an overview of dam safety in his country, Mozambique.

Elias Baptisla (Chair of ICOLD-YEF) explained the forum provides a network of young professionals (persons under 40 years of age) and opportunities for knowledge transfer and eonneciion of shared experiences. Baptisla then presented an overview of dam safety regulations in Mozambique. He identified Decree No. 33/2017 Dam Safely Regulation, and Decree No. 50/2017 Safety Regulation for Tailings Dams, as two of the most significant legal instruments in the country for the dam industry. Together, these decrees aimed to ensure reliable construction, and to reduce accidents and risk to life. The regulations apply in dams equal or greater than 15 m in height, or with a height of 10 m or more and a reservoir capacity more than 1 hm or to dams with a designed spillway discharge exceeding 2000 m-Vs. Dams are then classified by three leading criteria he said, "These are vulnerability, potential damage, and risk". Baptists highlighted the important role of MozCOD in drafting the regulations, as it had helped integrate the work of ICOLD.

YEF Board Member Mateja Klun from the University of Ljbljana, Slovenia, presented an overview of dam safety in her country. She noted that since the first rules had been introduced for large dams in 1966, legislation and guidelines had increased. including those released in 2012 and 2016 by the administration

ICOLD President Michael Rogers pays tribute to India's activities in the field of safety. and refurbishment of dams

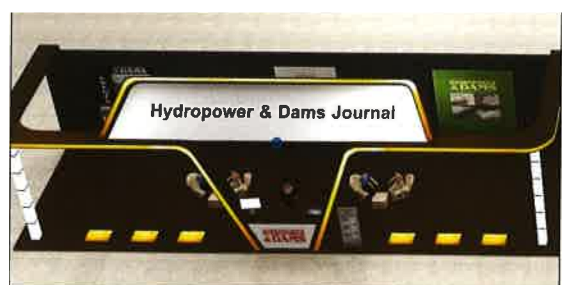
for the Civil Protection and Disaster Relief. Currently, for new dams, the monitoring scheme would be part of the design documents, and all dams had to have detailed reservoir operation scenarios and emergency plans, in case of partial or complete emptying of the reservoir. However, there was no centralized register of dams, and legislation remained fragmented, Klun added. "Abroad approach including appropriate legislative frameworks is necessary", she concluded.

11. CLOSING

In the closing session, on behalf of the international ICOLD delegates. President Michael Rogers paid tribute to India for its new regulations on dam safety, and also commended the DRIP initiative, in addressing the problems of rehabilitating dams to enhance safely. He fell the discussion among participants at the Symposium had played a part in helping to meet the challenges of the 21st century.

Closing remarks were made by ICOLD Vice President, D.K. Sharma; the Chairman of CWC, S.K. Haldar, who was chief guest; INCOLD Vice President, Dr R.K. Gupta; CMD of NHPC, A.K. Singh; and Director of THDC, R.K. Vishnoi. A vote of thanks was then given by Secretary-General of INCOLD, and Secretary, CBIP, A.K. Dinkar.

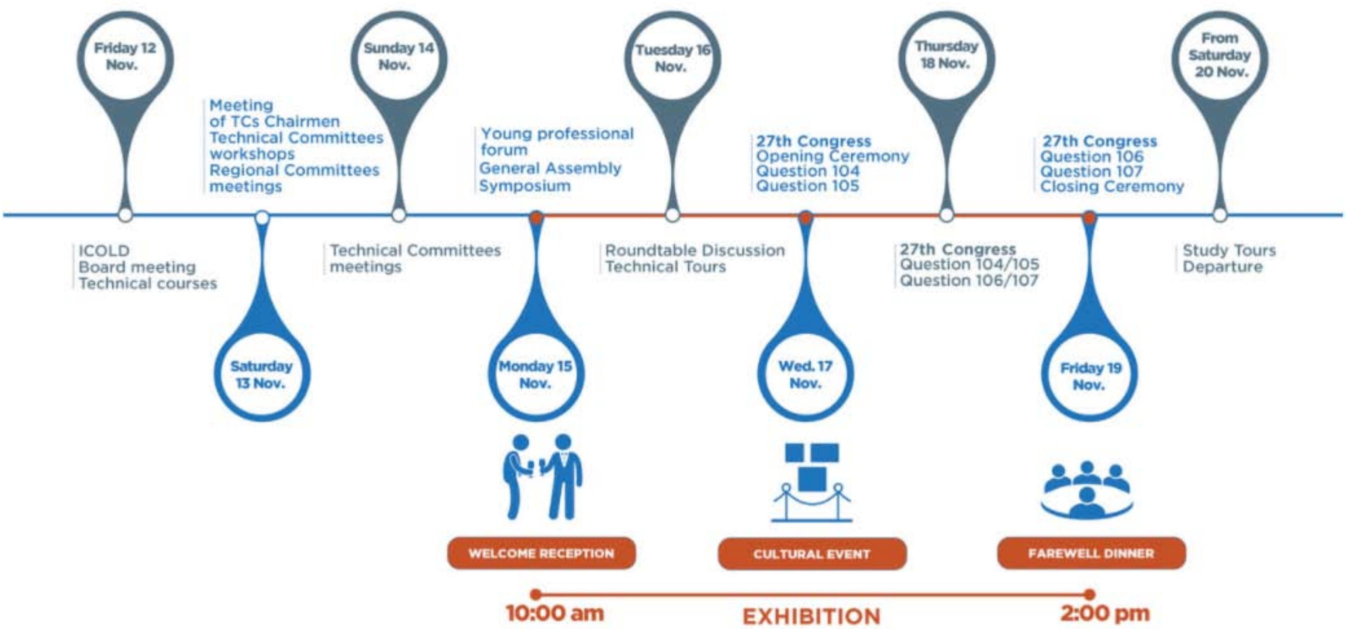
A number of technical workshops on specialized topics followed the Symposium.



As well as attending sessions to report on the Symposium, Hydropower & Dams was pleased to be among those who had a virtual exhibition stand

CMD of NHPC, A.K. Singh, preparing to make his closing remarks at the end of the symposium

PROGRAMME



CONTACT :

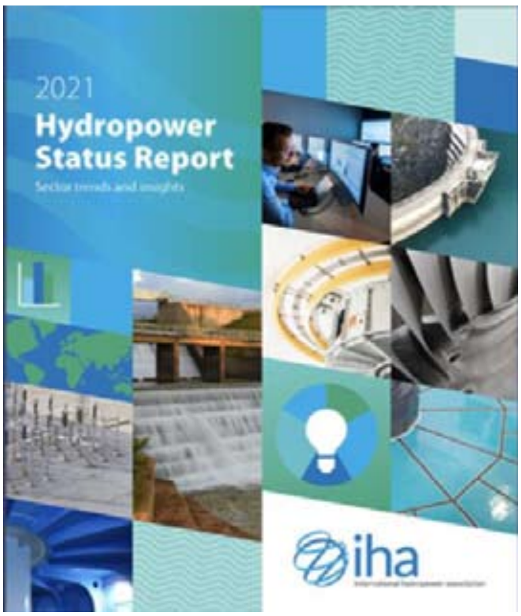
Registration and Information
MCO Congrès SAS
Administrative Secretariat
Ms. Claire Bellone
Villa Gaby
285 Corniche JF Kennedy, 13007 Marseille, France
Tel .: +33 (0) 4 9509 3800 / Fax: +33 (0) 4 9509 3801
Email: claire.bellone@mcocongres.com

Scientific Program and abstracts Symposium submission
The article for the congress should be submitted to the central office of ICOLD: secretaire.general@icold-cigb.org
MCO Congrès SAS
Ms. Claire Bellone
Villa Gaby
285 Corniche JF Kennedy, 13007 Marseille, France
Tel .: +33 (0) 4 9509 3800 / Fax: +33 (0) 4 9509 3801
Email: claire.bellone@mcocongres.com

INCOLD News

IHA PUBLISHES 2021 HYDROPOWER STATUS REPORT

11 June 2021



The International Hydropower Association (IHA) has announced the release of its 2021 Hydropower Status Report, with this year's report underscoring need for rapid growth to achieve net zero.

The report shows that installed hydropower capacity rose by 1.6% to 1330GW over the past year, despite the global disruption caused by the Covid-19 pandemic. However, the International Energy Agency (IEA) says the water power sector will need to double in size to 2600GW if it is to help limit dangerous global warming and achieve net zero by 2050. To achieve this figure would require building the same amount of capacity in the next 30 years as was built in the last 100 years.

"At the present rate of hydropower development, the global energy pathway to net zero emissions will not be realised," warns IHA President Roger Gill and IHA Chief Executive Eddie Rich in the report's foreword. "This is a wake-up call for policy-makers, hydropower developers and project financiers and provides clarity for the public.

"Investment in sustainably developed and responsibly operated hydropower is essential to support the massive expansion of variable renewables like wind and solar. However annual growth rates of 1.5 to 2 per cent cannot meet the doubling of installed capacity proposed by the International Energy Agency to achieve net zero by 2050."

According to the report, the Covid-19 crisis has further underlined how the power system flexibility provided by hydropower is now a prerequisite for the clean energy transition. Hydropower's critical role was illustrated by a recent near blackout incident in Europe in January 2021. Despite the slump in demand for fossil fuels experienced during 2020, hydropower generated a record 4,370 terawatt hours (TWh) of clean electricity – up from the previous record of 4,306 TWh in 2019.

During 2020, hydropower projects totalling 2 GW were put into operation, up on 2019's 15.6GW. Nearly two-thirds of this growth came from China, which saw 13.8GW of new capacity. Among other countries that added new capacity, only Turkey (2.5GW) contributed more than 1GW.

Major projects completed last year include the 2.1GW Lauca facility in Angola, the 1.8GW Jixi pumped storage facility in China and the Ilisu (1.2GW) and Lower Kaleköy (0.5GW) projects in Turkey. The single biggest project was Wudongde in China, which put eight of its 12 units online, adding 6.8GW to the Chinese grid. The remainder is expected to be commissioned in 2021.

China remains the world leader in respect of total hydropower installed capacity with over 370GW. Brazil (109GW), the US (102GW), Canada (82GW) and India (50GW) make up the rest of the top five. Japan and Russia are just behind India, followed by Norway (33GW) and Turkey (31GW).

KIDSTON PUMPED STORAGE PROJECT BREAKS GROUND

11 June 2021

Genex Power yesterday marked the construction of its flagship 250MW Kidston Pumped Storage Hydro Project in Queensland, Australia, with an official ground breaking ceremony.

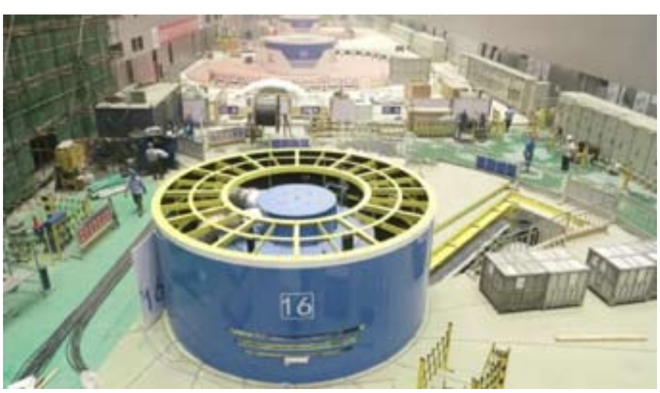
The Kidston Pumped Storage project is a $777 million project, creating over 800 jobs during the four-year

construction period and when operational, will contribute to significant benefits to the electricity network in North Queensland, as well as serving to lower electricity prices. The project is the first pumped storage power station to be built in Australia for nearly 40 years.

The ground breaking ceremony was attended by Senator Susan MacDonald who has been a long term supporter of Kidston's Clean Energy Hub and was representing the Prime Minister, the Minister for Energy and Emissions Reduction Angus Taylor and the Minister for Resources, Water and Northern Australia Keith Pitt. The Hon Glenn Butcher, Queensland Minister for Regional Development and Manufacturing and Minister for Water also attended, along with Robbie Katter, State MP for Traeger and Barry Hughes the Mayor, and Ken Timms the Council CEO of Etheridge Shire Council. In addition, Chris Wade, CEO of NAIF and representatives of ARENA attended.

FINAL PUSH AT BAIHETAN AS FIRST UNITS PREPARE FOR JULY COMMISSIONING

10 June 2021



China Three Gorges Corporation (CTG) has announced it has hoisted the runner for one of its 1GW hydraulic generators on the right bank and began dry commissioning on two power units on June 4 as it gets ready to put the first batch of power units into operation in July at the Baihetan hydropower project.

To date, four power units have finished dry commissioning and 10 runners have been hoisted. With 16 generators, Baihetan hydropower plant will have an installed capacity of 16GW, making it the second largest hydropower plant in the world once its commissioned.

CTG has scheduled the first batch of units to be commissioned by July 1, 2021, with all units by July 2022.

FLOATING SOLAR PLANT AT BANJA RESERVOIR STARTS COMMERCIAL OPERATION

9 June 2021

European renewable energy generator Statkraft, in cooperation with Norwegian supplier Ocean Sun, has started commercial operations at the first floating solar plant in Albania – located at reservoir attached to the 72 MW Banja hydropower plant.

After the successful completion of the first floating solar unit and connection to the grid, the plant is now generating renewable energy and injecting the power into the Albanian national electricity grid. Floating solar power involves installing solar panels on floating structures on a body of water, such as a lake, ocean, or in a hydropower reservoir. Each unit consists of a floating ring and a thin membrane. Combined with the cooling of the panels from the water below, it is this membrane and the large area that makes this concept unique. The technology is developed by Ocean Sun and although the membrane is only a few millimeters thick, it can easily withstand the weight of the solar panels and of personnel carrying out installation or maintenance tasks.

The first unit, comprising 1536 solar panels, has an installed capacity of 0.5MWp and covers almost 4,000 square meters. In addition, 160 equal panels have been placed on land for comparison and documentation of the cooling effect on the floating panels. The project is expected to continue its second implementation phase during the second half of 2021, whereby additional three floating units will be installed, with a combined additional capacity of 1.5 MWp. This is a great milestone in an innovative floating solar project, and it is exciting to see the plant come alive and provide additional renewable energy production in Albania," commented CEO of Statkraft, Christian Rynning-Tønnesen. "We are looking forward to the concrete results of this demonstration project to assess the potential for further expansion of this exciting technology."

"[This] achievement marks an important milestone for Statkraft in Albania and a further step in our mission to lead the shift to renewable energy through innovative solutions. After the start of commercial operations of our Banja and Moglice hydropower plants, we are looking into further optimising these renewable assets. The Banja Floating Solar Plant is a concrete example for further integration of different resources of renewable energy," added Rigela Gegprifti, Statkraft's Country Head in Albania.

"We are very pleased to start commercial operations of the new Ocean Sun flagship floater at Statkraft's Banja reservoir. This demonstrates the safe, simple and fast construction methodology. We were able to install the solar panels at record breaking speed. I wish to thank the proficient teams at Statkraft and the local contractor Doko. The collaboration has been excellent, and their competence and knowledge made the installation a pleasure from start to finish. We look forward to the second stage of the project and to demonstrate the high performance of our solution," said CEO of Ocean Sun, Børge Bjørneklett.

Albania has one of the highest shares of renewable energy in Southeast Europe. Hydropower accounts for the largest share of Albania's electricity generation, representing around 95% of its installed power capacity. In addition, Albania has some of Europe's highest number of sunshine hours per year, presenting significant potential for the development of solar power and a good fit with existing hydropower capacity.

JV TO IMPLEMENT RATLE PROJECT, INDIA

9 June 2021

Indian power company NHPC has incorporated a joint venture with Jammu & Kashmir State Power Development Corporation Ltd (JKSPDC) to implement the 850MW Ratle hydroelectric project on the River Chenab in the Union Territory of Jammu and Kashmir.

The JV will be majority owned by NHPC with 51%, with JKSPDC taking the remaining 49%.

Ratle will feature a 133m high concrete dam and a main underground powerhouse featuring 4x205MW units. A surface powerhouse near the dam toe will house a further 30MW unit.

RED JOHN PUMPED STORAGE PROJECT GETS OK FROM SCOTTISH GOVERNMENT

9 June 2021

The 450MW Red John pumped storage project proposed for the shores of Loch Ness has gained planning consent from the Scottish Government, developer ILI Group has announced. The consent comes after a report from a public inquiry was submitted to Ministers in February this year. "We are delighted that the Cabinet Secretary for Net-Zero, Energy, and Transport, Michael Matheson, has approved this project," said Mark Wilson, chief executive officer of ILI Group. "This will help pave the way for hundreds of millions of pounds of investment and hundreds of new jobs in the area and will be another major step in Scotland's ongoing journey to becoming a leader in renewable energy.

"There is currently a pipeline of over 5GW of pumped storage in the UK but we need to work closely with the UK Government to implement the market mechanisms that are needed to drive investment into these projects to ensure we hit our net zero targets." The Red John project will be located on the eastern shore of the north end of Loch Ness in the Highlands of Scotland. Loch Ness is to be the tail pond for the project, with the head pond to be newly constructed. It will use the natural topography between Loch Duntelchaig, Loch Ashie and Loch na Curra and Lochan an Eoin Ruadha, from where the development gets its Red John name.

"The Scottish Government has long been supportive of pumped hydro storage for its role in ensuring resilience in our electricity supplies, and for the tremendous opportunity it provides to unlock the potential of renewable energy and support Scotland's net zero ambitions," commented Cabinet Secretary for Net Zero, Energy and Transport, Michael Matheson. "Scotland is a leader in this field, with excellent hydroelectric power heritage built over the last century and this new scheme at Loch Ness will only add to that. As we add more renewable electricity generation across Scotland, investing in pumped hydro storage will be key to balancing our electricity demand with supply and keeping the system secure, as well as creating high quality, green jobs and enabling a green recovery from the COVID-19 pandemic."

AFDB AGREES LOANS FOR MALAGARASI HYDROPOWER PLANT, TANZANIA

8 June 2021

The African Development Bank Group (AFDB) has agreed to loan $140 million to the Government of Tanzania to finance the construction of the 50MW Malagarasi hydropower plant in Western Tanzania. The funds will be used to construct the plant and an evacuation transmission line, as well as to add 4250 rural electrification connections, providing reliable renewable energy to households, schools, clinics and small and medium-sized enterprises in the Kigoma Region. The project is one of Tanzania's priorities under its Second Five-Year Development Plan and will also advance the objectives of the country's Vision 2025. It also aligns with two of the Bank's High Five strategic priorities, namely, Light up and Power Africa and Improve the quality of life for the people of Africa.

"The signing of the loan agreements is another testimony of our joint commitment to working together to support Tanzania's development aspirations," commented Nnenna Nwabufo, Director General of the Bank Group's East Africa Regional Development and Business Delivery Office. "Malagarasi Hydropower is one of the flagship projects in Tanzania's Second Five-Year Plan. We appreciate the trust the Government has put in the African Development Bank and we are committed to remaining a privileged and trusted partner of choice."

"I would like to re-affirm the government's commitment to working closely with the Bank in efforts to realize our national and international development aspirations," added Emmanuel M. Tutuba, Permanent Secretary at the Tanzania Ministry of Finance and Planning. "The government will take all necessary measures to ensure successful implementation of this project as planned."The loan is split into a $120 million sovereign loan from the Bank and $20 million from the Africa Growing Together Fund (AGTF), which is administered by the Bank.

VOITH HYDRO AND MINE STORAGE TEAM UP FOR UNDERGROUND PUMPED STORAGE DEVELOPMENT

8 June 2021

Voith Hydro and Mine Storage have entered into a development partnership in a bid to become forerunners in the development of pumped storage hydropower in former mines. Swedish company Mine Storage focuses on the rapidly emerging market for large-scale, fast-responding energy storage and plans to build sustainable pumped storage facilities in underground mines. There are more than one million abandoned mines in the world, and with mature, proven energy storage technology, mine storages could be a game changer for the environment, the company said. Replicating traditional pumped storage with upper and lower reservoirs in a new setting, like underground mines, puts new demands on the technology available. Voith Hydro said it will take on these specific challenges, and, in collaboration with Mine Storage, it is now engaged in the early project development at two specific sites Sweden in order to develop the necessary technical solutions.

"We are committed to sustainable technologies and concepts for a decarbonized future. As Mine Storage has shown an innovative approach, impressive speed and competence in this field, we are delighted to now bring in our long-standing expertise in pumped storage technology in order to develop first projects together," commented Uwe Wehnhardt, President & CEO Voith Hydro. "Mine storages can have a huge impact on global CO_2 emissions by enabling renewable energy production to scale. We do not have time to wait; we must act now," added Thomas Johansson, CEO of Mine Storage. "Voith Hydro has shown a great flexibility and good understanding for the dynamics in early project development. Their approach and our shared vision of the global potential for mine storages make this partnership a valuable piece in our strategy to contribute to the phase-out of fossil fuels."

NEW HYDRO FOR SCOTLAND

2 June 2021

The four run-of-river power plants will supply more than 2800 average British households with power. Source: Vento Ludens Ltd.

Four run-of-river hydropower plants have been successfully completed on time in the Scottish Highlands, despite restrictions due to the coronavirus pandemic.

Koehler Renewable Energy, part of the Koehler Group, completed the joint project with Vento Ludens Ltd after winning a tendering process run by the Forestry Commission Scotland (now Forestry and Land Scotland) in 2014.

The power plants are part of a portfolio which includes a total of six run-of-river power plants. The first two projects in Kelburn and Ledard were successfully completed back in 2017.

“In retrospect, we chose a very challenging time to implement this project,” said Alan Mathewson, Head of Project Development at Vento Ludens. “Despite the challenges of the coronavirus pandemic, including the temporary suspension of building work, we are proud to have now completed the construction on time. The first of the four plants began supplying electricity back in December 2020.”

Nicolas Christoph, Division Head Wind Power, Solar, Hydro & Business Development at Koehler Renewable Energy added: “Thanks to their long service lives, these projects are ideally suited to the long-term strategy of family companies like Koehler and Vento Ludens. The lockdown measures made the construction phase a lot more difficult but the outstanding project management on site and the excellent collaboration with colleagues in Scotland made it possible to successfully perform commissioning without any significant delays.”

SNC LAVALIN IN DEAL TO EXPAND CAPACITY AT CANADIAN HYDROPOWER FACILITY

27 May 2021

SNC-Lavalin is to support additional hydropower capacity for facility in Atlin, British Columbia, Canada, following the award of a design and engineering contract by Tlingit Homeland Energy, which is owned by the Taku River Tlingit First Nation band government in Northern BC.

SNC-Lavalin will provide conceptual and advanced design, as well as support the selection of a contractor through the Early Contractor Involvement (ECI) process. The proposed work will involve expansion of the generating facility to enhance its capacity from 2. MW to 10MW by using the available power potential of Pine Creek, located in the Atlin region. "The path to decarbonization for remote communities in Canada must include a transition toward renewable energy and BC, with its rich hydro reserves, is well suited for clean energy production," said Dale Clarke, President, Infrastructure Services. “This project will produce hydropower in BC and feed into the Yukon grid, transcending provincial boundaries and exemplifying a collaborative approach to decarbonize Canada by 2050."

"We continue to own and operate the first project we built 11 years ago, which supplies all the electricity required by the community of Atlin, BC, and avoids about 4400t CO2 per year of diesel emissions," added Peter Kirby, President & CEO, Taku Group of Companies. "Once operational, the electricity produced by this second project will be exported to the Yukon, and it will increase dependable renewable hydroelectricity in Yukon by nearly 10% and displace thermal generation in the process."

GE LAUNCHES NEW PRODUCT FOR UNDERWATER HYDROPOWER TURBINE CONDITION ASSESSMENT

26 May 2021

GE Renewable Energy has introduced a new underwater robotized hydropower turbine inspection solution designed to be able to inspect between the runner blades of a turbine – which the company said is a first of its kind in the hydropower condition assessment field. Designed, developed and tested with GE Research Center, the product is based on remote operated vehicles (ROV) equipped with sensors and cameras, and can inspect hard-to-reach areas without dewatering the equipment.

This new condition assessment methodology allows on-demand and high-quality inspections with comparable results to dry visual inspection without having the services team enter into a turbine's confined space, said GE. The customized design of the ROV is able to inspect between runner blades of a turbine within openings of less than 200mm. The product has been designed to detect erosion, cavitation, corrosion, impact marks and presence of foreign bodies. Experts then review the information in real-time to ensure proper inspection of all critical surfaces. Video images are also recorded for further analysis if needed.

"Advances in underwater ROV technology have been tremendous in the past few years. As its use is progressively spreading in the hydropower industry, we wanted to accelerate its deployment with our cutting-edge underwater condition assessment solution," said Roberta Galli, Hydro Services Leader. "Our large assessment portfolio enables us to inspect our customers' hydropower equipment more quickly and more efficiently and provide faster services recommendations to better serve them." The validation process of this solution was performed at five hydropower plants in Canada. Trash racks, intake gates, vertical and horizontal turbines and downstream gates were successfully inspected. Inserting a 360-degree camera between the blades of Francis runners allowed teams to visually inspect the distributor, runner and draft tube.

TENDER FOR POLIHALI TRANSFER TUNNEL CONSTRUCTION, LESOTHO

26 May 2021

The Lesotho Highlands Development Authority (LHDA) has launched the tender for the construction of the Polihali Transfer Tunnel – a major contract in Phase II of the Lesotho Highlands Water Project – with the tender for the Polihali Dam construction expected to follow shortly. The Polihali Transfer Tunnel will be 38km long with a 5m nominal bore. It will transfer water from Polihali to the Katse reservoir. Tunnel boring and drill and blast methods will be used to excavate the tunnel.

The Polihali Dam will create a reservoir on the Senqu and Khubelu rivers with an estimated surface area of 5053 hectares and a full supply storage capacity of 2325 million m3. The flow from the Polihali reservoir through the transfer tunnel will increase the volume of water in the Katse Dam. The current water transfer volumes of 780 million m3 per year to the Gauteng region of South Africa will incrementally increase to 1270 million m3 per year, and will simultaneously increase the electricity generation at the Muela hydropower plant, a further step in the process of securing an independent power supply to meet Lesotho's domestic needs.

"Our objective is to attract firms with experience in the construction of major underground works under complex geological and geotechnical conditions, diverse environmental conditions, in remote areas and at high altitude. Equally important is to attract firms that have impeccable records in delivering projects of this magnitude within budget and the set timeframes," said Tente Tente, CE of the LHDA.

Interested construction firms have up to 30 August 2021, to submit tenders. Specific information on the requirements and conditions of the tender is available on the LHDA website at http://www.lhda.org.ls/tenderbulletin/currentProcurement.aspx.

The Metsi a Senqu-Khubelu Consultants (MSKC) Joint Venture was awarded the contract for the design and construction supervision of the Polihali Transfer Tunnel and its secondary structures. MSKC comprises Lesotho-based FM Associates (Pty) Ltd, and South African firms Zutari (Pty) Ltd, Hatch Africa (Pry) Ltd, Knight Piesold (Pty) Ltd and SMEC South Africa (Pty) Ltd.

The tender for the construction procurement of the transfer tunnel is launched as construction activity on ten advance infrastructure contracts progresses steadily with some contracts expected to be completed in 2021, including the Polihali diversion tunnels. Cumulative excavation progress in both tunnels is in the order of 1243m out of a total of 1810m to date. Construction of the 33kV line, which will provide temporary power supply to the Polihali village, was completed in 2020. Work on the 132kV line has advanced with construction of access roads, 91 tower foundations and erection of 84 towers out of a total of 93. The Polihali and Katse civil works; access roads, pipe laying for potable water and sewerage lines has been completed, and construction on the Phase II main access roads is progressing well.

According to the current master programme, water delivery is scheduled for 2027. Timely construction of the dam and transfer tunnel is critical to meeting the water delivery deadline of the project.

Phase II of the Lesotho Highlands Water Project builds on the successful completion of Phase I in 2003. It delivers water to the Gauteng region of South Africa and utilises the water delivery system to generate hydroelectricity in Lesotho.

Past Events and Forthcoming Events

Sr No	Description	Date	Country/Organizer
1	Enlit Australia (formerly Australian Utility Week & Power Utilities Australia)	10 Mar - 11 Mar 2021	Melbourne, Australia Organizers: Talk2ME URL: https://enlit-australia.com
2	Africa 2021: 4th International Conference & Exhibition on Water Storage and Hydropower Development for Africa	13 Apr - 15 Apr-2021	Lake Victoria, Uganda Organizers: Hydropower & Dams URL: www.hydropower-dams.com/Africa...
3	IWA World Water Congress & Exhibition	9 May - 14 May-2021	Copenhagen, DenmarkOrganizers: IWA URL: https://worldwatercongre
4	Power of Water Canada	25 May - 27 May-2021	White Oaks, Canada Organizers: Ontario Water Power Association URL: www.owa.ca/conference
5	World Hydropower Congress 2021	26 May - 28 May-2021	SanJosé,CostaRica Organizers: International Hydropower Association URL: https://congress.hydropower.or...
6	ICOLD 27th Congress - 89th Annual Meeting	5 Jun - 11 Jun-2021	Marseille, France Organizers: MCO Congrès SAS URL: http://cigb-icold2021.fr/en
7	Seanergy 2021	8 Jun - 11 Jun-2021	Nantes, France Organizers: Bluesign URL: www.seanergy-forum.com/en/sean...
8	24th International Congress on Irrigation & Drainage	6 Jul - 12 Jul-20201	Sydney, Australia Organizers: Irrigation Australia URL: www.irrigationaustralia.com.au
9	HydroVision 2022	12 Jul - 14 Jul-2022	Denver, CO, USA Organizers: PennWell Corp URL: www.hydroevent.com/future-even.

Life is more precious than gold, but not as precious as freshwater

Anthony T.Hincks

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Bulletin 150 - Cutoffs for dams
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A.K. Dinkar
Secretary General
Indian Committee on Large Dams (INCOLD)
CBIP Building, Malcha Marg, Chanakyapuri,
New Delhi-110021, India
Phone : 91-11-26115984, Fax : 91-11-26116347
E-mail : sunil@cbip.org; cbip@cbip.org; Web : www.cbip.org

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