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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; kalpana@cbip.org; contact@incold.co.in; Web: http//www.incold.co.in

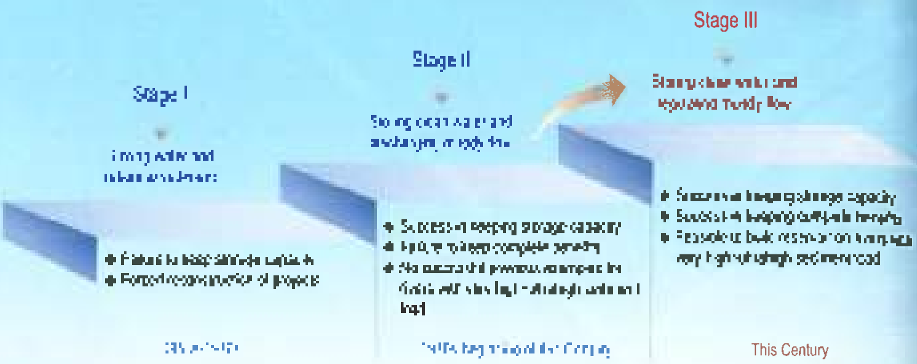
YREC

Critical Technologies and Application of 'Storing Clean Water and Regulating Muddy Flow' for Reservoirs on Sediment-laden Rivers

Introduction

Preserving the long-term storage capacity of reservoirs and achieving the objectives of development have always been key issues affecting the engineering design and operation of reservoirs on sediment-laden rivers. In China, the design and operation of reservoirs on sediment-laden rivers has been based on the principles of "storing water and retaining sediment" and "storing clean water and discharging muddy flow" successively. In the current stage, it is urgent to solve the critical technical challenges of:

- controlling the form of sedimentation in reservoir area;
- failure to exchange reservoir capacities for water and sediment; and,
- failure to realize annual regulation of runoff.



The Three Stages of Engineering Design and Operation of Reservoirs on Sediment-laden Rivers

To address these technical challenges, Yellow River Engineering Consulting Co., Ltd (YREC) is taking the lead in the key technology of "storing clean water and regulating muddy flow" for reservoirs on sediment-laden rivers. By virtue of its rich experience on more than 30 major national projects, YREC has developed studies on the engineering design and operation of reservoir on sediment-laden rivers, and conducted pilot work for the application of the study results, which has led to the establishment of a systematic set of theoretical methods and technical systems. Based on the related achievements, the engineering design and operation of such reservoirs has been developed from "storing clean water and discharging muddy flow" to "storing clean water and regulating muddy flow", so that the storage capacity of the reservoirs can be retained for a longer time, and the objectives of development can also be realized.

Representative Achievements:

(1) Theoretical methodology system for "storing clean water and regulating muddy flow" for reservoirs on sediment-laden rivers

(2) Technology to control the form of sedimentation in the reservoirs on sediment-laden rivers, which means that the form of sedimentation in the reservoir can be regulated in a proactive way, by operation of synchronous shaping of the floodplain and channel in the reservoir area

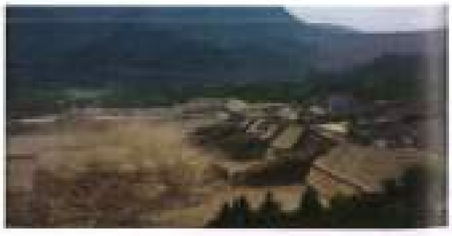
(3) Technology to enable the exchange and integrated use of reservoir storage capacity for water regulation and for sedimentation regulation in the reservoirs on sediment-laden rivers. Specifically, by establishing double datum levels of sediment erosion, an exchange between storage capacity for sediment regulation and part of the storage capacity for retaining sediment in the reservoir, on rivers featuring a high or even ultrahigh sediment concentration, can be achieved. This can break through the traditional application with a single function (storage capacity only for retaining sediment) as a result of a dynamic configuration and diversified application of storage capacity for sediment retention.

(4) Technology for annual or perennial regulation of runoff in reservoirs on sediment-laden rivers. By the integrated application (in series) of storage capacities for water and sediment regulation of cascade reservoirs, and the ability to separate water from sediment for reservoirs in parallel, the reservoir can benefit from complete (rather than formerly incomplete) annual regulation of runoff.

Typical Applications to Projects:

The Dongzhuang hydro project, with an annual average incoming sediment concentration of 140kg/m³. At this project, by applying the technology of establishing double datum levels of sediment erosion, the difficulty related to sedimentation which troubled the project approval for more than 50 years can be solved, so that 20% of the storage capacity for retaining sediment can be utilized repeatedly, to reduce the amount of sedimentation in the lower reaches of the Weihe River by 800 million t, and amount of sedimentation in the lower reaches of the Yellow River by 1 billion t.

The Xiaolangdi hydro project, with an annual average incoming sediment concentration of 32kg/m³. At this project, by applying the technology of synchronous shaping of the floodplain and channel, and diversified utilization of the storage capacity for sediment retention, the storage capacity on tributaries of 4.08 billion m³ can be used to the maximum extent, to extend the time for retaining sediment efficiently by 20 years. This technology has been applied to flood control corresponding to a moderate flood frequency for 13 times, to save 1.9 million people and 11.59 million Mu-time (1Mu=666.67m²) of arable land in the lower floodplain area from losses due to floods, with flood control benefits valued at RMB 115 billion achieved.


Real Photo of Water and Sediment Discharge at the Xiaolangdi hydro project


Design Sketch of Dongzhuang hydro project

Add. No.109 Jinshui Road, Zhengzhou, China P.C.: 450003
Tel. 0086-371-66026131 • http://www.yrec.cn • E-mail. yangfw@yrec.cn

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CONTENTS

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.

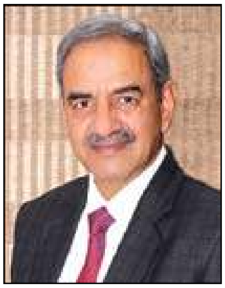
In addition to the information on the research work on the relevant subjects, the journal shall provide information on the related technical events in India and abroad such as conferences/training programmes/exhibitions etc. Information related to ICOLD activities shall also be highlighted.

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



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

Dams, being a major infrastructure component of water resources, play a vital role in providing significant benefits to humankind and also overall water security to the country. Storage of water behind dams regulates natural streamflow, allowing for benefits resulting from increased water availability, renewable energy production and reduction of adverse impacts caused by natural extremes of floods and drought. Growing population is causing a steady increase in demand for water, food and energy to meet basic needs as well as higher standards of living. At the same time dams may create new hazards with risks to downstream life and property in the event of dam failure resulting from an uncontrolled or catastrophic release of stored water. It is in this context, the Dams Engineering profession has a profound duty and moral responsibility: namely, building urgently needed dams, reservoirs and levees in the most effective and sustainable way, while also ensuring that they are safe during their whole lifespan.

For almost a century, the International Commission on Large Dams (ICOLD) has been committed to promote attention to dam safety. As an important part of societal concerns, this has always been among the highest organizational commitment as stated in the ICOLD Mission Statement:

> *"ICOLD leads the profession in setting standards and establishing guidelines to ensure that dams are built and operated safely, efficiently, economically, and are environmentally sustainable and socially equitable."*

ICOLD has played a significant role in improvement of dam safety, through its work in collecting and analysing information on the lessons learned from past failures and major incidents. Since its inception, ICOLD and its thousands of dam professionals in 104 member countries have continuously contributed to the improvement of dam safety through publication of technical papers and exchange of experience during Annual International Symposium Meetings held every year and Congresses held on triannual basis. Also playing a key role has been the work of its Technical Committees with the publication of Technical Bulletins summarizing the recommended state-of-the art best practices.

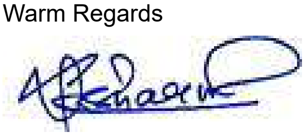
Since the creation of ICOLD, the number of failures compared to the total number of dams in operation have been reduced about tenfold, a dramatic achievement reflecting the worldwide influence of ICOLD. Nonetheless, constant vigilance and commitment to dam safety is still required in order to continue this successful record. Any dam incident is a matter of the graves concern to dam professionals and a reflection on all ICOLD members: Unintentional dam breaching can have catastrophic consequences, resulting in loss of life and injuries, as well as widespread damage to property, infrastructure and the environment. The understanding of the factors affecting dam safety is also in constant evolution. The changing conditions of dam safety include the following factors:

- The ageing of existing dams infrastructure is creating new concerns related to the ageing of construction material and equipment.
- More and more emerging and developing countries are now building dams, but they may lack experience in dam safety management.
- The increasing participation of the private sector in the dam business creates new governance conditions for dam safety.
- Climate change creates new opportunities and challenges for dams but at the same time it poses new natural hazards, which must be assessed and managed.
- Because the sites most suitable for dams have already been largely utilised, new dams have to be built on more and more challenging sites, especially regarding geological conditions.

ICOLD has come out with **World declaration on dam Safety** to restate the fundamentals of dam safety that have been learned by generations of engineers over the time. Furthermore, all involved institutions are reminded to ensure, through the fulfilment of their responsibilities, that those principles in order to minimize risks to humankind associated with dams and reservoirs be respected. This common effort will contribute immeasurably to the overarching ICOLD vision for **"Better dams for a better World."**

I welcome the ICOLD international experts and national experts in September, 2022 at Jaipur, India and hope that the 6th edition of Dam Safety Conference being organized by INCOLD, CWC and DRIP will be a grand success.

Warm Regards



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

Editorial

Dear Readers,

Greetings from INCOLD, New Delhi.

Development of water resources is recognized as a key element in the socio-economic development of many regions in the world. Since water availability and rainfall are unequally distributed both in space and time, so dams are crucial for storage of water as viable alternatives. Besides generation of hydro power, dams play a vital role in satisfying the ever increasing demand for irrigation and drinking water, for protecting man, property and environment from catastrophic floods, and for regulating the flow of rivers. Dams have contributed to the development of civilizations for over 2,000 years. Worldwide, there are more than 60,000 large dams listed by ICOLD, most of which have a height of over 15 meters except a few with height between 5 meters and 15 meters but having storage above 3mcm. Today, in developing countries, the focus is on the state-of-the-art technology in planning, design, and construction as well as use of new materials for dams, which are essential for the sustenance of human life and also for poverty alleviation.

Climate change and global warming issues are compelling nations to plan more and more for green energy sources. Many countries are targeting to cut their thermal power generations in a phased manner and make greater use of solar, wind and hydro power to fill the gap. Hydropower is the second largest contributor of energy generated in India. However, so far the country has utilized only about 32% of its total 145,000 MW hydropower potential and therefore, tremendous opportunities exist for future expansion. The greatest hydropower potential in India exists in the three major transboundary river basins (Ganges, Indus, and Brahmaputra), but all these basins have experienced substantial changes in precipitation and air temperature affecting the availability of water required for hydropower generation. A majority of hydropower projects in India are run-off-the-river (RoR) schemes and in future also, in lieu of storage schemes, RoR schemes with diurnal storage may be preferable due to submergence, site conditions and other environmental issues. But in the climate change scenario, uncertainty in stream flow patterns may have a major impact in peaking power generations due to small pondage of RoR schemes. In order to mitigate this, RoR schemes require certain increase in pondage capacity.

Keeping in view the importance of the subject, INCOLD (Indian Committee on Large Dams), CBIP (Central Board of Irrigation and Power) and THDC India Ltd. jointly organized a two-day International Conference on Hydropower and Dam Development for Water and Energy Security - Under Changing Climate from 7 April 2022 at Rishikesh followed by one day field visit to Tehri Dam for the delegates.

A set of recommendations emerged during the two days discussions by national and international experts have included in this issue, which will add new dimensions to the body of knowledge on the subject. It is hope that the deliberation of the conference would help in better understanding of the various aspects of sustainable development of dam and hydropower for meeting the water and energy security requirement under changing climate.

Indian Committee on Large Dams are grateful to the authors of papers for their contribution which are included in this issue. Our sincere thanks are also due to Shri D.K. Sharma, President, INCOLD and Vice President, ICOLD; Dr. R.K. Gupta, Chairman, CWC and Shri R.K. Vishnoi, Chairman, THDC India Ltd. for their support and guidance in mobilisation of national and international experts for presentation in the conference.

a.k. dinkar
Secretary General
Indian National Committee on Large Dams

dam Rehabilitation and Safety Improvement Project in Vietnam

L. Spasic-gril[1] and dr. T. Sy Ho[2]

aBSTraCT

With over 7,000 dams of different types and sizes Vietnam has a complex and evolving institutional framework for dam safety. There are more than 750 large dams, with the number of small dams estimated to be more than 6,000.

The Government of Vietnam has established a sectorial program for dam safety in recognition of the importance of securing the foundations for sustained and secure economic growth. The program was first launched in 2003, revised in 2009 and again revised in 2015, as part of the effort to revitalize the program activities and targets. Based on information available from Ministry of Agriculture and Rural Development (MARD), there are about 1,150 irrigation dams in need of urgent rehabilitation or upgrading until 2022. The program is currently being led by MARD Central Project Office (CPO), in collaboration with the Ministry of Industry and Trade (MoIT), the Ministry of Natural Resources and Environment and Provincial authorities with budget support from the national Government.

The Dam Rehabilitation and Safety Improvement Project (DRSIP) is designed to improve the safety of the dams and related works, as well as the safety of people and socio-economic infrastructure of the downstream communities. The project will also support Government to ensure a more holistic, basin level integrated development planning to improve institutional coordination, future development and operational safety. The DRSIP objectives are to provide a mix of both structural and non-structural measures to selected dams. Structural measures include the physical rehabilitation and upgrading safety work of existing dams and appurtenant structures, including instrumentation and associated dam safety plans. Such physical works represent the largest part of the project budget (>80%).

Structural measures have been proposed for 442 dams in 34 provinces. These dams were identified through an iterative, consultative prioritization process with the national authorities and provincial agencies.

The paper describes the main findings based on inspection and rehabilitation of about 20 dams currently evaluated by the International Dam Safety Panel of Experts.

1. dr SiP OBJECTiVES

The DRSIP objectives are to provide a mix of both structural and non-structural measures to selected dams.

Structural measures include the physical rehabilitation and upgrading safety work of existing dams and appurtenant structures, including instrumentation and associated dam safety plans. Such physical works represent the largest part of the project budget (>80%).

Structural measures have been initially proposed for 442 dams in 34 provinces, see Figure 1.1 below. These dams were identified through an iterative, consultative prioritization process with the national authorities and provincial agencies. The majority of those identified during preparation are classified as small dams, with 71% being less than 15m in height and with storage less than 3 MCM (see Section 4 below for classification). Ten provinces account for 50% of all dams. There is a total of 104 dams >15m in height. Large dams are found in 29 of the 34 provinces, with 50% of all large dams found in the eight provinces. 39 dams have storage in excess of 3MCM. The majority of the dams for which data exists were constructed more than 15 years ago, with 50 percent constructed between 1970 and 1990.

Non-structural interventions have been proposed to support a range of national institutional and regulatory measures, as well as pilot specific basin level measures. These basin level measures are aimed at integrating dam and reservoir operations, improving data collection and information management within the basin context and facilitating specific coordination and governance mechanisms between sectors within the provinces as

1. Chairperson of the Dam Safety Panel of Experts, Arup, London, UK

2. Vice Chairperson of the Dam Safety Panel of Experts, Thuyloi University, Vietnam

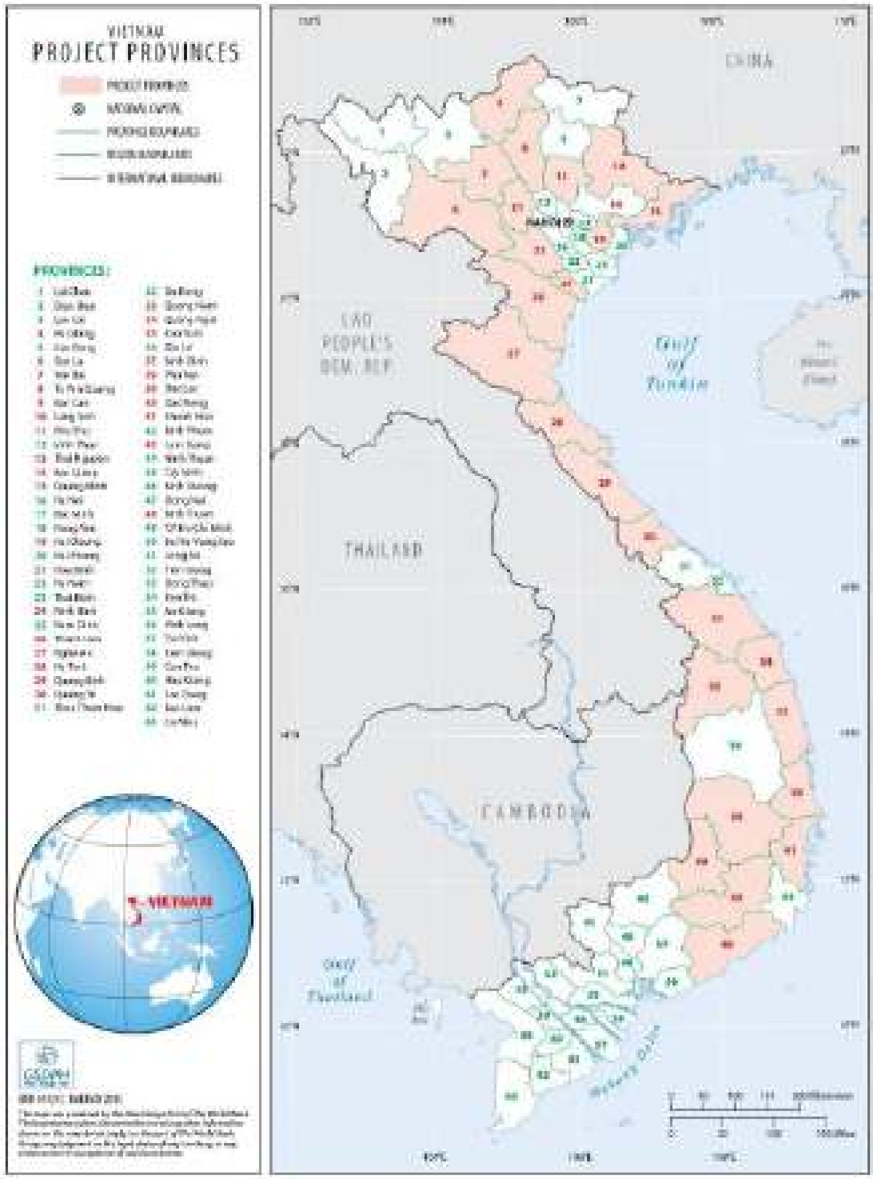


Fig. 1.1 : DRSIP Project – Map of Provinces where dams are located

well as between provinces to introduce a more holistic, long-term approach.

The project budget is estimated to US$ 443 Million; 93.3% of the budget is provided by the World Bank (WB) credit (93.3%) with 6.7% of the project budget is co-funded by the counterparts' funds. The credit agreement with the WB was signed on 8 April 2016, with a closing date 30 June 2022.

2. dr SiP COMPONENTS

The following are the DRSIP components:

Component 1 : Dam Rehabilitation (US$ 412 million). It is expected that 442 priority irrigation dams with reservoir capacity of more than 0.2 MCM and design grade from Grade IV to Special (Dau Tieng reservoir) will be rehabilitated. Large dams will be supported with Emergency Preparedness Plans (EPPs) and Operation & Maintenance (O&M) plans. In addition, the component shall support development of safeguards including: Environmental and Social Impact Assessment (ESIA), Resettlement Action Plan (RAP), Ethnic Minorities Development Plan (EMDP) to minimize negative impacts during project implementation.

Component 2 : Dam Safety Management (US$ 20 million). The component directly supports MARD, MoIT and MoNRE through implementation of non-structural measures, completion of legal framework, improvement of policies and proposal of sanctions for implementation. It also supports implementation of the model for 1 to 2 basins on integration of dam safety management with disaster management through implementation of regulations on institutions, policies, hydromet system equipment and information, information sharing mechanism between management agencies and dam owners and coordination practice of inter-reservoir operation in the basins. Development of reservoir management model with community participation and appropriate financial mechanism towards sustainability in investment. The component also provides support for monitoring and technical assistance of line agencies, management agencies and DSPE as required by the WB.

Component 3 : Project Management (US$ 11 million). This component supports financial provision for project management, audit (independent and financial statement), and technical assistance for project implementation. There are 4 provinces that have never participated in Official Development Assistance (ODA) projects, 13 provinces that are implementing for the first time and 17 provinces (50%) that are experienced in implementing ODA projects, therefore the component shall spend a part of the budget for strengthening capacity of management units through training activities, workshops and study tours.

3. dr SiP COMPONENT 1

Under this component 442 priority dams will be rehabilitated through 34 Provincial Project Management Units (PPMUs) and MARD. The Component 1 includes the following programme:

Phase 1 :

- Includes 12 first - year priority subprojects from 11 Provinces, and
- Around 250 subprojects for the following years

Phase 2 :

- The remaining subprojects

Out of 12 first - year priority dams, seven are classified as Large Dams. Also, only for one subproject, namely Song Quao Dam (Large Dam) in Binh Thuan province (see section 7 below), has been funded by the WB; the remaining 11 first-year subprojects have been funded by the counterpart funds.

4. Pr OJECT OPEra TiON Ma Nua L

Prior to commencement of the project a Project Operation Manual (POM) was prepared. The POM provides classification of dams and requirements for different dam. The POM also refers to applicable guidelines and standards that need to be applied for dam safety reviews. Requirements from the POM relevant for dam safety review are summarised below.

4.1 Classification of Dams

The POM defines Large Dams by combining requirements of WB OP 4.37 and Vietnamese standards, as follows:

Large Dams are:

- H>15m
- 10m<H<15m, Storage > 3 million m3
- 10m<H<15m, Crest length > 500m
- 10m<H<15m, Spillway capacity > 2000 m3/s
- 10m<H<15m, with special design complexities (e.g., large flood handling requirements, location in zone of high seismicity, retention of toxic materials) and a large number of people at risk in downstream area,
- H<10m if they are expected to become large dams during operation

Small Dams are:

- Dams below the aforementioned thresholds of large dams (which means normally H< 15 m), and subject to OP/BP4.01(Environmental Impact Assessment). This category includes, for example, farm ponds, local silt retention dams, and low embankment tanks.

4.2 Choice of design and Check Floods

The POM recommends the following:

- Use Vietnamese Standards (see Table 4.1 below);
- Use POM (see Table 4.2 below).

Table 4.1 : Recommended Design and Check Floods - Vietnamese Standards

Frequency of Flood	design grade				
	Special	i	ii	iii	iV
- Design flood frequency (%)	0.10	0.50	1.00	1.50	2.00
- Year return period (year)	1000	200	100	67	50
- Check flood frequency (%)	0.02	0.10	0.20	0.50	1.0
- Year return period (year)	5000	1000	500	200	100

As it can be seen from Table 4.1, a maximum Check Flood has a return period of 1 in 5,000 years, for the Special Design Grade dam.

1. Dam Design Grade in accordance with the Vietnamese Standards

Table 4.2 : Recommended Check Floods - as per POM

The number of households in the downstream (household)	Extreme flood frequency
> 10,000	PMF
1,000 ÷ 10,000	0.01% ÷ PMF
25 ÷ 1,000	0.01%
< 25	0.1%

As it can be seen from Table 4.2, a maximum Check Flood could vary from 1 in 1,000 years to the Probable Maximum Flood (PMF), depending on the downstream population at risk.

4.3 Specific Actions for Large and Small Dams

The following are the recommendations (as per OP 4.37) for Large Dams and High Hazard Dams in the POM:

- Prepare and submit a Dam Safety Report (DSR);
- DSPE to review dam safety conditions;
- Appoint Design Consultant for Rehabilitation and Dam Safety Improvement Works;
- Prepare Construction Supervision & Quality Assurance Plan (i.e. CSQA Plan);
- Prepare O&M Plan;
- Prepare Emergency Preparedness Plan (EPP).

For Small dams:

- Generic dam safety measures designed by qualified engineers;
- A Dam Safety Inspection Report (DSIR) to be prepared and reviewed by the DSPE;
- For small dams, the need for a simple O&M and an EPP should be reviewed;
- For dams above about 10m in height with significant downstream hazard a simple O&M documentation to be in place and an EPP in a simplified manner.

The POM details what needs to be done during Design, Implementation and O&M phases. It provides contents that inspection, reservoir operation documents would need to include. Contents of Dam Safety Report for large and small dams are also provided in the POM. For large dams' contents

Roles and responsibilities of the various entities are also defined in the POM.

5. DAM SAFETY PANEL OF EXPERTS

The Dam Safety Panel of Experts (DSPE) has been established by the Client to provide independent review and recommendations to the Client for ensuring that safety issues of the DRSIP to be financed by the WB are adequately addressed in terms of design, construction, operation and maintenance as required by the Dam Safety Safeguard Policy (OP4.37) of the WB and GoV.

The DSPE was established in February/March 2017 and it is to be maintained throughout the project implementation phase and even the first period of operation phase. The DSPE comprises three International and four National Experts; the authors of this paper, namely Ljiljana Spasic-Gril and Dr. Tam Sy Ho are the Chairperson of the DSPE and the Vice Chair respectively.

Since establishment, the International DSPE visited 19 dams during visits in 2018 and 2019 and reviewed design documentation related to these dams. The National DSPE accompanied the International DSPE during the visits, and also reviewed documentation for 321 dams (70 Large Dams and 251 Small Dams) and visited some of the dams. The visits of the International DSPE focused on the dams that are considered by the Client and the WB to be the most complicated for the rehabilitation.

6. FIRST MISSION BY THE DSPE AND SUMMARY OF MAIN FINDINGS

During the first mission in October 2018 the DSPE visited and reviewed design documents for five selected dams. One dam, Phu Vinh Dam (Classified as a Large Dam), h=27m, V=22.5Mm^3 L=1776m, is one of the 12 first - year priority dams. Other four dams visited are from Phase 1of the project, with three dams being the Large Dams.

A summary of the main findings related to the design/ review process, documents reviewed, and the dams inspected is presented below:

1. First-year priority dams: Phu Vinh Dam was visited by the DSPE during this mission; the most significant comments on the design were related to the choice of the Design and Check Flood and spillway capacity to discharge these floods, and the available freeboard. The original Check Flood was 431m^3/s, while, in accordance with the POM, the Check Flood should be $Q_{0.01\%}$ = 1770m^3/s. The DSPE stated that the Design and Check Floods were significantly underestimated, and the current design was not adequate. It was recommended to:
   - Urgently set up a procedure for the reservoir operation prior to the floods in order to provide sufficient flood routing capacity for the Check Flood;
   - Estimate households at risk downstream of the dam – initial estimate should be carried out by using the rapid method from the Guidelines to confirm the number of households at risk and the Check Flood to be used; check capacity of spillway and freeboard for the Check Flood; study feasible options for provision of the additional spillway capacity or storage to meet the flood requirements and implement the best option;

2. For the other four dams visited the following are the main recommendations:
   - Confirm the Check Flood based on the d/s hazard, adequacy of the spillway capacity and freeboard for the Check Flood; and if necessary, implement structural measures (but also see the following bullet point)
   - Check dispersive property by a combination of methods (Crumb, Pinhole, Double hydrometer and chemical); provide appropriate stabilization method by lime or gypsum and/or a combination of geotextile filter and stone pitching for the d/s slope;

3 As the current Vietnamese Guideline for the Seismic Design only defines accelerations for 1 in 475 year return period earthquakes, it is recommended to undertake seismic assessments of Large Dams in accordance with requirements of ICOLD Bulletin 148, i.e. check the dams for an OBE and SEE earthquakes; these assessments shall also include checks for susceptibility of the fill and foundation material to liquefaction, as for some dams fill material is largely composed of silty sand;

4 The DSPE is concerned about the capacity of the local Consultants to undertake the PMF estimates, dam break and seismic analysis. A possible training should be arranged in these fields; the training can be delivered by the DSPE members (National and International);

7. SECONd MiSSiON BY THE dSPE aNd SuMMar Y OF MaiN FiNdiNgS

During the second mission in October 2019 the DSPE visited 14 dams; nine dams are classified as Large Dams and five are classified as Small Dams in accordance with the POM.

Two dams from the first-year priority dams, namely Song Quao Dam (Large Dam) and Phu Vinh Dam (Large Dam), were visited. For these dams rehabilitation works are ongoing. Phu Vinh Dam was also visited during the first mission and was re-visited during the second mission to check implementation of the DSPE's recommendations.

Dau Tieng Dam in the Tay Ninh Province (Large Dam) has also been included in the second DSPE's mission. This dam has been classified as a Special Class Dam in accordance to the Vietnamese Standards; the dam is the largest irrigation dam in Vietnam that supplies water to more than 100,000ha of farmland, but it also supplies water for industrial and domestic use in Ho Chi Min City. The dam was commissioned in 1985. It has an average height of 28m, volume of 1,500Mm^3 and the crest length of 28,100m. The Check Flood in accordance with the Vietnamese standard is 1 in 5,000 years flood estimated to be 2,836m^3/s; however, the Feasibility Studies are currently being undertaken and the PMF has been estimated to be around 3,250m^3/s.

A summary of the key recommendations in the interest of safety, related to the dams inspected during the mission are presented below:

1. A large number of dams visited will have either the existing spillway widened or modified into a labyrinth weir, or a completely new emergency spillway proposed/ being constructed. Figure 7.1 below shows an emergency spillway just been constructed at Phu Vinh Dam (as recommended by the DSPE during the first mission). Figure 7.2 below shows a widened spillway at Khe Che Dam, which was very nearly overtopped during the 1995 flood. This clearly indicates insufficient spillway capacity for Design and Check Floods, which were originally estimated by the Vietnamese standards;

Fig. 7.1 : Newly constructed emergency spillway at Phu Vinh Dam

Fig. 7.2 : Khe Che Dam: the existing spillway has been widened (the white line shows the side wall of the original spillway)

2. Song Quao Dam, a Large Dam in Binh Thuan Province: this dam was constructed in 1980s and it comprises two main dams (left & right embankments), three saddle dams (No.1-3), gated spillway and irrigation intake. The reservoir volume is $81Mm^3$ and the maximum height of the main dams is 40m. The original Check Flood, estimated based on the Vietnamese standards, was 1,153m3/s and the Check Flood estimated in accordance with the POM, is $1,358m^3/s$. In order to provide an additional flood discharge outlet, an emergency spillway is to be constructed. However, although the main rehabilitation works are under way, the works on emergency spillway have not started yet because of the land take issues with the Forestry Department. The DSPE recommended that this situation is resolved as soon as possible; it is recommended that the contractor prepares a plan of emergency measures for the situation when the rehabilitation works are ongoing and there is no emergency spillway in place;
3. Dau Tieng Dam, the largest irrigation dam in Vietnam: the DSPE recommended that the PMF estimates are checked as they appear low; also, the bathymetric survey has never been done for this reservoir which was commissioned in 1985 – the DSPE strongly recommended that this survey is done so that height/storage curves for the reservoir could be updated; all the current flood capacity calculations are based on the original storage figures and largely vary; it is known that sand was mined from the reservoir, therefore sedimentation is clearly an issue;
4. For many dams visited seepage through the dam body, foundation or both was an issue. A typical anti-seepage measures proposed are a grouting wall. However, for many dams reviewed, the wall does not penetrate sufficiently into impermeable strata and will need to be deepened;
5. For homogeneous embankments that were constructed of dispersive soils need to ensure that testing is done for dispersion potential of the new embankment fill;
6. No monitoring instrumentation was envisaged for dams that are classified as Grade III and IV in accordance to the Vietnamese standards - the Panel recommends that a water level measurement gauge and a “V” notch weir at the lowest point of the drain at the d/s toe are provided as a minimum.

aCkNOWLEdgEMENT

The authors would like to express their gratitude to the CPO of MARD for approving publication of the paper.

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

challenges in execution of concrete Face Rock-Fill dams in Emerging Economies

S.C. Mittal[1], imran Sayeed[1], u.V. Hegde[1] and Senthil raja [1]

aBSTraCT

It is strongly believed that Concrete Face Rockfill Dams are proposed when the bed rock is not available at reasonable depth for placement of concrete dam. However, this is not the actual case. CFRDs offer economic solutions for suitable dams for power generation, irrigation or water supply in cases where there is a dearth of natural construction material either for concrete aggregates or for impervious core. Placement of CFRDs across rivers with thick RBM is definitely an added advantage particularly in Himalayas.

In India the first CFRD was constructed as a part of Dhauliganga Stage I hydroelectric power project in Uttarakhand, India. This 56m high dam was completed with a plinth on river deposits of 70m thickness and on bedrock on the banks.

DMR has carried out design and engineering for 60m high CFRD for 1200 MW Teesta III hydroelectric power project in Sikkim, India. In this case an innovative layout for spillway on both the banks and spillway tunnel on right bank were proposed.

Small dams have been developed for irrigation purpose in Nepal and Cambodia. The Dhap dam in Nepal has been completed with central spillway as bed rock of gneiss was available at a shallow depth. In case of Stung Tasal CFRD in Cambodia the 21m high dam also comprised central spillway as the sound rock was available at shallow depth below the weathered granite. At this project suitable impervious core material was not available for the earthen dam earlier contemplated. The paper discusses the advantages as well as challenges posed by CFRDs as a viable solution.

1. iNTr Odu CTiON

Concrete face rock-fill dams have an old history contrary to the popular belief that the concept is new. However it is a fact that modern period of CFRD from 1970s saw emergence of this type of dam as a viable alternative and a number of dams over 80m height were constructed. Since then, however, the technique has come of age and examples of very high CFRDs over 200 m are now available and have been successfully commissioned. In fact, after 2000 onwards a number of CFRDs over 140m have been constructed. Shuibuya dam in China at 233m is the highest commissioned CFRD in the world. In the pipeline the 315m high Rumia dam in Tibet Region, China is also proposed to come under construction.

The first CFRD can be traced to Sierra Naveda, California in 1850s. The segregated and dumped rock-fill as used earlier had a high compressibility and therefore affected the stability of concrete face as well. The damages to concrete face and consequent leakages make this type of dam unpopular. Subsequently in 1950s with the advancement of vibratory roller to compact the rock-fill, CFRD gained ground.

Clearly CFRDs have some advantages in the use of locally available material, good adaptability to site conditions and in economic considerations. Prior to 2000, empirical approach was used for design. Problems such as cracks in face slab and cushion layer, separation of face slab in cushion layer, concrete rupture along vertical joints, between face slabs and excessive leakage have been experienced in CFRDs. Later design approaches considered all aspects such as compressibility of foundation material as well as that of embankment material and many problems have been resolved.

The practicability and cost aspects with regards to CFRDs particularly in areas where there is heavy rainfall or in places where impervious clay core material is not available make such structures as sought after particularly in emerging economies.

2. FOu Nda TiON CONSid Era TiONS

In ICOLD Bulletin No 141 (2010) concepts for Design and Construction have been discussed in great detail. It is widely believed that CFRD can be placed in any type of foundation which can be alluvium also. While it is true that many CFRDs have been built when bedrock is not available in the river bed, ideally plinth should be resting on bedrock foundation. Alternatively if bed rock is not available in the river bed it should be either exposed on either banks or available at a shallow depth. In case

1. DMR Hydroengineering and Infrastructure Works, Faridabad, India

rock is not available both in the river bed and also in banks the plinth will neither be resting on rock nor could be tied to the abutments effectively. Moreover, seepage control below the dam as well as on the banks shall be a big challenge and such site shall not be technically or economically feasible.

It also pertinent to bring out here that a high CFRD say above 150m height is not desirable on weak foundation. However, if geotechnical parameters are known well in advance a higher consolidation effort shall be required to raise the safety factor and accordingly a higher construction period shall be necessary. It should be appreciated that for CFRDs constructed on bedrock, only the settlement of rock-fill affects the plinth, concrete face slab, joints etc whereas in alluvial foundation, the situation is more complex as the settlement at the crest is the result of settlement of rock-fill plus compression of foundation material.

The plinth is normally founded on hard, non-erodible fresh rock that can be treated by grouting. With treatment, weathered jointed rock is also acceptable. Joints need to be cleaned before pouring of foundation concrete for plinth and also it is necessary to prepare the geological map of foundation for construction record just as done for concrete gravity dam foundation. Other measures such as backfilling of cracks etc are also required. Plinths have been constructed on alluvial soils also in several projects. The height of such dams varies from 28 to 106m. It needs to be ensured in alluvial foundation that materials are stable under all loading conditions and deformations in foundation are small such that resultant moments in joints in the plinth or cracking of concrete face will not lead to excessive seepage (ICOLD 2010). Materials should have low compressibility and be stable under seismic loadings. It may be noted that the plinth connects the foundation with concrete slab and should be stable.

It has been advocated (Materon 2002) for ascertaining the width requirement of plinth RMR system (Bieniawski 1982) shall be used. In this manner external and internal plinth combined width can be devised.

3. EMBa Nk MENT MaTEria L

The availability of suitable material plays an important role in selection of type of dam. Economic considerations are important as this is the main portion of dam and if transport distances are large the dam itself could become unviable. The CFRD accommodates to the maximum extent locally available material.

Earlier in CFRDs a thin zone of dry masonry which was placed by crane constituted the support base for concrete face. Later with the advent of compaction equipment for rock-fill this practice was abandoned.

The table given below has been developed based on in principle main zones for concrete faced rock-fill dams (ICOLD 2010). Various countries have their variations also.

Table 1 : Typical Embankment Zones for CFRD

Zone	Material	Placement	Purpose
1A	Fine grained cohesion-less silt and fine sand with isolated gravel & cobble sized rock particles up to 150 mm	Placed in 200-300 mm layers and lightly compacted	Source material if required can migrate through cracks
1B	Random mix of silt, clays, sand, gravel and cobbles	Placed in 200-300 mm layers and compacted	Protection to Zone 1A
2A	Sand and gravel filter located within 2-3 meters of perimeter joint. Material quality is nearly equal to concrete aggregates	Placed in 200-400mm layers and well compacted by vibratory compactors	Filter material, secondary defence against leakage
2B	Sand and gravel size particles horizontal width varies from 2m to 4m depending on height of the dam. Material quality is nearly equal to concrete aggregates	Placed in 400 mm horizontal layers compacted with 4 passes of 10 ton smoothdrum vibratory roller	Provides support to concrete face
3A	Rock-fill with size 400 mm or less. Horizontal width varies from 2m to 4m depending on height of dam Rock-fill obtained from quarry or from crusher minus 300-400 mm size	Placed in 400 mm layers with 4 passes 10 ton heavy roller	Transition between Zone 2B and 3B.
3B	Rock-fill with maximum size 1000 mm	Placed in 1000 mm thick layers	

The above table has been developed from the ICOLD Bull. 141 and should serve as a guideline for embankment zones. Some countries have however developed their own standards and there could also be variations depending upon height of the dam and local availability of materials.

The CFRD therefore has a great adaptability for site conditions and material availability. Nevertheless certain basic criteria need to be ensured particularly when the height of dam increases.

Some examples below give the analysis for selection of CFRD dams and their importance as solutions for difficult sites in India, Cambodia and Nepal with which the authors have been associated:

4. dHau Liga Nga HYdr OELECTri C Pr OJECT STag E i, uTTara NCHa L, iNdia

Dhauliganga hydroelectric power project stage I is located in Pithoragrh District of Uttaranchal State close to India's border with Nepal. It is 500 km north-east of New Delhi and comprises of India's first 56m high Concrete Face Rock-fill Dam besides 5.6 km long head race tunnel and an underground power station having installed capacity of 280 MW. The dam is built across Dhauliganga River near Chirkila village and the power station discharges tail water in a stream close to Kali or Sharada River flowing on Indo-Nepal border. The construction was started in the year 2000 and the project was completed in 2005 highlighting one of the timely commissioning of hydropower plant in arduous Himalayas.

Geologically the project is located in Lesser Himalayas within a single rock formation locally known as Chiplakot Crystalline bounded by two thrust faults. The main central thrust is also 7 km upstream of the dam site. The bed rock at the dam site is biotite gneiss and schist as exposed on both the banks. In fact the left bank rises steeply after a small rocky spur that has been used to accommodate the left bank spillway. The river bed was extensively explored by six drill holes and other techniques in the investigation stage and it was found that bed rock is almost 70m below the existing river bed.

Alternative dam sites were also investigated in the vicinity but there was no indication of shallower bed rock profile. In fact the valley span also increased at other sites. The options were to excavate deep into the river bed for a concrete gravity dam or to have rock-fill dam. However there was lack of impervious clay deposits in the vicinity of dam site and it was difficult to transport the only clay deposit from about 50 km due lack of proper access road. Moreover the average annual rainfall in Pithoragarh district is 1500 mm out of which 80-85% falls during the monsoon season between June and September. The intensity of rainfall may also be particularly more severe during any period in monsoon as was later seen in 2013 floods when during a week in August more 230% above normal precipitation occurred. All these factors added uncertainty as well as additional costs in favour of a conventional rock-fill or a concrete dam. As such, it was decided after careful consideration to design and construct a Concrete Face Rock-fill Dam at Dhauliganga

4.1 Concrete Face Rock-fill Dam

The CFRD at Dhauliganga Stage I power plant is 56m high and 270m long at crest level excluding the spillway which comprises of two bays 10m high and 5m wide. The spillway is designed for a flood discharge of 3210 cumecs with flip bucket for energy dissipation. It was proposed as low level type for the combined function of flood release and flushing during monsoons of sediment accumulated in the reservoir during monsoons.

On the right bank where the spillway has been located on a rock pedestal, 500m long spillway tunnel also caters to the flood discharge (Figure 1)

Fig. 1 : Dhauliganga Hydroelectric Project Stage I: Layout of CFRD

The catchment area is 1360 km^2 with diversion tunnel catering to 1:30 year flood for 1335 cumecs discharge. This arrangement ensured smooth construction of the dam without any flood related problems. The dam top is at El 1351m, and FRL at 1345m thus leaving a free board of 6m. Besides this 1m high parapet wall is also constructed,

The dam section is provided with 1.5H:1V both upstream and d/s slopes. As seen in Figure 2 more gentler slope 2.5H:1V is provided at the u/s as well as d/s toe. The different zones along with the thickness of placement of layers in the main dam 3B and 3C of 80cm and 120 cm respectively are indicated in the cross section. The rock-fill material for this dam came from the locally available biotite gneiss rock.

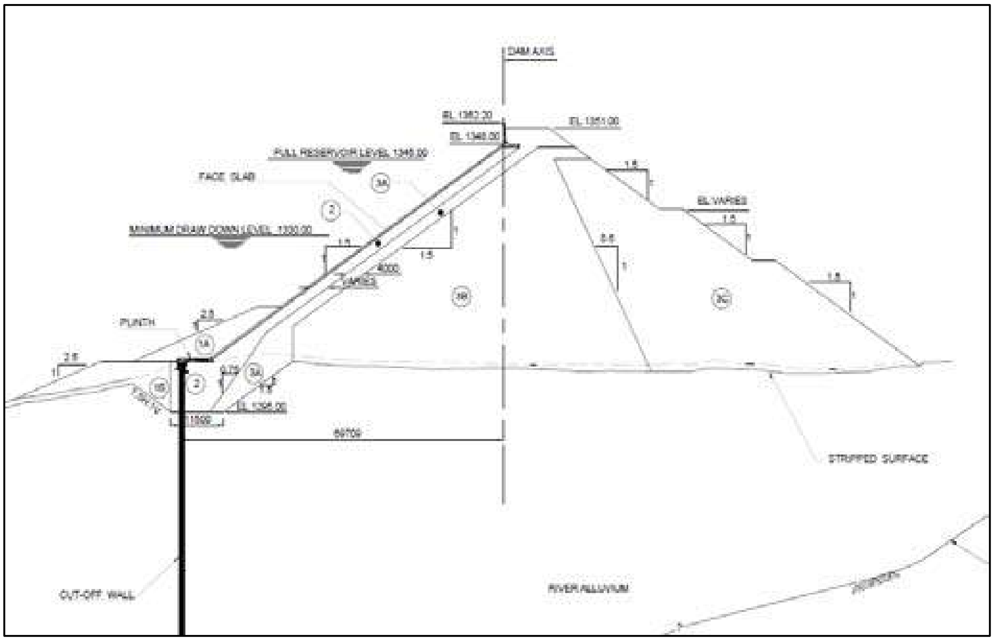


Fig. 2 : Dhauliganga Project: CFRD Section

The plinth in the river bed portion is connected to bed rock by means of plastic concrete diaphragm wall of 1m thickness thus precluding any possibility of seepage below the dam foundation which is placed on river alluvium. The river-fill material consisted of large sized boulders embedded in silty and sandy matrix having a permeability of 10-4 to 10-5 cm/sec. The alluvium fill extended down to a depth of 60m below the bed level of the river and consists of a upper layer of sand and gravel with pebbles and boulders, a central layer of sand lens upto 20m thick, and underlying zone again of sand and gravel with pebbles and boulders. Boulders of size of 2 to 3 m diameter embedded in the sand gravel layer exist in the river alluvium. Standard penetration tests were conducted for assessment of liquefaction potential and same was ruled out after detailed studies.

The plinth on the left bank continued and abutted into bed rock whereas on the right bank spillway was present and thus on the right flank the CFRD abutted against the spillway concrete pier wall. There were apprehensions regarding placement of plinth on river borne alluvium. However, examples such as Campo Moro dam in Italy, Kekeya and Tongjiezi dams in China, Chakoukane dam in Morocco, Santa Juana and Puclaro dams in Chile were studied and looking at the clear advantages of CFRD the decision was taken.

It was resolved that with careful design details of plinth and plinth cut off connection, it was possible to use river alluvium with boulders as foundation for the CFRD. The performance of Dhauliganga was severely tested during flood of 2013. Although there were damages to the spillway glacis due to heavy bed load the CFRD remained intact barring minor damages.

The specifications of the concrete face are as follows:

- Thickness of concrete face slab varied from 30 cm at top and 45 cm at the bottom
- Strength of concrete 25 N/mm2 at 28 days, 40 mm aggregate and 100 mm slump
- Reinforcement in each direction was specified as 0.35% of the concrete

5. TEESTa iii HYdr OELECTri C Pr OJECT, Sikki M, iNdia

Teesta III hydroelectric power project is located near Chungthang village in North district of Sikkim and harnesses the water from Teesta River to generate 1200 MWs of power. The site is located in Great Himalayas upstream of Main Central Thrust in Central crystalline consisting of hard gneiss with schist layers.

Teesta is the most important drainage system of Sikkim. The river rises at El 5280 m in the glaciated and snow bound Himalayas and actually forms by joining of two main tributaries the Lachen Chu and Lachaung Chu just 400 m upstream of dam site. The catchment area up to dam site is 2787 km^2 out of which 70% is snow bound. The diversion discharge is 1028 cumecs and flood discharge is 7000 cumecs.

During the feasibility stage a concrete gravity dam was proposed with huge excavation down to a depth of 50m. This quantity of 18 lac cum of excavation for the dam pit and associated structures and combined with 8 lac cum of concrete neither suited the site technically nor construction wise it could be economically scheduled and executed without major hiccups. Thus on techno economic considerations once again CFRD proved to be an appropriate choice where instead of deep excavation the foundation could be laid on river-fill material for the 60 m high dam. As done in Dhauliganga, plastic concrete diaphragm wall was provided for a maximum depth of 50m to socket into largely symmetrically underground bed rock profile.

5.1 Concrete Face Rock-fill Dam

The CFRD at Teesta III is 60m high with 1.5H:1V slope on either side. The spillway consists of two spillway tunnels of 10 m dia and 1.0 km length on left bank and two gated bays of 11x14m each as well. It also has an innovative 1 km long silt flushing tunnel of 5m dia on right bank close to the power tunnel intakes. The spillway bays, tunnels on left bank and SFT on right bank are designed to pass 7000 cumecs discharge. In Teesta III the diversion tunnel is not plugged and is also used a spillway tunnel. For plan and section of Teesta III CFRD Figures 3 and 4 may be referred.

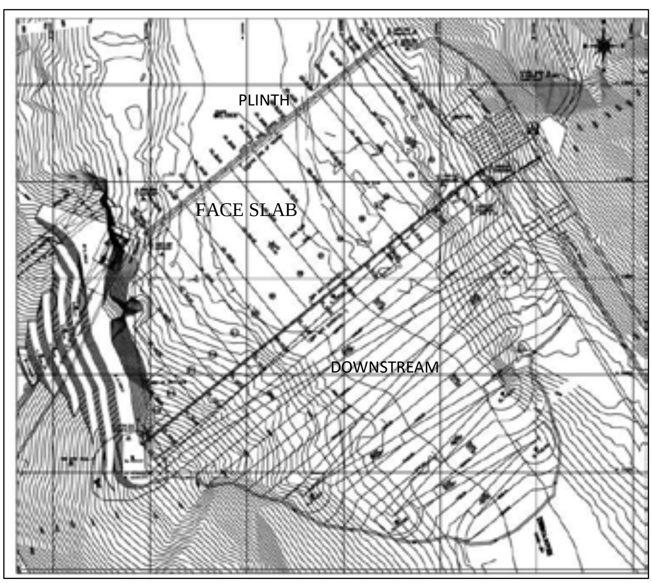


Fig. 3 : Teesta Hydropower Project Stage III : Layout of CFRD

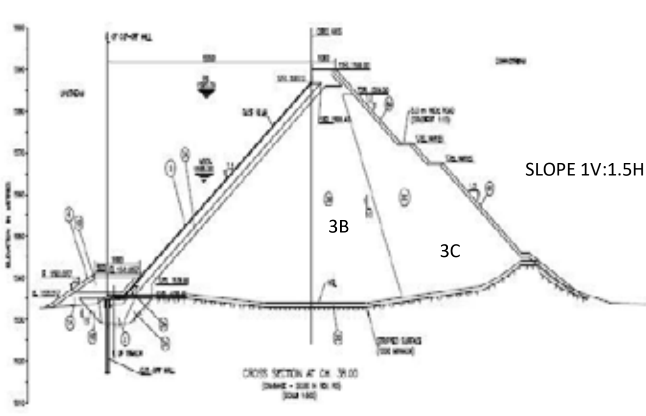


Fig. 4 : Teesta Project Stage III: CFRD Section

6. DHAP WATER SUPPLY PROJECT, NEPAL

Dhap Dam site is located near the famous tourist spot Chishapani about 40 km north of Kathmandu. It can be accessed by 20 km long all weather Kathmandu Sundarijal road and then by 21 km un-metalled road. The dam site is in Shivpuri hills at higher elevation and is in Shivpuri Nagarjuna national park. On the eastern side Sindhupalchok is present and on North Western side Nuwakotis present. Earlier a low dam was constructed by SNNP which is 350 m u/s of the dam site. A suitable site dam exists in lower reaches of Dhap valley where it narrows down. There is falter ground about 50m wide at the dam side with shallow streams flowing on either side near the banks.

Overall the proposed dam site is located within strongly metamorphosed basement rocks of the Higher Himalayan Tectonic Zone. Gneiss and schist are the two main rock types. Referring to “Engineering and Environmental Geological Map of the Kathmandu Valley”, in scale 1:50000 published by DMG, Nepal at the dam site Precambrian Shivapuri Gneiss Formation is present.

The Main Central Thrust (MCT) is present 5km north to the dam site at Patibhanjyang saddle. The Chishpani region was impacted by 2015 earthquake which indicated that the area is seismically sensitive.

At the dam site the Pre-Cambrian Shivpuri Gneiss formation is manifesting with mica gneiss, banded gneiss and biotite schist rocks with intrusions of muscovite granite. The weathering effect is pronounced in the rock. The top layer of bed rock below the organic soil had developed into residual soil due to long effect of weathering.

The purpose of construction of Dhap dam is to boost water supply in Bagmati river and eventually to Kathmandu in dry season. The project is being constructed by Department of Water Resources and Engineering, Bagmati river basin, Nepal through Guangzhou-Lama-Raman JV for which design was carried out. The scheme consists of main CFRD dam at the mouth of the valley and a saddle dam at the north east corner.

6.1 Concrete Face Rock-fill Dam

The 24m high and 190 m long dam with crest elevation at 2090.14 m would impound a small stream having a catchment area of 0.8 km^2 and reservoir storage of 1 MCM of water. The u/s and d/s slope of dam are kept as 1V:1.7H and width at crest being 8m and free board of 3m. The dam volume is 1,04,758 m^3. The discharge being very small diversion was achieved through a pipe. The plan showing layout of dam is given in Figure 5.

The plinth has been kept on bed rock on the banks and is secured by anchors.

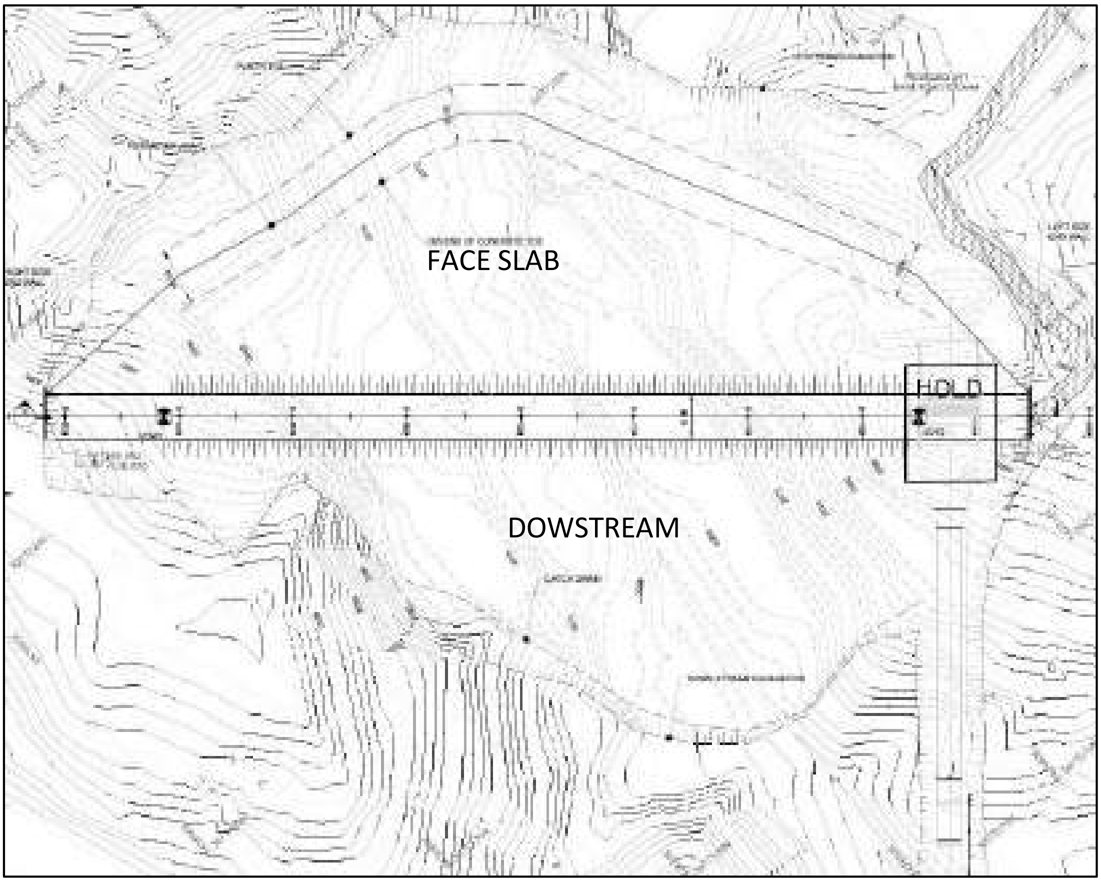


Fig. 5 : Dhap Water Supply Project: Layout of CFRD

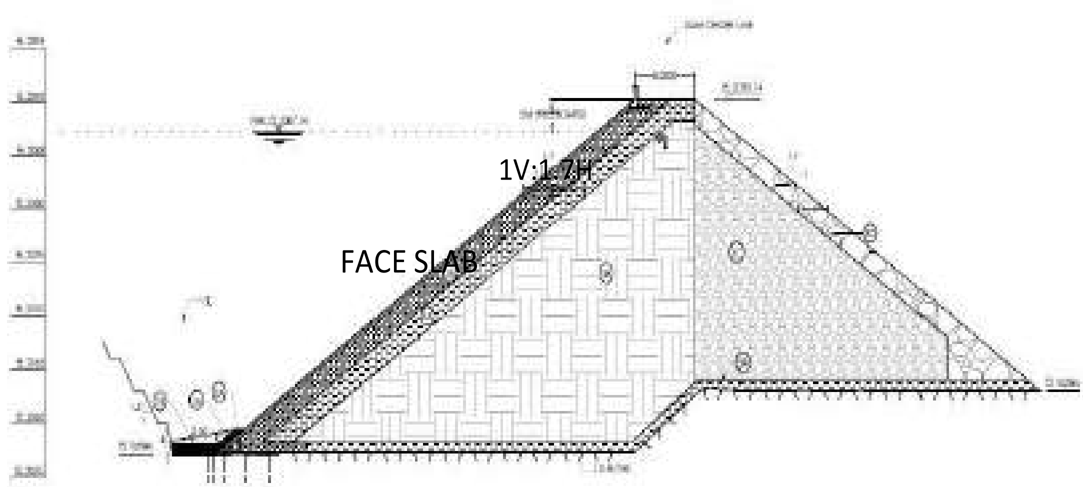


Figure 6 : Dhap Project: CFRD Section

7. STuNg TaSaL CFrd , CaMBOdia

Stung Tasal Dam is located in Aoral district in Kampong Sepu Province in Cambodia. It is included in overall development of Irrigation and drainage system and rehabilitation plan undertaken by Royal Government of Cambodia (RGC). Quite an extensive and detailed report on "Preparatory Survey for Irrigation and Drainage System Rehabilitation and Improvement Project in Kingdom of Cambodia" has been prepared by Japan International Cooperation Agency (JPIC) Nippon Koei Co Ltd for Ministry of Water Resources and Meteorology, RGC, The Kingdom of Cambodia. The climate and metrology, drainages, water availability in different basins and utilization through water resource projects for drinking, irrigation, tourism, fisheries and hydropower generation are discussed. In the southern central portion of the country the Stung Tasal dam is a part of 'The study on comprehensive agricultural development of PrekThnnot River Basin (Master Plan Study) 2005-08'. The site is in upper reaches on a Stung Tasal tributary of Prek Thnnot River. There are several projects in Prek Thnnot River basin out of which the Stung Tasal project was given high priority. It is being funded by Government of India for construction.

An agreement was signed in between MOWRAN, WAPCOS and Angelique International Limited (AIL) in Jan 2012.

As per feasibility report it was proposed to construct 21m high and 650m long rockfill dam across the Stung Tasal river to provide irrigation for an area of 10,000 ha. Besides, a hydropower station with an installed capacity of 750 KW at 60% load factor would be constructed about 70m d/s of the dam. The spillway was un-gated with a length of 90.5 m on the left bank, the inlet for irrigation sluices located on 20m long non overflow concrete section of right side of spillway and on left side of spillway power intake for penstocks would be housed on another 20m length of non-overflow concrete section. Benefits out of the scheme were (a) Irrigation for 10,000 ha, (b) electrical energy 4.0 million units and (c) flood moderation.

7.1 Concrete Face Rock-fill Dam

In the feasibility, a rock fill dam was envisaged but the investigations and testing revealed that suitable material for construction of rockfill dam was not available. The soil condition was found to be dispersive in the region due to which a concrete face rock fill dam was proposed. Finally the 21m high and 720m long CFRD was proposed and designed with two spillways and the same was completed in 2015 (Figure 7). The dam impounds water storage of 140 MCM. The project will immensely boost rice cultivation and fisheries in the region and would irrigate 10000 ha of area. It has been constructed with a line of credit of USD 30 million by Government of India.

The 720 m CFRD includes two spillways one in the middle of the river which is 45m wide with 3 bays and 3 under-sluices for irrigation discharges. The top of dam is at elevation 110.2m and the FRL is 108.2m. Another un-gated auxiliary spillway has been constructed on the left bank and the same is 30.5m wide with three bays and crest elevation of 108.2m.

The river valley at the dam site is U-shaped and wide but with well-defined banks. The river catchment up to the dam site is 465 sq km with an annual rainfall of raging from 3500 mm in the west to 1250mm in the east. The bed rocks at the dam site are quite heterogeneous with igneous, sedimentary and metamorphic rocks existing together. The strike of rocks is east-west with steep dips of 70 degrees. Some fractures are present within the formations but the left bank exhibited stronger rock conditions when compared to right bank. A shear zone was passing on the right bank.

The weaker bed rock conditions on the right bank were indicated by exploratory holes and found in the percussion drill holes carried out for grouting as well as in the excavation for plinth foundation on the right bank. At the upstream plinth, single row grout curtain has been placed extending down to 10m below the foundation level.

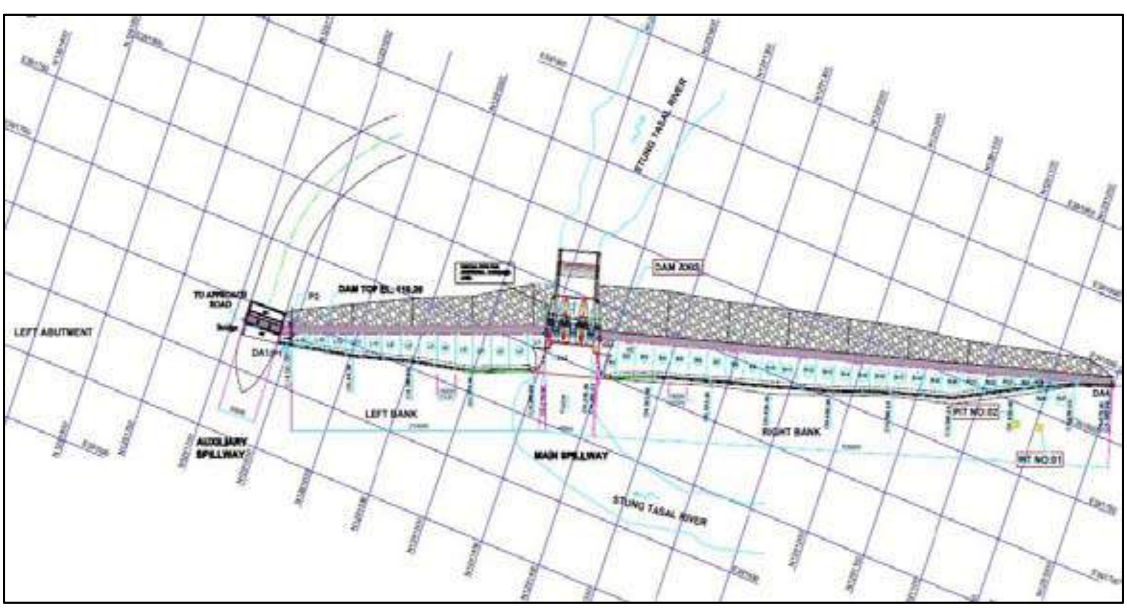


Figure 7 : Stung Tasal Project: Plan of CFRD

The main reason for the switch over to CFRD from conventional rockfill dam was that the material for clay core was not available. The impervious soil in the area was highly dispersive thus unsuitable for use in the impervious core.

Quartzite rock was used as rockfill and filter material which met the required specifications.

The face slab and plinth are of M25 grade concrete with the face slab being 250mm thick and underlain by 50mm thick M10 levelling concrete. The width of face slab panel is 15m.

A section of CFRD is given in Figure 8.

8. CONCLuSiONS

The CFRD dams in spite of being so adaptable to site conditions and materials for use in construction are not so popular amongst the water resource projects. World over out of 25 tallest dams only two are concrete face rock-fill/embankment dams and out of 50 tallest dams five are CFRD. Nonetheless, under construction category out of all major dams over 150m height 23.1 % are CFRD, 34.6% Embankment type, 30.8% are Concrete gravity and 11.5% are Concrete arch dams. Therefore, the engineering community appears to be growing in confidence about utility of CFRD structures.

In India all the CFRDs viz Dhauliganga Stage I, Teesta Stage III and Kishanganga belong to hydropower sector and fourth Pakal Dul which is 167m high is also in hydropower sector. There seems to be a lack of confidence about CFRDs in the irrigation sector. They could become a popular choice in irrigation and water supply also provided some of the challenges are overcome.

Out of the four cases discussed above in growing economies there were some common difficulties such as expertise in slip form shuttering for face concrete. As Dhauliganga stage I was the first CFRD in India it took a long time for adapting this type of design and gain acceptability from the evaluating agencies. The CFRD here offered solutions for the non-availability of impervious core material for rockfill dam, and also for deep bedrock in the river bed. The CFRD dam concreting for face slab and plinth is a specialized work and the same was overcome by going for international bidding and experienced agency. In projects like Dhap and Stung Tasal the availability of skilled agencies was a problem. The slip form for concreting of face slab and plinth concreting even though a small activity remains a challenge area as many construction agencies are not comfortable with the same as they have not executed such type of projects. As the concrete face is executed in panels the joints with copper stops gain significance. By international competitive bidding these problems can be overcome. A certain amount of caution is required for placing the foundation of tall CFRDs on overburden. Higher dams above 120m or so have not been placed on overburden. In any case loose gravel material or soil should be removed even for CFRDs also.

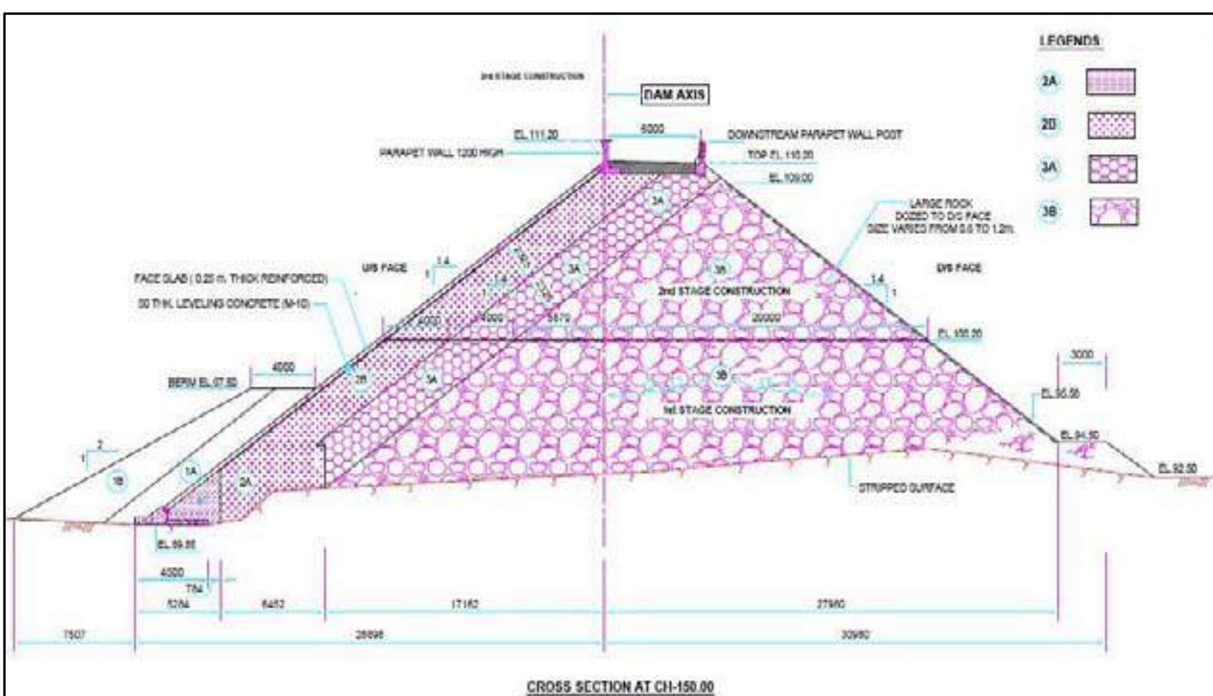


Figure 8 : Stung Tasal Project: CFRD Section

In Teesta III and Dhauliganga Stage I transport of hydrofrase cutter for execution of cut-off wall was an issue due to arduous terrain, narrow roads, sharp curves and inadequate bridges. The compaction of the rockfill material also remains an issue along with intricate design details of plinth etc. In developing countries facilities for specialized testing are not available with result that evaluations of rockfill or gravel material for construction are based on concrete aggregate tests. Consequently, many technical people believe that suitable material is not available which may not be the case for CFRD construction material. Another challenge is suitable place for finding the spillway especially when large discharge capacities are necessary.

Even though the above difficulties are there, CFRDs are having certain advantages such as placement of foundation either in overburden or on bed rock. This however is subject to height of dam and local conditions. Speed of construction and use of locally available materials is another big advantage that makes them attractive and economic. More awareness regarding design and quality testing aspects is necessary to make them acceptable and popular.

All the four cases discussed in the paper have resulted in not only technical solutions but have been cost effective also. It is suggested that they should be adopted more in irrigation and water supply projects as well.

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Save water today, secure your tomorrow

construction of the Kishanganga Hydroelectric Project concrete Faced Rock Fill dam, India

a. agarwal [1], M. Palmer [2] and Y. dadheech [3]

aBSTraCT

Kishanganga is the first mega hydropower plant located in the north western Himalayas, in the Gurez valley of Kashmir region of India. The Concrete Faced Rockfill Dam at an altitude of about 2400m, has a height of 33m and a crest length of 145m. The concrete face is tied to a 31m deep plastic concrete cut-off wall. Construction in the remote and mountainous terrain of Kashmir where the temperature drops below freezing for 4 months of each year, provides its own challenges. In addition, with few CFRD dams constructed in India, developing the trust and confidence of the owners and local community, was key to successful completion. The rock mass comprises fractured Panjal Volcanics and the abutments required investigations to assess joint shear strength parameters to allow assessment of stability and adaptation of rock slope design. A deep cut off wall in front of the dam made up of plastic concrete has been constructed using borehole drill and blast method to economize the cost and construction time with locally available technology. This paper presents the challenges and the solutions developed during the design and construction of the dam and in particular, the right bank plinth, extruded kerb, rock slope stabilization, face slab joints and cutoff wall.

1. Pr OJECT Ba Ckgr OuNd

1.1 introduction

The Kishanganga Hydroelectric Project is located in the Baramulla District of the Union territory of Jammu and Kashmir in north-west India. It is a run of river scheme which involves transfer of water from the Kishanganga River in the Gurez valley to the Bonar Nallah near Bandipore in the Kashmir valley. In 2009, the National Hydroelectric Power Corporation Ltd (NHPC) awarded the contract for the design and construction of the 330MW Kishanganga Hydroelectric Project to a joint venture of Hindustan Construction Company (HCC) and Halcrow (now Jacobs). The project would take nine years to complete with a capital value of contract as $554 million. As an engineering, procurement and construction contract, the joint venture was responsible for all civil and associated infrastructure works; supply, installation, testing and commissioning of all hydro-mechanical and electromechanical plant and machinery components including generating units. Jacobs were responsible for the detailed design of the civil works, co-ordination with the electrical and mechanical designer/contractor, and providing site design liaison and coordination.

1.2 geology of the dam Site

The bedrock geology of the dam site comprised andesitic rocks from the Panjal Volcanics Group. The dam was founded upon alluvial deposits, which were approximately 30m thick comprising boulders, cobbles and gravel in a sand and silt matrix.

1.3 Concrete Faced Rockfill Dam

The Concrete Faced Rockfill Dam (CFRD), has a maximum height of 32m, a crest length of 145m and a minimum crest width of 10m and the spillway on left of the dam has a 2000m3/sec capacity. The upstream concrete face is tied to the cut-off wall on the upstream end via a toe plinth slab. The maximum water level is retained at elevation 2390.0m with the dam crest at 2395.0m.

1.4 Headrace Tunnel

The scheme has a 665m gross head with the water passed via a 23km long headrace tunnel and steel lined high-pressure shaft to the underground powerhouse near Bandipore. The tunnel was constructed using drill and blast methods over 8.47km forming a 6.24m diameter horseshoe shape; with the remaining 14.53km length, 5.2m diameter segmentally lined circular section excavated using tunnel boring machine (TBM) technology. At depths of up to 1400m the TBM tunneling works represented a significant challenge and was the first TBM tunnel to be successfully constructed in the Himalaya (Swannell *et al*, 2016).

The anticipated squeezing conditions were such that, in some areas, it would not be possible to progress the TBM in the normal way and/or to provide a segmental lining of practicable strength to avoid overstressing without

1. Associate Director & Head, Water and Environment, Jacobs, India
2. Technical Director, Ground Engineering, Jacobs, UK
3. Senior. Engineer, Water and Environment, Jacobs, India

implementing special measures. Design and construction planning was therefore based on a risk management approach with contingency procedures and criteria developed to allow the risks to be managed effectively. The TBM was designed with specific features to reduce the risk of entrapment (Ariza et al, 2015). Special measures were adopted to reduce loads on the segmental lining included overcutting, pre-excavation grouting and consolidation grouting (Swannell *et al*, 2016).

1.5 Diversion Tunnel and Cofferdams for River diversion

The diversion tunnel comprised a 9.5m diameter concrete lined horseshoe tunnel 570m long and was constructed as a drill and blast tunnel with a design capacity of 1,000m^3/s on the left abutment of the spillway. On impoundment the diversion tunnel was closed by means of a bulkhead gate at its upstream end and a concrete plug was subsequently constructed within the tunnel.

An upstream cofferdam, with crest elevation El. 2384.0m, was built as a zoned rockfill embankment with an inclined clay core wall. Due to the thick alluvial deposits present, under-seepage was controlled by a grout curtain comprising of two rows of grout holes one meter apart each at 5m spacing. The downstream cofferdam, with crest elevation 2372.0m, is of a similar arrangement to the upstream cofferdam apart from the omission of a grout curtain as there was very little driving head in the upstream direction. The crest width of 7m enabled the crest to be trafficked during construction.

1.6 gated Spillway

The spillway is located on the left abutment and consists of the main spillway and the auxiliary spillway. The main spillway with a crest elevation of EL 2370m is a controlled chute spillway with three radial gates of 7.0m wide by 9.5m high clear opening and a flip bucket with concrete apron for energy dissipation at the downstream end. 1.3 m dia circular steel pipe of about 80m length for ecological release have been provided for the release of 9 cumec discharges throughout the year.

2. g ENEra L arra Ng EMENT OF THE da M

The dam comprises a zoned embankment. The upstream slope of the embankment is 1(vertical):1.75(horizontal) and downstream slope is 1:1.5 (Figure 1).

The concrete face included design to resist the ice cover as well as freeze thaw/thaw cycles and comprised 400mm thick 35MPa reinforced concrete forming slabs 10.3m wide with vertical shrinkage joints. The reinforcement represents approximately 0.4% of the concrete section in each direction for the slabs and was positioned to distribute uniformly the resistance to shrinkage and temperature cracking. Near the perimeter joint, reinforcement was increased to > 0.6 %.

At the planning stage of CFRD face slab design, a 350 mm thick concrete face slab was envisaged due to the limited head of water on the slab but also taking account of ICOLD guidelines and the boulder carrying trend of Himalayan rivers. However, NHPC's experience of damage on other dams during floods in Himalayan river resulted in an increase in the face slab thickness to 400mm together with and increase form 0.3% to 0.4% of reinforcement in the slab.

Seepage through the thick river-bed deposits is prevented by provision of a 1m thick plastic concrete cut-off wall having a maximum depth of 31m. The cut off wall is embedded 1m into the bed rock (Figure 2).

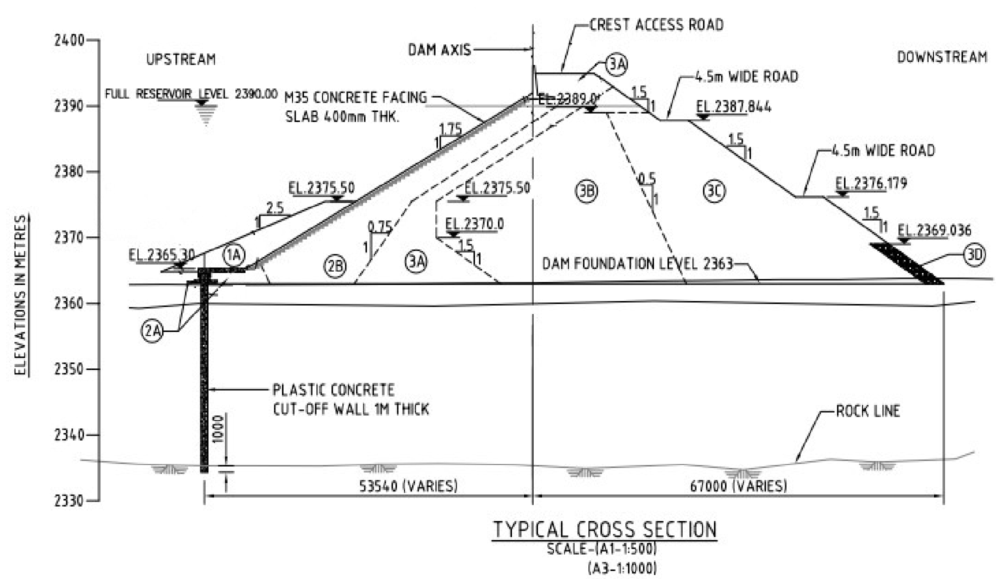

Figure 1 : CFRD typical cross section

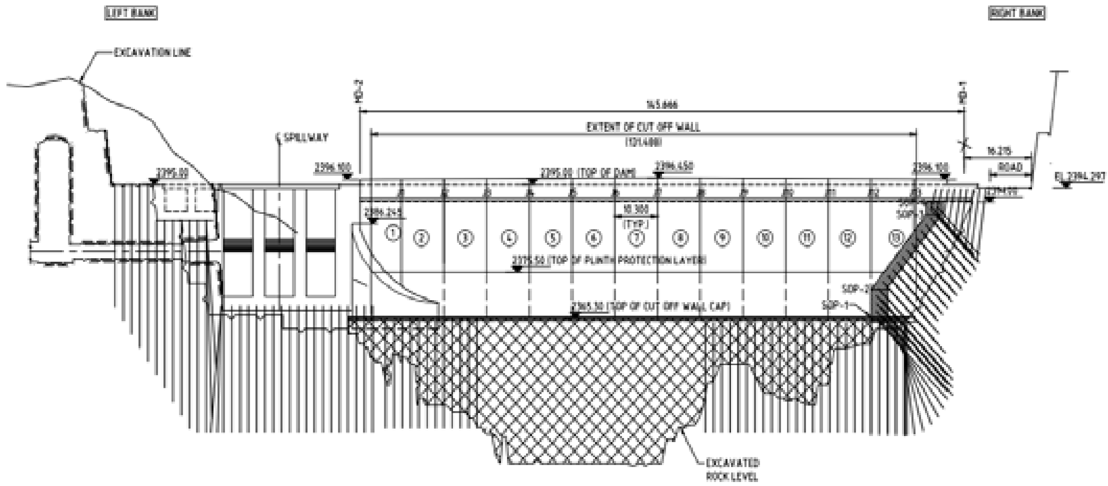

Figure 2 : Longitudinal section of dam and cut off wall

Where the bedrock was encountered at higher elevations (*i.e.* above elevation 2340m) grout-holes were drilled down through the cut-off wall to allow permeability testing of the rock and where necessary pressure grouting. The grout-hole within the section of the cut-off wall is not pressure grouted to avoid potential damage but was instead backfilled with tremmied grout. Thus, continuity between the cut-off wall and the grout curtain was achieved with the benefit that the grout-hole could be drilled without the need of casing as would be the case for holes drilled through the alluvium. In the rock foundations of the abutments and below the spillway, the cut-off barrier was similarly formed through pressure grouting using split-spacing approach reducing the spacing between holes from 8m to 2m.

Table 1 : Zoning of material

Zone	Material	description and Size
1A	Random Fill	Semi-pervious to impervious
1B	Random Fill	Semi-pervious to impervious
2A	Filter	Crushed unweatherd Max. size 37.5mm
2B	Filter	Crushed unweatherd Max. size 76mm
3A	Transition	Slightly weathered or better processed Max. size 20cm
3B	Compacted Rockfill	Slightly weathered or better Max. size 60cm
3C	Compacted Rockfill	Moderately weathered or better Max. size 80cm
3D	Uncompacted Rockfill	Slightly weathered or better Max. size 1.0m

The rockfill for dam construction (and the aggregates for concrete) was obtained from blasted materials excavated primarily from the left abutment (also some selected tunnel spoil) and excavated fluvial deposits from upstream of the dam site. The materials were deployed as follows:

3A – crusher run from blasted material (spillway excavation) and fluvial deposits

3B/3C – blasted material with limited processing to remove fines

A construction methodology for rock fill compaction was determined by undertaking trials where settlement was measured after each pass of a roller. The required number of passes was then defined as the point at which the incremental settlement was less than 10% of the total settlement. During construction, the vibratory roller was found to have a total weight of 10t rather than the specified drum weight of 10t and the effects of compaction were notably limited. The Contractor advised that due to the remoteness of the site, they were unable to locate a heavier roller. In light of this the solution was to reduce the layer thickness for all Zones to 600mm or less and where appropriate reducing the maximum particle size from 800mm to 600mm (in Zone 3C).

With the main body of the dam founded on alluvium, a 500mm thick plinth was constructed to allow flexibility between the concrete face slab and the cut-off wall. The plinth included transverse joints at 10.3m spacing. Where the plinth sits on bedrock (i.e. in the right abutment) the width is 1/20th of the water head but with a minimum width of 4.0m. On bedrock the plinth was constructed without shrinkage joints. The fill below the perimeter joint was filled with bitumen graded sand mixture to ensure a good support to the joint and limit differential displacements of the face. The toe plinth in right abutment was connected to the rock by grouted anchors to resist uplift and gravity induced sliding of pane. Uplift pressure beneath toe plinth (river-bed) was not significant due to presence of cut off wall and pervious zone towards downstream end which prevents the build-up of water pressure.

The potential settlement of the rockfill due to water load increases towards the center of dam resulting in movement of face slab units away from spillway and approach wing wall. Thus, the joint of the face slab and toe plinth with the wall (also known as perimeter joint) was designed to experience tension. Therefore, special treatment in the form of multiple waterstops was provided to arrest seepage.

The perimeter joint between the concrete face and the plinth, and other joints have two water stops (Figure 3). The first waterstop consisted of an IGAS-type mastic placed on the surface of a notch in the upper edge of the joint. The mastic, which will penetrate the joint if this latter opens, is covered with a Hypalon membrane fixed to the concrete by stainless steel plates and bolts in the exposed zone and galvanized steel in the submerged zone. The second water stop is a copper water stop placed at the bottom of the joint.

The vertical compression joints in the central part of the dam have one copper water stop, while the vertical tension joints near the abutments had two water stops, similar to the perimeter joint. The face/parapet wall joint has been designed to be watertight, and sufficiently flexible to accommodate displacements due to the water load, ice loads, and temperature changes. An initial space has been provided between the face and the parapet wall footing. Two water stops, similar to the perimeter joint water stops, have been provided. The parapet/parapet vertical joints in the compression zone are provided with one PVC water stop placed in the middle of the wall. The vertical joints near the abutments have been provided with two water stops, a PVC water stop and an IGAS type mastic covered by a Hypalon membrane.

Shrinkage joints in the compression zone of concrete face have only one water stop placed at the downstream face of the joint. The joints in the tension zone have an additional protection, similar to the perimeter joint. A parapet wall was constructed at a level to avoid ice loads acting on the parapet wall. The upstream face concrete slab is cast from the base of crest wall. The width at this level of dam provides sufficient space to accommodate face slip form equipment.

3. iNSTru MENTaTiON

Instrumentation is an essential tool, for monitoring of Dam Safety and its behaviour under different conditions of loadings. To allow the key elements of the dam structure and appurtenant works to be monitored instrumentation was installed (Table 2 and Figure 4) and a schedule for routine observations and documentation produced.

Observations of uplift pressure in the foundation of a rockfill dam and the pore pressures in the body of rockfill embankment across the dam section are monitored by means of piezometers and buried pressure transducers cells. The internal stress developed in various sections of the dam structure for different levels of reservoir are monitored to confirm that they are within the designed values and that the factor of safety adopted is not encroached upon in the normal functioning of the dam. Stresses can be obtained from strains measured with electrical strain gauges or can be directly measured with electro-acoustic strain meters. Deflection in the dam due to water pressure is also to be checked to compare to the permissible limits.

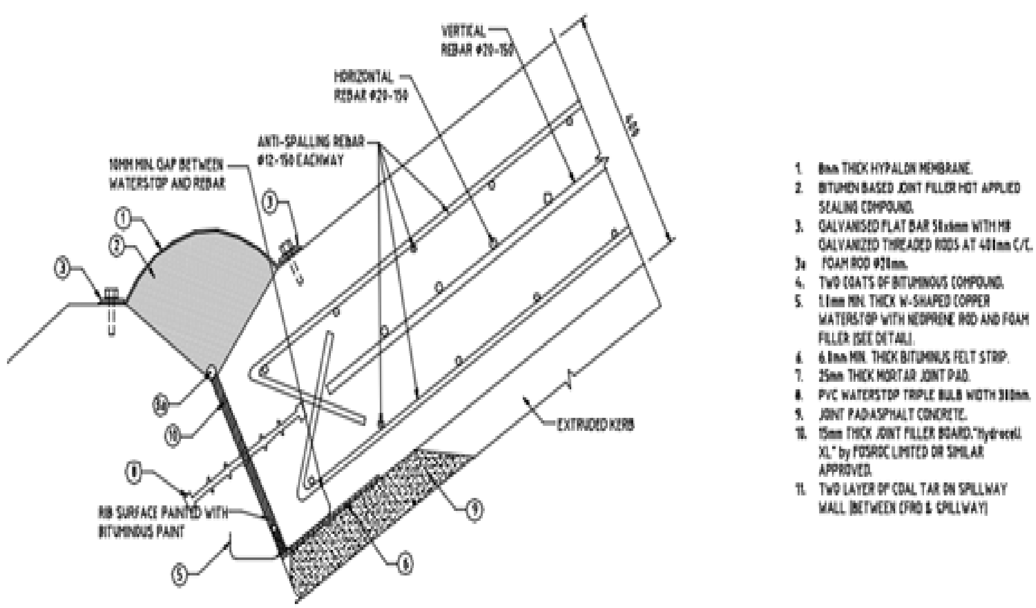

Figure 3 : Perimeter joint between toe plinth and face slab

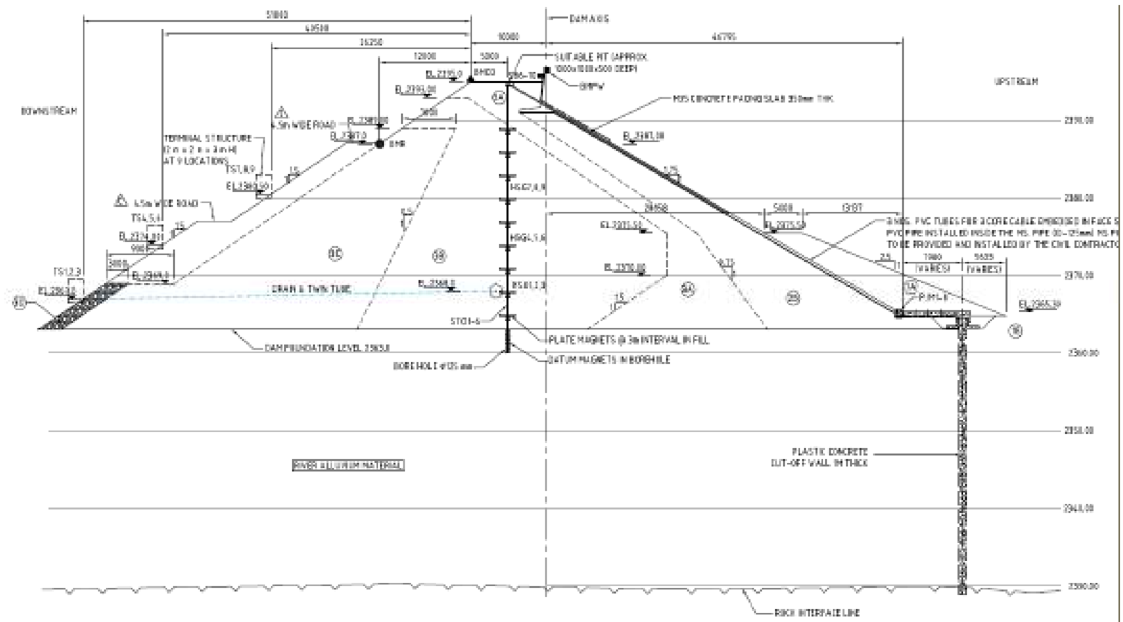

Figure 4 : Typical Cross section of instrumentation

Table 2 : Dam Instrumentation

description	**Location / arrangement**	**No.**
Surface displacement points in embankment (SSP)	Downstream rockfill face at EL2387m	10
Surface displacement points on face slab (SSP)	Upstream concrete face slab at EL2390m	10
Surface displacement points on parapet wall (SSP)	Crest along parapet wall	8
Hydraulic settlement gauge (HSG)	Arranged on 3 sections at 3 locations along crest of the dam	9
Perimetric joint meters (PJM)	At joint between concrete face slab and edge anchor blocks	8
Joint meters (JM) (PPG)	Set at joints between face slabs at alternate joints across width of dam at EL2387m	6
Pore pressure gauge (PPG)	Set at the upstream toe of the dam just below the upstream face slab	6
Stand pipe piezometers (SPM)	Located across the valley floor at the downstream toe of the dam and on the right abutment	5
Settlement tube cum vertical inclinometers tube (STCI)	Located at equal spacing along the crest of the dam set vertically (30m long)	6
Inclined inclinometers (II)	Bolted to the concrete face slab of alternative panels across dam width (25m long)	6
Water level measuring gauges (WL)	1 located upstream of the spillway + 1 Located downstream of the dam	2
Strong motion accelerograph (SMA)	1 Located at the dam crest + 1 located at dam toe	2
Automatic weather station (AWS)	Located close to the dam	1
Automatic data acquisition system (DAS)	Located on the downstream face of the dam	1

4. kEY CHaLLENgES iN CFrd dESigN aNd CONSTru CTiON

4.1 Construction challenges

The dam site is located in a region where temperatures remain below freezing for four months of the year, with temperatures falling to -20degrees C. Access to the Gurez valley is via the Razdan Pass at an elevation of 3600m along 75km of unsurfaced roads which are unpassable during the winter months. Consequently, construction of the dam was largely restricted to the months of May through to mid-December, although underground works continued throughout the year.

It was necessary to adapt aspects of the design to conform with the provisions of Indus Water Treaty and in the construction programme for parts of the work to accommodate requirements of the International Court of Arbitration in relation to the Treaty.

Not many CFRD dams have been constructed in India and it was important to work closely with the client and the local communities to create confidence in both the design and construction of the dam.

Impounding of the dam would result in the submergence houses in the village of Badwan village. Some of the villagers chose to be relocated in Bandipore whilst others preferred to remain in the area and move to the neighbouring village of Dabar. NHPC worked with the villagers to provide additional resources and facilities in the neighboring villages

The dam site is located in a sensitive area for the Indian military and an unusual challenge not normally met construction projects was shelling from across the border near dam area.

4.2 right bank plinth design

The toe plinth in right abutment was connected to the rock by grouted anchors to resist uplift and gravity induced sliding. The top of the plinth on the right abutment varies from elevation 2365.30m to 2391.45m. The uplift pressure beneath the toe plinth (on the river bed) is not significant due to presence of cut off wall and pervious zone towards downstream end which do not allow build-up of water pressure.

The right abutment has been blasted to achieve the design formation level for the plinth. There has been considerable overbreak in the foundations. As a consequence, the lower portion was made up with mass concrete to the approximate formation level. There were also localized places where additional trimming was necessary to achieve the minimum 4m width for the plinth. Adjacent to the plinth, the rock level was required to be a minimum of 1m below plinth level to provide a minimum thickness of Zone 2B material between the rock and the underside of the face slab. Again, some additional trimming was needed to meet this requirement. Modification was needed on site to appropriately set out the plinth and position the waterstops and the resulting solution was to increase the concrete face slab thickness and/or reduce the thickness of the plinth to 400mm where the make-up concrete is too high.

Figure 5 : Right abutment plinth

4.3 Stability of the Left abutment

The original pre-excavation design required the slope to be excavated first by stabilisation of crest overburden material followed by a series of rock benches with pattern rock anchor and shotcrete support installed as excavation progressed downwards, but with a requirement for review and modification of the support as actual rock conditions were exposed. However, difficulties in securing the crest excavation, poor blasting control and delay in installing support as excavation progressed, resulted in a poorly formed and damaged excavation profile and some major rock displacements in the upstream section of the slope when an underlying steeply dipping major sliding plane was exposed and allowed rock blocks to move. As excavation continued, resulting in further rock slippage, particularly over the winter seasons and progressive exposure of the major sliding plane required review and modification of the slope design to address the implications of this major feature.

The slope (Figure 6) was characterized by three key zones as follows: the crest (Zone 1), a blast-damaged, but generally more stable downstream area (Zone 2), and the upstream area of the major plane (Zone 3).

Further exposure of the major plane allowed more information on the likely joint characteristics to be obtained and specialist laboratory testing at Leeds University (UK) was undertaken to assess the shear strength of the rock joints at project scale based on measurement and analysis rather than empiricism allowed improved estimates of joint shear strength to be determined (Hencher and Richards,

Fig. 6 : Left Abutment

2014). Tests were needed to be carried out with great care and with appropriate corrections for dilation made so that the base friction value could be determined.

The overall dip of the major extensive sheet joint in Zone 3 was about 45degrees, similar to the small-scale friction. For sections of the joint where the first order roughness was favourable then the stability was shown to be adequate without reinforcement. (Hencher and Richards, 2014). However, for joints daylighting in the lower part of the near vertical spillway cut, where the dip of the plane increased the engineering design adopted was to install dowel bars and cable anchors to achieve an adequate factor of safety under static and dynamic loading conditions. For the downstream section (Zone 2), where joints are less persistent, a combination of concrete buttressing and local anchoring was adopted.

Constraints on land access at the crest (Zone 1) meant that the proposed removal of the unstable material at this location was not possible. The existing low factor of safety of the material on the steep slope, and the limitations on materials and plant access now possible at this high level, resulted in the use of a mass concrete buttresses anchored to the underlying rock with steel bar rock anchors. Patterns of drilled drain holes were also specified to minimize the risk of groundwater pressure developing on the sliding planes.

The design evolved during the course of the works due to significant changes in the slope profile and geometry, exposure upon excavation of potential significant failure surfaces, increasing information on the geometry and properties of the potential failure surfaces, and the need to accommodate HCC construction preferences, and access and land constraints.

4.4 use of Extruded curb

Initially it was proposed to apply a 75mm layer of shotcrete on the upstream face to protect the upstream face prior to placement of the concrete facing slab. However, during construction the concept of an extruded trapezium-shaped kerb was introduced. This is the first time this technique has been used in India although it has been applied elsewhere in the world.

The extruded curb (Figure 7) has a low percentage of cement providing an intermediate stiffness between that of concrete slab and underlying filter material. The kerb allows Zone 2B to be fully compacted across the full width of the zone and promoted the regularization of the face, allowing confinement and consequently the compaction in the transition zone. The technique worked well on site. However, some areas of kerb were constructed such that they were standing proud of the design profile and needed to be trimmed back to ensure that the design thickness of the concrete face slab (400mm) was achieved.

Figure 7 : Placement of Extruded Curb

5. CONCLUSION

Kishanganga is the first mega hydropower plant located in north western Himalayas in the Gurez valley of Kashmir region of India. This paper presents the challenges and the solutions developed during the design and construction of the dam. The solutions developed were based on international practices and adoptability at site. Post construction results monitored through installed instrumentation confirmed the water tightness of cut off wall as well dam face slab joints.

Kishanganga hydroelectric project has been awarded as best tunneling project of the year 2018 by Tunneling Association of India (Chapter of ITA) and outstanding concrete structure award 2019 by Indian Concrete Institute (ICI).

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Sustainable development in the construction of concrete dams in India

dr. S.C. Maiti [1]

abstract

The development in dam construction in India covering the use of right construction materials, distress observed due to deleterious alkali-aggregate reaction in some of the dams, current scenario in the use of blended cements with at least 25% flyash or with at least 50% ground granulated blast furnace slag and 5-10% silica fume (as necessary for the development of high strength and abrasion resistance of concrete) have been highlighted, with a few case histories. Recommendations have been made to use more and more factory-made blended cements in the construction of concrete dams, spillways, stilling basins, tunnel linings,desilting chambers and power house structures, towards a sustainable and durable concrete structures in hydro-electric projects, using green construction materials.

1. iNTr Odu CTiON

Dam construction started in India as early as 1950's. Most of the dams in India are concrete dams. A few rock fill dams and two roller-compacted concrete dams are also constructed. In those days (1950-1960), good construction materials were not available in India. Only ordinary Portland cement (ASTM type I) with higher alkali content was produced by the cement plants. The coarse aggregates were mostly river pebbles. River bed sand was available as fine aggregate. The pozzolanic material was not much available, except burnt clay pozzolana. Thermal power plants were just started, producing power not sufficient to cope up with the demand of India's growing industries.

The concrete dams were constructed mostly for flood control and irrigation. The power generation was just a by-product. With the development process towards the end of the 20thcentury, along with rapid industralisation, more and more thermal power stations were constructed, without a concern for global warming. In this century, as it started, the country's attention was more and more for green power, and so, more and more hydro-electric projects were taken up specially in the Himalayan regions and hilly areas of the country. In the present scenario, concrete dams are under construction, but at a very slow rate.

2. THEa Lka Li-SiLiCar EaCTiONiNCONCr ETE daMS iN iNdia

In two of the dams, cracks were developed due to alkali-silica reaction after about 30 years. One concrete dam suffered maximum deterioration due to this deleterious reaction. The power house structures cracked, and the power house was not operative for a number of years. Cracks were observed in the ogee crest of the spillway, 25mm wide and 100mm depth. The cracks in the columns of the penstock gallery were severe. One of the columns opened up at the crack, showed 9 of the 10 reinforcement bars of 45mm dia. had snapped at the end of the welded joints [1]. In those days the quality of OPCaswell as the quality of flyash were not good. The alkali content of OPC was high in the range of 1.2% to 1.8%. Although 15% flyash (total 13,000 tonnes) was used in concrete, cracks developed in many structures. Typical alkali-silica gel inside the concrete, and the cracaks in the aggregates (microscopic photographs) are shown in Fig.1 and Fig. 2.

Figure 1 : Alkali silica gel inside the concrete

1. Ex-Joint Director, National Council for Cement and Building Materials, New Delhi

Figure 2 : Cracks in aggregates inside the concrete due to alkali aggregate reaction

3. MaTEria LS OF CONSTru CTiON FOr HYdrO -ELECTriC PrOJECTS

In the present scenario, ordinary Portland cement (OPC), the Portland pozzolana cement (PPC) consisting of 15-35% of pulverized fuel ash (PFA) or flyash produced by the thermal plants, and Portland slag cement (PSC) consisting of 25-75% of granulated blast furnace slag (g.g.b.s.), the by-product of steel industries, are available for any construction activity. The OPC should be used as less as possible, not only for its high release of carbon di-oxide in the atmosphere during its production, its production is slowed down. More and more PPCs are produced by the cement industries. The production of PSC is limited to the availability of the g.g.b.s. Out of the total production of cement in the country at present (420 million tonnes), OPC is about30% , PPC is about 60% and PSC is about 10%.

The coarse and fine aggregates available for the construction of concrete dams are generally from the rocks, available near the sites of construction. They are crushed to produce coarse and fine aggregates. The concrete admixtures (chemical) are available in sufficient quantities, as required, as a large number of admixture companies (including some foreign companies) are able to produce and supply the required chemical admixtures. The mineral admixture silica fume or the micro-silica is being imported.

4. uSE OF Pr OPEr CEMENT a Nd MiNEra L adMiXTurES iN CONCrETE FOr HYdrO - ELECTriC PrOJECTS

The Codes of practices stipulate use of proper cement and mineral admixtures (flyash, g.g.b.s. and silica fume) in concrete for hydro-electric projects. The Indian Standard Code of practice for plain and reinforced concrete IS 456 [2] stipulates 'use of low alkali OPC having total alkali content not more than 0.6%, as Na_2O equivalent. The Code of practice further adds "further advantage can be obtained by use of flyash conforming to IS 3812 (Part 1) [3] or granulated blast furnace slag conforming to IS 12089 [4] as part replacement of OPC (having total alkali content as Na_2O equivalent not more than 0.6 percent), provided flyash content is at least 25 percent or slag content is at least 50 percent".

In the early years of the present century, the government of India's emphasis was to use more and more flyash as they are hazardous materials at the thermal power stations. But the quality of flyash deteriorated over the time and good quality flyash as specified in IS 3812 (Part 1) is not sufficiently available to cater the needs of the construction projects. However, two roller-compacted concrete dams have been constructed in these years, with about 60% flyash in concrete. The 100m high concrete dam has been constructed with Portland slag cement, with slag content of about 55% and more concrete dams are currently under construction with PSC having similar amount of g.g.b.s. In one site, the crushed rock coarse aggregate is not satisfying the limiting Los Angeles abrasion value for wearing surfaces as stipulated in the Indian Standard specification IS 383 [5] and so, 5-8% silica fume is being used in concrete.

4.1 use of blended cements in hydro-electric projects

In order to avoid the deleterious alkali-aggregate reaction in concrete dam projects, there are recommendations to use either PPC or PSC, with part replacement of OPC by flyash or by g.g.b.s. respectively. But since at present, the availability of good quality flyash is less, and there are variations in the properties of flyash from power stations to power stations, it is better to use Portland slag cement with at least 50% g.g.b.s. in it. The slag is a more consistent material than flyash. The ICOLD does not recommend the use of PPC in concrete for combating the deleterious alkali-aggregate reaction. The stipulations are as follows: "In the case of Portland pozzolanic cements, the cement manufacturers should be able to match the characteristics of the particular cement and pozzolana to ensure adequate compensatory action under the conditions of intended use, but, despite accumulated experience with Portland pozzolanic cements, the variability in their properties does not yet permit recommendations for their use in minimizing the risk of alkali- aggregate reaction [6]. On the other hand, on the use of Portland slag cement, the ICOLD bulletin states that, "there is now considerable experience of the use of Portland blast furnace slag cements with some types of reactive aggregates, and although the current recommendations probably are on the cautious side, there are no known instances of deleterious alkali reactions, when the stated limits of alkai i.e. less than 0.9% Na_2O

equivalent with more than 50% slag in cement, and less than 2.0% Na_2O equivalent with more than 65% slag, have been observed".

Spellman [7] observed beneficial effect with 40%, 50% and 65% slag in Portland slag cement in terms of percentage expansion in mortar bars as per ASTMC227 [8] test with pyrex glass. He observed expansion less than 0.1% when 50% slag was used in the blend of (OPC + slag) (Fig. 3). The alkali of cement was 1.15% as Na_2O equivalent.

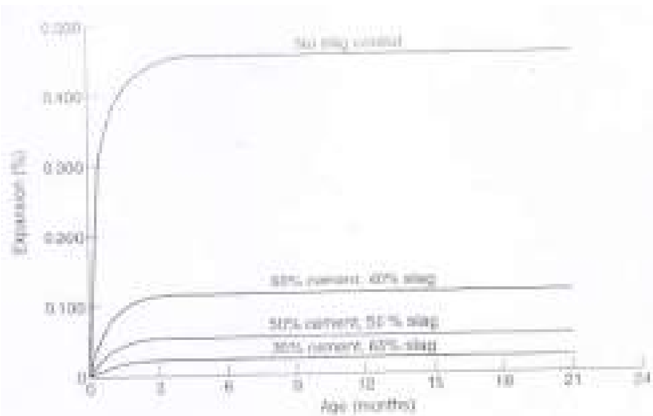

Fig. 3 : Linear expansion of mortar bars with pyrex glass showing less than 0.1% expansion with 50% slag in cement

The PSC with 55% slag has been used to combat the alkali-silica reaction in 17 km tunnel lining in a hydro-electric project in Himachal Pradesh.

5. CONSTRUCTION METHODOLOGY FOR HYDRO-ELECTRIC PROJECTS IN THE CURRENT SCENARIO

Looking into the availability of consistent products, the Portland slag cement is the best failsafe material, using slag from blast furnace steel plants. The cement made from this product arrests the alkali silica reaction and also is resistant to the sulphates and chlorides present in ground water.

The concrete dams are to be constructed with the available crushed rock aggregates at the sites of construction. The cement and the admixtures (mineral as well as chemical) are to be transported to sites of construction. Indian Standard Code of practice for plain and reinforced concrete [2] stipulates use of (low alkali OPC + flyash /g.g.b.s.) as binding material to combat the deleterious alkali silica reaction in concrete. But since low alkali OPC (alkali less than 0.6% as Na_2O equivalent) is not much available in the country, PPC or PSC has to be used, with minimum 25% flyash in PPC and with minimum 50% g.g.b.s. in PSC. ICOLD [6] does not recommend use of PPC, because of its variable characteristics. Therefore, factory-made PSC with at least 50% g.g.b.s. is the best choice. In the cement factory, OPC and g.g.b.s. are chosen with compatible characteristics. The control in the factory is much better, than mixing the two materials i.e. OPC and g.g.b.s., at the site concrete mixer.

At some construction sites, aggregates may not be strong enough and might have high Los Angeles abrasion value, unsuitable for wearing surfaces. In that case, 5-8% silica fume is required to be mixed in concrete. This is specially for tunnel lining, desilting chambers etc. For spillways and stilling basins, 8-10% silica fume will be required, as they are to be of high strength concrete i.e. 55-80 MPa compressive strength. The superpasticizers (Polycarboxylate ether based) shall provide the required workability of concrete. Sometimes, precast concrete tunnel lining is specified. In that case, usual steam curing of concrete will be required, to achieve the early strength of concrete. The dam concrete will be as usual of low strength (15MPa) and with lower slump of 25-50mm. Superplasticizer is not required for such concrete. Very low percentage of air entraining admixtures (0.1 to 0.2% by weight of cement) should be used in concrete to make it cohesive, with higher maximum size of aggregate of 80 or 150mm.

6. ABRASION RESISTANCE OF CONCRETE IN SPILLWAYS AND STILLING BASINS

Silica fume is well known in increasing the abrasion resistance of concrete. In two of the Indian concrete dam projects (completed during 2004-2010), 8-10% silica fume (% by weight of cement) has been used in their spillways, and the projects are performing satisfactory. Typical photograph of the spillway of a concrete dam made with 60 MPa concrete and with 8% silica fume is shown in Fig. 4. The Southern Illinois University test results [9] indicate more than 100% improvement in abrasion- resistance when 10% silica fume was included in concrete (Fig. 5). The test was conducted as per ASTMC779 [10]

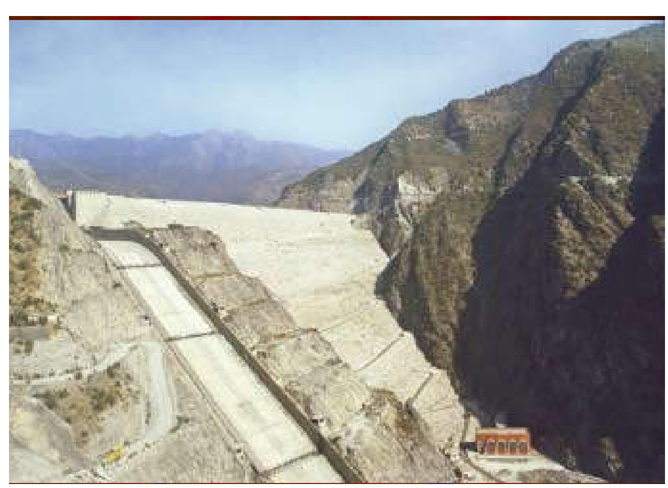

Fig. 5 : The spillway of 1000MW Tehri hydro-electric project,60MPa concrete with 8% silica fume

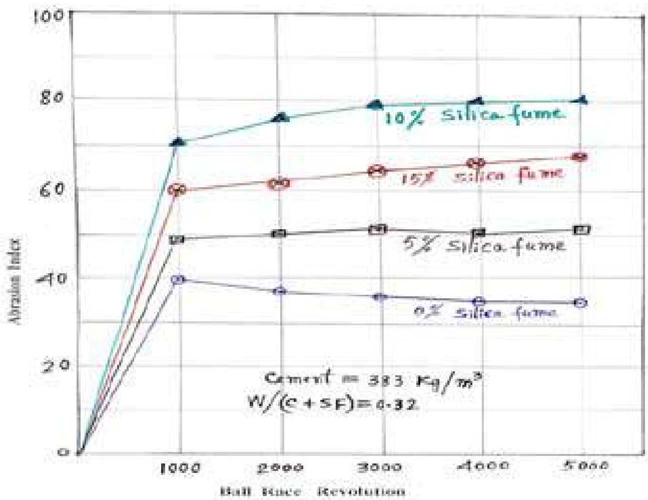

Fig. 6 : Abrasion index of silica fume concrete

The stilling basins of concrete dams have to be strong enough to resist the abrasion and impact of the boulders, stones and other abrasive materials. Generally concrete of 55 or 60 MPa compressive strength is being used in the stilling basins. The top 150-200mm concrete should include steel or polypropylene fibres for resisting impact and abrasion. On the stilling basin of one of the hydro-electric projects in India, steel girders were fixed on the top concrete to resist the impact and abrasion. In another project, the stilling basin consisting of concrete blocks (size :26m x 26m x 1m, 19m x 19m x 1m and 24m x 21m x 1m) of 55 MPa strength, were constructed using PSC and 11% silica fume. During construction period, thermal cracks developed in concrete after 3 days. In order avoid such cracks, the quantity of silica fume in concrete was reduced to 8% by weight of cement.

7. CONCLuSiONS aNd rECOMMENdaTiONS

Based on the distress observed due to alkali-silica reaction in some of the concrete dams in India, Indian Standard Code of practice for plain and reinforced concrete recommends use of low alkali ordinary Portland cement plus at least 25% flyash or at least 50% ground granulated blast furnace slag in concrete, in hydro-electric projects The availability of good quality flyash from thermal power plants is less. The International Commission on Large Dams does not recommend Portland pozzolana cement in concrete for minimizing the risk of alkali- aggregate reaction, due to its variable properties.

Therefore, best option is to use factory made Portland slag cement with at least 50% ground granulated slag in it. Beneficial effect in terms of expansion in mortar bars has been observed, when 50% or more slag was used in the blend. Use of such green cement in concrete shall provide a sustainable and durable concrete structures in hydro-electric projects.

Due to availability of weak aggregates in some of the construction sites, 5-8% silica fume is being used to increase the abrasion resistance of concrete in tunnel linings. In some of the spillways of concrete dams, 8-10% silica fume had been used in concrete of compressive strength, 60 to 80 MPa, for the development of high-strength and abrasion- resistance. The Southern Illinois University test results indicate more than 100% improvement in abrasion-resistance, when 10% silica fume was used in concrete.

In India, using Portland Slag Cement with 55% g.g.b.s, 60 MPa strength of concrete has been achieved. The International commission on large dams should recommend the use of Portland slag cement in hydro-electric projects throughout the world. This will ensure durability of concrete structures combating the deleterious alkali-silica reaction and arresting other evils present in water, deleterious to concrete and simultaneously saving the environment from the pollution of carbon dioxide to a great extent.

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

r.k. Vishnoi [1], gajendra Singh [1], ajay kumar [1], N. k.Ojha [1] and P. Vishwakarma[1]

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. iNTr Odu CTiON

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).

Fig. 1 : Location Map of Vishnugad Pipalkoti HEP.

1. THDC India Limited, Rishikesh, Uttarakhand, India

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.

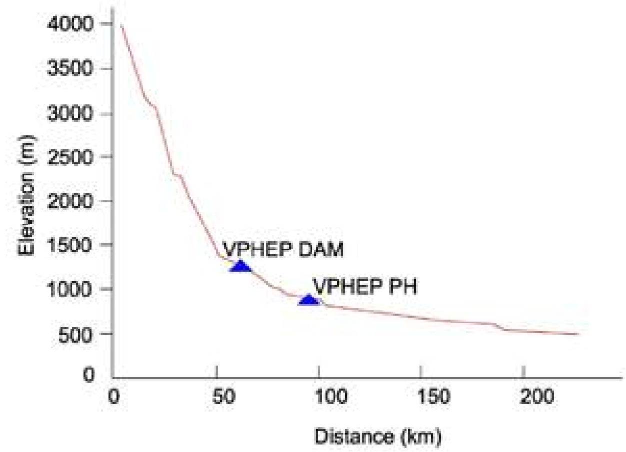

Fig. 2 : L Section of river Alaknanda along with location of Dam & Power House of VPHEP

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

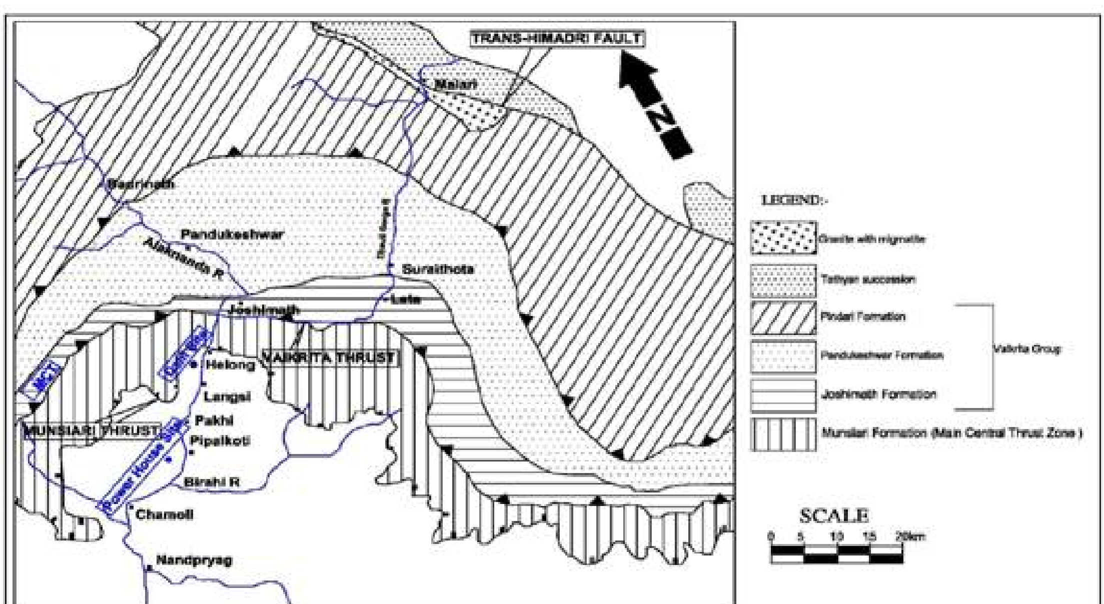

Fig. 3 . Regional geological map of VPHEP area (after Valdiya).

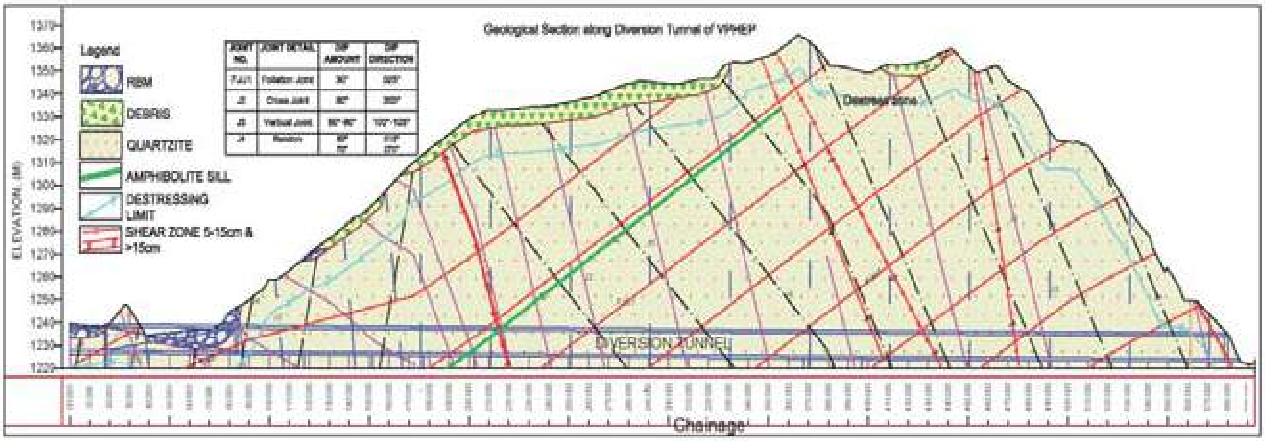

Fig. 4 : Geological section along Diversion Tunnel

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, 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 (Figure 5 and 6).

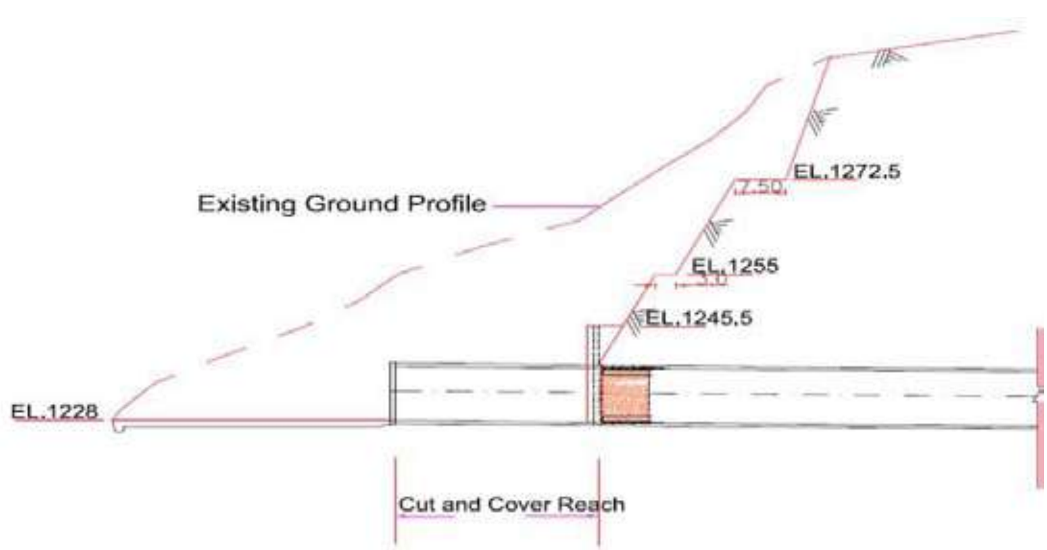

Fig. 5 : Section at DT Inlet during Tender stage before flood.

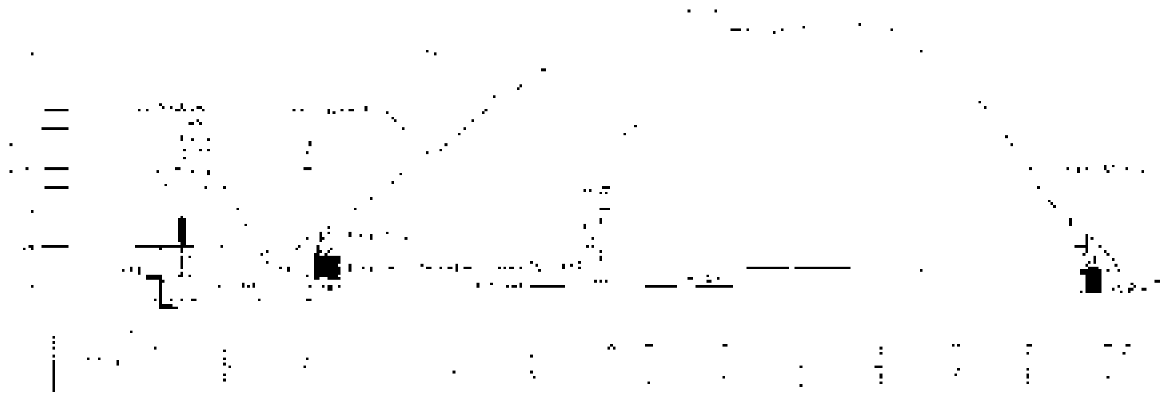

Fig. 6 : Section along DT after flood.

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).

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

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

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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Water – not a luxury but a necessity

Emerging challenge on Sustainable Water Management in India

Biswajit das [1]

aBSTraCT

Climate change is a reality and its impact are being felt all over India. The most impact of it will be on water resource. It will aggravate flood, cyclone and draught with devastation effect on human life. "Water is life" as defined in Veda; the oldest holy book of ancient India. Its importance and proper use were understood, researched and implemented in urban and rural areas in a most efficiently developed townships and agricultural fields in India more than 5000 years ago. India now have 18% of world population, 4% of renewable water resources and only 2.4% of land area of the world. Also, water availability in India widely varies with region and time, making the water management a most challenging issue. Major need of water in India is for irrigation, Industries, thermal power, drinking and domestic purpose besides renewable use in Hydroelectric Power Plants including secondary benefits for navigation and recreation facilities. This paper will focus on most challenging issues on water management in surface and ground water where its aggravation on scarcity and flood devastation will impact on human life, identify their short term and long-term solution based on research and planning by various organisation and individuals.

1. HiSTOr Y OF WaTEr MaNag EMENT iN iNdia

Water is essential for survival of human race. The United Nation defines water security as "The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." It encompasses security for adequate supply and quality of drinking water and of all household requirements of water, security to health, security of food grain production, security from spread of water borne diseases, security from natural disasters like floods and contribution towards energy security and quality of life with water as a resource of power. The discovery of ancient farming village Mehergarh in Baluchistan, now in Pakistan, is an example of scientific farming with irrigation and food storage technology in ancient India in 7000 BCE. The discovery of Harappa Mahenjodaro and other urban ruins and rural development in Indian subcontinent, the example of finest form of ancient civilization in 3300 to 2000 BCE is a glowing example of most scientific water use and conservation by planned water supply, sanitation, drainage, storm water management, water treatment system, irrigation, transportation for internal and international trade.

The gradual decline of Indus Valley civilization and its extinction between 2000 BCE and 1500 BCE is a most mysterious part of Indian History. The location where the Indus valley civilisation once flourished is a desert today. Perhaps they could not work out right water security system with forward planning in the climate change cycle. However, during Vedic period 2000 to 1000 BCE, highly developed civilizations continued to exist in other parts of India. Water usage in scientific ways also evolved. The Veda mentions only well-style irrigation, where kupa and avata (wells). This water was, diverted into channels to fields for irrigation. Later during Puranic period, in the 4th-century BCE Indian scholar Pāṇini, mentions tapping several rivers for irrigation. Buddhist texts from the 3rd century BCE also mention irrigation of crops. Texts from the Maurya Empire era (3rd century BCE) mention that the state raised revenue from charging farmers for irrigation services from rivers. In Tamil Nadu, the Grand Anicut (canal) across the Kaveri River was implemented in the 3rd century CE, and the basic design is still used today. The industrial, scientific and economic revolution in the recent past, particularly after India got its Independence in 1947, the standard of human life has risen to a phenomenal level i in India. From repeated famine during pre-independence period to food surplus situation in three decades of post-independence era with adding about 4000 Dams and reservoirs, now totalling over 5000 numbers from sixties to nineties with flood control, irrigation, water supply and hydropower benefits, agricultural revolution with research work and modern farming technology had created food and water security. Mining and Industrial revolution with steel, metals, coal and consumer's durables, machine and tools, increase of health services with increase in average life span are only a few examples which have put India to one of the fastest growing developing country. But with the population growth, India could not keep the pace to evolve

1. Executive Director, BGS-SGS-SOMA JV, New Delhi, India

adequate technique and systems for water management to get water security in ascending order. Again, history is trying to repeat itself with water shortage and threat to water security, challenging our existence. In today's context, it requires planning, efficient management, storage, conservation and distribution of water of suitable quality and quantity even in worst scenario with the aid of modern technology. Water security encompasses food, health, energy and all aspects of life for sustainable development. Present initiative on clean India, water, education, health, clean electricity for all is a right approach to sustainable development.

2. EMErgi Ng CHa LLENg ES

Today with 1.3 billion population is facing multi-fold challenges. India's all-round development, the average life span of population is increased rapidly and substantially. The basic infrastructure for sustained development are Road and Railway communication, housing and land development, water supply, agriculture and irrigation, Health and education, Electricity and fuel, protection from flood and drought. For a developing country like India, none of these factors can be termed as secondary or less priority. The urban development in India has a phenomenon growth with all the modern facilities in last three decades. However, the rural development, after irrigation and agriculture revolution, has seen a sharp rate of decline in all fronts when compared to urban development. As a result, there is mass migration of population from rural to urban in search of a better life. This trend has completely put an off balance on scientific development. Threat to health as a result of water pollution of water resources and our failure to provide right quality of drinking water to urban and rural population is a matter of urgent concern. Adding to it, the climate change factor has created another dimension of challenge, threatening the aggravation of drought and flood, shortage of water and food. Thus, future of India mostly depends on Water Security which in turn assures Life Security. The water security is like a life insurance. Whatever water we save from our use, it will protect us from future known and unknown risk and hazards. However, to achieve water security it is not like a simple financial solution. It needs elaborate planning and ground work for implementation. Some of the measures are enumerated as below:

2.1 Water Storage

(i) Multipurpose Storage Dams and Reservoirs with distribution system

(ii) Ground Water control and recharge from reservoirs and canals

2.2 Flood Protection

(i) Flood control Dams & Reservoir, embankment protection

(ii) Catchment Area Development and anti-erosion measures

2.3 Water Conservation and reuse

(i) Sprinklers & drip irrigation, rain water harvesting,

(ii) Domestic and Commercial use; Raw and Waste water treatment plant

(iii) Raw and waste water treatment plant

(iv) Water pollution treatment and revival of Rivers and Water Bodies

3. Pr ESENT STaTuS a Nd Tr ENd OF WaTEr STOragE

Table 1

Geographical Area	329 M ha
Flood Prone Area	40 M ha
Ultimate Irrigation Potential	140 M ha
Total Cultivable Land Area	184 M ha
Net Irrigated Area	50 M ha
Natural runoff (Surface & Ground)	1869 cubic km
Estimated Utilisable Surface Water Potential	690 cubic km *
Ground Water Resource	361 cubic km
Net Utilisable Ground Water Resource for Irrigation	325 cubic km

* Assessment is based on Projects where Preliminary Feasibility Report is prepared and feasibility is established. Further feasibility studies in other project locations are continuing.

Water storage in India today is highly inadequate considering emerging challenge on climate change when drought and flood will aggravate and for both we need storage for flood protection and Irrigation and water supply. Once a reservoir built for storage to combat the flood and drought the hydropower generation is a by-product of the same facility. Excess and controlled water release from reservoir during flood and drought will pass through the turbine to generate electricity. The Water Resources of India, assessed by National Institute of Hydrology is enumerated below:

In India, per capita water in cubic meter as on 2015 is as follows:

Table 2

Total effective Storage	175 cubic km
Population	1282 M
Per capita effective storage	136 cum
Minimum sustainable water storage per capita	300 cum **
Projected Population by 2030 in India	1528 M
To ensure per capita 300 Cum, the storage utilisation needed	458 cubic km< 690

** The present effective storage capacity of India is 175 Cubic Km is highly inadequate and minimum storage per capita of 300 cum is a rough estimate as indicated by various publications and papers.

The net irrigated area is only 50 million Ha as against total irrigable potential of 140 Million Ha. Which indicates that only 36% of agricultural land is covered by Irrigation and rest 64% depends on monsoon. In view of Climate Change there is an urgent need for increasing the storage capacity to at least 458 Cubic Km from present level of 175 Cubic Km in accelerated mode. The present status of surface water storage in India shows a negative trend for storage per capita. Figure.1 shows five yearly per capita effective storage. Till 1985-1990 the per capita storage is in ascending order and peaked at 172 cum per capita thereafter the curve declined steadily and in 2015 it stands at 136 cum per capita. Figure. 2 shows five yearly numbers of storage dams constructed in India. It peaked in 1975-80 to 1980-85 with 729 and 717 respectively thereafter the trend is declined. In 1985-90, the water resources projects commissioned on that five-year block stood as 503 nos. In 2010-15 five-year block only 19 nos. projects were commissioned. Due to stringent and often unfair restriction on environmental issues and agitation by local population with misguided information the projects are being stalled. A glaring example is in Arunachal Pradesh, where more than 35 major water resources are stalled even after Detailed Project Reports are prepared and allotted to private developers and PSU. It must be understood that there no alternative than that of water resources projects for survival of a nation. India has enough water potential and the 90% of water resources projects are environment friendly with multiple benefit such as Irrigation, water supply, flood control and hydropower. India can ill afford to starve the agricultural fields, remain in lowest range of per capita power consumption and per capita water storage, knowing fully well the impending danger of climate change.

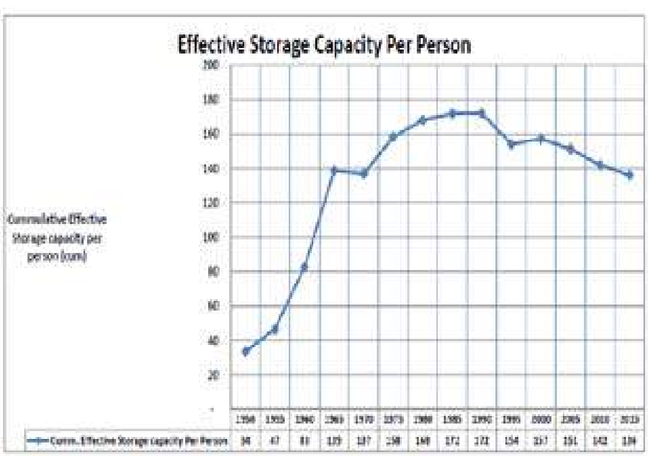

Figure 1 : Five yearly per capita storage of water in India

Figure 2 : Five yearly development of Dams and Reservoirs in India

4. BENEFiTS OF WaTEr r ESOur CES PrOJECTS

4.1 a water resources projects have multiple direct benefits

(i) Irrigation

(ii) Flood Control

(iii) Power

(iv) Navigation, if the reservoir is long

4.2 Other Benefits

(i) Tourism and recreation

(ii) Infrastructure development outside project for construction benefitted to local population

(iii) Infrastructure inside project developed for construction utilised for other institution

(iv) Medical facility of project rendered to local population

(v) Employment generation and on job training to local population, training during construction

(vi) Business generation for local population with increased potential of small, medium and large Industrial development

(vii) Increase of standard of living to local population by statutory social benefit rendered from project like education, water supply, sanitation, health service etc.

(viii) Fishery development

5. FLOOd da Mag E MiTiga TiON

As per National Disaster Management Authority the annual average loss, based on 1996 to 2005 data is Rs.

4745 Cr. and annual average human lives loss is 1600. Such losses are too high to be ignored. With climate change knocking at the door, the losses of property and lives will aggravate alarmingly. A short term and long-time strategy is the need of the day.

An extract of report on study of Brahmaputra basin by N.N. Bhattacharyya and A.K.Bora, which analysed the recurring devastating flood in Assam and Bangladesh is reproduced below:

Floods in the Brahmaputra basin of India are characterized by their extremely large magnitude, high frequency, and extensive devastation. The mean annual flood discharge of the river at Pandu is 47,608 m^3/s with a recurrence interval of 2.56 years.

Consequently, there have been regular flood onslaughts, adversely affecting the agrarian economy of the Brahmaputra valley.

The 2004 floods, over 25% of the population of Bangladesh or 36 million people, was affected by the floods; 800 lives were lost; 952,000 houses were destroyed and 1.4 million were badly damaged; 24,000 educational institutions were affected including the destruction of 1200 primary schools, 2 million governments and private tube wells were affected, over 3 million latrines were damaged or washed away, this increases the risks of waterborne diseases including diarrhoea and cholera. Also, 1.1 M ha of rice crop was submerged and lost before it could be harvested, with 7% of the yearly aus (early season) rice crop lost; 270,000 ha of grazing land was affected, 5600 livestock perished together with 25,400 poultry and 63 MT of lost fish production. Bangladesh topography does not have and feasibility of major water storage reservoir for flood control.

There are only a few minor diversion dams constructed in Northeast region of India purely for Hydro Power Generation without any significant storage in a few minor tributaries which have no flood control or flood modulation capacity.

For the sake of information, we can compare the history of development on Yellow River in China which was known as “China’s Sorrow”. In 1931 flood 1 million lives were lost during devastating flood. However, the magnitude of flood and discharge are much smaller than that of Brahmaputra. To mitigate such loses, since 1960 to 2016 as many as 16 Dams were constructed which controlled the flood, provided more irrigable land and generated Hydro Electric Power. As on 1999 Yellow River served 140 million people and Irrigated 74,000 Sq Km. of Agricultural land.

Table 3 : A general comparison of Yellow River and Brahmaputra is listed below

	Yellow river	Brahmaputra
Total watershed area	752,546 Sq. Km	712,035 Sq. km
Average discharge	2,110 Cumecs	19,800 cum
Flood discharge	25,000 Cumecs	100,000 cum
Storage Dams	16 nos	Nil
Surface Irrigation	74,000 Sq.Km	Nil

6. HYdr O POWEr aNd ri VEr LiNkiNg PrOJECT BENEFiTS

(i) Renewable, Cheap Power, minimum O&M cost

(ii) Minimum pollution and emission, environment friendly.

(iii) Fluctuation, Peak power management and Grid Stabilization unique capability

(iv) Long life of 40 to 60 years and life can be further extended economically by renovation and up gradation.

(v) Huge potential untapped. Universally preferred source of generation

(vi) One Scheme has three major multiple benefits, Irrigation, flood control & power

(vii) Only long-term benefits due to long gestation period. Small Hydro has short gestation period and can serve short term benefit.

In India, commercial generation of Hydro Power started in 1897 at Sidrapong Hydro Electric power station at Darjeeling, West Bengal, developed and operated by Darjeeling Municipality to supply power to Governor House and Govt. establishment.

After Independence, major Multipurpose Projects were planned and implemented like Bhakra and DVC for Irrigation, Flood Control and Electricity generation. In fact Electricity was a secondary product to first two major benefits. Many more projects came up in five year plans and till 1980 Hydro Power contributed 40.6% to total installed capacity of 26,680 MW. Balance was Thermal Projects. This was a very healthy mix in India with 60% to 40% load factor. Therefore, base load was shared by Thermal Power with 80% assured plant load factor sharing only 20% of low fluctuating load. While Hydropower shared 40% of fast fluctuating and peak load which thermal power cannot absorb.

However, this healthy trend was seriously disrupted due to focus of short term rapid demand of power and growth of coal based Thermal generation offsetting the healthy power mix.

Table 4 : Installed capacity by source in India

Source	installed capacity
Coal	203,954.50 MW (56.1%)
Large Hydro	45,399.22 MW (12.5%)
Small Hydro	4,610.81 MW (1.3%)
Wind Power	36,930.32 MW (10.2%)
Solar Power	31,101.71 MW (8.6%)
Biomass	9,271.30 MW (2.6%)
Nuclear	6,780.00 MW (1.9%)
Gas	24,937.22 MW (6.9%)
Diesel	509.71 MW (0.1%)
Total	363,484.79 MW

Table 5 : Energy generation in as on 30.11.19

Source	% of generation
Fossil Fuel	79.8%
Renewable	17.3%
Nuclear	2.9%

The grid failure in the world affecting largest area and population in July 2012 happened in India when half of India remained blacked out for 3 days and nights is still fresh in the memory. Besides stabilizing the grid against grid failure, it is only Hydro Power which can black start instantly and supply adequate power to thermal units for start-up. This is another reason as why blackout period continued for three days.

After cloudburst and devastating flood in Uttarakhand in June 2013, a PIL was filed in Supreme Court and by August 2013, 24 Hydro Project under Construction was stalled by the order of Supreme Court. A news item of International Commission of Large Dams (ICOLD) during same period published a report that Tehri Dam saved the Holy Cities of Hardwar and Rishikesh. The incoming peak flood of 7000 cum was stored in Tehri reservoir and a regulated flow of only 500 cum was discharged through the spillway, thus saving thickly populated areas of downstream. This report was given least priority in the media.

Another reason of diminishing storage capacity and fewer development of Multipurpose Projects is that in seventies onwards several PSU were formed like NHPC, SJVN, NEEPCO etc. to exclusively develop Hydro Power on the basis of power demand and their commercial viability. These Organizations neither have any direction nor authority to develop Multi-Purpose Projects. As a result, potential benefits of entire downstream population were denied. The stalling of Subansiri Lower Hydro Electric Project (2000MW) for 8 years by agitators on environment issue is a glaring example. A Report of Ministry of Development of North Eastern Region, as on January 2010, total Capacity of 48,167 MW for 86 projects, allotted to organizations of Centre, State and Private sectors have not yet seen the light of the day for too many wrangling processes in local issues. Status remain same as on 2020

For last 46 year we have not moved much on the Interlinking of river (ILR), a scheme drawn out and proposed by the eminent Engineer and Minister of Irrigation & Power Dr, K.L. Rao in 1972. The Figure. 3 shows the schematic plan of interlinking of Rivers (ILR) in India. The Project had following direct benefits as updated in 2003-04 by National Council of Applied Economic Research:

Table 6

Irrigation 30 million Ha @ Rs. 17,482/ha	=Rs. 52,444 Cr/ year
Power (net) 24,800 MW @ Rs. 1.67/KWH	=Rs.9072 Cr/year
Water Supply 12bcm @2paise /litre	=Rs. 24,000 Cr/year
Flood damage saving Rs. 27,000Cr/10 years	=Rs. 2700 Cr/year
Total Benefits per annum	=Rs. 88,216 Cr (20 % of Capital Cost)

Present net irrigated land is 50 million Ha adding 30 million Ha will boost by 60%. Hydro Power present installed capacity is 44765 MW, addition of 24,800 MW will enhance by 55.40%. Flood damage annual cost presently is Rs.4745 Cr. By saving of Rs.2400 Cr. per year will save the damage by 50.60%. There is no restriction of taking up these projects except a long-term planning and development. This scheme will store water during flood season only accruing benefit on flood control of both the countries. Bangladesh and India can share benefit of Flood Control, Hydro Power and Irrigation 14 Nos. River linking in Himalayan region and 15 nos. in peninsular region is proposed. Multipurpose benefits from flood control, irrigation, water supply and hydropower benefits were planned.

7. gr OuNd WaTEr ViS-À-ViS Sur FaCE WaTEr MaNagEMENT

The Ground water utilization and management is one of the most important and yet neglected part in overall water management. Overuse and underuse in different areas needs to be evaluated and action plan to be chalked out to have a sustainable a long-term strategy for this rich resource.

Figure 3 : Interlinking of Rivers (ILR) in India

Table 6 : The Surface and Ground water availability in India are assessed as below:

Annual Water availability	1869 Billion cum
Useable water assessed as on 2015	1123 Billion cum
Surface Water	690 Billion cum
Ground Water	433 Billion cum
Natural discharge of Ground water	32 Billion cum

The Ground water is also a renewable asset but its judicious extraction and use is an imperative necessity. In India 68% of Ground Water is recharged by Annual precipitation and 32% is recharged from Canal seepage, Irrigation field, Tanks, Ponds and Reservoirs. If monsoon fails, recharge from all source are also equally impacted.

Table 7 : As per estimate, assuming 68% to 50% is threshold limit of Ground water use which is expected to be recharged naturally from rain, actual extraction of State wise Ground Water is given in % use of availability as assessed in 2011 will show wide and alarming variations as below:

danger level of extraction >70%		Threshold level >50%<70%		Safe level <50%	
Punjab	172	Gujarat	67	Kerala	47
Delhi	137	MP	57	Bihar	44
Rajasthan	137	Uttarakhand	57	West Bengal	40
Haryana	133	Telangana	55	Andhra	37
Puducherry	90	Maharashtra	53	Chhattisgarh	35
Tamil Nadu	77			Jharkhand	32
UP	74			Odisha	28
HP	71			Sikkim	25
				Others	<10

Over extraction of Ground Water will lower ground water table, contaminate ground water with chemical used as pesticides and fertilizers. The demand of surface water irrigation will increase. In successive years the situation will be aggravated in dangerous level on water quality and quantity from well in rural population and on agricultural products.

89% of Ground Water extracted are used in Irrigation, 9% are for domestic consumption and 2% for industrial use. 50% of urban and 85% of rural domestic use are from Ground water.

61.6% of Irrigation water in India are used from Ground water and 24.5% are from canals and rest 3.9% from other sources, such as local ponds, direct streams etc. While earlier to 1980 the dependence on canal water was higher, the situation is reversed after green revolution, subsidised or free tariff of electricity for tube wells, subsides tariff for purchase of Tube wells by farmer, high demand of use of water with drastic reduction on development of reservoirs by construction of Dams and Barrages. Following figures will show the reversal and trend of uses of Surface and Ground water and Canal water use vis a vis Ground Water in India for irrigation.

Figure 4 shows increase in ground water utilization for irrigation

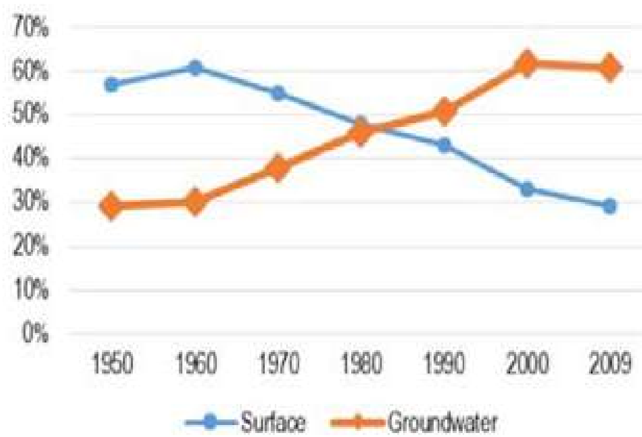

Fig. 4

Figure 5 shows tube well increasingly being the main source of irrigation

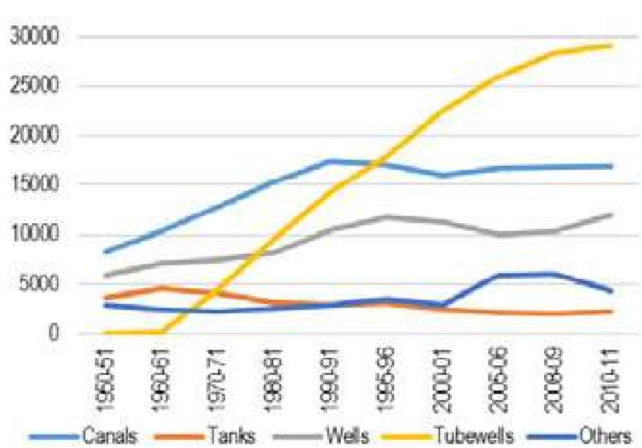

Fig. 5

In addition, the yield of Agricultural products in MT per cum of water used for irrigation, particularly on Rice, Wheat and Cotton are very low as compared China and USA as shown in following table.

Table 7 : Cubic meter of water use in irrigation for per MT of agricultural production

	BraZiL	**iNdia**	**uSa**	**CHiNa**
RICE	3,082	2,800	1,321	1,275
SUGARCANE	115	159	117	103
WHEAT	1,616	1,654	690	849
COTTON	2,777	8,264	1,419	2,535

With above data and figures it revels immediate attention to-

(i) Scientific assessment of soil, need of fertilizers, efficient irrigation to minimize water loss, use of more drip irrigation.

(ii) Increase of surface water use and reduction of indiscriminate ground ware use.

(iii) Climate change threat factors with periodical aggravation of flood and draught must be realistically assessed and incorporated in overall water resources planning

8. WaTEr POLLuTiON, rEViVaL OF riVErS & WaTEr BOdiES aNd WaTEr FOr aLL

The water pollution in urban area is growing steadily due to lack of Industrial waste and sewage water treatment and management. In rural areas the unchecked ground water extraction and untreated surface water is aggravating unchecked.

Present initiative of giving more emphasis of water pollution control projects to be accelerated.

9. CONCLuSiON & rECOMMENdaTiON

Water and its judicious use by human is directly linked with food production from Irrigation and agriculture, hydropower production, flood control, navigation, tourism etc. With emerging challenge of climate change and population growth, there is no alternative in India than to develop all feasible storage reservoirs to harness entire water flowing from Himalayas and running down to sea unused. Many developed countries have already harnessed all feasible water resources and are in the process of water conservation by increasing efficiency of water use. Countries. India have already started and have to continue in a war footing on following.

(i) Development of multipurpose project mega projects including implementation of ILR to be declared National project and planned for accelerated development.

(ii) Improve Agriculture system scientifically, reduce wastage of water with high yield

(iii) Develop water treatment plants in urban and rural area to reuse and reduce pollution

(iv) Surface and ground water be declared national wealth with Central Subject

(v) Present trend of quality of life improvement to be accelerated.

Sustainability of Thalpitigala dam in View of climate change Induced Sedimentation

d.M.T.S. dissanayake [1]

1. iNTr Odu CTiON

Reservoir sedimentation is worldwide issue and many reservoirs in Sri Lanka are also experiencing a similar threat. The country has got a topography where central part consists of hills with steep slopes. Almost all rivers start from the hill country and, as a consequence, carry large amount of silt during rain.

Sri Lanka has got nearly hundred major reservoirs and many are multi-purpose. Currently there are few ongoing reservoir projects and Thalpitigala reservoir is one of them. The proposed Thalpitigala reservoir is to be built across Uma-oya, a tributary of the Mahaweli River. The reservoir is to be constructed in the middle part of Mahaweli River basin and the dam will be 280 m in length. The capacity of the reservoir has planned to be 15.56 MCM. In addition to providing water for agriculture, it will generate 51.3 GWh of hydro energy. As the downstream area to the reservoir consists of a large extent of agricultural lands, Thalpitigala reservoir is a good intervention for drought risk mitigation. Further, the reservoir is capable of decreasing the probability of floods as Mahaweli river basin downstream areas are prone to flooding during rainy seasons.

A major part of the reservoir catchment consists of homesteads and agricultural land which are well known for poor land management. As a result, heavy soil erosion is occurring in the catchment. The heavy sediment load carried by the Uma-oya can be observed during rainy periods. The Rantambe hydro reservoir just located downstream to the proposed Thalpitigala reservoir location has silted up to almost half of its capacity by now.

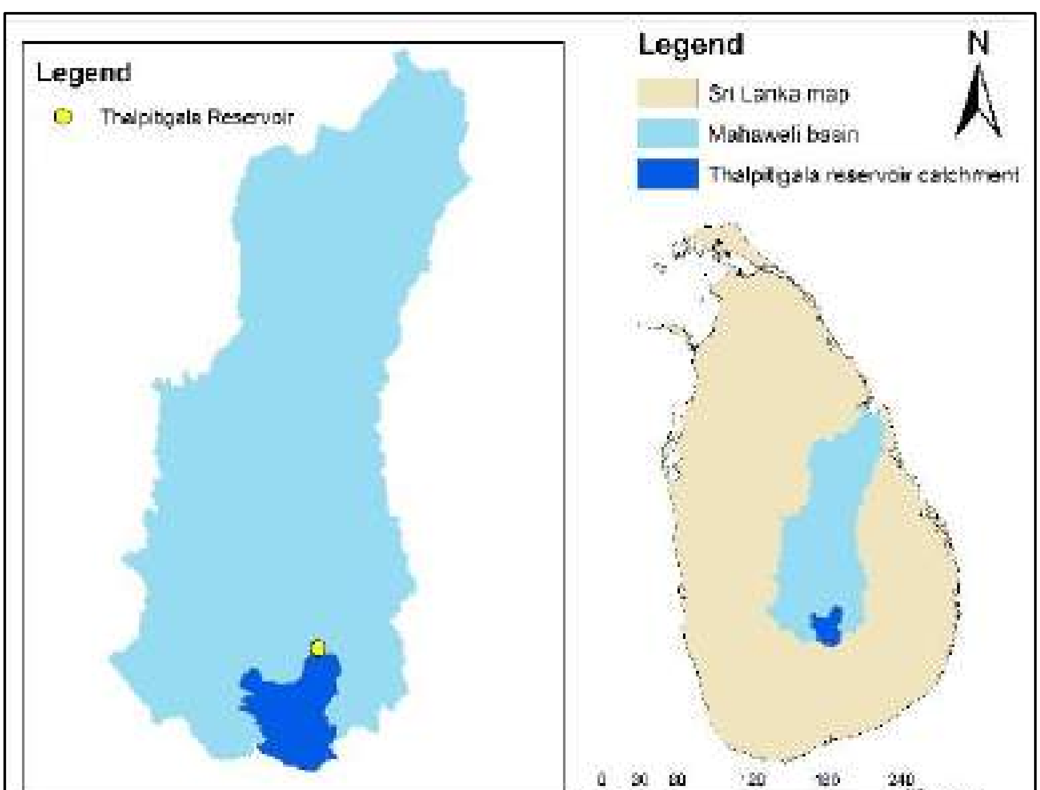

Fig. 1 : Location of the proposed reservoir

1. Chief Engineer, Irrigation Department, Sri Lanka

The catchment area of proposed Thalpitigala reservoir is 53,075.6 ha, where 37.7 % of it consists of slopes above 30%. Therefore, the potential for soil erosion is high which can be aggravated by probable high intensity rainfalls due to climate change. Eventually, this would cause rapid sedimentation of the reservoir. Although, sedimentation cannot be completely avoided rate of sedimentation is very important as far as expected lifespan of the reservoir is concerned. When expected objectives like providing water to agriculture and hydropower generation are concerned capacity reduction due to sedimentation will reduce such benefits.

The feasibility study for the project has already been done, where lifespan of the reservoir has been taken as 50 years. Accordingly, the Internal Rate of Return (IRR) of the project has been calculated to be 11.77%. If the active design storage does not remain constant during that lifespan of 50 years, the expected benefits related to agriculture and energy generation in will reduce. Accordingly, the IRR will be less than what has been calculated at the feasibility stage. Therefore, rate of sedimentation and consequent capacity reduction during the lifespan of the reservoir should be considered for economic viability of the project.

Further, it is important to control soil erosion in the catchment to mitigate reservoir sedimentation. Hence, it is necessary to identify erosion prone areas. Accordingly, proper mitigation options has to be planned and executed in order to retard soil erosion. As such, soil erosion rates in the catchment is also examined under this study.

Therefore, this study analyses mainly the rate of sedimentation of the reservoir and consequent loss of its capacity together with the sediment yield pattern in the catchment. The Soil Water Assessment Tool (SWAT), a semi distributed hydrological software model, is used for this analysis.

2. LiTEra Tur E r EViEW

2.1 Soil Erosion Process

The Modified Universal Soil Loss Equation (MUSLE) is widely used around the world to estimate soil erosion [Eq.1]. The SWAT model, which was used for this study and described under methodology, also uses the same equation to calculate erosion outputs (*Sed*) of a basin area [1].

$$Sed = 11.8 \times (Q_{surf} \times q_{peak} \times area_{hru})^{0.56} \times K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG \quad [1]$$

Where; Q_{surf} - Surface runoff volume (mm/ha)

q_{peak} - Peak runoff rate (m^3/s)

$area_{hru}$ - Area of hydrologic response unit (ha); defined under methodology

K_{USLE} - USLE soil erodibility factor

C_{USLE} - USLE cover and management factor

P_{USLE} - USLE support practice factor

LS_{USLE} - USLE topographic factor

$CFRG$ - Coarse fragment factor

As per the MUSLE all other factors except Q_{surf} and q_{peak} are unique characteristics of a basin area. As the same land use and soil map were used throughout the modelling period (1980-2016) of this study, as described under methodology, only Q_{surf} and q_{peak} were the varying parameters. Hence, any increase or decrease in erosion rates during the period considered for the analysis can be attributed to the variability of rainfall.

2.2 reservoir Sedimentation Process

Although, the coarse inflowing sediment is deposited in a reservoir, a portion of sediments containing silt and clay can be moved out of the reservoir with spill water especially during periods of high inflows. In addition, regular water releases for agriculture or power generation through bottom outlets can also contain sediment. Thus, the rate of sediment accumulation of a reservoir is called trap efficiency of a reservoir. The trap efficiency (*TE*) is the portion of inflowing sediment deposited in the reservoir, which is the ratio of deposited sediment to the total sediment inflow [Eq.2].

Modelling sediment deposition process within a reservoir is possible with SWAT. For that parameters like sediment particle size distribution and equilibrium sediment concentration in the reservoir must be known. As no such information is available, some other methodology had to be followed.

However, a limited number of studies has been reported in the field of reservoir sedimentation. Brune has proposed an empirical method to determine trap efficiency of reservoirs [3]. The trap efficiency is to be obtained according to the capacity and inflow to the reservoir. At present the Brune curve, extracted from Reservoir Sedimentation Handbook by Morris et.al. (Fig. 3), is being generally used for estimating trap efficiency of reservoirs. Therefore, Brune curve was used to determine the sediment trap efficiency of the reservoir.

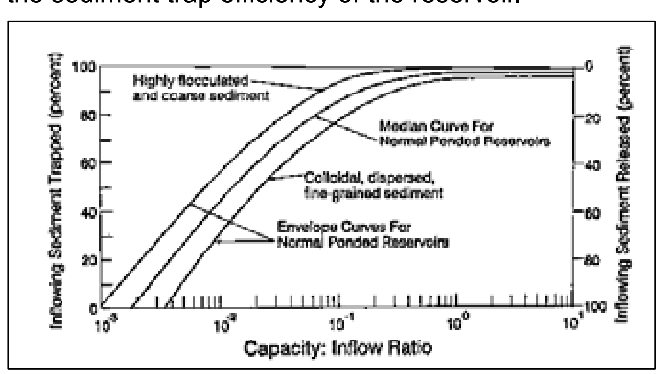

Fig. 2 : Brune curve

$$TE = \frac{Quantity\ of\ sediment\ depositing\ in\ reservoir}{Quantity\ of\ sediment\ inflowing\ to\ reservoir} \quad [2]$$

2.3 Trend analysis for a Time Series

One objective of this study was to check whether climate change has any impact on sedimentation of the reservoir. For finding that the sedimentation time series data had to be checked for presence of any trend.

The Spearman's rank correlation method is a useful tool for trend analysis of a time series [1]. The Spearman's rank correlation coefficient R_{SP} is defined as follows [Eq. 3].

$$R_{SP} = 1\text{-} \frac{6\times\sum_{i=1}^{n} D_i^2}{n(n^2-1)} \quad [3]$$

Where *n* is the total muber of data and *D* is difference, and *i* is chronological order number.

The difference between rankings is computed with;

$$Di = Kxi - Kyi \quad [4]$$

Where *Kx* is the rank of the variable *x* which is the chronological order number of the observations. The series of observations, y_i is transformed to its rank equivalent *Kyi* by assigning the chronological order number of an observation in the original series to the corresponding order number in the ranked series *y*.

$$t_t = R_{sp}[\frac{n-2}{1-R_{sp}^2}] \quad [5]$$

Where t_t, has Student's t-distribution with $v = n - 2$ degrees of freedom. At a significance level of 5 per cent (two-tailed) and the time series has no trend if;

$$t\{v, 2.5\%\} < t_t < t\{v, 97.5\%\} \quad [6]$$

Accordingly this methodology was applied to check whether sediment data time series has any trend.

3. METHOdOLOgY

3.1 Model description

Soil Water Assessment Tool (SWAT) was used as the modelling software for this study. SWAT is a continuous hydrological simulation tool jointly developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research [6]. It is GIS-based and simulations can be done at daily time intervals. In addition to hydrological modelling SWAT is capable of calculating the sediment yield of a river basin as well. Accordingly, a SWAT model was developed for the study at a daily time-step for the period 1980 to 2016. Although all the reservoirs has not been constructed yet, a longer period was taken into account to get a more realistic sedimentation rate.

The primary inputs to the model were the basin Digital Elevation Model (DEM), digital land use map, digital soil map, daily rainfall and temperature data of meteorological stations within the study area. A Subtle Radar Terrain Model (SRTM) downloaded from United States Geological Survey was used as the digital elevation model. The resolution of the model was adjusted to 60m. The elevation of the area varied from 411 m to 2064 m MSL. The land use data were obtained from Land Use Planning Policy Department and digital soil data from Agriculture Department. Daily rainfall data and temperature data were obtained from Meteorological Department.

Fig. 3 : Rain Gauge Stations

As no previous land use data maps were available the latest map was used for the total modelling period. In fact, there had not been any significant land use changes in the area and it was a valid reason for using the same map for the whole modelling period. The description of major land use categories are given with the percentages available in the study area (Table 1). It is interesting to note that nearly 30% of the area consists of homesteads which would highly contribute to overall sediment yield.

Daily rainfall data of seven rain gauge stations located within the area were used. For daily minimum and maximum temperature data three climatic stations, within and around the basin were used. Unavailable climatic data; solar radiation, wind speed and relative humidity were generated by the model itself using a weather generator provided with SWAT [4].

Table 1 : Land use categories in the study area

SWaT code	descriptive Term	% of Catchment area
URLD	Homestead	29.9
FRSE	Forest	24.9
AGRR	Tea	16.9
RICE	Paddy	14.9
AGRL	Other crops	4.5
SHRB	Scrub	4.3

3.2 Model Simulation

Model development was done using the QGIS QSWAT interface and associated SWAT Editor tool. The model generated the river network based on the DEM where the threshold value selected was 2 km2. According to this river network the model delineated 157 sub basins within the study area.

The DEM was categorized into four slope bands as 0-10%, 10-20% and 20-30% and above 30%. During the simulation model created similar sub units with similar hydrological response known as Hydrological Response Units (HRUs). HRUs are areas within the sub basins where slope, land use and soil types are similar. An area threshold of 10% was applied to land use types in order to avoid minor land use types in sub basins to simplify HRU creation. The model was run for the period 1980-2016 in a daily time steps and outputs were obtained in monthly time steps.

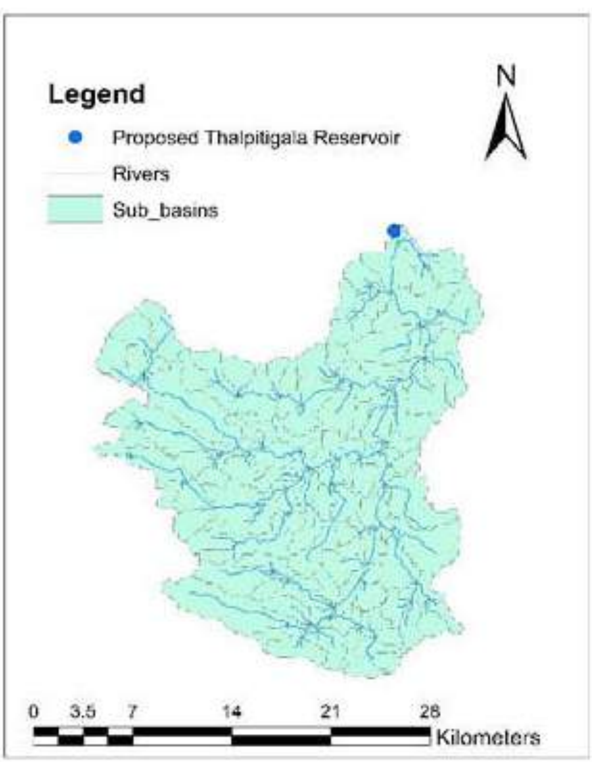

Fig. 4 : Sub-basin Map

4. rESuLTS aNd diSCuSSiON

The model calculated daily sediment load reaching the reservoir location from the beginning of 1980 to the end of 2016. As the rainfall is varying throughout the year the annual series of sediment load is more appropriate for calculating the average sediment load. The annual totals were plotted for analysis excluding the first two years of the modeling period to avoid modeling errors. Hence, model outputs from 1982 to 2106 are considered for the calculations.

It can be observed that highest sediment load at the reservoir location has been 497,847.2 t as reported in 2011. The average sediment load during the total period (1982-2016) has been 281,535.8 t/year. Accordingly, average sediment load is 8,043.88 t/ km2/year. According to a separate study carried out in the basin the sediment yield varies from 1,260 to 9,549 t/km2/year [5]. Hence, results given by the model is within that range and results are acceptable given the fact that no measured sediment data are available for calibrating the model.

The time series of sediment load calculated by the model were checked to see whether there was a trend. For that Spearman's Rank-Correlation Method was applied and the results are summarized in Table 2.

If there is no trend in the time series data the value of student's distribution, t_t should be such that; $-2.01 < t_t < 2.01$. As this condition is not satisfied where the calculated value of t_t equals to 2.46 (Table 2) it can be concluded that annual average sediment load from 1982 to 2016 has a considerable increasing trend. Accordingly, sediment load reaching the proposed reservoir site is on the rise.

Table 2 : Results of Spearman's rank correlation test

Parameter	Value
Spearman's rank correlation coefficient; (*Rsp*)	0.45
For Student's t distribution; (t_t)	2.46
Degree of freedom; v (= n −2)	35
For significance level of 5% values from t distribution; Upper level value Lower level value	 2.03 -2.03

Although, there is an increasing trend in the annual sediment load it is not known whether this same increasing trend will prevail for the future or not. Therefore, for the prediction of capacity reduction of the proposed reservoir the annual average sediment load is taken as a conservative approach. The annual capacity loss is calculated as in the table.

Table 3 : Reservoir sedimentation rate calculation

Parameter	Value
Average sediment load	281,535.8 t/year
Trap efficiency of reservoir	79%
Sediment amount trapped in the reservoir	222,413.3 t/year
Equivalent volume reduction in the reservoir (specific density of sediment =1.3)	171,087.2 m^3/year
Annual % reduction in volume	1.10 %

When sub basins of the catchment are considered soil erosion has a spatial variation (Fig. 5). For finding exact reasons for this variation requires physical inspection of the catchment in a detailed manner. Therefore, making conclusion on erosion rates of different areas within the study area is beyond the scope of this study.

Table 4 : Reduction in reservoir volume

Time after construction / Years	reduction in reservoir volume (%)
10	11
25	27.5
50	55
75	82.5
91	100

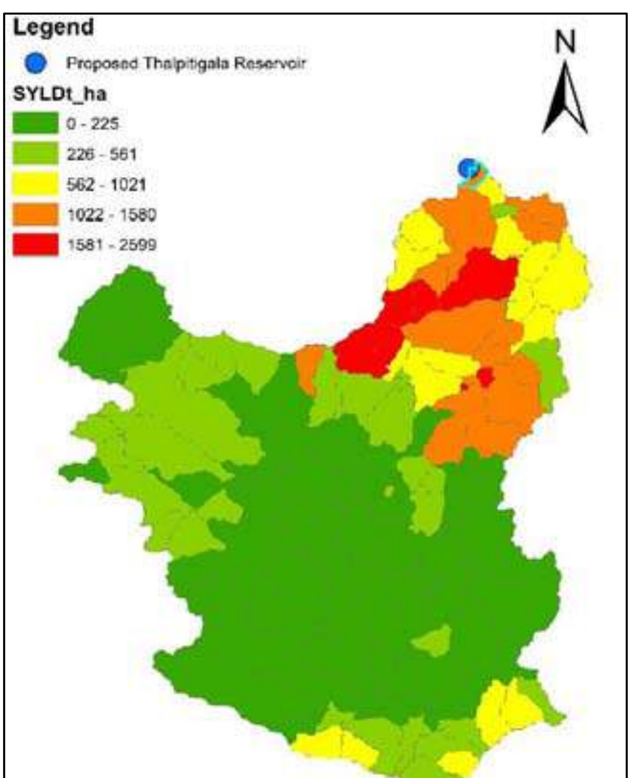

Fig. 5 : Sediment Yield Map

5. CONCLuSiON & rECOMMEdaTiONS

The expected annual average capacity loss of the proposed Thalpitigala reservoir due to sedimentation is 1.1%. Therefore, it can be predicted that according to the rate of sedimentation the reservoir will lose its whole capacity 91 years after its commissioning (Table 4). For the IRR calculations in the feasibility report the active lifespan has been taken as 50 years. Hence, during this lifespan of 50 years the active capacity will be gradually decreased to 55% (Table 4). Thus, the available capacity after 50 years will be 7.0 MCM. Therefore, economic benefits will be less than what has been calculated in the feasibility report. In order to calculate the actual economic benefits of the project the gradual capacity loss of the reservoir due to sedimentation has to be taken into account. Eventually, the real IRR can be examined, which is a vital factor for deciding the economic viability of the project.

Soil erosion was not spatially uniform throughout the study area and comparatively higher in some of the sub basins (Fig. 5). It is worth finding reasons for this higher erosion rate, which is beyond the scope of this study. Suitable soil conservation methods in agricultural lands, especially in homestead, and afforestation of bare lands are to be envisaged as measures for erosion mitigation. Further, the future developments within the area, which may take place to cater demands of increasing population, have to be well planned to minimize soil erosion.

aCkNOWLEgEMENTS

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key Words

Internal Rate of Return, Thalpitigala Reservoir, Sedimentation, SWAT

Role of Flood control dams in Managing Extreme climatic Events : A case Study of Kerala's Periyar Basin

k.a. Joshy [1], Soumya r Chandran [1] and Sudheer Padikkal[1]

aBSTraCT

Increased frequency of extreme climatic events indicates climate change. In this paper, we are investigating the role of flood control dams in managing extreme climatic events with a case study of Periyar basin in Kerala. Scientific analysis of Kerala floods in 2018 and 2019 have already proven that these floods were not dam induced. Rather, the role of flood control dams in managing similar extreme events are increasingly recognized. The master plan of Kerala's Periyar basin, which witnessed extreme flooding in 2018, had proposed two more dams in two different tributaries of this river. However, these dams were not constructed due to several reasons including the issues of environmental sustainability. Revisiting of the master plan of Periyar in the context of extreme events is attempted in this paper. It reiterates that these dams can be constructed and operated without compromising the environmental sustainability and they can be effective tools for managing extreme floods.

1. iNTr Odu CTiON

Extreme climate variations are significantly altering the structure and functioning of many ecosystems. Climate-driven extreme weather events, such as floods, droughts, heatwaves and cyclones, cold waves, devastating thunder clouds, cloudbursts and intense cyclonic storms have been occurring frequently over the globe and becomes a huge humanitarian challenge. Significant advances in the scientific understanding of climate change now makes it clear that there has been a change in climate that goes beyond the range of natural variability. Modern land use practices, increased development in flood plains and destruction of natural areas have left the landscape less able to accommodate heavy rainfall, increasing risk of floods and exacerbating their impacts. With rising global temperature due to increased heat trapping emissions, more water evaporates from the land and oceans. Warmer atmosphere holds more water vapour and when it rains, there is a higher potential for heavy rainfall, which is the main cause of inland flooding. The damage caused by climate change will increase as temperatures rise, and the Intergovernmental Panel on Climate Change (IPCC) warns that it will "disproportionately affect disadvantaged and vulnerable populations through food insecurity, higher food prices, income losses, lost livelihood opportunities, adverse health impacts, and population displacements" (IPCC 2014). Climate change threatens to create a vicious cycle for the world's poor, as further warming pushes more people into poverty, increasing their vulnerability to climate impacts. Nowhere is this clearer than in relation to climate-driven extreme weather events, such as floods, droughts, heatwaves and cyclones, which present a huge humanitarian challenge.

Kerala State lies along the coastline, to the extreme south west of the Indian peninsula, flanked by the Arabian Sea on the west and the mountains of the Western Ghats on the east. Though Kerala state is blessed with 44 rivers, it is not a water rich state. The extreme rainfall events during monsoon and severe drought in summer months causing acute drinking water shortage are becoming repetitive. Flood and landslides are the most common natural hazards in Kerala. In August 2018, a devastating flood struck Kerala, causing significant damage to life and property. Kerala Floods of 2018, as it is known in the print and social media has discussed it across its breadth and depth. Recently, the UN Secretary General referred to the Kerala floods, among other natural disasters across the world, to highlight the urgency of the climate crisis and the need to step up efforts to reverse course on climate change. The extreme rainfall and the very high population density made the deluge significantly affecting a population of 1.2 million. About 400 persons lost their lives and the basic infrastructure facilities were seriously damaged (PDNA 2018).

The state of Kerala is now on a massive mobilization drive to rebuild a new Kerala. RKI (Rebuild Kerala Initiative) focus on sustainability principles suggested in the Post Disaster Needs Assessment (PDNA) study. Integrated Water Resources Management (IWRM) based on principles of "room for river" and "living with water" has been identified in the PDNA as one of the four pillars of recovery strategy. In Kerala, the concept of Integrated Water Resources Management (IWRM) is well known but, yet, not adopted in its water resources management policies, planning and programmes. Robust institutional arrangements for the integrated river basin management,

1. Water Resources Department of Government of Kerala State, India

as suggested in the PDNA, does not exist now in Kerala. Therefore, an institutional setup, 'River Basin Authority of Kerala' (RBAK), for the successful implementation of recovery strategies suggested in the PDNA and for carrying forward IWRM programmes is being thought about with high level administrative and political support and is ought to be embedded in a long-term vision of Kerala's sustainable development.

But in Kerala it looks like climate change induced floods are becoming an annual affair. Following the 2018 deluge, the state was struck with devastating floods again in August of 2019, due to climate change, population pressure and unscientific land utilization. The present priority of the State is the development of an Integrated flood management approach aiming efficient use of flood plains and coastal zones, while minimizing the loss of life and impact on livelihoods and assets through protective measures. IFM is a paradigm shift from the conventional, fragmented and localized approach calls for the use of resources of a river basin as a whole, employing strategies to maintain or augment the productivity of floodplains (WMO 2009). Being a dynamic notion, it includes several emerging issues such as risk management, urban floods, climate variability and change and adaptive management. Moving towards integration of ecosystems, disaster risk reduction and adaptation to climate change is the need of the moment (IUCN 2013) and the State has set a goal for combining Engineering solutions and mainstreaming an Ecosystem based Disaster Risk Reduction (Eco-DRR) into development, as identified in the PDNA study.

Considering an integrated approach for flood management and in align with basic principles of IWRM and following the concept of 'Room for River project' of the Netherlands, the State is envisaging to provide more space for the water body so that it can manage extraordinary high-water levels during floods. Apart from the same, hard engineering solution of Detention reservoirs, without any environmental implications are also in the pipeline. This paper broadly highlights one such potential approach for flood control in Periyar basin, which was one among the worst affected during August 2018 floods, through hard engineering solution of Flood Control dams at two locations.

2. AREA PARTICULARS

2.1 Periyar river basin

Periyar is the longest river with largest discharge potential in the State. It has a total length of approximately 244 Km and a catchment area of 5,398 sqkm of which 5,284 sqkm is in Kerala and 114 sqkm is in Tamil Nadu. The basin has an inverted 'L' shape with a maximum width at the intersection. Major tributaries of the river are Mullayar, Cheruthoni Ar, Muthirapuzha, Perinjankutty Ar and Idamalayar, and most of the upstream tributaries flow through deep gorges and steep valleys. At Aluva, the river bifurcates into the Marthandavarma and the Mangalapuzha branches. The Mangalapuzha branch (primary) joins Chalakudy River and empties into the Sea and the Marthandavarma branch (secondary) flows southwards going through the Udhyogamandal area and finally draining into the Cochin backwater system (part of Vembanad Lake). The average annual rainfall in Periyar basin is around 1933 mm. Neelaswaram and Vendiperiyar are the two CWC HO stations located on the river.

Figure 1 : Periyar River Basin
(Including Chalakudy River System)

The stream flow in the basin is heavily regulated by 17 dams and reservoirs and 2 barrages, which are constructed mainly for hydroelectric power generation as well as irrigation, as depicted in Figure 1. Out of this, two major ones are Idukki and Idamalayar with 1.46 BCM and 1.0 BCM storage capacity respectively (CWC 2018). The water level in the Idukki reservoir, the largest reservoir of the basin, is maintained by three dams, viz. Idukki, Cheruthoni and Kulamavu dams. Among the various dams, the largest dams are the Idukki–Cheruthoni–Kulamavu trio and the Idamalayar. The major irrigation projects in the basin are the Periyar Valley Irrigation Project, and the Idamalayar Irrigation Project. The major inter-basin transfer projects from the basin are the Mullaperiyar Dam (to Vaigai River, Tamil Nadu) and the Idukki Hydroelectric Project (to Muvattupuzha River, Kerala), and minor water transfer to Bharathapuzha river (Kerala) also co-exist in the basin (Sudheer et al. 2019).

2.2 rainfall analysis

Periyar catchment received continuous rainfall from the beginning of June 2018 and reservoirs of Idukki and Idamalayar had reached almost FRL by end of July. Continuous spell of rainfall had already made the soil of the basin saturated, and the extreme rainfall that occurred in August resulted in higher runoff than normal conditions. The analysis of rainfall data as carried out by Central Water Commission specifies 5 that Kerala received about 2346.6 mm of rainfall during 1st June 2018 to 19th August 2018 against the normal rainfall of 1649.5 mm, which was 42% above the normal. During 1st August 2018 to 19th August 2018, total rainfall occurred in Kerala was about 758.6 mm against the normal of 287.6 mm, which was 164% above normal. The average cumulative rainfall of 15-17, August 2018 is about 414 mm for entire Kerala. The consequent cumulative runoff of three days for the entire Kerala (area about 38,800 sq.km) was about 12 BCM (12,000 MCM) for a runoff coefficient of 0.75.

During 15-17, August 2018, the 3-day rainfall depths realised in Periyar, Pamba, Chalakudi and Bharathapuzha sub-basins were 588 mm, 538 mm, 421 mm and 373 mm respectively. Due to severe rainfall from 15-17, August 2018, the gates of about 35 dams were also opened due to extremely large inflow of water in the reservoirs. August 2018 flood in Kerala was due to severe storm occurrences during 8-9, August 2018 and 15-17, August 2018. The storm of 15- 17, August 2018 resulted in heavy flooding in Periyar, Pamba, Chalakudi and Bharatpuzha sub-basins of Kerala5.

Sudheer et al. (2019) had simulated the flow in the basin for different scenarios such as virgin basin, actual floods and dams at various storage levels, for period from 1st August 2018 to 31st August 2018 to represent conditions prevalent within the catchment. The study had identified that reservoir operation could not have helped in avoiding the flood situation and that as the probability of extreme rainfall events of that kind in the month of August in Periyar was very small (0.6%) and any planned operation could not have helped in mitigating floods of such magnitude as the reservoir design might not have considered such events.

Padikkal & Joshy (2019) also had analysed the extreme rainfall event and dam management during Kerala floods of 2018 to investigate the dam safety – disaster management nexus. Major conclusions of the study were that the extreme rainfall event had a return period of 100 years or more and that Dam management did not contribute to the worsening of flood.

3. aPPr OaCH aNd METHOdOLOgY

Even though Periyar basin houses several water retaining structures, major ones being Idukki and Idamalayar, none of them are designed for flood control. An attempt has been made to identify the ideal location for detention reservoirs/flood control dams to mitigate damages due to extreme flood events.

Sudheer K P et.al6 had demonstrated that for Periyar River basin, the role of releases from the major reservoirs in the flood havoc was less. It proved that attenuated flood peak due to advance emptying of the reservoir would still be almost double the safe carrying capacity of the Periyar river section at Neeleswaram. Their analysis suggested that reservoir operations could not have helped in attenuating the flood peak as the bulk of runoff to the flooding was also contributed by the intermediate catchments without any reservoirs to control. The simulated and observed peak flows to Idukki reservoir (upstream of PRB) were 2763 and 2532 m3/s respectively. Similarly, the maximum discharge simulated at Neeleswaram was 9965 m^3/s against the measured value of 8800 m3/s. The flood hydrograph without dams (virgin simulation) and the actual flood event (simulation with reservoirs at storage capacity 85% by the end of July 2018) showed reduced peak discharge at immediately downstream of Idukki by 33% and at Neeleswaram by 17%, indicating the positive role of dams in attenuating the flood magnitude. The study also indicated that the major share of the total flood flow in the basin was from Perinjankutty stream (3500 m^3 /s), which is a near uncontrolled tributary, while the controlled releases from Idukki had contributed only 1860 m^3/s.

Based on the comparison of different scenarios of flooding undergone in the study by Sudheer K P et.al6 and data from CWC report5, four different scenarios were selected for comparison.

1. Actual Floods of 2018
2. Virgin scenario (without dams)
3. Idukki & Idamalayar dams being 50% empty
4. With Flood Control dams at two locations

3.1 Tentative location of Flood control dams

A potential location for flood control dam is identified as the uncontrolled catchment at the Perinjankutty stream at FRL of 270m, storage of 12 TMC and catchment area of 324 sqkm, while the other one at FRL of 659m, storage of 15 TMC and a catchment area of 390 sqkm, at the join of the downstream of Erattayar and Kallar dams.

Based on the data from the reference studies, the average rainfall recorded on Periyar basin during 15th, 16th & 17th August 2018 were considered. The location considered for the comparison is CWC Station at Neeleswaram and Maximum Flood Level (MFL) in each scenario were computed. From the comparison of different scenarios, it

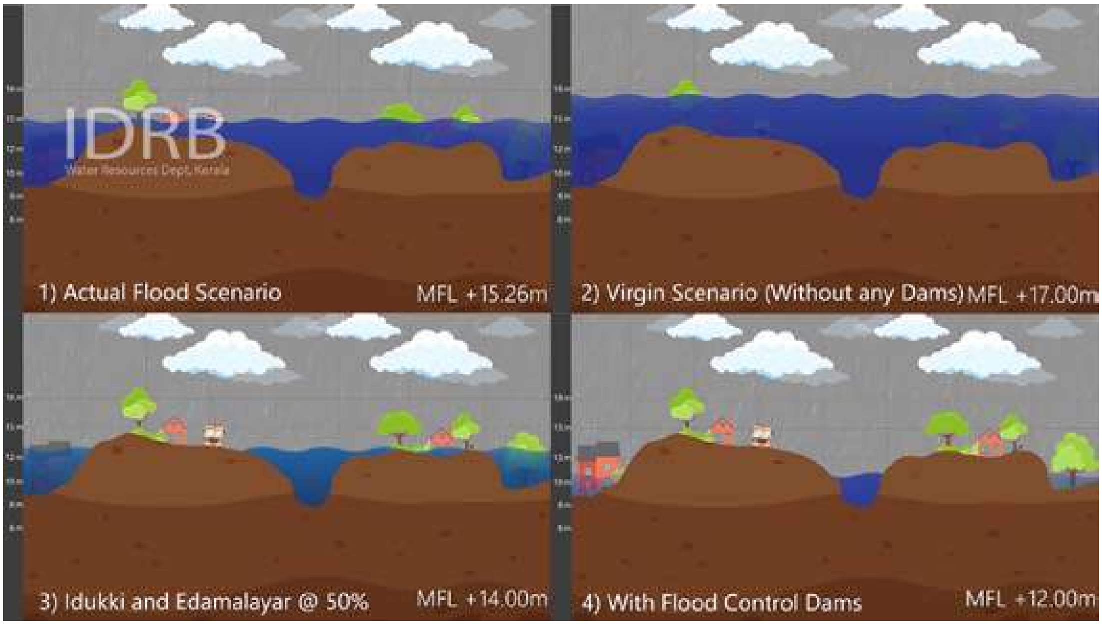

Fig. 2 : Inundation at Neeleswaram on comparison of different scenarios of flooding in Periyar

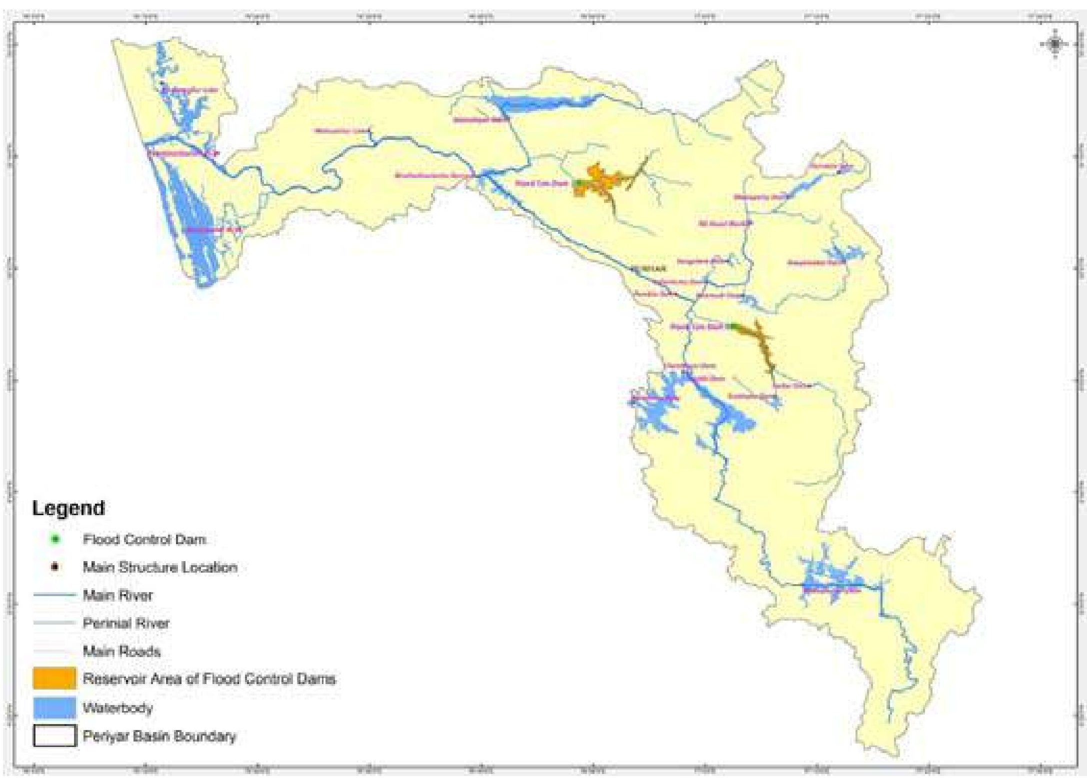

Fig. 3 : Proposed location of flood control dams in Periyar basin

is inferred that there is a considerable reduction of MFL by 3.26m with the introduction of flood control dams at the two locations, as compared to the original flooding scenario.

4. SUMMARY AND CONCLUSION

This paper has highlighted the flooding situation in Periyar basin keeping in view of the reference study reports. It has also put forward the effect of flood control dams in reducing the flooding situation in the basin. Major conclusions of this paper are:

1. Flood control dams are an engineering solution for management of flooding in Periyar basin

2. On comparison with actual flooding and with the introduction of Flood control dams at two locations, the depth of inundation has reduced by 3.26m based on the observation at Neeleswaram station.

After the Kerala Floods, a Post Disaster Needs Assessment (PDNA) was initiated on September 18, 2018 for a period of three weeks. IWRM is the main platform recommended by PDNA for Rebuilding a Resilient Kerala. It aims to break inter-sectoral barriers to establish a holistic framework for coordination. An integrated approach for management of floods in Kerala basins in alignment with Eco system-based Disaster Risk Reduction is the prime focus of the State. How these flood control dams can be effectively operated to facilitate the required environmental flows during lean months, thereby making them control more sustainable, is a sequel to this study to be taken up.

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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.

Adaptions to climate change Induced Uncertainties for Safeguarding Existing dams – case Study of Banas Basin, Gujarat, India

Vivek P. kapadia

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.

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

1. Water Resources Department, Government of Gujarat, Gandhinagar, India

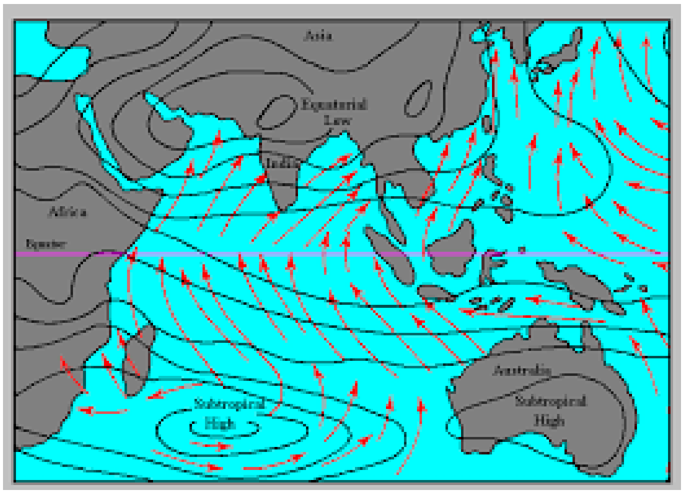

Figure 2 : Normal monsoon pattern for western India i.e. southwestern wind induced rain

Fig. 3 : Arvalli and Vindhyas mountain ranges

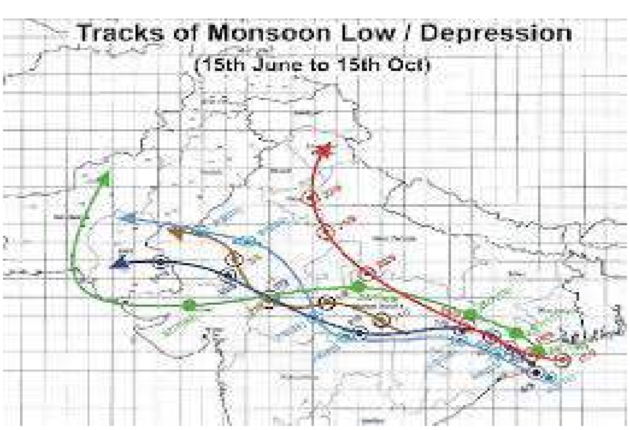

Fig. 4 : Exceptional monsoon pattern for western India

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

2. da NTiWada da M: LiMiTEd HYdr OLOgi CaL da Ta a Nd iTS CONSEQu ENCES

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.

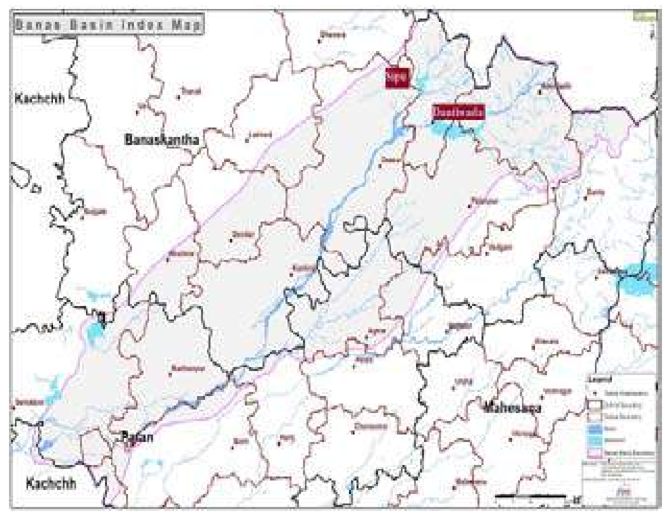

Fig. 5 : Index map of Banas basin

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

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

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 Figure 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. da NTiWada da M: r EViSiON OF HYdr OLOg Y

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

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

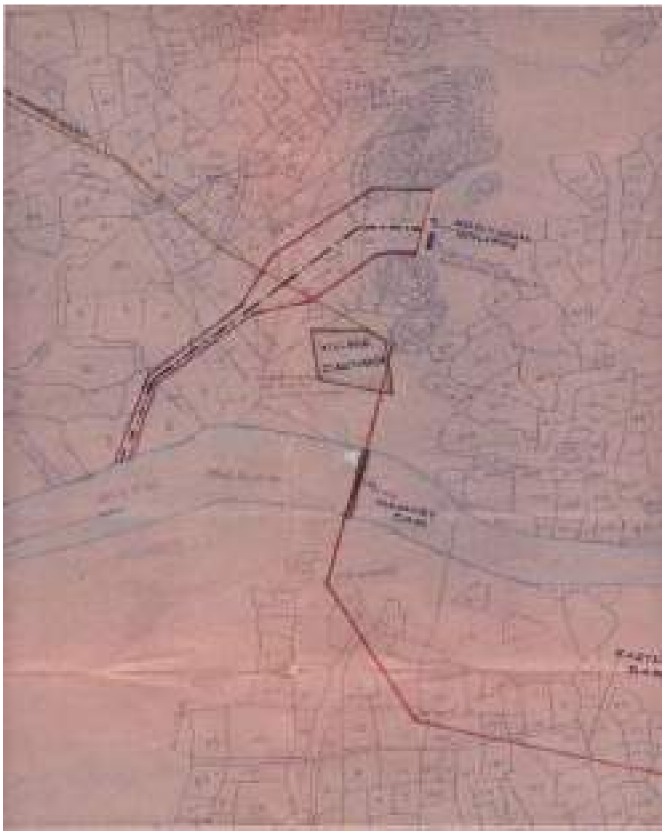

Fig. 9 : Alignment of Dantiwada Dam and Additional Spillway

4. SiPu da M: ENOug H HYdr OLOgi CaL da Ta BuT STiLL FaCEd CHaLLENgE

Fig. 10 : Storm intensity at different rain gauge stations

Sipu dam was envisaged to be constructed across river Sipu which is a tributary of river Banas. It was constructed in 1990s. Length of the dam is 8200 m. Its gross storage capacity is 177.78 Million Cubic Meter. The river has a total catchment of 1221 Km^2 out of which 970 Km^2 is in Rajasthan state. The geology of the Sipu river at the Sipu dam site was found very similar to that of the Banas river at the Dantiwada dam site. The spillway is in the gorge portion and has 12 radial gates of size 12.5 m X 8.23 m each. The design flood peak is 7080 m^3/ sec at H.F.L./ F.R.L. at R.L. 186.43 m. As per the Central Water Commission, Government of India, projects having storage capacity of more than 61.53 Million Cubic Meter should be designed as per Probable Maximum Flood (PMF). The two day catchment storm depth of 398 mm as per the observed isohyetal pattern of the storm of 1st and 2nd September, 1973 was taken as the basis. It was further maximized by 20% to get the PMF depth of 478 mm. From the short hourly distribution of rainfall the PMF peak was worked out as 8601 m^3/ sec. Length of the spillover section has been provided as 180 m with the crest level of R.L. 178.157 m. As Sipu dam was constructed long after Dantiwada dam, data availability was not a big issue and the flood of 1973 also became a source of reliable information to work out the PMF. Therefore, Sipu was designed not with empirical formula for hydrology but on actual data and with scientific method and was believed to be reliable.

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

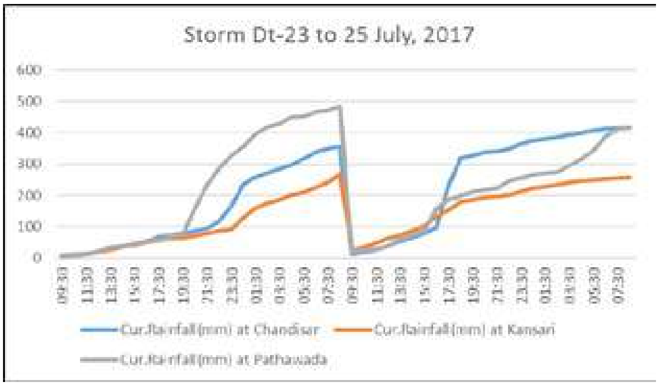

Fig. 11 : Storm intensity at different rain gauge stations

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

Fig. 12 : Proposed additional spillway

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

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

7. CONCLuSiON

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

Hydropower development on Glacial lakes

C. r. donnelly [1], J. M. reynolds [2], S. Bohrn[3], g. Schellenberg [3], B. Shah[4] and Pravin karkhi [5]

aBSTraCT

As much as 69% of the world's fresh water is stored in glaciers around the world. As these glaciers begin to melt and recede, they will leave behind a significant storage volume of water at high elevations. This combination of water storage and elevation presents unique and relatively untapped possibilities for hydropower development.Early estimates put the potentially developable hydropower from these glacial basins at over 1300 TW-h per year. While hydroelectric development of these lakes might avoid some of the typical perceived environmental challenges associated with hydropower, such as the flooding large amounts of otherwise useable land, there are also significant hazards that must be addressed before development can be considered. Some of these issues include access, harsh climatic conditions, transmission constraints, the use of un-engineered natural moraine dams as part, or all, of the water retention strategy and dealing with all of the typical hazards that confront hydroelectric developments in mountainous regions including flash flooding, landslides, debris flows and the reservoir sedimentation.

This paper discusses some of these issues and explores the potential that these developments have to reduce the greenhouse gas emissions regionally throughout the world to help address the commitments that were made as part of the Paris Climate Accord.

1. iNTr Odu CTiON

As the planet continues to adapt to the "new normal" being created by a changing climate, many aspects of the hydrologic cycle, such as an increasing the amount of evapotranspiration, increased convectional storm activity, shorter, warmer winters leading to decreased snow accumulations, the thawing of glaciers and permafrost and the type and frequency of natural hazards, will need to be accounted for by the hydroelectric power industry. Glacial ablation has and will result in a reduction of the total flows available for hydroelectric power generation and a change in the distribution of these flows from the summer months, when they are often most needed, to later in the year. responding to changing precipitation patterns.The negative aspects of climate change are well documented in the literature. However, these changes can also provide opportunities. In the case of glacial lakes, the receding glaciers have the potential to provide new source of clean water for irrigation and hydroelectric power that, properly managed, can mitigate some of the negative impacts.

This paper discusses some of these issues and explores the potential that these developments have to reduce the greenhouse gas emissions regionally throughout the world to help address the commitments that were made as part of the Paris Climate Accord.

1. Hatch Ltd., Niagara Falls., Ontario, Canada
2. Reynolds International Ltd., Mold, Flintshire, UK
3. Hatch Ltd., Winnipeg Manitoba, Canada
4. Hatch Ltd., Vancouver British Columbia. Canada
5. World Bank Group, Washington DC

2. CLiMaTE CHaNgr E aNd EXPaNdiNg gLaCiaL LakES

Glaciers act as natural reservoirs, storing water in a frozen state and modifyingstreamflow's, typically releasing most runoff during the warmest, driest periods when all other sources of water are at a minimum ()making glacier runoff a valuable water resource for hydropower. In Sweden, for example, Stenborg, 1970 noted that glacier runoff peaks at the height of the melt season July and August in the Northern Hemisphere while runoff from non-glacier alpine basins typically peaks in May and June (Figure 1). Unlike non-glacier runoff, glacier runoff correlates better with temperature than precipitation, due to the dominant role of glacier melt compared to precipitation in summer runoff from glacierized basins. This is also the reason for the strong diurnal nature of glacier runoff.

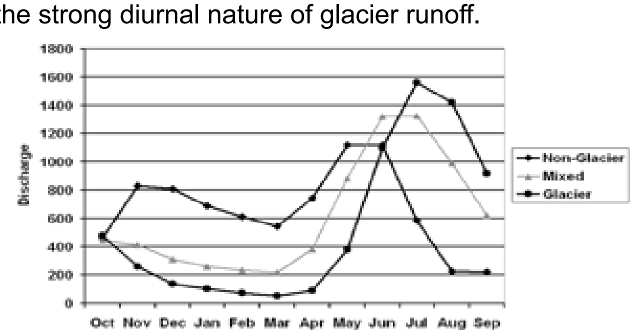

Fig. 1 : Comparison of glacial and non-glacial runoff conditions in 1957 at Mikkaglaciären in northern Sweden

Although glaciers have and will continue to recede as a result of climate change (Figure 2), at any given time, the total long-term runoff flows do not necessarily increase nor decrease as a result of a reduction in glacial meltwaterdue to the fact that the total runoff over a period of several years is determined largely by annual precipitation.

Figure 2 : New lake at the tongue of Trift Glacier on 30 June 2004 (top) and 3 July 2014 (bottum), illustrating the fast glacier retreat encountered in the Swiss periglacial environment.

In fact, there are two changes that occur as a result of the effects of climate change. The initial response is an increase in the glacier melt rate as has been observed in mountainous regions around the world (Andreassen et. al., 2005; Braun et. al., 2000; Zhang et. al., 2008)). Eventually the decline in the extent of the glacier culminates in a reduction decrease in glacier runoff. Typically, this occurs when there is a decline of more than 20% in glacier area(Pelto, 2008; Stahl and Moore, 2006). In the long run, glacier retreat has the impact of reducing summer flows with a corresponding increase in winter and spring flows consistent to periods when water supply is already high in most alpine regions. An example of the potential impacts of glacial recession on the available water resource is presented in Figure 3.

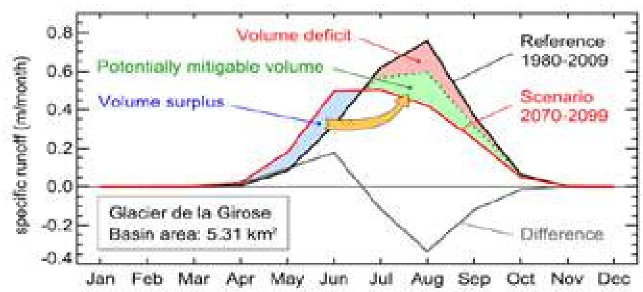

Figure 3 : Mitigating the impacts of glacial recession through water management at Glacier de la Girose in France (Farinotti, 2016).

As noted by The Swiss National Science Foundation, 2012;

"Glaciers store water and transfer winter precipitation into summer runoff. Once they have disappeared, we will need to manage these new reservoirs, which will take over this water storage role."

3. EXaMPLES OF HYdr OELECTri C POWEr gENEra TiON FrOM gLaCiaL ruNOFF

The use of glacial runoff for hydropower generation in general, and glacial lakes in particular, is not new. Countries around the world have long used glacial runoff as a reliable source of water and glacial lakes to store this water.

3.1 South america

A number of South American countries are highly dependent upon glaciers and glacial runoff for energy production. In the Andes region, hydropower supplies 81% of Peru's electricity, 73% of Colombia's, 72% of Ecuador's, and 50% of Bolivia's, in each country glaciers contribute a significant portion of this runoff. In the Cordillera Blanca, Peru glacial cover has been shrinking since the 70's, decreasing by 15% over a 25-year span. In the Rio Santa Basin of Peru glacier runoff comprises 35% of the total runoff (Vergara et. al., 2008).

In Peru, in 1941, a Glacial Lake Outburst Flood (GLOF) inundated the town of Huaraz in the Cordillera Blanca, killing over 5,000 people (Reynolds, 1992). Since then, the Peruvian government, and other associated agencies, have grappled with the hazards presented glacial lakes. One solution has been to drain the lakes. However, the Peruvian Government also recognized that the lakes themselves represented a significant resource. Over the decades that have followed since 1941, the Peruvian authorities have developed a strategy of both lowering some lake levels to reduce the hazard (Portocarrero, 2014) and managing the lakes, using the stored water for hydropower generation. For example, Laguna Parón(Figure 4) is a glacial lake that lies about 17 km to the east of Caraz at an elevation of about 4,000m. The lake is contained by the 250 m high Hatunraj moraine. Since 1958, hydroelectric power has been generated downstream of the lake at the Cañón del Pato hydroelectric scheme. Generation was enabled using the glacial lake through the construction of a retaining dam designed to reduce the potential for a GLOF and a tunnel, designed to release the lake's waters at about one meter per second (m/s) that provided reliable flow and allowed the lake level to be lowered in a controlled fashion by about 20 m (Reynolds, 1992). Over the years, there has been a 50% glacier runoff reduction that has resulted in a decrease in energy production from about 1540 gigawatt-hours to 1250 gigawatt-hours. The trend is expected to continue with an expected decline to 970 gigawatt-hours for a 100% glacier loss (Vergara, 2008). Clearly, the planning of hydropower facilities such as these must consider these realities (https://glaciers.nichols.edu/glacier-runoff-hydropower/)

Fig. 4 : Laguna Parón, Peru (Reynolds, 2018)

3.2 asia

In India, about 50% of the countries hydroelectric power is generated by streams draining Himalayan glaciers. Climate change is impacting the availability of water from these sources. For example, the Gangotri Glacier that forms the headwater of the Bhagirathi river with an area of 286 km^2, provides flows of up to 190 m^3/second (Singh et. al., 2006) but has retreated 1 km in the last 30 years which will change the amount and timing of the available flow. Similarly, in Pakistan, about 45% of hydropower along the Indus River is supplied by large glaciers of the Karokoram Range. Two of the largest, the Biafo and Baltura glaciers are retreating rapidlywhich has been reflected in a marked decline in flow.

In Tajikistan there are more than 8,000 glaciers with a combined area of 8.5 thousand sq. km. These glaciers supply most of the rivers in country. On Vakhsh river, for example, there are five of the largest facilities in Central Asia including the 3015 MW Nurek hydroelectric power stationwhich supplies almost 70% of the countries hydroelectric power. The facility is supplied by almost 13 km^3 of glacial meltwater during the peak summer months. (Normatov and Petrov, 2006).

3.3 Europe

In Europe, the total runoff yield from presently glacierized surfaces is expected to increase by about 0.25 to 1,8 km^3 in the period of 2010–2039 and subsequently decrease to between about 0.1 to 1.3 km^{3}in the period of 2070–2099 (Farinotti, 2019).

In Switzerland, glacial runoff supplies about 50% of the countries hydroelectric power (Paul, 2007). However, satellite observation of a sample of 270 glaciers indicates that there has been a 20% area loss in the period between 1973 and 1998, a trend that can be expected to accelerate due to the impacts of climate change. Water management has been identified as one of the solutions to maintain power flows. For example, the Grand Dixence Dam ,situated on the Dixence River, collects glacier meltwater during the summer months using a system of water supply tunnels over 100 km long that help to re-distribute the available flows. The Swiss Federal Institute for Forest, Snow and Landscape Research explored the potential for water management and the hydropower potential of areas that are expected to become ice-free during the course of this century. For the roughly 185,000 sites studied, they predicted a theoretical maximum storage and hydropower potential between 600 and 1100 km^3 and 800 1900 terawatt-hours per year could be available, although they cautioned that only part of it practicably exploitable.

Many of Austria's larger hydroelectric facilities are supplied by glacier meltwater. For example, the 700 MW Kaprun power station receives 60% of its water supply is from Pasteze Glacier by means of a 12 km long tunnel. This glacier has been reported to be retreating at a rate of 51 m/yrwhich, without adequate management measures, will reduce the available melt season runoff and hydroelectric power generation potential.

In Norway, about 15 percent of the hydroelectric power flows are derived from glacier melt with up to 80%, occurring during the summer months. In northern Norway, the 370 km^2 Svartisen glacier, and a number of smaller glaciers, provide about 50% of the flows utilized by the 600 MW Svartisen hydropower plant. The plant receives water from a number of rivers and streams west of the Svartisen glacier by means of a network consisting of a total of 100 kilometers of tunnels and 50 intakes.

The 22,5 MW Ilulissat hydropower project near the town of Ilulissat in Western Greenland harnesses the outflow of two glacial lakes by means of tunnels that tap into the bottom of the lakes (Figure 5).

Figure 5 : The 22.5 MW Ilulissat Hydroelectric Project in Greenland

3.4 North America

In Canada, 10-20% of annual flow and 50% of summer flows in the Columbia River are derived from glacier melt water. Large facilities such as the 2805 MW Mica and 2480 MW Revelstoke hydroelectric plants are principally glacier fed (Fleming and Clarke, 2005). However, BC glaciers are receding. For example, over the period of 1985-1999 glacial recession was found to be occurring at a rate of about 22 km^3 per year, with many streams in glaciated basins in BC showing a statistically significant decrease summer stream flows (Stahl and Moore, 2006) indicating the need to manage the available resource and the expanding glacial lakes.

In Washington, there are about 700 glaciers that store as much water as all of remainder of the state's lakes, rivers, and reservoirs combined, Washington's North Cascade Glaciers release approximately 230 billion gallons of water during the summer that is nearly fully utilized for irrigation, salmon fisheries and power generation. However, all 47 monitored glaciers in the region are retreating (Pelto and Hedlund, 2001) with an expected loss of volume over a 25-year period in the range of 20-40%.

4. HYDROPOWER AND THE NATURAL HAZARDS OF NEPAL

Nepal has no known oil or gas reserves and only limited lignite deposits. All commercial fossil fuels (mainly oil and coal) are either imported from India or from international markets routed through India. In this context, waterand hydroelectric power represents a means for significant economic growth. Following the devastating impacts of the 2015 Gorkha Earthquake and aftershocks in Nepal, the country embarked on an ambitious reconstruction plan that includes plans to develop up 15 GW of new hydroelectric power plants over the next decade for use domestically and for export. While these ambitious plans are unlikely to be realized in their entirety due to logistical and funding issues, there is a need for the power in the region and there is significant activity.

A summary of the existing and planned hydroelectric power in the region is provided in Table 1. In Figure 6, the locations of existing and planned hydropower facilities in Nepal are shown.

Table 1 : Existing and planned hydropower in Nepal.

Status	Number	Total Capacity (MW)	Average capacity (MW)	Total demand (MW)
Operating	90	1,015	11.3	
Licensed for construction	30	1,855	61.8	
Issued survey license	307	17,617	57.4	
Totals	427	20,487	48.0	17,929

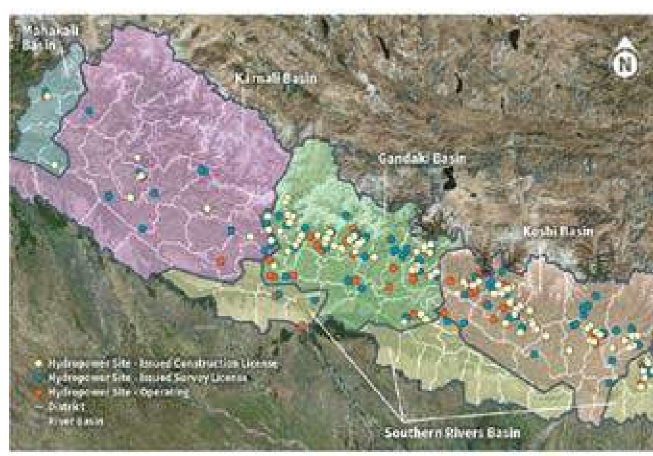

Figure 6 : Existing and Planned hydropower in the Seven Major Drainage Basins in Nepal

In geologically young and dynamically-active mountainous regions such as the Himalayas, the potential for natural hazards to occuris increased, introducing numerous challenges to hydroelectric power development

(Reynolds, 2018, Donnelly, 2018). These hazards can be further compounded by the effects of climate change. For example, rising temperatures affect glaciers, snowfields and melt-water run-off. Thawing high-altitude permafrost can result in destabilization of steep mountain flanksgiving rise to catastrophic mass movements including Glacial Lake Outburst Floods (GLOF's) or Landslide Dam Outburst Floods (LDOF's). All of these natural hazards, as summarized in Table 2, need to be carefully considered when planning, constructing and operating hydroelectric facilities in mountainous regions.

In addition to the impacts climate change has on natural hazards, it is also causing the worlds glaciers to melt, often at an accelerating rate. As glaciers recede, their retreat can lead to the formation of pro-glacial lakes dammed by moraines. These expanding lakes can in and of themselves increase the potential for natural hazards to develop. For example, if a rock and snow avalanche or a major landslide collapses into such a lake, an avalanche push wave can be generated that can overtop the moraine dam leading to its failure and a GLOF that can involve the discharge of millions of cubic meters of water and entrained debris that can flow for many tens of kilometers downstream.

Reservoir sedimentation is another significant factor in considering the future of hydropower development. The total volume of water stored in reservoirs used for hydropower and other purposes around the world currently exceeds 6,800 km^3 [White, 2001]. However, it has been estimated that 0.5-1% of global reservoir volume is lost every year due to sedimentation [White 2001, Morris, 2008]. It's estimated that, if these rates continue into the future, half of the world's reservoir storage would be lost within the next 50 to 100 years. As reported by Annandale, 2016, globally, storagespace to reservoir sedimentation global storage space percapita hasdecreased since about 1980 with a 2016 per capita net reservoirstorage space roughly equal to what it was in 1965 (Figure 7).Expanding glacial lakes provide a new source of water storage that can help to reduce this negative trend.

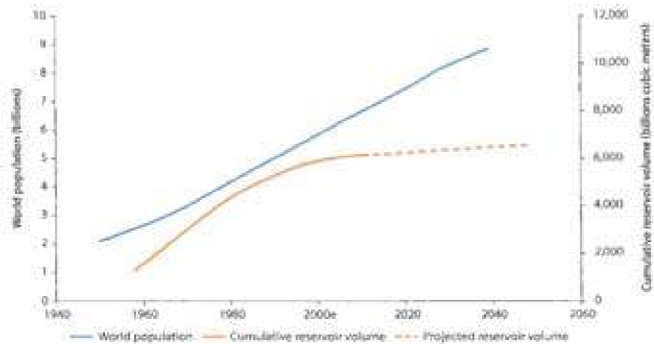

Figure 7 : Global Population Growth and Reservoir Storage Volume (Annandale, 2016)

5. GLACIAL LAKES IN NEPAL

Research based on topographic maps, aerial photographs and satellite images that began in 1999 identified 3,252 glaciers and 2,323 glacial lakes in Nepal (Figure 8). which can provide both positive and negative impacts to the countries existing and planned hydropower facilities. The researchers estimate 20 glacial lakes in Nepal are potentially dangerous, a figure that could increase as a result of glacial retreat. Almost all the glaciers in the Himalayas have been retreating since the Little Ice Age (1400-1650 AD). In more recent times, climate change is accelerating the retreat of mountain glaciers, enlarging

Table 2 : Triggers of disasters, their types and possible causes (modified from Reynolds, 2015)

Event Trigger/Process	Type	Possible Causes
Earthquakes	Geophysical	Tectonic activity.
Cloudbursts or exceptionally prolonged heavy rainfall1.	Hydro-meteorological.	Atmospheric processes possibly coupled with effects of climate change.
Rock-/ice-avalanches and landslides.	Geomechanical	Debuttressing of mountain flanks from retreat of glaciers*. Retreat of glaciers*. Thawing of high-altitude permafrost*. Earthquakes. Heavy and prolonged rainfall. Pre-conditioning by earthquakes
Debris flows, mudslides including Landslide Dam Outburst Flood and Glacial Lake Outburst Floods.	Hydrological and geological	Heavy and prolonged rainfall. Thawing of permafrost and ice in moraine dams Saturation of material. Pre-conditioning by earthquakes

* Triggers and causes are not necessarily mutually exclusive and may be associated with changing climate.

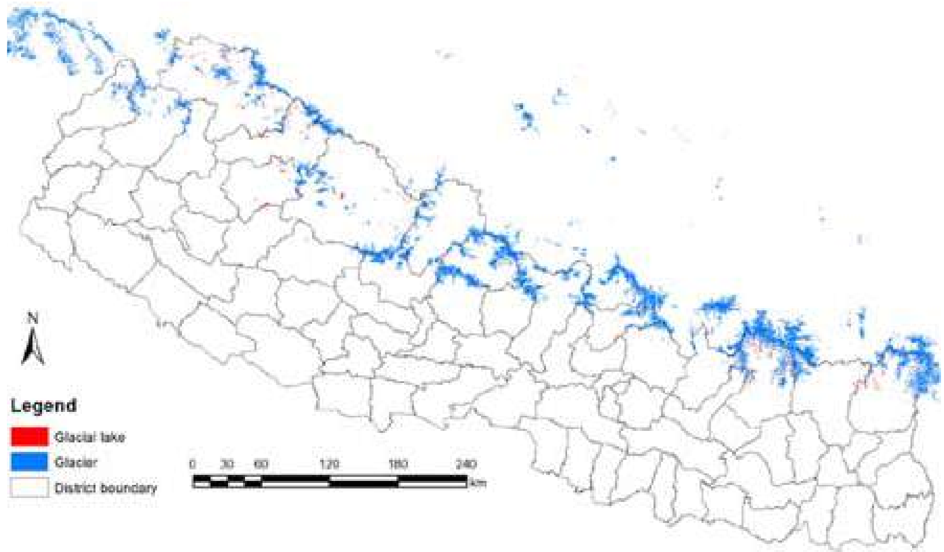

Figure 8 : The Glacial Lakes of Nepal

existing glacial lakes and forming new ones. To-date, on average, the glaciers in Nepal have retreated about 1 km resulting in the formation of some substantial lakes.

5.1 gLOF's in Nepal – Mitigating the risks

Glacial lakes in Nepal are retained by moraines that are typically composed of over-consolidated (dense) cohesive materials. Such natural dams are generally quite stable, as evidenced by the large number of moraine-dammed glacial lakes and the relatively small number of GLOFs that have occurred historically. When GLOFs do occur, it is typically because of a triggering event, such as a landslide or rock/snow avalanche collapsing into a lake producing waves that can overtop and erode the moraine dam causing regressive erosion and the subsequent release of water in the form of a Glacial Lake Outburst Flood (GLOF) (Richardson and Reynolds, 2000). While GLOF's are relatively rare. major GLOF events can travel for more than 200 km downstream and can cause major devastation along the river channel such that GLOF's and other debris flow events still constitute a significant risk, if not the greatest risk, to hydropower development in mountainous regions (Donnelly, 2018).

As reported by Reynolds, 2018, all of the countries in the Himalayan region have recognized the hazards represented byGLOFs and, similar to other regions in the world are taking steps to manage the risk.In Nepal, the Tsho Rolpa Glacial Lake is located at an elevation of 4580m.The lake is approximately 3 km long, 0.5 km wide and up to 130 m deepcontaining approximately 80 million cubic meters of water. As such it is the largest glacial lake in Nepal. The Tradkarding glacier, which feeds the Tsho Rolpa glacial lake, is retreating at a rate of over 20 meters a year and, in some years within the last decade, reached 100 meters per year. The expanding lake is contained by a 140m high natural moraine dam that is considered to be only marginally stable. Failure of this natural dam would inundate parts or all of 20 villages for over 100 km downstream and threaten up to 6000 lives, the site for the 60 MW Khimti hydroelectric project, and other infrastructure.

The first phase of the risk reduction strategy for this glacial Lake includedlowering the water level in a hazardous lake through construction of an open channel controlled by sluice gates (Rana et al., 2000). The phase 1 remediation project was completed in 2000, with a reduction in lake level of 3.5 m achieved. The final scheme will involve lowering the lake by 20 m relative to its level in 1994 (Reynolds, 2015). However, funding of this final phase has been an ongoing point of discussion since 2002. Recently, the discussion has broadened into an assessment of the feasibility of both remediating this lake by lowering its water level and then using the storage capacity to provide dry season flow for additional power generation such as has been dome in other regions of the world.

A notional scheme (Figure 9) for the phase 2 remediation of Tsho Rolpa glacial lake being considered is to lower the lake by means of a power tunnel that wouldtap into the bottom of the lake transporting the lake water to a 4.3-km long tunnel that would utilize the water for power generation. The additional stream flow during the dry season would be transported travel downstream to the proposed Upper Tama Koshi Extension intake and into the headrace tunnel to the Upper Tama Koshi HPP site at Lamabagar. Currently, it is postulated that the construction costs could be recoveredwithin four years through the additional revenue from generation from the extra dry season flow thereby provid ing an ideal solution to a potentially serious problem.

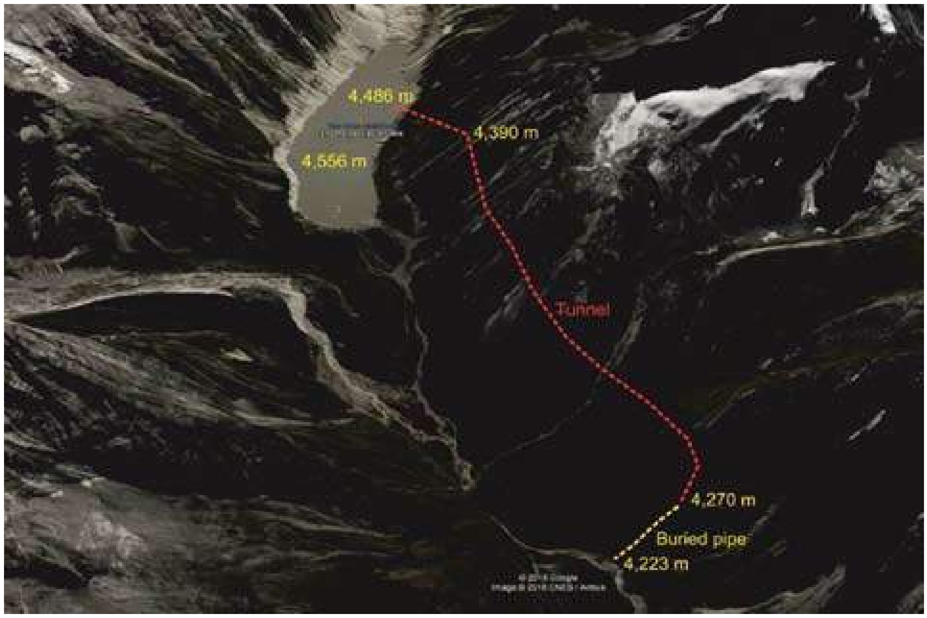

Figure 9 : Conceptual Tsho Rolpa Lake Remediation and Hydropower Scheme (Reynolds, 2018)

6. CONCLuSiONS

Climate change is causing widespread glacier retreat and a number of negative impacts such as diminishing water resources, shifts in runoff seasonality and an increase in the potential for natural hazards such as landslides, GLOF's and LFOF's to occur (Donnelly, 2018). However, glacial meltwater also represents a significant source of new stored energy world-wide (Farinotti, 2019) that can serve to counterbalance the world's loss in storage that is occurring due to sedimentation (Annondale, 2016), a process that can also be expected to accelerate in response to the impacts of climate change.

Farinotti, 2019 estimates that under a conservative climate change scenario, three quarters of the roughly 185,000 sites that are glacierized at present are anticipated to become ice-free by 2050. This will result in a loss of available meltwater for hydropower generation during the critical summer months. However, properly managed, Farinotti, 2019 determined that the potential additional storage volume in expanding glacial lakes would be enough to retain about half of the annual runoff potentially providing up to 300 to 700 terawatt-hours per year of practicably developable hydroelectric power, corresponding to about 13% of the current hydropower production worldwide. Aside from the obvious benefit of maintaining storage and redistributing available water resources, managing expanding glacial lakes can reduce the potential for a GLOF to occur by managing lake levels. Farinotti, 2016 undertook a first-order approach in order to assess whether 'replacing glaciers with dams is an option theoretically worth considering. While building dams at every glacier location is neitherrealistic nor sustainable, managing the available resources through dams and other means at a relatively small number of sites would provide significant benefits. For instance, it was determined that constructing dams at 1,000 of the roughly 185,000 glaciated sites examined would provide up to 31% of the total energy that is theoretically available. Environmentally, Nemergut, 2007 andHodson 2015 argue that managing glacial lakes also has environmental advantage because much of the infrastructure needed to exploit the lakes is underground and the new reservoirs are largely non-vegetated with relatively simple ecosystems where impacts can be readily managed.

Managing expanding glacial lakes as new storage reservoirs has been undertaken in countries around the world for almost eight decades, but not in Nepal where the need for hydroelectric power and the risks associated with GLOF's are significant. This solution has the potential to address both issues in a sustainable and environmentally friendly way.

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design case Analysis and Safety Management counter measure of High Tailings dam in china

Xuan Cui [1], Xiaofei Liu [2] and Hanmin ZHOu [2]

aBSTraCT

Because of the limit of land resources, a number of tailings dams constructed by upstream method were built in valley area of China, Which height reaches 200m. The design, operation and management of high tailings dam is very important for the success of mine production. Taking a 210m high tailings dam as an example, a generalized zoning model of tailings dam is established based on the characteristics of sedimentary tailings in the pond. The stability of high tailings dam is obtained by rigid limit equilibrium method, and the control indexes of tailings dam in different stack heights are analyzed. On this basis, construction method and seepage drainage facilities of the tailings pond are designed and safety management countermeasures are put forward.

1. iNTr Odu CTiON

The mining industry generates large quantities of tailings. This by-products, which may potentially be harmful to the environment, need to be safely managed. China is a big mining country, producing about 1.6 billion tons of tailings every year. Except for a few fillings, most of them are stored in tailings ponds. Due to the increasing demand for mineral resources and the limitation of land resources, China has designed and constructed a number of upstream tailings dams over 200 m and 300 m in valley area. The design and operation management of high tailings dam is very important to the success of mine production. *Finn,W.D.L(Finn.W.D.L, 1976,1990) believes that the upstream construction of tailings dams is potentially dangerous.*Vick,S.*G.(Vick.S.G., 1990)pointed out that all tailings dams reported to have flowing damage in earthquakes have been constructed by upstream method. The tailings in these tailings dams and tailings ponds are usually in a saturated and loose state, with finer particles and larger proportion, and are prone to liquefaction and destructive deformation in earthquakes. However, the upstream method has been the most widely used dam construction method in China for decades because of its simple technology and easy management(*CHEN,S.Y, 1995*). At present, the maximum design height of tailings dam of upstream method in China has reached 325m.*Jiayu YIN et al (YIN, J.Y, 1980), pointed out that the internal friction angle of tailings under high pressure would be lower than that under low pressure. Jianlong ZHANG et al(ZHANG, J. L, 1995), pointed out that the strength envelope of saturated tailings exhibited downward bending under higher stress conditions. Michael et al(Michael, R. 2008), conducted triaxial tests on tailings in earth quake-prone areas. The results show that the shrinkage and ductile failure of tailings under high effective stress are probably caused by particle breakage. Haiming LIU et al(LIU, H. M, 2012), deduced the power function formula of the molar strength of tailings under high pressure, and obtained the confining pressure threshold value of tailings material particle breakage during shearing process through particle analysis before and after the test. At present, the mechanical properties of tailings under high stress conditions have not yet been clearly designed, so it is urgent to carry out relevant engineering exploration and experience summary. Taking a 210m high tailings dam in China as an example, this paper puts forward a generalized zoning model of the tailings dam after on-site geological survey, verifies the stability of tailings dam through stability calculation, and finally introduces the safety management countermeasures of tailings dam. The results can provide guidance for the construction decision of high tailings dam of upstream method in the future.

2. ENgiNEEriNg BaCkgrOuNd

Tailings dam is an important structure in mining engineering and a potential dangerous source of high potential energy. Due to the restriction of land use and other factors, the number of high tailings dam is increasing. According to statistics, up to now, there are 5 tailings ponds with total dam height over 200m,

1. Beijing General Research Institute of Mining and Metallurgy Technology Group, Beijing, China and Beijing University of Science and Technology, Beijing, China

2. Beijing General Research Institute of Mining and Metallurgy Technology Group, Beijing, China

183 tailings ponds with total dam height in 100m to 200m, and 751 with height in 60m to 100m in China's all 8869 tailings ponds. This paper takes a tungsten-molybdenum tailings pond located in Henan Province as the background to carry out relevant research. The catchment area of the tailings pond is 6.87km^2. The valley distributes from northwest to southeast.

The terrain is high in northwest and low in southeast. The ratio of river bed is 0.08. The width of the valley is 4m to 25m. The longitudinal river bed is in V formation. The slope of the left bank is 25 to 50 degrees, the slope of the right bank is 20 to 40 degrees, and the relative elevation difference of the tailings pond area is 400m. The main lithology in the tailings pond area is dolomitic limestone with dolomite, besides a small amount of quaternary bleaching stone and quaternary slope gravel silty clay, as shown in Figure 1.

Fig. 1 : Topography and landform of tailings pond area.

The tailings pond is designed in the form of starter dam and upstream embankment. The total dam height is 210m, the total storage capacity is 59.90 million m^3, and the effective storage capacity is 53.91 million m^3, which is classified as grade two in China. The starter dam is a roller compacted rockfill dam with a height of 60 m and a slope ratio of 1:1.8 in the upstream and downstream slopes. The height of upstream embankment is 150m, the average accumulation slope ratio is 1:5, and the current tailings embankment height is 75m. The capacity of the tailings is designed to be 15000t/d. After the tailings are collected in the concentrator, they are transported to the tailings pond under pressure for discharge, and the weight concentration of the tailings slurry is 35%-37%. Tailings size data are shown in Table 1.

Table 1 : Table of tailings particle size composition.

Particle composition （%）	2mm~0.5mm	0.1
	0.5mm~0.25mm	9.9
	0.25mm~0.074mm	28.8
	0.074mm~0.037mm	27.4
	0.037mm~0.02mm	15.6
	0.02mm~0.01mm	11.5
	0.01mm~0.005mm	3.7
	0.005mm~0.002mm	2.1
	＜0.002mm	0.9
d10		0.013
d30		0.032
d60		0.072
+0.074mm taking (%)		38.8
-0.02mm taking (%)		18.2

3. SEdiMENTar Y LaW aNd gENEra LiZEd ZONiNg OF TaiLiNgS

Sedimentary regularity of tailings in upstream embankment is controlled by the slope of deposited beach, the nature of tailings, particle size, slurry concentration, dispersed ore drawing discharge and ore drawing form. The structure of tailings dam is complex, the number of lens bodies is large and interpenetrating each other, and the profile shape is very complex. According to the section diagram of engineering geological exploration results (shown in Fig. 2), the tailings deposit of the tailings dam presents three characteristics. (1) Tailings in front of dam are coarse and finer along the deposited beach. When the tailings slurry flows from the dam top to the direction of the tailings pond end, the ability of slurry to carry tailings gradually decreases, and tailings gradually deposit from coarse to fine. The median diameter d_{50} of sedimentary tailings in the range of 300m along deposited beach changed from 0.25mm to 0.074mm, and from 0.074mm to 0.035mm in the range of 300m to 420m. (2) The accumulative tailings are thick in the top and fine in the bottom in vertical direction. With the increase of the dam height, the top of the dam moves upward continuously, and fine tailings are deposited at the bottom of the dam body. From top to bottom, the thickness of tailings fine sand layer is 10-22m, thickness of tailings silt sand layer is 30-58m, and the thickness of tailings silty soil layer is 24-60m. (3) There have interbedded and different layers alternate with each other phenomena of the tailings in the embankment.

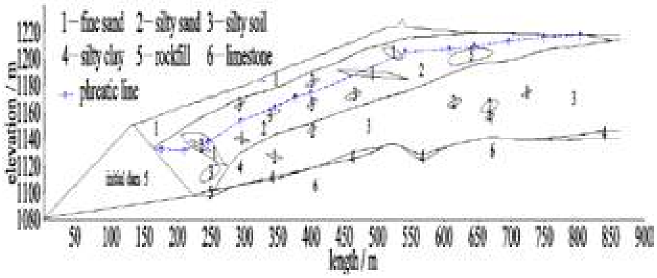

Fig. 2 : Engineering geological exploration profile of tailings dam

From Figure 2, it can be seen that the calculation of anti-sliding stability of tailings dam with complex profile and interpenetrating lenses requires a high computational program and a large amount of work. Therefore, the section can be simplified and the generalized zoning model can be formed before calculation. Specifically, it mainly includes, (1) Retain the larger lens and remove the smaller lens. (2) When the intensity of the lens is higher than that of the surrounding tailings, replace it with the surrounding soil. (3) When the intensity of the lens is smaller than that of the surrounding soil, it is retained. The computed section diagram obtained by such simplification (Fig. 3) can better reflect the measured results of engineering geological investigation.

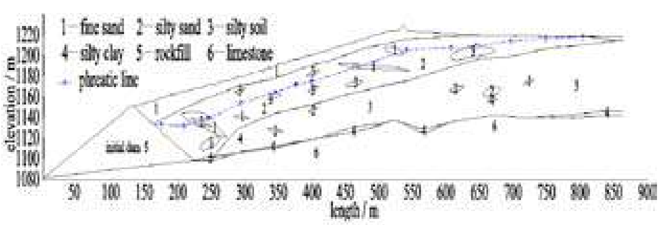

Fig. 3 : The profile of tailings dam after simplified treatment.

4. STud Y ON Sa FETY a Na LYSiS a Nd CONTr OL iNdEX OF TaiLiNgS daM

The anti-sliding stability of tailings dam decreases slowly with the gradual increase of dam (HU, M.J, 2004). High tailings dam break risk is high. Once dangerous situation occurs, it often brings extremely bad impact on the safety of life and property of surrounding people and environment. Therefore, there must be a higher safety reserve of high tailings dam. According to the relevant requirements of Code for design of tailings facilities(China Planning Publishing House, 2013), based on the above generalized zoning model and laboratory test results, the stability analysis of tailings pond is carried out by rigid body limit equilibrium method. In order to consider the influence of high stress conditions on the strength of tailings.

Use decrease value of the internal friction angle of tailings under high stress conditions recommended in the last reference(ZHOU, Q.Y. 2009), that of the tailings silty sand decreased by 3.2-6.0 degrees, the tailings silt soil by 2.4-2.7 degrees and tailings silty clay by 4.0-4.1 degrees. The calculation parameters of this stability analysis are shown in Table 2. Specific calculation scheme is as follows.

(1) Current dam height is 135m and final dam height is 210m.

(2) Normal conditions, flood conditions and earthquake conditions are considered.

(3) Swedish arc method and simplified Bishop method are used as computing methods.

Table 2 : Physical and mechanical properties of foundation and materials in tailings dam.

Material	unit weight kN/m³	Permeability coefficient *k* (cm/s)	Cohesive force C (kPa)	internal friction angle ϕ (°)
Tailings fine sand	21.4	1.65×10^{-3}	8	28
Tailings silty sand	20.9	4.93×10^{-4}	9	24
tailings silty soil	21.5	1.34×10^{-4}	9	20
Tailings silty clay	21.8	6.01×10^{-6}	18	12
Rockfill	21.0	4.56×10^{-1}	10	32

In the analysis of anti-sliding stability of tailings dam, firstly, the seepage field of tailings dam under normal water level and flood level is simulated by GeoStudio software. On this basis, the gravity of dam, pore water pressure, seepage pressure and seismic load are considered. Finally, the stability of tailings dam is analyzed by different calculation methods. The results are shown in Table 3.

The phreatic line is the lifeline of the safety of tailings dam. In order to strengthen the safety management of tailings dam during its operation, the controlled position of the phreatic line is proposed in Code for design of tailings facilities[10], that is, the phreatic line of tailings dam when the safety factor of anti-sliding stability can meet the minimum requirement in the code, and the phreatic line of tailings dam is always lower than the controlled phreatic line in the course of operation. For this reason, four groups of artificial fitting phreatic lines are adopted, and the buried depth of the phreatic line corresponds to 10m, 15m, 20m and 25m respectively. The anti-sliding stability analysis of the dam with different buried depth of the phreatic line is carried out. The results are shown in Fig. 4.

Table 3 : The results of dam stability.

dam height	Computing method	Condition	result	Value required in Code	analysis of stability results
135m	Swedish slice method	Normal	1.884	1.25	Meet the requirements
		flood	1.789	1.15	Meet the requirements
		earthquake	1.514	1.05	Meet the requirements
	Simplified Bishop method	Normal	2.009	1.35	Meet the requirements
		flood	1.912	1.25	Meet the requirements
		earthquake	1.616	1.15	Meet the requirements
210m	Swedish slice method	Normal	1.604	1.25	Meet the requirements
		flood	1.470	1.15	Meet the requirements
		earthquake	1.283	1.05	Meet the requirements
	Simplified Bishop method	Normal	1.672	1.35	Meet the requirements
		flood	1.555	1.25	Meet the requirements
		earthquake	1.338	1.15	Meet the requirements

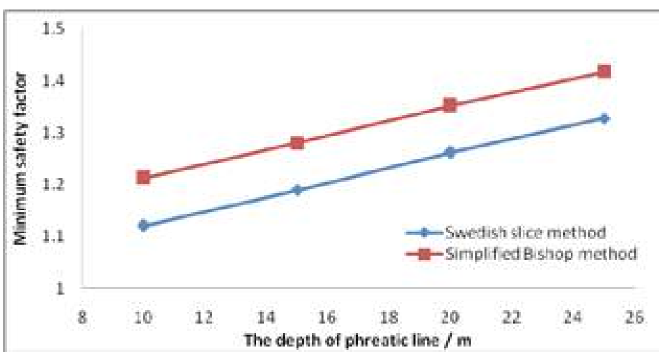

Fig. 4 : Calculation results of dam stability under different controlled positions of the phreatic line.

From Figure 4, it can be seen that the result 1.262 calculated by Swedish slice method is larger than the minimum safety factor 1.25 which is required in the code under the normal condition of 20m phreatic line depth. The stability safety factor calculated by the simplified Bishop method is 1.352, that is close to 1.35 which is the minimum safety factor required in the code. So the controlled phreatic line depth of the tailings dam is 20m.

5. SAFETY MANAGEMENT COUNTERMEASURE OF TAILINGS DAM

The safety of tailings dam is not only related to the normal production of mining companies, but also to the safety of life and property of residents downstream of the tailings pond area and the stability of the surrounding ecological environment. In order to strengthen the ability of safe operation and management of tailings ponds, the Chinese government and mining companies have formulated relatively perfect rules and regulations which mainly include the following points.

(1) The operation of tailings pond needs to declare safety production license. Mining companies need to entrust professional organizations to carry out safety evaluation of tailings pond every three years. Only after assessing as normal tailings ponds can they handle the extension of safety production license.

(2) Tailings pond chief system must be practicable. All the tailings pond chiefs must be selected from government departments to urge mining companies to investigate and deal with hidden dangers and to implement relevant safety input.

(3) The state requires strict monitoring of tailings pond operation parameters, including displacement monitoring, phreatic line monitoring, deposited beach length and slope monitoring, etc.

(4) Emergency rescue reserve plans for tailings ponds should be worked out and drills should be organized and the level of early warning, emergency rescue plans, disaster evacuation routes should be determined to curb the occurrence of major accidents.

6. CONCLUSIONS AND SUGGESTIONS

High tailings dam has become the necessity of tailings dam construction in China. On the basis of summarizing the mechanical characteristics of upstream tailings dam under high stress conditions, taking a 210m high tailings dam as an example, this paper establishes a generalized zoning model of tailings dam, and uses rigid body limit equilibrium method to analyze the stability of the tailings dam, and introduces the safety management countermeasures of the tailings dam in China. Through the above calculation and analysis, here are some points of understanding.

(1) According to the depositional law of the dam, the upstream embankment has the characteristics such as large number of weak layer and weak intercalated layer in bottom, and high phreatic line. So the upstream method should be avoided in high tailings dam as far as possible.

(2) Although the calculation results according to the existing mechanical parameters can meet the requirements of the code, the safety reserve of tailings dam is not enough, so the safety reserve of tailings dam can be improved by methods such as further reducing the dam phreatic line and strengthening the dam with geogrid.

(3) At present, the engineering mechanical properties of tailings under high stress conditions are not clear. It is necessary to study the structural failure characterization of tailings under high stress conditions and the related research on engineering mechanical properties and evolution law.

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Incold - YoUnG EnGInEERS FoRUM

INCOLD YEF Was officially launched on 2nd July 2021 with vision of Bringing together young engineers and students from pan India on a common platform to promote understanding and awareness of roles of Dams in beneficial and sustainable development. To Promote long-term direction for knowledge, career building and exploring of ideas by communicating internally and externally.

Official Launch dated 02.07.2021

The virtual event was organized in presence of eminent personalities of ICOLD, INCOLD, ICOLD YEF, Indian PSUs & State governments.

- Mr. Michel Rogers, President ICOLD
- Mr. D.K. Sharma, President INCOLD & Vice President ICOLD
- Mr. Michel de Vivo, Secretary General, ICOLD
- Mr. Elias Baptista, President ICOLD YEF & Board Members
- Dr. R.K. Gupta, Vice President, INCOLD
- Mr. A.K. Dinkar, Secretary General, INCOLD

The objective of iNCOLd YEY is to-

- Encourage the involvement of younger engineers at ICOLD meetings
- Provide an opportunity for knowledge transfer to the next generation and ensuring the long-term future of ICOLD
- Provide an opportunity for younger engineers to connect with each other to enable sharing of experiences
- Inspire younger engineers to become active in their National Committees to support the above three objectives nationally and internationally
- Provide a forum where country strategies around the attraction, encouragement, development and support of the younger engineers in the dam engineering industry can be shared.

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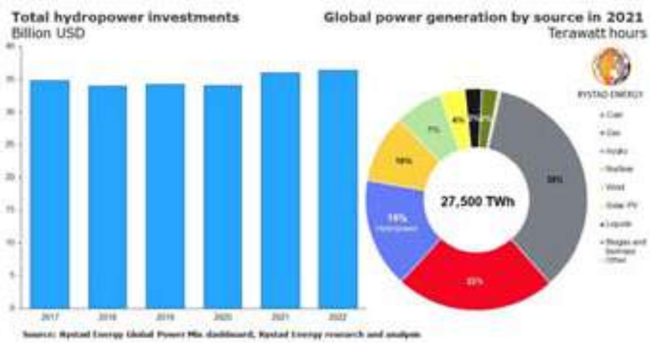
iNVESTMENTS iN HYdrO SET TO iNCrEaSE iN 2022 SaYS NEW r ESEar CH



Hydropower capacity in 2022 is set to exceed 1200GW and investments will climb to $36.3 billion, new research from Rystad Energy has suggested, with hydro set to solidify its position as the most popular renewable energy source.The research says that Investments in the sector slowed somewhat before 2020 as other renewable sources such as wind and solar PV gained momentum, a situation exacerbated by delays to several major hydropower projects and some regions' lack of policy changes, which also stunted growth. The industry is, however, experiencing a renaissance as countries are increasingly motivated to find suitable renewable options to decarbonize their energy supply.

"Hydropower is the backbone of low-carbon electricity generation and has been rising since the 1970s. Over the last two decades, the installed global capacity of hydropower has grown from 680 GW in 2000 to nearly 1,200 GW in 2021, a surge of more than 75%," says Rystad Energy analyst Karan Satwani.

China remains the world leader in total installed hydropower capacity with over 340 GW, with Brazil in second place with 112 GW. The US (84GW), Canada (81GW) and Russia (50GW) round out the top-five list for hydropower generation globally, followed by India (47GW), Norway (33GW), Turkey (30GW) and Japan (23GW). In recent years, Asian and South American countries, led by China and Brazil, have driven global capacity additions while other continents have stayed relatively flat. Combined installed capacity in Asia has risen from 462 GW in 2017 to an expected 514 GW in 2022, whereas total capacity in South America has climbed from 175 GW to an expected 192 GW over the same period.

Looking at 2022, China's Baihetan hydropower project, which began operations from two of its 16 units in June 2021, will be able to produce up to 16GW of energy annually once fully operational later this year. This will make it the second biggest hydroelectric project globally, eclipsed only by another Chinese mega-development, the Three Gorges Dam project in Hubei province. The Wudongde hydropower plant, another ambitious Chinese development, began full operations in June last year with an installed capacity of 10.2 GW, making the project the seventh-largest hydropower project worldwide.Most of the capacity additions until 2030 are expected to come from large-scale projects in Asia and Africa. In Africa specifically, installed capacity is expected to grow at a combined annual growth rate of 2.5% from 2017 to 2023, driven by Ethiopia, Mozambique and Uganda. Most of the large-scale projects in Asia and Africa are managed by state-owned companies. The research says a slowdown is expected in the pace of hydropower development in China over the coming years due to growing concerns over environmental impact and the shrinking availability of economically attractive sites for large projects. However, India's new long-term targets and financial incentives are expected to unlock a large pipeline of previously stalled projects as the government aims to boost hydropower capacity by about 55% this decade and reach 73 GW by 2030. No significant capacity additions are expected in North America and Europe for at least two years. Still, fleet modernization will be a priority in both continents during this decade.

On a regional basis, Sub-Saharan Africa and Asia-Pacific are expected to grow, as untapped potential is being developed to meet rising energy demand. These regions also need cost-effective power generation to expand electrification. This decade, a considerable portion of investments will be spent on modernizing aging plants in advanced economies. In addition, significant investments are required for existing infrastructure, including upgrades, replacements and the addition of turbines. Most of the spending on modernization will be in North America, Europe and Eurasia, where most of the world's aging fleet is located. Investments will be required to restore performance and adapt plants to operating conditions that have changed since the plants were built. Overall, the proportion of investments spent on modernizing and maintaining existing hydropower facilities and infrastructure will be significantly higher than spending on the construction of new power plants in younger markets.

HYdrOPOWEr SuSTai NaBi LiTY FuNd OPEN FOr aPPLiCa TiONS

Hydropower project developers and operators in over 40 countries can npw apply for funding to help finance an independent assessment of a project's sustainability performance as the Hydropower Sustainability ESG

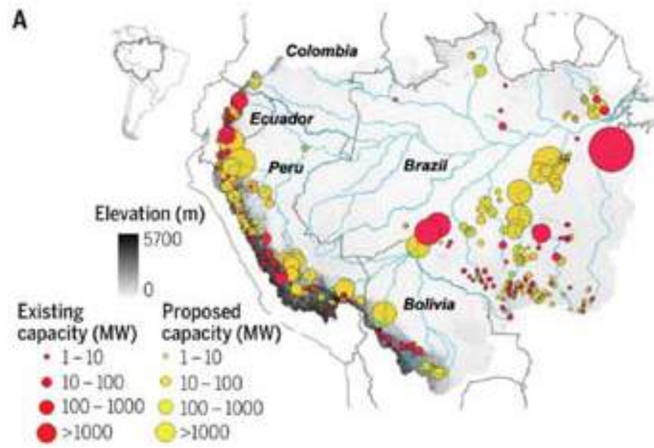
Assessment Fund opens for applications. Hydropower projects of all sizes and at any stage of development can apply for the funding to help conduct an independent assessment using an international recognised and sector-specific ESG tool. The Hydropower Sustainability ESG Gap Analysis Tool (HESG) assesses performance across twelve topics including biodiversity, cultural heritage, climate change mitigation and resilience, and water quality. This assessment is used to gain certification under the Hydropower Sustainability Standard. "The HESG Assessment Fund was established to make sustainability assessments accessible to all hydropower projects," explained João Costa, Head of Sustainability at the International Hydropower Association (IHA). "Our goal is to help hydropower developers in Africa, Asia, Europe and the Americas benchmark and raise their social and environmental performance. I would like to congratulate the previous winners of the HESG grant and encourage projects to apply for the upcoming round of funding."

Sustainability assessment using the HESG tool is a crucial step in a project's sustainability journey. As well as highlighting strengths and areas for improvement, the assessment can help demonstrate a project's eligibility for green bonds and is a prerequisite for certification against the Hydropower Sustainability Standard. This initiative, funded by the Swiss Government's State Secretariat for Economic Affairs (SECO), is now in its fourth round of funding and recently awarded six grants across six countries in Africa and South America. Building on the success of previous rounds, the new call for proposals is open to projects from the following countries: Albania, Algeria, Armenia, Azerbaijan, Bangladesh, Bolivia, Bosnia-Herzegovina, Burundi, Cambodia, Colombia, Democratic Republic of Congo, Egypt, Ethiopia, Eswatini, Georgia, Ghana, Haiti, Honduras, Indonesia, Kenya, Kosovo, Kyrgyz Republic, Lao People's Democratic Republic, Lesotho, Malawi, Moldova, Mongolia, Morocco, Mozambique, Nepal, Nicaragua, North Macedonia, Pakistan, Peru, Rwanda, Serbia, South Africa, Tajikistan, Tanzania, Tunisia, Ukraine, Uzbekistan, Vietnam, Zambia and Zimbabwe.

rESEArCH iNVESTiga TES SuSTaiNaBLE daM SiTiNg iN THE aMaZON

New research has been published that details a new computational approach for evaluating basin-level tradeoffs between hydropower and ecosystem services, with the goal of guiding sustainable dam siting in the Amazon.

The research - Reducing adverse impacts of Amazon hydropower expansion – was recently published in Science journal. As part of the research, an interdisciplinary team of environmental and computational experts developed 'Amazon EcoVistas', a novel framework to analyze proposed dam projects collectively – both for their energy generation, as well as their impacts on the environment. They analyzed five environmental criteria: river flow, river connectivity, sediment transport, fish biodiversity, and greenhouse gas emissions. The research says their tool uses artificial intelligence and high-performance computing to identify hydroelectric dam portfolios that meet energy production goals with the least environmental harm.



Locations and energy generation capacities of the 158 existing (red) and 351 proposed (yellow) hydropower dams in the Amazon basin (Flecker et al. 2022).

Coauthor Stephen Hamilton, an ecosystem ecologist at Cary Institute of Ecosystem Studies, explains: "Continued hydropower development in the Amazon is inevitable. So how can that proceed in a way that optimizes energy output at the lowest environmental cost? The answer comes in selecting projects strategically, taking into account multiple environmental criteria that have thus far been too difficult to account for simultaneously in planning large numbers of potential projects."

"Our tool allows us to evaluate hydroelectric projects for their collective impacts to nature and people on the scale of the entire watershed – a rare, yet critical approach, since the Amazon River and its tributaries flow through multiple countries with diverse topography," adds coauthor Rafael Almeida, a former visiting graduate student at Cary who is currently an Assistant Professor at the University of Texas, Rio Grande Valley. The tool can also screen out particularly harmful projects, with Almeida adding: "Fragmentation of river systems, blockage of fish migrations, trapping of sediment, and emission of methane are all worsened by the absence of basin-wide planning."

Running the 'Amazon EcoVistas' algorithm on the 158 existing and 351 proposed dams created scenarios based on all possible combinations of these projects. This allows it to determine the 'Pareto-optimal frontier' – or combination of hydropower projects that minimizes negative environmental effects for any given level of aggregate hydropower output. This process is extremely computationally intensive; between the 509 total projects, there are 2509 (or ~10153) possible combinations of projects – with six dimensions (energy output + the five environmental criteria) evaluated for each.

Lead author Alexander Flecker, Professor in the Department of Ecology and Evolutionary Biology at Cornell University, said: "All decisions around dam siting involve complex tradeoffs. The Pareto-optimal frontier provides a clear way to evaluate those tradeoffs as we seek to balance energy production and diverse environmental consequences.

"There's no one-size-fits-all solution to minimize negative environmental impacts of dam construction. But the most damaging impacts can be averted by weighing the various ecological and social costs of different combinations of projects. Our novel computational framework is the first to make this kind of evaluation possible on such a vast basin-wide scale."

The authors suggest that by identifying opportunities for more sustainable hydropower development, 'Amazon EcoVistas' could prove useful to energy planners, decision makers, and researchers working to implement strategic, whole-basin dam planning. It could also help evaluate priorities for dam removal in regions with aging dams such as North America and Europe, they said.

daM PrOJECT WiNS PEOPLE'S CHOiCE aWard iN BENTLEY EduCaTiON'S FuTurE iNFraSTruCTurE STar CHaLLENgE

As part of a Bentley Education program designed to inspire young minds to advance infrastructure and develop digital skills, Rodman Raul Cordova Rodriguez, won the People's Choice Award – which includes a US$2000 prize – for his innovative dam construction project addressing water shortage and the global energy crisis.

Bentley Systems launched its first Future Infrastructure Star Challenge as part of the program, asking students to conceptualize a world-changing infrastructure project addressing a global environmental issue, using Bentley applications. The program received 144 entries from over 60 countries, and 10 finalists were selected to design and present their conceptual idea to the public and a judging panel of experts. Rodman Raul Cordova Rodriguez, studying for his Ph.D. in geotechnical engineering at Pontifical Catholic University of Rio de Janeiro, was selected to win the People's Choice Award.

"More than 3 million people do not have access to water, and more than 2 billion are living with extreme water stress," stated Cordova Rodriguez. At the current usage rate, by 2025, 66% of the world's population could suffer from water scarcity. The ensuing energy crisis and climate change compound these deteriorating conditions. As both energy and water consumption continue to grow at four times and nine times the population growth rate, respectively, the impact to the communities and on our environment will only worsen and become more expensive to resolve. Inspired by these alarming facts, Rodriguez sought to implement infrastructure for clean energy generation and better water supply.

Conceptualizing a scalable, sustainable solution

Studying geotechnical engineering, Cordova Rodriguez proposed a solution related to earth and dam monitoring to generate hydroelectricity, a renewable energy source, and simultaneously contribute to the storage of drinking water. "I came up with an innovative idea for a sustainable earth dam that uses plastic recycled asphalt for the dam's core," explained Cordova Rodriguez. A flexible and ductile viscoelastic plastic material, the recycled asphalt provides waterproofing, prevents water seepage through the core of the dam, and has capacity to accommodate forensic displacements and seismic loads that could lead to the formation of cracks. The asphalt core will be a near ideal environment, remaining flexible, durable, and waterproof for the lifecycle of the dam.

By reusing and recycling materials, the dam obtains clean hydroelectric energy in a sustainable, profitable, safe, and reliable manner, aiming to preserve natural resources and achieving economic scalability. Integrating scalable technology in the form of sensors and IoT, Rodriguez's dam can be replicated in indigent areas where it is needed to tackle and avoid water scarcity, as well as contribute to the generation of electricity and have a positive impact on the health of the communities.

designing and executing

"I used PLAXIS software to perform geotechnical modeling and analysis and handle the different types of information involving my project," said Cordova Rodriguez. Using PLAXIS Designer, Rodriguez generated a 3D model of the earth structure with a crest length of 200 meters and height of 58 meters. He exported the model to PLAXIS 3D and created and integrated a groundwater model to analyze dam seepage, and a slope stability model to analyze and ensure structural integrity of the dam and the slopes of the reservoir basin. Some cross sections of the dam were then analyzed utilizing PLAXIS 2D to determine the safety of the upstream and downstream slope of the dam.

Using Bentley's PLAXIS applications, Cordova Rodriguez verified the technical feasibility, scalability, and longevity of the innovative dam infrastructure. The technology analysis results demonstrated that the recycled asphalt is functioning as desired and requires little or no maintenance. "I am very happy with my project because it has been proven that it is technically feasible with the use of technology, in this case Bentley's PLAXIS software," added Cordova Rodriguez. His dam infrastructure project can produce hydroelectric power and address the global energy crisis and water shortage in a sustainable, environmentally friendly, and economically efficient manner.

advancing digitalization

Bentley's PLAXIS application facilitates the integration of field geotechnical data and IoT, using internal and external sensors, such as seepage monitors, corner reflectors, and a weather station on the dam to measure and monitor different parameters. These parameters range from water pressure and displacements, to humidity, soil moisture, and wind speed. The dam also includes air sensors to determine the presence of harmful gases, and a drone station connected to the weather station and dam sensors. When the reservoir is at a low water level, the drones can fly into the clouds to generate rain.

All the data collected by the sensors will be sent to the data center in real time with a 5G connection to be shared with users, owners, public institutions, and local authorities in a web-based environment. The digital platform provides 24/7 secure access, with alarms to alert any issues, and automated report generation. "In terms of technology, the scalability of this project is huge," commented Cordova Rodriguez. It can be replicated in any area experiencing a lack of water supply. By applying advanced digital design, execution, and monitoring devices, Cordova Rodriguez has provided a conceptual solution to improve water supply and power generation that if not addressed presently, will pass along a more severe and more costly problem to future generations to resolve.

THrEE gOrgES CrOSSES 100B kWH POWEr gENEra TiON Mark i N 2021

The Three Gorges Power Station generated a total of 103.649 billion kWh electricity as of 12:00 a.m. December 31, 2021, crossing the 100 billion mark again, China Three Goroges Corporation has announced.

The 22.5GW Three Gorges Power Station is the world's largest hydropower plant in terms of installed capacity. It set a new record for annual power generation volume from a single hydropower station in 2020, beating the previous world record of 103.098 billion kilowatt-hours set by South America"s Itaipu Dam in 2016. Apart from achieving the annual power generation of over 100 billion kWh for two years in a row, the Three Gorges Project also achieved significant benefits in a wide range of areas such as flood control, navigation, and water resource utilization, said CTG.

The total inflow volume to the Three Gorges Reservoir in 2021 amounted to 453.638 billion cubic meters. During the dry season, the project served the role of a fresh water resource and replenished over 22.1 billion cubic meters of water to the lower reaches of the Yangtze River for 138 days.

Three targeted operations for fish species that produce viscid and demersal eggs were conducted at the Three Gorges Reservoir in 2021, during which around 300 million eggs were spawned. The four major breeds of Chinese domesticated fish spawned over 8.4 billion eggs in two eco-scheduling operations at the lower reaches of the Gezhouba Dam.

In 2021, the Three Gorges ship lock operated efficiently and safely 10,100 times, with 40,400 ships passing through carrying a total of 8038 passengers and 146 million tons of cargo, up 6.83% from a year earlier.

iHa rELEaSE NEW guidE ON ENgagiNg WiTH iNdigENOuS PEOPLES

A new guide has been released which details how hydropower developers can protect the rights of Indigenous Peoples.

The How-to Guide on Hydropower and Indigenous Peoples – published by the International Hydropower Association – explores how best to engage with these communities to ensure that hydropower projects respect the dignity and human rights of Indigenous Peoples throughout their operating life.

“As Indigenous Peoples are often among the most marginalised and vulnerable segments of the population, there is increasing recognition that they have special individual and collective rights and interests,” said Eduard Wojczynski, author of the new How-to Guide. “For hydropower, this requires developers and operators putting in place processes and implementing measures that respect Indigenous Peoples, their rights and their cultures. “I hope the good practices outlined in the guide will help ensure that hydropower can be a resource that protects the rights of Indigenous Peoples, enhancing their economic and social well-being.”

The new guide emphasises the need to involve Indigenous communities as early as possible in a project’s planning and delivery. By doing so, developers can better understand the concerns of those affected and where necessary make changes based on their inputs and perspectives.

Phurpa Tamang, an Indigenous Peoples representative and advocate said: "In the name of development, we should not destroy Indigenous Peoples’ culture and identity which they received from their ancestors. We should promote culture and identity together in a way that brings happiness and social harmony through development activities.

“If developers and operators follow the recommendations of this guide, hydropower can be developed, and cultural rights can be preserved without social conflict,” he added.

The guide highlights the Free, Prior and Informed Consent (FPIC) consultation process as an essential tool to achieve good practice outcomes. FPIC is a principle enshrined in the United Nations Declaration on the rights of Indigenous Peoples. It establishes a universal framework of minimum standards for the well-being of Indigenous People around the world.

Guidelines on how and when to effectively communicate and consult with Indigenous Peoples, to understand their livelihoods, traditions, culture and customs are included in the publication, to help developers and operators achieve FPIC.

“As we aim to meet our world’s clean energy needs, more projects might need to be located in remote areas, some of which may be owned or managed by Indigenous Peoples. Business as usual is no longer acceptable, especially in areas of such critical value,” commented Alain Kilajian, Senior Sustainability Specialist at IHA. “The goal is that hydropower developers and operators engage with Indigenous Peoples in good faith, with the aim of gaining their Free, Prior and Informed Consent. This guide provides them with the key strategies and approaches to make that goal a reality.”

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

Anthony T.Hincks

Forthcoming Events

Sr. No	description	date	Country/Organizer
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.
10	World Future Energy Summit	17 Jan - 19 Jan 2022	Abu Dhabi, UAE
11	DistribuTech International	26 Jan - 28 Jan 2022	TX, USA
12	Power Gen International	26 Jan - 28 Jan 2022	TX, USA
13	ASIA 2022	15 Mar - 17 Mar 2022	Kuala Lumpur, Malaysia
14	IEEE PES T&D Conference & Exposition	25 Apr - 28 Apr 2022	New Orleans, LA, USA
15	24th ICID International Congress + 73rd IEC Meeting	30 May - 6 Jun 2022	Adelaide, Australia
16	ICAAR 2021 (16th International Conference on Alkali Aggregate Reaction in Concrete)	31 May - 2 Jun 2022	Lisbon, Portugal
17	Hydro Vision 2022	12 Jul - 14 Jul 2022	Denver, CO, USA
18	IWA World Water Congress & Exhibition	11 Sep - 15 Sep 2022	Copenhagen, Denmark
19	Vienna Hydro 2020	9 Nov - 11 Nov 2022	Vienna, Austria
20	Valve World Expo 2022	29 Nov - 1 Dec 2022	Dusseldorf, Germany

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Bulletin 155 - Guidelines for use of numerical models in dam engineering
Bulletin 156 - Integrated flood risk management
Bulletin 157 - Small dams: Design, Surveillance and Rehabilitation
Bulletin 158 - Dam surveillance guide
Bulletin 159 - Supplement to the Position Paper on Dams and the Environment
Bulletin 160 - ICOLD Dam Decommissioning - Guidelines
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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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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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- Contemporary Developments in Technology, Construction Materials, Products, Instrumentation, and Services
- Dam Health Monitoring, Data Acquisition and Processing
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- DRIP Rehabilitation Case Studies

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contact Person : Mr. Sunil Sharma, Chief Manager
M : 9811299136 E-mail : sunil@cbip.org
Ms. Kalpana Adhikari, E-mail : kalpana@cbip.org

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