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# INCOLD

## JOURNAL

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### INDIAN COMMITTEE ON LARGE DAMS

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## ICOLD'2024 : Release of Special Publications

During the opening session of the prestigious 92nd Annual Meeting and Symposium of ICOLD'2024 held at Bharat Mandapam, New Delhi, the following Special Publications were officially released by INCOLD. These books were launched during the event by Ms. Debashree Mukharjee, the Hon'ble Secretary, Ministry of Jal Shakti, Government of India.

- *A Pictorial Display of Dams in India*
- *Dam Development in India - From Ancient to Modern Time*

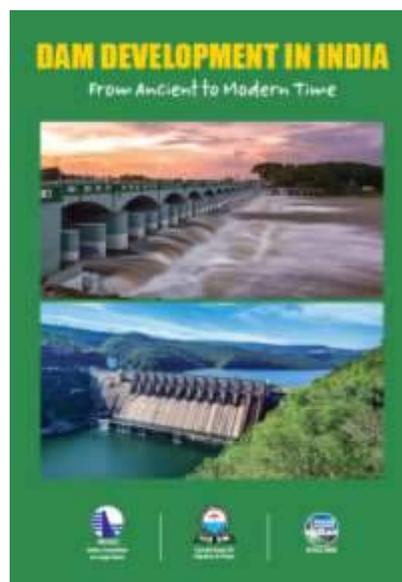
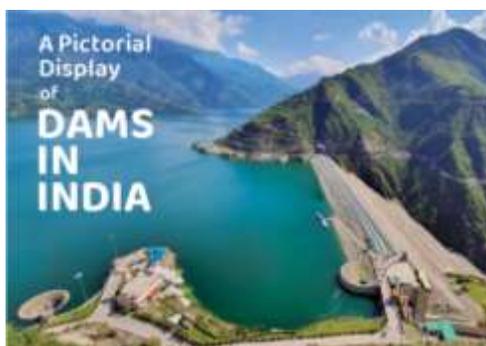
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*Kamlesh K. Singh, Treasurer, INCOLD & Director (Water Resources), Central Board of Irrigation & Power*

***A Pictorial Display of Dams in India:*** A Coffee table book that pictorially illustrates a panorama of dams built in India. The book showcases over hundred number of dams of various types, known for their merits based on great height, large reservoir capacity as well as for the design features and methodology of construction. Besides portraying state-of-the-art large multipurpose & hydropower dams and highlighting their technical features, the book also exhibits some of the old structures that rank among globally historic dams still in operation. *[234 pages]*

***Dam Development in India - From Ancient to Modern Time:*** This important publication documents the five thousand years of dam development history of India, to acquaint about the rich heritage of dam building of this nation. This book presents the chronology of dam development in India. It traces the evolution of dam building in this subcontinent, spanning across different eras - from Ancient to Modern time. It illustrates the knowledge of hydraulics that prevailed in the ancient time and portrays the engineering marvels built in this country through centuries. The activities during the different periods are elaborated that highlight the country as a leading dam building nation. *[208 pages]*



The publications are ideal additions to the libraries of policy makers, engineers, and professionals in the water resources sector, contributing to research and development in dam infrastructure.

### ***The cost of the publications (Hardbound):***

- **Dam Development in India:** ₹ 3,000 per copy, excluding Postal charges [USD 50, inclusive of Postal charges]
- **Dams in India:** ₹ 3,000 per copy, excluding Postal charges [USD 50, inclusive of Postal charges]
- **Set of two publications:** ₹ 5000, excluding Postal charges [USD 100, inclusive of Postal charges]

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# INCOLD Journal

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## ABOUT JOURNAL

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

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

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*Secretary General*

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# Editorial



Dear Readers,

Greetings from INCOLD, New Delhi.

Welcome to the latest edition of the half-yearly journal of the Committee of International Commission on Large Dams (INCOLD). This edition brings case studies focus on Proper design, construction, and maintenance to ensure the stability and functionality of dams. These case studies contribute to the propagate standardized safety protocols and regulatory frameworks, ultimately enhancing public safety and infrastructure resilience.

This journal includes case study Teesta river basin in India where NDSA has taken up investigation to understand the GLOF threat to existing and planned projects in Teesta Basin. They also frame strategies to manage the GLOF risk for all similar river basins in general and for Teesta basin in particular.

It also includes paper related to Koldam Hydro Power Station where they elaborates about the dam safety practices followed for this project .A comparative statistical analysis of dam failures across the globe and Proactive measures for dam safety is also discussed in this paper

This edition of journal covers case studies of Shongtong Karcham HEP (450 MW), India where FEM analysis have been utilized to arrive at solution for issue of creeping slope and Case Study of Dam Excavation in steep terrain in Helong area of District Chamoli, Uttarakhand, India.

This journal also cover highlights of 92nd ICOLD Annual Meeting &International Symposium 'Dams for People, Water, Environment & Development' held from September 29 to October 3, 2024, in New Delhi.

We extend our gratitude to the authors for their invaluable contributions and look forward to continued exploration and discovery in the field of large dam management. I encourage our members to actively engage and provide continuous support through case studies and research papers. These contributions will be instrumental in paving the way forward in the development and advancement of large dams.

**A.K. Dinkar**

*Secretary General*

Indian National Committee on Large Dams

# Strategies to Manage GLOF Risk in Hydroelectric Power Projects – A case study of Teesta River Basin in India

Anil Jain<sup>1</sup> and Shiv Kumar Sharma<sup>2</sup>

## ABSTRACT

*Hydroelectric power projects located on river fed by glaciers are susceptible to threat posed by Glacier Lake Outburst Flood (GLOF). Teesta river basin is fed by glaciers and has many hydroelectric power projects (HEP) which are operational / in various stages of planning, design and execution. Due to sudden release of water from the South Lhonak lake on 3rd /4th October 2023, the ensuing GLOF caused huge devastation in Teesta river basin which included washing away of the dam of Teesta III HEP as well as damages to downstream operational / under construction HEP's.*

*National Dam Safety Authority (NDSA) established by Government of India through Dam Safety Act, 2021 is responsible for matters related to dam safety at central level in India. Taking due cognizance of the matter, NDSA has taken up investigation to understand the GLOF threat to existing and planned hydroelectric power projects in Teesta Basin and also to frame strategies to manage the GLOF risk for all similar river basins in general and for Teesta basin in particular. This paper discusses appropriate robust design, early warning system etc. as the strategies to manage the GLOF*

## 1.0 INTRODUCTION

Teesta is the trunk river in Sikkim-Darjeeling Himalaya. It originates from the Pahunri (or Teesta Kangse) glacier above 7,068 m, and flows southward through gorges and rapids in the Sikkim Himalaya. The river then flows past the town of Rangpo where the Rangpo River joins, and where it forms the border between Sikkim and West Bengal up to Teesta Bazaar. Just before the Teesta Bridge, where the roads from Kalimpong and Darjeeling join, the river is met by its main tributary, the Rangeet River. At this point, it changes course southwards flowing into West Bengal. The river then goes merging up with the Brahmaputra River after it bifurcates the city of Jalpaiguri and flows just touching Cooch Behar district at Mekhliganj and moves to Fulchori in Bangladesh. Teesta river ultimately drains into Brahmaputra at Teestamukh Ghat in Kamarjani-Bahadurabad in Rangpur district of Bangladesh. Teesta and most of its tributaries are flashy mountain rivers and carry boulders and considerable quantity of sediment. The flow is turbulent and characterized by high velocities. The river is about 414 km long.

## 2.0 GLACIAL LAKES OF TEESTA BASIN

In Sikkim Himalaya, there are 5 Glacial lakes (GL) having area >100ha, 10 GL of area 50 to 100 ha and 32 GL having area of 10 to 50 ha as per NRSC data. South Lhonak Lake is a glacial-morainedammed lake, located in Sikkim's far north-western region. It has formed due to the melting of the Lhonak glacier. It is one of the fastest

expanding lakes in the Sikkim Himalaya region and one of the 14 potentially dangerous lakes susceptible to Glacial Lake outburst floods (GLOFs). The lake is located at 5200 m above sea level.

## 3.0 HYDROPOWER POTENTIAL OF TEESTA BASIN

Due to steep gradient, Teesta River is rich in hydropower potential. There are a number of existing / under construction / planned HEP's on main stem of Teesta river and its tributaries. Some of the HEP's on main stem of Teesta river are Teesta III (1200 MW), Teesta IV ( MW), Teesta V, Teesta VI, TLDP III & TLDP IV.

## 4.0 GLOF OF 3RD / 4TH OCTOBER 2023

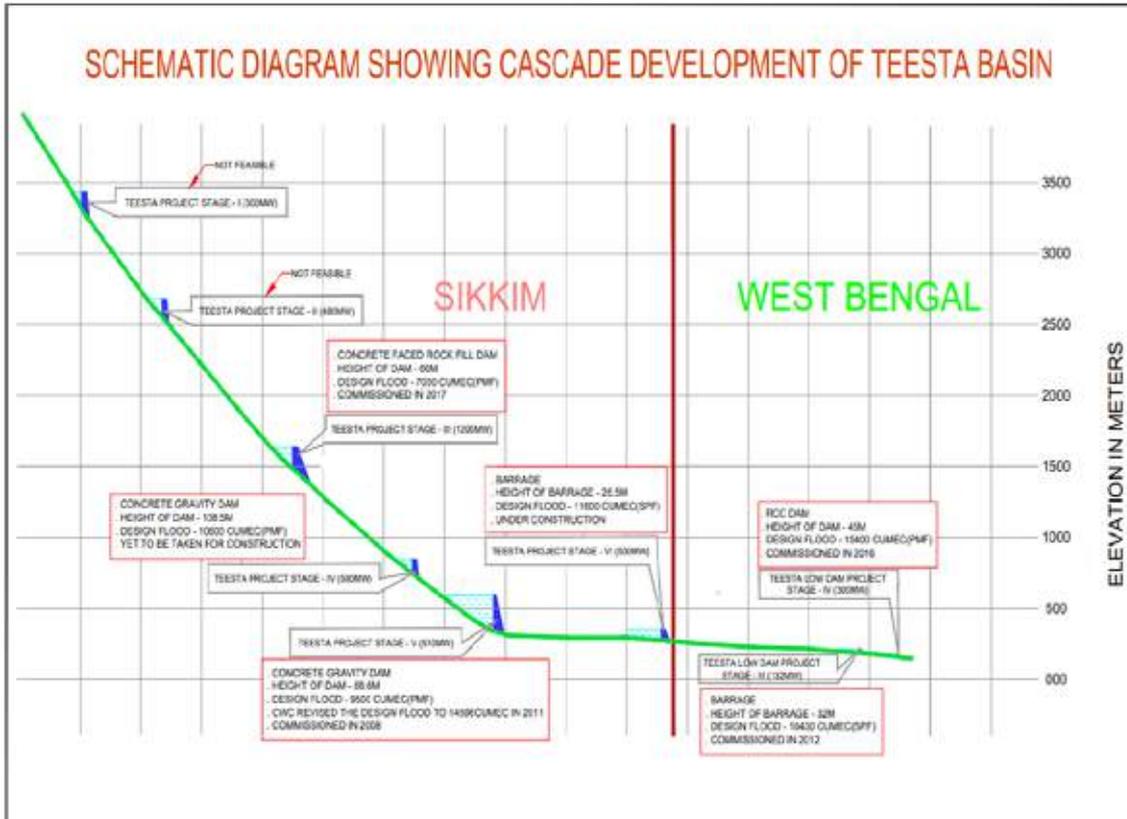
South Lhonak glacial Lake, reportedly burst in the late hours of 3rd October 2023, causing a flash flood in the Teesta River region. This GLOF caused immense loss of life and property. About 48 people died, and 75 more are reportedly missing and many bridges, houses, buildings were washed away due to the unprecedented flash flood. The flash flood caused a breach of the Concrete Faced Rockfill Dam (CFRD) dam of Teesta-III HEP located at Chungthang, about 70 km downstream of Lhonak Glacial Lake. It also caused major damages to Teesta-V HEP and other downstream HEPs.

## 5.0 DAMAGES TO TEESTA RIVER HEP'S

Whereas, GLOF event of 3rd / 4th October, 2023 caused immense loss of life and property, its effect on the

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HEP's was also very significant. Such damages can be categorized as follows:

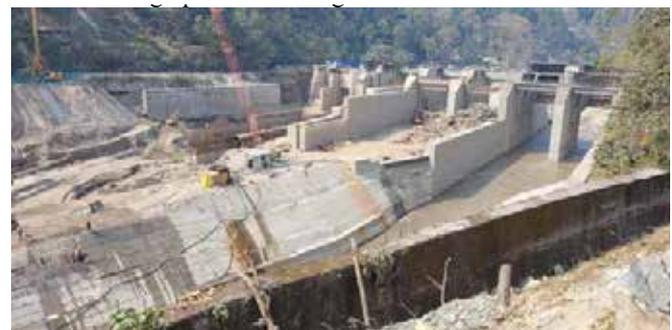
- (a) *Direct Damage*: The damage sustained by the dam structure and other appurtenant structures which is required to be repaired / rehabilitated before the HEP could be made operational / safe again.
- (b) *Indirect Damage*: The damages caused by loss of power generation due to high discharge and sediment load. It includes down time of turbine units during the event and till such time the plant was / will be made operational again. Indirect damage also includes the loss of power generation head due to excessive siltation caused due to GLOF.



Photograph – II : Damaged Dam of Teesta V HEP



Photograph – I : Breached CFRD Dam of Teesta III



Photograph – III : Silted Barrage of Teesta VI HEP



Photograph – IV : Silted Barrage of TLDP-III HEP

## 6.0 PROBABLE CAUSES FOR FAILURE OF TEESTA III DAM / DAMAGES TO OTHER HEP'S

Some of the probable causes of failure of Teesta III CFRD dam and damages sustained by other downstream HEP's is as follows:

- Insufficient Spillway capacity
- Lack of Early warning system / Protocols
- Delay in opening of Gates
- Blockage of spillway due to debris

### (a) Insufficient spillway Capacity

**Table I** : Design flood of HEP's on Teesta River

Name of the Project	Design Flood (cumec)	Design flood criteria as per IS:11223:1985
Teesta-III	7000	PMF
Teesta-IV	13000	PMF
Teesta-V	14596	PMF
Teesta-VI	11462	SPF
TLDP-III	10430	SPF
TLDP-IV	15400	PMF

GLOF was not considered in the estimation of spillway design flood for any of above HEP's on Teesta River making these projects vulnerable.

### (b) Lack of Early Warning System / Protocols

NHPC and Teesta Urja Ltd. are the two dam owners in Teesta basin. Early Warning System (EWS) installed by the dam owners are either river monitoring stations with real-time communication facility few kms upstream of their dams or real-time communication of releases from upstream project. No early warning system for GLOF was in place for Teesta – III HEP.

**Table II** : Distance from South Lhonak lake and estimated time of arrival of GLOF for HEP's on Teesta River

Name of the Project	Distance from Lake (Km)	Estimated time
Glacial Lake	0	0
Teesta-III	70	1 hr 20 min
Teesta-IV	97	1 hr 40 min
Teesta-V	110	2 hr 00 min
Teesta-VI	134	2 hr 35 min
TLDP-III	174	4 hr 30 min
TLDP-IV	186	5 hr 15 min

ITBP was the first agency to know about the incident and they communicated the same. However, due to lack of established protocols and very little lead time, the warning in the form of actionable input could not reach the Dam site in time. Govt. of Sikkim had made efforts with CDAC, NDMA and SDC for installation of GLOF Early Warning system in Teesta basin. However, at the time of incident (October 2023) the monitoring station was not functional.

Further well established protocols to follow in case of GLOF were not in place which lead to some avoidable damages for example flooding of water conductor system / powerhouse of some downstream HEP's.

### (c) Delay in opening of Gates

Due to operational reasons, spillway gates are not designed to be opened very quickly. The typical time for operation of spillway gate is around 30 to 80 cm / minute which may not provide sufficient spillway capacity for passing peak GLOF discharge.

### (d) Blockage of spillway due to debris

It was observed that very large size boulder (around 10 m) also moved along with GLOF. Such large sized debris / boulders reduced the spillway capacity by blocking the opening.

## 7.0 GENERAL RECOMMENDATIONS REGARDING MANAGING GLOF RISK TO HEP'S

Glacial Lake Outburst Flood (GLOF) is a type of flood occurring when water dammed by a glacier or a moraine is released suddenly. Since glaciers in the Himalayas are in a retreating phase, glacial lakes are growing and pose a potentially large risk to downstream infrastructure and life. Glaciers in the Indian Himalayan Region (IHR), are spread across 6 states and union territories i.e., Jammu-Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh. The Hydroelectric Power Projects (HEP's) located on upper reaches of rivers flowing in these states are at risk due to threat posed by GLOF. Risk of GLOF to HEP's can be categorized as follows:

## A. GLOF Hazard to HEP's

Hazard in this context implies potential occurrence of GLOF affecting HEP's. GLOF affects HEP's

- (a) Directly (loss of lives of personnel, washing away / damage to various components / assets of HEP's etc.) and
- (b) Indirectly (loss of generation due to high discharge, heavy sediment load that may cause issues such as reduction in spillway capacity / generation capacity etc.)

It is pertinent to mention here that HEP's may increase the GLOF hazard for downstream projects by adding to its discharge in case of breach of dam / sudden release etc. On the other hand, they may reduce the GLOF hazard also for downstream projects, if sufficient reservoir capacity is available at the time of GLOF.

## B. Exposure of HEP's to GLOF

All HEP's which located on upper reaches of rivers flowing in six states mentioned above are exposed to GLOF threat. Exposure to the uppermost projects is more due to very little warning time available. However, HEP's located downstream are also at high exposure in case of breach of upstream dam due to GLOF.

## C. Vulnerability of HEP's to GLOF

HEP's are capital intensive projects and are very much vulnerable in terms of lives and property such as washing away /overtopping /damage to its Dam / barrage which spans across the river or its other components, flooding of underground components, generation loss, reduction in generation capacity etc.

### 7.1 Estimation & Monitoring of GIOF Risk to HEP'S

GLOF affects not just HEP's but all infrastructure such as Bridges, Buildings, roads, fields etc. It is, therefore, expected that at the time of estimation of GLOF hazard potential, contribution of HEP's shall be duly considered. After assessing the hazard potential of the glacial lakes, intensive monitoring of glacial lakes having high hazard potential

### 7.2 GLOF Vulnerability Index

An index to measure GLOF vulnerability of HEP's may be devised for every GLOF affected river basin in consultation with all stakeholder agencies. Such index shall be useful for distributing the cost of Early Warning system as well as other risk mitigation measures. Some parameters in this regard are suggested as follows:

- (a) Proximity to Glacial Lake
- (b) Generation Capacity
- (c) Type of Dam (Embankment or Concrete Gravity)
- (d) Spillway Capacity

- (e) Size of Reservoir
- (f) Free Board
- (g) Reservoir Operation Criteria etc.

### 7.3 Reduction of GLOF Risk To HEP'S

Reduction of GLOF hazard to HEP's can be done by reducing the quantity of GLOF or by attenuating its peak or by reducing its debris load through structural measures to be carried out at the Glacier Lake or in its immediate vicinity. However, these measures may not always be feasible or techno-economically possible due to difficult site conditions.

- A. Lowering of Lake water level (siphoning / pumping / blasting)
- B. Construction of Artificial Drainage Channel
- C. Reinforcement / increase in Moraine Dam height
- D. River cross section strengthening / protection from erosion

### 7.4 Reduction Of Exposure / Vulnerability of HEP'S to GLOF

Reduction of Exposure / Vulnerability of HEP's to GLOF can be done through following measures:

#### 7.4.1 Structural Measures

#### A. Measures to ensure sufficient Spillway Capacity to prevent overtopping

- (a) Design Flood Review as per NDSA regulations and GLOF studies for all vulnerable HEP's. (Applicable to existing HEP's)
- (b) Review spillway capacity to pass Design flood + GLOF (Applicable to existing HEP's)
- (c) Criterion for passing Design flood + GLOF ( All gates operational) (Applicable to existing and planned HEP's)
- (d) Possible Measures for passing Design Flood and GLOF safely as per site conditions:

Additional Spillway capacity (Applicable to planned HEP's)  
Parapet wall (Applicable to existing and planned HEP's)  
Use of Diversion tunnels for passing flood (Applicable to existing/planned HEP's)  
Gates with faster opening time (Applicable to planned HEP's)

#### B. Measures to Ensure Debris Flow Passes without Major Damage

- (a) Appropriate measures to resist abrasion and impact of debris on to be provided on piers, floors (Applicable to existing and planned HEP's)
- (b) Gate size to be sufficient to allow debris to pass (Applicable to planned HEP's)
- (c) Cascading weirs or other devices to impede boulder movement (Applicable to existing and planned HEP's)

### C. Preventive Measures to Minimize Damages in the Event of Overtopping

- (a) Control room to be provided away from dam top and at a higher safe location (Applicable to existing and planned HEP's)
- (b) Remote operation of gates (Applicable to existing and planned HEP's)
- (c) Protection of vulnerable control elements such as power pack, trunion etc. through suitable cover (Applicable to existing and planned HEP's)
- (d) Parapet wall to be provided (Applicable to existing and planned HEP's)
- (e) RCC over crest and downstream of embankment dams (Applicable to existing and planned HEP's)

#### 7.4.2 Non-Structural Measures

##### A. Early Warning System (Applicable to Existing and Planned HEP'S)

Early Warning system (EWS) is a non-structural activity which can reduce exposure and vulnerability of HEP's to GLOF risk. However for development of EWS, following steps are required to be taken:

- (a) Monitoring of Glacier Lakes by designated agencies CWC/NRSC etc)
- (b) Continuous intensive monitoring of lakes in the project catchment identified as threat to existing HEP's / MPP's by the concerned Project authorities themselves or by agencies hired by them.
- (c) Development and installation of robust and effective Early Warning system (EWS)
- (d) Criterion for cost and data sharing of continuous intensive monitoring, risk reduction measures and EWS by Project authorities
- (e) Preparation of Emergency Action Plan
- (f) Fool proof communication system (e.g. Satellite phones) for vulnerable projects.

##### B. Awareness Generation (Applicable to Existing and Planned HEP'S)

To manage GLOF risk it is imperative that awareness at the community level as well as at the decision maker level may be increased. GLOF risk is peculiar in nature having its own dynamics, therefore, it is essential that all aspects related to its risk management be disseminated to all concerned.

##### C. Research & Development

Research and development is required in this field to understand various processes involved in formation and bursting of glacial lakes. A dedicated effort in this regard is required to be made at Centre / concerned State(UT) level with association with concerned HEP project owners.

### D. Training For Emergency Search & Rescue

Alternate routes may be developed and kept ready for emergencies. HEP's have extensive infrastructure in this regard and a lead may be taken by them.

### E. Training for Post Disaster Relief

Post disaster relief can save many lives. HEP's have extensive infrastructure in this regard and a lead may be taken by them.

### F. Formulation / Updating Codal Provisions Related to HEP'S

At present, various BIS codes do not give directions on various technical aspects and implications of GLOF such as incorporation of GLOF with SPF / PMF and related design parameters such as freeboard etc. Formulation of appropriate BIS codes / revision in existing codes may be taken urgently.

## 8.0 GENERAL RECOMMENDATIONS FOR ALL HEP'S OF TEESTA VALLEY

- (a) Comprehensive Early Warning System may be developed for Teesta Basin for Precipitation induced floods; Glacial Lake Outburst Floods (GLOF) and any other flash flood that occurs in this basin. The stakeholder agencies such as ITBP, Sikkim Urja Ltd., NHPC Ltd. DST, Govt of Sikkim, NRSC, CWC, NDSA, NDMA etc may be involved in formulation, implementation & execution of such system.
- (b) Drone monitoring of glacial lakes may be considered with permission of Army and ITBP. It is felt that the communication among the various project personnel and data observing agencies needs improvement and SOPs should be developed for fool proof real time sharing and communication of data during GLOF like extreme events.
- (c) Presently, Glacial Lakes are monitored on monthly basis during monsoon (June to October) by using remote sensing based approach. This is obviously not adequate. The South Lhonak GLOF occurred in October but could have occurred beyond monsoon season also. Further, monthly monitoring can't help much. Vulnerable glacier lakes should be monitored on shorter intervals by an agency which has requisite expertise and access to the desired resources in (near) real-time
- (d) A permanent committee of all stakeholder agencies such as ITBP, Sikkim Urja Ltd., NHPC Ltd. DST, Govt of Sikkim, NRSC, CWC, NDSA, NDMA etc may be formed to take timely decisions on reducing GLOF hazard through appropriate means such as syphoning of lake, blasting etc.
- (e) GLOF studies may be carried out for all the above mentioned HEP's. If required flood values

corresponding to SPF / PMF / 1 in 500 yr flood etc. may also be reassessed and approved from CWC along with GLOF values. Critical combination of SPF / PMF etc with GLOF may be formulated in consultation with CWC for checking adequacy of spillway capacity.

- (f) The river morphology has changed due to heavy sedimentation / scour caused by 4th Oct 2023 GLOF event. Hydrological / Hydraulic analysis of the complete river reach from upstream of Teesta III to downstream of TLDP – IV may be carried out to ascertain characteristics of new river regime. Such study shall help in flood routing studies and for formulating new flushing guidelines for all HEP's.
- (g) Fresh flood routing studies may be carried out to assess spillway capacity after conducting fresh bathymetric survey of HEP reservoir and updated tail water rating curve due to change in u/s and d/s river cross sections.
- (h) If fresh spillway capacity is found inadequate, strategies such as provision of additional spillway, operation of reservoir at lower level etc. may be formulated in consultation with NDSA / CWC to ensure safety against overtopping.
- (i) Adequacy of Energy dissipation arrangement may be reassessed with fresh tail water rating curve. If required appropriate strategies may be formulated to ensure safety of structure.
- (j) New flushing guidelines may be formulated to flush out the deposited sediment from HEP reservoirs and reclaim storage. Such guidelines should be prepared for in tandem operation of all HEP's.
- (k) The state of the art "SCADA system" / ARMAC system may be installed in all HEP's of Teesta Valley (i.e. Teesta – III, Teesta V, Teesta VI, TLDP III & TLDP IV). Such system shall be used for the centralized remote operation of gates from dam control room / powerhouse/ remote locations like regional offices etc. Reservoir level and tail water level shall also be integrated in SCADA system of powerhouse. It is also advised that instrumentation reading data from DAS and EWS data integration may also be incorporated in SCADA system. A parallel control of the dam gate operation shall be explored away from the dam / barrage at some safer level. The real time data base must be available at remote locations such as regional offices, corporate office etc.
- (l) Comprehensive Dam Safety Assessment may be carried out and its recommendations implemented for above mentioned HEP's. Dam break analysis may also be carried out.
- (m) Alternative routes to sites are required to be developed for timely access to sites by the security forces in case of such eventualities in future.

- (n) Inundation map due to GLOF at all project locations may be prepared. All critical infrastructure related to gate operation, data collection and real time communication should be located in such a way that it remains functional even during the GLOF like extreme events

## **9.0 SPECIFIC RECOMMENDATIONS FOR TEESTA III HEP, SIKKIM**

### **9.1 Teesta III HEP**

Major portion of CFRD dam of Teesta – III HEP got washed away due to overtopping in the GLOF event of 4th Oct 2023. Various other components of project such as Intake, powerhouse etc. have undergone damages. The project has since been non-functional. It is recommended to revive the project by constructing a new dam at this location.

### **9.2 TEESTA V HEP, SIKKIM:**

Due to the GLOF event of 4th Oct'2023, heavy damage has been caused to the civil structure like glacis, flip bucket, pier, breast wall liner, dam top railing, control room, power pack system, miscellaneous steel works provided at dam top, trunnion beam level, etc. At some places, reinforcement bars have been exposed and at some places, it is observed that reinforcement has been torn off. Hence a thorough health assessment of concrete structure impacted by GLOF of 4th Oct 2023 is required to be carried out before undertaking any repair works at the damaged areas. Further, To reinstall various HM components, the second stage concrete may have to be chipped away. The health of the concrete in this region may be examined critically. Subsequently, suitable protocol may be established to ensure proper bonding of old and new concrete and effective dispersal of stresses in this region before undertaking any repair works.

### **9.3 Teesta VI Project**

Teesta VI HEP is an under construction project which underwent damages due to GLOF event of 4th Oct 2023. It is recommended to restart construction after rectification of damages. Structural measures to withstand heavily sediment ridden GLOF discharge may be incorporated in the barrage structure. The design of coffer dam as well as other safety precautions may be reviewed in view of GLOF discharge.

### **9.4 TLDP - III HEP, Sikkim**

TLDP III HEP is a barrage with very high hydraulic head. Further it is founded on highly heterogeneous foundation. The extreme flood condition of 4th Oct 2023 might have impacted the stability of the structure. The joints between the blocks of barrage were observed to be under distress and seepage was taking place from a joint on downstream of pier implying undesirable settlement / movement.

Hence it is recommended that the stability of the barrage may be thoroughly reassessed from concerned experts in consultation with NDSA / CWC. Further, Suitable protection measures may be provided before monsoon season from the road side on right bank and from the downstream of draft tube deck floor to avoid flooding from the downstream side due to excessive sedimentation downstream of project.

### 9.5 TLDP – IV HEP, Sikkim

The GLOF discharge passed through spillway with some splashing on top of dam hence it is implied that the dam structure has withstood major stress incident. It is, therefore, recommended that the stability of dam may be thoroughly reassessed from concerned experts in consultation with NDSA / CWC.

### 9.6 South Lhonak Lake

- (i) South Lhonak Glacial Lake is one of the fastest growing lakes in Sikkim Himalaya. Lakes South Lhonak is a moraine-dammed lake mountain range, which poses a significant threat downstream due to its relatively high volume of water.
- (ii) Resistivity survey needs to be repeated in the South Lhonak lake to understand the present strength of moraine damming the lake. Subsequently, other studies can be taken up as below:
  - (a) Estimation of glacier melts contribution to the lake and its discharge.
  - (b) Water budgeting of glacial lakes
  - (c) Mapping of entire geometry/morphometry along the river valley downstream upto the strategic locations using 'drones' to develop high-resolution DEM for river geometry.
  - (d) Earth observation-based monitoring (InSAR, Optical) for glacier dynamics.

- (e) Siphoning of permafrost ponds to maintain the stability of the moraine dam.
- (f) Geotechnical investigation for moraine dam stability.
- (iii) If found feasible, the outlet of South Lhonak Lake may be designed to pass through flood water and construction of retaining wall/ gabion structure to prevent lateral erosion below the outlet of South Lhonak Lake.
- (iv) An effective Early Warning System (EWS) with self-sufficient energy back up may be provided. This shall trigger the alarm in the downstream towns and will give sufficient time to the concerned authorities to take up suitable measures.
- (v) The bathymetry survey of the lake could not be completed, therefore, a complete bathymetry survey may be undertaken at the earliest.

### Disclaimer

The views, thoughts and opinions expressed in the above paper are solely those of writer(s) and may not necessarily be of their respective organization(s).

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**Save water today, secure your tomorrow**

# Ensuring Dam Safety at Koldam HPS: Safety Compliances & Statistical Analysis

Akhilesh Chandra Joshi<sup>1</sup> and Madhukar Aggarwal<sup>2</sup>

## ABSTRACT

*This paper elaborates the dam safety compliances being followed rigorously at Koldam HPS and conclusion of safe dam condition from the analysis of previous dam failure data. Koldam Hydro Power Station is NTPC's flagship installation in the hydro sector. It is situated on river Satluj in district Bilaspur, Himachal Pradesh, India.*

*Koldam HPS is managing its operation and maintenance activities along with the compliances of Dam Safety Act 2021 with man megawatt ratio of approx. 0.1. In fulfilment of provisions of Dam Safety Act 2021, Dam safety unit at Kodam HPS is implementing the dam safety related assignment in true sense. A multi-disciplinary dam safety committee with diversified experienced minds has been set up for holistic examination and resolution of dam safety related issues at site level. Pre and Post monsoon inspections are carried out with a systematic approach in full details and time bound manner. An SOP has been framed and implemented for regulating the frequency of magnitude and intensity of various inspections. Inspection of all components of dam complex and reservoir rim is carried out after every critical eventuality e.g. high floods and earthquakes etc.*

*A comparative statistical analysis of dam failures across the globe is also presented in this paper. The failure phenomenon recorded in the historical data was compared with the parameters prevailing at Kodam e.g. most of the dam failures had occurred in the first two years after construction. Koldam is on the safer side as it is approaching about 10 years of age. Several such comparisons were attempted with the statistical data regarding type of dam, age of dam, height and storage capacity of dam, Spillway capacity and modernization in design philosophy etc. Based on the Statistical analysis of dam failure data, it can be safely concluded that Koldam is truly safe in all the aspects.*

*In recent past, the frequency of dam failure related incidents due to inadequate spillway capacity and malfunctioning of hydro-mechanical equipment has been reported from across the world. At Koldam, due care has been taken in designing spillway capacity after detailed hydraulic and hydrological studies, and scheduled maintenance and testing of HM equipment is ensured; to avoid any such untoward event. Proactive measures for dam safety such as information sharing with people downstream of dam, keeping them aware about EAP/DMP, mock drill for safe evacuation, marking of danger water levels, displays at entry points along the river etc. are also summarized in brief.*

## INTRODUCTION

A famous proverb says, "to err is human" Meaning it's basic human nature to meet errors. But in reference to dam safety even a small error can lead to a massive devastation, so there is no scope of error while dealing with dam safety. Hence the responsibility and importance both of such a critical topic is very pertinent in today's scenario.

Dams lay the foundations of a developed nation. As per the World Register of Large Dams published by ICOLD (International Commission On Large Dams) there are about 62,000 large dams in the world. India is at 3rd seniority position after China and USA. As per National

Register of Large Dams (NRLD) published by Central Water Commission (CWC), a nodal agency in India for all Hydro Projects in the country, there are about 6000 large dams in India. Out of which about 70% are older than 25 years of age, 20% are between 50 to 100 years and 5% are more than 100 years old. Hence the importance of dam safety increases exponentially while addressing the issues in the Indian context. As per ICOLD definition of large dams, dams having height of more than 15 meters or pondage more than 3 MCM are considered as large dams. Similar structures are addressed as Specified Dams in Dam Safety Act 2021. Even in the small state of Himachal Pradesh there are 23 Specified Dams.

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Figure 1 depicts the distribution of types of dams across the world. Most of the dams in the world are earthen dams (67%). Rockfill and gravity dams share an equal proportion of population of total dams. The Koldam Hydro Power project is basically a run-of-the river scheme with storage facility for the

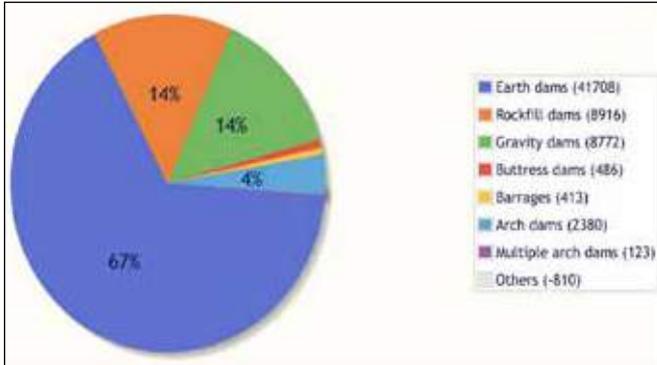


Fig. 1 : Type of Dams

initial 30 years. Koldam HPS envisages utilization of a head of about 140 m by constructing a 167m high (from the deepest foundation) rock/ gravel fill dam with impervious central clay core and a dam toe powerhouse with installation of 4 units of 200 MW each. The Gross capacity at FRL is 576 MCM and the dead storage capacity is 486 MCM.

As far as dam failures across the globe are concerned, the single largest dam failure mechanism is reported as overtopping. As per Association of State Dam Safety officials (ASDSO) data, the second largest mechanism triggering dam failures is unknown, indicating the quantum of uncertainty in this field and need of strengthening the understanding and practice of dam safety. Thus, the role of such critical avenues as of today's program is manifold and manifested.

After the recent dam failure events of Libya and Sikkim (India), the common public and media are raising many questions about the dam safety, responsibility of state, role of dam owners, preparedness to handle disasters caused by dam failures and many more issue.

**DAM FAILURE STATISTICS**

Dam failure data published by ICOLD and other sources were analyzed and inferred in relation to the prevailing parameters at Koldam. A holistic analysis of different dam failure mechanisms was done and results were compared with the site conditions prevailing at Koldam.

Figure 2 shows the probability of failure of a dam v/s its year of operation. It is observed that the highest probability of failure of dam is during the first impounding followed by the initial period when failures may occur due to unexpected design behavior of structure. Therefore, the relationship between the age of the dam and the risk of an incident depending upon the stage of the dam needs

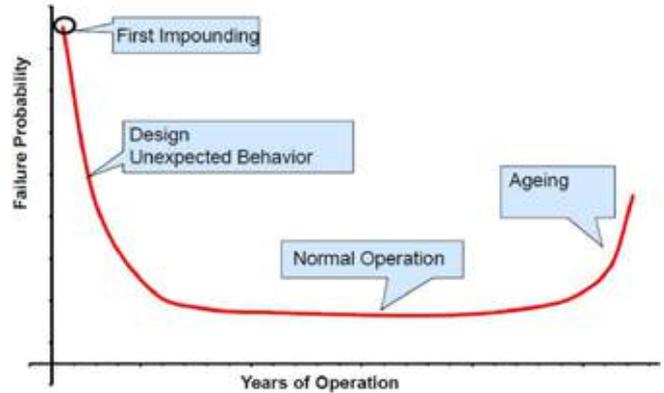


Fig. 2 : Probability of failure along the time (R. Melbinger, 2018)

to be evaluated. At Koldam smooth impounding was done in 2014-15 and it is running in 10th year of normal operation period, so the failure probability shall be lowest.

Figure 3 depicts the relation between the number of dam failures and the age of dam. As per statistical data published by ICOLD, maximum dams fail within the first 10 years of age and about 50% of dam failures had occurred within 2 years of age. The construction of dams and impounding of reservoirs are two very crucial phases in dam safety. The above data of ICOLD demonstrate that a dam would be in a relatively safer zone if it had sustained for the first ten years.

The Koldam Project is about to cross the age of 10 years from impounding and as inferred from data analysis, there is very less probability of failure. Further, as per ICOLD data regarding dam failures and height of dam, only 0.13% of dams have failed with height more than 100m. The main reason being that dams of such height are designed and constructed with best practices in the field and therefore the chances of their failure are the least.



Fig. 3 : Age at Failure and Number of failures

Figure 4 shows the failure causes of dams in different construction periods and failure modes of embankment dams. It has been observed from the dam failure pattern data that in earlier times say up to 1975 or maximum up

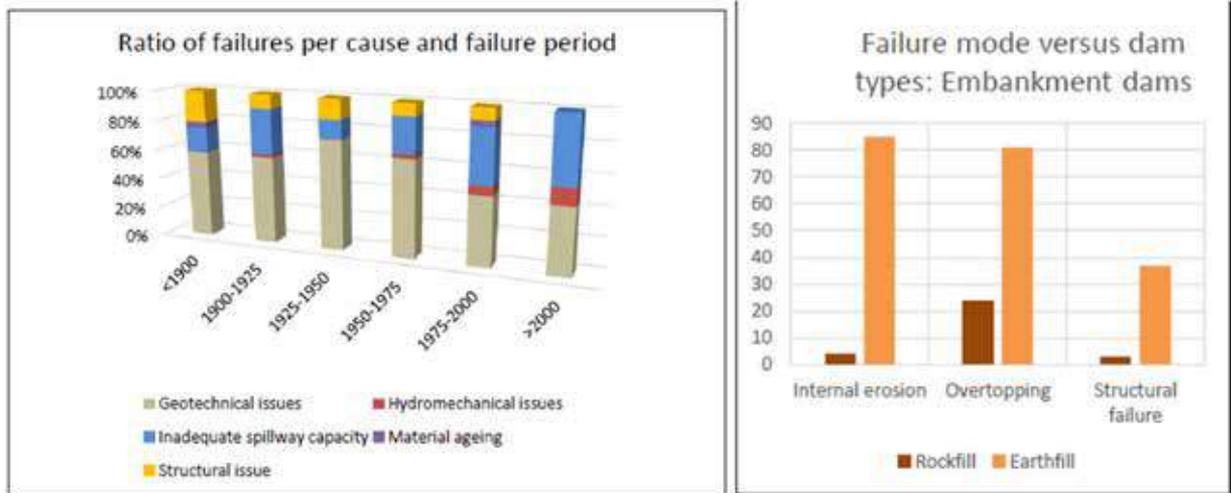


Fig. 4 : Failure per cause and failure period, failure modes of embankment dams

to year 2000, most of the dam failures are either due to geotechnical issues or due to structural issues. Due to improved understanding and analysis of geotechnical and structural issues, most of the dam failures after 1975 or 2000 have happened due to inadequate spillway capacity which has grown up to 50% since 2000. This effect is probably due to the climate change scenario across the globe and here comes the role of accuracy in predicting hydro meteorological events.

Further, from the above data it is evident that the failure rate of rock fill dams is about 10 to 20% of failure rates of earthfill dams. If the failure by dam type is considered, about 1.39% of rockfill dams have failed due to various reasons.

Koldam being a rockfill dam with design capacity of spillway as 16500 cumec corresponding to PMF (Probable Maximum Flood) will lead to lowest possible chances of failure. Being very far from the glaciers, the dam is not affected by GLOF and GLOF has an almost negligible contribution towards spillway PMF.

Figure 5 demonstrates the dams failures occurred in dams of different reservoir volumes. As per ICOLD data



Fig. 5 : Failed dams Vs reservoir volume

only 0.87% of dams failed under the category of storage volume more than 1000 hm. The total reservoir capacity of Koldam is 576 MCM, which is quite higher than 1000 hm (10MCM). With this historical data consideration also, the failure probability of Koldam is low.

Figure 6 shows the dam failure related data in India. Breaching failure due to flooding is the biggest reasons of dam failure in India, and secondly 25% failure are

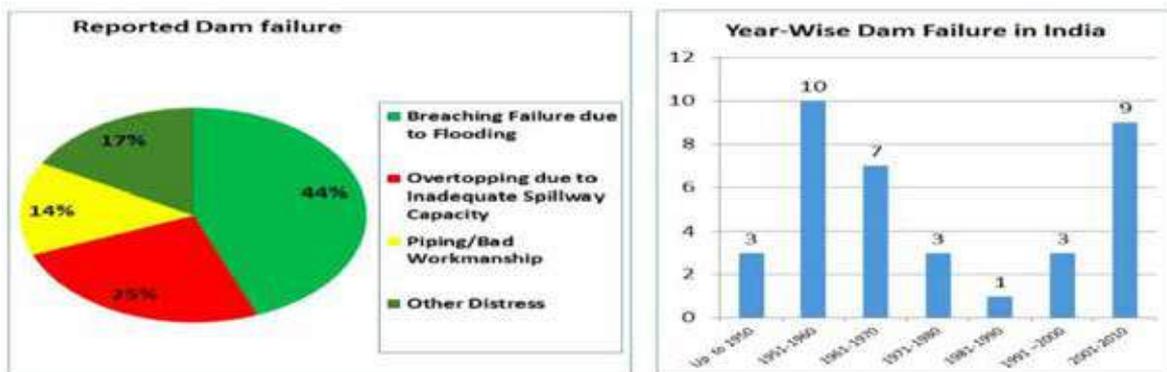


Fig. 6 : Dam failure data in India

attributable to inadequate spillway capacity. For all dam types most of the failures have occurred due to floods and during floods, so the dam authorities should be extra careful during the floods.

At Koldam spillway capacity is adequate with PMF of 16500 cumec, sufficient cushion is kept for absorbing the flood by keeping the reservoir level at the lowest possible level, proper maintenance of hydro mechanical equipment is practiced. Hence, as inferred from Indian historical data also, the failure probability of Koldam is lowest.

### **NEED OF DAM SAFETY IN INDIAN CONTEXT**

India has the third largest number of dams across the globe and a legislation to regulate dams is an essential and an important step towards ensuring dam safety in India. The Dam Safety Act 2021, which is the outcome of over 30 years of deliberations is a positive step in this direction.

Though 92% of the dams are located on inter-state rivers, most of them are built, owned and operated by the respective state governments. Hence, any law that seeks to provide a robust mechanism for dam safety must be based on the principle of cooperative federalism.

To cater the concerns related to dam safety in a comprehensive and uniform manner, Government of India has enacted Dam Safety Act 2021. It's a powerful tool to handle the issues related to dam safety. This act provides a legal framework for ensuring dam safety and it has a provision of governing bodies at central, state and local level. e.g. NDSA: National Dam Safety Authority at central level, State Dam Safety Organization (SDSO) at state level, Dam Safety Unit (DSU) at local/site level. The provision of Dam Safety Unit (DSU) at project level has been made to implement Dam Safety Act at Ground Zero or grass root level.

The dam safety unit compiles all technical documentation of the project and conducts various inspections of the dams namely pre and post monsoon inspections which include visual inspections of various components of the project as well as reservoir rim inspections. Apart from this, special inspections are also done in case of any event like sudden flood, earthquake etc. Dam safety unit also looks after various dam instrumentation data, it's analysis and trends. It briefs the management about the healthiness of the dam and actions to be taken for ensuring dam safety.

### **DAM SAFETY PRACTICES AT KOLDAM**

To maintain the dam in structurally and functionally safe condition without any loss in generation, Koldam HPS has undertaken many standard dam safety practices as per provisions of dam safety act along with some new initiatives in this direction. Key dam safety practices

being observed at Koldam Hydro Power Station are apprehended below:

The Dam Safety Unit is fully functional with cross functional team members from various disciplines like Mechanical, Electrical, C&I, Geology, Engineering, Quality, Disaster Management, Operation etc. The Dam Safety Unit takes care of holistic compliance of Dam Safety Act including pre and post monsoon inspections. Various technical documentation like DPR, inspection reports, Drawings, SOPs, Guidelines, Permissions, Clearances, Quality observations, as built drawings, relevant codes etc. have been compiled and proper online documentation is indexed for ready retrieval of the same.

Reservoir operation manual and the Rule curve are well documented and being followed rigorously. SOPs (standard operating procedure) and LMIs (Local Management Instructions) are formulated for various Dam inspections and instrumentation monitoring and analysis.

Proper scheduled of planned maintenance of all hydro mechanical equipment throughout the year is standard practice and trial of spillway gates and pumps is conducted before every monsoon. This practice ensures no malfunction of any hydro mechanical equipment or spillway gate happens during the monsoon season or other requirement.

Reservoir Rim Inspection: Entire reservoir rim of about 40 km length is inspected by a cross-functional team, in pre monsoon and post monsoon seasons. Different deformation and landslides along the reservoir rim are recorded. The pre and post monsoon condition of individual slide is compared. A comparison of movement and condition of slides in previous years is also done to analyze the relative position of the slide. The reason for slide movement and stabilization measures are suggested for active slides. For problems of bigger magnitude and critical in nature expert opinion is also taken. Figure 7 shows a comparison of the same landslide in pre and post monsoon seasons.

Pre and post monsoon inspections are performed by dam safety committee as per CWC guidelines. The analysis of reports is done to ensure the timely implementation of steps required for safety of dams. The reports are shared with SDSO and NDSA. Pre and post monsoon analysis of dam and spillway instrumentation is also done to summarize the quantum of equipment working properly, any need of repairs, variation in results of equipment and any alarming situation. Pre and post monsoon inspections carried out till date illustrate that all components of Koldam are behaving properly, all dam safety compliance are being followed and there are no major issues in any component.

Analysis of Instrumentation Data: Various instruments like piezometers, inclinometers, load cells, measurement



**Fig. 7 :** Comparison of same slide in pre and post monsoon reservoir rim inspections

beams, seepage measurement weirs, thermometers, SMA etc. are installed in different parts of dam including clay core and spillway.

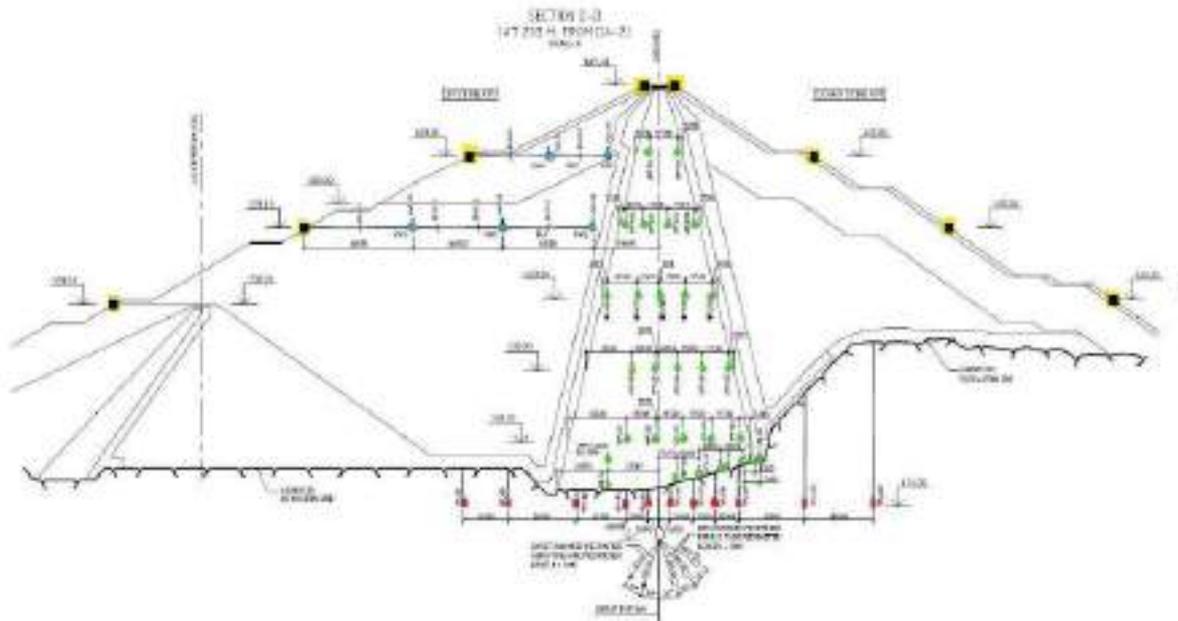
A typical dam section indicating Piezometers provided in dam is as in Fig 8.

Two types of analysis of instrumentation data are carried out for different purposes. Monthly analysis of instrumentation data is carried out to analyze short term variations, data of current month is compared with previous month. In case of any abnormal variation, the historical data is compared. Pre and post monsoon instrumentation data analysis is carried out to see the variations in the instrument readings and its interpretation in pre and post monsoon seasons. Instrumentation data

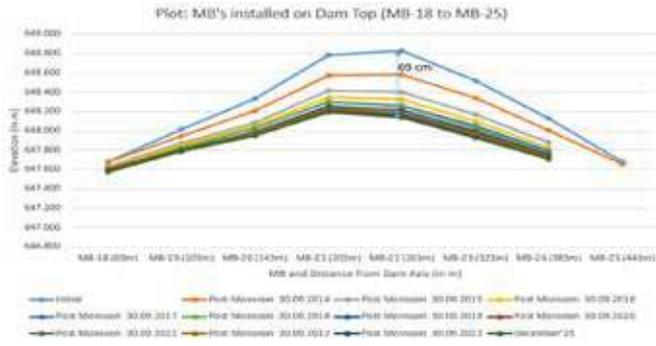
is recorded and stored in an automatic mode. Monthly dam safety inspection and analysis of instrumentation data reveals that the parameters of dam including settlement, seepage, temperature, water pressure etc. are within the permissible limits. The trend comparisons with previous years' data indicate that there is no unusual variation in the parameters in the long term. This is a further certification of the safer condition of the dam and its appurtenant structures.

As shown in figure 9 the maximum settlement of dam is 69 cm which is well within the design value i.e. 1% of dam height.

Emergency Action Plan (EAP) and Disaster Management Plan (DMP) are well documented and implemented and



**Fig. 8 :** Dam Section indicating typical details of Piezometers installed



**Fig. 9 :** Yearly variation of Dam settlement in Post and post monsoon season

these documents are being updated as per schedule and latest guidelines. Mock drills to handle various natural disasters are carried out in association with NDMA, SDMA, local administration and public. Villagers are being educated about dam safety and disaster management through newspapers, pamphlets, village level meetings, awareness sessions, Nukkad Nataks etc.

Hydro-meteorological stations and real time Inflow measurement: Hydro-meteorological stations including AWS (Automatic Weather Station) are installed at Koldam. Inflow is being measured at 40 km upstream of dam. The inflow information of the upstream project is also taken into account. This gives a lead time of about 3.5 hours in case of any excessive flow and to take corrective actions.

Automatic Weather Station (AWS), Early Warning System (EWS), river inflow and flood forecasting system etc. are fully functional at Koldam. Well planned and modern flood forecasting system and Early Warning system (EWS) keeps the dam and downstream population (man, material and machines) safe in case of any possible disaster.

Figure 10 depicts the layout of downstream Early Warning system (EWS) consisting of real time PA system with electrical hooters. Early warning for routine plant operation discharge and spillway operation both are being disseminated to common public by various means like hooter systems, PA system, announcement vehicle, SMS etc.

The inflow & flood forecasting system has been developed at Koldam which is capable of giving 10 Days Inflow forecast based on the weather conditions over catchment area. The predicted inflows are being compared with the measured inflows and found very reliable. The continuous display of measured inflow, predicted inflow and its comparison is shown at control room and other critical locations.

Siltation study by satellite data and drone survey is being carried out to estimate the silt deposition on the riverbanks near villages. Figure 11 shows the satellite image showing the siltation along two different zones in the reservoir. The siltation volume calculated from the satellite data was compared to the corresponding value obtained from the drone survey and found in good agreement.

Bathymetry survey of reservoir is being conducted on an annual basis to estimate the siltation in the reservoir and to understand the effective reservoir capacity available for generation as well as to handle any flood. It also helps in predicting balance reservoir life before it becomes a run-off-the river scheme.

As shown in figure 12, the area capacity curves are revised based on the inputs of bathymetry studies. It indicates the decrease in capacity of the reservoir with time. Regular study in this regard shall help in assessing the balance life of the reservoir.



**Fig. 10 :** Layout of Downstream EWS along with PA & Electric hooters

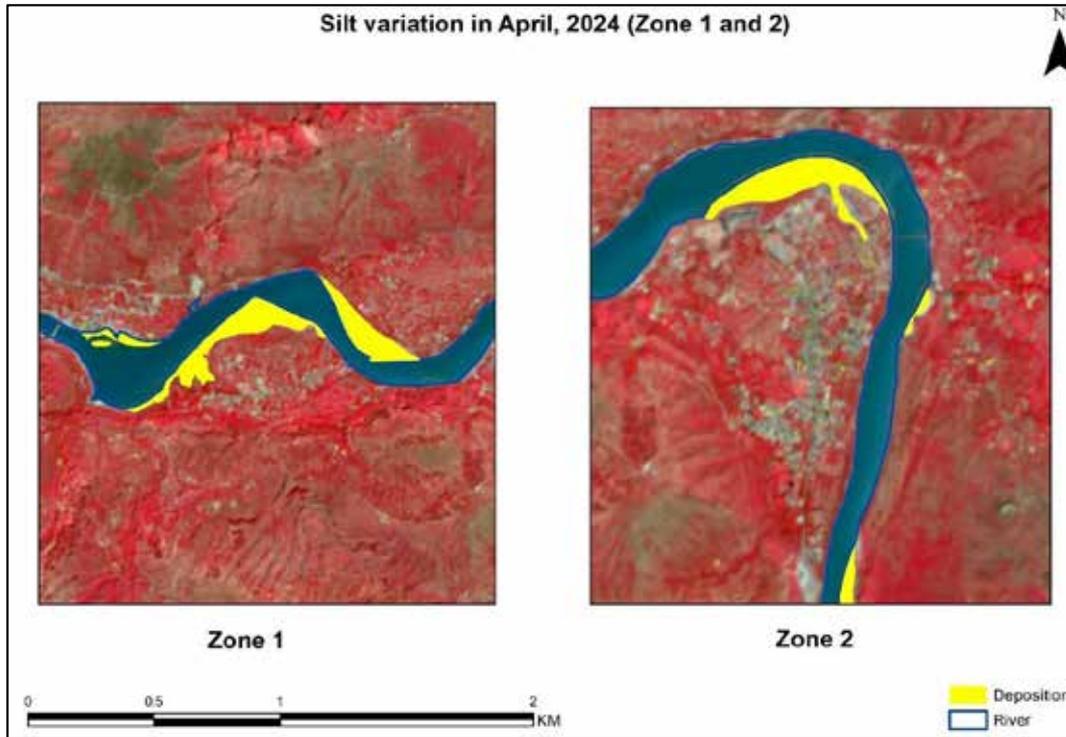


Fig. 11 : Siltation analysis along riverbanks using satellite image data

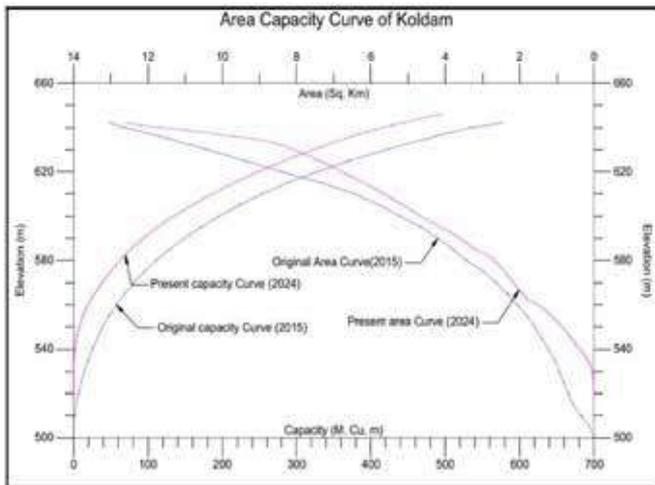


Fig. 12 : Revised area capacity curves based on bathymetry study

Quality control during the operation and maintenance of dams can significantly reduce the chances of dam failures. Koldam is a rockfill dam with a central clay core. A high degree of quality control was exercised during construction period for clay properties and field compaction of dam layers. Similarly, the critical tests of aggregates and boulders like Alkali reactivity test and slack durability test reduce the probability of deterioration of constituent materials and in turn of the dam and spillway structures.

The tests carried out during various maintenance activities for quality control assured that the test parameters are within the limits.

Two basic concepts of knowledge sharing and data sharing are being implemented at Koldam for educating more and more people about dam safety. For Knowledge sharing Dam Safety Unit attends various training programs, conferences, mutual discussions and deliberations about the practical learnings of dam safety among the various partners and dam owners.

As an effective medium of data sharing, the generation parameters of Koldam like reservoir level, inflow, out flow, generation MW, spillway discharge etc. are being updated online on an hourly basis for data sharing among the dam owners and SDSO, NDSA.

**CONCLUSIONS**

A comprehensive analysis of historical dam failure data was summarized in this paper along with the dam safety measures being implemented at Koldam. Different historical data related to dam failures, like type of dam, age, construction period, height, storage etc. are analyzed and compared with reference to Koldam which indicates that dam is behaving with no dam safety issue till date conforming to the summary provided in table 1.

**Table 1** : Summary of historical dam failure parameters and Status of Koldam

Sl. No.	Criteria of failure	Values	Koldam parameter	Status
1.	Age of dam	50% within 2 years	10 years	Safe
2.	Height of dam	≥100 m, 0.13%	167 m	Safe
3.	Tenure	Safe in normal operation	Normal operation	Safe
4.	Dam type	Rock fill 1.39 %	Rockfill	Safe
5.	Storage	≥ 1000 hm <sup>2</sup> , 0.87%	576 MCM	Safe
6.	Spillway capacity	Inadequate	PMF (16500 cumec)	Safe

In view of the details presented in the paper about the dam safety initiatives taken at Koldam, it would be safe to conclude that the Koldam HPS is maintaining all safety requirements as per Dam Safety Act 2021. The various inspections and analysis of instrumentation data reveal that the condition of Dam and spillway is good and it's safe in all aspects of monitoring.

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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.**

# Importance of FEM Analysis in Arriving at Structural System to Deal with Large Lateral Force due to Creeping Slope – A Case Study of Shongtong Karcham HEP (450 MW), India

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## ABSTRACT

*Geological surprises, encountered during construction of water resource projects, sometimes open up issues quite unexpected. One such is the case of Shongtom Karcham HEP (450 MW), India, wherein detailed geological investigations during construction stage led to the identification of creeping in right bank slope of the barrage structure. The creeping slope has been estimated to be a sliding mass with an extent of 1km into hill with varying depth (80-220m) and width in plan (1km at hill top which flares to 3km at river edge). Subsequent to detailed deliberations and studies of alternative proposals for the barrage from techno-economic aspects, the alternative finalized is the one in which the existing barrage complex is to be modified to make it capable to safely transfer the large creeping force onto competent left bank or into the foundation.*

*FE modeling of barrage complex along with its foundation has been carried out in MIDAS FEA-NX. Considering computational limitations, three separate FE models (one each for the intake-apron floor, the barrage and the stilling basin) along with their foundation and interface (defined using stiffness parameters) have been modeled. Re-designing the barrage complex to transfer such huge creep forces, which are estimated of the order of 17-20MN/m, without adversely impacting the hydraulics of the barrage, was an unprecedented task. Poor foundation conditions at barrage site further added to the complexities of the issue. Iterative analysis of the FE models for various load combinations of loads (hydrostatic, creep and uplift, seismic) were carried out. Based on the numerical studies, a design concept of barrage complex with highly stiff structural components which are capable of transferring unusual creeping forces was arrived at. Allowing limits of displacement and adequacy of various structural components, stresses in concrete portions, base pressures of the apron floor and hydraulics of the flow were critical parameters in arriving at the finally adopted concept of the barrage complex. Resizing of semi-gravity wall, introduction of monolithic horizontal struts, thickening of apron floor, introduction of divide wall in upstream apron, foundation improvement provisions, introduction of piling towards right bank, cable anchors below power intake, construction sequence and delineation of critical points for instrumentation and monitoring are major aspects leading to the unique structural form for the barrage complex.*

*The project, which otherwise was stalled due to the rare issue of creeping slope, is a typical example wherein capabilities of FEM analysis have been aptly utilized to arrive at an unconventional but technically viable solution in a short time span. The paper discusses this journey of the numerical studies carried out for the project, with specific emphasis on the interpretation of the results that led to the finally adopted structural form for the barrage complex.*

## 1. INTRODUCTION

Finite Element Analysis is a numerical analysis technique for obtaining approximate solutions. Historically, FEM was independently developed by engineers to address structural mechanics problems related to aerospace and civil engineering. Developments in FEM began in mid-1950s with the papers of Turner, Clough, Martin and Topp (1956), Argyris (1957), Babuska and Aziz

(1972). Literatures by Zienkiewicz (1971) and Strang, and Fix (1973) also laid foundations for developments in FEM. Advancement in computational power of modern computers have led to increased application of FEM in various fields including civil engineering (Bhat, 2021). Computer softwares developed exclusively for applying FEM facilitated its augmented preference among practicing engineers for using this method for planning and design of civil structures.

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FEM in the field of civil engineering is a powerful tool for numerically approximating physical structures that are too complex for regular analytical solutions. Generally, the solution region is analytically modelled or approximated by replacing it with an assemblage of discrete elements and are solved with margins of accepted approximations. As a result, FEA helps providing greater insight and understanding of overall behavior of complex structures which otherwise was impossible through conventional and analytical methods. Computational advancements leading to softwares based on FEM facilitate the experts in this matter.

## 2. PROBLEM IN HAND – CREEPING RIGHT BANK SLOPE AT BARRAGE AXIS

Owing to capital intensive and inter-disciplinary nature of water resource projects, their planning, design and construction demand diligent, holistic and technically adept thinking. In this era of advanced computational efficiencies, FEM is recognized as a powerful tool to facilitate this process. FEM like tools play crucial role especially when handling design loads/conditions which are unconventional and do not have much examples from past or established guidelines to refer to. One such is the case of Shongtong Karcham, wherein FEM is utilized effectively to arrive at the modified barrage structure for high creeping load. Instances of designing massive structures against high creeping loads is a rare necessity which cropped up in this project in its very advanced stage of construction. Insufficient geological investigations and wide-heterogeneous variation of geology in Himalayan terrain ought to have caused this geological surprise to this project.

Shongtong Karcham Hydro Electric Project is an under construction run-of-the-river project in River Satluj in the Kinnaur District of Himachal Pradesh and envisages to divert water by a barrage through 7.7 km long Head Race Tunnel (HRT) which eventually leads water to an underground power house with units of installed capacity of 450MW. Though construction of the project commenced way back in 2012 with an envisaged completion time of 60 months, geological phenomenon of creeping which got established only during the construction stage posed serious challenges in taking up the construction of barrage.

Creeping soil/overburden is a time dependent development of strains in soil mass which is manifested due to the state of constant effective stress. Being a slow process, its identification is generally deemed as difficult. The literature says that previous instances of soil/slope failures, evidence of soil ripples, curved tree trunks, tilting of poles/vertical slender structures, bulging in/out of fences etc. are indicators of creep in the soil mass (Shekhawat et al. 2022).

In Shongtong Karcham, vulnerability of right bank to creeping forces was identified and roughly assessed through various investigation and monitoring methods. Geological investigations (boreholes, exploratory drifts, electrical tomography, inclinometer findings and laboratory tests), photo documentation of slope by remote sensing method (LiDAR), geodetic systems, Surface Movement Monitoring (SMM) and desktop studies were employed for these purposes. However, none of these could establish/measure the rate of creep with reasonable credibility. In the absence of well-established or observed rate of creep from fields, analytical methods (Brandl&Dalmatiner and Rheological considerations) were employed to arrive at the design creeping rate of the right bank slope. The creeping slope that was to be managed in the project was identified/defined as below:

- (i) Slide mass is more than 1km wide at the top and flares to 3km at the river edge.
- (ii) Slide mass is around 80m deep near the toe and for higher reaches its depth may even exceed 200m
- (iii) The barrage and stilling basin areas needs to be designed for the estimated high creeping (design) load of the order of 17.5MN/m and 19.4MN/m respectively

Since creeping was neither identified nor included during the planning stage of the project and progress of other major components were close to its completion, it became imperative that barrage at its original location be modified to counter the impact of creeping forces necessarily without causing changes in the hydraulic features of the proposed barrage. After detailed studies carried out by various experts and agencies (namely HPPCL, Lahmeyer International, SMEC and Central Water Commission), an observational method for a suitably modified alternative structure was finally adopted for the project. In observational approach, remedial measures are incorporated in stages; the initially incorporated ones necessarily may not cover the worst scenario. Therefore, the effects of the preliminary implemented measures are monitored regularly and when the observed behavior of the structure deviates disadvantageously, additional predefined mitigation measures have to be applied (Shekhawat et al. 2022). Observational methods are applied when the forces or effect of the forces acting on the structure is uncertain; but conservative assumptions costs exorbitantly. Also, the elaborate studies/discussions of alternate studies brought out that modification in the existing structural arrangements of barrage complex to enable it to safely transfer the large creeping forces either onto the left bank or to the foundation is the best available choice with the project engineers; while doing so minimum interference in the hydraulics of flow, as envisaged during its planning stage, needs to be ensured.

### 3. FINITE ELEMENT ANALYSES

In simple words, problem in hand can be described as “devising design principle for a hydraulic structure to combat additional loading due to large creeping mass”. Keeping the nature of problem in hand, the study was carried out in two steps:

1. Slope Stability Studies
2. Stress Analysis of Modified Barrage Complex

Based on the investigations carried out in the creeping slope, marked differences were observed in the geological sections along the barrage complex as shown in Figures 1 and 2.

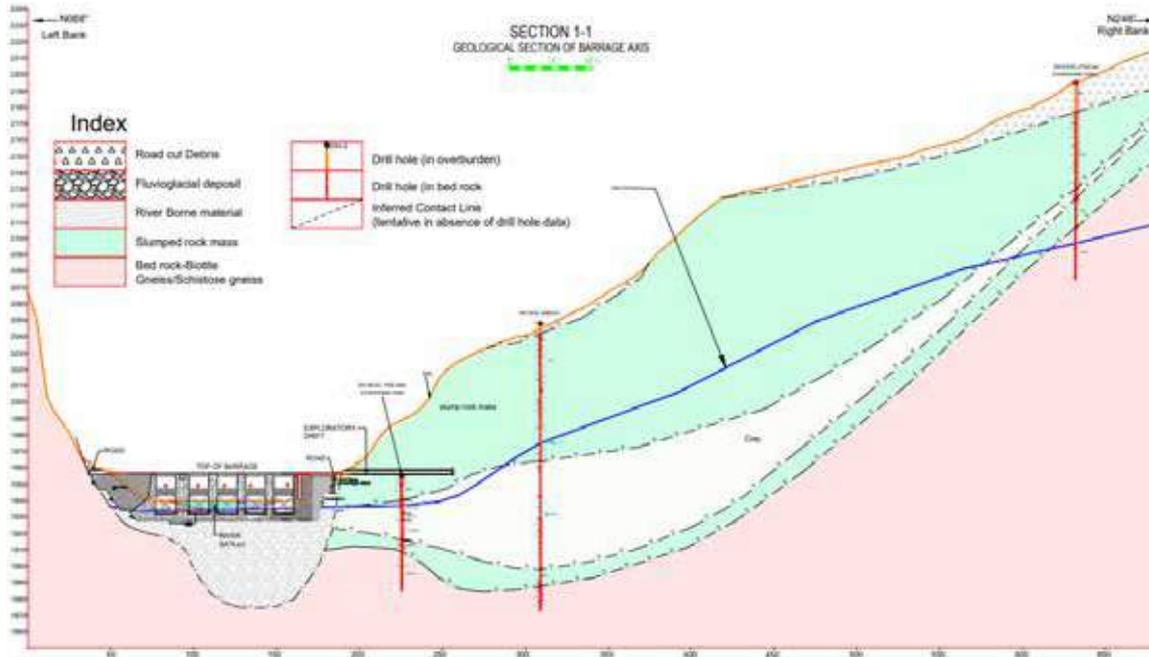


Fig. 1 : Geological section along the barrage axis

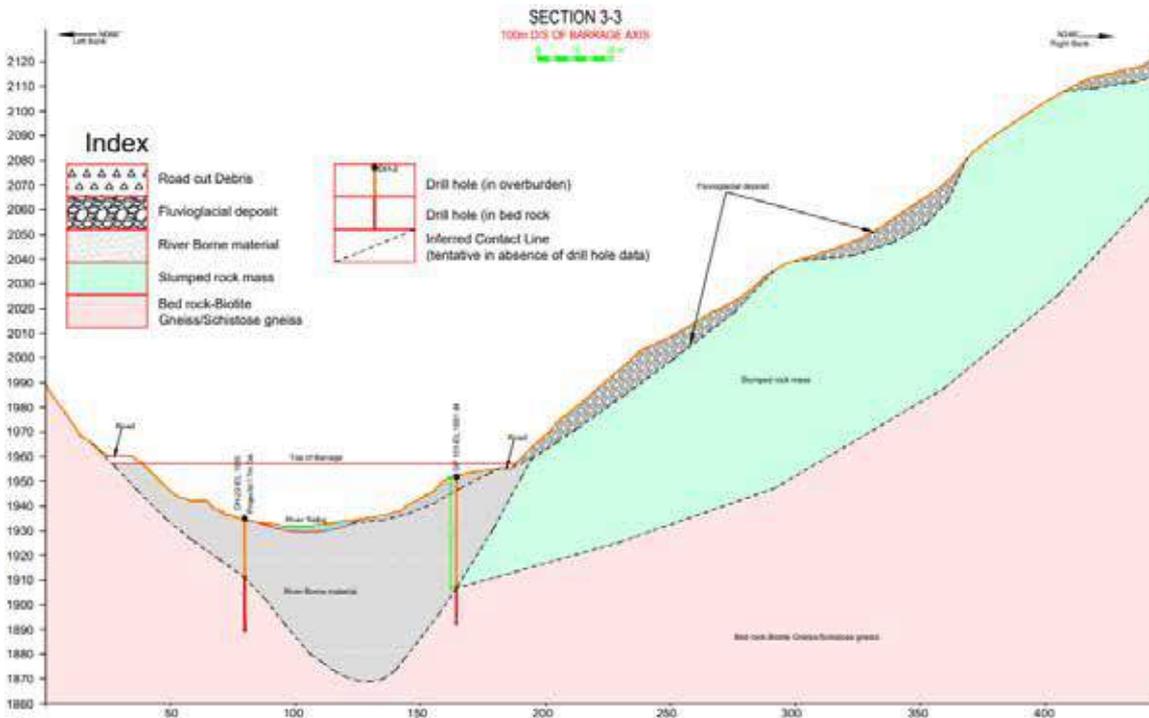


Fig. 2 : Geological section 100m downstream of barrage axis (stilling basin)

Looking into abrupt variation in the geology along barrage as shown above, slope stability analysis was carried out along two critical sections namely Barrage Axis and Stilling Basin Area. Coming onto stress analysis of barrage complex, in addition to the geological variations, keeping in view of the structural and hydraulic differences in the barrage components and computational limitations for solving bulky 3D model of entire barrage complex, analysis of the barrage complex was taken up in three separate FEM models: first for the apron region, second for the barrage and third for the stilling basin region.

Based on investigations and otherwise literature, material properties considered for the numerical analyses are given in the Table 1:

As per site specific seismic studies, for concrete barrage structure, maximum horizontal seismic coefficient is 0.21 and maximum vertical seismic coefficient is 0.14 for 5% damping and these values are 0.15 and 0.1 respectively for 10% damping,

### 3.1 Slope Stability Studies

Numerical modelling (finite element analysis) is carried out to check initial factor of safety for the slope and slip circle in case the failure occurs. Two dimensional analysis of slope for the selected two parts are carried out. The results of the analyses are expressed as a factor of safety which is defined as the ratio of available shear strength to the shear stresses developed on the sliding plane. For slope stability studies, all three stages of construction i.e. pre- construction stage, construction stage and post construction stage for barrage and stilling basin have been considered. Various cases studied are elucidated in Table 1.

The slope stability studies of the sliding mass were carried out in FEM based software (RS2) in addition to Limit Equilibrium Method (LEM) based software Slide2. Strength reduction factors (SRF)/Factor of Safety (FoS) for the creeping slopes for the stages of pre-construction, construction and post-construction for both normal and seismic conditions were checked to fall within acceptable ranges as shown in Table 2.

**Table 1 :** Properties of the materials used in the analysis

Soil/Rock	(Range/ Mean)	Overburden	Slumped Rock Mass	Shear Zone	Insitu Rock Saturated (Gneiss)
UCS (MPa)	Mean	0.03	38	7.5	63
Young Modulus (GPa)	Mean	0.008	2.5	0.07	25
Cohesion (MPa)	Range	0.004-0.013	0.2-0.3	0.025-0.1	3-12
	Mean	0.009	0.25	0.06	5
Angle of Internal Friction (Degree)	Mean	38.5	35	25	50
Dry Density (KN/m <sup>2</sup> )	Mean	12.9	26	24	27
Poissons ratio*	Mean	0.42	0.40	0.32	0.28

\*Poisson's ration considered from various literatures.

**Table 2 :** Comparative table showing factor of safety obtained from FEM and LEM

Sl. No.	Component	Construction Stage	Loading	SRF (FEM)	FoS (LEM)
1.	Barrage Axis	Pre-Construction	Normal	1.41	1.21
2.			Seismic	0.95	0.99
3.		Construction	Normal	1.33	1.24
4.			Seismic	0.91	0.91
5.		Post Construction	Normal	1.44	1.26
6.			Seismic	1.03	1.027
7.	Stilling Basin Area	Pre-Construction	Normal	1.82	1.004
8.			Seismic	0.84	0.922
9.		Construction	Normal	1.74	1.24
10.			Seismic	0.53	0.923
11.		Post Construction	Normal	2.12	1.24
12.			Seismic	0.83	0.923

From obtained SRF/FoS, it was evident that at both the component area, slopes are rather stable during various construction stages in normal loading case. However, in seismic loading condition for construction stage, support is needed for both the areas i.e. Barrage area and Stilling basin area. Therefore, while assessing the final support, as part of the observational approach, it was decided that behavior of cut slope needs to be monitored closely and if required, suitable support must be provided based on the detailed design.

**3.2 Stress Analysis of Modified Barrage Complex**

The alterations/changes in the barrage complex were carried out such that the functional hydraulics of the barrage were not impacted. Modification in barrage complex demanded an iterative study of the FEM based 3D model. This process was executed in MIDAS FEA-NX. 3D models of barrage complex along with its foundation (rock) were developed for apron floor, barrage and stilling basin.

Geometry of foundation was developed based on the surveyed river profile. Soil was modelled in segments along the depth with varying moduli of elasticity. Modulus of Elasticity values was varying from 75MPa at 3m depth (layer just below the raft) to 590MPa at 48m.

Interface elements between raft and foundation were defined using normal and stiffness parameters estimated between barrage and the overburden material (alluvium). The interface behavioral model is based on Coulomb’s law of friction (1785) and follows the assumption that the frictional force of an interface is proportional to the coefficient of friction and the confining forces perpendicular to the normal direction acting on the interface. Based on the relations mentioned in MIDAS FEA-NX manual used for evaluating interface stiffness parameters, normal and shear stiffness values  $K_n$  and  $K_t$  are estimated. Accordingly,  $K_n = 1.125 \text{ N/mm}^3$  and  $K_t = 0.1875 \text{ N/mm}^3$  are adopted for modeling.

In addition to self-weight, loads modelled in the analyses were hydrostatic, uplift, creep and seismic loads. Hydrostatic, uplift and creep were employed as pressure loads while self-weight of gate structures were modelled as point/concentrated load. Load combinations analyzed as part of the stress analyses are listed in Table 3.

Auto-generated hybrid mesh had been used for modeling. Mesh size and shape (P and N studies) was worked out for stress convergence. Lateral restraints are provided in left and right bank while bottom of modeled foundation is restrained in all directions.

**4. REMEDIAL MEASURES ARRIVED AT FROM INFERENCES OF FE ANALYSIS**

As discussed earlier, elaborate studies and deliberations of the problem in hand led the designers to take an observational approach, for both its structural and non-structural remedial measures. However, since this paper is aimed at elucidating how FE analysis was utilized to devise a technical solution to the problem in hand, discussions here are limited to measures devised exclusively from numerical studies as explained in succeeding paragraphs.

Arriving at the modified geometry of barrage which introduces rigidity and competency to transfer high creeping forces onto the foundation or left bank was the primary aim of the stress analysis. For the same, to start with, designers decided to adopt one or/and more of the following steps:

1. Introduction of struts in barrage complex
2. Modification/introduction of box-like shapes wherever technically viable for various components of the barrage
3. Removal of joints and provision of continuity in barrage complex

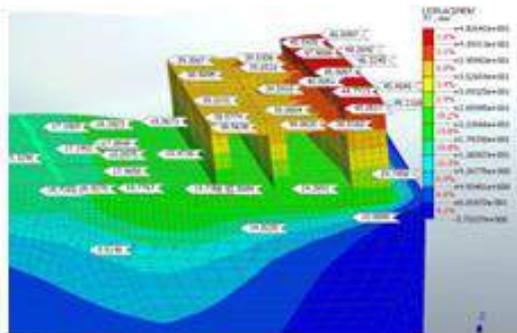
**Table 3 : Load combinations analyzed**

<b>Apron Floor (Intake area)</b>	<b>Barrage Structure</b>	<b>Stilling Basin Structure</b>
a. End of construction: Self-weight + creep pressure	a. End of construction: Self-weight + creep pressure	a. End of construction: Self-weight + creep pressure
b. Normal operation with uplift + creep pressure	b. Normal operation with uplift + creep pressure	b. Normal Operation+ creep pressure + uplift
c. Normal operation with uplift + creep pressure+ Seismic	c. Normal operation with uplift + creep pressure+ Seismic	c. Normal Operation+ creep pressure + uplift + Seismic
d. End of construction: Self-weight	d. End of construction: Self-weight	d. End of construction: Self-weight
e. Normal operation without uplift + creep pressure	e. Normal operation without uplift + creep pressure	
f. (Besides above, sudden drawdown condition for silt flushing operation is checked for u/s apron-intake area)		

4. Increased thicknesses for foundation floors (like increase in thickness of raft floors from 2m to 4m)
5. Right bank walls of barrage to be designed as gravity retaining structures
6. Measures to ensure proper transfer of loads onto the left bank

Displacements and solid stresses (principle maximum) of various components were primarily studied during each iteration to decide on the way forward with modifications of the barrage complex. Permissibility of solid stresses and displacements were considered the basis for re-designing. Whenever the tensile stresses surpassed the permissible limits, re-dimensioning of the components was done. Aspect, of how the results of numerical analysis were favourably used for modifying the barrage complex, can be understood from the following:

- (a) Necessity for higher stiffness near the right bank of barrage was evident from higher lateral displacement occurring at the right bank area (Figure 3 (a)).

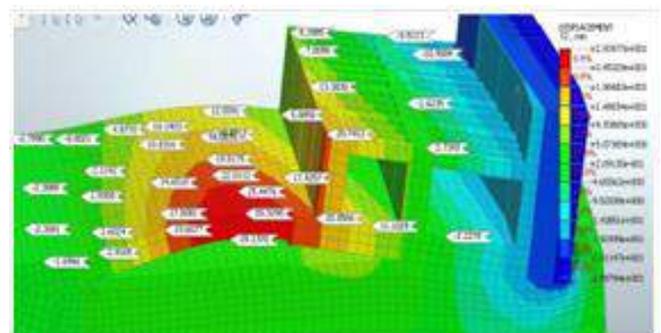


**Fig. 3(a)** : Vertical deformation (mm) in right part of apron area for critical creep force condition

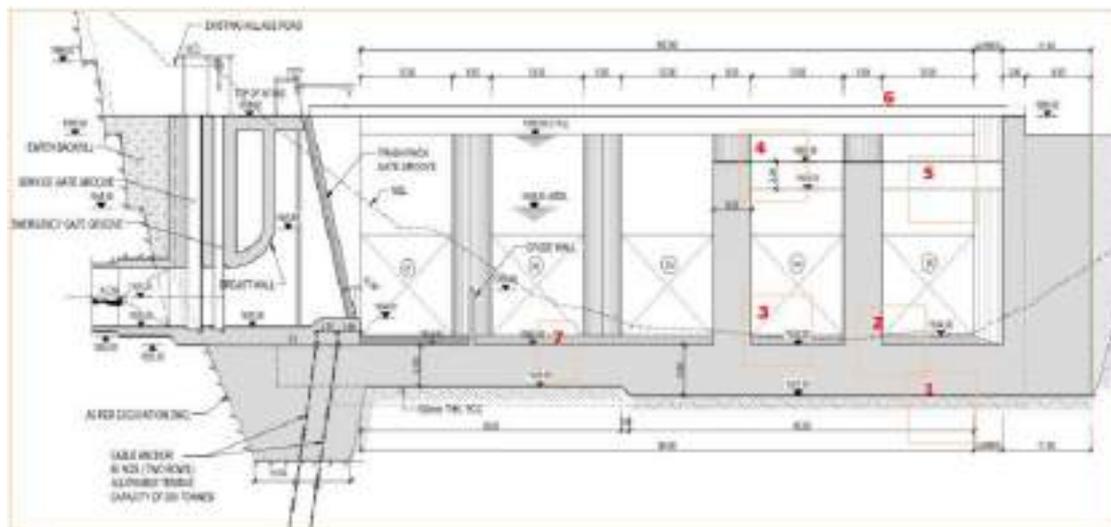
Accordingly, the right bank walls were designed to act as retaining wall. Also, divide walls of bay no 4 & 5 (towards the right bank) were extended upstream to provide box-like structure ( as seen in Figure 3(2) & Figure 6)

- (b) High displacements of raft floor (in the right bank upto bay 3) and showing critical tendency to detach during lateral movement due to creep and vertical displacement (Figure 3 (b)) during extreme uplift helped arrive at two major remedial measures as:

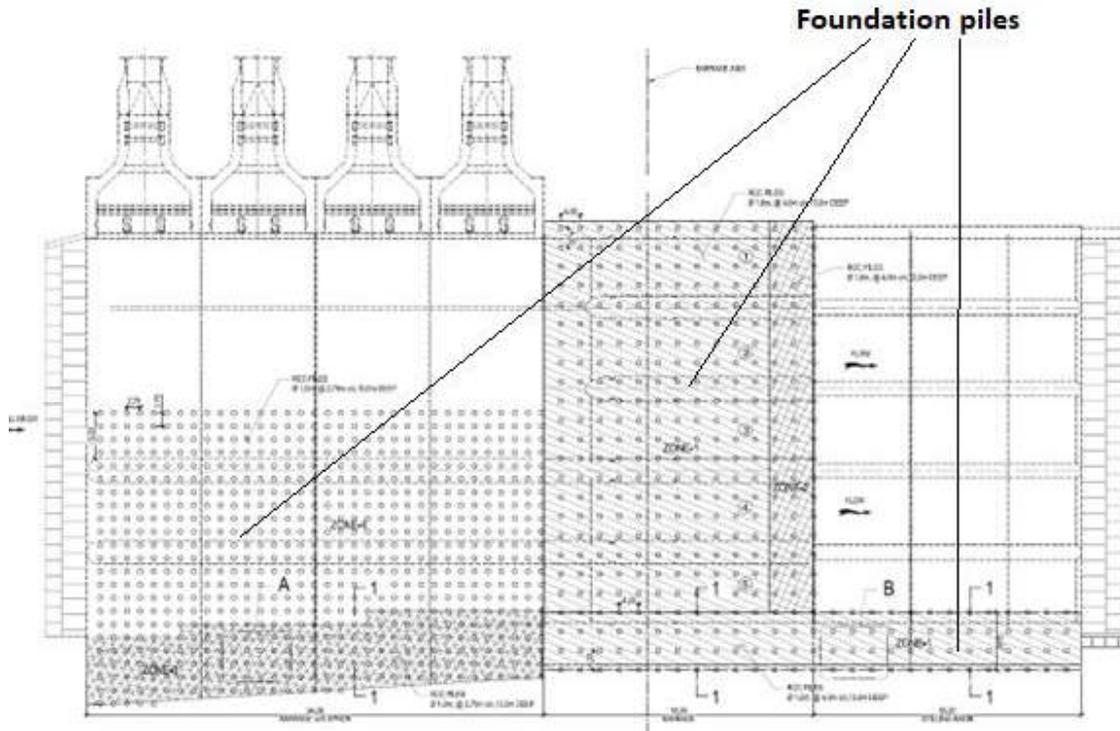
- To ensure better rigidity in addition to general thickening provided for the raft floor (from 2m to 4m), local increase in apron floor thickness (upto 5m) was provided from the right bank till bay 3 (Figure 4)
- Incompetency of barrage and apron floor areas to completely transfer the creeping load onto left bank was inferred and to counter the same use of foundation treatment methods were proposed for barrage and apron floors (Figure 5).



**Fig. 3(b)** : Vertical deformation (mm) in apron area (near bay 3) in sudden drawdown condition



**Fig. 4** : Cross section of apron area showing details of structural (thickening in apron floor, anchoring of power intake etc) and non-structural measures (numbered areas in red were identified as points of instrumentation for future monitoring).



**Fig. 5 :** Layout of foundation (friction piles) suggested for barrage complex

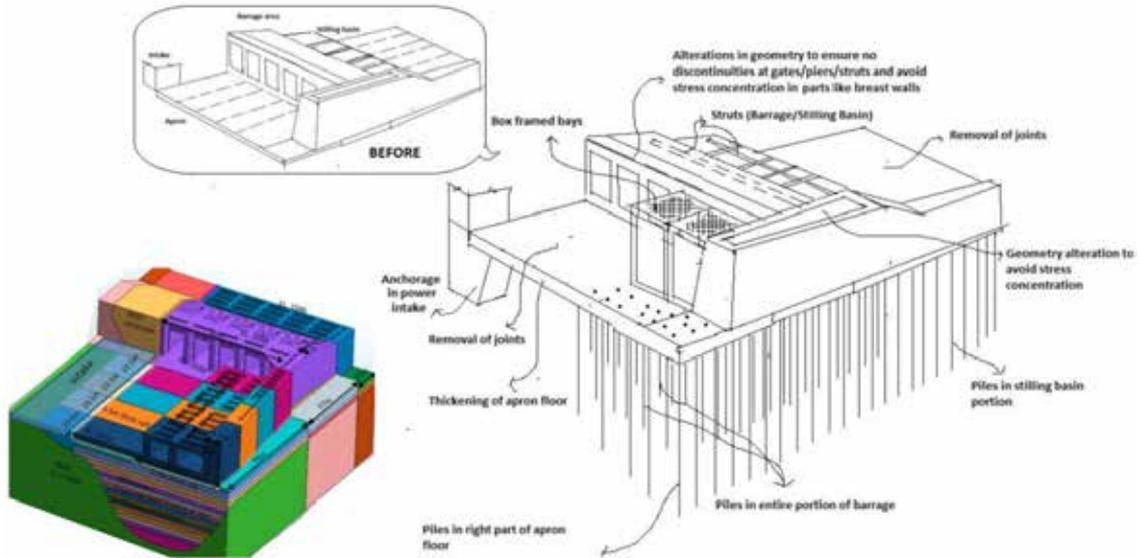
- In continuation to above point, modeling based on actually observed geological parameters of foundation verified the incompetency of river bed material under the barrage to sustain the effects of large creeping forces. This forced adoption of piles for delineated areas of barrage. Estimation of base pressures through numerical analyses helped to understand possible structure-foundation behavior and further with the demarcation and identification of barrage floor areas that needed to have foundation treatment (Figure 5).
- (c) Dimensioning and designing of struts and beams were based upon the principal maximum solid stress values observed from the iterative analyses. Critical stress values were utilized for finalizing the dimension and designing the reinforcements
- (d) Critical locations for monitoring the health of barrage complex in line with adopted observational approach were identified (as shown in Figure 3). Stress and high displacement points were noted as points of monitoring
- (e) Cable anchors are proposed below the intake structure (Figure 3) to stitch mass concrete with foundation rock also to achieve rigid boundary conditions at the interface of the intake structure and right abutment raft to deal with the reservoir's sudden drawdown condition

The numerical model of barrage complex finally arrived at after various iterations is shown in Figure 6.

## 5 CONCLUSIONS

Finite Element Method is an approximate method of solving equations. For unusual and huge structures, whose analyses are otherwise impossible with conventional design practices or guidelines, FEM based approximate solutions serve intended purposes of design. Evolution of technology has aided in the increased use of FEM for such technical challenges. This paper discusses one such case study of Shongtong Karcham wherein finite element analysis was employed to arrive at the conceptual design of the barrage complex of the project. Shongtong Karcham, a hydropower project in Himachal Pradesh, India had to deal with "devising design principle for its barrage to combat the additional loading due to large creeping mass". The barrage of the project needed to be modified so that technically it could tackle a huge creeping force of the order of 17-19MN/m in its right bank.

FEM was used to carry out slope stability and stress analysis in the project. Structure and foundation was modelled numerically. Geometry of the barrage complex was enriched with struts, monolithic floor, gravity side walls, box shaped bays etc to ensure increased rigidity and competency to transfer high creeping loads from right to left bank of the barrage. Limits of maximum



**Fig. 6 :** Numerically developed model of barrage complex and the schematic diagram of finally adopted barrage complex (barrage as before is shown in inset)

stresses and displacements observed in the model during various iterations of the numerical study helped firming up the structural modifications in the barrage. Foundation treatment methods, extension of box-shaped bays in apron areas, thickening of raft floor, dimensioning of struts and identification of critical monitoring points were specific structural modifications/remedies that were suggested purely based on the results of executed numerical studies.

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# Construction of Vishnugad-Pipalkoti HE Project (444MW) in Highly Adverse Geological Conditions and very Remote Location with Innovation - A Case Study of Dam Excavation in Steep Terrain in Helong area of District Chamoli, Uttarakhand

R. K. Khali<sup>1</sup> and S. Kumar<sup>2</sup>

## ABSTRACT

*Vishnugad Pipalkoti HE Project is our only ongoing prestigious project in the Ganga basin on the Alaknanda River, a tributary of River Ganga. The project is now in an advanced stage of construction. The main feature of this project is its concrete dam, 65 meters high and 200 meters long. Very soon will start the foundation-concrete work of the overflow blocks. The methodology adopted for the Diversion Tunnel, to facilitate dam excavation, is situating together the Diversion- cum-Spill Tunnel into one which will be the first and unique experiment for coping with the high flood situations. The authors want to highlight the latest techniques adopted with the most modern equipment and innovative devices adopted, during bench-excavation, for this remotely located projects. A variety of problems and challenges were faced by the working team locally owing to the unpredictable geology. They also dealt encounter natural hazards such as cloud bursts in 2017 and 2021. The authors believe that this case study will be helpful and pave way for the successful execution of similar projects for fellow engineers engaged in similar types of work in different project locations in India and abroad.*

**Keyword :** *Integration of conventional construction equipment with Robotic technology for building dams in time and cost-effective manner.*

## 1. INTRODUCTION

Vishnugad Pipalkoti HEP, with an installed capacity of 444 MW, is one of the major ongoing hydroelectric projects aiming at harnessing the vast power potential of the Alaknanda River. The project will utilize about 240 meters of water-head of the Alaknanda River, available in a stretch from Helong upstream to Birahi downstream. It is a run-of-the-river (ROR) scheme using diurnal storage. The annual energy generation from the project is estimated to be about 1813 MU.

The Main components of the project are as below:

- Concrete Gravity Dam of 65 m height with four under-sluices for passing 8004 cumecs of flood discharge.
- One Diversion Tunnel: 497m long x 10.5m dia with 65m cut and cover portion, and capacity to facilitate diversion of 725Cumecs of water for construction of dam.
- Three Power Intakes: followed by 03 Desilting chambers, each with a size of 390 m (L) x 16 m (W) x 21.5 m (H).
- One Head- Race- Tunnel: 8.8 m finished dia and 13.5 Km length, to be bored with the TBM and DBM methods.

- An underground Machine Hall: sizing 146 m (L) x 20.3 m (W) x 50 m (H).
- Underground Transformer Hall: measuring 142 m (L) x 16 m (W) x 24.5 m (H).
- Underground Surge tank: measuring 120 m (L) x 16 m (W) x 35 m (H).
- One Tail Race Tunnel: 8.8 m finished dia and 3.07 Km length.

3D view of the Dam and Desilting chambers and their location is shown as Fig.1:

## 2. GEOLOGY OF THE PROJECT AREA

The project area, on the slopes of the Alaknanda valley, exposes rocks belonging to the Garhwal Group and Central Himalayan Crystalline. These rocks are primarily composed of calcarenaceous rocks with basic intrusions and migmatite bodies, while low to medium-grade metamorphic rocks are exposed around Helong. The 'Carbonate Suite of Chamoli' of the Garhwal Group occurs between Chinka and Helong and contains the major magnesite bodies of this region. Generally, the magnesite deposits are restricted to the non-siliceous horizons of dolostones and exhibit distinct structural

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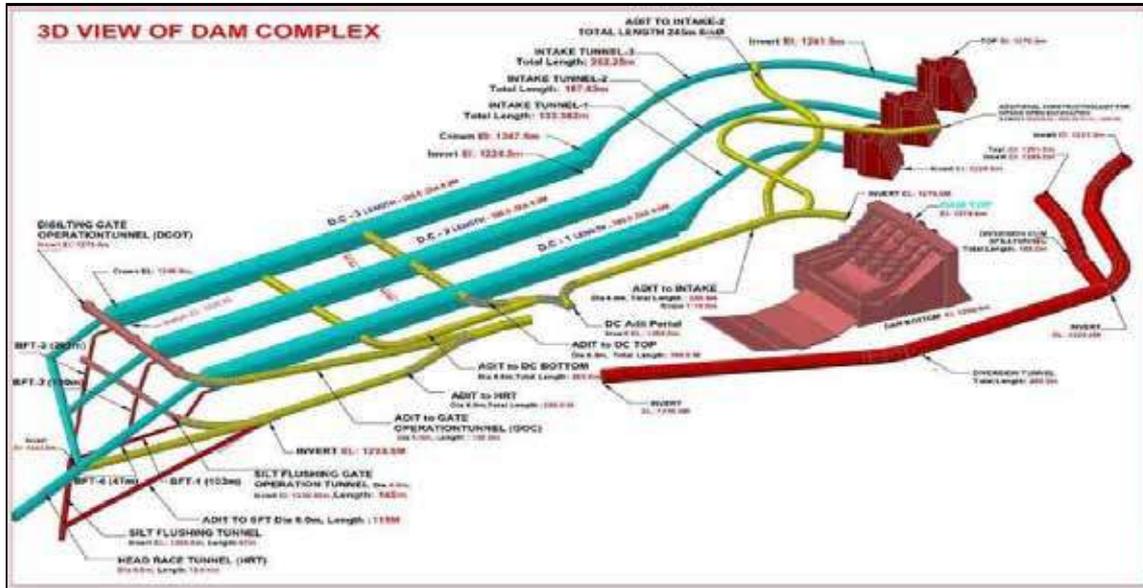


Fig. 1 : Project Dam, Diversion Tunnel & Desilting scheme, and location map

control. The Pipalkoti Anticline (a double plunging anticline) is a regional fold between Birahi and Helong rivers, representing the western continuation of the Tejam anticlinorium.

The project is located in the tectonic window known as the Pipalkoti Window (Carbonate Suite of Chamoli), the landscape exposing Lesser Himalayan meta-sedimentary rocks, enveloped by low to medium-grade metamorphic rocks of the Higher Himalaya. The Higher Himalayan crystalline rocks thrust over the Lesser Himalayan rocks alongside a major tectonic shear known as the Main Central Thrust (MCT) Zone, about 2 km upstream of the dam (Figure 2). The rocks of the 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 into a wide open regional domal structure known as the Pipalkoti Anticline, the same which is intersected by several faults, complicating the structural setup.

All project components are located between Birahi and Helong river valleys. The rocks at the dam and desilting chamber site are quartzites, and alongside most of the tunnel alignment, there are quartzites interbedded and interbanded with biotite schist, grey slates, and dolomites/limestones. Grey, thinly bedded slates with minor interbeds of limestone, dolomitic limestone with subordinate grey slates, grey pyritous shale/slates,

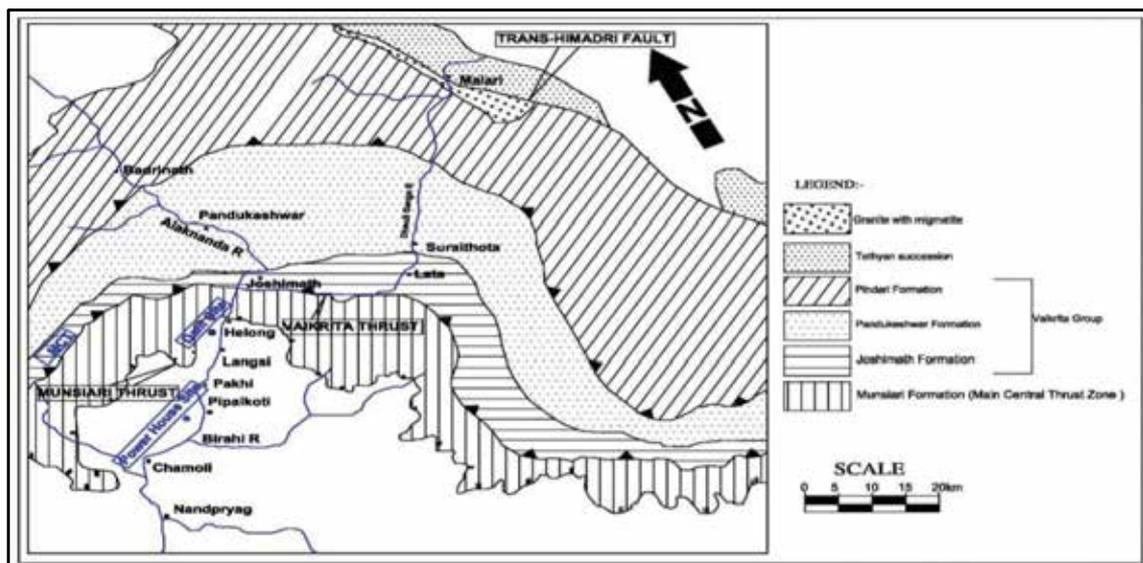


Fig. 2 : Regional geological map of VPHEP area

thinly bedded dolomitic limestones, grey slate/phyllite, white siliceous dolomite with magnesite, and talc schist are commonly present in the rock compositions. Light grey dolomite with stromatolitic structures, interbedded quartzite, phyllite, and dolomite all belong to the Garhwal Group. However, at the powerhouse site, the rocks are calcareous, shale, and dolomitic limestone/dolomite, while along the TRT, there are dolomitic limestone, metabasic rocks, augen gneisses, and schist. The rocks in general are very completely folded and faulted. The rocks of the area can be categorized into four formations: Pipalkoti Formation, Chinka Formation, Gulabkoti Formation, and Helong Formation.

At the dam site, on the left bank, where river diversion is planned, lye quartzite rock-mass bands of amphibolite-overlain by river-borne material along with the slope wash material in the diversion tunnel area (Figure 3). The upstream cofferdam is located on alluvial materials more than 20 meters thick. The diversion tunnel has been driven through quartzite with bands of amphibolite, characterized by moderately steep foliation and three other sets of discontinuities. The rock-mass condition along the diversion tunnel varies between Class II (193 meters) and Class III (255 meters) of RMR, with a very small patch of Class IV. The powerhouse complex has encountered mainly the Pipalkoti Formation of the Garhwal Group, consisting of slates and alternating bands of slate and dolomite with different sets of discontinuities and folding within the Pipalkoti Formation. There is a narrow gorge section just downstream of the powerhouse exploratory drift/MAT & CVT portal, which leads to ponding of the river in the vicinity during the rainy season.

**3. CONSTRUCTION PLANNING**

The quantum of work involved in the dam and other structures was huge and had to be completed in a time-bound manner, with an effective method of river diversion by constructing a diversion tunnel and a cofferdam.

Excavation, production, and placing of concrete had to be meticulously planned. As the work had to be carried out on both the banks, it was decided to use Dx-700, DQ-500, and commando drilling rigs in combination with ROC's, boomers, PC-200, PC-300/350/380 excavators, and 25T tippers for carrying out 2,200,000 m<sup>3</sup> of excavation. The entire establishment, including the crushing plant, batching plants, and tower cranes, was planned to be set up on the left bank of the dam site.

The crushing plants, with capacities of 150 tons/hour and 100 tons/hour inclusive of primary, secondary, and tertiary crushers and sand units for producing up to 2,000 m<sup>3</sup>/day, were established to meet the maximum concrete requirement on the left bank. For concrete production, two 120 m<sup>3</sup>/hour batching plants are planned. One is already operational, and the other will be established in a few months.

For transporting and placing the concrete, it was initially decided to use transit mixers with chute arrangements on both banks and to use BP 4000 concrete pumps where necessary. For the main concrete works, Shirke Potain tower cranes (2 units), with 3 m<sup>3</sup> buckets were mobilized to handle the main concrete of the main dam-blocks. In the coming days, as the volume of concrete increases, it is also planned to place a Rotek crane or Creter crane with conveyor arrangements with a boom length of 100 meters.

**4. DIVERSION WORKS**

The river diversion methodology adopted for the Vishnugad-Pipalkoti Hydro Electric Project was a meticulously planned and executed process involving multiple stages. Each stage addressed specific challenges associated with diverting the river and preparing the construction site for the main dam works. By implementing advanced techniques and using modern equipment, the project team successfully managed to create a stable and secure environment for constructing the concrete gravity

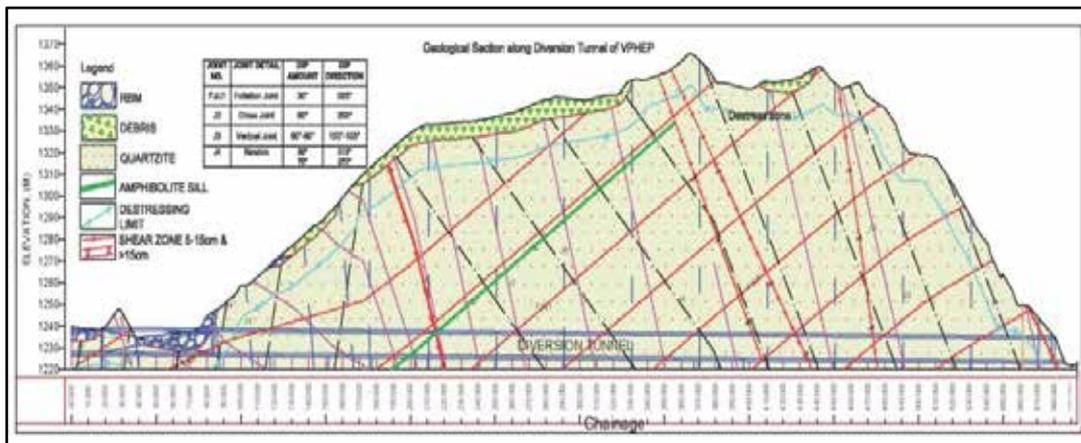


Fig. 3 : Geological section along Diversion Tunnel



### Stage 2 – Diversion Tunnel Heading Benching Works:

The next stage involved the excavation of the diversion tunnel, using the heading and benching method. Excavation of a total length of 497 meters was successfully completed, along with a 65-meter cut and cover portion. This process prepared the site for subsequent concrete works. Stable benching having been provided, stepped surfaces that facilitated safer and more efficient excavation and supported the tunnel structure during construction. This stage also included the initial lining and stabilization of the tunnel walls.

- **Concrete Work Scope:** Detailed planning and execution of the concrete works was critical for the integrity of the diversion tunnel. This included designing the concrete mix, scheduling pours, and ensuring the quality of materials used.
- **Sequence of Concrete Adopted for Diversion Tunnel:** A systematic approach was employed for the concrete pouring sequence. This ensured structural integrity and uniform setting of the concrete. Sequential pouring minimized the risk of cracks and structural weaknesses, supporting a strong and durable tunnel structure.
- **Formwork Adopted for Concreting:** Appropriate formwork was utilized to shape and support the concrete until it got set properly. This involved the use of Hydraulic tunnel lining gantry shutters mounted on a traveller arrangement, ensuring precise shaping and alignment of the concrete sections. This method guarantees a high-quality finish and durability. The steps involved in the concrete lining process are as follows:

**Kerb Concrete:** Concrete berms were laid on both sides of the tunnel up to the required level to accommodate the installation of the rail line for the movement of the tunnel lining-gantry.

**Overt Concrete:** Following the completion of the kerb concrete, the tunnel lining gantry was installed. Concrete was then placed behind the overt shutters to

cast the top curved portion of the tunnel, completing the concrete up to the kerb top at both the ends.

**Invert Concrete:** After completing the overt concrete along the entire tunnel stretch, final concrete was placed in the bottom portion of the tunnel between both kerbs, adhering to the specifications outlined in the GFC Drawing. (Fig. 6)

### Stage 3 – Left Bank of Diversion-Tunnel Inlet Cut and Cover Protection Work:

Excavation and protection work on the left bank was undertaken to ensure stability and prevent erosion. This involved cutting into the bank to create space for the tunnel inlet and covering exposed areas with protective layers (Fig. 6). Measures included:

- Installing retaining walls and barriers to prevent soil erosion.
- Using geotextiles and other erosion control materials.
- Implementing drainage solutions to manage surface water and reduce erosion risks.

### Stage 4 – Dyke Construction:

A dyke was constructed to control water flow and protect the construction site. The dyke acted as a barrier, diverting water away from the excavation areas and maintaining a dry and stable working environment. This stage involved:

- Designing the dyke to withstand expected water pressures.
- Using materials like earth, rock, and concrete to build the dyke.
- Ensuring that the dyke was properly sealed to prevent leaks.

### Stage 5 – Cofferdam Construction Upstream Side:

Constructing a coffer dam on the upstream side was essential for diverting water away from the construction area. This temporary dam allowed the main construction site to remain dry, enabling uninterrupted work on the dam foundation and other critical structures. Key activities involved: Planning the coffer dam location and design to

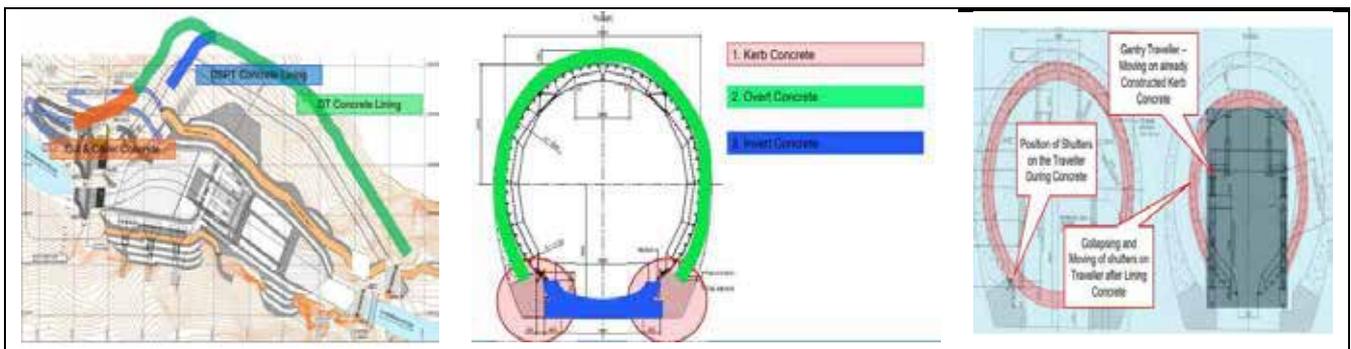


Fig. 6 : Diversion tunnel Concreting works and sequence of Concrete adopted

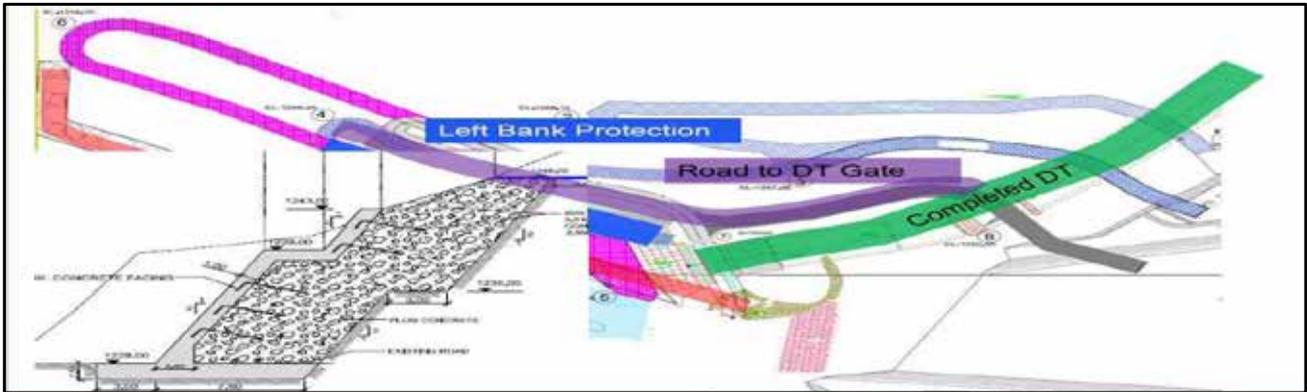


Fig. 7 : Left Bank of Diversion Tunnel Inlet Cut and Cover Protection Work

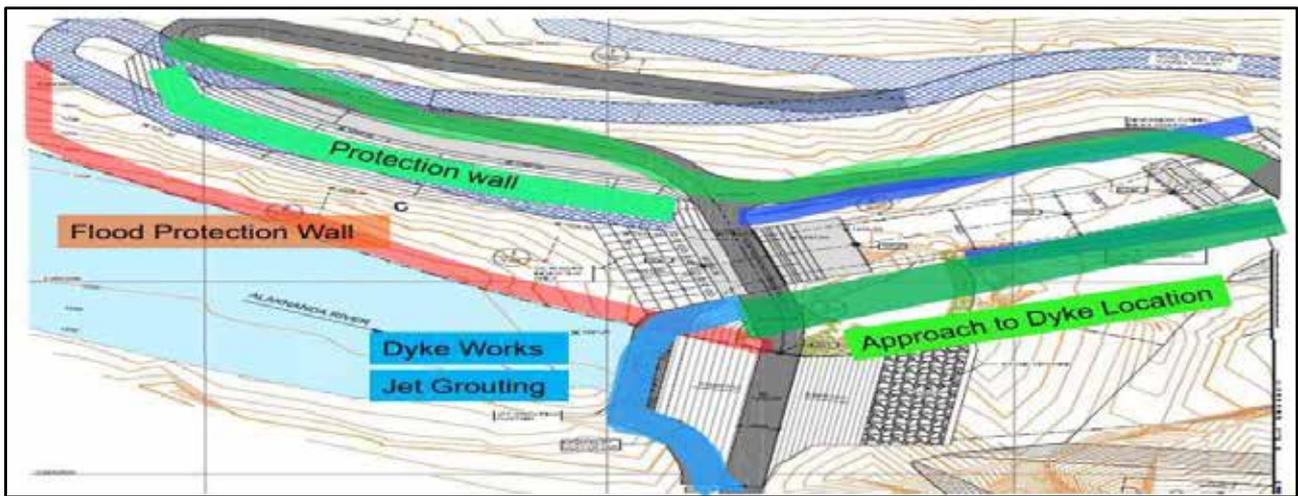


Fig. 8 : Showing Dyce construction plan and approach

effectively divert the water away. Using sheet piles, earth, and rockfill materials to construct the dam. Monitoring and

maintaining the coffer dam to ensure its effectiveness throughout the construction period. (Fig. 9)

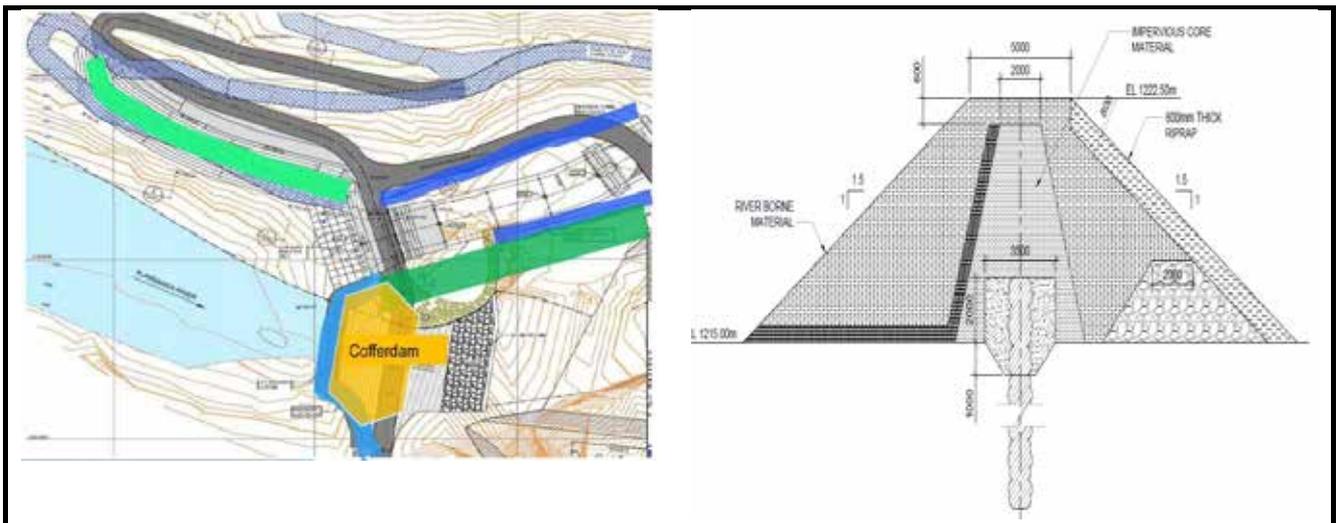


Figure 9 : showing Upstream Cofferdam location and Section

### Stage 6 – Cofferd Dam Construction Downstream Side:

A coffer dam was also constructed on the downstream side to manage water flow and create a dry work environment. This ensured that water from the upstream side did not flood the construction site. Activities involved:

- Extending the coffer dam to encompass the downstream area.
- Reinforcing the dam to resist potential water pressure from both upstream and downstream flows.
- Implementing additional drainage solutions to manage any seepage or overflow.

The excavated muck was progressively dozed off from the respective berm during excavation, starting from EL 1346.4 m and continuing until the abutment cutting reached EL 1290 m. With the diversion completed and the river dry, the muck accumulating from the right bank excavation was disposed of in the riverbed portion. The disposed muck was piled along the riverbed at EL 1218 m, specifically in the downstream (d/s) cofferdam location. Subsequently, a temporary access road was constructed to facilitate the removal of piled muck, with its alignment crossing the proposed cofferdam portion. Advance construction of the downstream cofferdam adjacent to the right abutment was completed prior to the commencement of right bank excavation, ensuring that the necessary infrastructure for access road construction was in place. (Fig. 10)

The Vishnugad-Pipalkoti Hydro Electric Project (VPHEP) exemplifies a sophisticated and methodically executed approach to river diversion, necessary for constructing a concrete gravity dam in a challenging geographical and environmental setting. The adoption of the diversion cum spill tunnel method is a pioneering solution, effectively addressing the high flood situations that are prevalent

in the region. This unique method not only ensured the safety and integrity of the construction site but also set a precedent for future hydroelectric projects facing similar challenges.

The project's success was underpinned through the deployment of the latest techniques and the most modern equipment, enabling the working team to navigate and overcome a variety of problems. These challenges included the difficult geology of the remote project location and the impact of natural calamities such as the cloud bursts of 2017 and 2021. The meticulous planning and execution progress from flood protection to the construction of coffer dams ensured that the site remained secure and stable, allowing space for uninterrupted progress.

## 5. CONSTRUCTION OF MAIN DAM

Upon the completion of the river diversion works, excavation of the dam's main body area was started on both the left and right banks. For the left bank, an approach road was developed from EL 1288.00 to EL 1270.00, facilitating easy access and movement of construction materials and equipment.

The right bank, however, posed additional challenges due to the lack of an existing approach. To address this, an Adit was excavated to Intake-3, with a length of 205.26 meters, opening at EL 1288.00. From this Adit, excavation began at EL 1357.00, with an approach road drawn, using excavators to navigate the steep mountain terrain.

### 5.1 Salient features of the Dam Overflow and Non-Overflow section

The Vishnugad-Pipalkoti Hydro Electric Project (VPHEP) Dam is a Concrete Gravity type structure, designed to address the region's geographical and hydrological

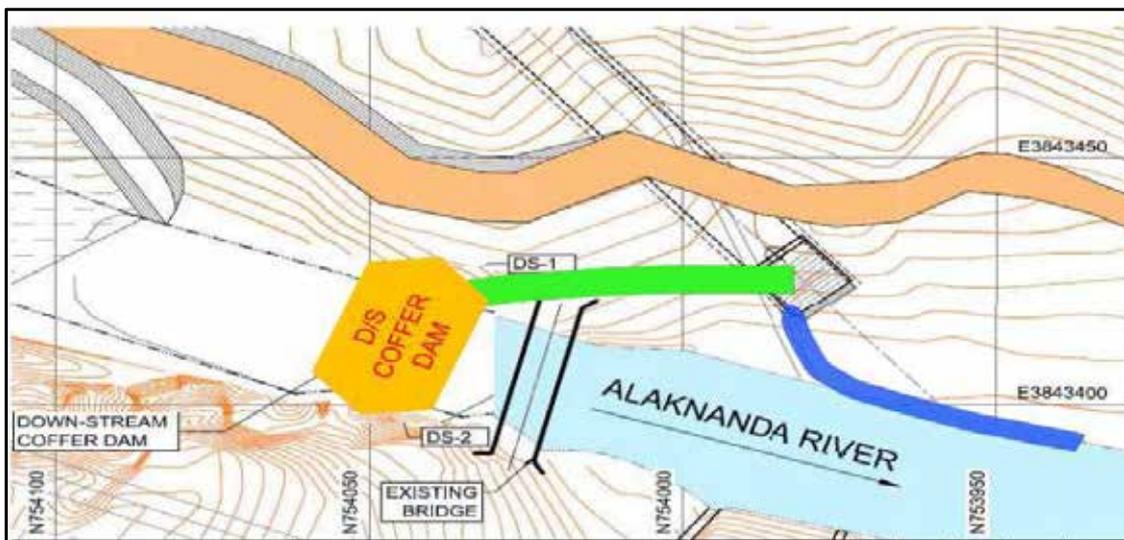


Fig. 10 : showing Downstream Cofferd dam location

challenges. The deepest foundation level of the dam is at EL. 1205m, with the gantry bridge top reaching EL. 1270m, and the crest level at EL. 1233m. The dam stands 65 meters high, emphasizing its substantial scale and capacity.

The overflow section of the dam consists of five sections divided into three blocks each (Blocks 2 to 4). Block B2 measures 26.5 meters in length and 71.5 meters in width, Block B3 is 26.5 meters long and 74.75 meters wide, and Block B4 is 14.0 meters long and 74.75 meters wide. The initial level of the foundation gallery is set at EL. 1207m, with dimensions of 2.0 meters in width and 2.5 meters in height, ensuring adequate support and stability for the structure.

In the non-overflow section, there are two blocks (Blocks 1 and 5). Block B1 measures 16.55 meters in length and 56 meters in width, whereas Block B5 is 15.0 meters long and 56 meters wide. The foundation level for these blocks is set at EL. 1218m, and the top level reaches EL. 1269.5m.

These detailed technical specifications and structural elements of the VPHEP dam illustrate the project's robust design and engineering, demonstrating its capability to effectively manage the region's demanding environmental conditions.

## 5.2 Dam Excavation

The right bank and left bank of the dam excavation involved a total of 9.0 lakh cubic meters of excavation, out of which 7.6 lakh cubic meters have been completed, and 1.4 lakh cubic meters remain in the riverbed area of the overflow blocks. The excavation sequence involves cutting benches for a 108-meter-high section from EL 1346.9 m to EL 1238 m, with bench lengths varying from 70 m to 180 m. Two 6-meter D-shaped Adit tunnels, 205.26 m and 150 m long, provided accesses, exiting at

EL 1270 m and EL 1290 m. A temporary access road was built from the EL 1290 m Adit tunnel to EL 1342 m (520 m), and another road was constructed from the EL 1270 m Adit tunnel to the intake top once excavation reached EL 1270 m, giving the road a permanent status.

### Stage 1 – Access Road construction from EL 1290.0 m to EL 1342.0 m for 520 m length

The construction of the access road followed the alignment sketch in the GFC drawing and methodology adopted for construction, ensuring the rock stability through an overhang cutting approach and maintaining required slopes between parallel road alignments at different levels. The hard rock geology of the right bank demanded no need for rock support measures like rock bolts and shotcrete. The temporary road facilitated the excavation and bench lowering from EL 1346.9 to EL 1290 m. The 4.5-meter-wide road, built at a gradient of 1 vertical to 10 horizontals (1V:10H), included site clearance and excavation of an overburden and hard rock, the latter done through drill and blast using hydraulic surface drill machines DC 301. Excavated muck was cleared by wheel loader and hydraulic excavator PC 200, temporarily dozed off to the riverbed level, then transported to a dumping area. As excavation progressed at upper stretches, muck deposits on previously completed middle and lower stretches were cleared by loader or dozer. (Figure 11)

### Stage 2 works –Excavation and rock support works from EL 1346.9 m to EL 1342.0 m

The trace path was excavated up to EL 1346.9m, the top level of the right bank portion. Stage 2 excavation, 24 meters downstream of the dam axis, involved site clearance, overburden removal, and hard rock excavation by drill and blast using hydraulic surface drill machines DC 301/DQ500. Overburden was removed with hydraulic excavators, and a 20-meter-long, 4.5-meter-wide access road stretch was created per cycle. Excavated muck was



Fig. 11 : Showing access road by overhang cutting approach (For Presentation Purpose only)

handled by wheel loaders/hydraulic excavators PC 200, temporarily dozed to the riverbed, then transported to a dumping area. While excavation progressed in the upper stretch, muck deposits on middle and lower stretches were cleared by loader or dozer. Post-excavation, rock support work, including rock bolts, shotcrete, and chain-link, were subsequently undertaken.

**Stage 3 works Excavation and rock support works from EL 1342.0 to berm at EL 1306.0m**

After completing stage 2 works, including clearing the access road above EL 1342 m, bench excavation was undertaken. Stage 3 excavation followed the same process as Stage 2. A catch drain, measuring 0.3m x

0.3m was constructed once excavation reached EL 1306m. (Figure 12)

**Stage 4, 5, 6 & 7: - Excavation works from EL 1306.00m to EL 1238.00m**

The excavation followed the sequence mentioned for Stage 3, aligning with the process described in Stage 2. Excavated muck below EL 1288 m was disposed of by lifting it from the bench location and transporting through dumpers. Catch drains of 0.3 m x 0.3 m were constructed at EL 1288, EL 1270, and EL 1238 m across width of the bench. With this, the excavation up to the riverbed level was completed, and the initial foundation concrete works were initiated. (Figure 13 and 14)

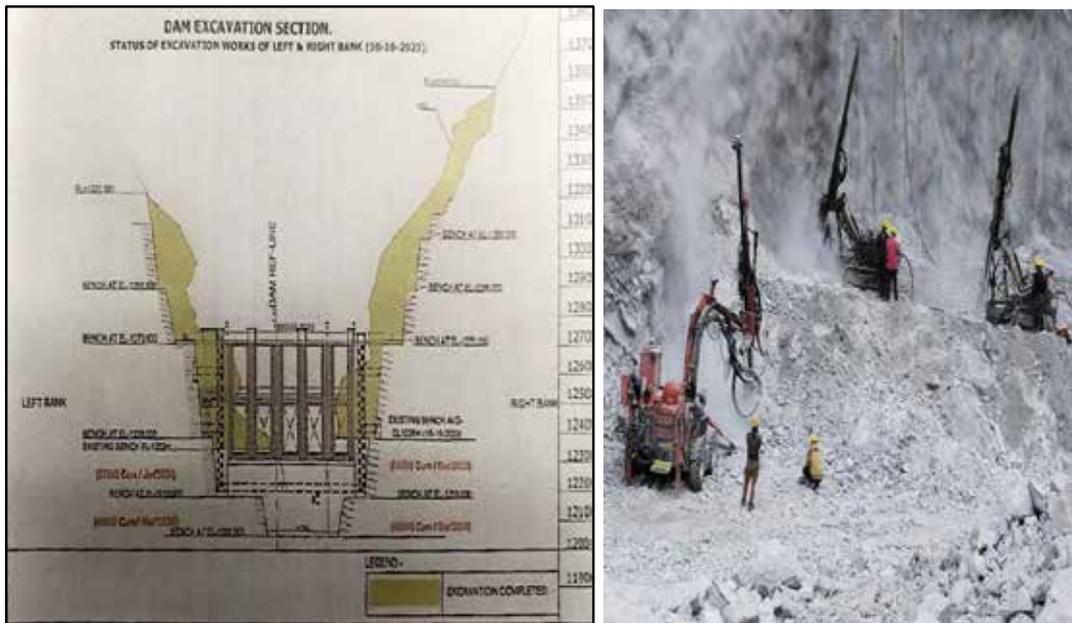


Fig. 12 : Showing excavation steps from El 1342 m to El 1238 m



Fig. 13 : Right bank dam excavation view



Fig. 14 : Left Bank Dam Excavation View

### 5.3 Foundation Concrete

Upon completion of excavation up to the required level, initial foundation concrete shall be placed. Since the concreting work is in the initial stage, the construction of the initial layers of reinforced concrete foundation is currently in progress, as depicted in the Figure 15 and 16.

### 6. SELECTION PLANNING AND LAYOUT OF EQUIPMENT'S

Selection of equipment's is to be carried out for the main activities, i.e., (1) Excavation (2) Stone quarry/ Excavated muck (3) Transportation (4) Crushing of aggregates (5) Collection and transportation of sand (6) Cooling of concrete (7) Mixing and batching of concrete (8) Placement of concrete.

The selection of equipment was based on parameters such as capacity, suitability, actual requirements, and compatibility with other plants in the series. In projects like these, progress depends heavily on the interconnected functioning of equipment in the series, and any weaker

link can hinder overall progress. Therefore, the success mantra is 'right capacity of equipment at the right location.

### 6.1 Quarrying of Stone/Excavated boulders and Transportation

Control and management of raw materials are central to dam construction. The completion of VPHEP Dam concreting was planned with a peak pouring quantity of 25,000 m<sup>3</sup> per month. Excavated boulders were planned to be utilized, with quarries available approximately 4 km from the dam site's crushing plant. Around 1,000 m<sup>3</sup> of serviceable boulders were to be quarried, excavated, and transported to the crusher plant dumping yard every day. Serviceable stones, with a maximum size of 500 mm, were produced from the blasting. The boulders were loaded into dumpers and transported directly to the crushing plant.

### 6.2 Crushing of Aggregates

Crushing plant of 150T/hour capacity was installed to produce required quantity of aggregate. The sizes required were 150mm, 80mm, 40mm and 20mm down. (Figure 17)



Fig. 15 : Shows initial Foundation concrete placing L/ bank



Fig. 16 : Shows initial foundation concrete at R/ bank



Fig. 17 : Shows the view of 150T/hour capacity operational crushing plant

Crushing plant was operated for an average 14 to 16 hours per day and the remaining 8 hours were used for maintenance of the plants. Sequential operation of plant is drawn in Figure 18 and 19.

### 7. DIFFICULTIES IN CONSTRUCTION AND INNOVATIVE SOLUTION ADOPTED

During construction, a battalion of difficulties surfaced and confronted the working team, which eventually were collectively sorted out through close coordination among clients, contractors, consultants, and local administration. Some of these difficulties are highlighted below:

#### 7.1 Fault and sinking zones encountered in left bank and along the centre line of dam

A fault zone along the centreline was encountered at both the banks, which was carefully handled by installing

props. Cladding concrete was also applied to some portions to restore the slope. As a result, the excavation work on both the banks faced significant challenges at one point. To consolidate the area, various SD anchors were provided to stabilize the slope, with the shotcreting events. This decision led to a turnaround, allowing us to complete the excavation on time.

On the left bank, upstream of the centreline, we encountered a sinking zone which resulted in the washout of the left bank approach, severely hampering vehicular movement and service support activities. Proper drains were constructed, and retaining walls followed by gabion work were implemented to strengthen the area. The decision to install vertical piles provided a permanent solution to this problem and successfully addressed the issue. With this approach, we were able to overcome the problem.

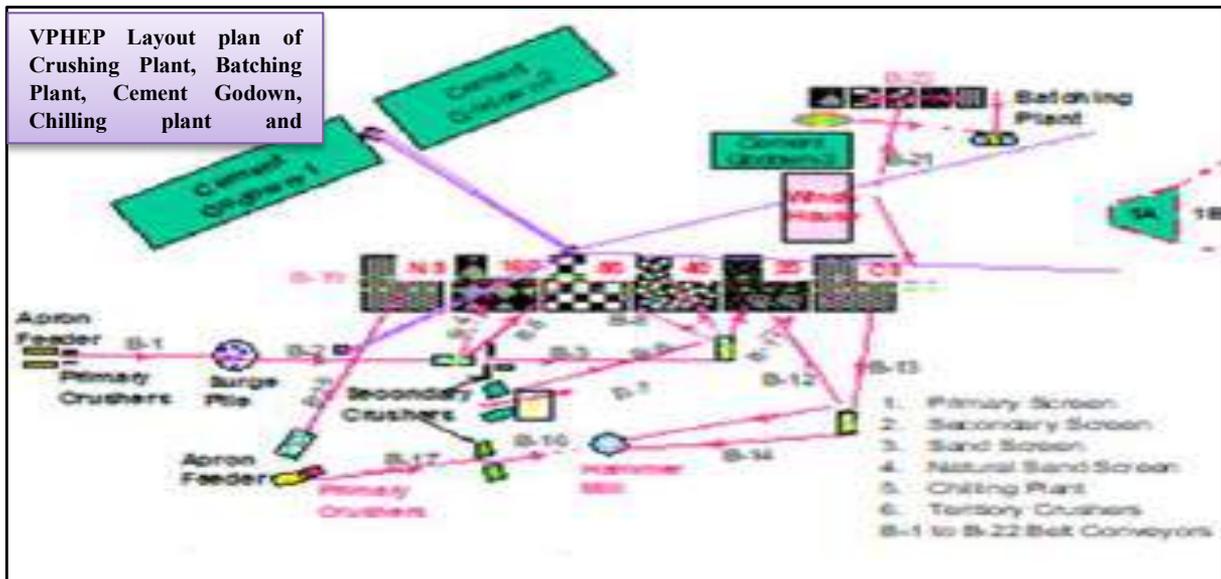


Fig. 18 : Sketch showing crushing plant, batching plant, cement go down and Tower Crane details

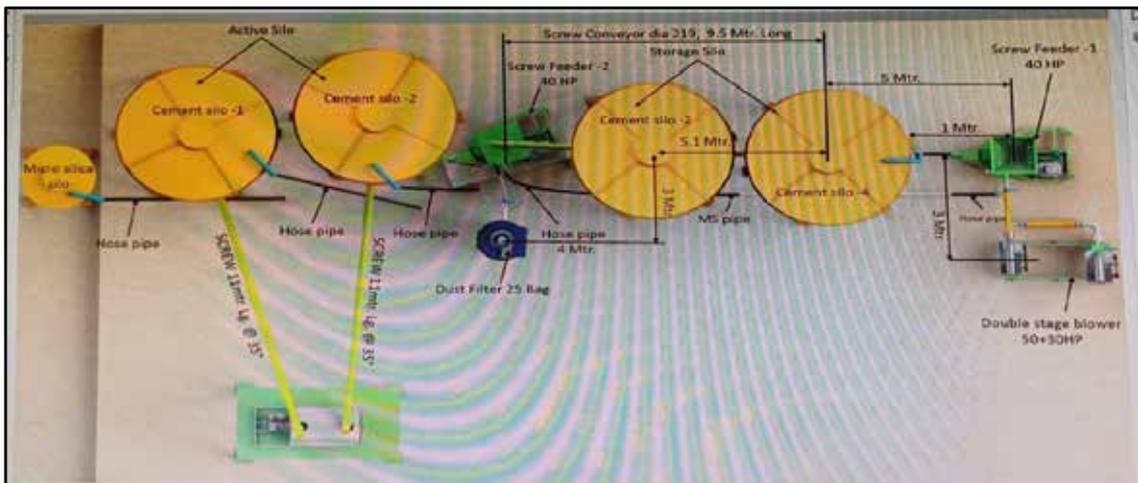


Fig. 19 : Sketch showing 120 Cum/hr. batching plant layout

## 7.2 Project Roads

The project is linked through the 240 km long Rishikesh-Helong National Highway up to Joshimath. This highway is severely affected by the vagaries of the winters and rains, often permitting only one-way traffic. It is further snarled due to an ongoing four-lane road widening for over four months a year. Consequently, transportation of construction materials, diesel, and other essential supplies is heavily disrupted, eventually escalating costs. Furthermore, the project approach roads are prone to landslides, frequently blocked by the falling slope debris. Maintenance is also challenging as anything done is quickly undone by the intermittent interference of road widening project.

Initially, heavy equipment was mobilized to the site via Tehri, as most bridges needed strengthening and could not support loads over 15 tons. Later, although proper bridges were constructed by BRO/NHIDCL for 70R loading, but this process also caused considerable work delays. During monsoons, roads were washed out and blocked by landslides, exacerbated by sinking stretches detached from mountain slopes. Poor road conditions not only delayed work significantly but also led to accidents, disrupting the supply chain for months together.

Efforts, equipment, and manpower were mobilized to restore operations. Despite roadblocks, the steep gradients and sharp bends limited our transport to six-wheel vehicles with restricted loads. The rainy season posed significant challenges, making life difficult and our own survival a daily struggle.

## 7.3 Muck Management and non-availability of Dumping yard

The disposal of excavated material or spoils was a major activity during the construction of the Diversion tunnel and dam excavation. Dumping this material into nearby water bodies can increase water turbidity, adversely affecting aquatic flora and fauna. Muck dumping yards are crucial facilities for the success of any dam and underground project. Therefore, a separate dumping yard was required at each location to accommodate the large quantity of excavated tunnel muck. The area's undulating terrain and steep slopes limited available land for disposal, compounded by the absence of approach roads at some locations.

Over time, systematic development of a designated dumping yard near the dam site included constructing gabion walls, increasing capacity from 6.5 lakh cubic meters to 9 lakh cubic meters. Negotiations to lease nearby land for dumping were unsuccessful due to excessive cost demands from locals. Collaborative efforts with clients and district administration were put together and we finally succeeded in securing land near Pagal

Nallh for dumping. Steeper locations were stabilized with benching, base drainage, and surface protection against erosion.

Excavated material was tested at reputed labs for reutilization as coarse and fine aggregates. Leftover material was repurposed for developing job facilities, playgrounds, and other project infrastructure.

## 7.4 Nonavailability of Area for Infrastructure

There was no available space for infrastructure at the site. Benches were constructed on the hills using dozers, and slopes were protected by gabions and shotcrete. Foundations were prepared at various work fronts for installing batching plants, crushing plants, compressors, transformers, etc. Significant additional efforts were still needed for the initial mobilization.

## 7.5 Natural disaster due to cloud burst and glacier breaking and flash flood

During construction upstream in the higher reaches of the project, part of a glacier broke due to a sudden cloud burst, causing a significant accumulation of water, boulders, and slushy material in the Dauliganga River a tributary of the mighty Alaknanda River. This led to a rapid rise in water levels, reaching up to 20 meters, and the flow began towards Vishnuprayag and our project site. Vishnugad Tapovan Project sustained considerable damage, while at our project site, water surged 5 meters above the upstream coffer dam, resulting in the accumulation of silt and slush at the dam foundation area. Thanks to timely information, all equipment and manpower were safely relocated to secure locations. Sludge pumps were deployed to clear the slush, and excavators and tippers were used to remove debris. A decision was made to raise the height of the coffer dam by 5 meters, and work commenced immediately, completing within the stipulated deadline. (Figure 20)

## 7.6 Problem due to local hostile unions and local land owners

A horde of problems were faced created by the local hostile unions universally pressing for their unreasonable demands and also because of the ever-increasing greed of and resultant interference of the local landowners who have signed up their land for the project. Local unions were demanding money salary increment and various other facilities outside the norms established in labour law. They frequently stopped the construction work to put pressure on the management. On the other hand, local land owners were demanding higher compensation, petty work-contracts, and employment. Totally unskilled, they wanted jobs and contracts. This resulted in sheer wastage of time and money; because if under duress and client's insistence any job was work given to them, they could never perform.



**Fig. 20** : Shows the view of raising of coffer dam height by 5m

Finally, to streamline the work and to adhere to the strict timeline set by the Power Ministry administrative action had to be initiated against the hostile element and they were removed from the site by deploying the CISF in the project area. Only then the work restarted started in full swing and now has been reported progressing very well. Hopefully the project will be completed on time.

### **7.7 Problem in supporting the top ledge during excavation at right bank**

Initially, it was challenging to transport equipment to the top bench of the right bank, we utilized jackhammers with pusher legs for blasting and rock bolting. Progress was slow until we employed a commando vertical drilling rig and ROC to construct a road to the top and conduct effective blasting and rock bolting on the first bench. Initially, we used a dry shotcrete machine but could only manage 16 cubic meters of shotcrete in three months. After extensive brainstorming with the team and clients, we transitioned to directly pumping shotcrete to heights of 100 meters using a Putzmeister small wet shotcrete machine equipped with a robotic arm and nozzle. With this innovation, we were able to achieve 16 cubic meters of shotcrete per hour. This breakthrough significantly streamlined excavation work, allowing us to complete the excavation benches smoothly thereafter.

## **8. HEALTH AND SAFETY IMPLEMENTATION**

To ensure the safety of the personnel at our mega project site, a dedicated health and safety department was established with a team of health experts and medical staff. Regular awareness programs were conducted to educate our team in work safety, PPE importance,

project activities, hazard identification, mitigation measures, safe procedures, basic safety rules, fire protection, accident prevention, emergency systems, and motivational training through safety presentations. Visitors underwent a comprehensive induction program before accessing the site. Given the inherent hazards of Dam operations, stringent precautions were taken during excavation: reinforcement, cableway and tower crane operations, and block concreting. Our Safety Management Plan was rigorously followed, with operators and support staff wearing appropriate PPE for working at heights. Excavation profiles were meticulously shaped and supported with designed rock methods for safety. Night work areas were well-lit, and warning signals were prominently displayed at all approaches. Blasting operations were closely monitored for rock stability, and thorough checks were conducted before drilling resumed to clear any debris or unexploded charges. Handling, storage, and use of explosives we adhered to strict protocols to minimize risks. Pumps were operated within safe limits to maintain system integrity and worker safety. Additionally, a well-equipped first-aid post with qualified medical staff and emergency facilities, including ambulance services, ensured prompt medical assistance. Liaison with nearby hospitals ensured immediate access to additional medical resources if needed.

## **9. CONCLUSION**

The Vishnugad Pipalkoti HE Project exemplifies significant advancements in hydroelectric power generation through innovation and adaptive engineering. The project highlights the successful integration of modern technology and sophisticated construction techniques in a geologically

complex environment. The challenges accepted during the construction of the project were working at remotest location where communication at local and national level was the priority. For the purpose, a comprehensive internet communication system was installed. The sets were used not only for telephonic communications but also for e communications like fax and email. Wireless sets were used for internal communications and ever ready vehicles for road communications. A dedicated team of engineers and workers was put together which was committed to working day and night and succeeded in completing the work on time. As a result, despite challenges such as natural calamities like cloud bursts in 2017 and 2021, the engineering team demonstrated resilience and adaptability to overcome the situation. The management of material needed and supplied was put in order, so that the work could not stop even for an hour. The latest technical know-how was used to maximize the construction speed and minimize the cost. Every department worked in coordination with other departments and took care of its own work. One of the secrets of the success was high priority maintenance of key plants like the crushing plants, batching plants, and Tower Cranes. And hovering like grace over the entire project world was the tender care we showered upon the employee's welfare. Treating each employee like a member of the project family, they were provided with

medical care, bonus, insurance, and financial support for any eventuality rising in their families. The following is the crux of experiences and experiments done and derived through this project.

- Proper planning and accurate layout.
- Simultaneous execution of jobs.
- Availability of raw material.
- Timely construction of Adit to access the right bank of the dam due to the non-availability of access road.
- A scientific human resource management and their safety from work hazards.
- Robust liaison with the departments of the district and state administration

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

*Sunday Adelaja*

# 92<sup>nd</sup> ICOLD Annual Meeting & International Symposium 'Dams for People, Water, Environment & Development'

September 29 to October 3, 2024, New Delhi



*View of the dais during inaugural session (L-R) Mr. Li Aili, CHINCOLD; Mr. A.K. Dinkar, General Secretary, INCOLD; Mr. R.K. Agrawal, CMD, WAPCOS & Vice President INCOLD; Mr. V.K. Dewangan, IAS, CMD, RECL; Mr. Abhay Kumar, IAS, Additional Chief Secretary, WRD Rajasthan; Mr. Ghanshyam Prasad, Chairperson, CEA and Ex Officio Secretary to Gov; Ms. Debashree Mukherjee, Secretary, MoJS; Mr. M. Lino, President of ICOLD; Mr. R.K. Vishnoi, President, INCOLD and CMD, THDCL; Mr. R.K. Chaudhary, CMD, NHPC; Mr. Manoj Tripathi, Chairman, BBMB; Mr. D.K. Sharma, Hon. Vice President (Asia), ICOLD & Chairman, HPERC and Dr. Marco Arcieri, President, ICID*

### Brief Report

The International Commission on Large Dams (ICOLD) is a prominent non-governmental international organization that serves as a vital forum for the exchange of knowledge and experience in dam engineering. Founded in 1928 and headquartered at Paris, ICOLD plays a crucial role in setting standards and guidelines to ensure that dams are constructed and operated safely, efficiently, and sustainably while also being socially equitable. With membership comprising National Committees from 106 countries, the Indian National Committee on Large Dams (INCOLD) represents India.

India is credited with having a long history of human intervention in the management of water due to its typical climatic conditions of intense monsoons followed by prolonged droughts. Irrigation of cultivable land has been practiced in India for many centuries. Ancient scriptures give insight into the traditional water storage and conservation systems prevailing in the past. Historical evidence reveals that dam building works in this subcontinent began about five thousand years ago, in 3rd millennium BC. The Kallanai dam (2nd Century AD) is considered to be the fourth oldest dam in the world which is still in use.

Medieval planners and hydraulic engineers had benefit of the knowledge system already established in the field of water harvesting. Traditional dams and big earthen embankments appear to have been designed with knowledge of hydraulics. Earthen as well as masonry dams were constructed in very large numbers from 2nd century to 17th century AD. Many of these are functioning even at present time. The advances in design of high masonry dams brought to this country by the British engineers had added to the construction technology and boosted dam development. During the Colonial period beginning 1800 AD, the British played a major role in numerous dam constructions. As construction of dams continued with increasing water needs, development in the design and types of these dams evolved. Large dams with storage reservoirs began to appear especially after the introduction of concrete in construction.

From the beginning in the Post-Independence time 1947, numerous dams of various types and sizes have been built for the purpose of irrigation, water supply, hydropower development, flood control and for catering to other multi-purpose needs. Remarkable development has been made in dam building during the last several decades. A

## Glimpses of the Opening Session of ICOLD 2024 Symposium



*Ms. Debashree Mukherjee, Secretary, MoJS, (Chief Guest), lighting the lamp during inaugural session*





**Release of Publication**

number of world-class large multi-purpose dams with storage facilities, and hydropower projects are being built in this nation and some of the dams are considered globally outstanding, based on their merits. Moreover, safety of the dams being important, the Government of India has taken due steps in this direction, including rehabilitation of the old structures as well.

As per the records of the National Register of Dams India has 6138 large dams in operation today, with another 143 under construction. As the demand for water is still steadily increasing with the economic and demographic growth, India continues to construct world-class large dams, involving state-of-the-art tools and technology, keeping in consideration the safety and sustainability concerns. Number of large multipurpose dams, including mega hydroelectric projects are being built in India, and in future, in meeting growing needs and mitigating the adversities of climate changes, the legacy of building world-class large dams will continue.

Indian Committee on Large Dams (INCOLD), the National Chapter of the International Commission on Large Dams (ICOLD), housed in CBIP had been making attempts in the recent past to organize an international meet here in India under the banner of ICOLD which should provide a good opportunity to discuss the relevant issues with global experts who shall be participating in the event. The bid submitted by INCOLD was officially accepted and the ICOLD community agreed to organize the 92nd ICOLD Annual Meeting and International Symposium in India. Accordingly, the 92nd INCOLD Annual Meeting and International Symposium on “Dams for People, Water, Environment, and Development” in was held from September 27 to October 3, 2024, at Bharat Mandapam, New Delhi, India.

Key highlights of the event include:

- ICOLD Board Meetings
- ICOLD Technical Meetings, Workshops and Short Courses
- International Symposium on “Dams for People, Water, Environment, and Development,” consisting of Technical Session and Poster Session
- INCOLD Workshops including special session by DRIP, NDSA and World Bank
- Technical Exhibition
- Social events

### **International Symposium on “Dams for People, Water, Environment, and Development,”**

This symposium was organised to provide an opportunity to Indian dam engineering professionals and agencies to share their experiences, ideas and latest developments in new materials and construction technologies, advancement in investigation techniques, best engineering practices, dam safety issues etc. Besides opportunity to networking with the world renowned dam experts from different countries and global organizations involved in Dam Construction, management and operation and maintenance for mutual benefits.



The symposium was inaugurated on 1st October 2024 by Ms. Debashree Mukherjee, Secretary, MoJS, Department of Water Resources, River Development and Ganga Rejuvenation at Bharat Mandapam, New Delhi. While addressing the participants during inaugural session of the ICOLD symposium, Ms. Debashree Mukherjee, Secretary, MoJS mentioned that ICOLD Symposium on the theme “Dams for People, Water, Environment, and Development” is among the most important subjects to be dealt world over particularly in developing and under developed countries.

Optimum utilization of water is the need of the hour for fulfilling the future demands. Energy has also a major role to play for the overall development of the infrastructure including water resources sector.

World over we are witnessing the effects of climate change with heavy rainfall in areas which were hither to being considered drought prone and scarce rainfall otherwise considered flood prone. The climate change could have unpredictable consequences on the water regime. Various studies point towards its adverse impact on the hydrologic cycle that could result in the intensification of both temporal and spatial variations in precipitations.

Floods in one part of the country and droughts in other are a matter of concern. With the climatic change said to be playing its game these imbalances are likely to intensify. The adverse impacts of climate change on the ground water table, its quality are also a matter of concern.

Ms. Debashree Mukherjee congratulated all professionals involved for their hard work and recognized the efforts of INCOLD and CBIP in organizing the Symposium.



The dignitaries who addressed during the opening ceremony besides Secretary, MoJs are:

- Mr. Ghanshyam Prasad, Chairperson, CEA and Ex Officio Secretary to GoI highlighted that Dams are essential for irrigation, flood control, and hydropower generation, contributing significantly to our nation's growth. Together, let us explore innovative solutions and collaborative approaches that prioritize the well-being of our people and the health of our ecosystems.
- Mr. Abhay Kumar, IAS, Additional Chief Secretary, WRD Rajasthan addressed state-level initiatives and the importance of effective policy-making in water resource management.
- Mr. V.K. Dewangan, IAS, CMD, RECL discussed the challenges and opportunities in the renewable energy sector, particularly in relation to dam operations.
- Mr. D. K. Sharma, Hon. Vice President (Asia), ICOLD & Chairman, HPERC stressed the need for innovative technologies in dam safety and management.
- Mr. Manoj Tripathi, Chairman, BBMB shared insights on the importance of collective efforts in dam construction and maintenance for regional development.

- Mr. R.K. Chaudhary, CMD, NHPC highlighted the contributions of NHPC in dam development and its commitment to sustainable practices.
- Dr. Marco Arcieri, President, ICID discussed the interconnection between irrigation and dam management, advocating for integrated approaches to water resource management.
- Mr. M. Lino, President of ICOLD, emphasized the role of dams in sustainable development and their impact on communities and the environment
- Mr. R.K. Agrawal, CMD, WAPCOS & Vice President INCOLD discussed the vital role that dams play in sustainable development, water management, and environmental protection. He encourage everyone to share their insights and experiences during this symposium, as we work together to harness the potential of dam infrastructure for the benefit of our communities and the environment.
- Mr. R.K. Vishnoi, President of INCOLD, warmly welcomed the attendees and set the tone for the event, highlighting the importance of collaboration in addressing global water and environmental challenges.
- Mr. Li Aili from CHINCOLD also extended invitation to all the professionals for participating the 28th ICOLD Congress and 93rd Annual Meeting in 2025 in Chengdu at China.

During opening session following two important publications were also released:

1. Dam Development in India - From Ancient to Modern Time
2. A Pictorial Display of Dams in India

At the end of opening session Shri A.K. Dinkar, Secretary General, INCOLD and Secretary, CBIP proposed the Vote of thanks.

#### **Key Themes of the Symposium included:**

1. Dams and People
2. Integrated Reservoir Management (Basin Approach)
3. Dams and Climate Change Adaptation
4. Dams and Renewable Energy
5. Dam Safety Management and Engineering
6. Modern Technology in Dam Construction
7. Dam Rehabilitation and Improvement
8. Environmental and Social Aspects

From 80 countries, 353 full text of technical papers received from the national and international dam experts out of which 219 presentations were presented during the 35 technical sessions besides more than 33 presentations in the 13 workshops were organized on 2024, These presentations were made to exchange the experiences and latest development related to the design, performance, rehabilitation and environmental aspects of dams which would certainly add new dimensions to the body of knowledge on the subject. More than 1000 participants from 80 different countries participated in the deliberations of the event.

#### **Press Conference**

On October 1, 2024, a press conference was convened at Bharat Mandapam, attracting media representatives from leading newspapers. The press conference featured prominent speakers, including Mr. Frederic Corregge, Mr. Michel



*View of dais during press conference arranged on 1st October 2024*

de Vivo, Mr. M. Lino, and Professor Arun Kumar from IIT Roorkee, who addressed various key topics.

During the press conference, journalists engaged actively, posing various questions and seeking clarifications. The officers from ICOLD/INCOLD provided detailed responses, ensuring the inquiries were addressed satisfactorily.

The discussion underscored the commitment of ICOLD/INCOLD to transparency and collaboration with the media, fostering an informed dialogue on critical issues.

Apart from the Symposium, a Special Session on ‘Innovative Financing of Dam Projects for High Penetration of Renewable Energy’ was held besides following eight workshops were also organised in association of ICOLD international experts, National Dam Safety Authority, India (NDSA), Central Water Commission, India (CWC) & World Bank to update the knowledge of professionals working with Govt. as well as private agencies who are involved with the development of dam engineering:

**Date: 29.09.2024 (17:00 – 18:30 hrs)**

**Workshop - “World Declaration on the Role of Dam in the Energy Transition & Climate change”**

**Date: 01.10.2024 (09:00 – 17:00 hrs)**

**Workshop - “Derna & Bu Mansur Dam Failure - Libya”**

**Date: 01.10.2024 (15:30 – 17:00 hrs)**

**Workshop - “African Regional Initiative”**

**Date: 01.10.2024 (14:00 – 17:00 hrs)**

**Workshop - Dam Repair & Rehabilitation – Deciding, Design & Safety Criteria**

- Dam Break Analysis (DBA) and Emergency Action Plan (EAP), a Case Study-Driven approach with Government Processes Re-Engineering for Enhancement & Potential Improvement under Dam Rehabilitation and Improvement Program (DRIP) with compliances to the Dam Safety Act 2021 in India
- Earthquake Vulnerability & Risk
- Climate Change Response Strategies for Dam Authorities.
- Development of a Stilling Basin with Diverging Side Walls.
- Performance Evaluation, Safety Assessment, Cost-Benefit Analysis, Augmentation: Virtual Reality Platform & underwater Robotics Inspection

**2nd October, 2024**

**Workshop - Design of Tailing Dams for Closure**

Topics deliberated during workshop:

- Closure Fails - legacy closure issues
- Alternative Processing/reprocessing



*Short Course on “Surveillance and Monitoring for Tailings and Embankment Dams”, 27 – 28 September 2024 at CBIP, New Delhi*

- Tailings Reuse - what are realistic opportunities for reprocessing tailings
- Landform and cover considerations
- Assessing closure options - making informed decisions
- Landform Design - Building a landform from scratch

The second half of the workshop session (14:00 – 17:00 hrs.) organized by MIDAS. The following topics were deliberated during the workshop:

- Seismic analysis of a concrete gravity dam - hydrodynamic forces as Westergaard's added mass and sloshing fluid medium using Midas FEA-NX software
- Crack propagation in the dam under seismic loading using the concrete smeared crack model using Midas FEA-NX software

**Date: 02.10.2024 (09:00 – 13:00 hrs)**

### **Workshop - Risk Informed Dam Safety**

Topics deliberated during workshop:

- Dam Health Monitoring Dam Health Monitoring by Analysis & Interpretation of Dam Instrumentation Data Management.
- Cementitious grouting of Masonry dams.
- Dam Safety and Protocol for Enhancing Climate Resilience of Existing and New Dams.
- fragility analysis of concrete gravity dams
- Structural Health Monitoring Dams & Water Retaining Bodies under DRIP Project.

**Date: 02.10.2024 (09:00 – 13:00 hrs)**

### **Workshop – Application of Geosynthetics in Dam Engineering**

Topics deliberated during workshop:

- Repairs of dam components subjected to dynamic loads with application of geosynthetics.
- Geosynthetics Application in sediment management of Dam Reservoir and regulated rivers.
- Long-Term Performance of Polyethylene Geomembrane for Efficient Water Conservation

**Date: 03.10.2024 (09:00 – 17:00 hrs)**

### **Workshop - Seismic response Analysis of dam – Numerical Analysis**

Topics deliberated during workshop:

- (i) Seismic Design Criteria of Large Dams and Selection of Ground Motion parameters.
- (ii) Methods Of Seismic Analysis Of Large Concrete And Embankment Dams.



*Short Course on "Tailings Dam Breach Analysis", 3rd October 2024 at CBIP Conference Hall, New Delhi*

- (iii) Finite Element Modeling and Stress Analysis of Concrete Gravity Dams.
- (iv) Quantification of seismic wave scattering considering site-specific SPT borehole data-based
- (v) non-uniformity and seismic absorbing boundary conditions.
- (vi) Seismic Design of Dams including Embankments.
- (vii) Preparing Dam Foundation in Seismically Active Zone

**Date: 03.10.2024 (09:00 – 17:00 hrs)**

### **Workshop - Sedimentation Management in Reservoirs for Sustainable Development**

Topics deliberated during workshop:

- Spatial Interpolation of Sediment Yield Estimated from Reservoir Siltation Data of India
- Exploring the efficacy of Magnitude Frequency Analysis in managing reservoir sedimentation.
- Reservoir Sedimentation using Remote Sensing and GIS.

### **Workshop - Pumped Hydro Power Storage – The Need to Support High Penetration of Renewable Energy.**

Topics deliberated during workshop:

- Design and Engineering Considerations.
- Construction and Project Management.
- Integration of Pump Storage with Renewable Energy.
- Future Perspectives and Research Directions.
- Economic and Financial Analysis.

### **TECHNICAL EXHIBITION REPORT**

As part of the symposium, a dynamic Technical Exhibition was organized to showcase innovative technologies that address the challenges of 21st-century dam development. The exhibition officially opened on September 29, 2024, with a ceremonial ribbon-cutting led by Mr. R.K. Vishnoi, President, INCOLD, and Mr. M. Lino, President, ICOLD.

The inaugural ceremony was attended by distinguished dignitaries, including Mr. D.K. Sharma, Hon. Vice President (Asia), ICOLD and Chairman of HPERC; Mr. Fredric Correge; Mr. Michel de Vivo; and Shri A.K. Dinkar, Secretary General of INCOLD and Secretary of CBIP. During the ceremony, both Mr. Vishnoi and Mr. Lino delivered insightful addresses, emphasizing the importance of innovation in the dam sector.

Shri Vishan Dutt, Advisor to INCOLD, concluded the opening ceremony with a heartfelt Vote of Thanks, acknowledging the contributions of the dignitaries and participants.

The exhibition served as a central hub for the ICOLD symposium, featuring a multi-functional space where products and services pertinent to the dam community were prominently displayed.

With over 80 stalls (list attached), the exhibition showcased leading dam organizations presenting their latest innovations and services. Delegates had ample opportunities to explore the booths, facilitating valuable networking and collaboration among various agencies.

This exhibition not only highlighted advancements in dam technology but also fostered collaboration and knowledge exchange among industry professionals, reinforcing the symposium's goal of promoting progress in the field. It was a vital platform for showcasing the future of dam development and reinforcing the commitment to enhancing infrastructure resilience.

Apart from the above symposium, following workshops; short courses & other meetings in collaboration with ICOLD Technical Committees were also organised:

1. Short Course on "Surveillance and Monitoring for Tailings and Embankment Dams"; 27th – 28th September 2024 at CBIP Conference Hall, New Delhi
2. Workshop by Young Professional Forum; 29th September 2024 at Bharat Mandapam, ITPO, New Delhi
3. Young Professional Forum Meeting; 29th September 2024 at Bharat Mandapam, ITPO, New Delhi

# Technical Exhibition - ICOLD 2024 – Glimpses of Opening Session







4. Workshop on “World Declaration on the role of Dam in the Energy Transition & Climate Change”; 29th September 2024 at Bharat Mandapam, ITPO, New Delhi
5. ICOLD Technical Committee Meetings
6. Regional Club Meetings
7. European Club Network Event; 30th September 2024
8. Press Conference; 1st October 2024 at Bharat Mandapam, ITPO, New Delhi
9. INCOLD Workshop on “Dam Repair & Rehabilitation-Deciding Design & Safety Criteria” in collaboration with Central Water Commission/ DRIP, 1st October 2024 at Bharat Mandapam, ITPO, New Delhi
10. Workshop on “Derna & Bu Mansur Dam failure – Libya”
11. Workshop on “African Regional Initiative”
12. Francophone Delegate Meeting
13. Poster Session
14. INCOLD Workshop on “Application of Geosynthetics in Dam Engineering”; 2nd October 2024 at Bharat Mandapam, ITPO, New Delhi
15. INCOLD Workshop on “Risk Informed Dam Safety Management” in collaboration with National Dam Safety Authority (NDSA); 2nd October 2024 at Bharat Mandapam, ITPO, New Delhi
16. Workshop on “Bulletin 194-Tailings Dam Safety” by ICOLD Committee ‘L’
17. Short Course on “Tailings Dam Breach Analysis” by Canadian Dam Association; 3rd October 2024, Bharat Mandapam, ITPO, New Delhi
18. ICOLD General Assembly Meeting - 3rd October 2024, Bharat Mandapam, ITPO, New Delhi
19. On 30th September the Regional club meetings were also held. The meetings were organised to facilitate the exchange of knowledge and experience between the regional countries.

## **SOCIAL EVENTS**

The ICOLD Symposium featured a series of engaging social events designed to foster networking and cultural exchange among participants. Below is a summary of the events organized:

### **WELCOME RECEPTION**

Theme: A Symphony of Rhythm

Date: Sunday, September 29

Time: 19:30 - 22:00

The Welcome Reception kicked off the symposium with a vibrant atmosphere celebrating diverse rhythms. Participants enjoyed an evening filled with music, dance, and the opportunity to connect with fellow delegates in a relaxed setting.

### **CULTURAL EVENING**

Theme: Regal India

Date: Tuesday, October 1

Venue: Open Amphitheatre, Bharat Mandapam, New Delhi

The Cultural Evening showcased the rich heritage of India through captivating performances that highlighted its regal history. Attendees experienced traditional music and dance, immersing themselves in the cultural richness that defines India.

### **FAREWELL DINNER**

Theme: Bharat Rang – Colors of India

Date: Thursday, October 3

Time: 19:00 - 22:30

Venue: Exhibition Hall No. 14, Ground Floor, Bharat Mandapam, New Delhi

The Farewell Dinner concluded the symposium with a spectacular celebration of India's diversity. With vibrant decorations and a festive atmosphere, participants enjoyed a delightful dinner while reflecting on the insights gained throughout the event.

These social events provided valuable opportunities for networking, cultural appreciation, and memorable experiences among the participants of the ICOLD Symposium. We thank everyone who joined us and contributed to the success of these gatherings.

### **CLOSING CEREMONY**

The Closing ceremony Mr. M, Lino, President, ICOLD, in his address by congratulating INCOLD for providing such an excellent platform to all the experts on water resources around the world to share ideas and plan to the way forward on the theme 'Dams for People, Water, Environment, and Development'. He mentioned that dams are essential to every aspect of life; social equity, human health, ecosystem integrity and economic sustainability. He concluded his address that this event would have provided valuable food for thought for the participants and the deliberations on Key topics will certainly be indispensable for the global dam community.

The other dignitaries who addressed during the closing ceremony are Mr. Fedric, Secretary General, ICOLD.

Shri A.K. Dinkar, Secretary General, INCOLD, proposed Vote of Thanks to the Guest and other dignitaries as well as to the participants.

At the end the baton was handed over to CHINCOLD for organisation of next ICOLD Annual Meeting at China.

### **ICOLD TECHNICAL COMMITTEES ASSOCIATED :**

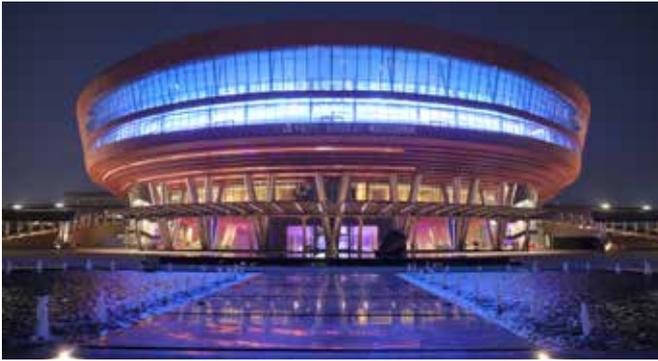
- Computational aspects of analysis and design of dams (2023-25)
- Seismic aspects of dam design (2023-26)

## Glimpses of Technical Session during ICOLD 2024





## Glimpses of Cultural Program



### Best Paper Award – In the Young Professionals Forum category

The Best Paper Award in the Young Professionals Forum category was presented to the following three papers during the 92nd ICOLD Annual Meeting and International Symposium:

1. Numerical Simulation of Fund Dam using Nor Sand Model by Dr. Sparsha Nagula; Dr. H. Liu Institute ; Dr. H.P. Jostad; Dr. L. Piciullo; Norwegian Geotechnical Institute, Oslo, Norway - This award is presented to : Dr. Sparsha Nagula; Norwegian Geotechnical Institute
2. Sediment Yield Modeling Using SWAT: Case of Aror Dam, Kenya by Epari Ritesh Patro, Water, Energy and Environmental Engineering Research Unit, University of Oulu, Finland Amit Gautam, Ph.D. Research Scholar (PT), Indian Institute of Technology, Delhi, New Delhi - This award is presented to : Mr. Amit Gautam, Ph.D. Research Scholar (PT), Indian Institute of Technology, New Delhi
3. Sustainable Sediment Management of Reservoirs using fully automated Dredges combined with Methane Gas Collectors” by Lara Gehrmann Hülskens Sediments, Wesel, Germany Thomas Gross Hülskens Sediments, Wesel, Germany - This award is presented to : Mrs. Lara Maria Gehrmann, Germany



- Hydraulics for dams (2021-25)
- Concrete dams (2021-24)
- Embankment dams (2023-27)
- Engineering activities with the planning process for waterresources projects (2014-25)
- Environment (2020-25)
- Dam safety (2021-24)
- Historical water structures (Water Heritage) (2021-24)
- Public safety around dams (2022-25)
- Sedimentation of reservoirs (2023-26)
- Integrated operation of hydropower stations and reservoirs (2023-27)
- Tailings dams & waste lagoons (2023-27)
- Levees (2018-24)
- Operation, maintenance and rehabilitation of dams (2023-26)
- Public awareness and education (2021-24)
- World register of dams and documentation (2021-24)
- Cemented material dams (2020-25)
- Dam surveillance (2023-24)
- Resettlement due to reservoirs (2021-24)
- Flood evaluation and dam safety (2020-24)
- Tropical residual soils (2023-26)
- Prospective and new challenges for dams and reservoirs in the 21st century (2023-27) (ad hoc committee)
- Dams and river basin management (2021-24)
- Hydro mechanical equipment (2023-26)
- Financial and advisory (ad hoc committee)

## Farewell Dinner



The baton was handed over to CHINCOLD for organisation of next ICOLD Annual Meeting at China.



- Climate change (2023-24)
- Capacity building and dams (2021-24)
- World Deceleration on the Role of Dam in the Energy Transition climate change (2023-25) (ad hoc committee)
- Gender Diversity and inclusion (2023-25) (ad hoc committee)
- Young Engineers
- Joint members for Committee E and M

## List of Exhibitors

COUNTRY	ORGANIZATION_NAME
UNITED STATES	GEOKON
ITALY	LSI LASTEM
INDIA	Dynasoure Concrete Treatment Pvt Ltd
JAPAN	Japan Commission on Large Dams
INDIA	Kaushiks International
INDIA	Carpi
FRANCE	HYDROPLUS
FRANCE	Soletanche Bachy - Freyssinet - Sixense
INDIA	Mapei
NEW ZEALAND	Seequent
UNITED STATES	Ballard Marine Construction
UNITED STATES	Hibbard Inshore, LLC
INDIA	Encardio-rite Electronics Pvt. Ltd.
JAPAN	Dam Safety Group
INDIA	Entura
SWITZERLAND	WALO International Ltd.
INDIA	Midas R&D Centre India Pvt. Ltd
INDIA	Bhakra Beas Management Board
GERMANY	Deutsches Talsperrenkommittee e.V. (DTK)
INDIA	Parsan Overseas Pvt. Ltd.
PHILIPPINES	SMEC
INDIA	Pan India Consultants Pvt. Ltd.
INDIA	Bauer Engineering India Pvt. Ltd.
UNITED STATES	Kinematics, Inc.
UNITED STATES	Willowstick Technologies, LLC
UNITED STATES	Campbell Scientific
CANADA	High Commission of Canada

COUNTRY	ORGANIZATION_NAME
CANADA	High Commission of Canada
UNITED STATES	CivilGEO, Inc.
INDIA	Signet Enerotech Pvt Ltd
DENMARK	Seisodin ApS
ITALY	TRE ALTAMIRA srl
INDIA	AVK Valves India Pvt. Ltd
Republic of Korea	KNCOLD
FRANCE	ICOLD
INDIA	Techfab India Industries Ltd.
SINGAPORE	Synspective Inc Japan
INDIA	NHPC
INDIA	THDC Ltd.
INDIA	NTPC Ltd.
INDIA	North Eastern Electric Power Corp. Ltd.
INDIA	SJVN Limited
INDIA	Greenko Group
INDIA	Damodar Valley Corporation
INDIA	Water Resources Department Govt. of Maharashtra
INDIA	Megaplast India Pvt. Ltd.
INDIA	GEO SOURCE
INDIA	AFRY India Pvt Limited
UNITED KINGDOM	Aqua-Media International Ltd
INDIA	Renuka Consultants
INDIA	Planys Technologies
India	IROV Technologies Private Ltd.
India	Suntech Geotextile Pvt. Ltd.
CHINA	CHINCOLD
INDIA	Miraishield Private Limited
INDIA	CBIP

# INCOLD News

## PANEL OF EXPERTS SOUGHT TO REVIEW DAM DESIGNS IN SRI LANKA



The Ministry of Agriculture, Livestock, Lands and Irrigation of the Democratic Socialist Republic of Sri Lanka, under the Climate Resilience Multiphase Programmatic Approach (CResMPA), is seeking to hire five individual experts to provide technical services as members of a Dam Safety Review Panel (DRP). The Project Director on behalf of CResMPA invites Expressions of Interest by 9 February in separate tenders for the roles of Hydraulics Engineering Expert, Structural Engineer/Dam Design Expert (concrete, rock fill, Roller Compacted Concrete dams); Geotechnical Engineering Expert; Hydrology, Hydraulics and Reservoir Operations Expert and Electro-mMechanical and Instruments Engineering Expert.

The Climate Resilience Multi-Phase Programmatic Approach (CResMPA) is being funded by the World Bank's International Bank for Reconstruction and Development (IBRD). The Dam Safety Review Panel, established under the CResMPA, will independently review feasibility study reports, geological and hydrological investigations and hydraulic model outputs, structural and mechanical designs, drawings, specifications for instrumentation, estimates and bidding documents of the three hydraulic structures for construction of the Ambathale Salinity barrier, Wee Oya reservoir and Upper Daraniyagala reservoir.

The role and responsibility of the DSRP and its members range from feasibility study up to the first impoundment of the reservoirs during the three financing phases of the CResMPA to ensure the safety of the dams. The objective is to provide an independent review of the deliverables of the consultants hired to conduct a feasibility study, developing detailed design and related studies of the dams, reports on investigations, detailed design, construction methods, and including Operation and Maintenance Plans and Emergency Preparedness Plans of dams to ensure the safety aspects of the dams.

The DSRP shall independently evaluate the technical soundness, adoption of modern and advanced state-of-the-art technology and green concepts for designing the dams for construction under the project in terms of safety of the dams, cost-effectiveness of construction, environmental friendliness of construction and ensure operational efficiency of dams and related structures developed by consultants hired by CResMPA.

The DSRP also inspects and reviews the construction works of the above-mentioned dams during the construction period to make sure that contractors hired by the project are adhering to the design requirements and construction standards, comply with environmental and social safeguard requirements necessary for ensuring dam safety by getting approval for the method statements in each stage of the construction of the dams, and also to make a recommendation to Project Coordinating Team for settling bills and liabilities to contractors in line with the World Bank's Operational Procedure (OP 4.37 – Safety of Dams) as per the financing agreement agreed by the government with the World Bank.

*Source* : Hydropower & Dams, January 27, 2025

## ESIA SOUGHT FOR INTEGRATED GONGRI-JERI HYDRO AND PUMPED STORAGE PROJECT IN BHUTAN

Druk Green Power Corporation (DGPC), Bhutan's state-controlled hydropower plant operator and developer, invites proposals by 6 January 2025 from qualified consultancy firms to prepare an Environment and Social Impact Assessment (ESIA) for the integrated Gongri hydropower project and Jeri pumped-storage project in eastern Bhutan.

The broad scope of the consultancy contract is to carry out an ESIA of the proposed project covering economic, social and environmental aspects, identify both the positive and negative impacts, assessment of impacts with its economic evaluation and prepare an Environmental Management Plan (EMP) to mitigate the adverse effects, including the socio-economic aspects, and a Resettlement & Rehabilitation (R&R) Plan for project affected people as well as an Environmental Flow (E-flow) Assessment. The environmental and social assessment is to be conducted as part of the Detailed Project Report (DPR) in line with the applicable requirements of the Government of Bhutan and international best practices (World Bank and the Asian Development Bank). The ESIA is to be completed within 15 months from contract signing.

To ensure energy security and meet growing power supply requirements resulting from the increased pace of socio-economic development of the country, the Department of

Energy (DoE) under the Ministry of Energy and Natural Resources (MoENR) has prioritized the preparation of the DPR of the 740 MW Gongri hydropower project with integration of the 1800 MW Jerichhu pumped-storage project, and in October 2022 accorded approval to DGPC to carry out the DPR studies for both projects.

The projects are planned in the Drangmechhu river basin, the biggest river system in Bhutan. The Gongri run-of-the-river project with pondage is planned on the Gongri river, one of the basin's two major rivers, on the boundary of the Trashigang and Mongar dzongkhags (districts), four km downstream of the confluence of the Gongri and Sherichhu rivers. The main project components include a concrete gravity dam with a maximum height above deepest foundation of 177 m, which would impound a reservoir with a gross storage of 427 x 106 m<sup>3</sup> and a live storage capacity of 351 x 106 m<sup>3</sup>, as well as a powerhouse to be equipped with four 185 MW vertical Francis turbines. The Gongri project envisages an installed capacity of 740 MW with an annual generation of 2721 GWh, and firm power of 129 MW.

A pre-feasibility study of Gongri, carried out by the DoE and submitted in February 2022, assessed the project to be techno-economically viable considering its geology and the potential for its integrated development as a pumped storage facility, with its reservoir to be utilized as the lower reservoir.

The Jeri pumped storage facility, which would be the country's first, is planned in Trashigang Dzongkhag on the river Jerichhu, which is the left bank tributary of Gongri. A reconnaissance study, which was conducted by Japan International Cooperation Agency (JICA) in the Power System Master Plan (PSMP) 2040 found the project to be technically viable. The open-loop pumped storage project, with a maximum capacity of 1800 MW, is designed with inflow connected to the upper reservoir and a tailrace tunnel connected to the lower dam, which would be part of the Gongri hydropower project. The upper dam is planned as a concrete gravity type with a height of 87 m from the deepest foundation level.

Source : Hydropower & Dams, December 11, 2024

## PANEL OF EXPERTS SOUGHT TO REVIEW LARGE DAM IN VIETNAM

Agence Française de Développement (AFD), France's development agency, seeks to engage a panel of experts (PoE) to undertake an independent safety review of a planned new large dam to be constructed in Vietnam's northwestern province of Dien Bien under AFD financing. Bids are invited by 24 January.

AFD is currently finalizing the appraisal of a project to build the Sai Luong dam allowing the creation of the Sai

Luong Reservoir in Nam Mun Commune in the district of Tuan Giao, which is planned to impound a reservoir of approximately 5.9 million m<sup>3</sup>, with a catchment area of around 8 km<sup>2</sup>. The dam is designed to create a reservoir that ensures sustainable water supply for the local rural downstream population for both human consumption and for irrigation. The project aims to achieve the recharge of the network heads of several villages in the district corresponding to 10 000 rural households, or 35 000 inhabitants (one third of the population of the district); An irrigation capacity of 17 000 ha of agricultural area on a seasonal basis benefiting about 30 000 farms; and efficient management of the local water supply system.

The dam is expected to be an earth dam, approximately 185 m in length, with a maximum height of 37 m, on a rock foundation. The project will also include installation of a 120 km-long pressure water pipe system, including intermediate storage tanks, a SCADA control system, an intelligent weather station and an irrigation system with humidity sensors.

The objective of the PoE is to provide an independent review of the investigation, design and construction of the dam and the start of operations and recommendations on the required actions to ensure the safety of the dam and associated facilities to acceptable standards as per the World Bank Environmental and Social Framework/ Environmental and Social Standard 4/Annex 1 on Dam Safety. Given the size of the Sai Luong dam and the associated risks, the objectives of social and environmental diligences concerning the Sai Luong dam were to conduct a compliance review of the Environmental Impact Assessment carried out, in relation to AFD's reference standards and in particular the World Bank's standards. The review by AFD of this compliance review led to an agreement with the authorities in Dien Bien Province on several actions, including the mobilization of a panel of independent experts to analyze the safety of the dam, the dam being considered as a "Large Dam" as defined by international standards (reservoir volume and dam size). At least one of the experts must be of Vietnamese nationality.

The required expertise is globally estimated at 80 men days, with three missions on site, one for each phase. The first mission could be in February or early March 2025. The second and third mission could be in 2026/2027 and 2029. The study will require three expert visits to the Tuan Giao District, including carrying out the study, restitution of the work to the various stakeholders.

The Province of Dien Bien will be the final beneficiary of the AFD financing, and the Tuan Giao People's Committee will be the project owner, through a project management unit (PMU).

Source : Hydropower & Dams, December 18, 2024

## Recent ICOLD Technical Bulletins

- Bulletin 124 (2002) Reservoir land slides : Investigation and management - Guidelines and case histories.
- Bulletin 125 (2003) Dams and Floods - Guidelines and case histories.
- Bulletin 126 (2003) Roller compacted concrete dams - State of the art and cast histories.
- Bulletin 127 (2004) Remote sensing for reservoir water quality management - Examples of initiatives
- Bulletin 128 (2004) Management of reservoir water quality - Introduction and recommendations.
- Bulletin 129 (2004) Dam Foundations - Geology considerations investigation Methods Treatment Monitoring.
- Bulletin 130 (2004) Risk Assessment - In Dam Safety Management - A Reconnaissance of Benefits, Methods and Current Applications.
- Bulletin 131 (2006) Role of Dams in Flood Mitigation - A Review
- Bulletin 132 (2008) Bulletin 132 - Shared Rivers : Principles and Practices
- Bulletin 133 (2008) Bulletin 133 - Embankment Dams on Permafrost
- Bulletin 134 (2008) Weak Rocks and Shales in Dams
- Bulletin 135 - Geomembrane Sealings Systems for Dams
- Bulletin 136 The Specification and Quality Control of Concrete Dams
- Bulletin 137 Reservoirs and Seismicity
- Bulletin 138 General Approach to Dam Surveillance
- Bulletin 139 Tailings Dams Safety
- Bulletin 140 Sediment Transport and Deposition in Reservoirs
- Bulletin 141 Concrete Rockfill Dams - Concepts for Design & Construction
- Bulletin 142 Report on Safe Passage of Extreme Floods
- Bulletin 143 Historical Review on Ancient Dams
- Bulletin 144 (2011) - Cost savings in Dams
- Bulletin 145 - The physical properties of hardened conventional concrete in dams
- Bulletin 146 - Dams and Resettlement - Lessons learnt and recommendations
- Bulletin 147 - Sedimentation and sustainable use of reservoirs and river systems
- Bulletin 148 - Selecting seismic parameters for large dams - Guidelines (revision of Bulletin 72)
- Bulletin 149 - Role of dams on the development and management of rivers basins.
- Bulletin 150 - Cutoffs for dams
- Bulletin 151 - Tropical residual soils as dam foundation and fill material
- Bulletin 152 - Cost savings in specific dams
- Bulletin 153 - Sustainable design and post-closure performance of tailings dams
- Bulletin 154 - Dam safety management: Operational phase of the dam life cycle
- 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
- Bulletin 161 - Dam and Water Transfers – An Overview
- Bulletin 162 - The Interaction of Hydraulic Processes of Reservoirs
- Bulletin 163 - Dams for Hydroelectric Energy
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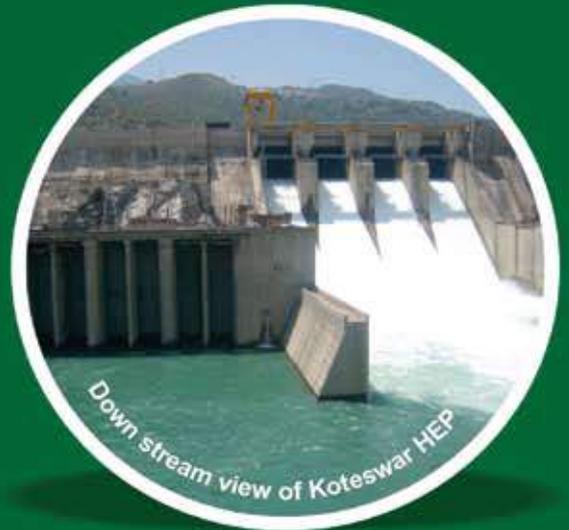
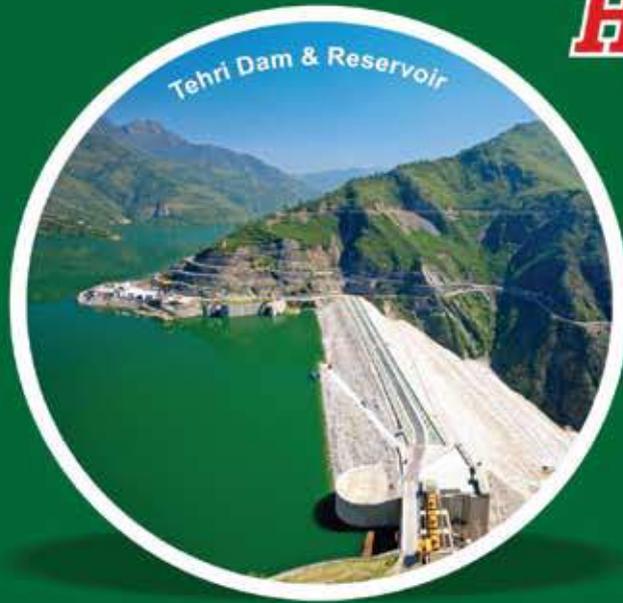
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