POST PROCEEDINGS

International Conference

DAM SAFETY-2025

Latest Technologies for Rehabilitation and Dam Safety

20-22 March 2025, Hotel Peterhoff, Shimla (H.P.), India

Workshop on

Grouting Technologies in Rehabilitation of Dams

19th March 2025, Shimla

Knowledge Partners

ICID•CIID

Central Water Commission

NDSA

DRIP Dam Rehabilitation & Improvement Project

NIH

CSMRS

HP PF Forum of the Hydro Power Producers

CWPRS

ICED International Centre of Excellence for Dams

Department of Water Resources Development & Management - IIT Roorkee

Dept. of Hydrology, IIT Roorkee

IISc, Bangaluru

MNIT, JAIPUR

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(From L-R) Shri Prabodh Saxena, Shri Rohit Thakur, Shri Sukhvinder Singh Sukhu, Shri Jagat Singh Negi & Shri Rajesh Dharmani

Dams being a major infrastructure component of water resources, play a vital role in providing significant benefits to humankind and also overall water security to the country. Our knowledge about the environment and consequent loads on the dam is evolving continuously and we have built the dams in accordance with our knowledge at those points of time in past. If these were to be reviewed as per current practices and standards, that are based on the present state-of-the-art, they may not fulfil the criteria. Moreover, coupled with the time induced deterioration and maintenance needs, such dams may be potentially hazardous. With the growing population in the river valleys downstream, the hazard potential of even a well maintained dam may also go up in time. In view of this, dam safety evaluation of existing dams needs greater attention. Dam safety is, therefore, considered as an extremely important aspect not only to safeguard the national interest and benefits derived from it but also to ensure the safety of human lives and properties in the downstream reaches of the dams.

In view of the innovative technological development in the field of dam safety, there is a need to update the knowledge of dam safety professionals, dam owners, contractors, consultants and the agencies involved in dam safety discipline. It has been recognized that dam safety aspects particularly of the existing dams, are not receiving much attention as they should be, especially in view of the fact that a number of these old/existing dams are ageing, leading to gradual natural degeneration. It is increasingly becoming evident that the dam safety has to begin right at the time of planning and construction as the inherent problems ignored at these stages or short-cuts adopted come to haunt us in the shape of safety problems and lead to much higher expenditure and effort to remedy them at a later stage. Even safety of some of the dams which have been constructed in the recent past may become questionable, if the flood characteristics or seismicity of the area has changed. These old dams may need research under today's technology. To create awareness about the rehabilitation issues affecting the dams and make the professionals aware about them, the Dam Safety Society (DSS) in collaboration with Directorate of Energy, Govt. of Himachal Pradesh, NHPC, SJVNL, and HPPPF organized the 2nd International Conference on “Latest Technologies for Rehabilitation and Dam Safety” in Hotel Peter-off on 20-22 March 2025 at Shimla, Himachal Pradesh.

Highlights of Inaugural Session

The International Conference Dam Safety - 2025 on theme Latest Technologies for Rehabilitation and Dam Safety was inaugurated by Hon'ble Chief Minister Shri Sukhvinder Singh Sukhu Honourable Chief Minister of Himachal Pradesh in the august presence of Revenue Minister, Shri Jagat Singh Negi , Education Minister, Shri Rohit Thakur, Technical Education Minister, Shri Rajesh Dharmani, Chief Secretary, Shri Prabodh Saxena, HPERC Chairman, Shri Devendra Kumar Sharma and Office Bearers of Dam Safety Society, New Delhi. Hon'ble Chief Minister, Technical Minister, Chief Secretary and Chairman, HPERC and addressed the august gathering of more than 260 dam professionals assembled from India, Sri Lanka, Nepal, Australia, Italy, USA as well as representatives of State Governments, Dam owners, Stakeholders, Consultants, Contractors, and Academicians.

Shri Sukhvinder Singh Sukhu Hon'ble Chief Minister Lighting the Lamp

The inaugural speech delivered by Hon'ble Chief Minister during the inaugural session is reproduced below:

It is a matter of great joy that this conference is being organized under the aegis of Dam Safety Society with the support of Energy Directorate, State Government, SJVNL and NHPC. We all know that our Himalayan region, which has

Hon'ble Chief Minister addressing the gathering

snow-capped peaks and important rivers, is famous for its beauty, and this region is becoming a center point in the whole world for hydroelectricity production and its development. In this region, dams are playing an important role in many works like renewable energy and water management.

Himachal Pradesh has a hydroelectric power potential of 24500 MW, out of which 11393 MW has been harnessed. A total of 24 dams in the state are established on these hydroelectric projects. Most of the dams have been built by Central Public Sector Undertakings (CPSUs), th e prominent ones among them are Bhakra, Pang Dam built by BBMB and Koldam built by NTPC. After the construction of Bhakra Dam in October, 1963, the construction of dams in Himachal Pradesh accelerated and the technical knowledge for building them also increased. A small state like Himachal Pradesh made a huge contribution to the nation by constructing Bhakra Dam in Bilaspur district. Himachal Pradesh borders up to 12 kilometers below the dam. We submerged our beautiful Bilaspur city to build this dam. At a time when there was a shortage of resources, our people living in Bilaspur and Una were displaced to Hisar district where nothing happened at that time, in extreme heat. Similarly, due to the construction of Pang Dam, people living in the most beautiful places of Kangra and the lap of the Dhaldhar River had to be displaced and move to the desert of Jaisalmer where the temperature goes up to 50 to 55 degrees centigrade. Even after so many years, the problem of Pang Dam displacements is yet to be solved.

Look at the irony, we had to knock the doors of the Hon'ble Supreme Court to get our share of electricity. Even now we are pleading for justice. From this you must have come to know how big is the contribution of this state in the construction of dams in the country. Every year during the monsoon season, during the floods in the state, the filling of water in the reservoirs of the dams brings prosperity to the state, but at the same time there is also a fear that if during the floods, more water has to be released somewhere, then the people living below the dam may have to face trouble.

Water is the main resource that our small state has. There are minerals in some states of the country, but instead of minerals, our main source is water. The economy of the state should have been strengthened with this water, but in that too, justice was not done to us and we were left behind. In the whole world, the license for exploitation of water resources is given for a limited period. Initially, our water resources were given forever without any time limit for setting up hydroelectric projects. Generally, the license period is 35 to 40 years. There are many such projects in which no time limit has been fixed. Our government will take adequate steps in this direction so that the interests of the state are protected and our future generations do not have to struggle on this issue like us.

We are making every effort to ensure the interests of our state and if required, we will ourselves construct such projects where our interests have not been taken into consideration. Safety of dams is also important because the nation has seen the failure of big dams and the losses caused by it. In 1979, 2000 people lost their lives due to the failure of Machhu dam in Gujarat. Recently in 2019, seven villages were submerged due to the collapse of Vatare dam (Maharashtra). There are many more examples of such dam failures.

Safety of dams is very important at various stages. It is very important to ensure quality control during construction. It has been observed that maximum failures of dams occur within five years of completion of their construction. Many failures occur when the reservoir is filled with water for the first time. It is the responsibility of all of you to pay attention to the quality of construction of dams. Maintenance and structural integrity are required to increase the life of dams and ensure their safety. Along with this, climate change and other reasons present new challenges for safety in the Himalayan region. Thus, we know that dam safety in the Himalayan region is an important issue and requires a multi-pronged approach.

These days, excessive floods are occurring due to climate change during rainy season. It should be kept in mind that the capacity of the gates installed in the dam should be fixed in such a way that these gates are capable of draining out the design flood of at least 200 to 10,000 (ten thousand) years. Along with this, special attention should also be paid to the maintenance of the gates installed in the dam. All you engineers will have to keep in mind that when designing new dams, the changes due to climate change should also be included in it. You will have to change the old design methods. All the employees involved in the maintenance of the dam should be trained from time to time. This will help them to take the right decision at the time of natural disaster.

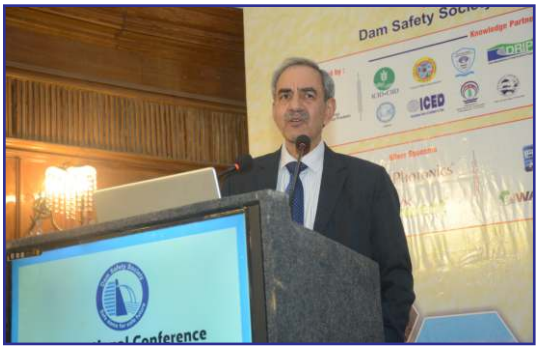
These provisions have been implemented in Himachal Pradesh also. Disaster Management Plan has been made mandatory for all dams. To ensure the safety of the dams situated in the state, the state government has constituted a Dam Safety Committee which monitors the maintenance and safety of all designated dams and is responsible for pre-monsoon and post-monsoon inspection. The role of the officers and employees who operate and maintain the dam is very important during a large magnitude earthquake. By properly operating the gates, the damage caused to the areas below the river can also be reduced. "Dam Safety Act, 2021" has been made for the safety of dams. This Act provides that the dam owner should make provision for Early Warning System and implement the Disaster Management Plan so that the safety of the people living below the dam can be ensured by informing them on time.

There are many issues related to the safety of dams such as: Instrumentation, Disaster Management, Routine Inspection of Dams, Repair of concrete in spillways, operation and maintenance of spillway gates. You should pay full attention to all these issues.

As I said in the beginning, dams are proving to be a boon for us but they are also creating a lot of challenges due to the geological and extreme climatic conditions in the region. Therefore, it is natural that continuous in-depth studies should be done to ensure dam safety in the Himalayan region and some such strategies should be made which include public information about these dams, strong disaster management, their maintenance and the latest information on the effects of climate change.

I believe that in this conference on dam safety, the experts related to hydropower production will understand this subject and will put forward their views and discuss in detail in the coming two days of this conference. I hope that there will be detailed discussions on this serious subject and in the end, some facts will come out of everyone's thoughts and research so that we can understand the major challenges in this subject and the latest techniques for dam safety and rehabilitation can be ensured. I hope that this Conference will prove to be very beneficial in the safety of dams in the state. I wish you all the success of this Conference. I also hope that after the Conference, you all will definitely take out some time to visit some places in this very beautiful state.

During the inaugural session, the other dignitaries who addressed the august gathering of dam professionals is Shri Rajesh Dharmani, Technical Education Minister, Shri Prabodh Saxena, Chief Secretary, Shri Devendra Kumar Sharma, Chairman HPERC. The speeches delivered by the Hon'ble Minister & Chief Secretary is given as Appendix. Shri Vivek Kapadia, Vice President Dam Safety Society welcomed the dignitaries on the dais and dam professionals from State WRDs.



Shri D.K. Sharma addressing the dam professionals

Conference Programme

Technical programme of the conference was organized under various special themes of relevance to the main theme of the conference:

THEME A : Latest technologies for dam health assessment
Dam Inspection, Geophysical and under water investigations, Seepage and Leakage Detection, Crack Mapping, Advancement in modern technology; Material testing and Investigations, Issues & challenges, Case Studies

THEME B : Dam Health Monitoring and Surveillance
Dam Health Monitoring, Data Acquisition and Processing; Dam Instrumentation for earthquake hazard assessment; Surveillance and monitoring by latest technologies (Satellite, terrestrial radar, laser based technologies); Real-time performance monitoring and analysis of data; Automation of instrumentation; Hydro-meteorological and Inflow forecasting systems; Communication and PA systems; Case Studies

Shri Vivek Kapadia delivering the Welcome address

THEME C : Latest technologies for repair and dam rehabilitation techniques
Dam rehabilitation techniques; Use of geo-membrane ; Dam Grouting – Cementitious and chemicals; Underwater works; Foundation grouting; Various aspects of rehabilitation- pre-rehabilitation investigations, technical regulations and current practices, institutional capacity building, project management, contractual challenges; Refurbishment of Gates; Dam Rehabilitation Case Studies; Reservoir De-sedimentation

THEME D : Dam safety assurance under climate change
Climate change impacts on dam safety; Flood risk management; Design flood review and managing revised floods; GLOF Management; Optimization of reservoir operation and integrated reservoir management

THEME E : Safety evaluation of existing dams
Comprehensive Safety Evaluation of Existing Dams - Structural, Hydraulic, Hydrologic and Geotechnical safety Assessments; Risk Analysis and Risk Management

THEME F : Safe operation and disaster management
Disaster and emergency management; Resources and capacity building for Emergency Management; EAP; Integration of Operation, Maintenance and Emergency Management

THEME G : Lessons learnt from dam failure incidents
Causes of dam failures; case histories of dam failures incidents; lessons learnt

The conference brought together 265 (give number here) dam professionals and experts in the various inter-related disciplines, to discuss, reflect and share knowledge, technology and experience in addressing dam safety issues. The conference have eight Technical Sessions, and one Session dedicated to Industry contributions. There were valuable presentations during the different Technical Sessions by eminent dam safety professionals which covered various facets of dam safety. National organizations showcase contemporary developments in technologies, construction materials, products, instrumentation, and services in an exhibition organized at the Conference venue.

Prof. N.K. Goel making the presentation

Plenary Session

A plenary session followed the inauguration to highlight the key issues of dam safety and sectoral thoughts on them. The following presentations were made by the eminent dam professionals during the Plenary Session:

1. Recent Advances in Hydrological Safety Evaluation of Dams – *N.K. Goel, Fellow, Emeritus Fellow, International Centre of Excellence for Dams (ICED), and IIT Roorkee*

The presentation by Prof. N.K. Goel, emeritus fellow at the International Centre of Excellence for Dams (ICED) and IIT Roorkee, offered a comprehensive overview of the evolving landscape in hydrological safety evaluation of dams, especially in the face of rising water demands, climate change, and population growth. Prof. Goel highlighted that while water is becoming increasingly scarce globally, India faces a particularly alarming scenario due to its high population density and limited water resources. With the population having grown nearly eightfold since 1900 and water demand having increased even more, the pressures on water infrastructure are immense. This calls for robust water management strategies, including storage and transfer mechanisms like dams and canals.

He elaborated on the growing hydrological challenges linked to climate change, including shifts in rainfall patterns, more frequent and intense precipitation events, increased evapo-transpiration, and declining snow cover. These phenomena contribute to greater variability and unpredictability in hydrological designs, requiring the use of more dense data networks and longer data sets to reduce estimation errors. Moreover, the implications of increased population density near flood plains significantly elevate dam safety concerns, necessitating rigorous dam breach analysis, flood hazard classification, and Emergency Action Plan (EAP) development.

The presentation further explored the multifaceted components of hydrological safety evaluations, encompassing design flood estimation, reservoir routing, spillway capacity determination, dam break analysis, inflow forecasting, and hazard classification. Prof. Goel underscored the critical importance of data both space and time-oriented and the role of various instruments such as digital automatic weather stations (AWS) with data loggers. He cautioned against excessive reliance on digital datasets, advocating for cross-verification with conventional sources to ensure accuracy.

Techniques for hydrological evaluation were discussed, ranging from deterministic to stochastic methods, with emphasis on validating assumptions through cross-checking. Prof. Goel examined various design flood estimation methods, recommending the use of statistical and hydro-meteorological approaches while advising caution with empirical and rational methods, especially for large dams. He also called for a revision of IS:11223-1988 standards to include new dam categories based on head and storage combinations to prevent unrealistic design flood estimations.

A significant portion of the presentation was dedicated to recent technological advancements. These included the application of Artificial Intelligence (AI) and Machine Learning (ML) for reservoir inflow forecasting and optimization,

dynamic rule curves updated with real-time data, and remote sensing technologies such as LiDAR, GPM-IMERG, and satellite-based altimetry for real-time reservoir monitoring. The use of GIS and advanced modelling tools for rainfall-runoff simulations in ungauged basins was also highlighted.

Prof. Goel emphasized the role of the newly established International Centre of Excellence for Dams (ICED) at IIT Roorkee. ICED aims to serve as a national hub for research, capacity building, and consulting in dam safety. It brings together experts from multiple disciplines and offers flexible postgraduate programs, training modules, and research initiatives on dam safety including seismic evaluation, sediment management, geotechnical and structural assessments, hydrological modelling, instrumentation, and environmental impacts. The Centre supports integrated solutions for the entire lifecycle of dams in alignment with the Dam Safety Act 2021.

In conclusion, the way forward, as suggested by Prof. Goel, includes the creation of interdisciplinary cells comprising dam safety managers, hydrologists, hydraulic and geotechnical engineers, structural engineers, seismologists, and other specialists. These teams are crucial for addressing the complex and interlinked challenges associated with hydrological safety and ensuring sustainable, resilient dam infrastructure in the future.

Prof. N.K. Goel, made the presentation on “Recent advances in hydrological safety evaluation of dams” and focus on genesis of hydrological issues and their implications in hydrological designs; approaches for hydrological safety evaluation- Techniques, limitations and needs; data, techniques, recommendations; and role of ICED for the dam owners. He also mentioned about the need for enhancing data collection, refining risk assessment methodologies, and incorporating AI and advanced modelling techniques, to improve dam safety management. This includes the development of tools like DHARMA (Dam Health and Rehabilitation Monitoring Application) for data management and monitoring, and the use of Artificial Intelligence, to analyze dam performance and predict potential issues.

While briefing about the formation of ICED and its activities, he informed that it has been established at IIT Roorkee on April 11, 2023 in a very close collaboration between IIT Roorkee and CWC, MoJS, by faculty members of the Department of Hydrology, Civil Engineering, Earthquake Engineering and other Departments of IIT Roorkee and CWC and National and International experts. The focus areas of Centre are seismic hazard mapping and analysis; reservoir sedimentation and silt control and management. The new areas shall be added as needed in the implementation of the Dam Safety Act 2021are inflow forecasting system for dams and comprehensive risk assessment of dams. Longer run- complete life cycle of dams; Flexible course and stay structure of M. Tech. programme; research with Extensive professional experience- No stay needed; Faculty recruitment- Faculty of Practice/ Adjunct Faculty, Visiting Faculty, Visiting Professor etc. and Short-term National and International training programmes.

Seismic safety evaluation of dams; Sediment management in reservoirs; Inflow forecasting system for dams; Comprehensive Risk Assessment of dams; Hydrologic Safety Evaluation of dams, Dam break, EAP etc. ; Geotechnical Safety Evaluation of Dams; Ground Improvement, Geo-synthetics, Grout and Geomaterials; Physical and mathematical modelling of dams, spillways, and energy Dissipators; Hydraulic Safety Evaluation; hydraulic design; Structural safety Evaluation and Structural design of dams, spillways, and energy Dissipators; Instrumentation in dams

The following are the take away from the presentation based on the recent advancements:

i. Data Collection and Management:

- **Automated Data Collection:** Improved data collection through automation and electronic processing of large data sets, enhancing the accuracy and efficiency of hydrological analysis.
- **DHARMA:** The Dam Health and Rehabilitation Monitoring Application (DHARMA) is a web-based tool designed to capture and manage data for all dams, enabling better monitoring and rehabilitation planning.
- **Real-time Monitoring:** Integration of real-time data collection systems with dam monitoring to provide immediate insights into dam performance.

ii Refined Risk Assessment Methods:

- **Risk-Informed Approaches:** Adopting risk-informed dam safety programs that integrate risk assessment into design and operational procedures, focusing on identifying potential failure modes and quantifying associated risks.
- **Climate Change Impacts:** Incorporating climate change scenarios into hydrological models to assess the impact of changing precipitation patterns and reservoir levels on dam safety.
- **Uncertainty Analysis:** Developing stochastic approaches that consider all sources of uncertainty in hydrological modelling and dam safety assessments.

iii. Advanced Modelling and Technology:

- **AI and Machine Learning:** Utilizing AI and machine learning algorithms, to analyze dam data, predict potential issues, and optimize operational strategies.
- **Advanced Hydrological Models:** Employing more sophisticated hydrological models to simulate reservoir behaviour

and assess the impact of different inflow scenarios.

- **Remote Sensing and GIS:** Using remote sensing and Geographic Information Systems (GIS) to monitor dam condition and analyze the surrounding environment.

iv. Best Practices and Standards:

- **Global Guidelines:** Adopting global best practices and standards for dam safety management, including risk assessment, inspection, and emergency planning.
- **Training and Professional Development:** Providing training and professional development opportunities for dam safety personnel to enhance their skills and knowledge.
- **Collaboration and Knowledge Sharing:** There is a need for fostering collaboration among dam safety professionals and researchers, to share knowledge and best practices. These advancements aim to create more robust and resilient dam infrastructure by leveraging technology, improving data management, and adopting a more risk-informed approach to dam safety.

Dr. Sanjay Rana making the presentation

2. Advancing Dam Safety: Modern Inspection Techniques and Internal Condition Assessment – *Dr. Sanjay Rana, Managing Director, Parsan Overseas*

Modern dam safety relies on a combination of routine visual inspections, advanced remote sensing techniques like drones and LiDAR, and internal condition assessments using techniques like seismic and radar surveys. These methods help identify anomalies, track changes over time, and assess the overall health of the dam structure, enabling proactive maintenance and rehabilitation.

Dr. Sanjay Rana focused on the following important points:

- Dam Inspection and assessment for structural repairs & rehabilitation- Current Practices
- Drone-Based Inspections for Dams - Cutting-edge technologies in Drone-Based Dam Inspections
- Underwater Inspections for Dams..... enhancing safety and efficiency: ROVs v/s. Diver Inspections
- Internal Condition Assessment- Geophysical Investigations…

The following recommendations were made by the presenter while delivering the concluding remarks:

- **Integrate geophysics into dam safety protocols**
  Geophysical investigations should be institutionalized as a core component of dam safety inspections—before, during, and after rehabilitation—to enable non-destructive, scientific assessment of internal conditions.

- **Ensure periodic inspections of all large dams**
  Periodic geophysical assessments must be mandated for all large dams to facilitate early detection of internal anomalies, in line with the Dam Safety Act 2021 goals of inspecting 6,000+ dams over the next five years.

- **Adopt and implement existing guidelines**
  Existing guideline documents on geophysical investigations for dam safety should be reviewed, discussed, and formally adopted by agencies to standardize and accelerate implementation, including extended use for canals, stilling basins, and other hydraulic structures.

2. Next Steps for Long Running Dam Safety Programme – *A.B. Pandya, President, Dam Safety Society*

In his keynote address at the International Conference on Dam Safety 2025, Shri Ashwin B. Pandya, President of the Dam Safety Society and Professor of Practice at ICDES IIT Roorkee, highlighted issues needed to be addressed for a sustainable dam safety programme. He opined that a beginning has been made but there is a long path to traverse to establish the dam safety practices on a wide spread basis. Dam safety is a discipline needing eternal surveillance and actions and should not be treated as a one shot affair. In the field of dam safety, the engineers and administrators do not have the luxury of sitting on their laurels of having executed and concluded a programme well. Dam safety assurance and rehabilitation presents a complex web of activities needing extensive field work for inspections, investigations and improvements. A large group of professionals well versed in analytical and field techniques are needed for tackling a large population of dams of all sizes and features. He discussed the need for comprehensive dam safety reviews and approach to

be adopted for carrying out the same. Dam operators training and familiarization with the new techniques and features is an important aspect for a sustained dam safety regime. Adequate funds flow is a necessity for sustaining the soft and hard measures for ensuring the dam safety in the country.

Shri Pandya also highlighted the critical next steps for a long-running and effective dam safety programme in India. He emphasized the transformative impact of the Dam Safety Act enacted by the Union Government, marking a landmark shift in India's water governance. The Act has unified the previously fragmented state-level governance mechanisms, codifying essential safety practices and mobilizing dam-owning organizations to adopt more structured safety mechanisms. Backed by the Dam Rehabilitation and Improvement Project (DRIP), this legislative framework has facilitated the development of several standards and advisories to guide practitioners across the country.

Shri Ashwin B. Pandya

Shri Pandya noted that post-enactment key institutions such as the National Dam Safety Authority and the National Committee on Dam Safety have been established, with standardized requirements introduced for instrumentation, inspections, and reporting. However, he cautioned that India's dam safety ecosystem remains a complex web of responsibilities requiring a sustained and systemic approach. Among the crucial steps ahead, Shri Pandya emphasized the need for regular inspections by experienced professionals using standardized protocols, improved analytical methods for health assessments, and the creation of a dam health baseline. He called for joint financial support from the states and the Union government to ensure the programme's continuity and advocated leveraging market mechanisms for sustainable investigations and rehabilitation.

He pointed out the challenges facing current dam safety programmes, including anecdotal implementation, inadequate professional capacity, and inconsistent dam selection for expert review. Shri Pandya stressed that dam safety reviews must not be one-off efforts; rather, they require consistent and long-term involvement of expert panels. These reviews should culminate in actionable rehabilitation plans, with continuous monitoring to ensure recommendations are implemented effectively. Comprehensive dam safety reviews, he stated, must cover the entire dam structure regardless of visible signs of distress and should yield quantifiable evaluations relative to contemporary safety standards. The newly introduced requirement for Independent Panels of Experts (IPoE) is a step in the right direction, but continuity and transparency must be maintained.

Delving deeper, Shri Pandya highlighted gaps in current assessments, including the lack of site-specific investigations, inadequate integration of structural and hydrological performance data, and outdated design assumptions. He advocated for an advanced assessment techniques that evolve from simple to complex, incorporating both onsite and offsite evaluations and leveraging newer methodologies. Recognizing the changing operational realities, he emphasized the need for emergency preparedness through mock drills and training, given that many on-ground personnel may never have encountered extreme events.

To ensure the long-term sustainability of the dam safety framework, Shri Pandya stressed the need for nurturing a skilled cadre of professionals. As dam infrastructure ages, emphasis must shift from new designs to ensuring the safety of existing structures. He called for structured training programs and the preservation of institutional knowledge from senior experts. Furthermore, he advocated for fostering demand for innovative approaches by actively evaluating emerging technologies and engaging with developers beyond traditional contractor-client relationships. Lastly, Shri Pandya addressed the financial underpinning of these efforts, urging rapid financial assessments and long-term funding mechanisms to support dam safety initiatives. He concluded by emphasizing the urgent need for collaborative financial dialogue, particularly between States and Union Government, to ensure the robust and resilient future of India's dam safety regime.

3. Dam Safety – Broad aspects - *Devendra Kumar Sharma, Hon. Vice President, ICOLD and Chairman, HPERC*

Mr. Devendra Kumar Sharma, delivered a comprehensive address on the broad aspects of dam safety. He opened by highlighting the global scale of dam infrastructure, noting that there are approximately 60,000 large dams worldwide, with India alone accounting for around 6,000 of these structures. Sharma emphasized ICOLD's pivotal role since its establishment in Paris in 1928 in developing guidelines that ensure dams are constructed safely, economically, and in an environmentally and socially sustainable manner. With the support of 27 technical committees and around 700 experts working on bulletins over multi-year periods, ICOLD continues to lead the global dam engineering profession.

One of the significant contributions of ICOLD, as discussed by Mr. Sharma, is the maintenance and periodic update of a dam incident and failure database. This initiative acknowledges the value of learning from engineering failures. In 2021, ICOLD updated Bulletin 99 to include 322 cases, and in 2022, made this database publicly accessible online. These records provide essential insights into dam performance and failures, which are critical for improving future safety standards.

Further elaborating on ICOLD's efforts, Mr. Sharma referred to Bulletin 188 on dam inspection, underscoring how ICOLD has shaped inspection methodologies and practices. He noted the alarming trend of increased dam failure ratios in structures built after the year 2000, citing examples such as the tragic Machhu Dam failure in Gujarat, India, in 1979, and the

Xe Pian-Xe Namnoy dam failure in Laos in 2018. The latter case involved a homogeneous dike on an untreated lateritic foundation, which experienced abnormal settlement and regressive erosion, resulting in the release of 0.5 billion m³ of water, 140 casualties, and over 12,000 affected individuals.

Mr. Sharma also highlighted the ICOLD mission statement and the issuance of the World Declaration on Dam Safety in 2019, co-chaired by himself and Mr. Enrique Cifres of Spain. The declaration urges the global community to develop storage capacity, accelerate hydropower generation, recognize energy storage as a key function of reservoirs, establish regulatory frameworks for such storage, and promote administrative and environmental reforms. It also calls for enhanced dam safety management, sustainable water and sediment management, and increased research and development in the sector.

Shri D. K. Sharma making the presentation

Addressing the pressing issue of climate change, Mr. Sharma presented data showing that climate models predict a wetter future climate, with an increase in precipitation up to 7% by the near future and up to 29% by the year 2100. Temperature projections for India estimate a rise between 1.5°C to 3°C by 2060, and 2.5°C to 4°C by year 2100. Referring to the Paris Agreement of the year 2015, signed by 196 countries, Mr. Sharma also underscored the importance of limiting global temperature rise to below 2°C or ideally 1.5°C. He stressed that achieving these targets requires the addition of 850 GW to 1200 GW of hydropower capacity globally by the year 2050, placing an immense responsibility on dam engineers and policymakers to integrate climate resilience into hydropower development.

Technical Session 1 : Dam Health Assessment

4. Unveiling The Unknown-Rov Inspection Of Flooded Tunnel - A Case Study - *Kannappa Palaniappan, Akhil and Ashok Kumar Manisery*

Water conveyance tunnels are essential elements in infrastructure systems because they are commonly utilized for hydroelectric power generation. Due to continuing operations and great efforts required for their commissioning and operation, the tunnels once put in operation can not be easily dewatered for inspection and evaluation. The safety and dependability of these systems depend heavily on maintaining their structural soundness and operating effectiveness. However, because of their inaccessibility, changing surroundings, and possible risks, water-charged tunnels provide special obstacles for inspection and maintenance. Water pressure, sedimentation, and structural wear are just some of the stresses that these tunnels must withstand; therefore, routine inspection is crucial to preserving their durability, safety, and effectiveness. A case study was presented where ROV-based inspection was effectively used for the inspection of a 5.2 km long tunnel to understand its structural details and furthermore, the potential for thorough and effective data collecting is highlighted by the incorporation of cutting-edge instruments like sonar, high-resolution cameras, and environmental sensors into ROV systems.

In order to ensure long-term sustainability and resilience, the presentation made by Mr. Kannappa Palaniappan, helped to further knowledge of how cutting-edge technologies might improve the administration and upkeep of vital water infrastructure.

Using remotely operated vehicles (ROVs) for tunnel inspection is a revolutionary method of maintaining vital infrastructure. Compared to conventional techniques, ROVs improve the precision, effectiveness, and safety of tunnel inspections by combining sophisticated robotics, high-definition photography, and data analytics. These technologies reduce human exposure to dangers while guaranteeing comprehensive assessment because they can function in dangerous situations, enter restricted areas, and give real-time data.

Ms. Kannappa Palaniappan making the presentation

The thorough ROV-based survey helps in understanding the flaws and weak zones of the tunnel in the early stage itself. This technology allows predictive maintenance, minimizes inspection expenses, and cuts downtime. This proactive strategy guarantees the structural integrity and user safety of tunnels while also extending their service life. An important step toward more intelligent and sustainable infrastructure management is the use of ROVs in tunnel inspection. The end results of the ROV survey can be made into a user-friendly

Group photograph of Technical Session -1

manner and which helps the authorities to get a clear understanding about the structure and make necessary decisions to protect them

5. Geotechnical Investigation carried out to study the causes for substantial seepage of earthen embankment between LS 350m and 500m of Nanganjiyar Dam - *K. Lavaniya, T. Kanimozhi and N. Suresh Babu*

Nanganjiyar Reservoir has been constructed across Nanganjiyar River in Oddanchattram Taluk of Dindigul District. The reservoir was first opened for irrigation on 06.04.2008. It is an earth cum masonry dam constructed for a length of 2680m. The surplus arrangement of this reservoir is an uncontrolled spillway from LS 1325m to 1755m with a crest level of +231.00m, the discharging capacity of the spillway is 3467.45 cumecs.

Dam Safety Review Panel (DSRP) inspected the dam on 21.02.2023 (DSRP – 27 /2023). On the date of inspection, the reservoir level was at 230.92m (FRL @ 231.00m). From LS 350m to LS 500m (Left flank of earthen dam) significant water seepage was seen in the toe drain. The observed seepage on the date of inspection in the left V – 1 (LS 850m, representing left flank) notch was 14.42 lps. The maximum seepage recorded on the left flank was 18.00 lps. Water sample collected from the toe drain was clear and no soil particles were seen.

Between LS 350m and LS 500m, downstream area of the toe drain and service road, numbers of irrigation wells were present. The water was overflowing from the well on to the road. The quantity of seepage water appeared to be more than permissible seepage in the earth Dam. Considering the above aspects, the panel recommended for geotechnical investigation to identify the cause of seepage and to conduct a flow net analysis for the seeping earthen dam section from LS 350m to LS 500m. The following conclusion was made by the author at the end of presentation:

1. The laboratory investigation shows the embankment of Nanganjiyar dam is made up of different layers of soil and there is no specific core material encountered.

2. In general, the cut off trench of the earthen embankment is to be made of clay soil having co-efficient of Permeability 'k' value in the order of 10^{-6} cm/sec. However, the soil below the embankment at LS 350 m and at LS 450m has a co-efficient of Permeability 'k' in the order of 10^{-4} cm/sec and 10^{-2}cm/sec, which indicates the pervious nature of the soil. The pervious to semi-pervious nature of the soil in the foundation of the embankment is the cause for the profuse seepage between LS 350m to LS 500m.

Ms. T. Kanimozhi making the presentation

3. From the flow-net analysis, it is learnt that the seepage through the Nanganjiyar Dam is not under the permissible limit and needs to be attended.

Hence, the profuse seepage between LS 350m to LS 500m in the earthen embankment of Nanganjiyar Reservoir needs to be attended by proper upstream treatment methods

6. Earthen dam failure investigations: Correlating geophysical methods with geotechnical ground truthing for enhanced reliability - *Dr. Yogini Deshpande, Sandip Deshpande & Mahesh Mandape*

Earthen dams are crucial infrastructure elements for water storage, flood control, and irrigation. However, they are vulnerable to structural distress and failures caused by factors such as seepage, piping, differential settlement, and slope instability. Timely detection of such issues is essential to ensure dam safety and prevent catastrophic failures. To achieve this, geophysical methods offer an effective means of non-intrusive subsurface investigation, providing rapid and cost-efficient assessments of dam health.

Among the various geophysical techniques, Multi-Channel Analysis of Surface Waves (MASW) has gained significant attention for its ability to assess subsurface stiffness characteristics. MASW is a seismic method that analyzes surface wave dispersion to estimate the shear wave velocity (Vs) profile of the subsurface. Since shear wave velocity is directly

related to soil stiffness and compaction, MASW can be used to detect zones of weak material, voids, or potential failure planes within an earthen dam. Compared to conventional seismic methods, MASW offers advantages such as better resolution in near-surface layers, robustness against noise, and the ability to function in difficult terrains.

In addition to MASW, other geophysical techniques such as Electrical Resistivity Imaging (ERI), Ground Penetrating Radar (GPR), and Seismic Refraction Tomography (SRT) are widely used for detecting seepage paths, internal erosion, and structural anomalies. However, the reliability of geophysical findings is significantly enhanced when validated with geotechnical ground truthing methods, including borehole drilling, Standard Penetration Tests (SPT), and soil sampling. This integration of intrusive and non-intrusive methods ensures accurate identification of distressed locations and provides a comprehensive assessment of dam stability.

Dr. Sandip Deshpande making the presentation

This paper was presented by Mr. Sandeep Deshpande - A case study of an earthen dam failure investigation, where geophysical methods, including MASW, were utilized to detect anomalies, and the results were validated through geotechnical ground truthing. The study highlights the advantages and limitations of MASW, the necessity of corroborating geophysical data with direct intrusive methods, and the significance of a multi-disciplinary approach in dam failure diagnostics.

The findings from this study reinforce the need for an integrated framework that combines geophysical and geotechnical investigations to enhance the reliability of failure assessments. By systematically utilizing MASW and complementary geophysical techniques, engineers can improve the accuracy of dam distress evaluations and develop effective remedial measures for sustaining dam safety.

It was concluded that the integrated approach of non-invasive and invasive assessment greatly improves the confidence in embankment stability evaluations compared to relying solely on geophysical investigations. By calibrating geophysical findings with geotechnical evaluations, the reliability of the analysis is enhanced, ensuring more informed and data-driven decision-making in dam safety assessments.

7. Integrated geotechnical and geophysical investigations for health assessment of Embankment Dams: A Case Study of Musi Dam - *Veerla Sunitha*

Geophysical and, geotechnical data fusion minimizes uncertainties of hidden problems like seepage and cavities. It provides a holistic, non-invasive approach to dam health monitoring. Allows multi-scale assessment from shallow defects to deep-seated anomalies. Evaluate Seepage & Structural Analysis – Integration with numerical models (e.g., FEM, FDM) improves predictive accuracy of dam behavior under different loading conditions. Early Detection of Failure Mechanisms helps in identifying internal erosion, piping, settlement, and liquefaction susceptibility before catastrophic failure. It enhances decision-making for dam safety authorities and acts as early warning system. Reduces failure risks and supports proactive maintenance strategies.

Technical Session-2: Dam Rehabilitation Techniques

8. Latest Techniques in Improving Watertightness in Dams - Geomembrane Sealing System - *Jagadeesan Subramanian, Business Unit Head, Carpi India, Chennai, Tamil Nadu, India*

In a presentation titled “Latest Techniques in Improving Watertightness in Dams – Geomembrane Sealing System”, Mr. Jagadeesan Subramanian, Business Unit Head, Carpi India, Chennai, Tamil Nadu, introduced PVC geomembranes as an innovative solution to improve dam watertightness. PVC geomembranes are thin, flexible materials with low permeability and are applicable to all types of dams. They are cost-effective, have a low carbon footprint, and when combined with a geotextile during production, they form a geo-composite. The geotextile component provides dimensional stability, anti-puncture protection, and drainage capability, thereby enhancing the overall effectiveness of the system.

Ms. Veerla Sunitha making the presentation

Highlighting the special characteristics necessary for selecting a geomembrane for hydraulic structures, Mr. Subramanian emphasized that flexibility is crucial to distribute water loads evenly across the dam surface, minimizing the risk of damage from

concentrated loads. The material must also exhibit high resistance to puncture, bursting under water pressure, tear propagation in the event of accidents, and impacts from floating debris, ice, or boats.

Explaining how the Geomembrane Sealing System differs from other dam rehabilitation methods, he noted that traditional approaches like grouting and repointing address only localized issues, often requiring repeated interventions. In contrast, a geomembrane installed on the upstream face acts as a protective barrier, preventing further deterioration, eliminating the need for frequent grouting, and enhancing the structural strength of the dam.

The engineered PVC geocomposite solution offers a durable, effective, and sustainable watertightness solution for over 50 years. The membranes are lightweight, easy to transport and install, and can be applied in dry or underwater conditions. They adapt well to the rigid dam face, exhibit a very low carbon footprint, and require almost zero maintenance even after decades. Notably, they include an inbuilt drainage arrangement, significantly reducing the need for further maintenance activities.

The Carpi geomembrane sealing system involves installing a PVC geo-composite material, including a drainage system, from the dam crest down to the foundation. Major functional elements of the system include the PVC geo-composite material, an anti-puncture geotextile cushion layer, anchorage elements to withstand wind and waterhead forces, and a drainage system using geonets.

Shri Jagadeessan Subramanian making the presentation

The presentation detailed several successful case studies, with special emphasis on the Kadamparai Dam, India's first dam to use a geomembrane sealing system in 2005. The Kadamparai Dam, a composite stone masonry and gravity structure, experienced significant leakage issues from 1984 to the mid-1990s, with leakage increasing from 1,120 LPM to 38,200 LPM despite extensive local repairs and grouting efforts. In 2003, Carpi Tech SA assessed the situation and proposed a geomembrane solution. By late 2004, Carpi India commenced work, installing stainless steel face anchors, a drainage geonet with pipes, a 2,000 gsm anti-puncture geotextile, and the PVC geo-composite. The geo-composite panels were overlapped, welded together, and secured with external tensioning profiles and watertight perimeter seals using chemical anchors and gaskets.

The result was a dramatic reduction in seepage from 30,000 liters per minute to just 80 liters per minute, with the installation completed six weeks ahead of schedule. In recognition of this success, the project received the India Power Award for Excellence in Water & Energy Management in 2008. Even after two decades, leakage remains low at around 100 LPM, enabling full operation at Full Reservoir Level (FRL) and full power generation of 400 MW.

Mr. Subramanian also presented additional case studies from the Upper Bhavani Dam, Servalar Dam, and Bajoli Holi Headrace Tunnel, demonstrating the adaptability of the geomembrane system to various hydraulic structures. In some projects, Carpi India incorporated advanced Fiber Optic Cable Leakage Detection Systems based on the Heat Pulse Method. This method sandwiches a fiber optic cable behind the geomembrane and geonet, enabling real-time detection of water entry and monitoring of the waterproofing system's performance.

In conclusion, Mr. Subramanian emphasized that the Geomembrane Sealing System is an engineered solution rather than a mere product supply. The watertightness achieved is long-lasting, with systems performing effectively over decades. In all projects presented, the Carpi solution not only restored the watertightness of hydraulic structures but also contributed to additional power generation, minimized plant outages due to leakage, and extended the life cycle of the infrastructure. Considering the overall project lifespan and maintenance savings, the geomembrane sealing system has proven to be one of the most reliable and trusted technologies for dam rehabilitation worldwide.

9. Chemical Grouting to Arrest Water Loss Through Aging Dams Using Sunanda Make Sungeogrout- *S. K. Manjrekar*

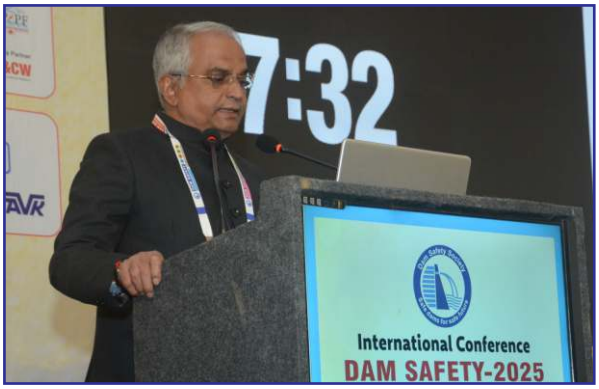
Most of the dams in the country are more than 50 years old. The most common indicators of seepage in concrete and masonry dams are; wetness and seepage on the downstream face of the dam, and in inspection and foundation galleries. The main causes of seepage from ageing dam body is the continuously increasing porosity of the concrete and masonry along with hydrostatic pressure head exerted by the reservoir created by the dam. Due to the seepage, the cementitious and other fine particulate matter gets washed away further increasing the seepage. Thus, seepage aggravates if left untreated properly. Grouting is the classical method of treating seepage. However, the grout has a tendency to get washed away in course of time if proper material and methodology is not adopted, requiring frequent grouting operation.

It is experienced that, leakages cannot be brought under total control and hence the grouting with cementitious materials is needed to be done periodically because of the continuous loss of cementitious material from the body of the dam. The loss of fines weakens the structure. In addition, the cement grout has limited penetration ability in the capillaries, pores in sub-micron region compared to the chemical grouts.

Capillary and pores in mortar or concrete range from 100 Nm to few microns. The Gel pores are of size 0.5 to 10 Nm while larger voids (macro pores) are of several millimetres. The cement Particle size is 15000 Nm, which obviously cannot penetrate through the capillaries, pores less than 15000 Nm in size. Hence, subsequent to cementitious grout, chemical grout with particle size less than 5 Nm is to be used to get a complete impervious compact material.

While giving the concluding remarks, the presenter proposed the following recommendations:

I. Chemical grouting is an established, effective technique for treatment of seepage in dams.
ii. Nano-particles of the grout improve the penetration capability of the grout.
iii. It is possible to explore various combinations of chemical grout reactants to enter into micron, nano and sub nano particle zones.
iv. Entering into the nano zone may enhance the performance of the grout in terms of unconfined compressive strength and overall economics. As a result chemical grouts can be injected into dam body containing voids that are too small to be penetrated by cementitious or other grouts containing suspended solid particles. This enhances the in-situ strength as well as overall integrity of the dam structure.



Shri S.K. Manjrekar making the presentation

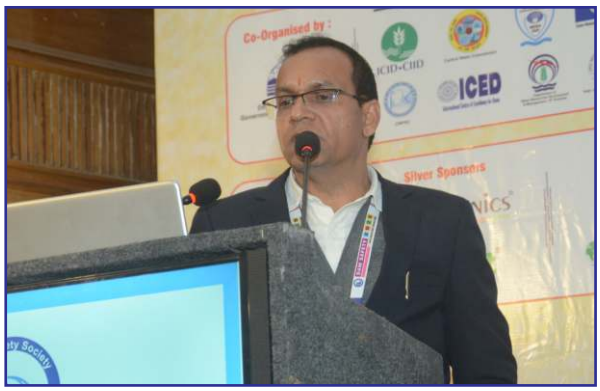
v. Chemical Grouts, once reacted, become a material analogous to sandstone and hence have no detrimental effect on the soil and ground water but have great binding factor.
vi. Chemical grouts have an adaptability over a wide range of applications in various types of dams.
vii. Nano grouts are the strongest and nontoxic in the existing range of chemical grouts.

10. High-Performance Concrete for Repair of Sluice Spillway of Nathpa Dam- *Raman Revati and Jaswant Kapoor from SJVN Limited*

The presentation titled "High-Performance Concrete for Repair of Sluice Spillway of Nathpa Dam" by Raman Revati and Jaswant Kapoor provided an in-depth overview of the inspection methodologies and best practices adopted at the Nathpa Dam, a vital component of the 1500 MW Nathpa Jhakri Hydro Power Station (NJHPS) and the 412 MW Rampur Hydro Power Station (RHPS), both operated by SJVN Limited, a Navratna CPSE under the Ministry of Power, Government of India. The Nathpa Dam, a 62.5-meter-high concrete gravity dam, plays a critical role in maintaining continuous hydropower generation. The presentation emphasized the importance of maintaining structural integrity, operational reliability, and proactive risk mitigation through a robust, institutionalized inspection regime.

The dam showcases several complex structural features such as desilting chambers, a 27.4 km long Head Race Tunnel (HRT), a deep 301-meter surge shaft, and underground machine and transformer halls. A notable highlight of the system is the reuse of tailrace water from NJHPS by the Rampur Hydro Power Station, commissioned in 2015, reflecting efficient and integrated water resource management. The dam is equipped with five sluice spillway gates and an overhead spillway for regulating excess water discharge.

The Sutlej River, originating from the Tibetan Plateau and traversing through the Himalayas, carries a substantial sediment load comprising boulders, sand, silt, and gravel. Monsoon and glacial melt seasons transport boulders up to 5 meters in diameter, resulting in significant erosion of riverbanks and riverbeds. This high-energy flow affects the performance and longevity of hydropower structures, making the annual silt flushing through the sluice spillways a critical operation. The sluice spillways of Nathpa Dam have been severely impacted by abrasion and erosion, leading to reduced service life of concrete structures, increased maintenance costs, and elevated safety risks.



Shri Raman Revati making the presentation

Recognizing the abrasion resistance of concrete as being predominantly influenced by its compressive strength, the presentation outlined the necessity of using high-strength concrete for hydraulic structures. However, challenges such as increased hydration temperature and shrinkage from high cement content

necessitated the use of supplementary cementitious materials like fly ash and silica fume. These materials contribute to lower heat generation during hydration, minimized shrinkage cracking, and improved long-term durability. The abrasion resistance of concrete was also influenced by factors such as aggregate type, fiber reinforcement (steel, polypropylene, cellulose), surface finish, and curing practices.

In collaboration with the Indian Institute of Technology Delhi, SJVN explored the application of two types of M80 grade concretes: High-Performance Concrete (HPC) and High-Performance Fiber-Reinforced Concrete (HPFRC). Mixes were designed using 53-grade Ordinary Portland Cement, un-densified silica fume, fly ash, locally available aggregates, and a low water-to-cement ratio of 0.28. Micro-steel fibers (13 mm length, 0.3 mm diameter) were added at a volume fraction of 1.5% for the HPFRC variant. Properties of binders and aggregates were meticulously analyzed, ensuring specific gravity and water absorption values were within acceptable ranges. Although the coarse aggregates marginally exceeded the crushing value limit, their impact and abrasion properties were compliant and thus deemed suitable for use in the repair works.

The final concrete mix design targeted a compressive strength of 80 MPa, incorporating 12.5% silica fume for early-age strength gain and 25-30% fly ash to control hydration heat and shrinkage. A chemical admixture was added at 0.5-1.5% to enhance workability. Compressive strength tests were conducted at 7 and 28 days in accordance with BIS 516-2004 standards. Results showed that both HPC and HPFRC mixes achieved the desired target strength, with HPFRC displaying enhanced crack resistance due to the bridging effect of fibers.

The application of these high-performance concretes was carried out systematically across different sluice spillways. At Gate No. 3, the abraded surfaces were cleaned using a high-pressure air gun, new reinforcements were installed, and a bonding agent was applied before repairing with a combination of HPC and HPFRC. At Gate No. 4, significant damage, especially in the flip bucket region, was repaired using M80 grade HPC. Gate No. 5, suffering from major deterioration, underwent repairs using a combination of HPC and HPFRC, with special measures like mounting new rails and using sacrificial steel rods to protect rail bolts and anchors. Hydro-demolition and bonding coat applications ensured effective adhesion and durability.

The performance of HPC and HPFRC in resisting abrasion and erosion will be evaluated over time through core extraction, residual strength testing, and visual inspections. Preliminary observations suggest a significant improvement in abrasion resistance, but long-term monitoring will provide definitive insights.

In conclusion, the use of M80 grade HPC and HPFRC marks the first instance of such an application for sluice spillway repairs at Nathpa Dam. The methodology adopted is expected to substantially enhance the durability and long-term performance of the hydraulic structures. The findings from this innovative repair approach will be shared with the industry and engineering fraternity, establishing a potential new standard for repairing high-abrasion hydraulic structures.

11. Innovative Corrosion Protection System to Gates of Middle Vaitarna, Barvi & Ransai Dams- *S. K. Manjrekar and J. K. Kulkarni*

Innovative corrosion protection system to gates of the dams at Middle Vaitarna (2019), Barvi (April 2021) & Ransai (April 2024) was carried out and as a representative case the Ransai Dam gates protection treatment is presented in this paper. Ransai Dam is built across Vindhane river by Maharashtra Industrial Development Corporation (MIDC) in Raigad district near Mumbai. The part of 1st stage masonry dam up to RL 30.48 M was completed in 1970 and the remaining work of providing automatic tilting gates of size 6.00m x 2.00m at FRL 37.2 M was completed in the year 1981. During routine inspection in 2023 it was noted that the corrosion protection coating to the gates & its supporting mechanism is in advanced stage.

Generally coal tar epoxy coatings are applied and provided for in various schedule of rates. This is a hazardous process from health point of view also besides having short service life, as the coal tar contents are carcinogenic and should be avoided for any structure related to drinking water. In addition, the quantum of epoxy content also is compromised. Reduction of epoxy and there by addition of coal tar reduces abrasion properties along with susceptibility to UV attack resulting into early decay and hence over all corrosion losses lead to substantial life cycle reduction.

As per the studies conducted by National Association of Corrosion Engineers (NACE), the yearly loss due to corrosion in major sectors in India is about 4.2% of the GDP,R1 which is quite substantial. Therefore, for a developing country like India proper selection, application, regular inspections, and maintenance of the coatings are all crucial for a successful life span without much necessary stress on economic resources. Paper discussed the innovative corrosion protection system of total rust removing chemical treatment followed by :

a) High build special epoxies modified with extended chemical chain and
b) Tailor made polyurethane coating with cyclic nature offered to the molecules. The coating thus becomes more resistant to decomposition as more energy is required to destroy cyclic arrangement of molecules rather than in case of normal straight aliphatic chain.

These novel developmental efforts enhanced manifold the performance properties of the system as observed in Vaitarna and Barvi Dam. As a result MIDC took up the work of corrosion prevention treatment of gates of one more dam viz. Ransai Dam in March 2024. Post treatment and post monsoon in 2024, the gates were checked for the performance in January 2025 and is reported to be very satisfactory. This presentation dealt with the novel and effective protective systems for the important member of a dam assembly i.e. automatic tilting gates.

Shri S.K. Manjrekar making the presentation

12. Feasibility Study of Suitable Grouting Technique for Seepage Remediation in Sikaser Dam of Chhattisgarh- *Shreya Rathod, and Akanksha Tyagi, IIT, Roorkee*

In a presentation titled "Feasibility Study of Suitable Grouting Technique for Seepage Remediation in Sikaser Dam of Chhattisgarh" an earthen structure located in Gariyaband district of Chhattisgarh, features a main dam length of 876.31 meters, a saddle dam length of 666.60 meters, and a height of 31.7 meters. It is designed for a discharge capacity of 35.37 cumecs and has a catchment area of 497 square kilometers. An inspection conducted by the State Dam Safety Review Panel (DSRP) on February 9, 2022, highlighted significant leakage at chainage 28.75 on the downstream slope, approximately 3 - 4 meters above ground level. The seepage was observed to increase with rising reservoir levels, suggesting potential piping through the dam body. The DSRP recommended reconstruction or replacement of the core section as a remedial measure and emphasized monitoring of seepage discharges.

Further investigation using Electrical Resistivity Imaging (ERI) by the School of Studies in Geology & WRM, Pt. Ravishankar Shukla University, Raipur, provided detailed insights into seepage pathways. Two profiles were established: Profile 1 along the reservoir side and Profile 2 along the downstream side, each utilizing 48 electrodes spaced at 5 meters. Low resistivity zones (LRZ) indicative of seepage was identified from 1.25 to 28.7 meters depth on the reservoir side and 3 to 33.8 meters on the downstream side. Circular, box-shaped, and elliptical moisture-filled zones pointed to concentrated seepage pathways.

Site visits were conducted on July 6, 2024, and September 6, 2024. The initial visit noted a significant expansion of the seepage cavity under dry conditions. In September, after rainfall, an increase in seepage discharge was observed, with flow extending further downstream. Sandbags were temporarily placed to manage the issue. Soil samples were collected from five locations surrounding the seepage cavity for laboratory analysis.

A comprehensive laboratory investigation was undertaken, including density bottle tests, grain size analysis (wet sieve and hydrometer), Atterberg limits, unconfined compressive strength (UCS) tests, dry density by core cutter method, falling head permeability tests, and dispersion tests (double hydrometer and crumb tests), following IS and ASTM standards. The soils were classified as CL-ML, SM-SC, CL, SC, and CL, with fines ranging from 44% to 61%. Liquid limits and plastic limits ranged between 21% - 27% and 13% - 17%, respectively. The average specific gravity was found to be 2.618, with a permeability of 1.26×10^{-6} m/s. UCS results indicated medium to stiff clay characteristics, with an average undrained cohesion of 55k Pa.

Dispersion testing revealed intermediate dispersive behavior (31.62% dispersion), although crumb test results showed no significant turbidity, underlining the site-specific nature of dispersion characteristics. Based on laboratory results, the feasibility of permeation grouting was assessed. Although chemical grouts such as acrylic resin and colloidal silica have been reported to be effective for soils with permeabilities as low as 10^{-6} m/s, their application in low-plasticity silts and clays remain uncertain. Given the soil conditions at Sikaser Dam, permeation grouting with these chemical grouts was not deemed suitable.

Ms. Shreya Rathod making the presentation

Jet grouting emerged as a more viable technique, as it does not rely on natural soil permeability but instead creates soil-cement columns through high-energy jets of grout that erode and mix the in-situ material. Deep Soil Mixing (DSM) was also considered a feasible method. Both techniques allow the construction of effective cutoff barriers. DSM employs cutting and mixing tools to blend cement slurry with soil, while Jet Grouting (JG) uses high-pressure grout jets.

Considering the site conditions and laboratory findings, constructing a cutoff wall using overlapping columns formed via Jet Grouting or Deep Soil Mixing with Ordinary Portland Cement (OPC) and a water-to-binder ratio of 1.5 to 2, supplemented with 3% bentonite, is recommended for seepage remediation at Sikaser Dam.

Technical Session-3: Dam Health Monitoring

13. Framework for Developing an Effective Early Warning System (EWS) For Dams in Compliance with Dam Safety Act 2021 In India" - *Vijay Dubey, Director, Jomiso Consulting Pvt. Ltd.*

Mr. Vijay Dubey delivered a comprehensive and insightful presentation on the development of an effective Early Warning System (EWS) for dams, aligned with the provisions and mandates of the Dam Safety Act 2021. His session focused on the critical need for robust monitoring and communication mechanisms to ensure public safety, mitigate disaster risks, and support decision-making in emergency scenarios related to dam operations.

Shri Milon Mukhopadhyay presenting memento to speakers

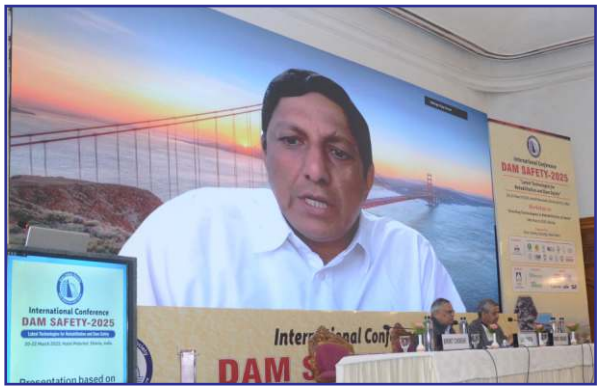
Key Highlights of the Presentation:

• Context and Regulatory Framework: The presentation began with a concise overview of the Dam Safety Act, 2021, emphasizing its critical role in shaping dam safety governance across India. The Act outlines the legal responsibilities of dam owners, particularly concerning the implementation and maintenance of Early Warning Systems (EWS). It also elaborates on the institutional framework established under the Act, highlighting the functions of the National Committee on Dam Safety and corresponding State Committees. These bodies are tasked with overseeing dam safety measures, ensuring compliance, and fostering coordination among various stakeholders.

• Importance of Early Warning Systems (EWS): Early Warning Systems were underscored as a cornerstone of comprehensive risk management. The presentation explained how EWS integrates both structural and non-structural components to facilitate hazard identification, continuous monitoring, and timely dissemination of warnings to vulnerable populations. Case studies were presented to illustrate how effective EWS implementations have successfully mitigated the impact of dam-related emergencies, thereby safeguarding lives and property.

• Framework for Developing an Effective EWS: A structured framework based on the four key pillars of an EWS was detailed: (i) Risk Knowledge, (ii) Monitoring & Warning Services, (iii) Dissemination & Communication, and (iv) Response Capability. A step-by-step methodology was proposed for designing and executing a functional EWS tailored to dam sites. Special emphasis was placed on community-centric planning, coordination among multiple stakeholders, and ongoing capacity-building initiatives to ensure local preparedness and responsive action during emergencies.

• Technological Integration: The role of modern technology in enhancing the effectiveness of EWS was discussed extensively. Real-time data acquisition systems, telemetry, GIS, hydrological modeling, and automated alert mechanisms were identified as key technological tools. The presentation recommended adopting advanced solutions such as IoT-enabled devices, satellite-based communication, and artificial intelligence for improved forecasting, risk analysis, and timely decision-making.



Shri Vijay Dubey making the presentation

• Challenges and Recommendations: The session concluded with a critical look at the existing challenges in implementing robust EWS systems. Issues such as limited funding, coordination gaps between agencies, and insufficient technical capacity were highlighted. To address these, the presentation called for the development of standardized protocols, continuous training programs, public awareness campaigns, and regular mock drills. Additionally, the involvement of the private sector and the adoption of Public-Private Partnership (PPP) models were encouraged to ensure the long-term sustainability and scalability of EWS initiatives.

Mr. Vijay Dubey's presentation underscored the urgent need for dam owners and regulatory bodies to act proactively in building robust Early Warning Systems, in compliance with the Dam Safety Act 2021. The session provided valuable direction and practical recommendations that can aid in strengthening dam safety mechanisms across the country, ultimately aiming to protect lives, livelihoods, and infrastructure in downstream areas.

14. Advanced Condition Assessment of Dam Structures: Leveraging NDT Technologies and Instrumentation for Comprehensive Structural Health Evaluation - *Nirmit Chokshi, SBU Head, TrafikSol ITS Technologies Ltd.*

Mr. Nirmit Chokshi delivered a highly technical and insightful presentation focusing on advanced techniques for the assessment of dam structures, with a specific case study of Ukai Dam in Gujarat. The presentation emphasized the

integration of Non-Destructive Testing (NDT) technologies and modern instrumentation tools to conduct a comprehensive evaluation of dam piers, particularly in the context of replacing dam gates.

Proceeding Notes: Case Study – Condition Assessment of Dam Piers at Ukai Dam, Gujarat
The case study focused on the structural condition assessment of the dam piers at Ukai Dam in Gujarat, which houses 22 gates with each pier having a width of 4.2 meters. The primary objective of the assessment was to evaluate the structural health of the piers to support the planned replacement of the dam gates, ensuring safety and long-term operational integrity.

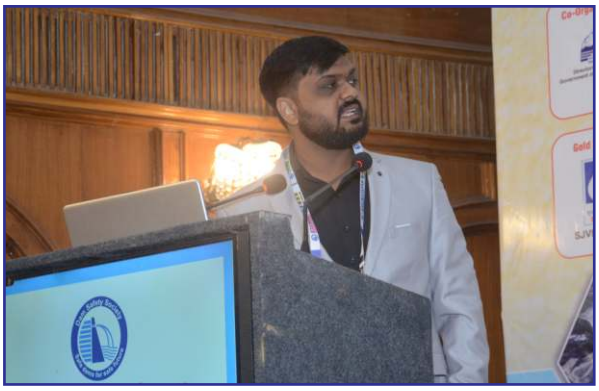
(i) Parameters Assessed and Methodologies Used

- Reinforcement Details: To determine the internal reinforcement layout of the dam piers, Ground Penetrating Radar (GPR) technology was employed. This non-invasive method helped in accurately detecting the placement and distribution of steel reinforcement within the concrete.

- Homogeneity of Concrete: Ultrasonic Tomography, specifically multi-channel pulse echo technology, was used to assess the homogeneity of the concrete. This method enabled the identification of internal voids and provided insights into the overall uniformity and integrity of the concrete structure.

- Concrete Strength Evaluation: The compressive strength of the concrete was evaluated using core samples of 155 mm diameter. These samples were tested to determine the actual strength values, offering a reliable measure of the piers' load-bearing capacity.

- Chemical Condition of Concrete: Chemical tests were conducted to assess carbonation depth and sulphate content. The pH values of the samples ranged from 8.53 to 10.88, and the levels of chlorides and sulphates were found to be within permissible limits. This indicated the presence of chemical degradation, although it had not fully penetrated the depth of the concrete.


Shri Nirmit Chokshi making the presentation

- Permeability of Concrete: Permeability testing was carried out using the double packer method, which is effective both above and below the water table. This test addressed challenges such as varying borehole diameters, presence of lift joints, and high-pressure zones, helping to understand water ingress behavior through the concrete.

(ii) Key Findings from the NDT Assessment of Dam Piers: The assessment revealed variability in compressive strength across the piers, ranging between 35 MPa and 60 MPa. Minor structural deficiencies, such as internal voids and pinholes, were detected particularly in Pier-2 and Pier-9. The thickness of the concrete cover ranged from 73 mm to 290 mm, with most values lying between 150 mm and 250 mm. Though signs of chemical degradation were observed, they had not yet reached critical depth, indicating that the piers were still structurally sound but required timely intervention.

(iii) Recommended Strengthening Scheme: To address the observed deficiencies and enhance the durability of the dam piers, the use of the Poly Ironies Ceramic Cementitious (PICC) system was recommended. This strengthening technology is characterized by its high compressive strength (exceeding 45 Mpa), resistance to ultraviolet radiation, excellent bonding capability, and non-shrink, impermeable protective properties.

(iv) Application Process: The strengthening process involves several preparatory and application steps, including thorough surface cleaning, grouting of voids, patching of lift joints, and resurfacing with a 10 mm thick layer of PICC mortar. This comprehensive treatment aims to restore the structural integrity and extend the service life of the dam piers, ensuring safety and performance during and after the gate replacement process.

In addition to the above case study on condition assessment, Mr. Chokshi introduced a cutting-edge IoT-based Wireless Bridge Health Monitoring System, marking a major innovation in real-time structural health monitoring.

Key Features:
- Fully wireless communication and power supply
- Autonomous battery-powered sensors with integrated data loggers
- IoT-driven architecture with real-time data delivery and onboard memory
- Custom-built 3D visualization dashboard (first-of-its-kind in India)

The IoT-based Wireless Health Monitoring System incorporates a variety of advanced sensors, each designed for specific

structural monitoring functions. Accelerometers are installed on the bridge deck or at the top of pylons to measure natural frequencies and vibrations. Displacement sensors are positioned at expansion joints and bearings to capture linear movements. Strain gauges are embedded in the bridge deck to monitor material strain, while inclinometers are installed on pylons to detect angular displacement or tilting. Corrosion sensors are used on both the deck and pylons to assess the extent of material degradation over time. Weigh-In-Motion (WIM) sensors are placed at the start of the bridge to measure the weight of vehicles as they pass. Load cell sensors, mounted on cable supports, are essential for tracking load transfer and structural stress. Finally, GPS units installed at the top of pylons provide real-time spatial movement and location data to track any structural shifts or deformations.

Mr. Nirmit Chokshi's presentation provided an in-depth perspective on the use of advanced NDT methods and instrumentation to accurately assess and maintain the structural integrity of dam piers. His case study of Ukai Dam effectively demonstrated the practical application of these technologies. The added introduction of the IoT-based Wireless Health Monitoring System showcased the future of dam and bridge health management in India, highlighting innovation, accuracy, and real-time responsiveness as key pillars of structural safety.

15. Baselining the condition and progressing to efficient dam monitoring methods by Creating Digital Portfolio Using Robotic and AI-Based Automated Defects Mapping Technology - *Tushar Gupta, Head of Sales & Marketing - Niricson India & Asia, Dr. Harsh Rathod, CEO & Co-Founder, Niricson Canada.*

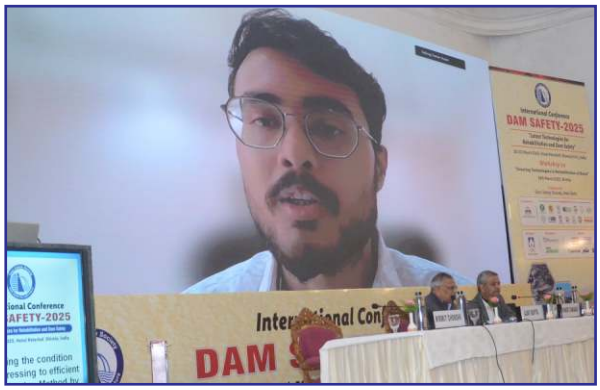
The session presented by Mr. Tushar Gupta and Dr. Harsh Rathod focused on the transformative approach of leveraging AI-based technologies and robotics to enhance dam infrastructure safety and longevity. The speakers, representing Niricson, a global leader in digital infrastructure assessment, emphasized the need for digitization to ensure safer, more efficient, and cost-effective condition monitoring of dam structures.

Niricson operates globally across four continents and serves major heavy civil infrastructure clients such as WaterNSW, BC Hydro, PG&E, and Ontario Power Generation. With a portfolio of 40+ clients and over 100 major infrastructure assets, the company is the only provider with Automated Digital Defect Change Detection and remote delamination detection capabilities. Their approach is uniquely designed by civil engineers for civil engineers.

The presentation opened with a strong case for why condition assessments are more critical than ever. Aging dam infrastructure, increasing frequency of extreme weather events, and limited forecasting abilities for maintenance costs demand a data-driven and predictive approach. Traditional inspection methods—such as rope access, scaffolding, or visual assessments—are often labor-intensive, incomplete, and subjective, leading to missed defects and inconsistent reporting.

To address these challenges, the speakers introduced Niricson's proprietary tools like DRONIC™ for robotic data collection and AUTOSPEX™ for processing and analysis. Their Digital Portfolio Management System enables a multi-layered data approach (2D + 3D), advanced defect mapping, and prioritized deterioration modeling.

A key aspect of the session was the detailed explanation of AI-powered decision-making workflows, which classify defects based on severity-structurally significant, monitorable, or health and safety-related and link them directly to actionable maintenance strategies and work orders.



Shri Tushar Gupta making the presentation

Future Maintenance and Monitoring Strategy: The speakers presented a structured five-step approach for future maintenance planning and monitoring of critical infrastructure, focusing on optimizing condition assessments and repair strategies. The first step involves mapping deterioration using advanced filtering and analysis techniques to visualize the extent and nature of damage. This is followed by identifying focus areas prone to failure, enabling prioritization of maintenance efforts. Based on this, targeted repair plans are developed to address specific issues efficiently. The fourth step includes establishing appropriate scanning frequencies and monitoring schedules, ensuring timely inspections. Finally, multiple scans are performed over time to track condition trends and facilitate early interventions before issues escalate.

They further emphasized an Asset Portfolio-wide Implementation Strategy, where UAV (Unmanned Aerial Vehicle) scanning frequencies are aligned with asset condition classifications. The strategy begins with Step 1: Establishing baseline asset conditions using tools like AUTOSPEX. In Step 2, each asset is assigned to a condition rating or vulnerability index, which then guides the maintenance strategy.

The condition ratings and corresponding actions were detailed as follows:

- Poor Condition: Requires immediate repair or retrofitting; subject to Level 3 UAV scanning annually.
- Moderate Condition: Focus on repairing potential failure areas; undergoes Level 2 UAV scanning every two years.
- Good/Satisfactory Condition: Routine maintenance is sufficient; Level 1 UAV scanning every three years is recommended.
- Level 4 scanning is reserved for performance-based assessments, tailored to asset usage intensity and criticality.

Key Takeaways from the Presentation: The speakers highlighted several advantages of incorporating AI and robotics-based assessments in dam infrastructure monitoring. These technologies provide highly detailed and accurate detection of defects, surpassing traditional inspection methods. Importantly, they enhance personnel safety by reducing the need for manual inspections in hazardous areas. The approach encourages a proactive rather than reactive maintenance culture, helping to prevent failures before they occur. It also supports predictive maintenance strategies, thereby extending the useful life of assets. The adoption of these practices facilitates standardization and enables year-over-year comparability in inspection outcomes. Moreover, the system allows for automated and traceable report generation, greatly improving data integrity and supporting informed decision-making in asset management.

The presentation concluded with a strong emphasis on data-driven capital planning, where AI and automation play a pivotal role in reducing costs, preventing failures, and maximizing the performance and safety of aging dam infrastructures.

16. Safety Inspections of Nathpa Dam - *Jaswant Kapoor, Head of Department (Civil Design), SJVN Limited*

The presentation offered a comprehensive overview of the safety inspection methodologies and best practices implemented at Nathpa Dam, a critical infrastructure component of the 1500 MW Nathpa Jhakri Hydro Power Station (NJHPS) and the 412 MW Rampur Hydro Power Station (RHPS) operated by SJVN Limited, a Navratna CPSE under the Ministry of Power, Government of India. The Nathpa Dam, a 62.5 m high concrete gravity dam, is integral to ensuring consistent hydropower generation for both upstream and downstream stations. Emphasizing the significance of structural integrity, operational reliability, and risk mitigation, the presentation detailed a robust inspection regime that SJVN has institutionalized over the years.

The Nathpa Dam boasts several advanced structural and operational features that contribute to its performance and complexity. These include desilting chambers, a long Head Race Tunnel (HRT) stretching 27.4 km, a deep surge shaft of 301 meters, and underground machine and transformer halls. A notable highlight is the reuse of tailrace water from NJHPS (Nathpa Jhakri Hydro Power Station) by the Rampur Hydro Power Station (RHPS), commissioned in 2015, showcasing efficient and integrated water resource utilization.

Safety Inspection Regimen: A structured inspection and maintenance regimen is in place to ensure continued dam safety and structural integrity.

- Pre-Monsoon Safety Inspections: Conducted annually during March–April, these inspections aim at preventive maintenance and preparing the structure for the upcoming monsoon season. A multidisciplinary team comprising experts in civil engineering, hydro-mechanical systems, geology, and instrumentation carries out the inspections. The scope includes assessment of critical components such as sluice spillways, under sluices, galleries, and drainage holes, alongside monitoring instruments like stress meters, piezometers, and strong motion accelerographs. Additionally, radial gates, intake gates, and control panels undergo visual and operational checks. Geological inspections focus on rock slope stability and bank anchoring systems.

- Key observations include persistent erosion in sluice spillways from boulder impacts during floods, routine rusting and clogging of V-notches requiring replacement, and the need for restoration of non-functional instruments and gate mechanisms.

Shri Jaswant Kapoor making the presentation

- Post-Monsoon Safety Inspections: These inspections are carried out during September–October, aimed at evaluating the impacts of monsoon-induced stresses. The entire dam structure is reassessed for signs of seepage, erosion, or hydrodynamic loading. It also involves validating pre-monsoon recommendations and guiding condition-based maintenance actions.

- External Agency Inspection: The Dam Safety Organization (DSO), Nashik, under the Government of Maharashtra, conducts independent inspections to provide unbiased expert evaluations. Their role includes detailed inspection of structural and monitoring components, validation of internal reports, and proposing remedial measures and long-term strategies. The use of modern tools such as

non-destructive testing (NDT), real-time data acquisition, and remote sensing is integrated into these inspections.

In addressing erosion challenges, the dam authority is collaborating with IIT Delhi to implement advanced materials, specifically High-Performance Concrete (HPC) and High-Performance Fiber-Reinforced Concrete (HPFRC), both of M80 grade. These materials are expected to significantly enhance the durability of spillway surfaces and reduce structural degradation, especially in high-abrasion zones.

Conclusions and Takeaways:

- Nathpa Dam is a critical component of India's renewable energy infrastructure, contributing significantly to power generation through integrated water usage.
- The multi-tiered inspection framework, consisting of internal (pre- and post-monsoon) and external (third-party) reviews, ensures continuous structural oversight.
- The incorporation of advanced monitoring technologies supports predictive maintenance, reducing the risk of unexpected failures.
- Outcomes from inspections have driven essential safety interventions, such as structural rehabilitation, slope stabilization, and upgradation of instrumentation.
- The ongoing R&D initiative with IIT Delhi reflects a shift toward innovative and sustainable engineering solutions.
- The proactive efforts of SJVN (Satluj Jal Vidyut Nigam) serve as a model for dam safety management, integrating operational efficiency with robust structural health protocols.

The presentation by Mr. Jaswant Kapoor highlighted the strategic foresight and engineering discipline embraced by SJVN in ensuring dam safety. Through comprehensive inspections, integration of modern technologies, and academic collaborations, Nathpa Dam stands as a benchmark for efficient dam safety protocols and infrastructure management in India's hydropower sector.

17. Site-Specific Case Study On "Optimizing Seismic Monitoring Systems for Enhancing Safety at Tehri Dam – Uttarakhand- *Vinod Tamaar, Director (Technical), Photonics Watertech Pvt. Ltd.*

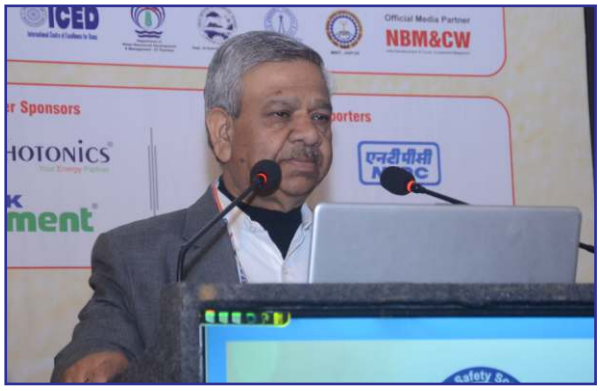
A detailed technical presentation was delivered by Mr. Vinod Tamaar, Director (Technical), Photonics Watertech Pvt. Ltd., focussing on the optimization of seismic monitoring systems at the Tehri Dam in Uttarakhand. The presentation offered valuable insights into the implementation, significance, and long-term performance of seismic instrumentation and geotechnical instruments in ensuring dam safety and structural integrity.

Photonics is a leading provider of advanced geotechnical and seismic instrumentation solutions for critical infrastructure such as dams and bridges. Their portfolio includes Seismic Instruments Strong Motion Accelerographs (SMA) and Geotechnical Instruments ranging from VW Piezometers, Crack Meters, V-Notches, Survey Markers, Joint Meters, Uplift Pressure Gauges, Temperature Sensors, Tilt Meters (including wireless versions), Optical Displacement Meters, and Joint Meters.

Key Projects Completed: Tehri Dam, Uttarakhand, Teesta Urja Limited, Sikkim, Ranjit Sagar Dam , Pathankot, Idukki Dam, Kerala and Bandra Worli Sea Link, Mumbai

- **Case Study: Project Background-Tehri and Koteshwar Dam Instrumentation**

The structural health monitoring initiative for the Tehri and Koteshwar Dams was undertaken with a focus on enhancing dam safety through advanced instrumentation. Strategic placement of sensors and monitoring equipment was a key component of this effort. At Tehri Dam, instrumentation was installed at the top of the inspection gallery, within the AGBR Tunnel, and in the powerhouse area. Similarly, for the Koteshwar Dam, the sensors were positioned at the top of the dam, the central section, and the foundation. These installations were driven by the region's seismic sensitivity and the strategic importance of both dams in terms of water resource management, hydropower generation, flood control, and irrigation.



Shri Vinod Tamaar making the presentation

- **Project Execution at Tehri and Koteshwar Dams:** The initial installation of the seismic monitoring systems at Tehri and Koteshwar Dams was completed in 2013. The system was configured to stream data via broadband telephone lines using static IPs, ensuring a reliable real-time connection to IIT Roorkee, which served as the consulting partner for THDC. Photonics, the implementation partner, has been delivering continuous technical support, conducting monthly inspections, and maintaining the systems since inception. With over 12 years of uninterrupted operation, the system has proven its reliability in delivering valuable seismic data. Currently, a dedicated

in-house team from Photonics is responsible for managing data analysis and reporting activities, thereby ensuring the long-term sustainability and effectiveness of the monitoring framework.

- **Importance of Seismic Monitoring in Dam Safety:** Seismic monitoring plays a crucial role in ensuring the operational reliability and structural integrity of dams, especially in regions classified as high seismic risk zones. The implementation of such monitoring involves comprehensive site-specific prefeasibility analyses, optimal placement of sensors such as Strong Motion Accelerographs (SMAs) and Broadband Seismographs (BBSs), and continuous, real-time observation of the structural response to seismic events. This enables early detection of stress points or potential damage, which is essential for proactive maintenance and the formulation of emergency response plans.

- **Key Benefits and Features of Seismic Monitoring:** Seismic monitoring systems provide uninterrupted data on both minor and major seismic events, offering valuable analytical insights into dam performance under dynamic conditions. These insights help evaluate the resilience of the structures against seismic activity. Furthermore, the data supports a deeper understanding of dam behavior as well as surrounding geotechnical characteristics. Over time, this knowledge contributes to the development of improved dam design standards and more effective mitigation strategies.

- **Critical Components in Seismic Monitoring Implementation:** Successful seismic monitoring hinges on the precise selection and placement of sensors across various structural elements such as dam bodies, abutments, and foundations. The systems also integrate automated alarm mechanisms and threshold-based triggers to alert operators to any anomalies. A robust power supply with backup ensures uninterrupted functionality, while strong communication systems safeguard data transmission integrity. Consistent performance is achieved through regular calibration and maintenance of all equipment. Additionally, advanced data analysis, graphical visualization, and detailed reporting are central to the monitoring system's effectiveness.

- **Key Takeaways**
  - Strategic seismic instrumentation enhances the safety and resilience of dams in seismic zones.
  - Long-term reliability of instrumentation requires consistent monitoring, data integration, and institutional collaboration.
  - The success at Tehri Dam demonstrates the effectiveness of indigenous technology and public-private partnerships in dam safety management.

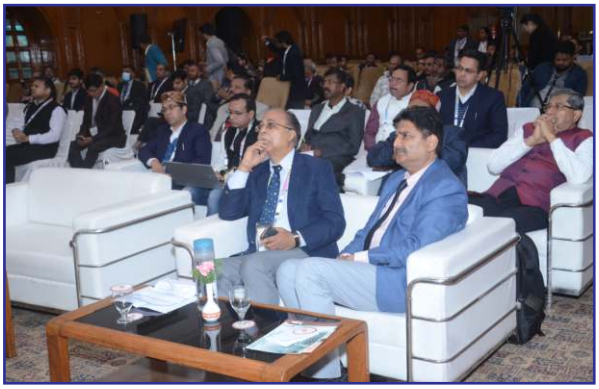
Mr. Vinod Tamaar's presentation emphasized the critical role of customized seismic monitoring solutions in optimizing dam safety. The successful long-term implementation at Tehri Dam showcases a model of technological excellence, sustained maintenance, and real-time risk mitigation, setting a benchmark for other dam safety programs across India.

Technical Session-4: Hydrological Safety of Dams

18. Design Flood Review and Managing Revised Floods- *Arnab Bardhan and Manish Raj, Hydrology Unit, DMR Hydroengineering & Infrastructures Ltd.*

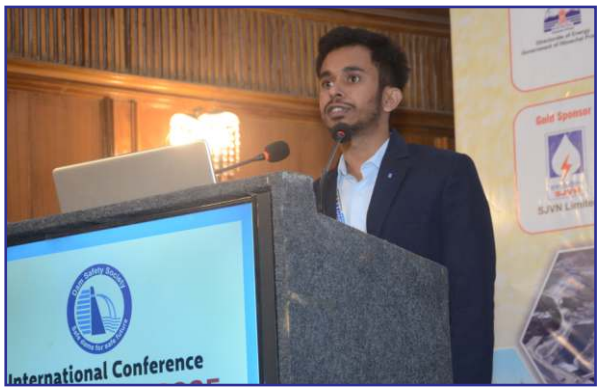
The presentation commenced with an overview of large dams in India, highlighting that India ranks third globally after China and the USA in terms of the number of large dams. According to the National Register of Large Dams 2023, India has a total of 6,281 large dams, out of which 6,138 are operational, and 143 are under construction. The speakers emphasized the critical impact of climate change on dam design, noting the increasing frequency of extreme rainfall events such as cloudbursts, cyclones, and intense short-span rainfall. Many Indian dams were originally designed using empirical methods based on limited historical hydrological data, without consideration for more severe events like the Standard Project Flood (SPF) or Probable Maximum Flood (PMF).

A brief description of the Dam Rehabilitation and Improvement Project (DRIP) was provided. Supported by the World Bank, DRIP aims to strengthen dam safety in India and was initially implemented across Kerala, Madhya Pradesh, Odisha, and Tamil Nadu. It was later expanded to include Karnataka, Damodar Valley Corporation Ltd., and Uttaranchal Jal Vidyut Nigam Ltd., with Central Water Commission (CWC) overseeing the overall coordination with assistance from an engineering and management consulting firm. The rehabilitation measures under DRIP focus on enhancing hydrological, operational, and structural safety, controlling seepage, and improving basic dam safety facilities such as monitoring and early warning systems.



View of Audience

The concept of Inflow Design Flood (IDF) was explained, stressing its vital role in dam safety and design. As per IS 11223:1985, IDF selection depends on the dam classification based on gross storage capacity and static head, ranging from a 100-year flood for small dams to the PMF for large dams. Recent CWC guidelines published in 2021 provide a structured approach for determining IDFs for existing



Shri Manish Raj making the presentation

dams. A pressing need for periodic review of design floods was highlighted, citing that many older dams do not meet contemporary flood safety standards, exposing populations to increased risks. The catastrophic failure of the Machchu-II Dam in 1979, caused by overtopping due to unprecedented rainfall, served as a stark reminder of the consequences of inadequate flood design. The data presented showed that, upon review, 56% of reservoirs exhibited a revised design flood more than 50% higher than the original, and for 33% of reservoirs, the revised flood was more than double, reinforcing the need for periodic reassessment.

The speakers detailed design flood risk mitigation measures, including augmenting spillway capacity, providing breaching sections or fuse plugs, increasing freeboard levels, establishing early warning systems (EWS), and increasing flood storage capacities. Two case studies were shared to demonstrate successful flood mitigation efforts. At Hirakud Dam, the existing spillway capacity of 42,450 m³/s was found insufficient against the revised design flood of 69,632 m³/s. Consequently, the construction of an additional spillway was initiated, with the World Bank supporting the proposal. Another case study at Chandpatha Dam highlighted the installation of 17 Godbole-type automatic tilting gates, enhancing the flood handling capacity from 424.8 cumec to 1,226 cumec. These gates automatically adjust to changing upstream water levels, offering both automatic and manual operation modes, thereby significantly improving flood management.

In conclusion, the presenters underscored the importance of enhancing spillway capacities, adopting advanced flood control systems like automatic gates, and implementing non-structural measures such as EWS and Emergency Action Plans (EAPs). They emphasized that revised flood risk assessments are crucial in the context of changing rainfall patterns induced by climate change. A comprehensive risk management strategy combining structural upgrades with non-structural measures was advocated to bolster flood resilience. Continuous investment in infrastructure, technology, and governance was deemed essential to ensuring the long-term safety and adaptability of India's dams in the face of evolving hydrological challenges.

19. Dam Safety Assurance under Climate Change - *Rajib Chakraborty, Chief Advisor, Water Resources Department, Lea Associates South Asia, New Delhi, India*

The presentation began by defining climate change as long-term shifts in temperatures and weather patterns, emphasizing its emerging role as a major cause of dam failures across the globe. It was highlighted that nearly 70,000 dams worldwide now face heightened risks due to the increasing frequency and intensity of extreme weather events driven by climate change. A sharp rise in dam failure events was observed in 2024, illustrating the urgent need for addressing climate-related vulnerabilities. Specific cases were cited, including the catastrophic collapse of the Alua Dam in Nigeria, which caused extensive flooding in Borno State, resulting in over 150 fatalities and the displacement of around 419,000 people. Similarly, the failure of the Arbaat Dam in Sudan led to massive downstream flooding, with over 60 reported deaths and the destruction of 20 villages. In Kenya, the Nakuru Dam burst due to heavy rains and flash floods, causing more than 168 deaths and displacing over 150,000 individuals. The Orsk Dam collapse in Russia was another example of climate-induced flooding impacts. Within India, the Malana Dam in Himachal Pradesh collapsed in August 2024, and the cascading impacts of a Glacial Lake Outburst Flood (GLOF) led to the destruction of the Teesta III hydropower project dam in North Sikkim in October 2023, followed by a severe landslide in August 2024 that devastated the Teesta-V hydropower station operated by NHPC Limited.

Moving forward, the impact of climate change on dam safety was discussed using a risk modeling framework, which consists of three key components: the loads on the system, the system response or failure probability, and the consequences, including economic losses and loss of life. In modern dam safety risk analysis, it is critical to evaluate total risk while integrating climate change impacts and considering the interdependencies among different risk factors.

Shri Rajiv Chakraborty making the presentation

Flood risk management was identified as a crucial strategy for dam safety under changing climatic conditions. Effective flood risk management involves proper estimation of flood magnitudes, careful control of reservoir water levels, improvement in the performance of dam gates, and the adoption of robust flood routing strategies.

Special attention was given to the management of Glacial Lake Outburst Floods (GLOFs), a growing concern in mountainous

regions. GLOF management strategies include reducing the volume of water in glacial lakes through controlled breaching, construction of outlet control structures, pumping or siphoning water, or tunneling through moraine barriers. Additional measures involve implementing preventative actions around the lake areas, protecting critical infrastructure from surge forces, and setting up monitoring and early warning systems. It was noted that India's National Disaster Management Authority (NDMA), in collaboration with the Swiss Agency for Development and Cooperation (SDC), has developed comprehensive guidelines for managing GLOF hazards.

Lastly, the importance of optimizing reservoir operations and implementing integrated reservoir management practices was stressed. This includes short-term, long-term, and seasonal optimization of reservoir storage and releases, as well as the development of comprehensive river models to support more adaptive and resilient water management decisions.

The session concluded with a strong message that through the meticulous application of these flood management, GLOF mitigation, and reservoir optimization strategies, the risks to dam safety arising from climate change can be substantially reduced, safeguarding lives, property, and critical water infrastructure for the future.

Mr. Evangelos (Angelos) Rabias making the presentation

20. Increasing Dam Safety Against Floods: Rehabilitation of a Dam with Fusegates in the USA- A Case Study - *Subramanian Jagadeesan and Evangelos (Angelos) Rabias, Business Development Manager, Hydroplus*

The presentation focused on the rehabilitation of a dam located near Cullowhee, North Carolina, used for both hydropower generation and recreational purposes. The dam is a rock-fill embankment with an earth core, standing 52.73 meters high and extending 179.83 meters along the crest. The dam's principal spillway was equipped with a Tainter gate measuring 7.62 meters by 7.62 meters, and the auxiliary spillway consisted of two fuseplugs with a combined length of 60.96 meters, designed to activate only for safety purposes.

Following new regulatory requirements by FERC mandating the safe passage of the full Probable Maximum Flood (PMF) downstream, the dam owner, Duke Energy, needed to upgrade the spillway to enhance safety, increase spillway capacity, and find a cost-effective solution. Hydroplus was engaged to address these challenges by providing a solution that required no human intervention or external power, increased water discharge capacity, and remained economical compared to other available alternatives.

The selected solution involved the installation of Fusegates — a passive system designed to safely pass the required PMF downstream. The semi-labyrinth shape of the Fusegates allowed an increase in spillway discharge capacity without the need for extensive spillway expansion or difficult excavation work. This solution also significantly reduced construction time and costs, required minimal maintenance, and had no operation costs. The Fusegates operate by forming a watertight barrier, with each unit bearing against small abutment blocks set in the sill to prevent sliding. A drainage chamber at the base, connected to an inlet well at the upstream crest, activates the gates automatically when the reservoir reaches a specific level.

The design featured six semi-labyrinth-type Fusegates, each 7.62 meters in height and 12.70 meters wide, installed along a 76.20-meter-long spillway sill. Six remote-protected inlet wells and one protected well tower were also part of the system. Physical modeling was critical to the design process, starting with a 1:8 scale model of a single gate to understand air entrainment characteristics, followed by a 1:19 scale model of the entire system to ensure accurate calibration. One important finding was that the Fusegates are self-ventilating, eliminating the need for an additional ventilation system.

Construction activities included inspecting the spillway sill and abutment walls for tolerance, laying out Fuse gate locations, constructing and installing the Fusegates, determining their weight and center of gravity through jacking, placing ballast concrete, installing the watertightness system, and completing a final as-built survey. The construction, completed between December and May under challenging winter conditions, successfully delivered the upgraded spillway system.

The project concluded with a significant increase in dam safety through a passive, cost-effective solution that enhanced the spillway capacity without requiring operational maintenance or external power sources, thereby fulfilling all regulatory and safety objectives effectively.

Mr. Peter Thomson making the presentation

21. The Purpose of the Right Dam Control Valves for Precise Regulation of Water Levels and Flow Rates - *Peter Thomson, AVK Group*

Mr. Peter Thomson from AVK Group delivered an insightful presentation on the importance of selecting the right control valves for precise regulation of water levels and flow rates in dams and reservoirs. AVK, headquartered in Denmark, is a global leader with operations in over 107 countries, operating more than 40 factories worldwide, including two key facilities in India-AVK Valves India Pvt Ltd in Malur, Karnataka, and ORBINOX India in Coimbatore. The group employs over 6,300 people and boasts an annual turnover exceeding 10,000 crore INR.

Highlighting the role of valves and gates as safety-critical equipment, Thomson emphasized their vital applications in everyday water extraction, sediment management, hydropower and pumped storage systems, environmental flow regulation, and emergency discharges. He stressed that dam safety is increasingly challenged by aging infrastructure, outdated design standards, sediment accumulation affecting inlet gate reliability, and the rising frequency of extreme weather events due to climate change. Furthermore, maintaining environmental flows has now become a legal obligation, adding another layer of responsibility in dam operations.

The presentation outlined the various applications of control valves in spillways, canals, intermediate outlets, bottom outlets, and hydropower systems. For intermediate and bottom outlet discharges, a range of valve options was discussed, including Fixed Cone (Hollow Jet) Valves, Submerged Discharge Valves, and Needle Valves. Fixed Cone Valves, in particular, were highlighted for their ability to handle high-velocity discharges, offer linear control, dissipate energy directly to the atmosphere, and tolerate sediment loads - making them highly suitable for challenging dam operations.

Thomson also introduced the Glenfield - AVK reservoir specification gate valves, designed to accommodate increased flow velocities and ensure extended product longevity. These valves come standard with features such as shoes and channel guides, jacking or easing screws, additional pinning for body and wedge rings, stainless steel fasteners, and enhanced coating thickness for durability.

The presentation concluded by reinforcing the critical role of selecting the right valves and gates to ensure the safe, efficient, and sustainable operation of dams and reservoirs, especially in the face of evolving environmental and operational challenges.

View of Panelists

Technical Session-5: Panel Discussions

Conclusive Notes on Panel Discussion: Issues & Challenges in Dam Health Assessment, Monitoring and Rehabilitation

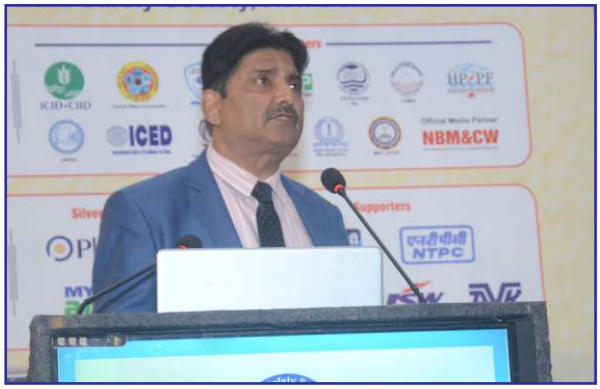
The health assessment, monitoring, and rehabilitation of dams are critical for ensuring their structural integrity, operational safety, and longevity. However, several issues and challenges hinder these processes. One major challenge is ageing infrastructure, as many dams have exceeded or are approaching their designed service life, leading to deterioration in concrete, steel, and embankment materials. Inadequate instrumentation and outdated monitoring systems often result in insufficient real-time data, making it difficult to detect early signs of distress or evolving failure mechanisms. Data management and interpretation is another key challenge; despite available data, converting it into actionable insights requires advanced analytics, specialized expertise, and sometimes AI and ML integration. The lack of standardized guidelines for health monitoring, especially for small and medium-sized dams, further complicates consistent assessments.

Environmental factors such as seismic activity, extreme weather events, and climate change-induced hydrological shifts introduce additional stressors that existing dam designs might not have considered. Resource constraints, both financial and technical, particularly affect dam owners' ability to conduct frequent inspections, maintenance, or upgrades. Furthermore, rehabilitation planning often faces logistical hurdles including project prioritization, environmental clearances, downstream impact assessments, and stakeholder coordination.

Technological advancements, such as remote sensing, smart sensors, fiber optic monitoring, UAV-based inspections, and digital twin modeling, are beginning to address some of these gaps, but mainstream adoption remains limited due to cost, skill gaps, and institutional inertia. There is also a pressing need for capacity building, involving the training of personnel in advanced monitoring techniques, and establishing risk-based prioritization frameworks for rehabilitation investments.

Finally, policy and regulatory support plays a vital role. Strengthened frameworks that enforce regular health assessments,

promote innovative rehabilitation technologies, and encourage public-private collaboration are essential. The path forward must be holistic, combining robust engineering practices, smart technologies, adequate funding, and strong governance to ensure the sustainable safety and functionality of dams.



Shri Vijai Saran making the presentation

Technical Session-6: Implementing Dam Safety Act

22. Challenges in Implementation of Dam Safety Act in India- *Shri Vijai Saran, Former Chief Engineer, Central Water Commission*

The presentation titled “Challenges in Implementation of Dam Safety Act in India” by Shri Vijai Saran, Former Chief Engineer, Central Water Commission, delivered a detailed examination of India's dam safety landscape in the wake of the Dam Safety Act, 2021. With over 6,500 large dams and several under construction, India ranks third globally in dam count. However, a significant proportion of these structures are aged, some over 100 years old presenting considerable safety and operational risks. Shri Saran contextualized this legislative milestone by first tracing India's dam-building evolution and highlighting the state-wise and age-wise distribution of large dams using data from the DHARMA Portal.

The presentation then delved into historical dam failures in India, underlining the vulnerabilities of earthen dams which constitute the majority of failures due to flooding, overtopping, and structural weaknesses. Against this backdrop, the Dam Safety Act, 2021, emerges as a comprehensive statutory framework aiming to ensure the structured surveillance, inspection, maintenance, and risk management of specified dams across the country. The Act mandates uniform procedures and institutionalizes dam safety governance through the creation of bodies such as the National Committee on Dam Safety (NCDS), National Dam Safety Authority (NDSA), State Committees on Dam Safety (SCDS), and State Dam Safety Organizations (SDSOs).

Shri Saran provided an in-depth breakdown of the Act's statutory provisions, detailing responsibilities of dam owners and state agencies across sections related to hazard classification (Sections 16 and 17), operation and maintenance documentation (Section 28), instrumentation and monitoring (Sections 32 and 34), emergency preparedness (Section 36), and Comprehensive Dam Safety Evaluations (Section 38). He emphasized the importance of hazard-based dam classification, pre- and post-monsoon inspections, hydrological and seismic instrumentation, and emergency action planning. These components demand extensive capacity building and role-specific training in technical areas such as dam break analysis, risk assessment, instrumentation setup, flood forecasting, and seismic hazard studies.

A core focus was placed on Emergency Action Plans (EAPs) and Comprehensive Dam Safety Evaluations (CDSE). Shri Saran explained the necessity of dam break analysis for EAPs and its role in generating accurate inundation maps used for disaster mitigation. He discussed breach parameters for different dam types, simulation tools like HEC-RAS and MIKE, and the integration of EAPs with district- and state-level emergency protocols. Regarding CDSEs, he highlighted hydrological reevaluation and Site-Specific Seismic Hazard Assessments (SSSHA), referencing new NDSA mandates and the NCSDP guidelines issued by the Central Water Commission in June 2024. These evaluations are essential for assessing spillway adequacy and seismic resilience of existing dams, especially those in active seismic zones or with a history of geological changes.

The presentation also addressed national-scale inspection efforts post-enactment, citing data from the 2024 inspection cycle. Over 6,800 dams were assessed post-monsoon, with a structured categorization system identifying critical safety threats (Category-I) and major deficiencies (Category-II), feeding into prioritization under programs such as DRIP (Dam Rehabilitation and Improvement Project).

In conclusion, Shri Saran underscored that the real challenge lies not in the provisions of the Dam Safety Act itself, but in its implementation. Key hurdles include inadequate technical capacity, the need for standardized procedures, inter-agency coordination, and timely compliance. He advocated for continuous professional development, knowledge transfer, and investment in monitoring technologies to support sustainable dam safety practices in India. The presentation served as a call to action for strengthening institutional mechanisms, enhancing technical competencies, and promoting a culture of proactive dam risk governance in a country with one of the world's most complex and aging dam inventories.

23. Importance of Dam Safety in India and Dam Safety Act 2021” - *Er. Abhishek, DGM, Civil Design, SJVN Limited.*

Er. Abhishek, DGM, Civil Design at SJVN Limited, delivered an insightful presentation on the “Importance of Dam Safety in India and Dam Safety Act 2021,” emphasizing the growing relevance of dam safety in the backdrop of ageing infrastructure and increasing hydrological risks. He began by defining "dam" and "dam failure" as per the Dam Safety Act, 2021, which

comprehensively includes barrages, weirs, and similar water impounding structures while excluding canal and flood regulation structures. The Act also characterizes dam failure as any structural or operational breakdown leading to uncontrolled release of water, posing significant threats to life, property, and ecosystems. With India ranking third globally in terms of number of large dams (5,334), Er. Abhishek stressed the economic, strategic, and social importance of these structures, noting that most existing dams are single purpose, primarily for irrigation (48%), followed by hydropower and water supply. Quoting India's first Prime Minister who called dams the "Temples of Modern India," he reiterated their foundational role in national development.

Shri Abhishek making the presentation

He detailed the various causes of dam failures, highlighting overtopping due to inadequate spillway capacity, foundation defects like settlement and slope instability, and internal erosion (piping) caused by seepage through structural anomalies. India has experienced over 40 dam failures, including the catastrophic Machu Dam disaster in 1979 which claimed around 15,000 lives. The recent Teesta-III (Chungthang) dam failure in Sikkim due to a glacial lake outburst further underlined the need for robust dam safety frameworks. Er. Abhishek cited statistics that over 80% of India's dams are more than 25 years old, with many exceeding 100 years, necessitating urgent attention to structural deficiencies, outdated instrumentation, and poor monitoring systems. He identified institutional challenges such as insufficient technical capacity, budgetary constraints, and lack of real-time forecasting systems, making dams increasingly vulnerable.

In response to these risks, the presentation elaborated on the evolution and provisions of the Dam Safety Act, 2021, a landmark legislation enacted after several lapses of earlier bills since 1987. The Act establishes a cohesive legal and institutional framework comprising the National Committee on Dam Safety (NCDS), National Dam Safety Authority (NDSA), State Committees on Dam Safety (SCDS), and State Dam Safety Organizations (SDSO) to enforce dam safety norms, facilitate technical support, and ensure uniform standards across India. It mandates periodic surveillance, classification of dams by hazard potential, instrumentation, hydrometeorological networks, seismic monitoring, risk assessments, and the formulation of Emergency Action Plans (EAPs). Specific roles and responsibilities are assigned to dam owners, including earmarking funds for maintenance, facilitating inspections, and ensuring data transparency.

The presentation also touched upon significant government initiatives such as DRIP (Dam Rehabilitation and Improvement Project), DHARMA (Dam Health and Rehabilitation Monitoring Application), and SHAISYS (Seismic Hazard Assessment Information System). Prior to this legislation, dam safety protocols issued by the Central Water Commission (CWC) were largely advisory in nature. The Act now empowers implementing agencies with enforcement authority, including penal provisions for non-compliance—up to two years of imprisonment in cases resulting in loss of life. Er. Abhishek concluded with a strong message: for a country like India, where millions live downstream of large reservoirs, dam safety is not just an engineering concern but a national imperative. The Dam Safety Act, 2021, represents a paradigm shift granting legal force to dam safety protocols and aiming to ensure a future where safe dams contribute to a safe nation.

24. Measures and Compliance of Dam Safety Aspects in NHPC Presented - *Rakesh Kumar Dubey, GM (Civil) and Thota Venugopal, DGM (Civil), NHPC Limited*

The presentation titled "Measures and Compliance of Dam Safety Aspects in NHPC" delivered by Mr. Rakesh Kumar Dubey and Mr. Thota Venugopal highlighted the critical importance of dam safety in the context of national infrastructure. Dams, being strategic assets, are pivotal to water resource management, energy production, flood mitigation, and food security. However, they face increasing challenges due to aging infrastructure, impacts of climate change, and global warming. To continue deriving uninterrupted benefits from dams and to ensure downstream safety and public confidence, the health and structural integrity of these assets must be consistently assessed and upheld. Dam safety is essential to maintain performance, identify deficiencies, and implement proper operation and maintenance (O&M). The onus for safe O&M, repairs, and rehabilitation lies with dam owners, as the failure of a dam poses significant hazards to human lives, property, and the environment downstream.


Shri Thota Venugopal making the presentation

The advancement of modern technologies, superior construction materials, and improved techniques for investigation, design, and construction have collectively contributed to reducing dam-related failures. NHPC Limited, a key player in India's hydropower sector, owns and operates 21 dams and 5 barrages with a cumulative capacity of 7233 MW, which includes 6971 MW from hydro sources and 262 MW from renewable energy. Additionally, around 9300 MW is

in the pipeline, with 9 dams under various stages of construction. NHPC has proactively adopted dam safety measures, even before the enactment of the Dam Safety Act 2021 and the subsequent 19 regulations. The company has established mechanisms for surveillance, inspection, operation, and maintenance, along with institutional frameworks to ensure the safe functioning of its dam infrastructure.

NHPC carries out scheduled pre- and post-monsoon dam safety inspections (DSI) for both Civil and Hydro-Mechanical components through dedicated dam safety teams and units established at each project. These inspections culminate in detailed reporting and rapid risk screening. A digital module facilitates effective monitoring and closure of actionable points. NHPC maintains regular technical engagements with project sites and state authorities and periodically undertakes comprehensive dam safety reviews. These reviews are conducted by a Panel of Experts (PoE), referred to as the Dam Safety Review Panel (DSRP), comprising specialists from diverse fields including design, safety, construction, hydrology, geology, and hydro-mechanical engineering. These reviews are scheduled once every ten years from the date of commissioning.

To standardize and expedite repair and rehabilitation, NHPC has developed comprehensive guidelines covering damage evaluation, cause analysis, selection of repair materials and techniques, and preparation of technical specifications, bill of quantities (BoQ), and execution drawings. Generic documentation such as the Emergency Action Plan (EAP), Standard Operating Procedures (SOPs) for sudden downstream releases, Early Warning Systems (EWS), reservoir operation manuals, and instrumentation manuals are prepared in line with the latest CWC guidelines of January 2018.

The EAP outlines a detailed response strategy to mitigate downstream impacts in the event of sudden releases or dam failures. It defines roles and responsibilities, emergency levels (Blue, Orange, Red), detection protocols, communication plans, and termination procedures. NHPC has EAPs in place for all operational dams. The EWS, enabled through a master control room and advanced software (eABHAAS), supports 24x7 real-time monitoring and automated alert generation to ensure timely evacuation during flood-like scenarios.

Seismic monitoring is another cornerstone of NHPC's dam safety framework. A network of 56 Strong Motion Accelerographs (SMAs) records data in real time through LAN connectivity with the Real Time Seismic Data Centre (RTSDC). Geophysical techniques such as resistivity imaging, seismic tomography, and ground-penetrating radar (GPR) are utilized for subsurface geological and geotechnical investigations. For SOPs related to sudden water releases, NHPC has identified vulnerable downstream areas and has installed safety measures including warning boards, sirens, barricades, and coordination protocols with upstream/downstream projects and state authorities.

In repair interventions, advanced materials and innovative techniques have been employed, especially at Dhauliganga and other critical sites. These include high-performance cementitious mortars (EN:1504-3, R4 grade), steel liners fixed with countersunk bolts, epoxy compounds compliant with ASTM standards, high-performance concrete (HPC), and use of Concrete Face Rockfill Dams (CFRDs). Non-destructive and semi-destructive tests such as rebound hammer, ultrasonic pulse velocity (UPV), cover meter tests, core sampling, and thickness measurements of penstocks and gates are used to evaluate structural integrity.

Erosion conditions have been categorized into mild, moderate, and severe based on hydraulic head, sediment load, and material impact. Repair strategies are aligned accordingly, using materials such as M25–M30 concrete for mild erosion, M65–M80 HPC for moderate, and steel liners combined with cementitious mortars for severe cases.

These systematic and technically sound measures have led to notable outcomes—enhanced dam health and safety, reduced repair costs and frequency, maintained live storage capacity, increased generation due to fewer forced shutdowns, and prevention of accidents or loss of life. NHPC is also implementing Comprehensive Dam Safety Evaluation (CDSE) for each specified dam within five years of the Dam Safety Act's enactment. CDSE includes design, construction, O&M data review, hydrologic and seismic safety assessment, and further investigations. Of the 20 NHPC dams, reports for five have already been submitted to the National Dam Safety Authority (NDSA), and work is ongoing for others through Independent Panels of Experts (IPoEs). However, challenges persist such as limited availability of domain experts and the need to complete assessments within the mandated timeframe of 1.5 years.

The presentation effectively underscored NHPC's commitment to dam safety through meticulous planning, advanced technologies, proactive institutional mechanisms, and continuous compliance with statutory regulations and best practices.

25. Dam Safety-Priority Areas: Experiences in Dam Engineering- *Amitabh Tripathi, P. Sumana and S.S. Walia, WAPCOS*

The presentation by Sh. Amitabh Tripathi, a distinguished professional from WAPCOS, provided deep insights into dam safety as a priority area, drawing from decades of experience in dam engineering. He began by introducing WAPCOS, a Government of India undertaking, which began its journey in 1969 with only 7 members and operations limited to Afghanistan. Fast forward to 2024, WAPCOS has transformed into a true Indian multinational, operating in over 50 countries, employing more than 4600 professionals, and maintaining 57 international offices, in addition to 100+ domestic

project offices across India. The organization provides a wide spectrum of consultancy and construction services, from concept to commissioning, encompassing preliminary investigations, feasibility studies, socio-economic surveys, engineering design, construction supervision, operation and maintenance, and institutional development.

Shri Amitabh Tripathi making the presentation

The core of the presentation focused on the priority areas in dam safety, highlighting the increasing challenges posed by aging dam infrastructure. India houses 222 large dams that are over a century old. These aging structures face multiple risks including structural deficiencies, inadequate monitoring facilities, and an inability to meet current hydrological and structural design standards. Further compounding the issue is the lack of institutional and technical capacities at the state level, along with budgetary constraints in maintaining and upgrading dam safety mechanisms.

Sh. Tripathi emphasized the grave threats posed by dam failures, including significant loss of life, destruction of property and infrastructure, economic disruptions, and long-lasting environmental damage. These dangers necessitated the enactment of the Dam Safety Act, 2021, which came into force in December 2021. This legislation aims to institutionalize dam safety practices by introducing uniform standards, mandating regular inspections, surveillance, and maintenance. It applies to dams with a height greater than 15 meters or between 10 to 15 meters under certain structural conditions. The Act establishes mechanisms at both the central and state levels to ensure effective implementation.

WAPCOS's extensive capabilities in dam safety align closely with the mandates of the Dam Safety Act. These include preparation of Operation and Maintenance Manuals (Section 28), conducting Dam Safety Audits and Inspections (Section 31), reviewing dam instrumentation systems (Section 32), and performing Dam Break Analysis using advanced tools like HEC-RAS and MIKE to assess downstream inundation and risk. The organization also undertakes Hydrological Studies and Design Flood Reviews (Section 33) using site-specific hydrometeorological data and rainfall-runoff models to determine appropriate design flood levels. Notably, older dams built before the concept of Glacial Lake Outburst Floods (GLOFs) emerged in the early 2000s are particularly vulnerable, especially in the Himalayan region.

In addition to technical analyses, WAPCOS prepares Emergency Action Plans (Section 36) tailored to each site. These include inundation mapping for various flood scenarios, assessment of downstream risks to lives and property, allocation of emergency roles and resources, and detailed notification and communication protocols to facilitate timely evacuation and disaster response.

The organization also excels in Stability Analysis through slope stability assessments and 3D stress analysis using Finite Element Methods (FEM), and in conducting in-situ tests such as Groutability Tests, Non-Destructive Testing (e.g., Rebound Hammer, Ultrasonic Pulse Velocity), and comprehensive geotechnical investigations.

Highlighting their Design Flood Study capabilities, Sh. Tripathi explained WAPCOS's multidisciplinary approach which includes data collection, hydrological and hydraulic modeling, climate change impact assessments, risk mitigation recommendations, and adherence to national and international safety guidelines. Their portfolio includes landmark projects such as the Pancheshwar Multipurpose Project in Nepal and Kurigongri Hydro Electric Project in Bhutan, with design floods exceeding 25,000 cumecs.

Further, WAPCOS integrates flood risk analysis within broader Integrated Water Resources Management (IWRM) frameworks, optimizing dam operations for flood control and hydropower generation. Their rich experience spans both greenfield and brownfield projects across India and internationally, underlining their role as a key contributor in enhancing dam safety and resilience in an era of increasing hydrological uncertainties and climate change challenges.

Ms. Suchismita Das making the presentation

In conclusion, the presentation was a comprehensive overview of the evolving landscape of dam safety, backed by WAPCOS's decades-long expertise. It stressed the urgent need for modernization, systematic inspections, emergency preparedness, and data-driven decision-making to safeguard the nation's aging dam infrastructure.

26. Re-Energizing Power Plants Through Renovation, Modernization and Life Extension of Hydroelectric Projects - *Shrish Dubey, Prashant Jaiswal, and Suchismita Das of NHPC Ltd., India*

The above presentation delved into the pressing need and implementation strategies for enhancing the performance and extending the life span of aging hydroelectric power stations. Hydroelectric plants, due to prolonged usage and wear over time, face operational and maintenance challenges, particularly in their electro-mechanical components which have a normative lifespan of 35–40 years, although the civil structures are typically designed for over a century of service. The Renovation, Modernization, Uprating, and Life Extension (RMU & LE) programs emerge as viable, cost-effective solutions to improve efficiency, reliability, and reduce maintenance, often extending plant life by an additional 25 years.

The presentation detailed the benefits of RMU & LE initiatives, including overcoming issues of aging infrastructure, fatigue, obsolescence in technology, and de-rating of components. The case of Loktak Power Station in Imphal, Manipur, was extensively discussed as a successful example of an RMU project. Commissioned in 1983, this 105 MW plant is part of the Loktak Lake Multipurpose Project and plays a critical role in power supply to Northeast India. Having completed its normative life by June 2018, a comprehensive R&M plan was initiated by NHPC based on CEA guidelines, aiming to extend the plant's operational life by another 25 years.

The assessment phase involved detailed inspections and a series of non-destructive and semi-destructive tests, including Rebound Hammer Tests, Ultrasonic Pulse Velocity Tests, Cover Meter Tests, and core sampling to evaluate the condition of civil structures such as the barrage, surge shaft, powerhouse, and switchyard. These investigations confirmed that most civil structures were in sound condition and could be retained with minimal repairs. Key R&M works identified included repairs to erosion and scouring in the Ithai Barrage, stabilization of slopes near the penstock and bypass tunnel, and improvements to civil structures supporting hydro-mechanical and electro-mechanical systems.

The implementation strategy involved packaging the R&M works into 12 distinct contracts of five civil, one hydro-mechanical, four electro-mechanical, and two miscellaneous. The Ithai Barrage underwent repairs using high-strength materials, with enhancements made to mitigate future scouring through installation of gabions, concrete blocks, and a new wing wall. Damaged bamboo trash racks, crucial for restricting the inflow of aquatic weeds, were repaired or replaced. Similarly, the intake power channel and Tiddim Bridge were restored with underwater epoxy mortar and minor structural repairs.

The bypass and penstock areas posed significant geotechnical challenges due to past landslides and geological instability. Observations during inspections revealed severe damage to existing bored piles, crushed pile caps, dislodged rocker supports, and damaged inclinometers. To address these issues, the R&M plan proposed installation of 500mm dia RCC piles, slope stabilization measures, restoration of the drainage network, and deployment of additional instrumentation for monitoring.

Within the powerhouse, wear and deterioration were observed in floors and walls, with minor seepage and erosion of draft tube piers. Repairs included the application of cementitious mortars, restoration of damaged elements, face-lifting, and improvements in aesthetics and functionality. The tailpool and pressure relief systems were also overhauled.

For hydro-mechanical components, issues like gate distortion and hoist malfunction prompted plans for replacement and strengthening of critical elements, including installation of an integrated control and monitoring system. The electro-mechanical refurbishment plans involved replacement or upgrading of major systems turbines, generators, transformers, governors, excitation systems, and auxiliaries to ensure sustained performance and reliability.

In conclusion, the speakers emphasized that RMU & LE programs, such as the one undertaken at Loktak Power Station, offer a timely and economically efficient means of restoring capacity and extending the life of aging hydroelectric infrastructure. These efforts align with national priorities, helping bridge power demand-supply gaps amid resource constraints. The ongoing work at Loktak is expected to yield significant improvements in efficiency, availability, and output, reinforcing the importance of continued investment in hydroelectric modernization.

Technical Session-7: Latest Technologies for Dam Safety

27. Application of Environmental Tracers in Reservoirs Leakage/Seepage Studies - A Case Study: Shehjad Dam, Presented - *Gopal Krishan, Scientist-E, with study team Dr. S. D. Khobragade and Er. Shailesh Kumar, National Institute of Hydrology, Roorkee, Uttarakhand*

The presentation delivered by Gopal Krishan and his team at the National Institute of Hydrology, Roorkee, focused on the application of environmental tracers in investigating leakage and seepage issues in reservoir systems, with a case study of Shehjad Dam in Uttar

Shri Gopal Krishan making the presentation

Pradesh. The sustainability of dams is under increasing threat due to several factors, among which sedimentation and leakage are critical. Leakage, though often an inevitable aspect of reservoir behavior, becomes a concern when it poses threats to dam safety or results in unmanageable water losses. Unfortunately, leakage problems are frequently underestimated during site investigations, particularly when attention is concentrated only on the dam structure, neglecting the broader reservoir and surrounding geological settings.

Historical examples of dam failures in India, such as the Panshet Dam in Maharashtra (1961) and Nanak Sagar Dam in Uttar Pradesh (1967), underline the consequences of improper site selection and lack of comprehensive subsurface investigation. These incidents stress the need for adopting robust diagnostic tools for leakage detection, especially before undertaking repair measures, which are often costly and sometimes ineffective without proper diagnosis.

The presentation explored various non-tracer and tracer techniques available for seepage investigations. Non-tracer techniques include traditional methods such as water balance calculations, piezometric studies, water level-seepage correlations, and borehole flow measurements. However, the use of tracer techniques, especially environmental isotopes like stable isotopes of oxygen (^{18}O) and hydrogen (^{2}H), as well as radioactive isotopes such as tritium (^{3}H) and carbon-14 (^{14}C), can significantly enhance the understanding of seepage pathways and source identification. These isotopes help differentiate between reservoir water, local groundwater, or a mixture of both, thus aiding in the precise determination of leakage sources.

Further, the use of artificial tracers such as iodine-131, bromine-82, and dye tracers in controlled flow tests enables direct assessment of groundwater movement through techniques like point dilution and point injection in boreholes. These tests can quantify horizontal and vertical groundwater velocities, which are vital for identifying seepage flow paths beneath or around the dam structure.

The specific case of Shehjad Dam, constructed on the Shahzad River in the Lalitpur district of Uttar Pradesh, was highlighted. With a gross storage capacity of 127.42 MCM and a live storage of 118.93 MCM, the dam serves an extensive irrigation network. Morphometric and geological assessments indicated the presence of highly permeable crystalline and sedimentary formations, contributing to significant infiltration and subsurface flow. These geological characteristics necessitated the use of isotope hydrology and tracer methods to delineate seepage sources and pathways effectively.

In conclusion, the study emphasized the indispensable role of integrated investigation methodologies combining geological reconnaissance, hydrogeological assessments, and advanced tracer techniques for successful identification and mitigation of reservoir leakage problems. The authors stressed that such investigations should precede any rehabilitation or repair work, as failures often result from inadequate understanding of subsurface conditions. The cost of proper diagnostic studies is minimal compared to the financial and safety risks posed by improperly addressed seepage issues.

28. Integrating Dam Safety Aspects in Pumped Storage Projects for Sustainable Hydropower Development: A GIS-Based Approach - *S.S. Bakshi, Sajal Mittal and Vikash Yadav, CWC*

The presentation titled "Integrating Dam Safety Aspects in Pumped Storage Projects for Sustainable Hydropower Development: A GIS-Based Approach" by S.S. Bakshi, Sajal Mittal, and Vikash Yadav from the Central Water Commission (CWC), emphasizes the vital role of Pumped Storage Projects (PSPs) in achieving India's sustainable energy targets. PSPs function as hydroelectric energy storage systems utilizing two reservoirs at different elevations. During periods of excess energy availability, typically from renewable sources like solar or wind, water is pumped to the upper reservoir, and during peak demand, this water is released back down through turbines to generate electricity. Acting like a large battery, PSPs help manage the intermittency of renewable energy sources, ensuring grid stability and reliability.

The need for PSPs is underscored by India's ambitious climate goals, including a commitment to achieving 50% of its installed energy capacity from non-fossil fuel sources by 2030. The renewable energy sector has already seen exponential growth, with solar capacity increasing over 30-fold in the last decade from 2.8 GW in 2014 to 89 GW in 2024. However, the variable nature of renewable power sources necessitates large-scale energy storage solutions like PSPs. According to the Central Electricity Authority (CEA), the likely installed capacity of PSPs in India is projected to reach approximately 39 GW by 2029-30.

Shri Sajal Mittal making the presentation

PSPs can be classified into three types based on reservoir location: off-stream closed loop (both reservoirs away from a river or stream), off-stream open loop (one reservoir on a river/stream and the other off-stream), and on-stream PSPs (both reservoirs on a river/stream). Closed loop schemes are more flexible in terms of site selection as

they only require favorable topography and an adequate head difference, unlike on-stream or open loop schemes which follow stricter site constraints similar to conventional hydroelectric projects.

To identify potential PSP sites, a systematic GIS-based approach is recommended. The process involves identifying drainage patterns, reclassifying topography, selecting target study areas, generating buffer zones from a central point, locating feasible reservoirs, and producing contour maps for detailed assessment. This geospatial method enhances the efficiency and objectivity in preliminary site selection for PSPs.

The presentation also discusses critical technical considerations during the preparation of Detailed Project Reports (DPRs) for PSPs. These include assessments of hill slope stability and dam toe safety, particularly through tests for cohesion ©, angle of internal friction (φ), and rock integrity. For pit-type surface powerhouses, which are common in PSPs, thorough geotechnical investigations are essential. This includes drilling vertically and inclined boreholes to detect rock discontinuities and conducting a suite of tests such as the Standard Penetration Test (SPT), Pressure meter Test, Cross-hole Seismic Testing, Uniaxial Compressive Strength (UCS), and Permeability Tests.

The legal framework governing dam safety is also explored, particularly in the context of the Dam Safety Act, 2021. The Act defines a dam as an artificial barrier constructed across rivers or tributaries to impound or divert water. However, this definition excludes off-stream structures, which creates a regulatory loophole for many PSPs that do not lie on river systems but still meet the structural height criteria for dams. Given that most PSPs are off-stream and often exceed the height threshold of 15 meters from the foundation to crest, the presentation advocates for amending the Act to explicitly include off-stream pumped storage projects under its purview.

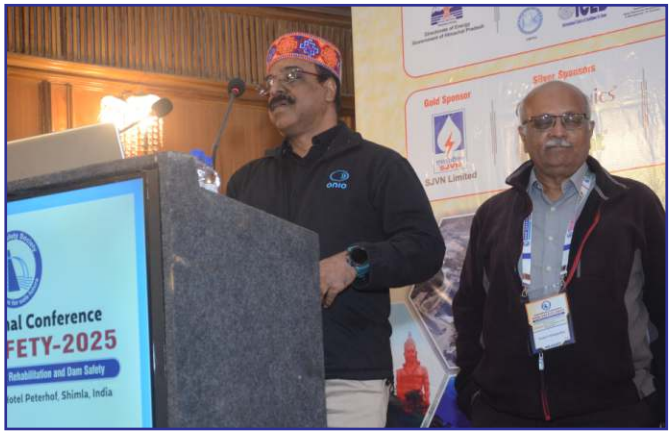
In conclusion, the presentation highlights that integrating dam safety considerations into the planning and implementation of Pumped Storage Projects is essential for the secure and sustainable growth of India's hydropower capacity. It calls for a regulatory update to ensure comprehensive oversight of all types of PSPs, particularly off-stream structures, thereby aligning legal frameworks with emerging energy infrastructure needs.

29. Autonomous Technology for Dam Safety, Maintenance and Rehabilitation- *Sanjeev Afzulpurkar, Alok Mukherjee, Raja Mahbubani, Prakash Khanzode, and Sunny Sebatian, i4 Marine Technologies Pvt. Ltd., Pune, India*

The presentation by i4 Marine Technologies Pvt. Ltd., a Pune-based start-up, showcased cutting-edge innovations in autonomous technologies tailored for dam safety, maintenance, and rehabilitation. Founded by a group of seasoned product designers and technocrats, i4 Marine is driven by the vision of designing, developing, and manufacturing indigenous surface and underwater autonomous systems for marine applications. True to their commitment to innovation and self-reliance, all technologies and products are developed and manufactured in-house, with no reliance on sourced or traded components.

The company's portfolio includes Unmanned Surface Platforms such as Autonomous Surface Vehicles (ASVs), Autonomous Underwater Platforms including Remote Operated Vehicles (ROVs), and a variety of advanced underwater sensors and human-computer interface (HCI) systems. These technologies collectively support critical areas of dam safety, addressing global challenges and emerging needs for the future of dam maintenance and rehabilitation.

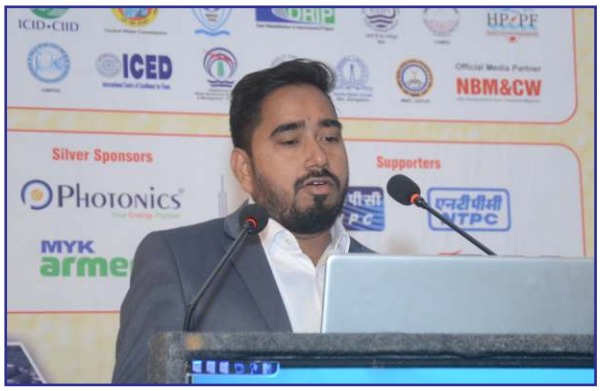
The presentation outlined several vital applications of these technologies in dam safety, including capacity assessment, sedimentation monitoring, estimation of unequal loading on dam walls, surface crack detection, and structural health monitoring. Additionally, the use of autonomous systems enables precise assessment of underwater civil and mechanical structures, identification of anomalies at critical depths, and real-time data analysis during and post-bathymetric surveys.



Shri Sanjeev Afzulpurkar & Alok Mukherjee making the presentation

Emphasizing the “Make in India” initiative, the speakers presented several indigenous solutions ready for deployment with backing from the Department of Science and Technology (DST) and Indian Institutes of Technology (IITs). Key technological developments included the indigenization of thrusters and controllers, portable scanner systems for canal discharge and status monitoring, and autonomous platforms for water quality monitoring in rivers and lakes. Further innovations highlighted included the enhancement of the Aquanaut system for operations up to 100 meters depth, autonomous monitoring solutions for cloud bursts and glacial lake status, and the deployment of laser indicators and readers for precise line tracking.

The presenters strongly advocated for the integration of autonomous technologies into the Dam Safety Act and other relevant policy frameworks to accelerate the national adoption of these transformative solutions. Their work reflects a paradigm shift in dam health assessment, promoting sustainability, efficiency, and real-time responsiveness in managing India's vast dam infrastructure.



Shri Virendra Kumar making the presentation

30. Innovative Technologies in Dam Safety and Rehabilitation of Tanakpur Barrage: A Case Study - *Shrish Dubey, Prashant Jaiswal, and Virendra Kumar, NHPC Ltd.*

Based on the case study shared by speaker during his presentation, the Tanakpur Power Station, a 94.2 MW run-of-river project in Uttarakhand's Champawat district, operates with a 475.3-meter-long barrage on the Sharda River, designed to handle annual generation of 460 MU. To address siltation and sediment management challenges in the reservoir, particularly after major floods in 2013 and 2014, an innovative rehabilitation program was undertaken. This included the excavation of a 700-meter-long central channel to improve flow distribution and safety of afflux bunds, followed by further widening between RD 900 - 2100m and revision of reservoir flushing guidelines in 2016. These measures significantly improved sediment flushing efficiency and restored reservoir capacity.

To safeguard hydraulic structures prone to damage from sediment-laden high flows, specialized repair methodologies were adopted. The spillway glacis and stilling basin were repaired using epoxy and cementitious mortars, conforming to ASTM C881 and EN 1504-3 (R4), while High Performance Concrete (HPC) was applied in areas with deeper cavities. This approach has extended maintenance intervals up to a decade. Spillway piers were also rehabilitated using cementitious mortar with strong bonding properties, and severely damaged launching aprons were reconstructed using large interlocked concrete blocks to resist scouring.

The distressed warp wall at the downstream end of the right guide bund, exhibiting settlement up to 2 meters, was effectively repurposed as a gravity retaining wall instead of being dismantled. Its performance has remained stable since 2015, with movement monitored via reflective targets. Furthermore, spurs constructed using PP rope gabions, hexagonal wire mesh, and tetrapods have proven effective in guiding river flow and preventing bank erosion.

Afflux bund rehabilitation was addressed through modern techniques, replacing traditional hand-woven wire mesh with factory-made mechanically woven gabions, enhancing durability and ease of deployment. PP rope gabions, known for flexibility and resistance to deformation, have been deployed since 2014–15 and remain effective in emergency response scenarios. Toe protection was further enhanced with tetrapods, toe walls, concrete cladding, and launching aprons, all of which performed well during subsequent monsoons.

This case study highlights the importance of understanding river behavior, updating operational protocols, and using engineered solutions tailored to site-specific hydraulic forces. Adoption of standardized materials, technical specifications, and a structured repair methodology has reduced repair frequency, optimized cost, and ensured structural safety across the Tanakpur Barrage.

Technical Session-8: Assuring Dam Safety

31. Risk analysis of the Koyna dam using reduced order model and machine learning - *Chandan Bharti, Varsha P & Debraj Ghosh, Civil Engineering Department, IISc Bangalore*.

The presentation delivered by Chandan Bharti from the Civil Engineering Department at IISc Bangalore, explored an innovative computational framework for seismic risk assessment of dams, with a specific focus on the Koyna Dam in Maharashtra. Constructed in 1964, the Koyna Dam suffered significant damage following a magnitude 6.5 earthquake in 1967. This historical event raised a critical question central to the study: how can the safety of such vital infrastructure be ensured through computationally efficient yet accurate methods?

Shri Chandan Bharti making the presentation

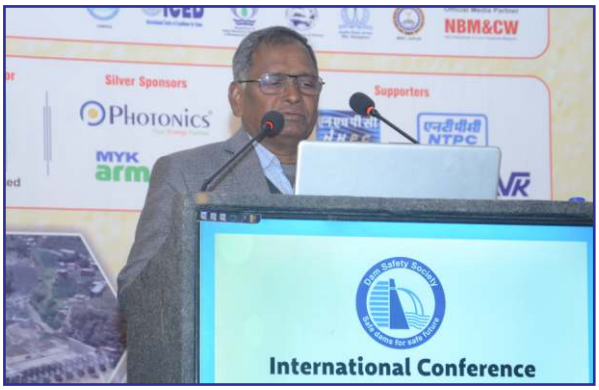
The team addressed this challenge using fragility curves, which estimate the conditional probability of structural failure as a function of earthquake intensity measures (IM), based on predefined limit states. Traditionally, generating these curves involves Incremental Dynamic Analysis (IDA), a method known for its high computational cost. To

overcome this, the researchers adopted a Reduced Order Modeling (ROM) approach combined with machine learning and advanced computing tools. They developed a cost-efficient yet high-fidelity framework by integrating a state-of-the-art method and modifying it to consider both excitation and material uncertainties.

The proposed methodology included a well-structured workflow. Earthquake ground motions were simulated using MATLAB, followed by detailed structural modeling of the dam in Abaqus. The output from Abaqus was extracted from ODB files using custom Python scripts, and results were reformatted to represent desired response states. This workflow enabled streamlined analysis across different complexities of the dam model—ranging from 2D linear to 3D nonlinear configurations, with and without incorporating material uncertainties. The team harnessed the computational capabilities of GPU and multi-core CPU systems to enhance efficiency.

Material properties were represented stochastically, with key parameters like modulus of elasticity and dilation angle modeled using log-normal distributions. The simulations covered various configurations, including 2D linear and nonlinear analyses, models with material uncertainties, and a comprehensive 3D nonlinear model.

The study concluded with the development of a modified Long Short-Term Memory (LSTM)-integrated ROM that demonstrated high accuracy and offered a computational gain of three orders of magnitude. Moreover, the team successfully built an automated in-house workflow for fragility analysis, marking a pioneering application of ROM in the field of dam engineering. This advancement not only opens new avenues for efficient seismic risk analysis but also significantly reduces computational burdens traditionally associated with such studies.



Shri Mandapalli Raju making the presentation

32. A few concepts of Geology applicable to dam safety - *Mandapalli Raju, Formerly Director General, Geological Survey of India*

The presentation highlighted the crucial role that geology plays in the planning, construction, and maintenance of dam infrastructure. Drawing from historical data, it was emphasized that while flood events, earthquakes, landslides, slope instability, structural malfunctions, and equipment failures are common causes of dam failures, more than 50% of dam failures are rooted in geological reasons. According to USBR (1998), 34% of failures were due to overtopping, 30% due to foundation defects, 28% from piping and seepage, and 8% from other causes, many of which are influenced by inadequate geological assessment.

The presentation underscored the multi-stage approach required for effective geological investigations during the investigation stage of dam projects. This involves reconnaissance, preliminary, and detailed investigations, with activities such as geological mapping to characterize rock formations and soils, supported by geophysical studies including seismic, magnetic, electrical, and gravity methods. An essential aspect is evaluating the seismicity of the region to ensure the dam can withstand expected seismic forces. Investigations also involve test pits, trenches, boreholes, and in-situ tests like packer permeability assessments. Laboratory testing of soil (grain size, permeability, cohesion) and rock (compressive and tensile strength) is also crucial. The presentation stressed that ideal dam sites are rare in nature, and the goal of geological investigations is to identify and mitigate problematic features such as pervious strata, faults, shear zones, and other unfavorable conditions, forming the basis for the baseline geological report.

Attention was drawn to specific geological phenomena that pose significant risks, such as karst topography, which can feature sinkholes, cavities, and solution channels in limestone terrains, raising concerns about water retention. Likewise, paleochannels ancient, buried riverbeds can undermine foundations if not properly identified. Stability of the reservoir rim must also be assessed to detect landslides or unstable slopes, and liquefaction potential in saturated soils during seismic events must be avoided through careful terrain selection.

During the construction stage, geological studies continue to play a vital role. Unforeseen conditions such as faults, shear zones, or shattered rock often emerge during excavation. These require responsive actions, such as foundation mapping and dental treatment, which involves removing weak material and backfilling with concrete. The Shasta Formula, originally developed by the USBR, provides guidelines for the depth of excavation required to treat weak zones and restore foundation integrity. This is supplemented by practices like consolidation grouting and curtain grouting, which help to reinforce the foundation and control seepage.

Post-construction geological assessments are also essential, especially in diagnosing performance issues that may be rooted in foundational geology. Reviewing geological maps and construction records can help identify lapses and guide remediation. Defects such as differential settlement, foundation cracking, slope instability, excessive seepage, and piping must be carefully evaluated. Other concerns in the post-construction phase include plunge pool erosion, the acidic nature of water, alkali-aggregate reactions, and reservoir siltation.

The presentation concluded with a call for systematic and periodic review of aging dams. India, with the third highest number of large dams globally, is approaching a critical phase where a large portion of its dam infrastructure is becoming old. By 2025, 1,115 dams will be over 50 years old, 234 over 100 years, and 64 over 150 years. As dams age, issues such as rock fatigue become prominent, increasing the likelihood of failure. It was emphasized that annual reviews should be conducted for dams over 100 years old, while all dams above 50 years should be assessed periodically to inform maintenance or decommissioning decisions. Importantly, the presentation concluded with a strong recommendation that competent engineering geologists must be engaged at every stage of a dam's lifecycle from planning through maintenance with proper documentation and integration of geological observations into dam safety protocols.

Ms. Khushboo Yadav making the presentation

33. Lessons Learned from Dam Failure Incidents - *Gyanendra Sharan, Khushboo Yadav, Saumya Singh, Anshul Gautam, State Dam Safety Organization, Uttar Pradesh*

The presentation emphasized the critical importance of understanding past dam failures to enhance future dam safety. Dams, while pivotal for water management, flood control, and hydroelectric power generation, have historically posed significant hazards when they fail resulting in extensive loss of life, environmental degradation, and economic hardship. Recognizing the recurring causes of such failures is vital to institute robust safety frameworks.

The presentation categorized dam failures into key causes: structural deficiencies and design flaws; overtopping due to inadequate spillways; seepage through foundations; insufficient maintenance or operational errors; and natural disasters including earthquakes, landslides, and extreme weather. These issues were examined through several notable international and national case studies that provided insightful lessons for dam safety management.

The Malpasset Dam failure (France, 1959) was attributed to poor foundation stability and an inadequate grout curtain, leading to a catastrophic collapse that claimed 423 lives. The incident highlighted the need for detailed site investigations and rigorous design validation. The Teton Dam failure (USA, 1976) resulted from unchecked seepage through a highly permeable foundation, underscoring the importance of geological scrutiny and proper seepage control measures for embankment dams. Similarly, the Vaiont Dam disaster (Italy, 1963) involved a massive landslide due to unstable geology, leading to overtopping and over 2,000 fatalities. This case emphasized the need for robust geological assessments and risk management strategies for natural hazards.

India's Machchu-2 Dam failure (1979) illustrated the consequences of inadequate spillway capacity and poor maintenance. Built in 1959 and overwhelmed by heavy monsoon rains two decades later, the dam's failure led to the deaths of approximately 1,000 people. Lessons from this incident point to the necessity for designing adequate spillway systems and enforcing rigorous maintenance regimes. The recent Teesta Dam failure (India, 2023), which caused extensive flooding and infrastructure damage across Sikkim and surrounding areas, reinforced the need for continuous structural inspections, early warning systems, and community-based evacuation planning.

From these failures, several overarching lessons have emerged. The importance of comprehensive risk assessments prior to construction cannot be overstated. Incorporating improved design standards, conducting regular maintenance, deploying real-time monitoring systems, and establishing early warning mechanisms are all essential steps in minimizing dam-related disasters. Additionally, enhancing public awareness and community preparedness through Emergency Action Plans (EAPs) was emphasized.

The Dam Safety Act, 2021, was discussed as a landmark regulatory framework in India that institutionalizes dam safety. It mandates routine inspections, detailed risk evaluations, and dam break analyses, and introduces stringent compliance requirements backed by penal provisions. This legal foundation provides the necessary enforcement mechanism to ensure that dam owners and operators maintain the highest safety standards.

Summing Up the Proceedings

On the whole, the conference was an unqualified success indicating a keen interest of the dam engineering and policy planning communities in various areas of dam safety management and rehabilitation.

In conclusion, the presenters strongly advocated that learning from the past is indispensable to building a safer future. Dam failures, though tragic, offer valuable insights. With appropriate investment in inspection, monitoring technologies, public engagement, and strict regulatory compliance, the risks associated with dam infrastructure can be effectively mitigated, ultimately safeguarding lives, property, and the environment.

Shri Sunil Sharma for proposing the Vote of thanks

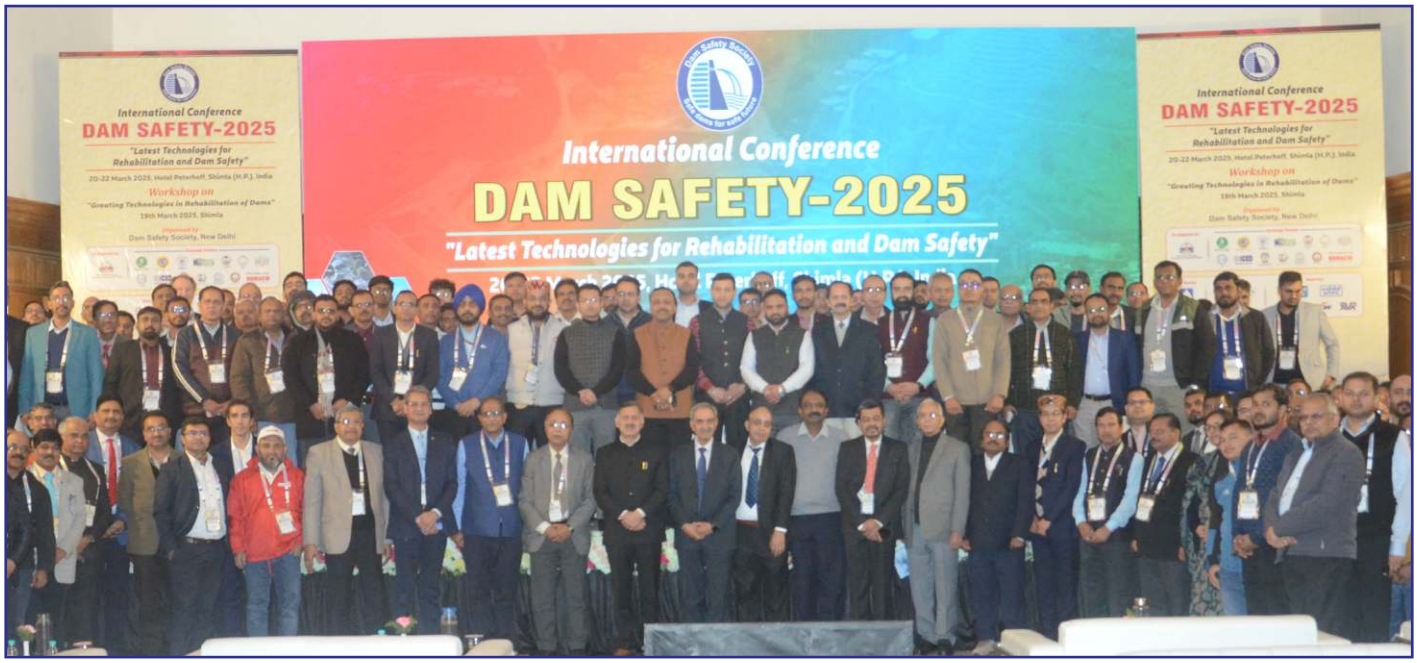
The conference highlighted a number of emerging technologies and innovative solutions for assessing the dam health, distress extent and magnitude evaluation and other investigative and monitoring technologies. The benefits of using such technological solutions was well demonstrated by the authors.

There are increasing uses of advanced technologies utilizing AI and Deep Learning models for the application in the dam health evaluation areas. Such methods of image interpretation, communication are quite useful for large scale operations. These techniques are also capable of providing basis for Decision Support to the dam portfolio managers.

This conference is the second in line flagship unique event established by the Dam Safety Society. The continued interest and enthusiasm of the dam engineering community in the areas being addressed by the conference strengthen the relevance of the dam safety conference of the society towards establishment and sustainability of the dam safety programme in India and in the Global South.

At the end, the final vote of thanks was proposed by Mr. Sunil Sharma, Secretary General, Dam Safety Society to the dignitaries who participated in the opening ceremony, Chairmen of the Technical Sessions, Resource Speakers, authors who made the presentations during the three days deliberations of the conference.

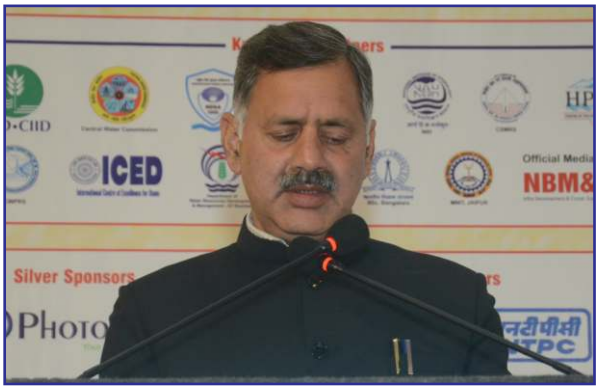
View of Audience



Group Photograph with Participants

Appendix

The speech delivered by Shri Rajesh Dharmani, Hon'ble Technical Education Minister, Govt. of Himachal Pradesh during the inaugural session



Shri Rajrsh Dharmani, Hon'ble Minister delivering Speech

The Himalayan region, renowned for its majestic peaks and vital river systems, is increasingly becoming a focal point for hydropower development. While dams in this area offer significant benefits, such as renewable energy and water management, they also present unique challenges due to the region's geological and climatic conditions. Ensuring dam safety in the Himalayas necessitates a comprehensive understanding of potential failure causes, proactive public awareness, robust disaster management strategies, diligent maintenance practices, and an acute awareness of climate change impacts.

Causes of Dam Failures in the Himalayan Region

The Himalayas' dynamic environment contributes to several factors that can compromise dam integrity:

- ***Seismic Activity**: The region's location along active tectonic plates makes it highly susceptible to earthquakes. For instance, a magnitude 6.8 earthquake in Tibet recently resulted in 126 fatalities and damaged four reservoirs, underscoring the seismic risks associated with dam infrastructure.*

- ***Glacial Lake Outburst Floods (GLOFs)**: Climate-induced glacial melting has led to the formation of unstable glacial lakes. The sudden breach of these lakes can release massive water volumes, posing significant threats to downstream dams. A study highlighted that approximately 15 million people globally are at risk from such glacial floods, with many residing in the Himalayan region.*

- ***Landslides**: The steep and unstable terrains of the Himalayas are prone to landslides, which can obstruct rivers and create temporary dams. The sudden failure of these natural dams can unleash destructive floods, jeopardizing existing dam structures downstream.*

Public Awareness and Community Engagement

Empowering local communities with knowledge is crucial for enhancing dam safety:

- ***Education Programs**: Implementing community-centric approaches to manage climate risks can significantly reduce vulnerabilities. For example, in Himachal Pradesh, changes in cropping patterns due to climate impacts have been observed, emphasizing the need for localized education on environmental changes.*

- ***Early Warning Systems**: Establishing and maintaining reliable early warning mechanisms can provide timely alerts to communities, allowing for swift evacuation and risk mitigation.*

Disaster Management Strategies

Effective disaster management is vital to address potential dam-related emergencies:

- ***Emergency Action Plans (EAPs)**: Developing and regularly updating EAPs ensures preparedness for unforeseen events. The importance of such programs has been emphasized in various contexts, including Nepal, where tailored strategies are essential due to the region's unique challenges.*

- ***Simulation Drills**: Conducting regular drills involving local communities and authorities can enhance readiness and coordination during actual emergencies.*

Maintenance and Structural Integrity

Regular maintenance is fundamental to prolonging the lifespan and ensuring the safety of dams:

- ***Routine Inspections**: Periodic assessments can identify structural weaknesses early, allowing for timely interventions.*
- ***Technological Integration**: Utilizing advanced monitoring technologies can provide real-time data on dam health, facilitating proactive maintenance.*

Climate Change and Its Implications

The effects of climate change present new challenges for dam safety in the Himalayas:

- ***Increased Precipitation and Flooding**: Unpredictable and intense rainfall can lead to severe flooding. For instance, in year 2023 HP experienced devastating floods following rains, highlighting the need for resilient infrastructure.*

- ***Accelerated Glacial Melt**: Rising temperatures contribute to the rapid melting of glaciers, increasing the risk of GLOFs and impacting water availability.*

- ***Ecosystem Disruptions**: Climate-induced changes can alter river ecosystems, affecting sediment transport and potentially undermining dam foundations.*

In conclusion, safeguarding dams in the Himalayan region requires a multifaceted approach that addresses geological, climatic, and human factors. By understanding the unique challenges and implementing comprehensive strategies encompassing public awareness, disaster preparedness, diligent maintenance, and climate adaptation, the resilience and safety of these critical infrastructures can be ensured.

The speech delivered by Shri Prabodh Saxena,
Chief Secretary, Govt. of Himachal Pradesh during the inaugural session

Shri Prabodh Saxena delivering the speech

India has a history of Dam construction, maintenance and operation since long. Kallanai Dam (Grand Anicut) is the oldest Dam in India, built by Cholas about 2000 years before, Kodivery Dam is another dam constructed by King Kongalvan in 11th Century. India is ranked 3rd after China and USA in the world as far as Large Dams is concerned. At present there are more than 5500 operational and more than 400 under construction dams in the country.

Due to enormous size & storage Dam Safety becomes one of the most important aspects of such structure and the Govt. of India was working on it since 1979 for effectively addressing these aspects. The first step towards this was when Central Water Commission was established in 1979. Later Standing Committee was constituted in 1982, to review the existing practices and evolve uniform procedures. Standing Committee recommended for uniform procedures and legislations.

In 2002 a comprehensive Dam Safety Bill was prepared and circulated to states for comments and Ministry of Water Resources finalized and circulated to inter- ministries in 2009. Further a Proposal of Dam Safety Act was approved by Cabinet on 13th May 2010. A Bill was tabled before Parliament on 30th August 2010 and referred to Parliamentary Standing Committee. After that a Committee recommended significant changes & Modifications. With Changes, modifications Dam Safety Act -2018 bill prepared but couldn't be tabled. Finally Government of India enacted Dam Safety Act, 2021 on 14th December 2021 and it has come into force w.e.f. 30.12.2021.

Talking about Himachal Pradesh the state is blessed with rich hydro power potential. State has 5 big rivers and has an estimated hydro power potential to the tune of 27,000 MW out of which 24,567MW is harnessable. The hydro power capacity is being harnessed through constructing water barriers. Most of the power projects are run off the river projects wherein by constructing the Dam/Weir/ Barrage the water is diverted and by utilizing the head, power generation take place. This is the usual practice adopted for safe guarding the environment and leading towards sustainable development. However, few multipurpose projects do exists in the State wherein the high dams have been constructed and the large water bodies have come up behind these dams.

Bhakra Dam is such dam completed in earlier 1960s which was named Modern Temple of India at that time by the then Hon'ble Prime Minister, Pandit Jawahar Lal Nehru. This dam is serving since then and has brought in the drastic change economically and geographically by resolving food reliability concern of nation through green revolution and at the same time serving the Country by providing cheaper power and ensuring the water requirements in North Western Indian States like Rajasthan, Punjab, Haryana.

There are few other dams like Pong Dam, Pandoh Dam, Koldam, Chamera-I Dam which are serving the country as a whole in this way. At present there are 24 existing specified dams (large Dams having height more than 15 meter. from the deepest foundation level) and 7 are under construction in the State. Earlier individual Dam

Authorities were looking after the safety aspects of their respective dams on their own. Further Govt. of Himachal Pradesh on its own constituted an Authority for hydroelectric project safety, Quality Control & Water Management in Directorate of Energy, in 2013. This Authority was entrusted with roles and responsibilities for developing monitoring Implementation Mechanism for the dam safety, quality control, management of water flows of HEPs, ensuring long term generation capacity and residual life of Hydro Projects in State. After the enactment of Dam Safety Act, 2021 by Government of India in December, 2021, the safety of the dams are being governed as per the provision and mandate of act.

In line with the Dam Safety Act provisions, the State of Himachal Pradesh has constituted a State Committee of Dam Safety (SCDS- HP) and State Dam Safety Organization (SDSO-HP) in the year 2022. Through this committee and organization the State is committed for ensuring the safety of all existing 24 specified dams and 7 under construction specified dams in the State.

As per Dam Safety Act, 2021 the monitoring of Central & Joint Sector PSU Dams is with NDSA (National Dam Safety Authority) and out of 24 dams in State there are 10 such dams (BBMB-3, SJVNL-1, NHPC-5, NTPC-1). However, State on its own through SDSO HP (State Dam Safety Organization-HP) is also monitoring safety aspects of all such dams. Though most of these dams have been constructed way back and being owned, operated and maintained by the individual dam authorities and CPSUs but the recent floods of year 2023-24 has exposed the preparedness and readiness of these dams with respect of having the proper Early Warning Systems and having the basic safe implementations measures and norms w.r.t. dams safety aspects & provisions. The State faced a huge loss of property on account of the excessive flooding due to BBMB & NHPC dams and the evacuation to the tune of about 2500 stranded people was taken up in urgency. Due to the promptness of GoHP agencies the life loss was avoided. This was also established through the high level committee report which was constituted by GoHP which stated that had there been proper EWS and proper implementation of Dam safety provisions the losses could have been minimized if not avoided.

The State through its agency has been continuously monitoring and taking up the matter regularly with these dams authorities and also moving ahead on taking the matter appropriately through various provisions of Act. But it is essential that NCDS, NDSA and CPSUs do come forward for effective implementation of DSA-2021 provisions by taking the responsibility towards ensuring the safety of the downstream habitations.

On the part of the State Govt. we are committed to ensure the safe operations of these dams through all the dams owning agencies and also for strengthening & upgrading the monitoring mechanism/State agency for having by implementation of the best International level standards and practices. I would like to further add that these kind of workshops and seminars on such an important aspects will certainly strengthen the State commitment towards Dam Safety. I wish all the best to the organizers and the participants on this occasion.

View of Audience

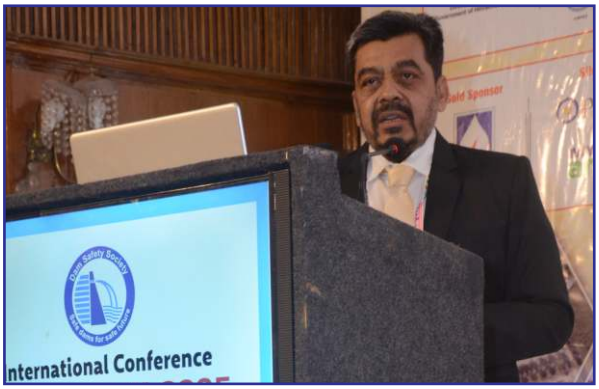
Workshop on
Grouting Technologies for Dam Rehabilitation

19th March 2025 at Hotel Peterhof, Shimla

A workshop on Grouting Technologies for Dam Rehabilitation was organized by the Dam Safety Society in association with the leading organizations in the field, to create awareness and to address the weak zones, using grouting, to address leaks, and employing various grouting techniques for different dam types and purposes besides to provide the baseline for selection of appropriate materials for grout depending on the requirements. The aim of the workshop was to share with the dam engineers, academicians, research institutes and the construction agencies about the methods, materials and other aspects to be adopted for grouting of dams. Grouting is one of the but not a only remedial measure, to arrest the seepage in dams and also to strengthen the dam from the point of integrity and stability.

The presentations from reputed institutes like IITs, individual experts, academicians, construction agencies, were delivered during the workshop. The presentations, discussions and deliberations proved to be very much appealing making the subject widely open to the dam engineers and others who practices grouting of dam. A number of dams in India are under repairs and rehabilitations during which grouting is one of the major aspect and hence the workshop will hopefully share each and every aspect of the subjects. As the methods and materials for each of the dam are different unless a thorough know-how of grouting the dam is there, the grouting do not become effective, however incorrect procedure sometimes poses problems.
The workshop covered the technologies and criteria involved for executing a successful grouting programme on a dam. Besides the pressure grouting as a method to improve strength properties of the concrete/ masonry dams and geotechnical properties of soils and rock masses, with special focus on mechanisms, theories, and practical applications of grouting to ground densification and strengthening, permeability reduction and groundwater cut-offs. The recommendations from such a workshop would emphasize the importance of proper grouting procedures, the selection of appropriate grout materials, and the use of advanced techniques like GIN grouting for efficiency and cost-effectiveness. The following topics were deliberated during the workshop:

- Need of grouting in existing dams and barrages – An overview
- Planning, design and execution of grouting programme for dam rehabilitation
- Latest Investigations Techniques for establishing the requirements of grouting in existing dams
- Grout materials, mixes and their properties and quality control
- Grouting techniques - issues and challenges – Case studies
- Under water grouting - Leakage control in structures – Leakage routes, Locating the source
- Grouting Under High-Head and High-Flow Conditions for dam rehabilitation
- Grouting in extreme environments
- Advance grouting techniques for Dam Rehabilitation – Case studies
- Role of contractor in execution of grouting techniques



Shri Vivek Kapadia welcoming the participants and introducing the subject

Shri Vivek Kapadia, Vice President, Dam Safety Society welcomed the participants and speakers from the Govt. Departments, academia, construction agencies as well as from the material suppliers and given the brief background for selection of this important topic of the workshop and also presented the overview of grouting technologies in dam rehabilitation.

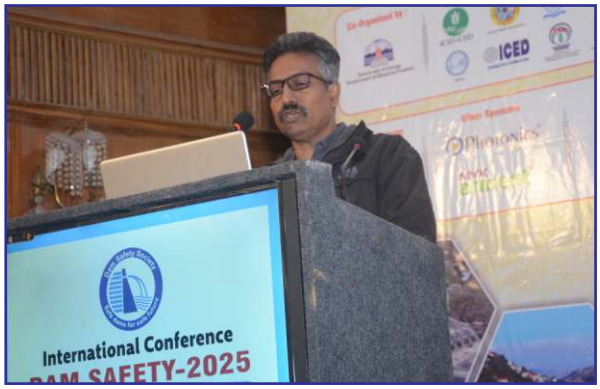
Shri Rizwan Ali making the presentation

The following presentations were made by the professionals and shared their grouting experiences in different projects:

Technical Session – 1

(I) Issues in Gravity Dams – Diagnosis and remedial measures – *Rizwan Ali, Scientist E, CWPRS*

Shri Rizwan Ali highlighted the various issues in the old as wells in new dams and the various investigation methods to be adopted to diagnosis the issues. Unless the diagnosis is done precisely, repairs become difficult and directionless. He highlighted the facilities available with CWPRS, for the diagnosis of causes and also the



Shri Sunil J. Pillai making the presentation

remedial measures, to overcome the defects. The other capabilities of CWPRS in field of Hydraulics, Port & Harbours, Hydro mechanicals, Gates and Valves, Instrumentation, Physical and mathematical modelling were presented

(ii) Seepage control measures using cementitious grouting of Masonry Gravity Dams – CWPRS Experiences - *Sunil J. Pillai, Scientist C, CWPRS*

Hydraulic structures like dams store water for meeting various needs such as irrigation, drinking, hydropower etc. and also help immensely to attain self-sufficiency in agro- productions, flood control, drought mitigation and meeting electricity demands. Masonry dams exhibit leakages/seepage due to poor quality construction, leaching of cementitious material, cracking, design deficiency and ageing effect. The maintenance of the dams and their preservation in sound health is a matter of great national and international importance. Maintaining safety of dams is a significant issue which needs to be continuously monitored to ensure public confidence, protection of downstream areas from flood hazard and to ensure continued benefits from the national investments. Unwarranted seepages in a dam are a sign of distress and need to be attended immediately. To restore the structural integrity of the dam and make the distressed structure serviceable again, various methods are adopted either one or in combination.

Cementitious grouting is one of the most common and effective technique for controlling seepage and restoring/improving safety of the masonry Dams through reduction in seepage as well as enhancing strength parameters. Dam body grouting using proper mix design is a well proven, economical and effective tool to control seepage and improve structural integrity of the distressed masonry dams. Design of cementitious grout mix is important and necessarily be done by conducting laboratory tests on different materials. After conducting the suitability tests in laboratory by using many mix proportions, a suitable design mix is arrived at for carrying out grouting in the field. The seepage has considerably reduced in many grouted masonry dams namely Temghar, Bhatsa, Domihira, Damini,

Shri S J Pillai, mentioned mainly about the requirements of grouting of masonry dams, identifying grout mixes on basis of laboratory studies with some case histories where grouting of dams has successfully arrested seepages.
The presenter proposed the following recommendations after the presentation:

- Dam body grouting using proper mix design is a well proven, economical and effective tool to control seepage and improve structural integrity of the distressed masonry dams.
- Design of cementitious grout mix is important and necessarily be done by conducting laboratory tests on different materials. After conducting the suitability tests in laboratory by using many mix proportions, a suitable design mix is arrived at for carrying out grouting in the field.
- The seepage has considerably reduced in many grouted masonry dams namely Temghar, Bhatsa, Domihira, Dhamni, Tillari, Warna dams etc. using cementitious grout mix design carried out at CWPRS.
- Grouting technique is also very useful in stabilizing rock mass. Rock slope stability analysis studies and NDT tests, shall be carried out on the rock mass to reveal voids, cavities and jointed rocks up to a depth of 6 m and advised to grout the top portion up to a depth of about 10 m before carrying out anchoring of rock mass to prevent further rock fall.

Technical Session – 2

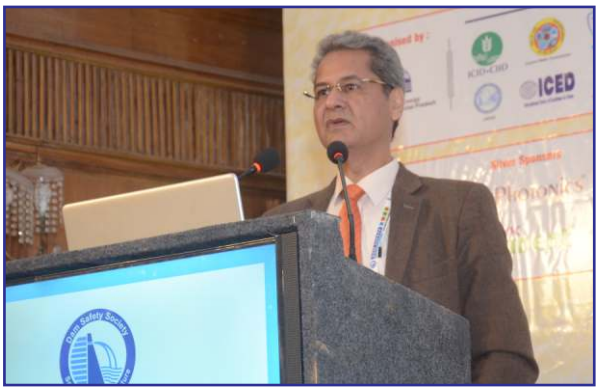
(iii) Grouting of dams – methodology, materials and Case Studies –*Vijay Desai, Former, Senior Research Officer, CWPRS*

Shri Desai brought out the important issues and steps of grouting in details about each and every aspect of masonry dam grouting, including care to be taken during grouting. The grout mix test procedures were explained in details with sketches of equipment. The calculations of permeability, the importance of permeability tests, the grout hole spacing, choosing the grout zones and locations were presented in a well understandable way. He presented successful case studies of Ukai masonry dam and the grouting below key trench of earthen Dyke 1 of Dharoi dam where excessive leakage was observed. The two case studies were very informative.

Shri Vijay Desai making the presentation

(iv) Monitoring techniques of structural scanning and health assessment though geophysical investigation – *Dr. Sanjay Rana, Managing Director, Parsan Overseas*

The geophysical methods presented by Dr. Sanjay Rana, were very much informative. He broadly explained the importance pf each geophysical method for diagnosis of issues. The geophysical investigation is an aid for correct assessment of the locations of seepage, weak points and anomalies in the dam was nicely brought to the knowledge of engineers through this presentation. The case studies presented by the presenter were very much informative and have certainly provided guidance to the engineers and academicians.



Dr. Sanjay Rana making the presentation

(v) Available material, technology for water ingress control and under water concrete crack repair in dam - Indian case studies – *Milon Mukhopadhyay, Managing Director, Milon Mukhopadhyay Associates*

Shri Milon Mukhopadhyay making the presentation

The presentation by Mr. Milon Mukhopadhyay, delivered on the available materials and technologies for arresting the seepage in dams and also to improve the health conditions of dam from point of integrity and stability. Various materials and grouting techniques were explained in detail with applications. He detailed about the criticalities during underwater grouting, the underwater materials, their identifications etc. The presentation was very much useful to dam engineers as there is urgent need of underwater repairs to dams in the country.

Technical Session - 3

(vi) Dam Rehabilitation – Case Studies –*Manish Kumar, EVP & CTO, ITD Cementation Ltd.*

Shri Manish Kumar, presented in details the application methodology of treatment to scour on downstream of the Gandhisgar dam. Presentation included construction of a cofferdam dam, the col-grouting methodology adopted to fill the steel cylinders for supporting the coffer dam platform and placing of concreting in damaged apron. He highlighted the difficulties in achieving the target but at the end was a successful achievement. He explained with picture and photographs each step of repairs which was self-explanatory and was well understood. The presentation will prove to be a guidelines to dam engineers and other for similar repairs at their sites. He also dealt in detail the grouting and shotcreting treatments to Linganmakki dam,Karnataka and their succes in arresting the seepage through dam body.

Shri Manish Kumar making the presentation

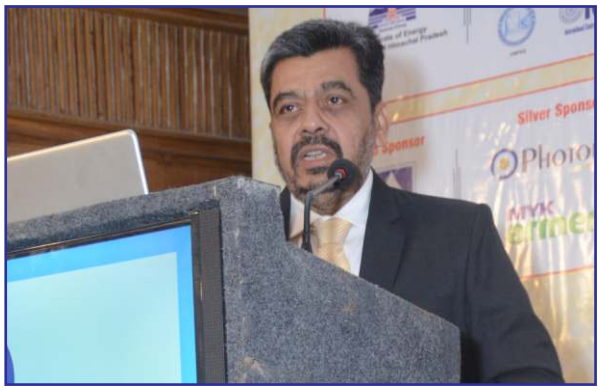
(vii) Enhancing dam rehabilitation: leveraging geophysical data for strategic structural– *Dr. Sanjay Rana*

Dr. Sanjay rana in his presentation gave details of each of the geophysical method, and their applications. He explained the methods with pictures and details which will prove to be and aid to dam engineers and other for diagnosing the problems in dams.

(viii) Strengthening dams from within: The critical role of advance grouting solution to enhance dam safety and longevity – *Jay Joshi*, *GeoConstech*

Shri Jay Joshi made a presentation on distinction between Polyurethene (PU) and Polyeurthene Resin (PUR) and their uses in dam applications, their benefits, etc . He highlighted the chemical grouting in dams with specialized chemical solutions for different

purposes like foundation to seal the cracks, reducing water seepage, improving permeability. He also discussed both advantage and disadvantage and the causes of cracks development, whatever the challenges are to be faced during the process etc. He briefed the successful case studies of overcoming the problems faced in aligning the HRT by grouting Polyurethene at Maneri Bhali project. He also considered an effective solution in arresting heavy water ingress and face consolidation of Hurla Nallah, Parbati Stage 2 project. His presentation was very informative as he discussed the upcoming PU technologies for repairs and rehabilitations of dams and related structures



Shri Vivek Kapadia making the presentation

(ix) Precautions in grouting earthen embankments –*Vivek Kapadia*

Shri Vivek Kapadia made the presentation on the precautions to be taken while grouting in earth dam will prove to be helpful to dam engineers. Many issues which are uncontrollable may arise if the grouting of earth dams is not done systematically and methodologically after proper diagnosis and relevant geotechnical investigation. If not done methodologically, the final result after grouting may not be effective. The presentation with literature based evidences and case studies was a eye opener for dam engineers highlighting the seriousness of issue of grouting of dams.

Technical Session – 4

(x) Strengthening of damaged hydraulic structures by epoxy grouting – Some examples/ Case Studies of underwater grouting in concrete dam.– *Vijay Desai*

The presentation by Shri Vijay Desai on strengthening of hydraulic structures using epoxy resins mainly focused on the type of cracks in concrete structures, types of grouts. Identification of suitable grout materials for grouting damaged concrete structures. Each laboratory test with its importance was presented in detail. The tools like pumps required for grouting, the details of grout procedure as per crack orientation, grout pressure etc was explained . He presented some crucial case studies of epoxy grouting of Konar dam , Hirakud dam, Chillapowe house, etc. The video presentation of HIrakud dam underwater grouting of cracks was very informative.

Shri Vijay Desai making the presentation

Ms. Akanksha Tyagi making the presentation

(xi) In-situ mixing methods - Jet grouting and deep soil mixing: Application to barrier systems – Case studies -
Prof. *Akanksha Tyagi, ICED, IIT Roorkee*

(xii) Grout materials, mixes and their properties and quality control – Prof. *Akanksha Tyagi, ICED, IIT Roorkee*

Dr Akansha Tyagi, gave a presentation on Jet grouting and Deep soil mixing application to barrier system. She mentioned that the Cement-admixture technique which involves applying high-pressure jets of water or grout in order to modify the existing ground and hence improves its properties. The various advantages mentioned such as the prevention of ground or structure movement during excavation or tunnelling; controlling groundwater during tunneling & excavations; preventing or reducing water seepage through a water retention structure such as a dam or flood defense structure; and preventing or reducing contamination flow through the ground. She also mentioned about the application of jet grouting in India at Polarvaram Dam Project where Ground water barrier using Jet Grouting. She considered in detail the In-situ mixing methods, jet grouting technique, applications for barrier systems in dams, sampling methods, Properties of admixture treated soils Hydraulic conductivity of admixture treated soils and partial variability in field properties.

The laboratory studies for determination of properties and influence of each property in getting required results in field was explained in detail. The jet grouting method was explained in detail with applications in dams. She also considered the grout materials, their application based evaluation and the quality control of the mixes at site as per the laboratory evaluation of properties.

(xiii) Rehablitation of water retaining structure dams & concrete structures – *Arvind Kachroo, Business Head India (Repair Restoration & Grouts), MYK Arment*

Shri Arvind Kachroo while giving the presentation focussed on the selection criteria and types of grout which depends on loading conditions (Dynamic and Static); compressive strength; flow distance; ambient temperature; high temperature exposure; timelines available for installation/grouting of machinery and grout section thickness. He mentioned that there are mainly two types of grouts are available – Cementitious & Epoxy. A case studies of concrete repair in Kameng, Kopili and Teesta Low Dam hydropower projects were presented.

Shri Arvind Kachroo making the presentation

Key Recommendations:
Based on the presentations made by the different resource speakers, the folloing key recommendations were emerged:

Comprehensive Dam Safety Assessment:

- Historical floods in many dams exceeded the original design capacity on a number of occasion. Dam safety guidelines and design manuals should mandate periodic reassessment of design flood parameters using updated hydrological data and climate change projections. Regular inspections, health monitoring, and emergency action plans are crucial for identifying potential issues and ensuring the long-term safety of dams.
- Regular underwater inspections should be enforced, particularly after high inflow events, to identify hidden scouring, retrogression, or foundation weakening especially after exposure to suspect conditions.
- The use of interlocked steel cylinder-based cofferdam has proven highly effective for underwater construction. This technique remains relevant and should be formally documented and promoted through standard guidelines.
- Future dam designs must incorporate provisions for maintenance access from both banks to facilitate emergency or planned rehabilitation works.
- Early-stage consultation with experienced contractors and technical institutions is essential for the effective planning and execution of complex rehabilitation projects.
- Time-bound rehabilitation works require meticulous planning, sequencing, and resource management to achieve successful execution.
- It is recommended to conduct underwater health surveys of submerged dam faces and buckets using ROVs or divers to assess erosion related damage.
- Implement routine vegetation removal and surface inspection to prevent root-induced erosion and crack propagation on the upstream surface of the Dam
- The effectiveness of the grouting operation is highly dependent on precise execution rather than merely relying on a scheme. Improper flushing, inadequate hole cleaning, or inconsistent pressure control can result in poor grout penetration and bonding, leading to ineffective seepage control.
- A well-planned rehabilitation scheme for U/S, D/S and for the body and foundation of the Dam resulted in controlling seepage to more than 98%. Similar schemes can be developed to achieve high degree of effectiveness to control seepage and for strengthening of the Dam.

Geophysical Surveys and Leakage Detection:
Geophysical surveys may be employed to assess the subsurface conditions to plan well-informed rehabilitation work. Using geophysical techniques like scanning to pinpoint weak zones and areas of leakage is essential for targeted grouting efforts.

- **Integrate Geophysics into Dam Safety Protocols**

Geophysical investigations should be institutionalized as a core component of dam safety inspections—before, during, and after rehabilitation—to enable non-destructive, scientific assessment of internal conditions.

- **Ensure Periodic Inspections of all large dams**

Periodic geophysical assessments must be mandated for all large dams to facilitate early detection of internal anomalies, in line with the Dam Safety Act 2021 goals of inspecting 6,000+ dams over the next five years.

- **Adopt and implement existing Guidelines**

Existing guideline documents on geophysical investigations for dam safety should be reviewed, discussed, and formally adopted by agencies to standardize and accelerate implementation, including extended use for canals, stilling basins, and other hydraulic structures.

- **Grouting for Leakage Control:**
  Grouting can be used to fill leakage holes and create a waterproof seal, preventing water from seeping through the dam.
- **Material Selection:**
  The choice of grout material depends on the specific dam type and the nature of the problem. Polyurethane mortar and micro-concrete can be used for specific applications.
- **GIN Grouting Method:**
  GIN grouting or Grouting Intensity Number is an efficient and cost-effective method used in geotechnical engineering for structural stabilization, especially in rock masses for foundation treatment, particularly in larger projects, as it reduces time and labour costs. It involves controlling the energy induced in rock fractures by limiting the product of grout pressure and volume injected.
- **Underwater Repair:**
  Techniques for underwater repairs and rehabilitation, including grouting, are important for addressing issues that occur below the water surface. It is recommended to conduct underwater health surveys of submerged dam faces and buckets using ROVs or divers to assess erosion related damage.
- **Grouting in Different Materials:**
  Understanding the specific grouting procedures for masonry and concrete dams, as well as the foundations of earth dams, is crucial.
- **Continuous Monitoring and Evaluation:**
  Monitoring the effectiveness of grouting procedures and evaluating the long-term performance of the dam is necessary to ensure the safety and longevity of the structure.
- **Training and Skill Development:**
  Providing training and education to dam owners, consultants, and other stakeholders on the latest grouting technologies and best practices is important for ensuring proper implementation.

Examples of Grouting Applications:

- **Foundation Treatment:**
  Grouting can be used to stabilize the foundation of dams, improving their stability and preventing potential issues.
- **Seepage Reduction:**
  Grouting can be used to reduce seepage through the dam, ensuring the dam's structural integrity and preventing potential failures.
- **Spillway Repair:**
  Grouting can be used to repair damaged spillways, ensuring their proper functionality and preventing flooding risks.
- **Diaphragm Wall Construction:**
  Drilling and grouting can be used to create a diaphragm wall, a key component in many dam construction projects.

Masonry dams

- For masonry dam grouting, investigation studies like extraction of cores, Tele view imaging/ bore hole videography of bore holes, identification of path of seepage by tracers, geophysical investigation to identify anomalies like weak zones, conducting permeability tests in certain zones is necessary . Methodology to drill holes for grouting shall be appropriate depending on the condition of masonry. Diamond drilling of holes is well suited as it involves less disturbance to structure. During drilling each step to watched like drop of bit, change in speed of drilling, damage to drill bit. The data becomes very much useful in deciding grout methodology and material. Conducting the permeability tests at every stage is helpful to assess efficacy of grouting. Study of seepage data of the dam provides clues to devise appropriate methodology for grouting.

- Masonry dams are to be grouted when water level in the reservoir is minimum. In many dam such conditions is not possible and hence grouting is to be done carefully. It is recommended that grouting to be done after giving suitable treatment to upstream face of dams to arrest entry of water. In such case the fear of connection of reservoir water to drill holes is less which otherwise is a critical stage. Grouting from downstream face of the dam shall be avoided , unless treatment to upstream face is given.

View of Audience

- Ordinary Portland cement with non-shrink admixture is best suited grout mix. If found necessary fine sand can be added depending on consumption at each stage. Grout methodology as applicable to masonry condition like step, stop or series grouting to be chosen. Grout pressure, grout mixes those discussed in presentations shall be followed as a guidance

Concrete dams:

- The main problems with concrete dams is leakages through lift joints, block joints ,foundation interface and honey combings in body. These anomalies shall be identified first by investigations. Lift joints shall be treated from upstream face and then grouted by fine cements like ALCOFINE cement by double packer systems . The grout holes shall be taken from top and close to upstream face . Use of PU foam for arresting leakages in gallery of concrete dams may also work well.

Earth dams

- The grouting in earth dam shall be done very carefully under guidance and supervision of geotechnical expert after carefully studying the causes and analysis like seepage studies.

- Foundation seepage of earth dam to be taken up after detail foundation investigations and study of geology of foundations, The grouting of foundations shall be done under careful supervision of expert geologist.

General

- Due to busy schedule of dam engineers many a dam engineers are unable to attend a centralized work shop . Hence such workshops may be conducted at each of the state venues.
- The presentations shall be elaborative and mainly deal with case studies and experiences , dos and do not dos, . The participation from application agencies shall be given preference in addition to researchers, academicians .
- The institutes participating in the workshop shall elaborate their experiences in various case studies and not only academic. These institutes shall also participate in the quality control inspections during actual grouting process.
- The work shop had good response and was quite educative. It has definitely provided precise knowledge to engineers and others in the field of grouting of dams.
- The Dam Safety Society in future shall aim to deal other crucial issues like Seepage Control measures , Strengthening of dams by different techniques like pre -stressing, providing buttresses, providing concrete backing etc. The other most important topics of workshop can be stability analysis of dams with case studies, dam instrumentation including identification , installation, obtaining data, analysis of data, interpretation and effects on health of dam.

Other suggestions:

1. DRIP has established capacity building agencies for the dam related works. During inspection of dams, member from these institutes may remain present with the DSRP panels.
2. The presentations /papers for conference shall deal with case studies and not much on dam safety act, codes, manuals or bills etc.
3. The role of Dam Safety panel now is only to inspect the dam and submit a report. The role and involvement of DSRP has to be broadened a little. Dam Safety panel shall be involved at each step of rehabilitation (except financial issues). The specifications for investigation, repair works , inspection during actual repair/ rehabilitation work at site shall also be monitored by DSRP members to check whether the recommended methodologies and measures are followed properly.

At the end of the workshop, Shri Vivek Kapadia proposed the Vote of thanks to the speakers who made very educative presentations and active interaction by the participants to make the workshop more lively. The workshop was attended by more than 150 participants from State dam owners, CPSUs, PSUs, Consultants, contractors and material suppliers.

Group Photograph