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ABOuT JOuRNAL

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

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

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Secretary General

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

Editorial



Dear Readers,

Greetings from INCOLD, New Delhi.

India ranks third position globally with 5334 large dams in operation and 411 dams under construction. Over 80% of our existing dams are more than 25 years old and many of them may be experiencing distress and require rehabilitation to restore their operational performance and safety. Central Water Commission (CWC) with financial assistance from the World Bank, embarked upon the Dam Rehabilitation and Improvement Project (DRIP) to rehabilitate 223 dams in seven States in Phase – 1 and more than 700 dams in DRIP Phase 2 &3. The objectives of DRIP besides rehabilitation of selected dams,

includes promotion of new technologies and institutional capacity building in dam safety areas in DRIP Implementing Agencies including the Central Water Commission and selected premier academic and research institutes of the country for the same.

As part of the institutional capacity building activity, Dam Safety Conferences are being organized every year in different States in collaboration with the implementing agencies and leading academic institutes, to provide a common platform for all stakeholders including non-DRIP States, to update the knowledge of dam professionals. This Conference would bring together the policy makers, senior functionaries and technocrats from Central/State/UT Governments, academicians, World Bank, to focus on the best global practices; technological advancements, emerging dam safety challenges in addressing dam safety concerns.

The 6th in the series, the International Dam Safety Conference - 2022 being held during 10-12 October, 2022 at Birla Auditorium at Jaipur, Rajasthan, is a joint initiative of the DRIP, Central Water Commission, Government of India; Committee for the International Commission on Large Dams, India (INCOLD) and CBIP, under the aegis of the ongoing World Bank assisted Dam Rehabilitation and Improvement Project (DRIP) Phase – II and III.

The Conference received an overwhelming response from dam professionals from both within the country and abroad. More than 400 registered for participation in the Conference and 85 technical papers are received from Indian and overseas experts. 20 national and overseas organizations are showcasing their technologies, products, and services in an exhibition being organized concurrently at the Conference venue. In the Industry Session, 8 organizations came forward to project the contemporary developments in technology, instrumentation, materials, and services for the dam construction and rehabilitation activities. We are thankful to all the sponsors, authors, delegates and exhibitors for their participation in the Conference.

The technical papers brought out as Proceedings Volume is a valuable reference material for the decision-makers as well as dam professionals engaged in various aspects of dam design, construction, operation, maintenance, and rehabilitation. This Proceedings Volume contains the accepted technical papers and is available for download from the INCOLD website www.incold.co.in; and DRIP website www.damsafety.in by all the interested dam professionals for their reference and use. We hope all concerned will make best use of the information contained in the Proceedings Volume in shaping their dam safety initiatives.



A.k. dinkar

Secretary General

Indian National Committee on Large Dams

change in Methodology in construction of Plastic concrete Cut-Off Wall Adapted in Kishanganga HE Project

A,k, Singh¹ and Sunil J Ganvir²

ABSTrACT

In the Himalaya, rivers have carved out deeply incised valleys where construction of dams is a challenge as a number of sites have thick overburden in the river bed. At Kishanganga HEP in J&K, a 37m high concrete face rock fill dam with 33m deep cut-off wall was planned and efficaciously executed. Construction of the project began in 2009 and all the three units (3 x 110 MW) were successfully commissioned in March 2018.

One of the key aspects of the project was the construction of a 134m long, 1m wide plastic concrete cut-off wall (diaphragm wall) below the dam upto the maximum depth of 33m in overburden. Based upon the previous experience gained from different projects, significant amount of desk studies were taken up during the design stage to develop a scope of work for the possibility of construction of cut-off wall either through mechanical means like trench cutter or drill-blast method.

Unlike the prevailing mechanical method like trench cutters, the cut-off wall in Kishanganga HEP was executed by drill and blast & hydraulic grab picking method due to the presence of high strength boulders and other reasons. Highly specialized methodologies as well as equipment deployed have also been discussed.

Keywords : Plastic concrete, cut-off wall, water tight, seepage barriers, ground conditions.

1. iNTr Odu CTiON

The Kishanganga Hydroelectric project (KHEP) of 330 MW installed capacity has been constructed on the river Kishanganga (a tributary of river Jhelum) and is located in Bandipore District of Jammu & Kashmir. The power house site is accessible by 75 km long all weather double lane road from Srinagar whilst the dam site is further north and can be approached by 84 km long road which is single lane for considerable length and crosses hilly terrain.

The project comprises of 37m high Concrete Face Rock fill Dam; 134m long, 33m deep, cut-off wall at upstream toe of dam; One number of 23km long, 6.24/5.2m diameter, horse shoe / circular shaped HRT and 905m long, 5m dia, horse shoe shaped Tail Race Tunnel. The underground power house accommodated 3 units of 110MW capacity each designed to operate under the net rated head of 646m and generating 1713 MU in a 90% dependable year. Construction on the project began in 2009 and all the three units (3 x 110 MW) were commissioned and synchronized with the electricity grid during March 2018.

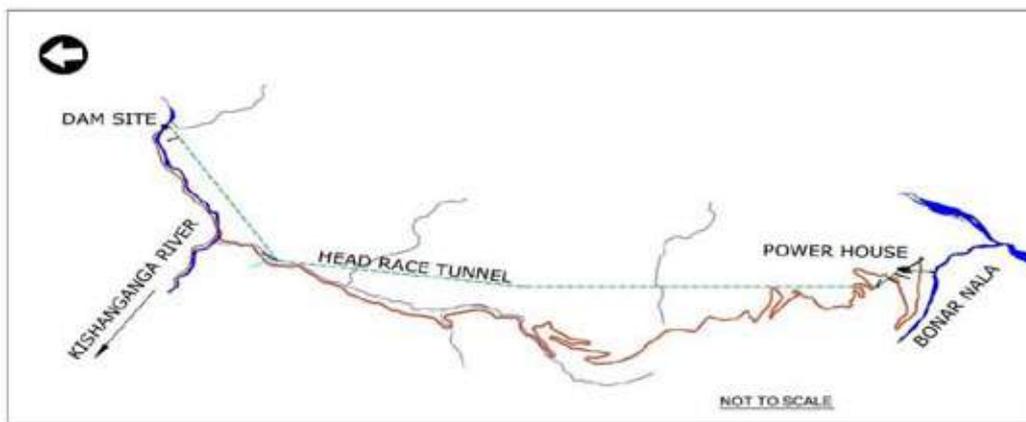


Fig. 1 : Schematic layout plan of the project

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2. Senior Manager (Geology), NHPC Limited, India

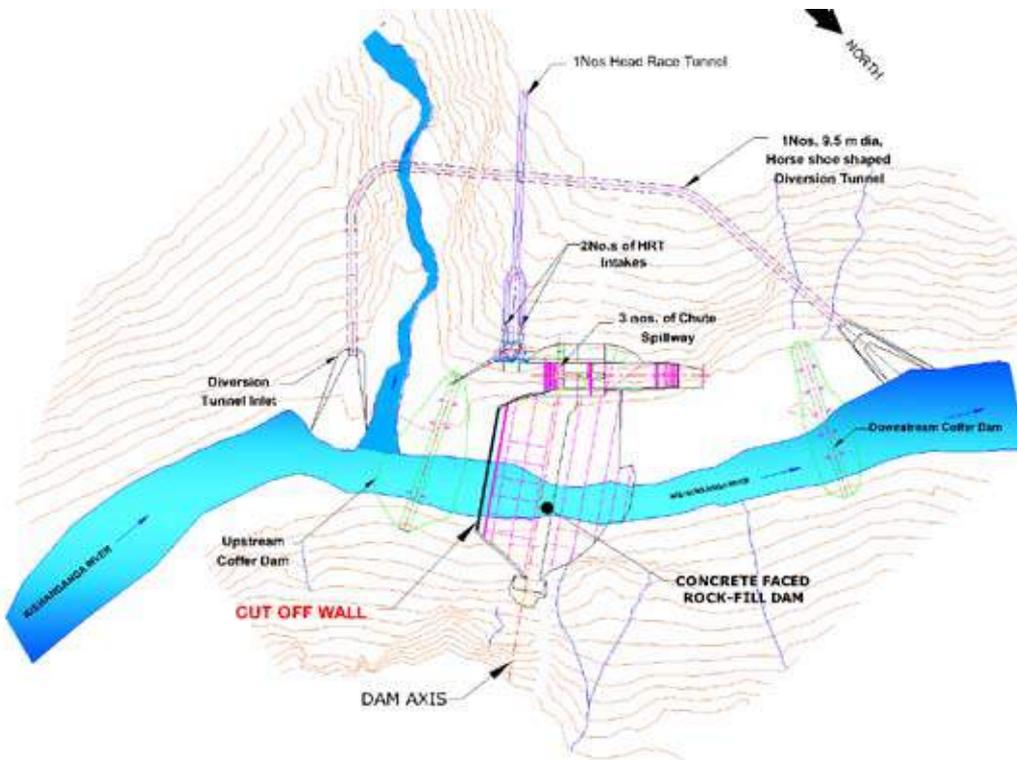


Fig. 2 : Schematic layout plan of Dam Area

The underground power house with installed capacity of 330 MW houses 3 units of 110MW capacity each designed to operate under the net rated head of 646m and generating 1713 MU in a 90% dependable year.

2. SITE GEOLOGY

Kishanganga project is located in Gurez valley in west central Kashmir Himalaya and has a long history. Conceived in 1960s the project was investigated by State as well as Central Power Utilities. However the active construction was completed in 9 years beginning from 2009. This is a worthy achievement considering the 84 km long mostly single lane access road from Bandipore to Gurez going over Razdan pass (3500 M) which is closed in winter season and other difficulties. Geologically the project is situated in Kashmir nappe within the Basaltic/andesitic Panjal Volcanics of Permo-Triassic age and Madhumati Group belonging to Cambro-Silurian age.

The dam is located in picturesque Gurez within a U-shaped valley having steep abutments where Panjal Volcanics are manifesting. At this location river width is about 90m with nearly 30m wide main channel being confined to the right bank due to exposures of slope wash & low level fluvial terrace deposit. The left bank of river channel comprises of river borne material at river bed level. The overburden materials consist of boulders, pebbles and cobbles of Andesite, granite, dolomitic limestone and gneiss embedded in a sandy silty matrix. The depth of the

overburden along the dam axis varies from 1.9m to 33m with hole collars being at around El. 2364.00 m.

Both the abutments on either bank above the river bed are exposed with bedrock of greenish in colour, fine grained and massive Andesite flows of Panjal Volcanic rock. Laboratory tests on core samples as carried out indicate that the uniaxial compressive strength (UCS) of the rock ranges from 95 to 265 MPa. Thus the strength of rock was variable and quite hard. From the 15 number of drill holes and other investigations carried out in dam area, the Andesite of Panjal Volcanics rock were found to be deeply weathered (up to 7 to 9m depth) and permeability of bedrock ranged from 12 to 50 Lugeons. The rock quality from the deformability considerations however was considered from good to very good.

3. NEED FOR POSITIVE CUT-OFF WALL

The key part of the whole project was the construction of a 134m long, about 1m wide plastic concrete cut-off wall (or diaphragm wall) without reinforcement underneath the main dam at upstream toe area to a maximum depth of 33m in overburden consisting of bouldery zone along with 1m socket into bedrock through drill-blast & grab picking method which was an innovative technology.

The objective of providing cut-off wall at upstream heel of the Concrete Faced Rock fill Dam was to restrict seepage of water within the overburden and rock

formations beneath dam and to enhance long term stability/service life of the dam against internal erosion and uplift pressure.

Unlike some of the other conventional cut-offs where the path of seepage is diverted below the dam, in this case the placement of positive cut-off wall into socket of bed rock sealed the water seepage below the dam body as illustrated below.

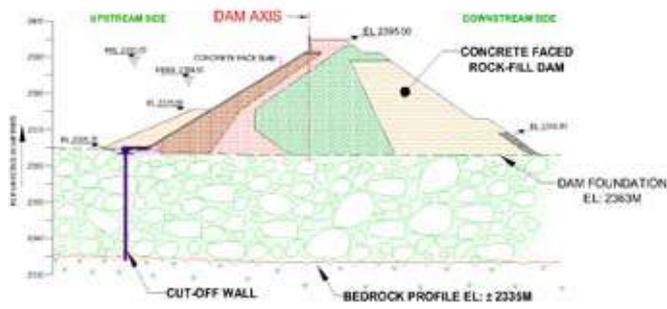


Fig. 3 : Cross Section of CFRD

As already mentioned above, the thickness of the overburden along the cut-off wall in the river bed section varies from 1.9 to 33.0m consisting of riverine materials like boulders, pebbles and cobbles of Andesite, granite, dolomitic limestone and gneiss embedded in a sandy silty matrix which are underlain by bedrock of massive to moderately jointed, compact, hard Panjal volcanics.

During the construction of cut-off wall, riverine deposits have been excavated and the resulting void backfilled with a barrier material of well defined properties. Unlike the prevailing mechanical method like trench cutters, the constructions of cut-off wall in Kishanganga HEP has been executed by drill and blast method (DBM) & hydraulic grab picking method due to the presence of high strength boulders in an relatively unknown quantity and size.

Based upon the previous experience gained from different projects, significant amount of desk studies were taken up during the design stage to develop a scope of work for the possibility of construction of cut-off wall either through mechanical means like trench cutter or drill-blast method. With the deployment of Hydromill type Trench cutter in geological conditions like hard boulder range more than 200MPa, the excavation output may have dropped rapidly and wear & tear on the cutters may have becomes high. As such, alternative excavation processes as combination of drill-blast method, the mechanical grab system were adopted in Kishanganga HEP and was found to be successful.

The concrete for the cut-off wall was required to be homogeneous, which can be readily placed and uniformly workable. It was to have following main properties:

- Maximum grain size 30 mm
- Unconfined compressive strength (28 days) > 1.5 MPa
- Confined compressive strength > 2.5 MPa
- Strain at failure (unconfined test) >5%
- Permeability <10⁻⁸ m/s

In Kishanganga the plastic concrete cut-off wall was designed to be 1m thick with maximum depth of 33m and average depth of 30m and surface area of 3600 sq m.

4. GEOLOGY Ar OuNd POSiTiVe CuT-OFF WALL

The depth of the overburden along the cut-off wall in the river bed section varies from 1.9m to 33.0m consisting of riverine materials underlain by bedrock of massive to moderately jointed, compact, hard Panjal volcanics. The overburden materials consists boulders, pebbles and cobbles of Andesite, granite, dolomitic limestone and gneiss is embedded in a sandy silty matrix.

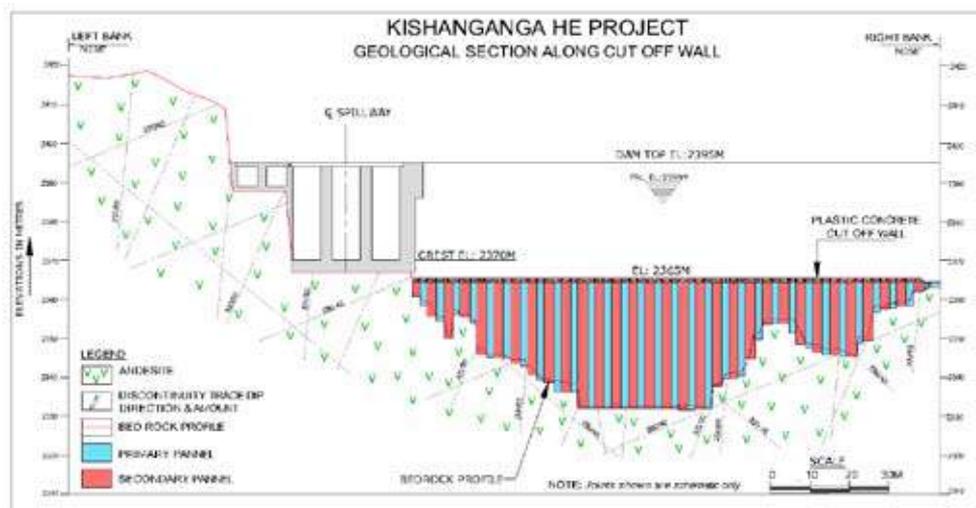


Fig. 4 : Geological Section of Cut-Off Wall

5. SITE INVESTIGATION

In Dam area, total 10 no exploratory bore holes with cumulative length of 425.0m were drilled to assess the rock condition beneath the dam foundations. Additional 04 nos of exploratory boreholes were drilled in which availability of fresh rock along the cut-off wall at a depth 1.9 to 33m was observed. In Geophysical survey, seismic refraction survey was also carried out by NHPC to assess the overburden/bedrock interface.

5.1 key Outcomes from Site investigation included:

- Detailed geological section based on site investigation provided a high level of confidence to decide the overburden, weathered rock and fresh rock levels.
- Permeability of the overburden ranges from 2.1 x 10⁻³ cm/sec to 98 x 10⁻³ cm/sec.
- Laboratory tests on core samples done indicate that the uniaxial compressive strength (UCS) of the rock ranges from 95 to 265 MPa. The Andesite of Panjal Volcanics rock deeply weathered (upto 7 to 9m depth) and Permeability of bedrock ranges from 12 to 50 Lugeons.

6. drilling

Down the hole hammer (DTHH) drilling system of dia 115mm & 250 mm were carried out as blast and relief holes respectively in riverine deposits in which one meter in bedrock has been ensured.

The drilling pattern in a series of 5-metre stretch consisting of 12 No. x Ø 115 mm holes and 05 No. x Ø 250 mm holes were made for the drilling and blasting preparatory operation to the cut-off wall excavation for entire length consisting total of about 400 nos. of drill holes.

As the drillholes were carried out through DTHH, so logging of the individual holes were done based on the penetration rate, hardness evidenced by the drilling, the

rate of advance, cuttings and the sound produced. This has facilitated determination of the location of the charges and their intensity to achieve the desired result of rock shattering, without damaging the adjoining strata.

Subsequent to completion of drilling a hole, an inclinometer test was performed on selected holes to accurately measure the verticality and the straightness. Tolerance on hole final depth of ± 150mm has been ensured.

6.1 key Finding during drilling

The length was 2.5m for primary & secondary panels after the concreting. According to the plan shown below, the depth of each module was adjusted as per deepest hole of the panel that makes easy for grabbing the material.

7. BLASTING

For charging the hole, long delay Nonel has been used at multiple intervals through Bottom Initiation System (BOS). A charge density of 0.7 to 1.5 kg/m was used in the blast holes. As group of four numbers Ø115 mm holes with a Ø 250 mm hole at the centre of this module was blasted all at once. This module of 4+1 holes repeats itself every after 1000mm interval. This repetitive module was blasted one after another with the suitable charges.

In the rock socket the first charge was placed in position with a nominal 300 mm cushion below the charge to avoid any damage to the underlying bed rock. Depending on the depth of the cut-off, where 6 or more charges placed within the hole at those locations, dictated by adverse soil conditions (e.g. large boulders). The blast holes were cased with PVC pipes jointed with a socket joint (75mm O.D. & 70.4mm I.D.). Each charge was pre-packed on the ground in a PVC charge-tube (63mm O.D. with 57mm I.D.) which was lowered down hole to the designated depth defined during drilling. Multiple charges was lowered down hole, one at a time, only after adequate stemming has been performed for the previous charge.

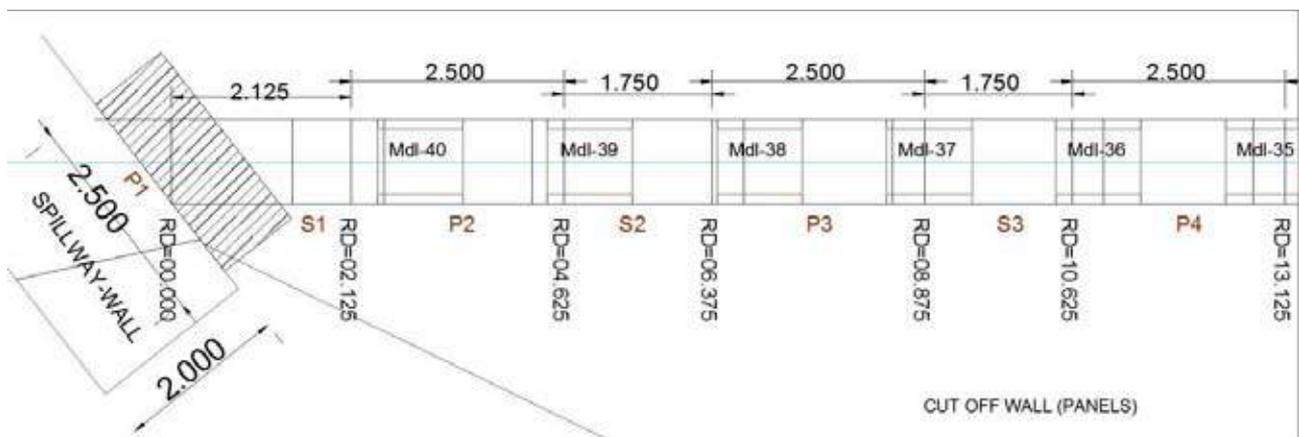


Fig. 5 : Module drilling pattern

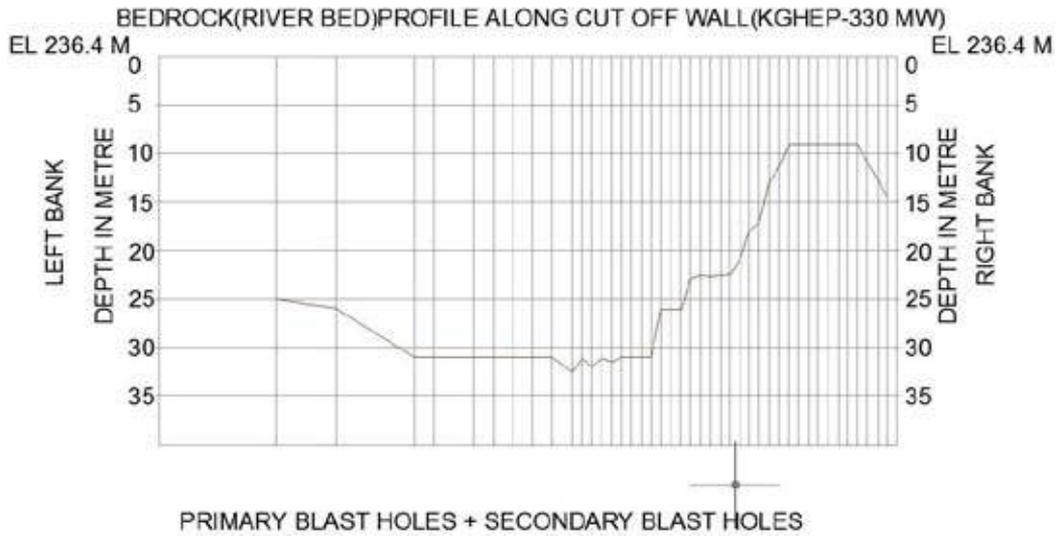


Fig. 6 : Primary & Secondary blast hole

The holes were initiated and blasting occurred according to the sequence mentioned above. Prior to initiating the explosive charges, safety muffle pads made of reinforced concrete (typically, 2500mm x 2500mm x 1500mm) in a truncated square pyramid form, was placed above the charged holes to avoid fly rock and surface damage. After completing the charging and blasting for one primary panel length of 7 m, Ø 250 mm hole, only one in between the two earlier blasted 4-hole patterns, were drilled with the necessary logging precautions.

CONSTRuCTION OF Guide WALL

Prior to construction of diaphragm wall it was important to construct guide walls to maintain the alignment. The guide walls ensured the following:

- To maintain and confirm the correct alignment of the excavation. Panel locations and numbers were systematically set out on the guide walls.
- Stability of the upper trench has been kept as it may have got disturbed by cranes and heavy traffic close by.

- It also gave protection against washing due to fluctuating levels of bentonite slurry thus avoiding upper soil instability.
- As stated above due various reasons the upper part of trench is protected against loads due to traffic etc.
- The guide walls were mainly constructed as an in-situ cast reinforced unit and offered support for vertical loads imposed by extraction of stop ends and ends and whose extractor jacks in-turn were supported by guide wall.

8. Gr ABBiNG /EXCAVATION OF PANELS

- At Kishanganga, the excavation tool was a heavy wire rope-suspended mechanical clamshell grab. That was operated by using a large lattice boom hydraulic crawler crane (e.g., an 80-tonne Kobelco nominal bite dimension, were approx. 4.5 metres tall with the jaws opened and weighed 7 tonnes or 9 tonnes).
- Prior to commencement of excavation of the primary panel, the mud reservoir was created by excavating

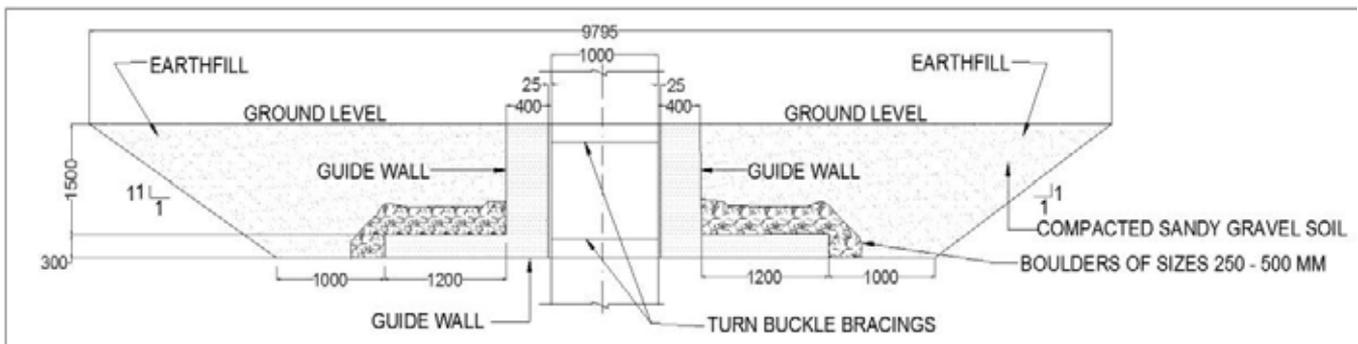


Fig. 7 : Cross section of guide wall

within the guide walls, for a depth of 800mm to 1.0m, a trench extending for approximately 3.0 metres beyond the ends of the panel trench. This was filled with bentonite slurry and acted as a surge tank to minimize the fluctuations of the bentonite level within the trench as the grab was lowered into it and removed from it during grabbing operations.

- The excavation cut-off wall trench was performed by mechanical grabbing after shattering of river borne materials by light controlled blasting was done.
- Walls of excavated trench were kept supported by bentonite slurry as usual.
- Chisel was used to break the boulders if by any chance some corners of boulders still left unbroken and obstruct the grabbing.

9. PLACEMENT PLASTIC CONCRETE WITHIN PANEL

- Concrete was placed within the panel trench by means of tremie pipes supported by a crane, when necessary, subjected to jerk to promote the outflow of the concrete from the submerged bottom of the tremie.
- With the steel tremie suspension device in place, the tremie pipe (minimum \varnothing 250 mm) was introduced into

the trench down to 200 mm from the bottom. If two tremie pipe assemblies were used, as in multi-bite primary panels, then they placed at least 1.0 m from the panel ends and not closer than 3.0 m from one another.

- Possible across the panel width. During concrete placement, the end of the tremies was kept immersed below the surface of the fresh concrete at all times.
- As soon as placement was completed, scum which accumulated on the surface of the concrete was removed by shovel or other means.
- All handling of concrete were such that discharge of each batch was completed within 90 minutes of the introduction of the cement in the mix.
- Properties of plastic concrete is provided in Table 1

10. CONCLUSIONS

Now-a-days deep diaphragm cut-off walls are more frequently in use and provide optimum solution for an effective water barrier within the soil and weak rock formations beneath dam. The successful construction of the cut-off wall has also ensured foundation treatment work for dam which has resulted both in stability and impermeability (water tightness) of the underlying foundation rock by avoiding unacceptable under-dam water seepage.

Table 1 : Mix Design for Plastic Concrete

OPC (kg/cum)	Bentonite (kg/cum)	Aggregate 10mm (kg/cum)	Fine Aggregate (kg/cum)	Water (kg/cum)	Admixture W _r A (kg/cum)	Slump At 60min (mm)	uCS 28 days (mPa)	Permeability (m/s)
150	80	551	1023	350	0.98	180	1.57	10 ⁻¹²



Fig. 8 : Crawler Crane



Fig. 9 : Mechanical Grab



Fig. 10 : Heavy chisel



Fig. 11 : Placement of Bentonite Slurry



Fig. 12 : View of Koden test Equipment



Fig. 13 : View of placement of plastic concrete inside cut-off wall panel

In Kishanganga project, by selecting the most appropriate excavation methodology, cut-off wall with depth to the order of 30m in difficult ground conditions like hard bouldery zone has been executed successfully through drill-blast method followed by excavation through mechanically operated clamshell grab. Simultaneous poring and bentonite slurry and later replacement by plastic concrete ensured the success without collapse.

The Cut-off Wall was successfully constructed by advance planning to reduce geological uncertainties by conducting seismic refraction survey and exploratory drilling that helped in assessing the overburden-bedrock interface. Further, with the use of drill-blast methodology instead of conventional trench cutter method resulted in limited risk of cost variation and time overrun. Clearly the use of most modern technology in the remotest corner of the country has indicated the highest degree of logistic planning for transport and for beating the adverse winters also. The successful execution of the cut-off wall in such a scenario in Kishanganga and in some other projects such as Dhauliganga Stage-I, Parbati Stage-III, Teesta Stage-III and MangdeChhu has opened new vistas in tackling deep bed rock profiles in river valley development projects in the Himalayas. This solution can be used elsewhere also.

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Heightening of Dhanikhari Concrete Dam

Y.k. Chaubey¹, Sankhadip Chowdhury² and mukesh Bhoria³

ABSTRACT

Aimed at mitigating the shortage of potable water requirements of South Andaman area of Anadaman & Nicobar Island (India), the scheme to augment the live storage capacity of existing Dhanikhari reservoir by 3.23 mcm through raising the height of dam by 5 meters was an important project executed by NHPC Ltd. The 132 m long existing dam across the Dhanikhari nallah with dam top EL 62.5 m, consisted of eight non-overflow blocks and two spillway bays on a central overflow block of ± 32 m height above deepest foundation, impounding a reservoir with gross storage capacity of 4.61 mcm at FRL 61 m. The entire water supply requirement of Port Blair is met from this reservoir.

Detail study of augmentation of the existing storage capacity of Dhanikhari reservoir, included evaluation of heightening of dam by two methods i.e. Prestressed Anchors and Backing Concrete methods. Backing concrete method was adopted due to its techno economic advantage. Several issues in this method were addressed viz. effect of permanently built-in stress on new concrete, effect of shrinkage in new concrete on old concrete, restraining effect of old concrete on new concrete, bonding between old & new concrete, enhancement of spillway capacity and seismic retrofitting, etc.

While heightening the dam, the existing overflow section was partially demolished, to construct a new spillway with augmented spillway capacity of 225 cumecs. The heightening was completed on december 2014.

Keywords : Gravity dam, Heightening

1. INTRODUCTION

Port Blair is the capital town of A&N islands, India. Dhanikhari dam is constructed across Dhanikhari nallah in the year 1973 by APWD to cater the drinking water needs of the Port Blair town. The existing Dhanikhari water supply scheme comprised a 32.25 m high (from deepest foundation), 132 m long concrete gravity dam constructed across the Dhanikhari nallah with dam top level at EL 62.5 m, and a storage capacity of 4.61 M cum at an FRL of EL 61 m. In order to augment the water supply to cater the rising demand levels of future, after detailed study [1], it was found that by raising the height of existing Dhanikhari Concrete Dam by 5 m present live storage capacity can be increased by nearly eighty percent of existing storage capacity. The additional storage was suitable to cater the projected drinking water needs for the forthcoming 15 years.

Two methods of dam heightening i.e. Pre-stressed Anchorage method and Backing Concrete Method was explored. Due to construction constraints and non-availability of indigenous specialized agencies the former method has not been pursued. During the detailed study the existing condition of dam was found good and suitable

for increasing the height. Subsequently following was deliberated,

- Various design parameters of the dam and rock parameters of foundation and abutments were verified.
- Hydrological data of Dhanikhari Nallah and its catchment was examined to arrive at the design flood for increased height of dam.
- The geological and geotechnical studies of dam area have been carried out to ascertain the strata underlying the dam and rock parameters of dam foundation and abutments.
- The reservoir geology has also been studied.
- The seismicity of the region has been studied and earthquake parameters of the Dhanikhari dam have been evaluated.
- Construction material survey and testing have been carried out for identification and suitability of construction material.
- A preliminary environmental study has been conducted to evaluate the effects on flora and fauna and other socio-economic aspects due to raising in height of dam.

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Fig. 1 : Downstream face of Dam before Heightening



Fig. 2 : Downstream face of Dam after Heightening

2. dEmANd ASSESSmENT

The Dhanikhari dam was conceived and constructed for a live storage capacity of 3.24 mcm at its full reservoir level of EL 58.50 m. Since the demand of water increased, the storage level was raised by 2.0 m by providing two no. of 7.9 x 2.2 m vertical gate and thus enhancing the live storage capacity to 4.37 mcm. But the incumbent increase in population of Port Blair town has concerned the A & N administration on future water demand. In this regard demand assessment up to AD 2010 has been carried by APWD, which indicated a deficit of 23.69 lgpd which is equivalent to an additional storage requirement of 2.31 mcm for 215 days dry period. Thus, dam heightening of Dhanikari dam 5 m was envisaged.

3. FiELd WORk

3.1 General

Following field investigations were carried out to fulfill the following objectives:

- Determination of the area due to additional submergence.
- Evaluation of the existing condition of the dam.
- Investigation for ascertaining rock parameter of the foundation of the existing dam.
- Evaluation of strength and design parameters.
- Preliminary assessment of Environmental Impact due to additional submergence.
- Construction Material Survey

3.2 Topographical Survey

Topographical survey was carried out in the entire reservoir area during the investigation up to EL 70 m to identify any low pockets i.e. having elevation less than EL 66 m in the reservoir rim.

3.3 investigation on Existing dam

Investigation on existing dam has been carried out to ascertain various concrete and rock parameters. Drilling through foundation gallery for collecting rock and concrete samples of the foundation were carried out at both Overflow blocks and Non-Overflow blocks at different elevations. Concrete core from upstream & downstream face of the dam were collected for ascertaining the compressive strength of the present concrete. Pullout test was conducted inside the foundation gallery to evaluate the bond strength between the concrete and rock of existing dam. Following laboratory tests were conducted on concrete and rock samples,

- Modulus of Elasticity of concrete core,
- Poisson's ratio of concrete core,
- Shear strength parameters of interface between concrete & rock,
- Compressive strength of rock,
- Compressive strength of foundation concrete sample,
- Tensile strength at concrete and rock joint,
- Direct shear strength test on old concrete and new concrete.

Instrumentation in the form of 4 Nos. Vibrating type electrical piezometers were installed in the foundation to record the uplift parameter of the existing dam. One Vibrating wire type electrical thermometer was also placed in the downstream face of right non overflow block to record the temperature of the face of dam body and its behavior with respect to changing ambient temperature, which is a vital parameter in finalizing the suitability of backing concrete method.

It was seen from the plots that the piezometric head downstream of grout curtain is about 1/10th to 1/8th of the

corresponding head in reservoir. This uplift is considered very small compared to the design value considered in the stability analysis. This low uplift is considered due to the ingress of fine silt in the rock joints and a blanket on the floor of the reservoir.

3.4 Construction material Survey

The designated quarry for production of coarse & fine aggregates for use in South Andaman is located in carbines Cove Area, situated at about 16 km from the Dam site. Development of a quarry near Dhanikhari Dam was very remote possibility due to MOEF restriction & Hon'ble Supreme Court order. For the raising of height of the existing dam, sufficient quantity, around 2.5 lakh cum of material for the production / processing of coarse and fine aggregate is available from the rock quarry. The physical test results of the quarry material indicate that the material is suitable for the production of concrete for wearing as well as non-wearing surface. The petrographic analysis indicated aggregates are Trachy Basalt, which is a volcanic igneous rock.

4. HYdro OLOGY

The hydrological analysis has been carried out with a view to,

- Determine the additional reservoir capacity for a raise of 5 m in dam height.
- Review the spillway design flood.

Reservoir Elevation Area-Capacity curve has been prepared based on the contour maps received from site in the scale of 1:2000 at 2 m contour interval. The dam envisages a gross storage of 4.61 M cum at maximum water level of 61 m and the difference between maximum water level and minimum water level is 14.5 m. Hence as per IS 11223:1985, the dam is to be designated for Standard project Flood (SPF). SPF has been found by convoluting the 1-day Standard Project Storm (SPS) equal to 40.34 cm on the unit hydrographs computed using Clark's, Snyder's and Traingular methods. Base flow of 5.0 cumec and infiltration loss at a constant rate of 2.0 mm/hr is taken. Using these parameters, the various values of 1-day SPF are obtained. The value of design flood, i.e. 1-day SPF, recommended is 225 cumec based on the developed design flood hydrographs. The 1-day SPF hydrograph is then routed through the reservoir by keeping the impinging level equal to FRL i.e. EL 66 m. After routing, a maximum level of 66.17 m and maximum outflow of 193.93 cumec was obtained.

5. ENGINEERING GEOLOGY

The bedrock constituting the Dam site comprises of mainly buff to grey, fine to medium grained, massive sandstone with minor bands of well bedded flaky, very fine grained sandstone or siltstone. The strike of the

stratification is ENE-WSW with dips of 45 to 67° generally towards the left abutment. There is a gradual swing in the bedding direction from due south in the left bank to SE in the right banks d/s of the bend. Surface indications of a minor local fault parallel to the dam axis with fault plane dipping steeply d/s, have been observed 56 m d/s of the Dam axis.

Eight nos. bore holes, 3-5 m deep in the dam foundation, and about 2 m into bedrock has been done in the drainage gallery which generally intercepted grayish green fine grained sandstone exhibiting core recovery from 62-90% and RQD values ranging from 50-80%.

Engineering properties viz. density, crushing strength and triaxial shear strength were determined by laboratory tests. Laboratory test revealed UCS values of sandstone ranging from 23 MPa to 67 MPa whereas a single sample of shale has indicated UCS value of 55.8 MPa.

The project area has been shown in zone V of the seismic zoning map of India. The maximum value of peak ground acceleration (PGA) worked out to be 0.51g. The report on the site-specific earthquake parameters prepared by the Department of Earthquake Engineering, IIT Roorkee.

6. DESIGN AND ENGINEERING ASPECTS

6.1 The Existing dam

The existing dam consists of eight non-overflow blocks and one overflow block. The design flood of spillway was considered as 141.5 Cumecs.

6.2 Selection of method of Heightening

Two possible methods were identified to achieve the objective of raising the dam. These methods are:

- Use of permanent pre-stressed anchors,
- Adding additional concrete on downstream face of dam to achieve a cross-section corresponding to increased height.

Due to construction constraints and non-availability of indigenous specialized agencies the former method was not pursued.

6.3 Finally Selected method – Backing Concrete method

Backing concrete method has been adopted with a considerable degree of success in heightening and strengthening of gravity dams worldwide. However following principal issues were deliberated during selection of this method.

- The new concrete placement, if done while the old structure is under load, deformed and in a state of stress, the placing of new concrete on the downstream face will tend to retain and permanently build-in these stresses. To minimize this affect, the reservoir is kept

preferably at MDDL during placement of new concrete so that the unfavorable stresses due to high water level are not locked in.

- The shrinkage of the new concrete induces unfavorable pre-stressing in the old concrete on one hand and restraining effect of old concrete causes stresses in new concrete on the other. To minimize this effect various measures such as using low heat cement and controlling the rise of temperature of new concrete by artificial cooling.
- Method to ensure essential monolithic character of the completed structure.

6.4 Adopted Section

In the existing arrangement, top of the dam was at EL 62.5 m with 5 m top width. While heightening the dam, the level of the dam top has been raised by 3.5 m at EL 66.00 m which corresponds to the maximum water level after raising. The dam top is kept at EL 67.5 m by a thick mass concrete parapet to account for free board of 1.5 m which is considered sufficient. The existing overflow section was to be demolished up-to EL 56.00 m and replaced with new concrete having modified spillway profile. 3 nos. opening size 3.6 m (w) X 3.6 m (h) are provided in the overflow block which discharge into the common chute. 3 nos. vertical gates operated from EL 66.00 m are provided to regulate the discharge from spillway.

6.5 interface of Old Concrete and New Concrete

Test had been got done to obtain the shear strength of old concrete / new concrete interface and following values of shear strength at interface were obtained.

- Using M-25 as new concrete cohesion= 14.5 kg/cm², $\phi = 42^\circ$
- Using M-15 as new concrete cohesion= 8.6 kg/cm², $\phi = 47^\circ$

Shear stress of the order of 2 kg/cm² was calculated using elementary beam theory.

6.6 Stability & Earthquake Analysis

The overflow and non-overflow portions of dam were designed as gravity sections and were checked for stability (IS 6512-1984) for the following loading conditions:

- Load combination A (construction condition) – Dam completed but no water in reservoir and no tail water.
- Load combination B (Normal operating condition) i.e. Full reservoir elevation, normal day weather tail water, normal uplift (drains operative).
- Load combination C (Flood discharge condition) maximum flood pool reservoir elevation, tail water at flood pool elevation, normal uplift (drains operative)
- Load combination D – combination A with earthquake
- Load combination E – combination B with earthquake but no ice.
- Load combination F – combination C, but with extreme uplift (drains inoperative)
- Load combination G – combination E, but with extreme uplift (drains inoperative)

Stresses, forces and moments due to static forces i.e. weight of dam, reservoir hydrostatic force, uplift force (both normal uplift and extreme uplift) were calculated for A, B, C, F load combinations.

The tensile stresses in the dam in earthquake (DBE conditions) were found significantly low compared to its strength. For the dam site, Earthquake Engg. Department, IIT Roorkee, has recommended 0.51g and 0.255g as peak ground acceleration (PGA) corresponding to MCE and DBE conditions.



Fig. 3 : View of foundation under extended Dam toe



Fig. 4 : Dam Heightening under progress

It was found that Dhanikhari dam in its raised from incorporates all necessary design details for an earthquake resistant design and excellent behaviour of this dam after raising should be expected during earthquakes in future.

6.7 Spillway and Energy dissipation System

The hydraulic design of Spillway and Energy Dissipation System was firmed up through hydraulic model studies

Spillway had its overflow profile conforming, as nearly as possible, to the profile of the lower nappe of a ventilated jet of water issuing through an orifice. Spillways openings were provided below MWL for considerations of increasing and regulating storage of flood discharge.

The design flood for the spillway worked out as 225 Cumecs. The discharging capacity of 2 Bays of sizes 4.5 m (W) x 2.5m (H), corresponding to reservoir at EL 66.00 M, was computed as 192 cumecs.

The existing stilling basin length was increased by 9 m and the height of the side increased by 1.5 m to accommodate the spillway discharge.

6.8 Temperature Studies for mass Concrete

Peak temperature rises in mass concrete, needed to be controlled so that minimal thermal stresses were induced in the old concrete due to placement of new concrete. The average ambient temperature, for not allowing the temperature of concrete to rise above the stable temperature of concrete, was 27°C.

Many measures were taken to restrain the net temperature rise to acceptable levels like placement temperature kept as 12°C, using Portland – Pozzolana cement. Also, maximum aggregate size was fixed as 80 mm to minimize segregation problem.

A study was conducted through FEM with idealized construction schedule wherein concrete upto El. 55 m was done in season one and concrete above El. 55 m was done in second season. A lift height of 1.5 m has been considered in the model with a gap of 72 hours in between two lifts.

Following inputs were considered in FEM analysis

Material properties for thermal analysis

- Unit weight (ρ): 2400 kg/m³ (concrete) and 2500 kg/m³ (rock)
- Specific heat (C): 0.85 kJ/kg/°C (concrete and rock)
- Conductivity (k): 7.5 kJ/m/h/°C (concrete corresponding to aggregate type Trachy Basalt)
- Conductivity (k): 12 kJ/m/h/°C (rocking corresponding to foundation rockmass type Sandstone)

Cementitious materials of 210 kg/m³ has been considered with following proportions

- Cement: 157.5 kg/ m³
- Flyash: 52.5 kg/m³ (it is assumed that heat of hydration of flyash is ca. 50 % of that of cement and that the time development curves of cement and fly ash are identical, in reality fly ash leads to a retardation of the heat of hydration process)
- Equivalent cement content (cc): 157.5 kg/m³ (cement) plus 50% of 52.5 kg/m³ flyash (this corresponds to an equivalent cement content of 26.25 kg/m³) = 183.75 kg/m³

Maximum adiabatic temperature rise computed by using equation (1) below according to IS 14591 [2] gives $T_o = 28.3^\circ\text{C}$ (considering heat of hydration of cement at 28 days $q_c = 314 \text{ kJ/kg}$).

$$T_o = \frac{c_c q_c}{\rho C} \quad \dots(1)$$

The adiabatic temperature rise curve, T(t), is determined using equation (2)

$$T(t) = T_o (1 - e^{-mt}) \quad (2)$$

where $m = 0.025/h$

Rate of heat of hydration of mass concrete is determined through equation (3)

$$h(t) = \rho C \frac{dT(t)}{dt} = \frac{c_c q_c}{T_o} \frac{dT(t)}{dt} \quad \dots(3)$$

The heat loss is modeled through a convective boundary. The Convection coefficient (h_c) between, concrete and air and rock and air are determined using equation (4) suggested in ETL 1110-2-542 [3].

$$h_c = 5.622 + 1.086 v \text{ in } W/m^2/^\circ\text{C} \quad (4)$$

$h_c = 954 \text{ kJ/m}^2/^\circ\text{C/day}$; where wind speed $v = 5 \text{ km/h}$ has been considered

Initial steady state temperature distribution (Fig. 5) was established for old dam section considering ambient air and water temperature as 27°C and 22°C respectively.

A stage construction analysis was carried out to estimate the temperature rise in backing concrete and at the interface with old dam section.

As can be seen from the results of the analysis below (Fig. 6 to 8), the maximum temperature attained by concrete within the lift of backing concrete is approximately 32.9°C and the maximum temperature at the interface of old concrete is about 28°C. The differential of 5°C between ambient temperature and maximum temperature attained by concrete within the lift of backing concrete and raise of interface temperature by 1°C is found acceptable.

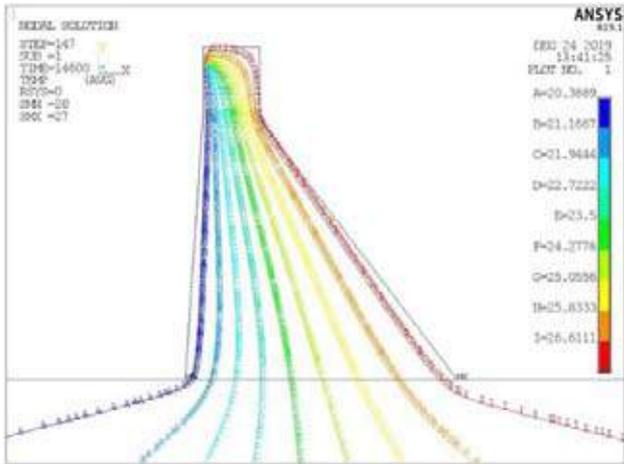


Fig. 5 : Estimated initial steady state temperature distribution

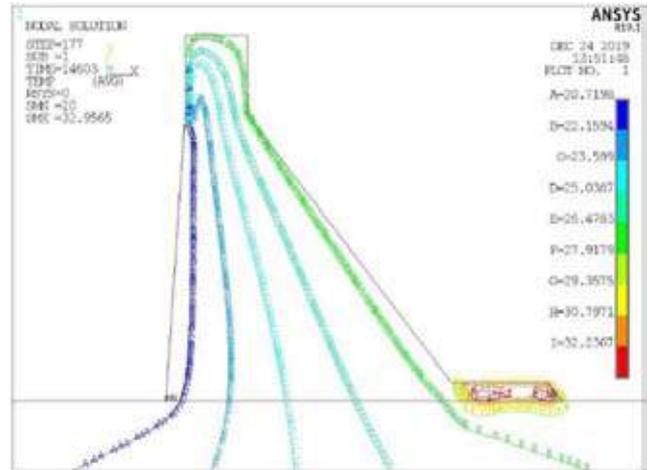


Fig. 6 : Estimated temperature distribution after 3 days of casting of first lift

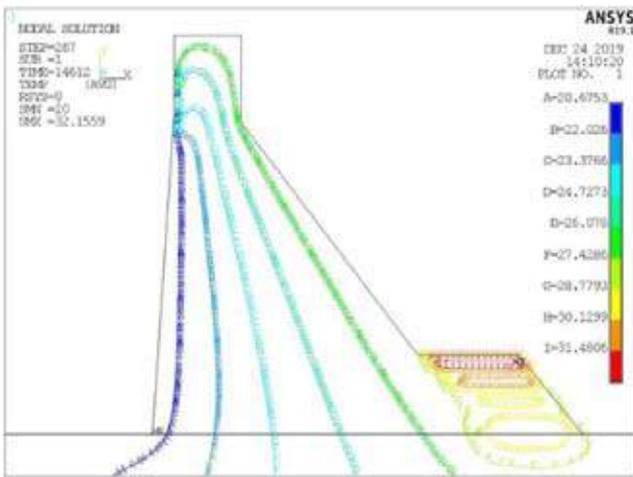


Fig. 7 : Estimated temperature distribution after 3 days of casting of fourth lift

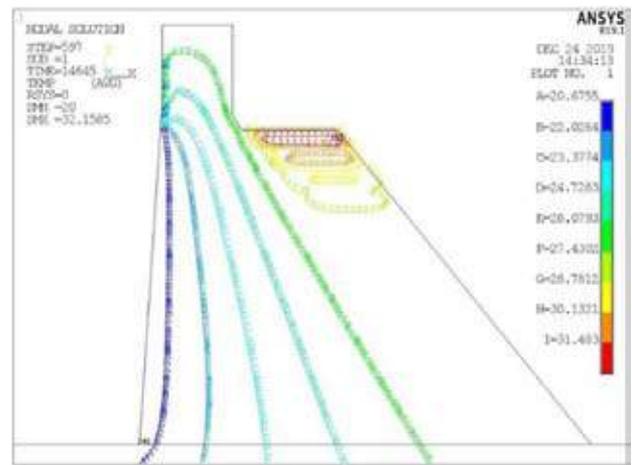


Fig. 8 : Estimated temperature distribution after 3 days of casting of concrete up to El. 55.00 m in first season

Concrete placement temperature was maintained by washing of aggregate, spraying chilled water for a reasonable time before un-loading into bins of batching plant, using ice flakes during mixing.

6.9 reservoir management during Construction

In an ideal situation, placement of concrete on the downstream face of an existing dam should be carried out when the dam is completely empty. However, in the present case the existing water supply arrangements cannot be allowed to be seriously disrupted during placement of concrete. Thus, concrete placement was carried out during the months when the reservoir level is low.

According to Robert B. Jansen [4], a drawdown of 20% of total head provides 75% of the relieving effect that can be obtained with a complete reservoir draining. Based upon

practical considerations, it was proposed to carry out the concrete placement during the period when the reservoir level is at or below EL 52.00M (i.e. 8m less than existing full reservoir level of 60 M). The proposal was analyzed through FEM. The stresses were observed for two cases of analysis, Case-I: The backing of concrete was done with water level at El. 52.00 m (Fig. 9. & Fig.10.) and Case-II: The backing of concrete was done with water level at EL 61.00 m (FRL, Fig. 11. & Fig.12.). The dam foundation was modeled as fixed. In both the cases the reservoir was brought down to El. 45.00 m (MDDL) after placement of backing concrete and the stresses along lift line was noted. It was observed that in Case –I there was no tensile stress on the downstream portion of backing concrete whereas in Case-II the tensile stresses were notice in downstream face. The results of the analysis is shown above in Fig. 9 to 12 (-ve is tension).

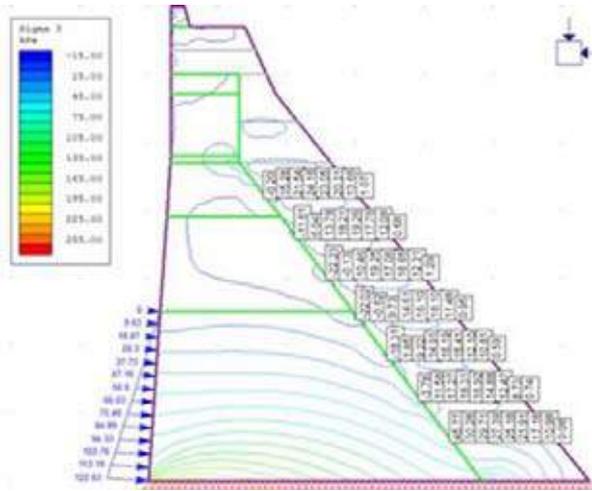


Fig. 9 : Case-I; Third principal stress

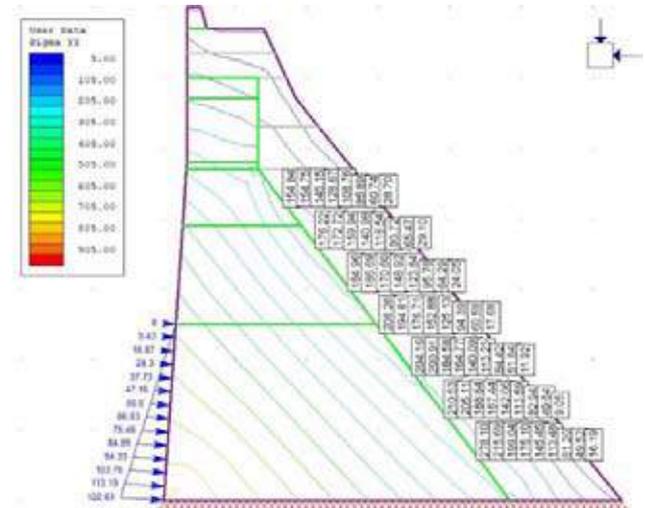


Fig. 10 : Case-I; Vertical stress

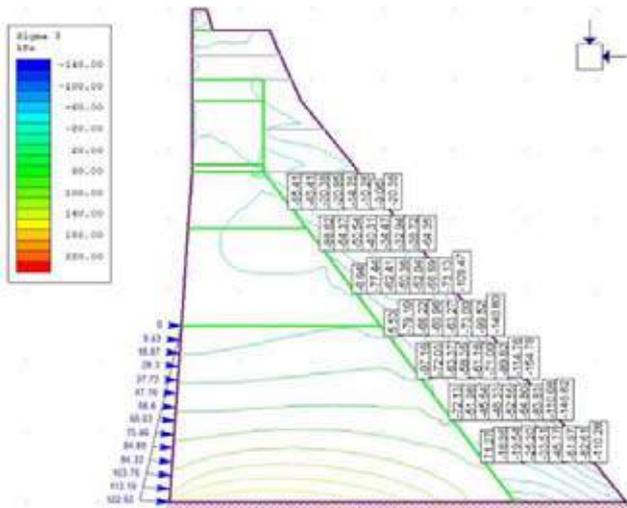


Fig. 11 : Case-II; Third principal stress

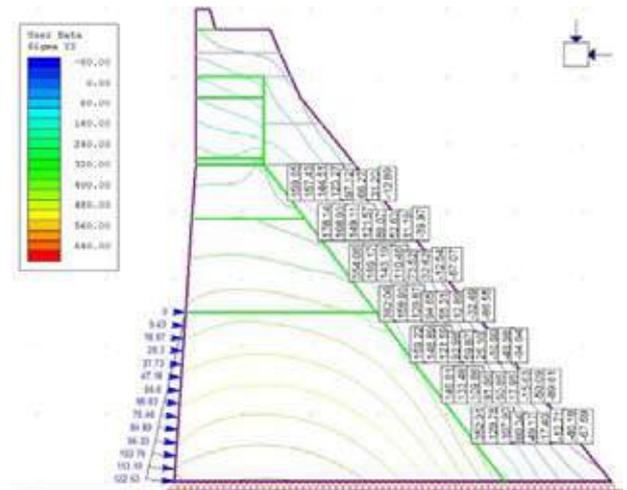


Fig. 12 : Case-II; Vertical stress

Therefore, in order to maintain a biaxial compression state in the whole dam body reservoir levels shown in Table 1 were recommended for adoption during construction

Table 1 : Recommended reservoir levels during construction

month	reservoir level (m)
March	EI. 52.00
April	EI. 50.00
May	EI. 48
June	EI. 50

6.10 Shrinkage Analysis

The shrinkage of the new concrete induces un-favorable pre-stressing in the old concrete on one hand and restraining effect of old concrete causes stresses in new concrete on the other hand.

The total shrinkage of concrete depends upon the constituents of concrete, size of the member and environmental conditions. For a given humidity and temperature, the total shrinkage of concrete is most influenced by the total amount of water present in the concrete at the time of mixing and, to a lesser extent, by the cement content.

The total shrinkage strain is composed of two components, the autogenous shrinkage strain and the drying shrinkage strain.

The autogenous shrinkage strain develops during hardening of concrete; the major part develops in the early days after casting. Autogenous shrinkage is a linear function of concrete strength. It should be considered specifically when new concrete is cast against hardened concrete.

Hence the temporal effect of autogenous shrinkage strain was modelled with stage construction model of dam as done for thermal analysis. The autogenous shrinkage strain parameters were taken as per equation (5) according to IS 1343 [5]

$$\varepsilon_{ca}(t) \beta_{as}(t) \varepsilon_{ca} \quad \dots(5)$$

Where

$$\beta_{as}(t) = 1 - e^{-0.2t^{0.5}} \text{ and } \varepsilon_{ca} = 0.0003; t \text{ is time in days}$$

The maximum tensile stress only due to shrinkage was about 1.8 MPa (tensile, Fig. 13) at the toe of the backing concrete. Therefore, a mass concrete of higher compressive strength envisaged at foundation grade. However, the maximum stress due to shrinkage at interface of old and new concrete was restricted to about 0.4 MPa which was found acceptable.

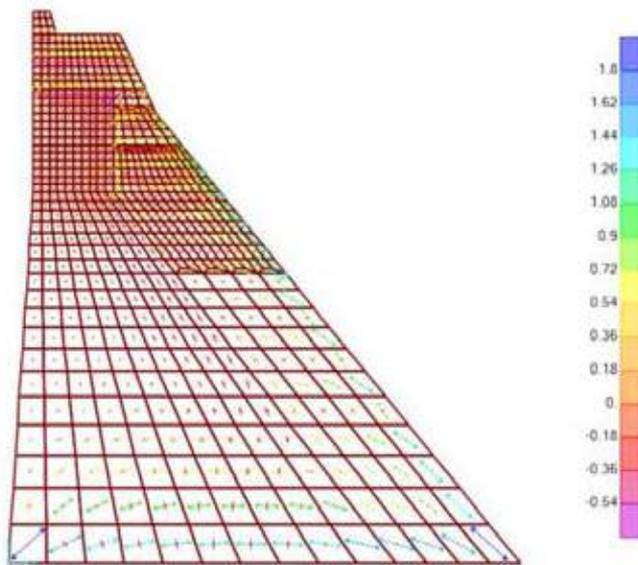


Fig. 13 : Principal stress vectors due to shrinkage at 10th year

6.11 Foundation Treatment

At the time of construction of existing Dhanikhari concrete dam, foundation treatment like consolidation grouting, contact grouting and drilling of drainage holes were carried out. Also installed piezometers indicates piezometric head downstream of grout curtain of about 1/10th to 1/8th of the corresponding head in reservoir, which is very small compared to the design value considered in the stability analysis.

Seepage monitoring was continued in year 2002 corresponding to different reservoir level. The seepage

from body of dam through formed drains was 10 lpm corresponding to reservoir level 54.15 m which increases to 45 lpm corresponding to reservoir level of EL 60.4 m. So increased seepage corresponding to raised reservoir level after dam heightening to a level of 66 m was not difficult to handle.

Due to excellent performance of the dam both from uplift and seepage points of view, no special treatments were foreseen due to raising of dam and subsequent rise in reservoir level from present FRL of EL 61.00 m to reservoir level of EL 66.00 m.

However, at both banks, the grout curtain provided previously ends at EL \pm 56.00 m. This curtain was required to be extended on both banks from EL 56.00 m to EL 66.00 m. This was achieved by providing only 10 m deep holes from the surface at 3m c/c to achieve permeability of the order of 5 lugeons. In addition, the previously drilled drainage holes in the gallery, which had been subsequently plugged, were re-drilled up to a depth of 15 m. Also, in the foundation of all the blocks weak pockets were excavated and filled back with concrete.

7. CONCLUSION

Several issues viz. effect of permanently built-in stress on new concrete, effect of shrinkage in new concrete on old concrete, restraining effect of old concrete on new concrete, bonding between old & new concrete, enhancement of spillway capacity and seismic retrofitting, etc. were addressed during the design and engineering for raising the height of Dhanikhari dam. The effect of permanently built in stress were addressed through lowering the reservoir during placement of the backing concrete. The temperature gradient of the backing concrete was with ambient air temperature was restricted to 5°C by keeping the placement temperature at 12°C and the effect of shrinkage has addressed by using higher grade concrete at foundation grade

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On Investigation of Magnitude and Frequency of Annual Maximum Daily Precipitation in the Catchment of Bhakra Dam

Sagar rohidas ¹ Chavan and Neha Gupta¹

ABSTRACT

The catchment of the Bhakra dam had witnessed many incidents of extreme precipitation resulting in catastrophic floods. The dam has played a pivotal role in protecting its downstream from catastrophic floods in the past. The present study examines the magnitude and frequency of annual maximum daily precipitation in Bhakra catchment for 110 years (1901-2010) using the gridded data of 0.250 collated from the Indian Meteorological Department (IMD). The change in the magnitude is examined by various Non-parametric tests like Mann-Kendell, modified Mann-Kendell, Spearman Rank Correlation, Sens'slope, and innovative trend Analysis (ITA). The presence of sudden or abrupt change-point in the rainfall records is assessed by the nonparametric Pettitt test. Results indicated the presence of both positive and negative trends for annual maximum precipitation over the Bhakra catchment. Investigation on the frequency of annual maximum precipitation is conducted by using the framework of Generalized extreme value (GEV) distribution in terms of their upper tail behavior. Investigation reveals that the presence of heavy-tail behavior in the annual maximum precipitation over the Bhakra catchment. Knowledge of the changes in magnitude and tail behavior of the extremes shall be helpful while planning the water resources-related projects in Bhakra Catchment.

Keyword: extreme precipitation, nonparametric tests, upper tail, Generalized extreme value distribution; Bhakra Catchment

1. INTRODUCTION

Recent developments in the field of hydro-meteorology have provided ample evidence of an increase in magnitude and frequency of rainfall events due to climate change (Koutsoyiannis, 1999; Goswami et al., 2006; Rajeevan et al., 2008; Guhathakurta et al., 2011; Mueller and Seneviratne, 2012; Douville et al., 2013; Xu et al., 2013; Wasko et al., 2016). According to Intergovernmental Panel on Climate Change (IPCC, 2007), "wet extremes are projected to become more severe in many areas where mean precipitation is expected to increase, and dry extremes are projected to become more severe in areas where mean precipitation is projected to decrease". A recent analysis of rainfall trends on a global scale shows an increase in the frequency of extreme events in many parts of the world (Myhre et al., 2019; Papalexiou and Montanari, 2019). Ray and Srivastava (2000) have performed the trend analysis of heavy rainfall events and found a significant increasing trend over the northern parts (Himachal Pradesh, Haryana, and Punjab) of India. Guhathakurta et al. (2011) concluded that extreme rainfall and flood risk are increasing significantly in India except in some parts of central India. Turkey et al. (2020) explored the precipitation variability over the Satluj basin, Himachal Pradesh, and noticed that both positive and negative

trends are detected in monthly and seasonal precipitation. They also found that the basin showed a greater inter-annual variability of post-monsoon precipitation than that of annual precipitation. The increase in trends of floods and droughts has been linked to the changes in precipitation trends (Le Comte 1998; Mishra and Singh, 2010; Papalexiou and Montanari, 2019), and hence, it becomes important to understand the changes in magnitude and frequency of extreme precipitation for proper management and decision-making concerning the efficient use of water resources.

A variable like precipitation has time-dependent characteristics and is affected by many factors such as climatic change and anthropogenic activities. One of the main steps in water resources work is to identify the trends in historical precipitation and their distribution in space and time. Changes in precipitation generally occur gradually (monotonic trend) or abruptly (step or jump). These changes may affect the statistical properties of precipitation such as mean, median or variance, etc. When the change occurs in only one direction overtime then it is known as monotonic change. Contrary to this, the abrupt change in the statistical properties of precipitation (i.e., mean or median) is treated as a step change. The main difference between abrupt and slowly varying changes is

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that when a trend is detected, it is likely to continue in the future, while the presence of a change point indicates the shift from one regime to another, and the status is likely to remain the same until a new regime shift occurs. Most of the global or regional studies (Prokop and Walanus 2003, 2015; Murata et al., 2007; Choudhury et al., 2012; Jain et al., 2013; Sonali and Nagesh, 2013; Meshram et al., 2017; Sah et al., 2020) used non-parametric approaches like Mann–Kendall (MK) (Kendall, 1948; Mann, 1945) and Spearman rank correlation (SRC) test to detect a monotonic trend. Sen's slope (referred to as SS) method which is also a non-parametric approach was used in estimating the magnitude of trend (Sen, 1968) Less attention was paid to check for autocorrelation in the data series (Hamed and Rao, 1998; Yue et al., 2002a, b). The most employed statistical approaches which consider the effect of serial correlation are Pre-whitening (referred to as PW) (Shivam et al., 2017; Wang et al., 2020) trend-free pre-whitening (referred to as TFPW), variance correction approach (VC) by Hamed and Rao (1998) with MK test (referred as MK-CF1), Yue and Wang (2004) with MK test (referred as MK-CF2). However, several studies reported that pre-whitening can remove some portion of actual trend and may not be effective if the serial correlation exists beyond the first-order autoregressive process and if the sample size is large (Bayazit and Önöz, 2007; Reeves et al., 2007; Khaliq et al., 2009; Kumar et al., 2009; Piyooosh et al., 2016). To tackle this issue, Şen (2012) proposed a new method, known as the innovative trend analysis (ITA) method, which can overcome the problem of trend detection in an autocorrelated time series data. The reliability of the ITA method has been established in many studies around the world (Romaguera et al., 2010; Şen 2014; Wu and Qian 2017; Alashan 2018; Serencam 2019; Caloiero 2020; Güçlü et al. 2020; Wang et al. 2020). In this study, annual maximum series from 32 grids lying in the catchment area are examined and the main focus revolves around (a) determination of the spatial and temporal trends of extremes in the catchment using different non-parametric and graphical methods to examine the trend and also, (b) investigating the validity of the stationarity assumption in the annual maximum rainfall record and analyzing the upper tail of distributions using GEV distribution over Bhakra Catchment in India. A time series is considered stationary if it is invariant under temporal translations (Brillinger, 2001), meaning that it is free of slow and abrupt changes and periodicities (Salas, 1993).

The tail of the distribution, in general, refers to the upper part of the distribution that controls both the magnitude and frequency of extreme events (Papalexiou and Koutsoyiannis, 2013; Papalexiou et al., 2018). The framework of generalized extreme value was used by (Coles, 2001; Villaini et al., 2011;) to examine the upper tail properties of seasonal and annual maximum rainfall.

The cumulative distribution function (CDF) of GEV distribution can be written as:

$$F(x | \mu, \sigma, \xi) = \exp \left\{ - \left[1 + \xi \left(\frac{x - \mu}{\sigma} \right) \right]^{-1/\xi} \right\} \quad \dots(1)$$

Where X is a random variable, $\mu \in (-\infty, +\infty)$ is the location parameter, $\sigma > 0$ is the scale parameter, and $\xi \in (-\infty, +\infty)$ is the shape parameter which is related to the tail of the distribution (it provides information about the probability of occurrence of extreme events) (Resnick, 2006; El Adlouni et al., 2008). Based on the value of the shape parameter we can categorize the GEV into three distribution types. For $\xi > 0$, the distribution is unbounded above with a heavy tail (Frechet distribution). For $\xi < 0$ (Weibull distribution), the distribution is bounded above with an upper bound of $\mu - \sigma/\xi$). The Gumbel distribution is the special case for $\xi \rightarrow 0$ and corresponds to the case of unbounded, light upper tails. The implication of heavy and light is that for distribution with a heavy tail the extremes are more likely to occur (Resnick, 2006; El Adlouni et al., 2008; Foss et al., 2013; Papalexiou et al., 2013, 2018; Nerantzaki and Papalexiou, 2019).

The present study examines the magnitude and frequency of annual maximum daily precipitation in Bhakra catchment for 110 years (1901-2010) using the gridded data of 0.250 collated from the Indian Meteorological Department (IMD). In near future, the results from the study could be beneficial to BBMB in understanding spatiotemporal behavior of rainfall extremes in the catchment and in implementing the Dam Rehabilitation and Improvement Project (DRIP), a Government of India Initiative with World Bank coordinated and supervised by Central Water Commission (CWC) to plan effective damage control strategies such as Emergency Action Plan (EAP) corresponding to dam breach scenarios.

2. STUDY AREA AND DATA

The study area for the present research is the Sutlej River Basin – a mountainous basin that forms a key and central part of the Indian Himalayan region. The basin is characterized by undulating hilly terrain, steep hills, and deep valleys. The Sutlej rises beyond Indian borders in the Southern slope of the Kailash Mountain near Mansarovar Lake in Tibet. The geographical limits of the Sutlej basin up to Bhakra dam – an important dam in the region – lie between latitudes 30° N and 33°N and longitudes 76°E and 83°E. The total length of the river is 1,448 km. The Sutlej leaves Himachal Pradesh to enter the plains of Punjab at Bhakra. The catchment area of the river Sutlej up to Bhakra dam is about 56,876 km² out of which about 36,900 km² falls in Tibet and 19,975 km² in India. The important tributaries of river Sutlej are Baspa river, Spiti river, the Nogli Khad, and Soan river. Finally, Sutlej drains into the Indus in Pakistan. The basin plays

a predominant role in the national energy supply through several hydropower projects. Bhakra – a major dam – is situated on River Sutlej and is a principal provider of hydropower and drinking water to several north Indian provinces (Himachal Pradesh, Punjab, Haryana, and Rajasthan).

In this study, we examine precipitation trends on annual basis using the gridded rainfall data of 0.25° procured from the India Meteorological Department (IMD). This data was prepared based on daily rainfall record from extensive coverage of 6955 actual observation sites. The data is archived at the National Data Centre, IMD, Pune. The gridded data was prepared using interpolation based on Shepard’s method (Pai et al. 2014). There are 32 grids with a uniform record length of 110 years (1951-2004) over the entire catchment lying in India. Annual series were prepared by the use of daily gridded datasets. The locations of all stations over the bhakhra catchment can be seen in Figure 1.

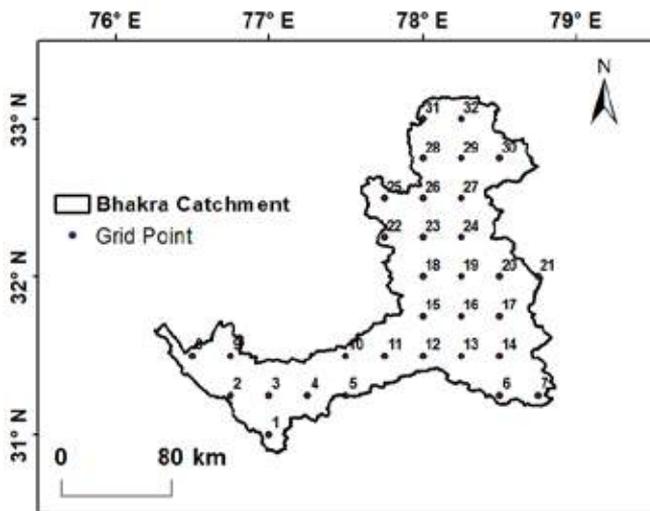


Fig. 1 : Location map of Bhakra Catchment showing different grids

3. mETHOdOLOGY

The methodology used for the evaluation of trends for individual grids is carried out using various statistical trend detection techniques like Mann–Kendall (MK) test, Spearman rank correlation (SR) test (Dahmen and Hall, 1990), Sen’s slope (SS), Trend-free pre-whitening with MK (MK-TFPW), Variance correction approach with MK test based on Hamed and Rao (1998) (MK-CF1), and Innovative trend analysis approach (ITA) based on Şen (2012). Before applying any test significance of autocorrelation was detected at lag-1 in annual series and different tests like MK/ modified MK were applied to non-autocorrelated/autocorrelated series, respectively. Each method is explained below.

3.1 mann–kendall (mk) Test

The MK test is a non-parametric rank-based test used to assesses an increasing or decreasing trend (monotonic trends) in a series, within a predetermined level of significance. Time series need to be independent and identically distributed (i.e., No serial correlation). The sample collection, handling, and measurement methods provide unbiased and representative observations of the underlying populations over time. No requirement that the measurements be normally distributed or that the trend, if present, is linear. MK test statistics S is described as:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^N \text{sgn}(x_j - x_i)$$

$$\text{sgn}(x) = \begin{cases} -1, (x_j - x_i) < 0 \\ 0, (x_j - x_i) = 0 \\ +1, (x_j - x_i) > 0 \end{cases}$$

$$E[S] = 0$$

$$\text{Var}(S) = \frac{N(N-1)(2N+5) - \sum_{i=1}^N t_i i(i-1)(2i+5)}{18}$$

... (2)

where x_i and x_j are sequential data for i th and j th term, n is the sample size. t_i is the number of data points in i th tied group, i is the number of tied groups.

A positive/negative value of S indicates an upward trend/downward with time. Standardized test statistic Z is computed by

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{Var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & S < 0 \end{cases}$$

... (3)

This statistic follows the standard normal distribution with a mean of zero and variance of one. To test for monotonic trend at a significance level, the null hypothesis of no trend is rejected if the absolute value of standardized test statistic Z is greater than $Z_{1-\alpha/2}$ obtained from the standard normal cumulative distribution tables.

3.2 Spearman rank Correlation (SrC) Test

In the SRC test, the test statistic is based on the Spearman rank correlation coefficient r_{SRC}

$$r_{SRC} = 1 - \left(6 \sum_{i=1}^N d_i^2 \right) / [N(N^2 - 1)]$$

... (4)

where i represents the chronological order and n is the total number of data points in the series. $d_i = RX_i - RY_i$ is the difference between ranking, where RX_i is the

rank of variable X_i , which is the chronological order of observations. The series of observations Y_i is transformed to its rank equivalent RY_i by assigning the chronological order in the ranked series. For the ties, average rank is considered.

The test statistic t_{SRC} is given by

$$t_{SRC} = r_{SRC} [(N - 2) / (1 - r_{SRC}^2)]^{0.5} \quad \dots(5)$$

The null hypothesis implying no trend will not be rejected if $t_{v,\alpha/2} < t_{SRC} < t_{SRC}$. Where test statistic follows a student's t-distribution with degrees of freedom $v = n - 2$ and significance level α .

3.3 Sen's slope (SS) Test

Sen (1968) approach is used to find the magnitude of the slope of the trend. The approach involves computing slopes for all the pairs of ordinal time points using the median of these slopes as an estimate of the overall slope.

The slope of all data pairs

$$T_i = \frac{x_q - x_r}{q - r} \quad \dots(6)$$

For $i = 1, 2, 3, \dots, M$, where $M = n(n-1)/2$. x_q, x_r are data at time q and r . The median of these MT_i 's is

$$\beta = \begin{cases} T_{\frac{M+1}{2}} & \text{when } M \text{ is odd} \\ \frac{1}{2} \left(T_{\frac{M}{2}} + T_{\frac{M+1}{2}} \right) & \text{when } M \text{ is even} \end{cases} \quad \dots(7)$$

The positive and negative sign of test statistics represents an increasing trend and decreasing trend respectively.

3.4 Trend-free Pre-whitening with mk (mk-TFPW)

As the pre-whitening approach affects the magnitude of true slope, Trend-free pre-whitening approach was suggested by Yue et al. (2002b). Steps followed in Trend-free pre-whitening with MK are summarized below.

1. Estimate the slope b of a trend of the time series using Sen's slope method. If the slope is almost equal to zero, then it is not necessary to continue to conduct trend analysis. If it differs from zero, then it is assumed to be linear, and the sample data are detrended by $X'_t = X_t - T_t = X_t - bt$
2. Find the lag-1 correlation coefficient from the detrended series with some defined significance level α . If Lag-1 serial correlation coefficient is non-significant at the chosen level then the trend identification test is applied to the original time series. Pre-whitening procedure applied to the detrending series is referred to as the trend-free pre-whitening (TFPW) procedure and results in to a residual series

which should be independent as given below.

$$Y'_t = X'_t - r_1 X'_{t-1}$$

3. Now the residual series and the identified trend series are blended to form a blended series which is supposed to preserve the true trend and is no longer influenced by the effects of autocorrelation. If the lag-1 correlation coefficient is significant with the considered significance level, then the MK test will apply to the blended series, else apply the MK test to the original series. The blended series is as given.

$$Y_t = Y'_t + T_t$$

3.5 Variance Correction Approaches with mk (mk-CF1)

Generally, n serially correlated observations contain the same information as effective sample size, n^* which is always less than the original sample size. Presence of positive (negative) serial correlation results in an increase (decrease) in the variance of Mann- Kendall test statistic S . Due to this problem, the variance correction approach was proposed by Hamed and Rao (1998). The modified variance of the MK test statistic, $V^*(s)$ is given by

$$V^*(s) = \text{var}(s) \frac{n}{n^*} = \frac{n(n-1)(2n+5)}{18} \cdot \frac{n}{n_s^*} \quad \dots(8)$$

Where CF is (n/n^*) which is known as a correction factor proposed by Hamed and Rao (1998) and is given as

$$CF_1 = 1 + \frac{2}{n(n-1)(n-2)} \sum_{k=1}^{n-1} (n-k)(n-k-1)(n-k-2)r_k^R$$

where r_k^R : lag- k serial correlation coefficient of rank RX_t of sample data X_t .

r_k : lag- k serial correlation coefficient of data

n : is the total length of the series.

n^* : is effective length of the series

MK test with the CF1 is referred to as MK-CF1

3.6 innovative Trend Analysis Test

If two-time series are identical to each other, their plot against each other shows a scatter of points along 1:1 (i.e. 45°) line on the Cartesian coordinate system implying no trend present. One important conclusion from the plot is that data values sort themselves in order along the 1:1 line. This idea is used in trend detection based on Innovative trend analysis where the first half of the time series is plotted against the second half. If scatter points lie above (below) the 1:1 line, then it indicates an increasing (decreasing) monotonic trend. If scatter points lie on both sides it indicates the presence of non-monotonic increasing or decreasing trend hidden at a different scale in the same time series. All the assumptions like the independent structure of the time series, normality

of the distribution functions (PDFs), and length of data (sample size) are avoided in this test.

3.7 Pettitt Test

After analyzing the monotonic trends using the above-mentioned trend detection methods, sudden or abrupt changes are also detected using the Pettitt test (Pettitt, 1979). The abrupt changes can be due to climatic or anthropogenic effects. (Villarini et al., 2011). Pettitt tests allow the detection of one change point in mean at an unspecified point in time. Being a non-parametric test it is less sensitive to the skewed distribution and outliers. For

the grids where a significant change-point in the mean is not detected along with the absence of monotonic trends, GEV fitting is done at those grids to the annual maximum records to find the upper tail property (Villarini et al., 2010; 2011(a) (b)).

4. rES uLTS ANd di SCuSSiON

Various statistical tests were performed for identifying the monotonic trends in the annual maximum rainfall series at 32 grids lying in the Bhakra catchment, India. The result of different trend tests are given in Table 1 and the spatial variation of trends obtained from different

Table 1 : Trend detection for annual maximum rainfall using MK, MK-TFPW, MK-CF1, SRC, and SS method for the period (1901-2010). * represents grids with significant autocorrelation at lag-1. CP and NCP denote "Change Point" and "No Change Point".

Grid Point	Test interpretation				Sens slope (mm/year)	Pettite
	mk	mk-TFPW	mk-CF1	SrC		
1	-1	-1	-1	-1	-0.1095	NCP
2	0	0	0	0	-0.0162	NCP
3	-1	-1	-1	-1	-0.1205	CP
4*	-1	-1	-1	-1	-0.2110	NCP
5*	0	0	0	0	0.2067	CP
6	0	0	0	0	0.0146	NCP
7	1	1	1	1	0.0792	NCP
8	1	1	1	1	0.0326	NCP
9	1	1	1	1	0.3588	CP
10	0	0	0	0	0.1437	CP
11	0	0	0	0	0.1442	CP
12	0	0	0	0	0.0787	NCP
13	0	0	0	0	0.0342	NCP
14	0	0	0	0	-0.0198	NCP
15	0	0	0	0	0.0583	NCP
16	0	0	0	0	0.0358	NCP
17	0	0	0	0	-0.0009	NCP
18	0	0	0	0	0.0884	NCP
19	0	0	0	0	0.0161	NCP
20	0	0	0	0	0.0200	NCP
21	0	0	0	0	0.0346	NCP
22	1	0	1	1	0.2185	CP
23	0	0	1	0	0.1686	CP
24	0	0	0	0	0.0586	NCP
25*	1	1	1	1	0.1572	CP
26	1	1	1	1	0.2530	CP
27	1	0	1	0	0.1415	CP
28	1	1	1	1	0.1696	CP
29	1	1	1	1	0.2345	CP
30	0	0	0	0	0.0190	CP
P31*	1	1	1	1	0.4782	CP
32*	1	1	1	1	0.6243	CP

methods for all grids are shown in Figure 2 (a-d). The significance of autocorrelation was detected at lag-1 in the annual series at each grid point. In the annual time scale, five grids namely 4, 5, 25, 31, and 32 were found to be autocorrelated. For all grids, the MK-TFPW, as well as MK-CF1 was applied after doing the pre-whitening and finding the correlation coefficient as discussed in the methodology. All tests were considered at a nominal significance level of 0.05. Twenty-one out of 32 grids shows a positive value (increasing trend) based on the z statistic value of MK test, while the rest showed a negative trend (decreasing trend). The trends are found to show a significant increase at 11 grids while it appears to be significantly decreasing at only three grids. To simplify the understanding of trends we have used 0, 1 and -1 as

trend indicator which means that '0' indicates no trend, '1' indicates an upward positive trend and '-1' indicate the downward negative trend in the table for MK, MK-TFPW, MK-CF1, SR TEST. 'No trend' means no significant positive or negative trend. The magnitude of trend was determined by Sens's slope which was found to have a maximum value 0.6243 for grid 32.

For the MK-TFPW test, 9 grids showed a significant increase while 3 grids showed a significantly decreasing trend. For MK-CF1 twelve grids showed an upward positive trend while three grids showed a downward trend. SRC test shows ten grids to have an upward positive trend while the same three grids show a negative trend (see all plots in Figure 2).

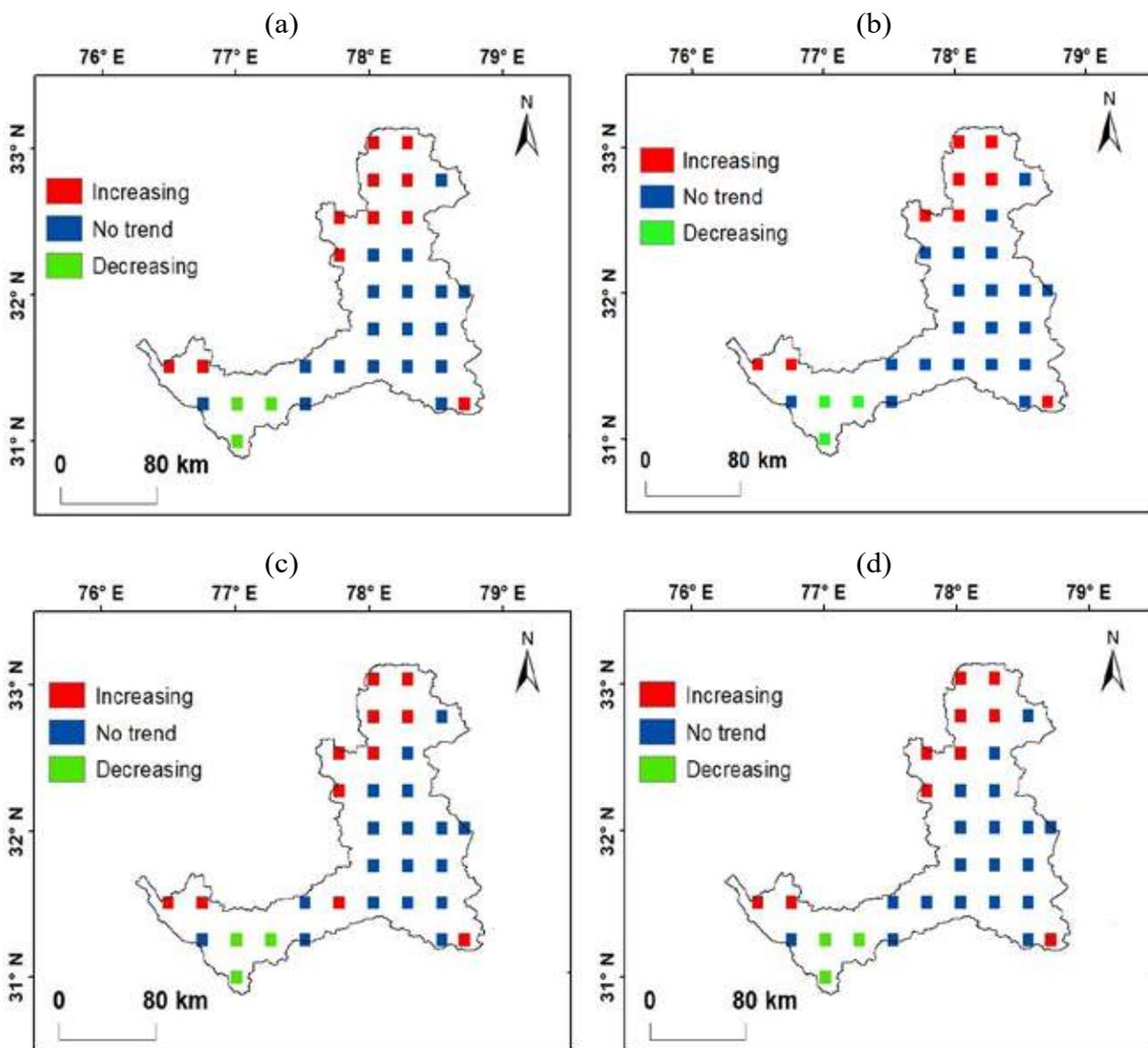


Fig. 2 : Spatial distribution of trends in annual maximum rainfall from 1901-2010 using (a) Mann Kendall (MK) test (b) Trend-free pre-whitening with Mann-Kendall (MK-TFPW) (c) Variance correction approach with Mann-Kendall (MK-CF1) and (d) Spearman rank correlation (SRC)

Next, we applied the Innovative trend analysis (ITA) approach given by Sen (2012) to all the grids. Irrespective of the presence of serial correlation, this methodology can show the symptom of a trend in terms of sub-series plots (Sen, 2014; Sen 2017; Marak et al., 2020; Alifujiang et al., 2020). This method gives a clear picture of the preliminary analysis of any trend detection study. All the scatter points appeared below the scatter point line at grids 1 and 3 while they appeared above the line for nearly eighteen out of 32 grids namely 5, 7, 9, 10, 11, 12, 15, 16, 22, P23, 24, 25, 26, 27, 29, 30, 31, and 32. For the rest of the grids, the plots illustrated a combination of the monotonic and non-monotonic increasing trend at different hidden scales in the same time series. Results of ITA are presented in the plots for 3 typical grids Figure 3, for brevity. In plots for grids 5, 9, 31, and 32, higher trend magnitudes were observed as compared to other grids.

The results from different trend tests sometimes give similar insights about a location's trend, however, there may be disagreement between different methodologies implemented. Specifically, in the case of grid 23, the trend is detected only by the MK-CF1 like or in the case of grid 22, the trend is detected by all methods except for TFPW-MK. It was also observed that MK-CF1 and MK detected a trend at grid 27 but it was absent according

to TFPW-MK and SRC. Further, it is observed that the trend detected by ITA can differ from other trend detection methods (e.g., grids 5, 6, 10, 11, 12, 13, 16, 17, 25, and 31). This may happen because of a basic reason that the ITM investigates the variation of the second half of the time series with respect to the first half of the time series, while other methods evaluate the whole time series. ITM in this study has identified trends at more locations and has also provided information related to hidden trends of the data series which are not detected by other methods. Different trend detection techniques have the variable capacity to detect trends. Hence it is always advisable to use more than one trend detection technique for the identification of trends.

After detecting the presence of a monotonic and non-monotonic trend, the records were checked for abrupt changes in mean and variance of distribution using the Pettitt test. Fifteen out of 32 grids had a statistically significant change-point in mean over time as seen in Figure 4. Fourteen grids showed an increased mean after the change point while one grid shows a decreased mean after the change point. The stationary GEV distribution is fitted only to those records which do not present any statistically significant trend and change point as shown in Figure 5(a).

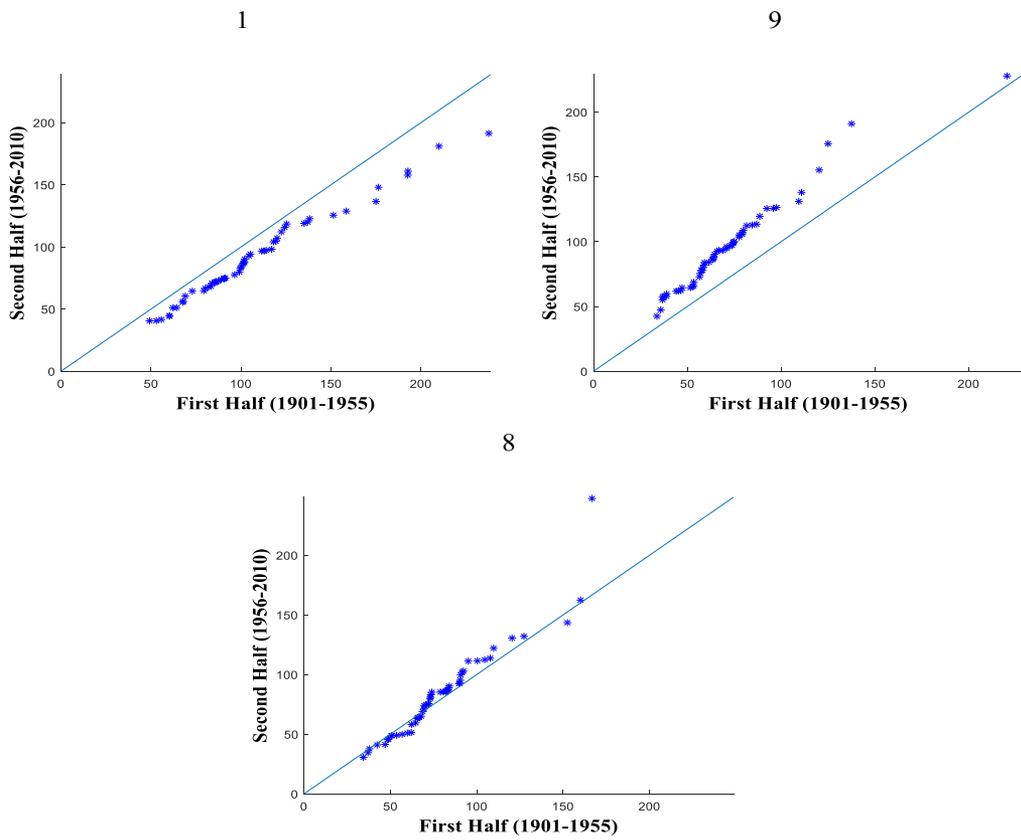


Fig. 3 : ITA plot for 32 IMD grid points for annual maximum rainfall in the Bhakra catchment. Numbers represent grid points in the Bhakra catchment.

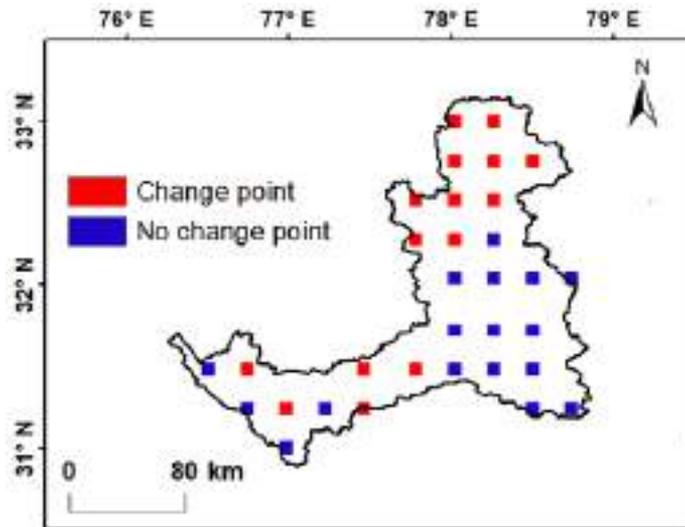


Fig. 4 : Map showing grids that are having a change point or no change point based on the Pettite test for annual maximum daily rainfall significant at 0.05 level

(a)

(b)

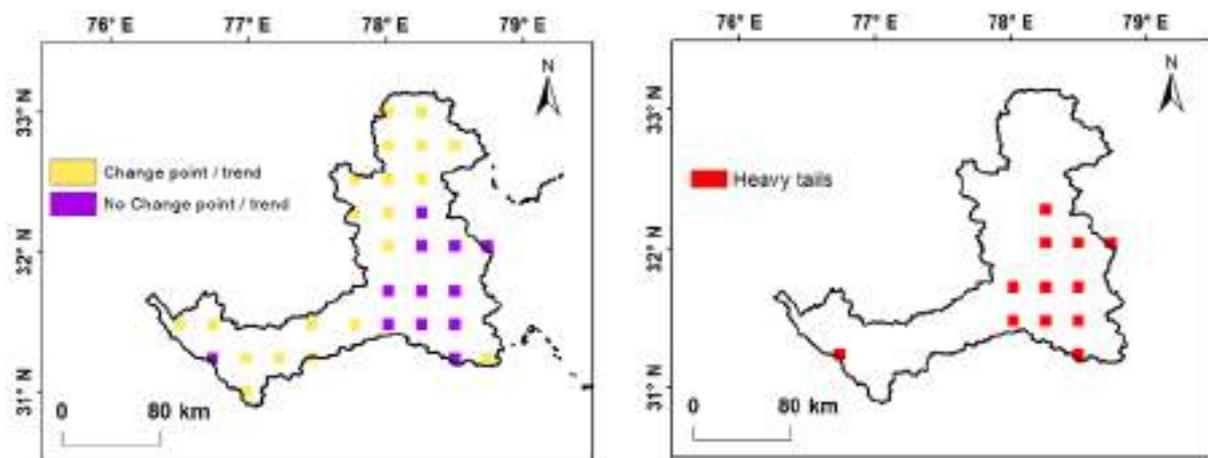


Fig. 5 : Maps with the location of the stations (a) without any abrupt change or monotonic trend, (b) Upper tail behavior at the grids which do not violate the stationarity assumption in annual maximum rainfall records

Table 2 : Detail of the shape, scale, and location estimated for annual maximum rainfall records using GEV framework

Grid Point	shape (ξ)	scale (σ)	Location (μ)
P2	0.0816	21.8373	63.8425
P6	0.2664	16.8240	38.4469
P12	0.3360	20.3486	43.5176
P13	0.3208	18.3832	39.1230
P14	0.2848	18.4650	39.6017
P15	0.3104	17.8577	39.4269
P16	0.3393	18.9340	38.8930
P17	0.2860	19.3158	39.0933
P19	0.2561	19.8440	39.2630
P20	0.2576	20.4305	39.7241
P21	0.2595	20.5576	39.8149
P24	0.2705	18.5837	40.2898

The parameter is estimated and the detail of which is given in Table 2. Different studies in past have pointed to an unbounded-above and heavy tail behavior in extreme rainfall (Katz et al., 2002; Papalexious et al., 2013). Even for this study area the values of shape parameter larger than zero points towards the heavy tail behavior of all the rainfall records for which the GEV framework is used to investigate the upper tail property (Figure 5(b)).

5. CONCLUSIONS

In this paper, we analyzed the annual maximum rainfall record from 32 grids lying in the catchment of Bhakra dam with a record length of 110 years for the presence of monotonic trends using the different non-parametric trend tests like MK, MK-TFPW, MK-VC1, SRC, and ITA. Along with the monotonic trend, sudden or abrupt changes in the rainfall records were identified using the Pettite test. The graphical nature of the ITA test enables the easier perception of even the non-monotonic trends. Since the ITA method is relatively new, we validated the authenticity of ITA using a widely used method of the MK test. The efficiency and testing power of different tests were compared and somewhat similar results were obtained except for few grids. A consistent increasing trend was detected in annual maximum rainfall records with few grids showing a negative trend. Application of Sen's slope methodology also indicated an increased magnitude of the trend at most of the grids during 1901-2010. Increasing trends and the presence of abrupt changes led us to the fact that the magnitude of the extreme rainfall in this Bhakra catchment is increasing. In most cases, violation of the stationarity assumption in annual maximum rainfall records was observed due to the abrupt changes in the mean of the record. These abrupt changes are often associated with anthropogenic modifications of the catchments (e.g., river training, dams for hydro-power production, changes in land use/ land cover) or with the change in the climate regime. The GEV distribution framework was used for the examination of upper tail properties of annual maximum rainfall records free from any type of trend or change. The location and scale parameters exhibit a power-law behavior. Heavy tail behavior of the rainfall distribution indicates that the probability of occurrence of extreme precipitation is considerable i.e., extreme precipitation events are not rare in the Bhakra catchment. Findings from this study regarding the changes in magnitude and tail behavior of the extremes shall be helpful while planning the water resources-related projects in Bhakra Catchment.

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Water – Not a luxury but a Necessity

Tehri Dam – A Savior from Climate Change Led Extreme Events

Atul kumar Singh¹, muhar man² and rajeev Vishnoi³

ABSTRACT

Himalayan region is prone to rapidly changing weather at micro levels due to its topography, geology, tectonic activities and ecological fragility. In recent years, anthropogenic factors such as population, deforestation, land-use change and emissions due to urbanization have been implicated in extreme weather events in the Himalayas. The extreme events of cloud bursts, glacial lake formation and their outbursts, and significant changes in distribution of rainfall over space and time are common. Large reservoir based hydro projects are need of the hour in each and every Himalayan river basin to regulate the highly unevenly distributed runoffs for sustenance of dependent civilizations. Tehri dam project is built as a mega project on river Bhagirathi in one of the largest river Ganga Basin of India. It is a multipurpose scheme designed for storing surplus water of river Bhagirathi during monsoon period in its reservoir and releasing the stored water after monsoon period from the reservoir through power house to fulfill the irrigation and drinking water requirements of population in the downstream while providing 1000MW peaking power to Northern grid. It is not only providing the water for consumptive use of downstream population but also safeguarding them from the fury of recurrent floods. It is providing irrigation support to 8.74 Lac Ha. Land in UP by way of additional irrigation to 2.70 Lac. Ha. area and stabilization of 6.04 Lac. Ha. already irrigated area. It has created biggest reservoir in this region which has vast potential for saving the downstream population from extreme events happening due to climate change. THDC India Ltd., as a responsible owner of Tehri project, is in pursuit of new technologies and methodologies for continual improvements in its reservoir management program for ensuring safety of downstream population from recurrent floods, and safety of beneficiaries from droughts and water scarcity.

1. CONTEXT

India has a portion of its territory drought prone and some obligated to flooding. Around 80% of the surface water of the rivers goes to the sea unutilized while nation reels under the flood- drought syndrome. In our country significant lump of rainfall takes place amid around 90 days. This water needs to be stored for drinking, irrigation, generating power throughout the year along with the provisions of mitigating flood issues. Further, the inflow in the streams amid the lean time frame is extremely less when contrasted with storm and storage of water is additionally required to be done to enlarge the flows during lean period.

Sudden high-intensity rainfall (exceeding 100mm per hour) over a small area is termed as cloudbursts which mainly depend on geography of the area. Himalayan region is prone to rapidly changing weather at micro levels due to its topography, geology, tectonic activities and ecological fragility. It is being reported by scientists that cloudburst-like events in the Himalayas saw a steep increase from an average of five days per year between

2001 and 2005 to over 15 days per year between 2006 and 2013. While high-intensity rainfall events have increased, there has also been a fall in the annual number of days with rainfall in India. The average number of rain days has fallen from around 80 per year in early 2000s to 65 in the past 10 years.

In recent years, anthropogenic factors such as population, deforestation, land-use change and emissions due to urbanization have been implicated in extreme weather events in the Himalayas. The Intergovernmental Panel on Climate Change says glaciers in the Himalayas are receding faster than in any other mountain range. Glacial lakes formed by melting glaciers are constrained by ice dams. Since the Indian summer monsoon coincides with the melting of glaciers, ice dams are weakened by the additional stress of the monsoons and are prone to bursting. A flash flood in Kargil in May 2016 was attributed to this.

While global temperature is recorded to have increased by about 0.8°C in recent decades, the increase has been greater in regions at higher altitudes. This is especially

-
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ominous considering that mountains are not only affected by climatic patterns but also contribute to the changing climate owing to the enormous deposits of water they hold in the form of glaciers, ice and snow. Nowhere is this situation truer than in the Himalayan-Tibetan massif, the world's highest region, where warming of 0.15-0.6°C per decade has been observed in the past three decades. The warming, according to some scientists, has wreaked havoc on the monsoonal patterns in the Himalayas.

In such a scenario when distribution of water over time and space is becoming highly uneven, large reservoirs could play an important role. One of the important roles of Tehri dam is to store flood water in the reservoir and safeguarding the downstream population from its devastating effect. Tehri dam, even in the worst scenario is capable to store the highest peak of Bhagirathi flood and thereafter passing the same to the downstream in a regulated manner to mitigate the impact of flood.

2. INTr Odu CTiON TO TEHri dAm Pr OJECT

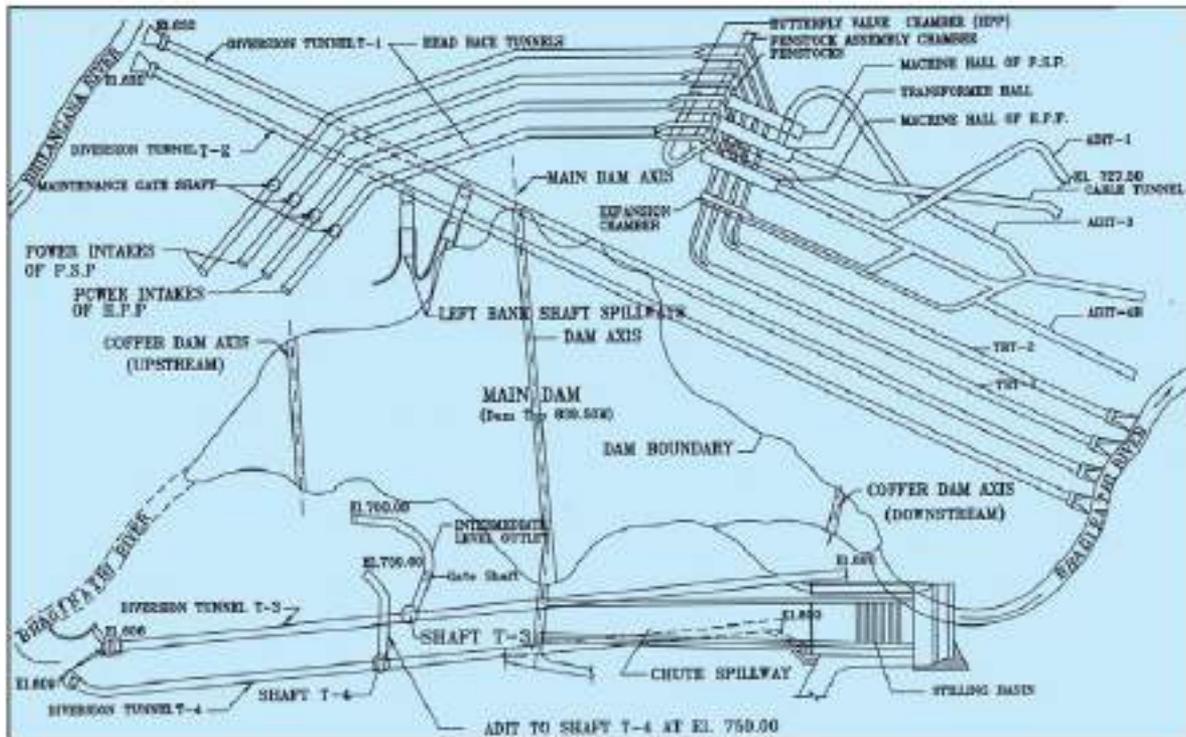
Tehri dam project (Tehri HPP) is a multipurpose scheme designed for providing water for irrigation and drinking purposes along with generating 1000 MW of peaking power. At Tehri, a 260.5 M high with its crest at EL 839.5m, Earth and Rockfill Dam has been constructed across river Bhagirathi, just downstream of its confluence with river Bhilangana. The gross storage of dam is about 3540MCM at Full Reservoir Level (FRL, EL 830m). The live storage

i.e. usable storage between FRL and Minimum Draw Down Level (MDDL, EL 740m) below which no power generation takes place is 2615MCM.

The basic purpose of constructing such a big dam at Tehri is to store surplus water of floods during monsoon and thereafter releasing the same during non-monsoon for irrigation and drinking purposes through power plant when river flow becomes lean. River Bhagirathi while traversing down joins river Alaknanda at Devprayag after 42 kms and river Ganga is formed. Thereafter, river Ganga traverses down towards Indian Ocean through Gangetic plains having major cities like Rishikesh and Haridwar in Uttarkhand; Kanpur, Allahabad and Varanasi in UP; Patna in Bihar, and Kolkata in West Bengal. So, the consequences of river Ganga floods could be disastrous for millions of people living along the river.

3. r ESEr VOir mANAGEmENT AT TEHri dAm

The hydrology year in the Central Himalaya starts from 21st June. Around this time the reservoir level is brought down to its minimum at EL 740.00 i.e. MDDL. From 21st June to 31st October, which is monsoon period, excess water of floods is allowed to fill in the reservoir in such a manner that it reaches FRL by the time monsoon is over. From 1st November to 20th June, water stored in the reservoir between MDDL and FRL is allowed to be released thus touching MDDL by 20th June.



Layout of Tehri Dam Project



A View of Tehri Dam Project

4. r ELEASE OF WATER FOR irri GATION, drINKiNG And OTHER PurPOSES

Water stored in the Tehri dam is for the intended use of population living downstream of Tehri dam and it is capable to irrigate 2.70 Lac hectares additional area and stabilization of 6.04 Lac hectares of already irrigated area in the Gangetic plains of Uttarakhand and Uttar Pradesh apart from providing 300 cusecs of water for drinking purposes of Delhi and 200 cusecs for UP states. As an estimate, it fulfills the drinking water requirement of 40Lacs population in Delhi and 30Lacs in UP. During lean months, discharge of river Bhagirathi at Tehri becomes as low as 40- 50cumecs whereas minimum 150 cumecs is released from Tehri dam which increase availability of water in river Ganga.

5. ArrANGEmENTS FOR FLOOD rEGuLATION

The spillway system of Tehri dam has been designed to cater a PMF (1 in 10,000 years return period flood) of 15540cumes whereas the peak flood discharge of about 7500 cumecs has been observed so far in river Bhagirathi at Tehri. Its flood regulation system consists of gated chute spillway having 3 bays of 10.5m each with crest at EL 815m, gated left bank shaft spillway (LBSS)

having 2 bays of 10.5m each with crest at EL 815m and 2 nos. un-gated right bank shaft spillways (RBSS) with crest at EL 830.2m. The routed flood discharge of complete spillway system (Chute Spillway, LBSS & RBSS) is 13043cumecs by allowing a lift of 5m in reservoir level above FRL (i.e water level rises to MWL EL 835m).

6. OPERATIOn OF SPILLWAYS FOR PrEVENTION OF FLOOD

The operation of reservoir is governed by the reservoir rule curves which help reservoir operation team in taking decision about the regulation of discharge through power plant and spillway system. As per sequence of the spillways operation, Chute Spillway on the right bank goes into operation first by simultaneous lifting of all the three gates in case the water level in the spillage zone of reservoir tends to rise above the desired level followed. If the rate of rise is still not controlled, the Left Bank Shaft Spillway (LBSS) is operated by simultaneous lifting of both the gates. If the reservoir level continues to rise and reaches EL 830.2m with full opening of all the gates of chute spillway & left bank shaft spillway, the Right Bank Shaft Spillway (RBSS) start discharging the flood water automatically.



Chute Spillway (U/s & D/s), Right Bank & Left Bank Shaft Spillways (clockwise from top)

7. PREVENTION OF FLOOD

One of the important roles of Tehri dam is to store flood water in the reservoir and safeguarding the downstream population from its devastating effect. Tehri dam, even in the worst scenario (1 in 10,000 years return period flood) is capable to store the peak of flood and thereafter passing the same to the downstream in a regulated manner when the flood recedes in river Alaknanda to mitigate the impact of flood. Since Tehri dam came into operation, maximum observed outflow has been about 1400 cumecs whereas maximum observed inflow has been about 7500 cumecs.

Tehri dam has stored water of almost every flood event so far. It is not out of context to mention here that during the floods of 2010 and 2011, Tehri dam played a crucial role in averting the flood of higher order in the river Ganges by storing high flood inflows of Bhagirathi | and Bhilangana and mitigated flood impacts on

habitation along river Ganges in Rishikesh and Haridwar towns.

In the year 2010, when all the major rivers were running at their highest on 19-20 Sep, the discharge of river Bhagirathi went above 3500 Cumecs (1,22,500 Cusecs) at Tehri whereas only 800-900 cumecs (28,000-31,500 Cusecs) was released from the Tehri dam at the time of peak discharge. At this point of time discharge from Alaknanda and other tributaries of Ganga were also heavy and flood situation at Rishikesh and Hardwar was grim and water was much above danger level. Tehri dam by storing the most of the flood water of river Bhagirathi in its reservoir, mitigated the flood discharge in the river Ganges which otherwise would have further increased the water level at Rishikesh and Hardwar 1.5-2.0m. In the year 2011 on 16th Aug also, Bhagirathi discharge went above 3600 cumecs (1,26,000 Cusecs) but only 900 cumecs (31,500 Cusecs) was released



Spillways in Operation during 2010 Flood

In the flood of river Ganga during 16th & 17th June, 2013, discharge at Haridwar rose up to around 15,000 cumecs (5,25,000 Cusecs) and water level reached 295.90m in the evening of 17th (i.e. 1.90m above danger mark of 294.00m). In fact, this flood was the contribution of river Alaknanda and tributaries of river Ganga in between Devprayag and Haridwar only as the flood

of the order of about 7,500 Cumecs (2,62,500 Cusecs) peak discharge in river Bhagirathi had been stored in the Tehri reservoir by releasing only 500 Cumecs (17,500 Cusecs). Had the Bhagirathi flood not been stored in Tehri dam, the peak discharge could have gone up to around 22,000 Cumecs (7,70,000 Cusecs) and devastation by this flood, not only at Haridwar but above and below Haridwar also, would have been beyond imagination with anticipated rise of 2.5 to 3.0m in water level above the observed highest level. It is gathered from the available records that June-2013 flood in Ganges would have been of the order or even higher which had happened in the year 1924, had Bhagirathi flood not been held by Tehri dam.

This phenomenon can be easily imagined with the Tehri and non-Tehri scenarios. The actual observed discharge data of Bhagirathi at Tehri and Ganga at Haridwar from 16-18 June has been analyzed to understand this phenomenon. As velocity of water increases with the increase in discharge, the travel time of water from Tehri dam to Rishikesh and Haridwar via Devprayag is about 8-14 hrs and 10-16 hrs respectively depending upon the discharge. In the case of 2013 flood, as the discharges in the rivers were high, travel time from Tehri to Rishikesh and Haridwar would have been about 10 hrs and 12 hrs respectively.

Graphs have been plotted to depict the probable impact of Bhagirathi flood on the flood of river Ganga at Rishikesh and Haridwar. In Fig-1, graphs showing inflow and outflow at Tehri have been plotted from 0.00hrs of 16th which depicts the discharge stored in the Tehri reservoir. In Fig-2, graphs showing observed discharge at Rishikesh from 10.00hrs of 16th and anticipated discharge at Rishikesh after superimposing the stored discharge of Bhagirathi at Tehri over the observed discharges of

Ganga at Rishikesh with 10hrs time lag have been plotted. The same procedure is adopted for plotting anticipated discharge at Haridwar (Fig.-3) after superimposing the stored discharge of Bhagirathi at Tehri over the observed discharges of Ganga at Haridwar with 12hrs time lag.

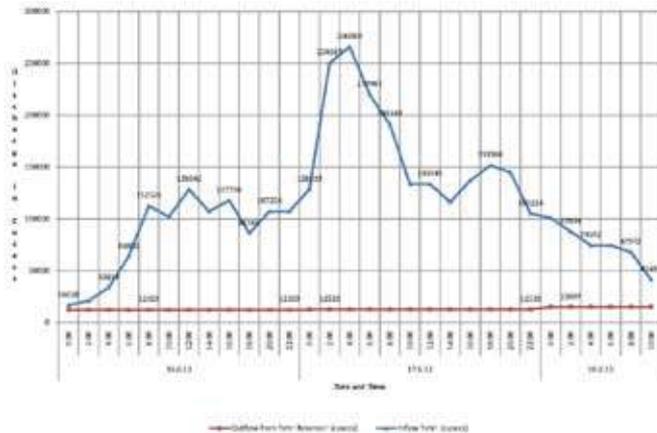


Fig. 1 : Actual observed inflow and outflow at Tehri

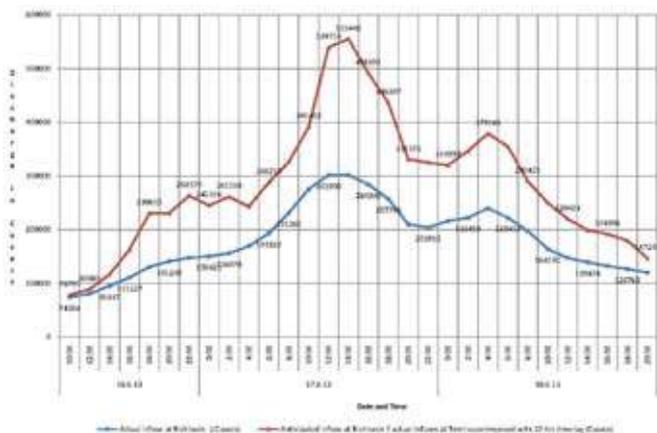


Fig. 2 : Actual observed discharge of Ganga at Rishikesh and anticipated discharges after superimposing Tehri actual inflows with 10 hrs time lag

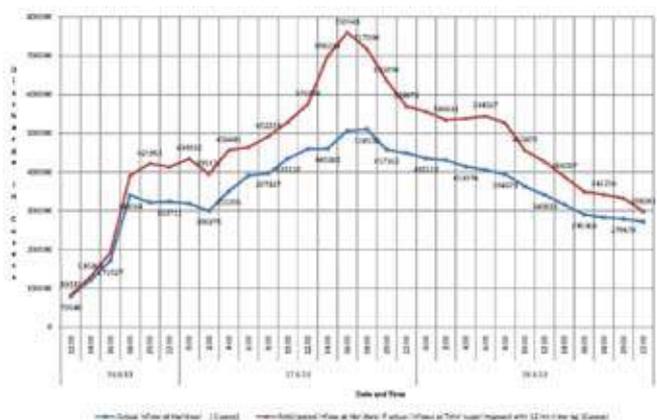


Fig. 3 : Actual observed discharge of Ganga at Haridwar and anticipated discharges after superimposing Tehri actual inflows with 12 hrs time lag

8. LEVER AGiNG TECHNOLOGiES For ENSuri NG SAFETY OF dOWNSTReAm POPuLATION

The safety of habitation and infrastructure in the downstream of dam is paramount for which dam owner need to make all out efforts for the safe operation and maintenance of dam. Unsafe operation of dam could be disastrous instead of saving the downstream habitation. Realizing this fact, THDCIL is taking all the measures suggested by CWC for safety of dam. Real Time Inflow Forecasting System for Tehri dam and Advance Early Warning System for downstream areas are among such measures taken by THDCIL.

8.1 Real Time Inflow Forecasting System

The catchment area of Tehri Dam is 7511 sq. km. out of which approximately 2323 sq. km. is snow bound. The catchment is prone to flash floods now a day. The inflow forecast helps in better management of reservoir, ensures safety of Dam by giving advance information regarding the inflow into the reservoir from the catchment and increases the flood warning time to ensure safety of downstream population. Real time inflow forecasting system has been established for Tehri dam reservoir which comprises of eleven number automatic weather stations and four number automatic G&D stations in its catchment area with control room (earth station) at Tehri dam. The system is capable to observe real time meteorological and hydrological data and transmitting the same to earth station established at Tehri for further processing of data for forecasting the inflow for Tehri reservoir. Mathematical models for forecasting the inflow has been developed by IIT, Roorkee. The system is presently operational and issuing the forecasts with 6 hrs lead time based on observed data, and day ahead forecasts based on observed data and IMD forecasts.

8.2 Advance Early Warning System

Once decision for releasing water from the dam is taken, there should be arrangements to disseminate the information quickly and reliably. In order to disseminate information to the downstream population up to Rishikesh about water releases from Tehri and Koteshwar dams, an early warning system has been established through Disaster Mitigation and Management Centre (DMMC), GOUK, Dehradun. The system with its control rooms at Koteshwar dam and DMMC, Dehradun comprises of sirens and speakers at eight stations from downstream of Koteshwar dam to Triveni Ghat, Rishikesh. The complete system including sirens, speakers and command software etc. are from M/s Federal Signal, USA. The mode of communication from control room to sirens is VSAT and GSM based. The system is having features like programmed activation, live paging, sirens, recorded voice messages and direct plug in facility for announcements at siren locations. The system is presently operational

and ensures safety of downstream population by alerting them through sirens and recorded voice message about the increase of water level due to release of water from PH and Spillways.

9. CONCLUSION

In the Himalayan region, it is observed that high intensity rainfall events are increasing rapidly whereas annual number of days with rainfall in India is decreasing. In Uttarakhand only, 13 incidents of cloud bursts were observed during 2018 whereas in 2019, numbers of such incidents increased to 23. It is also surprising that despite so many cloud burst incidents, Uttarakhand received 18% less monsoon rainfall in 2019. In the present scenario when naturally available water is varying over space and time drastically, none other than storage reservoir based scheme like Tehri dam project could be helpful in conserving the precious water. Small schemes like ROR or regulating dams / barrages could be a solution for power requirement or regulation but they can't withstand flash floods caused by cloud burst. In order to fulfill ever increasing demand of our population, integrated watershed management consisting of regulating structures like dams (big as well as small), barrages and canal network is also required for proper distribution and utilization of available water. The river linking project is the ultimate long term solution for water woes of India.

Tehri dam, as conceived and designed, is playing its role of conservation of surplus water during monsoon season even in the recent trend of varied spatial and temporal distribution of rainfall within its catchment area. The releases from the dam have been nominal even in the worst cases since its commissioning which is clearly evident from the records of year 2010, 2011 and 2013. Apart from providing 1000 MW peaking power to stabilized the Northern grid, it is providing additional water to the downstream population for use in drinking and irrigation purposes, and also for safeguarding them from the fury of recurrent floods. The systems installed at Tehri dam ensure safety of the downstream population even more than it was prior to it came into operation. Apart from direct benefits, there are so many indirect benefits also like tourism, adventure sports and hospitality etc. which also can't be undermined.

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Sharing Water : Multipurpose uses of Reservoirs and Innovation

iCOLd SYmPOSium rEPOrT

Nearly 1400 international delegates joined ICOLD's one-day Symposium, which preceded the triennial Congress in Marseille. The topical themes of multipurpose reservoirs and innovation had been chosen by the French Committee, and sub-topics for the three parallel tracks of sessions were: territorial and multipurpose water issues; governance and funding; and, innovative uses of reservoirs. The following are some highlights from the opening session, and presentations. The Symposium concluded with a Roundtable discussion.

In his welcome address at the beginning of the Symposium, President Michael Rogers thanked participants warmly for travelling to Marseille, in many cases from distant countries. He commented that ICOLD members were returning to the country where ICOLD had been founded, ICOLD 94 years ago. Reflecting on ICOLD's work, he said that engineers and scientists loved to solve problems, based on their experience, and he added that today, in addition to technical issues, there were new challenges such as climate change, increasing populations, and the great need to train, share experience and mentor young professionals.

Secretary-General Michel de Vivo reported that at least 1388 international participants were attending the meetings, representing 70 countries, and these included 205 young engineers.

He referred to ICOLD as a 'guardian of knowledge', constantly building on information and experience, with a view to developing precious water resources.

Yoann La Corte, Minister of Ecological Transition and of Territorial Cohesion, said that the theme of the Symposium had great resonance for the work of his Ministry, which included preserving the quality of water, and prioritizing the development of renewable energy. He stressed how essential dams and reservoirs were, especially for water supply and electricity production, and he drew attention to the great

work of the main organizations in France playing a role in water resources development, EDF, CNR, and Societe du Canal de Provence, as well as some of the major consulting companies in the country. He added that these organizations were also using their expertise for developments abroad.

Referring to the importance France attached to dam safety, La Corte mentioned that the Government had established a Permanent Committee on the subject; today it was clear that climate change was having an impact on safety, he added.

The next speaker was the Minister of Public Works of Indonesia, Mr Basuki Hadimuljono, who is also the former President of Indonesia's National Committee, INACOLD, and had hosted the 82nd Annual Meeting of ICOLD in Bali, in 2014. He began by saying that he felt ICOLD was not just a professional association, but a family bringing together the global dam engineering community. During



General view of the Symposium, during the welcome message from President Michael Rogers



Speakers in the opening session, clockwise from top left: Minister Yoann La Corte, Minister Basuki Hadimuljono, D.K. Sharma and Michel de Vivo

his talk, Minister Basuki spoke of global increases in water demand, as a result of population growth, and he noted that around 700 million people in 43 countries were suffering from water shortages. Some reserves were becoming depleted, and posing huge challenges for water resources development.

Reporting on recent progress in his country, Minister Basuki said that since the Bali meeting, 61 new large dams had been constructed, and a number of others had been upgraded, with modifications being made either to the dam body or the spillway. Flood protection was a priority, and gateworks had been improved at 21 dams. He added that there had been increasing use of artificial intelligence in reservoir operation, including flood forecasting.

ICOLD Vice President D.K. Sharma then spoke of challenges in his country, including the uneven distribution of water resources, in both space and time, an example being 1100 mm of annual rainfall occurring within 90 days. Major studies were underway, he said, on adaptation measures for climate change, and three major reports were to be completed soon. Shanna reported that India has 5300 large dams, with 411 more under construction. The country's target was to have tap water available for the whole population by 2024.

He referred also to the major DRIP rehabilitation project, supported by the World Bank, which was now in its third stage. He added that in 2021, major government Support had been agreed for flood control, and the creation of more storage schemes.

Michel Lino, President of the French National Committee (CFBR) then presented a talk in which he focused on the sharing of water resources, and he began by reflecting on some of the great ancient 'hydraulic civilizations', starting with the canals for the Hanging Gardens of

Babylon, excavated 3000 years ago, and the Dujiangyan irrigation system in Sichuan Province, China, designed in the third century BC. In ancient Rome, he commented, water supply had been a constant concern, requiring the establishment of hydraulic works. He also drew attention to the Pont du Gard aqueduct in France, which had supplied the city of Nimes with drinking water for five centuries.

Lino moved on to new challenges for water resources in recent years, for example, those resulting from the changing climate, and he cited some examples of the many extreme floods that had occurred during 2021, as well as droughts, especially in Asia.

A key element of his talk was to underline the benefits of cross-border collaboration and benefit sharing, and he discussed some examples such as OMVS in western Africa, which facilitated collaboration in development of the Senegal river basin for Senegal, Mali, Mauritania and Guinea.

Other examples he cited were collaboration between countries in the Aral sea area, to ease potential conflict, and the Mekong River Commission, which enhanced dialogue between the riparian countries of the Mekong. "In Europe, international commissions existed for the Protection of the Rhine and Danube rivers, he added.

Christine Noret and Laurent Peyras of Fiance, on behalf of the Organizing Committee, gave a joint presentation in which they introduced the topics to be discussed at the Symposium. Regarding the overall theme. Peyras commented that the role of reservoirs in sharing water, and the multipurpose use of reservoirs, had been an important topic for at least two decades, and was continuing to be the focus of attention of world leaders.



Bruno Grawitz of SCP, France. During his talk he drew attention to a web service available from his company, to assist with irrigation management.

Far right: Michel Lino, who focused in his talk on the sharing of water resources. He referred to some ancient hydraulic works, as well as present day schemes and associated benefits.



Christine Noret and Laurent Peyras, 'members of the organizing committee, set out some of the reasons for the Symposium topics selected. Among other things, Noret referred to the "need to find water-wise and nature-based solutions to turn climate risks into opportunities for action".

Noret referred to the outcomes of the UNCC COP26 Conference, and the World Water Forum, and said that key reasons for the current Symposium were to focus on:

- meeting renewable energy targets, while keeping rivers and communities resilient;
- providing renewable and environmentally friendly hydropower, and ensuring long-term water availability, and preventing water-related disasters: and.
- the need to find water-wise nature-based solutions to turn climate risks into opportunities for action.

Brtmo Grawitz, of Soeieie du Canal de Provence (SCP), responsible for hydraulic infrastructure for the distribution of water in the Provence region of southern France, gave a talk to underline the importance of multipurpose structures for Provence. While this is generally a dry region or France, with a rainfall deficit recently threatening crops of olives and almonds, it is also subjected to Hash Hoods, and, Grawitz said, these were becoming more intense as a result of the changing climate. Dams were thus vital to provide protection, he said. Among the most important major dams in the region, he continued, was the 123 m-high Serre Ponton multipurpose dam, on the Durance river, constructed by BDF in the mid-1950s, with a reservoir capacity of $1.2 \times 10^9 \text{ m}^3$ (one of the largest in western Europe).

Grawitz said that a risk evaluation study had recently been undertaken by INRAH, to model the effects of climate change to 2050. He also mentioned that a web service developed by and available from SCP provided for irrigation management and programming.

Finally, he mentioned the installation of a 10 MW floating solar PV system on the Vallon Dol multipurpose reservoir in Provence.

Theme 1: Territorial and multipurpose water issues

The two sessions on this theme were chaired by G. Ruggeri of Italy, and J. Gailhard of France.

Wang Xiang, a Vice-President of PowerChina, gave a talk on resettlement and benefit-sharing relating to the Nam Ou river basin in Laos. This was a priority scheme for the country, and was being funded by Chinese organizations as part of the Belt and Road Initiative, Wang explained. He said that the principles of benefit sharing with the population to be resettled were fundamental from the initial planning and design stage of the scheme. The local stakeholders had been involved throughout. He demonstrated how the participation of the local people had been beneficial to the eventual resettlement. In his talk, he outlined the extensive research that had been devoted to these aspects.

Richard Donnelly, of Hatch, Canada, presented a paper that had been co-authored by Dr Andy Zielinski, of

Canada, and others from the Central Water Commission of India, Halpin Consulting and RTT International of the USA, and the World Bank.

His talk described a risk screening indexing tool that had been developed to prioritize remedial works to enhance dam safety, and he focused on the DRIP programme in India, under which more than 5000 dams are being refurbished, to bring them in line with modern safety standards. Donnelly said that the tool had been developed based on established principles of risk analysis, but that some simplifications had been achieved, and a comprehensive validation process had taken place.

The simplifications meant that generating a risk index for a single dam could take as little as a few hours, if sufficient data were available, and if personnel carrying out the work were familiar with the dam. In the case of the large number of dams being upgraded within the DRIP programme, this was particularly useful in prioritizing schemes to be undertaken.

A presentation by Antonella Frigerio of Italy described ITCOLD's initiatives to promote proactive dialogue and stakeholder involvement in dam projects. She explained that since 2014, ITCOLD had been organizing annual workshops to encourage dialogue between dam owners and interested parties, to identify points where the various interests could be balanced, thus minimizing conflict. She stressed the importance of this kind of collaboration to improve public perception of the role of dams.

A joint presentation by Celine Dusservais of EDF and Olivier Guerri of EPIDOR (a public body responsible for the Dordogne river basin), focused on adapting the management of large hydro plants in the basin to new social, economic and environmental challenges. Since the schemes had been built, new concerns had emerged, such as: those resulting from climate change; reduced drinking water supplies and water for agriculture; the preservation, of biodiversity; and, the importance of recreational use of reservoirs.



Giovanni Ruggeri of Italy, encouraging discussion during the session he chaired on Territorial and multipurpose water issues'



Antonella Frigerio of Italy, discussing ITCOLD initiatives to encourage stakeholder involvement in dam projects.



Julien Lecollinet of SCP, discussing a GIS-based system used to identify suitable land for irrigation in Kosovo.

Various programmes had been implemented over the years to address these issues, and since 2012, the Dordogne basin had been recognized by UNESCO as a Biosphere Reserve.

Daisuke Nohara, of Kyoto University, Japan, described a decision-support tool that could determine the appropriate time to release water from a reservoir to maximize storage capacity before a flood. The system was based on medium range ensemble forecasts available from ECMWF (the European Centre for Medium-Range Weather Forecasts). He described a case study where the method had been applied at the Shin-Nariwagawa reservoir in his country.

Arnaud Le Peillet, of Egis Eau, France, gave a talk about the Malewa water supply dam in Kenya, where some modifications had been made to a design originally studied during the 1990s. A feasibility study by the World Bank had led to a revised design, taking into account additional needs, for example, relating to climate change, increased water scarcity and greater awareness of environmental impacts. The new dam design had also allowed for the use of compensation flows to generate hydropower, which could be used to pump water to a nearby treatment plant.

Dongwon Kan, of Korea, described steps that had been taken in his country to improve policy making in the field of water resources management, and to improve awareness of the benefits of IWRM. He reported that inefficient water management in the past had been caused by what he described as "a jumble of agreements, treaties and regulations", with a number of organizations being involved, which he said were not keeping up with changing requirements and conditions for dam operation. He described a pilot project, following government mediation and some revisions to water use rights and priorities. This had succeeded in promoting the rational use of water by multiple stakeholders, he said.

Julien Lecollinet, of Societe du Canal de Provence, France, gave a presentation on studies aimed to achieve sustainable irrigation development in Kosovo. He said that the country was aiming to revitalize its agricultural sector, and modernize development, and had established a national strategy for this purpose. Lecollinet said that a GIS-based system had been used as a tool to assess resources and analyse land suitable for irrigation. Problems identified by the study included a lack of storage facilities, and a predicted increases in hydrological variability. The advantages of multipurpose development in this case were apparent, he concluded.

Theme 2: Governance and operating multipurpose facilities

The track of sessions on 'Governance and Financing' and 'Operating multi-purpose reservoirs, and innovations' essentially looked at the challenges to, and solutions for, the optimal use of water resources between multiple shareholders with competing interests in the context of climate change.

The main takeaways were that a combination of increased use of decision-making and forecasting tools, infrastructure improvements and close collaboration between all sector players could enhance the management of water resources and river habitats, as well as ensure greater resilience of dams.

Professor Tetsuya Sumi of the Kyoto University, Japan, discussed the positive impact of policy changes on flood control operations in the aftermath of extreme flooding, in July 2018, to mitigate the risks to public safety and infrastructure. The deaths and damage caused in 2018 by the heaviest rainfall recorded in the last 30 years in Japan underlined the lack of preparedness and flood control capacity to cope with extreme events of a number of dams managed by the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), the Japan Water Agency (JWA) and local municipalities. As a result, a special



Prof. Tetsuyu Siuni of Japan reported on policy changes in his country following extreme flooding in 2018, which had improved public safety.

panel of experts set up by the MILT advocated structural measures, such as upgrading of existing dams, non-structural measures, such as pre-release operations prior to forecast flood events, to ensure adequate storage capacity in reservoirs, and the organization of evacuation activities, through improved dissemination of risk information to the local population by dam operators, local municipalities and meteorological agencies. The impact of these expert recommendations was already seen during Typhoon Hagibis, in 2019, when 33 reservoirs out of 140 where operators were required to carry out flood control operations had previously had pre-release conducted in preparation. As of November 2021, the number of non-hydropower dams under the jurisdiction of the MILT, JWA and local prefectures with flood control functions had almost doubled, while there had been an almost eightfold increase in the number of other dams operated for hydropower generation and irrigation that had incorporated flood control functions. The use of forecasting tools, under the Cross-Ministerial Strategic Innovation Promotion (SIP) programme, had helped to improve the effectiveness of disaster warning systems for Japan, said

Sumi, though he noted that the uncertainty of rainfall predictions on the suitable amount of preliminary releases from reservoirs had caused issues, requiring a trade-off between hydropower generators and other water users.

The threat of increased drought and water shortages, caused by climate change in the Mediterranean area, meant that social and environmental aspects should be taken more into account in the economic evaluations of investments in multipurpose dams, according to a presentation by Mokhtar Bzioui, of Morocco, President of the Mediterranean Water Institute (IME). He also called for innovative approaches for the financing of dams,

including PPPs, as well as the increased use of green funds to ensure the resilience of dams in the face of climate change and for the adoption of new governance approaches to ensure better appropriation of investments by users,

The importance of collaboration and the use of support tools to manage water resources better and improve forecasting was the subject of a presentation by Pascal Dumoulin of Le Syndicat Mixte d'Aménagement de la Vallée de la Durance (SMAVD), a public body that manages the river Durance in southern France between the Serre-Poncon dam and the river's confluence with the Rhone, and Catherine Le Normant of EDF-Hydro-Mediterranee, operator of the river's hydroelectric facilities. The paper presented a joint project to find sustainable solutions to climatic and anthropological changes on the balance between water supply and demand and competing interests for the period to 2050 for the Durance river basin, which constitutes the main water resources of the Provence-Alpes-Cote d'Azur region. A study carried out in 2015, known as the R2D2-2050 project had predicted future issues related to the availability and use of water resources for several scenarios of climate and land use change and had shown the need to strengthen adaptation measures. These issues had prompted the regional actors to launch a collective project for water management and resource preservation at the scale of the catchment area. The emergence of a Water Development and Management Plan had been identified as an appropriate approach to unite the actors, to objectify and share knowledge and to grasp common issues in a bottom-up and pragmatic way, they said. To support this project, the SMAVD is developing a C3PO decision support tool (resource-use-infrastructure modelling under WEAP), which brings together stakeholders and scientists. The mutual interests around management of the river basin's water resources had given rise to a close partnership



M. Bzioui of Morocco, the President of IME, who called for more innovative approaches to financing dams

between SMAVD, and EDF, well beyond the exchange of data, the authors said.

Ensuring the balanced development of the Roselend dam and reservoir in the French region of Savoie between various stakeholders, using the most innovative forms of consultation, governance and financing, was the subject of a presentation entitled "Together, in Roselend, bringing our heritage to life" by David Lemarquis of EDF Hydro. The collaboration between private, institutional and civil society players had been born from a shared acknowledgement of the multi-uses of the reservoir where hydroelectricity, tourism and pastoralism co-existed, since the construction of the dam, in an area rich in remarkable biodiversity, said Lemarquis. "The Roselend project has brought together all the actors in a collective undertaking, underpinned by shared values, which allows everyone to understand the concerns and interests of others and to act together for the common good," he said. The shared territorial governance set up by the four founding partners had made it possible to organize a framework for exchanges, and to offer and implement adapted and shared solutions, he added.

The presentation by Ronny Rosilette of the Collectivite Territoriale de la Martinique, a French island in the Caribbean, concerned the studies performed to predict the effects of climate change on the river flows and natural hazards (such as storms or droughts), as well as analysis of the resilience and adaptability of the Manzo dam. It showed the importance of a global reflection and of the collaboration between dam users and owners to optimize the use of water in the future. Numerical modelling, developed by BRGM, based on Meteo France climate projections, showed the expected worsening of climate change and its predicted effect on Martinique's water resources by 2081-2100. Studies had shown temperatures rising by +2°C to 3°C, leading to an increase of 15 per cent in evapo-transpiration in the southeast region of the island (>5 mm/day), intensification of the seasons, with up to 38 per cent more precipitation in the wet season and 25-50 per cent less rainfall during the dry season and as a result a soil water deficit as well as a deterioration in water quality owing to soil erosion and pollution load. This would necessitate resilient and adaptive strategies, including implementation of an irrigation master-plan and a territorial hydro-economic model, as well as an assessment of Martinique's irrigation potential (groundwater and treated wastewater reuse), changes in agricultural practices and the creation of more hillside storage reservoirs, Rosilette said.

Wilberforce Manirakiza, of Uganda's state power producer UEGCL, said that consistently higher-than-normal precipitation, coupled with accelerating land use changes, had resulted in higher inflows into Lake Victoria, greatly affecting hydropower generation in the White Nile



Pascal Dumoulin of SMAVD, France, who discussed a water management plan for the Durance river

Cascade, disrupting socio-economic activities around the lake and along the river, and imposing a higher potential threat for the safety of the dams. In May 2020, the lake had reached its highest ever recorded level of 13.47 m, surpassing the record set in 1964. In the wake of rising water levels, the Nile Cascade Coordination (NCC) had been formed under UCOLD, he said, to address the lack of streamlined coordination of discharges, and had to date resulted in improved production planning and reduced safety risks, he said. Discharge tests had been carried out to improve and streamline cascade operation of dams during high flows, to evaluate the consistency and accuracy of discharge, to identify constraints to hydropower production at extreme releases and to study reservoir regulation and monitoring of the variation of tailwater. For dam break analysis and emergency preparedness, a Dam Safety Management System (DSMS) had been developed in 2018, under which a study had been undertaken to model the worst-case scenarios associated with dam failures of the Nile cascade. Dam operators are required to undertake periodic public awareness workshops on emergency preparedness as well as dam break drills under the umbrella of the NCC Committee. This had permitted a gradual increase in the Nile flows to minimize shocks to the ecosystem and allow the public time to adjust to the high discharges. In addition, an integrated multi-sectoral framework had been adopted to assess and mitigate the risks, the frequency of dam surveillance has been increased, and an Emergency Preparedness Awareness Campaign was undertaken to prepare the public. To manage dam safety risks better, Manirakiza recommended three solutions: the adoption of a risk-informed strategy, the need and to create dam safety legislation in Uganda and improve cascade cooperation to avert the impact of climate change.

Francois Welt, of Hatch Consulting, Canada, presented the benefits of a project being carried out on behalf of



Aries Firman, of Indonesia, and Laurence Duchesne, of France, who co-chaired Theme 3 of the Symposium, giving an introduction to the presentations



Ozge Turk of Switzerland a PhD candidate at the University of Geneva, Switzerland, who proposed a simple system for allocating water from a shared river.

the Mahaweli Authority of Sri Lanka (MASL) to address the challenges of multipurpose reservoir management. The project aimed to modernize software, better integrate data and automation to optimize water resources and improve forecasting for MASL, which manages 15 major hydropower plants, 32 irrigation areas and multiple canals in five river basins in central Sri Lanka, he explained. The deployment of Hatch's own Vista Decision Support System (DSS) suite, a toolbox used by system operators, dispatchers, and engineering-operations staff to help determine long-term storage planning and management, short-term scheduling, and real-time dispatch, has enabled the integration of all data into a single system and provided for optimization and forecasting. Based on previous uses of the system, the Vista toolbox could deliver an increase of 2-5 per cent in hydropower production and a 5-10 per cent growth in revenue, he said. Welt noted the optimization of the management of multipurpose reservoirs in Sri Lanka, predominantly being used for hydropower generation and irrigation for agriculture, posed significant challenges owing to economic development, changing demographics and Urbanization, and climate change.



Clement Balique of BRLi, France, who shared experiences of benefit sharing in the Volta river basin in Africa

Theme 3: innovative solutions in reservoir uses

Aries Firman or the Indonesian Dam Safety Commission and Laurence Duchesne of CNR, France, co-chaired this session and began by introducing some of the innovative Copies to be presented. Examples included new renewable; on the Rhone, floating solar PV. fish-friendly turbines, and sediment control and waier flow management between France and Switzerland.

Clement Balique or BRLi, France, gave the first presentation, speaking about hydro production at the Akosombu dam, and the development of irrigation on the Volta river in Ghana. The Volta river basin extends across six countries, Benin, Burkina Faso. Cote d'Ivoire, Ghana. Mali and Togo, Balique said, These states, he continued, were members of the Volta Basin Authority and had committed to drawing up a 'water charter'. "One of the challenges of this international agreement is to agree on a reasonable level of abstraction to reconcile food and energy security for the populations. while guaranteeing the minimum needs of the ecosystems", Balique said. His analysis had revealed that the economic value of each cubic metre withdrawn to develop irrigated agriculture upstream of the basin was higher than that of each cubic metre turbined at the Akosombo-Kpong complex. "Within the limit of an acceptable reduction of hydropower production, the economic development of the basin as a whole would thus benefit from the development of irrigated agriculture", he concluded.

In a question raised by one delegate in the audience, it was noted that sediment retention by upstream projects could benefit downstream schemes. Balique was asked about his experience of this. "This was not monitored directly", he replied, " but flooding downstream is an important issue and, although not directly in relation to sedimentation. disaster risk reduction learns downstream work closely with their upstream colleagues". He added that this cooperation was supported by the project.



Takahiro Koshiba of Kyoto University, Japan, reported the performance of sediment bypass tunnels in Japan

Ozge Tiirk, a PhD Candidate at the University of Geneva, Switzerland, also spoke about sharing trans-boundary waters. She reported on existing practices, disputes, and criteria of some of the international financial institutions to manage these shared resources. Allocating water from a shared river to every riparian state was a complex and sensitive issue, she said. Therefore, most riparian states did not allocate water between each other. Turk proposed a simple water-sharing method to allocate the water of the trans-boundary water courses between riparian states. The method was based on sharing the trans boundary water quantities using a 1:3 ratio for the downstream state and 2:3 for the upstream state. "The method envisages compensation payments to other riparian states in different forms, in case of excess water usage", she concluded.

Samuel Renaud of Tractebel, France, described a hybridization study for modelling PV with hydro. "Coupling a solar powerplant with a hydroelectric scheme can be a solution to optimize the generation of hydraulic energy", he said, it may also offer more flexible seasonal storage thanks to the additional solar production, Renaud added. Further benefit was achieved, he continued, from the reduced amount of investment required for the installation of the solar plant as it could be optimized, especially through the existing grid interconnection infrastructure and access roads. Renaud reported that a tool had been specifically developed by Tractebel to quantify the synergies for all types of projects, and to identify the optimal operating conditions to maximize these benefits that were primarily related to intermittence and variability.

Takahiro Koshiba of Kyoto University, Japan, described a study for a sediment bypass tunnel (SBT) at the Koshobo dam in Japan. He explained that the SBTs at the Asahi and Miwa dams had been successfully operated for more than ten years, and the SBT at Koshibu dam was the newest in Japan and had been built in 2016 with



Alice Devot of Oreade Breche, France, described how community consultation and participation can increase a projects success and local acceptance.

extensive monitoring systems. These systems had revealed the amount of sediment transported during each season, Koshiba said. He presented this in relation to hydrographs and sediment inflows, and the spatial transient of sediment transport peak levels. According to these observations, Koshiba suggested rules for SBT operations. "Although the Koshibu SBT is not used in winter, the total volume of sediment yield from snowmelt runoff accounts for 25 per cent of the annual sediment inflow, so operation during this period is worth further consideration", he said.

In a question from the audience, the issue of abrasion was raised as a potential problem in bypass tunnels. Koshiba responded that this was monitored each year and did indeed present a serious challenge. "There is now ongoing discussion about performing maintenance solutions, which include strong concrete and efforts to reduce impact rates. However, abrasion cannot be completely prevented, so tolerance is built in", he added.

Another delegate asked what percentage of sediments were bypassed compared with the amount arriving at the reservoir. "The SBT is designed to be used only three or four times a year, and when in use, bypass efficiency, is about 70 to 90 per cent", Koshiba replied.

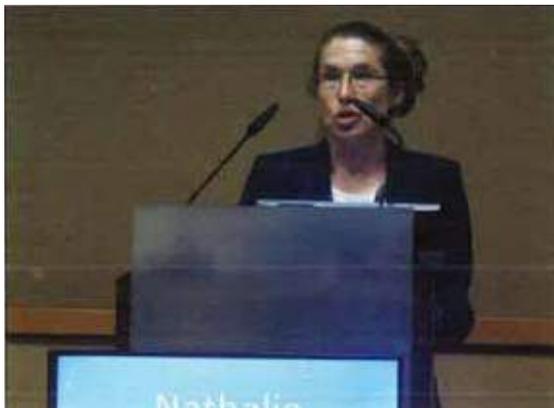
Luc Deroo, of ISL, France, proposed that the present time should be regarded as a new golden era for dams. "The need for water, renewable electricity and protection against floods and droughts is considerable", he said. "Water storage is a historical and natural way to contribute to this. Yet the pace of construction of new reservoirs is slower than the increase in demand". Deroo proposed innovation as one essential avenue to address this mismatch. He felt it was possible now to propose new options, driven by societal issues that were "changing the game".

"These factors include falling prices of solar and wind energy, changes in public opinion on environmental

issues, climate change, resource scarcity and natural disasters, changes in project financing methods, and digitalization", he said. New projects were increasingly multipurpose, while some of the important benefits such as biodiversity provisions, would have non-market values, he noted. "Dams at sea, hydro-solar reservoirs, twin dams, reservoirs fed by flood pumping, and biodiversity reservoirs could help fuel a new golden age for dams", he concluded.

Alice Devot of Oreade Breche, France, reported on the social and environmental acceptability of new reservoirs, with a focus on climate change adaptation. In recent years, the Sivens and Caussade projects had been developed in France, she said, to mobilize water resources for irrigation and low-flow support, but had been a source of conflict. In response to the experience at Sivens, the French Government had defined the modalities of development of new water resource mobilization projects. Devot explained that this was done within the framework of the 'Territorial Projects for Water Resource Management' and aimed to strengthen dialogue, and support the social and environmental acceptability of such projects. Devot emphasized that the involvement of stakeholders in the development process was a key factor for the appropriate preparation and implementation of projects. In her conclusions, she reported other key success factors for water storage structures, including consistency with other water planning and management policies, state policies and water agency policies. "On the other hand", she commented, "high costs associated with undertaking the required studies, long consultative processes, and the individual involvement of numerous stakeholders, can make participatory approaches more challenging".

Nathalie Tomczak of Tractebel, France, discussed reservoir operation simulation studies for existing and planned hydropower projects in the Niger and Benue catchments in Nigeria. The study had covered simulations



Nathalie Tomczak of Tractebel, France, reporting on optimization studies undertaken for reservoir management in Africa

of energy production and meeting water demand using the MIKE HYDRO Basin software. The modelling approach had been based on maximizing energy production and maintaining a target mean load factor. She highlighted water resources allocation modelling as being a powerful tool for objective comparison between multiple development paths that enabled the analysis of possible outcomes over the short-term, medium-term or long-term. "Future constraints, such as climate change or new water demands, can affect the ability of multipurpose projects to fulfil set objectives and these factors can be integrated into the process of modelling and results analyses", Tomczak said. Reservoir operations simulations, therefore, provided a solid basis for focusing planning and decision-making, she concluded.

round table on dams and reservoirs: Challenges of tomorrow

The Symposium concluded with a Round Table discussion, entitled 'Dams and reservoirs: Tomorrow's challenges'; this was a new format for an ICOLD meeting, which had been developed by the French National Committee. It brought together a number of experts on water resources development, from professional associations (ICOLD, the World Water Forum, ICID, and IHA), representatives of the World Bank, environmental specialists (including IUCN), and various institutes associated with world water issues.

Michel Lino, President of the French Committee (CFBR) opened the discussions.

He drew attention to the fact that the situation of the world today was critical. "Water is our most precious asset, and energy is totally indispensable", he said. He added that dams and their reservoirs had played a major role in social and environmental development throughout history and said "Today we are at a turning point, Will our profession be able to meet the challenge?"

Alison Barlle, of Aqua-Media International, made some opening remarks, and set out the proposed format for the discussions. She commented that there had probably been no more important time than the present to focus in some depth on global water issues, challenges, and the innovative approaches to planning, project design, construction and operation, of the future projects which are badly needed. "We are in an era when it is possible to measure seismic activity on Mars, and contemplate unpiloted aircraft, and yet in the water sector, domestic and industrial water shortages, and a lack of food security, still prevail in so many parts of the world", she said. She added that with increasing concerns about global warming, and changing hydrological conditions, more initiatives and actions were urgently needed.

The 17 UN Sustainable Development Goals (SDGs) set ambitious targets, Barlle continued, and it seemed that, so



Moderators for the first two parts of the Roundtable. left, Emmanuel Grenier; ICOLD's Communications Officer; and, Alison Bartle, publisher of Hydropower & Dams.

far, success in meeting the goals had been limited. With 2030 only eight years away, it seemed highly unlikely that many, if any, targets would be met, she said. Renewed efforts therefore had to be made, for the sake of present and future generations, and it was clear that building more dams, particularly multipurpose ones, upgrading existing ones, and looking at adapting infrastructure to meet new challenges such as climate change, would be closely linked in fulfilling the UN objectives set out in the SDGs.

The Round Table, she said, would focus on SDG No. 6, 'Universal and equitable access to safe and affordable drinking water for all', but at least five or six other SDGs had direct links with the provision of clean water resources and renewable energy resulting from the construction of dams and reservoirs.

The discussions would be in three inter-related parts, Bartle explained, the first setting out some data about the current status of global water resources, and projections about the future situation in years to come. This would be followed by some viewpoints from officers of the major professional associations and other organizations that were influential in the water and energy policy, setting out some of the challenges ahead. The third part of the discussions would comprise a number of 'short stories' from various stakeholders, who would briefly present examples of innovative solutions which were being applied to tackle world water issues, across Europe, Asia, Africa, and the Americas.

1. Establishing the data

Bartle was then moderator for the first part of the session, where, to set the scene for the discussions that would follow, she posed three basic questions to Dr Thierry Caquet, Scientific Director for the Environment at INRAE, the French National Research Institute for Agriculture, Food and the Environment. She first asked

him to comment on the current distribution of world water resources, and, taking account of factors such as climate change, to give his views on the resources that would be available by 2050 and beyond.

He replied that at present research showed that around 1.9 billion people lived in potentially severely water scarce areas, but with population increases and climate change impacts, it was likely that by 2050, 3.6 to 4.6 billion people could be living with water stress, and of those 93 per cent would be in Asia and Africa.

She then turned to specific sectors for water consumption, and asked Dr Caquet for his perspective on demand for water for domestic consumption, irrigation agriculture, at present, and projections until the end of the century, especially in the light of increasing populations.

He replied that current global water demand was around 4600 km³/year; 70 per cent of total water use was for irrigation. It was expected that demand would increase by 20-30 per cent by 2050, mostly for industry and energy: the greatest increases would be in Africa and parts of Asia, as well as Central and South America.

The next question to Dr Caquet concerned the role of water storage, and hydropower, in the global transition towards renewable energy, and the role for hydro in synergy with other renewables. He replied that the International Energy Agency predicted that by 2050, renewables could account for about two-thirds of energy use. To keep global warming limited to < 2°, at least 850 GW more hydropower would need to be implemented, and for 1.5°, the requirement would be 1170 GW of hydro. He added that hydro reservoirs had other vital roles to play, such as hosting floating solar panels, buffering for the variability of intermittent renewables, and coupling with H2 projects.

The last question concerned water quality and environmental protection. Bartle asked Dr Caquet to comment on the impacts on water quality over the past decades, and the associated effects on ecology and biodiversity. His prediction was grim, as he pointed out that 12 per cent of the world population at present was drinking water from unimproved and unsafe sources, and about 30 per cent of the population had no form of sanitation. Water pollution was set to intensify over the next few decades, he said, and he concluded that pollution would be one of the main drivers of biodiversity erosion, and would affect ecosystem services delivery to humans.

2. Challenges and needs

ICOLD's Communications Officer Emmanuel Grenier, moderated the next section of the discussion. Satoru Ueda, Lead Dam Specialist at the World Bank, spoke of how dam construction had slowed as a result of



World Water Council President Loi'c Fauchon, calling for more focus on hydro diplomacy; beside him is ICOLD President Michael Rogers, who spoke of progress in dam safety



Satoru Ueda of the World Bank, who spoke of ways to prepare projects for financing; and ICID President, Dr Ragab Ragab speaking about water use for irrigated agriculture

environmental concerns, but he gave encouragement by advising on how schemes could be prepared; he also spoke of the Bank's role in promoting dam development, refurbishment and safety. ICID President, Dr Ragab Ragab, spoke of water needs for irrigation, and Debbie Gray, Climate Policy Manager at IHA, discussed the major role of hydropower in the energy transition, and the potential that existed for further development. President of the World Water Council, Loi'c Fauchon, spoke of the need for hydro-diplomacy, to avoid global water-related conflicts. ICOLD President, Michael Rogers, spoke of the urgent need to keep the world's ageing dams safe, and referred to ICOLD's work in this respect.

3. innovation and solutions

After two parts of the Roundtable identifying problems, challenges and global needs, the final part, moderated by Luc Deroo of France, featured short (three minute) 'stories' from a number of experts and stakeholders, representing a wide variety of topics, but all with the theme of innovation, in response to some of the issues which had been raised.

To begin, Laurent Bessadi, of EDF, showed a video made by his company, focusing on the role and benefits of water infrastructure, and demonstrating the 'legacy of dams and reservoirs'. Guido Mazza of the 'Dams and Territories' initiative of ITCOLD, focusing on increasing public awareness about the role of dams, through a series of workshops throughout the country.

Julien Verdonck, of BRL, France, gave a short talk on developments in IT for water management. Gregoie Jeanson, of Freyssinet, and Jean-Philippe Cattin, of Razel Bee (both France), spoke of the upgrading work at Kariba dam, relating to the topic of preserving and enhancing existing dams. Prof Tetsuya Sumi of Japan discussed some of the latest research and development in sedimentation management, as well as the preservation of biodiversity.

Kimberly Lyon, of the World Bank, spoke of the Bank's support in taking measures to address the increasing "water gap". Michel Ho Ta Kanh, of the French Committee, reported on the use of floating solar PV panels on reservoirs in his country, with special reference to the Dami scheme, completed in 2019, which had a capacity of 47.5 MW of solar power, on the reservoir of the 175 MW Dami hydro plant.

Prof Anton Schleiss, of Switzerland, spoke of the major prospects for pumped storage, which today, he pointed out, was playing an increasingly important part as a catalyst in the energy transition. Filipe Guerra, of EDP, Portugal, spoke of the increasing trend in hybridizing solar and hydropower, and the benefits of such hybrid schemes. Priska Hiller, of Norway, spoke of the synergy between new technologies for different applications relating to water resources, from recreation through to hydrology and climate.



left: Luc Deroo of France, who called on a number of stakeholders to present three minute 'short stories' on innovative approaches to water resources management

Prof Anton Schleiss of Switzerland, who underlined the major role of pumped storage



ICOLD Congress focuses on Concrete Dams, Safety, Monitoring and Climate Issues

As usual four Technical Questions, with a number of sub-topics for each, were studied in detail with presentations, questions and discussions over the two days of the Congress. Three (Q105-107) had been selected by a voting process at the Annual Meeting in Ottawa in 2019, and Q104 was the President's chosen topic, in this case concrete dams. The 27th Congress was attended by around 1300 participants.

In his opening remarks to ICOLD's 27th Congress, President Michael Rogers spoke of ICOLD's unique role in reviewing and improving best practice and highlighting what is good in the dam engineering industry. He reflected on the topics selected for the four Technical Questions this year, noting the importance of Q104, as concrete dams had not been studied in detail at a Congress for several years. Today concrete dams were being built to greater heights, with some being more than 300 m high, he observed, underlining the importance of discussions on their design and construction.

The subject of Q105, represented a major focus for ICOLD, the most important principle for the organization being the safety of dams and levees for the protection of human life. In this respect he underlined the value of learning from incidents and failures, on which discussions would focus. Instruments and monitoring systems, which would be discussed during Q106, were vital because they were the principal way of understanding the health of water infrastructure.

Regarding Q107, climate change, Rogers said that this phenomenon was already having a strong impact on water resources, in terms of extreme climatic events; dams were part of the solution, he added.

Loi'c Fauchon, President of the World Water Council, presented some opening remarks, and began by describing the Council's role in bringing together a 'family' of water professionals, and in working to convince politicians to regard water as an issue of priority. Today, water was at the forefront of political discussion, he said, and there were numerous crises around the world relating to water resources, in particular associated with sanitation, food security, military issues, diplomatic issues, and climate concerns. He predicted more difficulties to come, not only relating to climate, but also population growth and movement, the development of megacities, and pollution generated by human activities. "We cannot remain complacent" he said, "but must face up to our responsibilities". He felt that innovative technology had an important role to play in mobilizing more water resources. Storage was key to mitigating many problems, Fauchon continued. He added that dams had had a 'bad press' in

the past generally because of a lack of public awareness about the role they play.

Emanuelle Verger, Director of Hydro at EDF, spoke of the importance of hydropower in France's energy mix, especially because of its reliability and flexibility for the grid. She felt that the benefits of hydro were underestimated by decision makers, and so an important task was to spread knowledge and increase visibility. Even if the future potential for new schemes in France might be limited, Verger said, there were opportunities to upgrade existing plants and to optimize storage; particularly important was to develop more pumped storage, she said.

The President of Compagnie Nationale du Rhone (CNR), Laurence Borie-Bancel, described her company's role in the development multipurpose schemes on the Rhone, for hydropower, navigation, and environmental protection. She referred to changing priorities over the years, with enhanced emphasis on the environment, and, in recent years, climate issues.

She pointed out that CNR had 19 run-of-river hydro plants on the Rhone, adding that the river's waters were turbined 19 times before discharging to the Mediterranean. She underlined that hydropower was fundamental in the energy transition, and echoed the view expressed by



Speakers during the opening plenary session of the Congress. From left: Loi'c Fauchon, Emmamelle Verger, Fabienne Joly, Laurence Borie-Bancel, Michel de Vivo, Michael Rogers and Michel Lino

Emanuelle Verger that some politicians underrated the importance of this resource.

She went on to point out how older plants could be adapted, and how environmental flows could be used to maintain the ecological system of the Rhone.

Fabienne Joly, President of the Chamber of Agriculture for the Var region, and President of Societe du Canal de Provence, described the system of 45 canals in Provence, and also the importance of the Durance and Verdon river systems, which provided 10 per cent of France's hydro capacity. She described the role of Societe du Canal de Provence, which secured the water supply for the Provence region of France, and its roles in fulfilling the needs of multiple water users.

The 2022 Innovation awards were then presented; the Gold Prize was awarded to Carpi and EDF, in recognition of Carpi's Sibelon mat, which allows for the underwater repair of canals without interrupting flow. It has been applied at an EDF scheme in France.

Question 104: Concrete dam design - innovation and performance

Q104 General report

The General Reporter for this Question was Rafael Ibañez de Aldecoa, Chairman of SPANCOLD's Technical Committee on Concrete Dams. He commented, during his presentation, that the last time ICOLD had devoted a Congress Question specifically to concrete dams had been in 1988. Since the 1980s, there had been a number of impressive breakthroughs in concrete dam engineering. Examples were, advances in structural analysis, the development of RCC, RCD and hardfill dams. Also, over the past decade, six double curvature concrete arch dams had been built, which were higher than 270 m. The leading countries for such very high arch dams, he added, were China, Iran, and Turkey.

Ibañez de Aldecoa also referred to new developments in surveying and monitoring concrete dams, in concrete pathology, and in materials for rehabilitation.

He remarked that ICOLD had produced plenty of Bulletins dealing with various aspects of concrete dam engineering: a total of 28 since 1960. For Q104, a total of 41 reports had been received from 19 countries.

Ibañez de Aldecoa commented that arch dams were the most challenging, in terms of their structural behaviour, design and construction. The construction of new arch dams was limited, mainly because of the need for sites with good geological and geotechnical conditions, and some other factors related to dam site geometry. But when these conditions could be met, arch dams could be very competitive, especially for very high dams.



Alberto Scuero and Gabriella Vaschetti of Carpi Tech. accepting ICOLD's Gold Prize for Innovation

He gave some examples of very high arch dams, especially in China and Turkey.

He then spoke of some of the very high RCC dams around the world, noting that the highest again was in China. He commented that it had taken several years of RCC dam construction for the profession to become confident enough to build extremely high structures of this type. Now 16 per cent of the world's large RCC dams were more than 100 m high, and four of these were higher than 200 m. The planned Batoka dam, on the Zambezi river, he said, would be 185 m high, ranking it among the highest in the world.

Ibañez de Aldecoa noted that one report dealt with the concept of hybrid RCC and rockfill dams, a combination which could lead to an economical and safe composite structure.

Another paper dealt with innovative methods for forming the faces of RCC dams, for example the use of immersion-vibrated RCC.

Ibañez de Aldecoa then referred to cases that had been described in reports about raising the height of existing concrete dams, and some innovative methods that had been used, noting that at some sites, new dams had been built downstream. The reasons for choosing this kind of project had been dealt with by several authors, for example, from Switzerland and the USA.

Papers from China dealt with innovative features of the Jinping I high arch dam, and the foundation treatment that had been necessary, as well as the monitoring system installed.

On issues relating to very high RCC dams, there was a report on the use of geomembranes to provide or restore watertightness, with one example being La Miel I in Colombia; another dealt with first impounding of the Grand Ethiopian Renaissance dam in Ethiopia.

Ibañez de Aldecoa reported that the operational performance of concrete dams during their lifecycle, including in extreme conditions, had been the subject of 11 reports.

These covered a variety of issues, including foundation conditions, various concrete pathologies (relating to AAR, freeze thaw actions, and so on), scouring downstream, ineffectiveness of impervious elements or drainage curtains, and ageing monitoring systems. He felt that a fundamental conclusion from several reports was the importance of the design, implementation and follow-up checks on the monitoring and surveillance systems; this was especially important in cases where major modifications were made to dams, such as buttressing or heightening.

In his concluding remarks, Ibañez de Aldecoa said that, although there were fewer and fewer suitable sites available for the construction of new dams today, particularly for concrete dams, there was still great potential for the design and construction of new concrete dams of all possible types in many countries, as well as for the heightening of existing concrete dams. Also the need for rehabilitation and upgrading of existing dam structures was increasing. In some cases, raising the height of an existing structure could be a more practical and effective alternative to the construction of a new dam.

There had been important advances in the design and construction of concrete dams over the last three decades, he continued, and the technology has been continuously developing, thanks to the dedication of hundreds of engineers and other professionals. Young engineers and scientists had taken the advantage of working closely with their mentors, and in this way, the expertise would be maintained and further evolved.

Ibañez de Aldecoa concluded his General Report saying that he believed in a promising future for successful operations of existing concrete dams and for the construction of new ones in the years to come; he added that these would be led by advancements in state-of-the-art technology.

innovations in the analysis and design of new and heightened CVC and rCC arch dams

In this session, ICOLD Vice-President Ali Noorzad, of Iran, presented the results of a study into the role of wave propagation effects in the correct estimation of stress levels in the body of a concrete dam. In the study, a half-space with a semi-cylindrical valley had been analysed under inclined harmonic shear waves, with various angles of incidence, for investigation of surface amplification, using a domain reduction method (DRM). The analysis had shown that although applicable to gravity and arched concrete dams, the wave propagation effects were more significant for the latter. In a second paper, Noorzad noted that earthquake analysis of concrete gravity dams was mostly done under the assumption of elastic foundation, while a non-linear response of the foundation rock had not been addressed frequently. However, it had been



Rafael Ibañez de Aldecoa of Spain, presenting his General Report for Q104. He said he believed in a promising future for the successful operation of existing concrete dams and for the construction of new ones in the years to come

observed that the dam-foundation interface was highly susceptible to cracking as a result of its geometrical properties, whereas assuming elastic response for foundation prevented crack propagation within this medium and forced the crack to propagate in a straight direction at the interface.

Taking the Koyna concrete gravity dam in India as an example, Noorzad analysed a dam-foundation-reservoir system considering non-linear responses of the dam and the foundation, subjected to seismic loading. A comparison analysis had also been performed with linear response of the foundation rock. The results, he said, had revealed a completely different crack pattern at the heel of the dam, depending on whether the foundation was considered elastic, or with non-linear properties. In the first case, the crack had been forced to propagate along the dam-foundation interface. In the second case, cracks had propagated within the foundation rock, and a different overall response for the system had been obtained.

Prof Anil K. Chopra, Emeritus Professor at the University of California Berkeley, USA, discussed the direct finite element method (FEM) for earthquake analysis of arch dams and all aspects of dam-water-foundation interaction, using the case study of the Morrow Point dam, a 143 m-high double-curvature arch concrete dam in Colorado, as well as outlining methods for selection and scaling of ground motions. His report explained how direct FEM could overcome the limitations of standard FEM by introducing wave-absorbing (or non-reflecting) boundaries at the upstream end of the fluid domain, to model its essentially semi-infinite length, and at the bottom and side boundaries of the foundation domain, to model its semi-unbounded geometry. The fluid domain model included water compressibility and wave absorption in the sediments at the reservoir base, and the model of



the foundation domain included mass, stiffness, and material damping appropriate for the rock, he explained. As a result, the assumptions of massless rock foundation and incompressible water were avoided.

A paper jointly prepared by Emmanuel Robbe of EDF and Nicolas Ulrich of Artelia (both France) compared shear phenomena at the concrete-rock contact of arch dams. Their presentation emphasized that most of the existing arch dams in France had been built during the two decades following World War II, when the design methods used at the time had been based on simplified calculation methods founded on an assessment of the upstream and downstream face stresses and, in particular, did not include an analysis of the state of shear at the concrete-rock contact. The paper referred to French Guidelines for analysing the behaviour of arch dams, which suggest assessing the shear state at the base of the cantilevers, and describe some related failure mechanisms, differentiating between the central and side cantilevers. A comparative numerical analysis of ten arch dams between 23 and 150 m high had revealed "quite high shearing at the dam/foundation contact with mobilized shear stress exceeding 1 MPa", much higher than the 100 kPa usually considered in France for calculating the stability of gravity dams. Finite-element or finite-difference method calculations had been used with nonlinear models capable of releasing the tensile stresses, often at a previously implanted joint. For most of the arch dams analysed, no downstream displacement at the toe had been measured. Results were also presented of the specific mechanical behaviour of four double-arch and one single-arch dams in France, with heights of up to 70 m, which had been analysed by several major consulting companies, as well as the solutions that had been implemented, such as reinforcement of the downstream rock abutment, reinforcement by anchoring the arch's supports, thickening the side cantilevers and piezometric monitoring at the toe of the central cantilevers.

Dr Quentin Shaw of ARQ Consulting Engineers, South Africa, described the differences between the early behaviour of RCC and CVC in large dams and how these differences required a slightly different design approach, taking into account an additional property of concrete in the form of stress-relaxation creep (SRC). Shaw highlighted the difference between the vertical and horizontal approaches for the construction of CVC and RCC dams, respectively, which together with the use of high levels of supplementary cementitious materials (SCM) typical in RCC mixes, introduced two key factors that could together create significantly different early behaviour and related design requirements. First, the levels of concrete shrinkage experienced during the hydration process could be substantially less than traditionally assumed for CVC when high levels of flyash

were used. Second, horizontal concrete placement implied the mass of the dam would not necessarily be carried directly or vertically down into the foundation, particularly when concrete shrinkage levels were low. Therefore, the typical historical design based on 2D analysis of CVC gravity dams might not be valid for RCC gravity dams. This was more important when the RCC dam has lower length/height ratio (< 6), Shaw said, and in this case, knowledge of the applicable level of SRC was essential in developing a good understanding of the 3D structural function. On the contrary, he noted, that when the gravity dam was long in relation to its height and adjacent blocks were of similar height, the level of SRC would be of little importance and the dam could be designed, or analysed, as a 2D structure.

Heightening of existing dams

A number of papers dealt with structural modifications in the context of climate change. Using the diverse examples of the Cambambe dam in Angola and Vieux Emosson dam in the Swiss Alps, Alexandre Wohnlich, of Gruner, Switzerland, said that arch dams could readily be heightened thanks to their 3D behaviour and high degree of redundant constraints; this also usually made such heightening projects economically interesting. However, he stressed that arch dams were also the most challenging dam type in terms of structural behaviour, design and construction technologies to be implemented. Therefore, heightening of such slender structures should be carefully conceived, designed, planned and managed, he said. "A deep knowledge and wide experience of arch dam technology, spanning from the most theoretical issues of arch dam behaviour and stress pattern to the practical construction issues such as concrete mix design, concrete cooling, or joint grouting technology, are critical to the heightening of this type of dam," he concluded.

Y.K. Chaubey, of NHPC, India, described the 5 m height increase implemented at the 32 m-high Dhanikhari CVC gravity dam on Andaman and Nicobar Island; this consisted of concrete buttressing on the downstream side, which included performing various FEM studies, namely a thermal analysis, a stress analysis and a shrinkage stress-strain analysis. The design and construction work had been greatly influenced by the fact that the reservoir could not be drawn down, as the water supply system had to be maintained. Accordingly, the concrete had been placed when the reservoir level had been lowest, to minimize the loading on the dam so that the new composite structure could react to the largest range of water loading.

Marc Balissat, of Gruner, Switzerland presented a description of the replacement of the 114 m-high Spitalamm arch gravity dam in Switzerland with a double-curvature arch structure. Instead of constructing a new

double-curvature arch dam on the sound mass concrete of the existing dam, it had been decided to build a new dam downstream. This had presented two important advantages: no interference with the operation of the existing reservoir; and, no need for demolition of the existing dam, which could be left in place with a bypass system to balance the water levels at the reservoir and in the open space between both dams. Considering the space limitations and the excellent foundation conditions, a double-curvature arch dam had been the best option, he said. The crest of the dam had settled at the same elevation as the existing dam, with the possibility of a future heightening. The geometry of the new dam had been defined by sets of parabolas both horizontally and vertically. 3D stress analyses had been carried out for both, the basic configuration and for the heightened dam, to make sure that no strengthening would be required at a later stage. For that reason, relatively thick arches had been adopted for the basic configuration. A dynamic analysis of the dam had also been conducted, by applying three non-dependent synthetic accelerograms to the structure.

The studies and analysis used to increase the evacuation capacity of the spillway system at the Orlik concrete gravity dam in the Czech Republic, following the largest flood event in its history in 2002, was the subject of a presentation by Milan Zukal from the Czech Technical University in Prague. Construction of three new gated spillways outside the dam, next to the right abutment, and managed based on BIM methodology, had begun in 2021, he explained, to comply with more stringent dam safety regulations adopted by the Czech authorities in the aftermath of the floods. An assessment had determined that Orlik needed to be able to cope with a 10 000-year flood, with a peak discharge of 5300 m³/s. The 91 m-high dam, built between 1957 and 1960, impounds the largest volume reservoir in the country, and had been designed to cope with a 100-year flood event. Although the dam had withstood the flood reliably, despite peak inflow appreciably exceeding the 100-year flood value, it had suffered considerable damage. A physical model of the dam body and spillways had been set up, Zukal said, to assess the parameters of the discharge and extrapolating them to water levels matching a 10 000-year flood.

Comprehensive calculations using FEM had been carried out based on an engineering geological survey of the bedrock and, in particular, of the contact between the dam body and the bedrock at the dam base. The new spillway design had been refined based on 3D modelling (CFM) and used to assess and optimize the flow, and subsequently verified and further optimized by using the physical model.

S.P Bansal, of SJVN, India, presented some of the lessons learnt from the hydraulic design of an 18.5 m-high



Milan Zukal of the Czech Republic, describing a scheme to increase the discharge capacity of the reservoir at Orlik dam in his country

reinforced concrete barrage, for the diversion of water for power generation, as the most upstream component of the ongoing 60 MW Naitwar Mori project in his country. The experience gained from designing a project located on the upper reaches of a Himalayan river with a heavy boulder bed load and deep pervious strata (conditions not appropriate for large concrete dams) would allow for uniform development of more small projects on tributaries of major Himalayan rivers, he said. In the absence of any proven guidelines, the hydraulic design of the barrage had been based on various theories adopted in boulder-dominant rivers, and considered potential modes of failure, including foundation failure caused by scouring, piping of material underneath caused by excessive seepage, exit gradient and suffusion risk. The design had been verified by seepage numerical analysis using Slide software, to obtain the net flow and exit gradient diagrams. Experience gained from the performance of the barrage structure, after commissioning in 2022, was to be shared with the industry in the future Bansal said.

innovations in RCC gravity dam materials and mixes

Using the example of the 103 m-high Enciso dam in Spain, commissioned in 2018, Francisco Ortega of FOSCE Consulting Engineers, Spain, stressed that the use of immersion-vibrated RCC (IV-RCC) for the face of the dam had successfully solved most of the critical issues encountered in early RCC dams. The performance after first impoundment of the Enciso dam had confirmed an extraordinary improvement in quality, compared with previously constructed RCC dams, he said. IV-RCC, a mix halfway between the high cementitious RCC (HCRCC) and the traditional very stiff (low to zero slump) CVC for dams, had technical advantages as well as ensuring simplicity and economy of construction from avoiding the additional resources and personnel for production, transportation, placement and quality control of the

CVC or grout, otherwise required for consolidation by immersion vibration, he explained. The same concrete mix could be used, Ortega said, for the dam faces, the adjacent core of the dam, as well as contact against rock at the abutments and against previously built CVC structures, with both developing similar strength and elastic and thermal properties. In addition, the bonding between both concretes was perfect, with no interface, provided that the respective consolidation of both concrete mixes (face and core) were correctly executed.

Malcolm Dunstan highlighted the benefits of an early implementation and extensive scope of a trial mix programme for the 84 m-high Mwache dam, the first RCC dam to be constructed in Kenya. The main objective of the trial mix programme for the RCC dam was to provide sets of mixture proportions for the various combinations of locally available cementitious materials for the specification of the bidding documents for the construction of the multipurpose project.

One of the main findings had been that specific retarders had had to be designed, to obtain the specified setting times for the RCCs containing the available cementitious materials. This research had taken time that would not have been available if the trial mix programme had not been undertaken so early, Dunstan said. Also, it had been found that some combinations of the potential cementitious materials were extremely efficient. An RCC mix containing 32.5 kg/m³ of Portland cement and a low-lime fly ash content of 187.5 kg/m³ and a further RCC mix containing a Portland cement content of 50 kg/m³ and a natural pozzolan content of 170 kg/m³, had both conformed to all the project's requirements. The early and extensive programme had allowed ranges of mixture proportions and specific retarders to be included in the bidding documents, enabling contractors to bid on a reasonably certain basis.

CVC gravity dam construction

Japan's Shimizu Corporation, Japan, presented the concept of 'dam concrete automatic placing system', the main objectives of which was to improve productivity and reduce the needs for skilled personnel, by applying information technology. His presentation pointed out that concrete placement in gravity dams accounted for about 60 per cent of the construction cost, and about 50 per cent of the construction time. The new system integrated the automation technology that had previously been applied to the batching plant and transfer car with automation of the rail rope cable crane, Yamashita said. The system, which had been tested during the placement of concrete using the cable crane at the 77 m-high Yanagawa dam, had reduced the cycle time per placement by about 10 per cent and the number of workers for placement by 33 per cent, while still ensuring the same working efficiency.



Dr Malcolm Dunsian of the UK, who spoke of the benefits of the early implementation of trial mix programme at the Mwache RCC dam in Kenya

The use of a modular precast concrete system on the sidewalls for the downstream channel of the spillway of the Margatiga dam in Indonesia aimed to speed up the construction schedule time, according to Stella Monica, Site Engineering Officer for the developer PT Waskita Karya, Indonesia. Its benefits, compared with conventional methods, were: the ease of installation, as it did not require formwork and scaffolding during implementation; a smaller labour requirement; simplified quality control; and, improvement in product quality. The system, however, required precise planning, she continued, as its level of flexibility was low compared with the conventional system. The transportation and installation of the precast concrete modules, given their dimensions and weight, could be a limiting factor in their wider use, Monica concluded.

Hybrid dams

The concept of hybrid RCC rockfill dams was tackled in a presentation by Luc Deroo, President of ISL Ingenierie, France, who spoke in favour of the advantages of RCC-R and R-RCC hybrid dams over CFRD and RCC dam types in terms of economy, safety and environmental footprint. His report assessed the advisability of combining both dam typologies to build economical and safe composite dams, based on the return of the experience of similar structures, on the calculations, and on a multi-criteria evaluation of the advantages and disadvantages.

Although the study had examined structures of only a few tens of metres high, he said that there was no apparent reason why the concepts could not be applied to dams higher than 100 m; but he added it would be logical to have feedback first from experiences on earlier, more modest structures. Two RCC and rockfill hybridization options were presented. The first is called RCC-R, with the two parts of the dam body being erected simultaneously, with the RCC at the upstream side constituting the



Luc Deroo of France, who spoke in favour of the advantages of RCC-R and R-RCC hybrid dams over CFRD and RCC dam types in terms of economy, safety and environmental footprint

impervious element, and the downstream face of the RCC not formed. Zoning of the downstream backfill could be considered, to optimize costs and mechanical behaviour, particularly at the interface.

The whole range of RCCs was possible, from high cementitious to hardfill, Deroo said, with the geometry adapted accordingly. A geomembrane could be considered upstream to address the issues of cracking and seepage. The R-RCC option involved the two parts of the dam body being erected simultaneously, but with the RCC at the downstream side. Watertightness was provided by an upstream facing of the rockfill (typically in reinforced concrete, or by a geomembrane). Zoning of the backfill was necessary, Deroo explained, as with CFRDs, to provide support for the facing, and to ensure increasing permeability. The RCC was designed to be highly permeable, for example, by providing drainage galleries. In certain conditions, a spillway could be fitted.

innovations for extremely high concrete dams

The first speaker was Dr Malcolm Dunstan, of MD&A, UK, who underlined the value of time, in his talk on the speed of RCC construction. He began by noting that by the end of 2021, there were around 1000 RCC dams in operation, which were large according to ICOLD's definition (> 15 m). The average height was 66 m. He presented details of the distribution of RCC dams around the world, and referred to the database he had been keeping for 35 years (extracts from which were published annually in the World Atlas of Hydro -power & Dams).

Dunstan showed a table giving details of the 13 RCC dams which had achieved the highest rates of placement, noting that eight of these had placement rates of more than 100 000 m³ month.

However, he commented that fewer than 5 per cent of RCC dams were being constructed as rapidly as they should be, primarily because RCC dams today seemed to be moving away from the essential simplicity of the

early dams of this type. He said in the case of two similar RCC dams, one had had a placement rate four times faster than the other.

He then gave details of some of the large RCC dams that had been completed ahead of schedule, with high average placement rates, such as Longtan in China, and Upper Stillwater in the USA (completed in the mid-1980s as the first on such a scale, with some challenges such as a large temperature range on site throughout the year, meaning that placement could only take place during a five-month period). He also referred to Olivenhain in the USA, Beni Haroun in Algeria, and Nam Ngiep 1 in Laos, all of which had been completed ahead of initial schedules, despite a number of challenges.

To demonstrate the value of time, Dunstan reported that at the lower dam for the Ghatgar pumped-storage scheme in India, completion three years early as a result of the selection of RCC for the dam type had allowed for the generation of 1350 GWh of power during this period, the revenue from which was equivalent to half of the cost of the project (INR 5200 million or about US\$ 65.4 million). Similarly, at the Son La and Lai Chau RCC dams in Laos, some US\$ 600 million worth of extra power had been generated as a result of early completion of the dams.

In his conclusion, Dunstan stressed that the original concept of RCC dams was to provide a simple method of construction, with RCC spread horizontally from one abutment to the other. This would lead (and had led) to rapid construction. He felt it was unfortunate that some of this simplicity was being lost with some modern RCC dams, and so the majority of RCC dams were not being constructed as rapidly as they could be.

Alberto Scuero of Carpi Tech, Switzerland, gave a talk on the challenges and solutions of using geomembranes at very high concrete dams, taking as an example the 188 m-high Miel I RCC dam in Colombia. At this project, an exposed geomembrane system had been installed as an additional safety barrier on an RCC facing dam



A. Bezzi of Italy discussing the characteristics of the RCC mixes for the Grand Ethiopian Renaissance Dam in Ethiopia

enriched with vibrated cement grout. The project had set a milestone, Scuero said, in waterproofing of new RCC dams with exposed geomembranes.

To allow for the geomembrane works to be carried out completely independently from the other civil works, said Scuero, the waterproofing contractor had designed a railing system that could support the travelling platforms from which all activities were carried out, and could be assembled and dismantled at different elevations.

The use of GE-RCC had allowed good compaction of the mix to be achieved at the upstream face, assuring a good finishing of the upstream concrete surface. Construction of the dam had taken a total of 26 months, including the waterproofing system, and the scheme had been completed seven months ahead of schedule, and allowing for early power generation.

A. Bezzi, of Studio Pietrangeli, Italy, discussed the stress-strain characterization of the RCC mixes for the 175 m-high Grand Ethiopian Renaissance Dam in Ethiopia. He described the extensive tests that had been carried out to define the specific mixes for the various areas, which had led to the choice of five mixes, with guaranteed compressive strengths ranging from 8 to 15 MPa.

Design goals had been achieved, he reported, principally as a result of the following procedures:

- carrying out an intensive testing campaign for the RCC, including numerous boreholes, with about 500 core samples;
- performing an accurate thermal analysis, based on thermal parameters and model calibration verified on site by back-analysis on a prototype;
- carrying out an advanced dynamic analysis under seismic conditions, using FEM models (2 and 3D) to verify the tensile stresses derived from time history analysis; and,
- implementing an advanced early warning temperature monitoring procedure to prevent the risk of cracking in the dam body.

Y. Aosaka of Kansai Electric Power, Japan gave a talk on investigations and measures taken relating to cracking, which had occurred as a result of thermal stresses at the Nam Ngiep 1 RCC dam in Laos.

During construction, cracks in the direction of the dam axis had emerged on the surface of the RCC on the left bank side, where RCC placement had been suspended to install penstocks, which were to be embedded in the dam body. The NNP1 Power Company had conducted a crack investigation and thermal stress analysis, and it had been found that the main cause was the difference in concrete temperature between the inner and surface portions of the RCC resulting from a sudden drop in



Chen Guanfu of Power China, giving a presentation on the Jinping I arch dam, currently the highest in the world, at 305 m

ambient temperature in mid-December, which had been larger than what would occur in an average year. His talk covered the investigation, related root cause analyses, the dam stability check and effective measures taken to control cracks in RCC. He mentioned that water spray curing had been conducted, but the temperature variation had greatly affected the concrete cooling rate on the surface.

One of his conclusions was the suggestion that in such cases, the RCC placement surface could be covered with an insulation curing sheet and a layer of sand, in addition to the use of wet curing.

Regarding checks on the dam's stability, Aosaka said that both the analysed and monitored values for dam displacement and uplift had been in good agreement. Also, there had been almost no leakage from the drainage holes in the dam body, and no leakage from horizontal joints on downstream surface of the dam body had been confirmed. Based on these results, it could be concluded that the necessary requirements for the dam body have been achieved and the dam's stability had been secured. He added that the cracks may continue propagating to a certain depth, but it was assumed that they would stop at a point where the increase in the thermal stress and the concrete shrinkage caused by the effect of the ambient temperature would reach an equilibrium.

Chen Guanfu of Power China, and Deputy Secretary-General of CHINCOLD, gave one of two talks on the Jinping arch dam, which was the highest in the world, at 305 m.

He pointed out that the reservoir had reached its normal full supply level six times, since it had been completed in 2013. His presentation focused on the safety evaluation that had been conducted on the dam to predict the long-term deformations, which could occur at the left abutment slope, and the possible impacts on the safety of the dam. The work had also been aimed at studying overall stability analysis of arch dams and foundations, to provide references for the future.

He explained that the dam was located in a non-symmetrical deep V-shaped canyon, with a slope of 50-65° on the left bank, and 60-85° on the right bank. The foundations were extremely complex, he said. Many studies and extensive monitoring had been carried out during the design and construction of the scheme, and a number of special measures had been taken.

According to the characteristics of the slope deformation of the left bank, Chen said, the slope deformation could be expected to last for a certain period, which could be considered in three stages: the excavation and unloading deformation stage, the adjustment stage, while the effective stress adjustment and softening of the rock mass would take place after being immersed in water during the initial water storage stage, and the stage of long-term deformation convergence. He then described in detail the extensive research that had been carried out.

The safety analysis had shown that the left bank slope deformation could be expected to last until 2034, but the long-term deformation would have little effect on the arch dam, and the slope could be considered stable.

The overload analysis of long-term deformation had shown that the arch dam had strong overload capacity to slope deformation. Importantly, Chen said, deformation of the dam foundation was small, so the slope was stable, and the dam would be safe with long-term deformation of the slope.

However, the effect of long-term deformation of the slope was complex, he added, and would still require comprehensive studies, with a complex model, taking into account concrete creep, dam temperature rise, slope and foundation deformation and other factors.

Question 105: incidents and accidents concerning dams

Q10S General report

General reporter, Michel Poupart, of France, introduced the topic by noting that 51 papers were submitted for Question 105, which incorporated four themes:

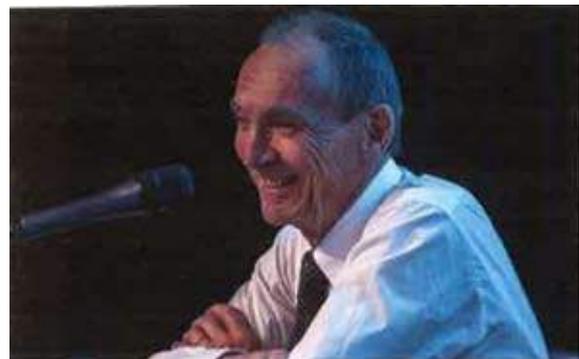
- Recent lessons learned from dam incidents and accidents.
- The evaluation of the flows and floods.
- The regulation and organisation of emergency plans.
- The governance of safety.

Summarizing the work of the first theme, Poupart highlighted some key lessons learnt to help avoid repeating past incidents, and improve the design or operation of current and future projects. An abridged selection of Poupart's overview presentation of the work is reported here.

He began by defining the terms 'failure incident' and 'accident incident', as used by ICOLD. "A failure is defined as an uncontrolled release of water from the impoundment or loss of integrity that no longer allows the dam to perform its function safely. An example is the San Fernando dam failure. Following a failure, it is sometimes possible to repair the dam, otherwise it is permanently abandoned", he said. Meanwhile: "An accident is an incident that has been prevented from developing into a failure by taking immediate corrective action to make the structure safe. An example of a corrective action is reservoir emptying or lowering".

Poupart went on to report that ICOLD had undertaken surveys of all its members to gather as much information as possible on dam incidents. These surveys had resulted in three publications in 1974, 1983, and 1995 (updated in 2019 to incorporate failures and incidents that have occurred since 1991 through 2019). In addition to these publications devoted exclusively to dam incidents, several Bulletins had mentioned dam incidents for specific loading conditions or degradation processes. These three ICOLD publications and various supporting studies had successively evaluated failure statistics by looking for the influence of dam type and year of construction, among other things, he said. While Poupart noted "the significant differences in the accuracy and reliability of the failure reports among ICOLD countries, making it necessary to discard some data so as not to distort the results of the statistical analysis", a number of findings could be presented.

First, he said, the ratio of the number of failures divided by the total number of existing large dams was continuously decreasing, from 1.42 per cent during the years 1900 to 1925 to 0.12 per cent since 2000. However, the ratio of failed dams built during a certain period provided a less positive view. This ratio was 0.29 per cent for the years 1975 to 1999 and is 0.38 per cent since 2000. "This could illustrate a slight increase in the failure rate over the last 20 years, or another explanation could be a better detection and reporting of dam failures since 2000 facilitated by, for



Michel Poupart, General Reporter for Question 105 on incidents and accidents, noted in his opening remarks how the number of failures at dams has continued to decrease since the early twentieth century



Dean Durkee, of Gunnell Fleming, USA, presented a review of recent dam failures in his country and how risk is managed to help avoid them..



Laurent Mouvet of Hydro Operation International, Switzerland, who chaired Q105.

example, improved information technology", Poupart said. Since the year 2000, Poupart pointed out, 70 per cent of failures had occurred during a flood. In comparison, earthquakes had caused only a very low number of failures. This indicated that while design deficiencies were the most important cause of dam failures prior to 1950, more recently operation or maintenance had become the most important causes. Recent dam failures since 2000, such as Taum Sauk, Delhi, Ivanovo or Oaky, supported this observation, he added.

Summarizing the analyses presented under Theme A, Poupart noted the main lessons to be learned from the incidents that had occurred during the last 25 years included: the observation that incidents were increasingly occurring in a flood context, and, as a result, their causes needed to be sought in operational or maintenance deficiencies. "In these contexts, the root causes linked to human factors are very present", he said.

Lessons from accidents and incidents

Introduced by the Session Chair, Laurent Mouvet of Hydro Operation International, Switzerland, the first presentation in this session was given by Moussa Kabore of BUCOLD, Burkina Faso, on behalf of Adama Nombre (Hon. President of ICOLD). Kabore reported that his country had about 1000 dams, of which about 30 were large dams, as defined by ICOLD. Most dams were small earthfill structures, he said, located in very rural areas, providing mostly for potable water, while 20 per cent are for hydro generation. "Each year there are some failures or incidents, mainly at small dams", he continued. "During bad years, there can be as many as ten failures, often linked to rainfall. The recent Bempela dam breach is an example of this", he said, adding "although there was no loss of life, farm land was destroyed causing losses to income". The damage and the repair cost of the dam structure was likely to exceed US\$ 2 million, he noted. Kabore identified "a very weak regulation system, as well as lack of local capacity and expertise", as important factors limiting dam safety in Burkina Faso.

Dean Durkee, of Gannett Fleming, USA, presented a review of recent dam failures in the USA, and also spoke about some of the anticipated impacts of risk-informed decision making there. "Hydropower owners in the USA have invested considerable resources in performing potential failure mode analyses (PFMA) for their dams, to meet Federal Energy Regulatory Commission (FERC) requirements as an element of dam safety assessments", he said. While PFMA provided a much improved understanding of the safety of a dam, they stopped short of providing a portrayal of the dam safety risk, he felt. "The PFMA process does not typically provide adequate differentiation of the likelihood or consequences of failure to allow for distinction or prioritization of individual potential failure modes for dam safety actions or decisions. As a result, FERC has released 'Draft Risk-Informed Decision-Making Guidelines' for use by licensees to supplement their dam safety programmes", Durkee reported. He used the incidents at Taum Sauk and Oroville dams as reference cases, to discuss how and whether a risk-informed approach earlier in the project life would have affected the outcome. In both these cases, he concluded: "If performed properly, with appropriate dam professionals, for the given structure, a risk analysis approach should reduce the likelihood and consequences of failure". However, he continued: "In both cases, human factors were as important as physical factors in the years leading up to the failures. Organizational, regulatory, and industry factors had contributed to the failures, and these influences are not always flushed out during a PFMA or risk analysis workshop", he said.

A delegate asked: "If the probable failure modes had been known prior to the Oroville accident, would action have been taken?". A lively discussion followed with the opinion expressed being, probably not, considering the risk and cost. Adding to this discussion, Hon President Prof Anton Schleiss of Switzerland commented: "Using the contemporary state-of-the-art is a good starting point to understand potential failure modes, even for older schemes".



Ahmed Chraibi of Morocco describing how the foundations of the saddle dam at the Xe-Pian Xe-Nam Noy scheme in Laos contributed to the failure of the structure



Remy Tourment, of INRAE, France, spoke about floods in his country and reported lessons learnt to help address future events

Remy Tourment of INRAE, France, reported on flood and inundation events during the past three decades, along three sections of rivers in France: the middle course of the Loire, the downstream reach of the Rhone and the Agly river. He said the most important lessons learned had been to include good governance, and to recognize the need to manage overflows using resilient systems. "Design engineering, diagnosis, and risk analysis all benefit from this knowledge", he said. Historical knowledge of structures and the recent events that they have encountered is very valuable and should continue to be utilised both locally and nationally, he felt. "A certain 'standardization' in the way of presenting and analysing events is desirable for their use and shared utility", he added, "but we have, unfortunately, often observed in the past relaxed attention to these issues after a long period without floods", Tourment concluded.

Ahmed F. Chraibi, Consultant, Morocco described lessons learnt from the 2018 saddle dam failure at the Xe-Pian Xe-Nam Noy scheme in Laos. The failure of Saddle dam D had occurred during the first filling of the reservoir, he said. The independent expert panel mobilized by the government of Laos, had found that the root cause of the failure had been related to the high permeability of the foundation, combined with the presence of erodible horizons in connection with the existence of canaliculus interconnected paths. "The foundation was without doubt involved in the failure, which could have been prevented by adequate treatment measures", he said (see also H&D Issue 1, 2019).

Chraibi presented 12 specific recommendations in a way that he hoped would help avoid similar failure incidents in the future. The recommendations, he reported, based on the work of the independent expert panel and further investigations, included:

- Large hydropower and dam projects should be accompanied by an independent panel of experts,

- which ensures the required high safety standards according to international best practice from early design stages to the construction project.
- The first filling of the reservoir is among the most critical phases. Experienced dam monitoring specialists should be permanently on site, to help detect and make a correct interpretation of any anomaly of dam behaviour and to take timely action in order to avoid catastrophic incidents.

Fjola Guorun Sigtryggisdottir of NTNU, Norway, presented a case study of a cofferdam failure at a temporary structure in Bergen, Norway. The example she gave demonstrated that a cofferdam, originally identified to be only of risk for the construction site, could quickly become a threat for a larger area further downstream. "This can occur", she said, "when an existing dam is partly weakened or removed, leaving the cofferdam as the last barrier between the reservoir and the downstream area". Sigtryggisdottir reported that the risk associated with the cofferdam in Bergen had been misjudged and "it was only a few days before the failure that it was recognized that the cofferdam was a dam with potential consequences". In



Fjola Gudrun Sigtryggisdottir of NTNU, Norway, who emphasized the importance of emergency preparedness plans for dam safety.



Richard Donnelly of Hatch, Canada, described emergency works on the cutoff wall at the Ituango scheme in Colombia.

total, 133 people had been evacuated, and a major road had been closed before the cofferdam failure released a flood which damaged a marina, cars, and hiking trails. She outlined a number of lessons learnt from the incident, which included the need for appropriate planning by a qualified dam engineer for dewatering and water diversion during construction and before the construction starts.

In addition, Sigtryggdottir said, "Risk assessments must be updated with new information for emergency pre-paredness plans". Evacuation, according to the emergency preparedness plans, updated on the day of the cofferdam failure in Bergen, had been successful and demonstrated the importance of such planning, she added.

Richard Donnelly of Hatch, Canada, discussed a safety assessment of the Ituango cutoff wall, in Colombia. During construction of the 235 m-high rockfill dam, a landslide had blocked the diversion tunnel, resulting in an uncontrolled rise in the reservoir level, while the dam and spillway were still under construction. Attempts to unseal the diversion tunnels had ultimately been unsuccessful, leading to the very real possibility that the dam could be overtopped. To address this risk, Donnelly said, the heightening scheme had been developed to ensure the dam crest remained above the rising reservoir level. The scheme had involved construction of a 35 m-high cement ben-tonite cutoff in the upper portion of the dam and the diversion of water through the partially completed powerhouse complex, he said. "The solution proved effective with the dam and spillway being completed without incident, although extensive damage to the powerhouse complex occurred, which is still being addressed", Donnelly said. Following these emergency works, a detailed deformation assessment had been commissioned for the cement-bentonite cutoff wall under conditions of future settlement, using the finite element method within both a two-dimensional and three-dimensional framework. Overall, the results



Juan Mata of LNEC reported a number of significant developments relating to emergency planning in Portugal

of the analyses had indicated that the Ituango dam was safe. "The wall is currently functioning as intended, and would only be expected to exhibit any material cracking under the effects of a safety evaluation earthquake. This damage would not be expected to lead to sudden failure of the dam allowing repairs to be performed", Donnelly concluded.

Louis C. Hattingh of Hattingh Anderson Associates in South Africa, presented lessons learned from incidents and failures of small earthfill dams in South Africa. For small dams, the failure mechanisms causing incidents and failures were not always investigated in detail because of a lack of funding and limited time availability for repairs. "Many structures are located in financially poor areas", he commented. Hattingh said this could result in a loss of opportunity for lessons to be learnt. To help address this knowledge gap, he said the study had involved nine case histories of incidents or failures that had happened at small earthfill dams, focusing not only on internal erosion and overtopping potential failure modes, but also spillway erosion and slope failure. With respect to internal erosion and slope failure, the most important lessons, he noted, included appropriate clay core and core trench compaction, and proper core cutoff trench excavation down to the foundation material. With respect to spillways, Hattingh said a key lesson learnt had been to line the vulnerable part or the complete spillway of a small dam to prevent undercutting or erosion of rock.

Matteo Scolari of Rina Consulting, Italy, described the case of a retrofitting project at the Badana dam in Italy, after structural damage there. The dam, built in 1914, is a masonry gravity dam with a maximum height of 56.25 m and crest length of 216 m, he said, In 2006, the structure had been subjected to heavy damage, resulting in three leaks on the downstream side, two on the left bank and one on the right bank. This had required the adoption of urgent safety measures, including the rapid drawdown of the reservoir. To restore operation of the



Felipe Lazaro of the World Bank, USA, presented key messages related to emergency preparedness plans taken from a recent publication by his organisation titled; 'Good Practice note on Dam Safety'



Kimberly Lyon and Satoru Ueda, both of the World Bank, USA, noted that safety regulations and good governance require regular updating

reservoir fully, Scolari reported that retrofitting works had been undertaken, which included the demolition of the damaged part of the existing dam and the reshaping of it with new cast concrete. "The project was informed by finite element modelling, which considered both thermal and structural properties to help evaluate the interaction between the existing masonry dam and the new cast concrete during the entire curing phase", he said. The detailed design of the proposed intervention had finally been approved by the Dams General Direction (Italian Ministry of Infrastructures) in 2017. Compared with demolition and rebuilding of the entire dam, the proposed design "allows a reduction in the construction time, environmental impact, and cost, as a result of the lower amount of material needed to fully restore the reservoir", he concluded.

Juan Mata of LNEC in Portugal described emergency planning procedures in his country. "Since 2007, increased attention has been given by different dam safety stakeholders to the preparation, update and implementation of emergency action plans (EAPs), supported by a revised version of the 'Portuguese Regulation for Safety of Dams'", Mata said. There had been a number of significant developments relating to emergency planning in Portugal in recent years, namely with the publication of specific guidelines and complementary documentation seeking to organize and clarify applicable rules and procedures, he reported. Mata summarized some of these developments and an ongoing pilot project regarding an emergency planning interface with flood warning. On the eve of the exercise, the Autoridade Nacional de Emergência e Protecção Civil (ANEPC) had disseminated several simulations on meteorological reports and the occurrence of earthquakes that framed the exercise. One of the lessons learnt, Mata said, was that information transmitted to the population regarding the exercise in the downstream valley would not

have been sufficient to inform them of the circumstances adequately". To help improve communications, he recommended that "the exchange of information between the participants of the exercise highlighted the interest in having the EAP documentation in files with formats enabling them to be moved electronically and therefore faster".

Jonathan Fauriel, of Alpiq in Switzerland, reported how the regulatory framework for emergency planning in Switzerland had been evolving, and some of the key lessons learned from this process. Cleuson dam had been chosen as a pilot case to establish emergency regulations and carry out an emergency exercise, he said, to test whether the regulations were sufficient in the event of a safety-related event. By involving operating staff, experts and the owner, the internal and external communication channels had been tested, as well as the emergency strategies, Fauriel said. He noted that such exercises were essential to detect and adapt weak points in the system. The exposure of stakeholders into a realistic exercise scenario helped to identify the effectiveness of the emergency plan and allowed for ongoing adaptation. This was the only way to guarantee a good preparation in case of a development of the event, he concluded.

Felipe Lazaro of the World Bank, USA, spoke about an emergency preparedness plan (EPP) framework as published recently by the Bank in Appendix 4 of its 'Good Practice note on Dam Safety' document. "This sample framework outlines the key elements of the EPP, such as roles and responsibilities of relevant entities, emergency response matrix, EPP response process, preparedness activities, dam break inundation mapping, and consequence assessment". The framework indicates that when an unusual or emergency incident is detected at a dam, the dam owner or operator should generally follow four steps:

- emergency identification, evaluation, and classification procedures;
- notification procedure;
- preventive and emergency actions; and,
- emergency termination and documentation.

"In emergency situations, dam owners or operators have no time to read a report, even if they have been sufficiently trained in emergency handling", he said. Thus, Lazaro added: "The EPP should include the emergency response matrix (ERM). The existence of such a tool empowers operators to undertake required actions in an expeditious manner. The ERM represents a correlation between different emergency situations, with corresponding emergency/response levels".

Giving an example from Africa, and the case of a control room that had been flooded as a result of a valve failure, an audience member commented that emergency preparation plans should include plans for staff as well as the public downstream. A number of speakers agreed with this comment, and Lazaro added that the World Bank document included direct reference to this point.

Satoru Ueda and Kimberly Lyon, of the World Bank, USA, jointly presented a global review of safety regulations and consequences of governance on safety. Their talk was based on a recently published World Bank report, entitled 'Laying the foundations: a global analysis of regulator frameworks for the safety of dams and downstream communities'.

Lyon described this report as "setting out the foundations for dam safety assurance by providing a comparative analysis of regulatory frameworks and assessing the range of legal, institutional, technical, and financial options that can be used by countries to inform the development of appropriate frameworks for sustainable assurance". Ueda noted that the study provided a comprehensive set of country case studies with representation among a diverse set of countries with varying economic, political, and cultural circumstances. He said: "It recommends a set of legal, institutional, technical, and financial elements suitable for different country circumstances supported by a menu of options for consideration by policy makers". Furthermore, Ueda added, "It is important to establish a continuous process of improvement that can ensure that institutional arrangements adapt to the changing nature of the portfolio and downstream demographics".

Lee Mauney of HDR Engineering, USA, described the work of the Dam Failures and Incidents Committee (DFIC) of the Association of State Dam Safety Officials, to help investigate and disseminate lessons learned from dam failures and incidents in the USA. Since its formation in 2010, the DFIC had produced a voluminous body of work with the aim of contributing to improved dam safety on a



Georges- Darbre, of the Swiss Agency for Development and Cooperation, and Botialhep Malaykham, of the Lao Ministry of Energy and Mines jointly presenting ongoing work in Lao PDR to develop robust dam safety practices there.

global scale, he said. Since its foundation, ASDSO had begun to gather dam safety incident information (both failures and non-failures) from the state dam safety programmes, he said. The majority of the incident records had been collected from state programmes following the year in which they had occurred, Mauney said. The database was not considered comprehensive of all dam safety incidents, either historic or current, and reflects only the data that ASDSO has been able to collect, he noted. Data on the information fields collected could be found on the ASDSO website, he added. The database currently contains 1074 total incident records, 390 failures and 684 non-failures.

"The dam safety industry has made considerable and measurable progress, in large part by learning from past failures and incidents", he said. The great majority of dams do not fail, but the relatively rare outliers are the ones which get publicity. "To speak of engineering failures is indirectly to celebrate the overwhelming numbers of successes.", Mauney added.

Georges Darbre, of the Swiss Agency for Development and Cooperation, and Bouathep Malaykham, of the Lao PDR Ministry of Energy and Mines, jointly presented an extensive review of the dam safety institutional framework prevailing in Laos. Darbre described how this review had been used to compare domestic efforts with international practice. He reported that topics covered by the study included institutional organization and enforcement, legislation and regulations, as well as capacity building and development. Based on the findings, Darbre said recommendations had been made on ways to strengthen the dam safety institutional framework. "A key element of this is the separation of dam safety supervision from hydropower generation supervision, with the associated adaptation of the organizational and legal frameworks, as

well as development of education and training". Other recommendations were reported by Darbre including, enacting a law on dam safety and introducing an educational module in dam safety. The Ministry of Energy and Mines (MEM) is currently analysing the strengthening measures proposed and an MEM internal Taskforce has been appointed to that effect. "An obvious challenge lies in the balance between resources needed and available", Malaykham concluded.

A delegate remarked that Laos is a member of the Mekong River Commission and asked how dam safety was managed with consideration to other downstream countries. Darbre replied that before construction had begun, the Government had worked with the MRC regarding dam safety considerations before applying domestic standards and obtaining further MEM review.

In his concluding session comments, General Reporter Michel Poupart asked what lessons could be learnt from accidents. He felt that in many cases, when there were anomalies, following the correct procedures and practices would lead to a good outcome. These cases should be analysed just as much as the failure cases, as it would be possible to learn equally from both types of experience".

Question 106: Surveillance, instrumentation, monitoring and data acquisition and processing

This Technical Question was chaired by Pierre Choquet of France, who remarked that it was very timely for ICOLD to be focussing on the topic, as three paradigms had become more prevalent in society today:

- the ageing of original instrumentation systems, which might no longer be functioning, and could be embedded in the structure;
- dam failures, which were naturally not socially acceptable, and there had been some in recent years, including serious tailings dam failures (mining companies were, however, now adhering to new standards, which included the installation of instruments at all new structures); and,
- the complimentary nature of safety to environmental concerns, and the need for society to have full transparency.

He stressed the need to "keep track of data", describing dam engineers as the physicians of dams, needing historical data to refer to. Inspections of dams should be formal and periodic, he said, adding that surveying of data would mean nothing if not followed by thorough potential failure mode analysis. It was essential, Choquet said, to manage risk by the early detection of issues. Multipurpose schemes could create additional needs for surveillance, Choquet continued, for example monitoring of water quality.

Choquet underlined the importance of checking the long-term performance of existing monitoring systems, as more and more dams were at least 30-50 years old. Throughout the life of a dam, information should be reviewed, so as to identify any vulnerabilities. He added that visual inspections represented the most important tool and activity, and that regular inspections should be well documented.

Q106 General report

General Reporter for Question 106, Manuel G. Membrillera Ortuno, began the presentation of his report by recalling that dam surveillance was the main foundation on which dam safety was built, requiring a series of well directed and organized activities. He outlined some of the frameworks for action, which had been set out in a number of ICOLD Bulletins over the year.

On the subject of dam surveillance, he pointed out that instrumentation should be regarded in perspective, because it was just one pillar within the broader dam surveillance framework. Motivated people trained in the maintenance, observation, processing, and interpretation of data remained "the backbone of dam surveillance, where the human eye continues to be the best of all instruments".

Membrillera stressed the importance of explicitly including the inspection and potential instrumentation of appurtenant facilities in the surveillance plans, because of the impact they could have on the dam-reservoir safety and operational failures.

He pointed out that the following appurtenant structures should always be included in dam surveillance and monitoring plans, where appropriate:

- Access roads to key facilities, because many operational failures can be greatly impacted by the possibility of having access to key facilities. This would include bridges, drainage systems, slope stability, and any other element that makes up access roads.
- Hydromechanical equipment, which always serves other facilities, such as spillways, outlet works or intakes.
- Power supply and telecommunications, which are crucial to the safety of most dams.
- Spillways, which should be regularly inspected and maintained to ensure they are capable of discharging the inflow design flow safely. This should include gates, if they are part of the spillway, inlet structures, chutes, or tunnels, as well as the energy dissipation elements to check for the development of scour.
- Outlet works, usually located near the foundation, as they are essential facilities for safe dam operation. Functioning of these outlets depends primarily, but



Manuel Membrillera of Spain, presenting his General Report for Q106. He stressed the importance of explicitly including the inspection and potential instrumentation of appurtenant facilities in the surveillance plans

not only, on the performance of their moving parts. It is vital for dam safety that these facilities can be operated in all circumstances, whenever required.

- Intakes, which convey flow directly to a conveyance structure. They can be integrated into, or located next to concrete dams, or in towers at embankment dams, or simply somewhere within the reservoir rim.
- Conveyance structures, which can also be critical to dam safety. They can be closed conduits, such as penstocks, or chutes, canals and tunnels.
- Reservoir rims should always be considered in the surveillance plans because of the potential for landslides, which could initiate a failure sequence involving overtopping, or blockage of key hydraulic structures.
- Downstream conditions, in terms of existing infrastructure and population at risk, can also represent an important component of risk.

Incorporation of the surveillance of appurtenant structures, in terms of tailored inspection and instrumentation procedures, could be one of the most important challenges in the realm of dam surveillance, Membrillera said.

Regarding the long-term performance of surveillance systems, Membrillera said that the scope of a surveillance programme should be tailored depending on the type, uses and size of the dam, the hazard classification, the age and condition of the dam, the key parameters to be measured, regulations, and appropriate funding for lifecycle costs. Indeed, a successful surveillance programme should incorporate both initial capital costs and annual budgets for O&M, and training, he added.

A surveillance and monitoring plan should be treated as a living and flexible document, he continued, which should be adapted over time to the dam conditions.

Membrillera commented that manually read instruments were simpler and less expensive than automated ones, but if a project needed many instruments or if conditions were expected to change rapidly, then electronic instruments connected to automated data acquisition systems (ADAS) would allow for the collection of much more data than would be practical to collect manually, or with portable read-out units. In general, monitoring instruments are made up of three components, he said: a sensor or transducer that measures a physical variable, a data acquisition system, and a link between them.

In addition, the instruments should be chosen according to the measuring range expected, he said, and it was essential to make sure the instruments were installed correctly to ensure a high reliability of the readings, which was a condition for adequate interpretation of the results.

Turning to innovation in monitoring and surveillance systems, Membrillera observed that, along with the traditional and proven manual instrumentation and inspections, the dam industry had gradually incorporated new technologies involving sensors, electronics, computers, communications, and information technology. The development of these techniques and technologies had been extremely rapid, he said, and he added that the role of the operational staff and the dam engineer should never be downplayed.

Long-term performance of surveillance systems:
Reliability and accuracy

Rosella Caruana, of Enel Greenpower, Italy, referred to studies, controls and visual inspections carried out at about 40 Italian dams that had been affected by a series of severe earthquakes, which had occurred in the centre of the country in 2016 and 2017. Three had been close to the epicentres of the events.

Caruana explained that the Italian authority responsible for the supervision of dams was the General Management Office for Dams, Hydraulic and Electrical Infrastructure, which was within the Ministry of Infrastructure and Transport. This directorate identified the dams to be checked following the earthquakes, based on an online database tool, which also provided the characteristics of the dams and the owners/operators responsible for their safety. A national protocol, developed in 2022, was in place to activate the necessary checks to be conducted; the events in 2016/17 provided an opportunity to test it.

In fact, after 2017, some updates had been made to the system, Caruana said.

She reported on the analysis of readings from accelerometers and from visual inspections.

No major issues had been reported that could have compromised the safety of the dams, but a seismic

re-assessment of appurtenant works had been undertaken.

Ludovica Ruggeri, also of Enel Greenpower, continued on the subject of the analysis of the large Italian dams affected by the earthquakes of 2016-17, and she elaborated on the revised protocol developed in 2017, and launched in 2018. She said that, after 15 years, it had been realised that the criterion defining the screening area was rather conservative, meaning that there had been a need to carry out the same types of inspections and controls for dams in the epicentral areas, as well as for those much farther away. She explained that the new procedure allowed for a narrower screening area in the case of low-to-medium magnitude earthquakes. Post-earthquake inspections, she said, were now divided into Level 1 and Level 2, activated when the shaking at the site reached 0.04 g and 0.07 g, respectively.

Mathieu Desjardins, a Senior Geotechnical Engineer at De Beers, Canada, reported on some lessons learned from long-term surveillance at two tailings storage structures at the company's mining operations in the arctic region of northern Canada, which were being prepared for long-term closure. The monitoring systems used, he said, were based on Canadian Dam Association guidelines. He discussed the importance of high quality monitoring and surveillance and also the particular challenges of surveillance in this region with such extreme weather conditions.

The instrumentation systems at both structures had been upgraded in 2017 and 2018, Desjardins said, and it had been learnt that cabling systems could be damaged by lightning strikes, particularly if they were not aligned in accordance with the tailings dam closure plan; it was therefore preferable to use wireless systems.

Satellite-based monitoring systems also had shortcomings in these conditions. The use of an InSAR system had had limited value, in view of the short summer period during which data could be collected. Also, erosion channels were just at the limit of being able to be detected.

Remote cameras had been installed for use during winter, but there had been a build-up of hoar frost on the lenses. The site team had then worked with the camera suppliers to re-design the system to limit frosting, with a heating system to pre-warm the camera lens before the image is taken.

Desjardins offered recommendations for others working in arctic conditions, but noted that there was no "silver bullet" solution that would be suitable for all sites, as each would have unique challenges.

C. Richard Donnelly, of Hatch, Canada, gave a talk on the rehabilitation and long-term monitoring of the Waba dam in Canada, an 18 m-high structure built on very compressible foundations; this had been presented also at the on-line HYDRO 2020 conference, and an article based on the paper appears on pp40-47. The operating life of the structure has been extended by around 50 years following the scheme, which was completed in 2020. Donnelly described the instrumentation system, much of which was automatic, he said, but with manual backup.

Joaquim Pimenta de Avila, a Geotechnical Engineering Consultant from Brazil (and elected ICOLD Vice President for the Americas during the General Assembly on 31 May), gave a talk on the planning of risk-based monitoring. The importance of such a plan, he said, was to obtain information to feed an analysis of the performance of a dam, which in turn could be applied to a risk management system.



Ludovica Ruggeri gave a talk on the effect on Italian dams of the earthquakes in 2016 and 2017



Joaquim Pimenta de Avila, discussing risk-based monitoring. He stressed the importance of deciding on exactly what and where to monitor and which instruments to use

It was critical, he said, to define what should be monitored, where to monitor, and which instruments should be used; without answers to these questions, instruments could be spread out across a dam, and be wasted in terms of the information they would provide.

A risk management plan, Pimenta de Avila continued, required continuous knowledge of the behaviour of the dam, at a level of detail that could permit the simulation of different conditions, and to evaluate the probability of failure.

He concluded by stressing the importance of conducting a risk analysis ahead of planning the monitoring system; consideration of failure modes would constitute a more rational approach for monitoring and managing specific risks, and for prioritizing which instruments to install.

Pauline Boffety, of EDF, France, spoke about the importance of in-situ measurements, as an asset for assessing how representative numerical modelling could be. She commented that the understanding of concrete swelling in dams, and also behaviour during seismic loading was improving, thanks to developments in numerical modelling. But she added that to validate the models, it was very important to compare results with in-situ measurements.

To demonstrate this, she referred to some studies relating to EDF dams. Ambient vibration recordings, she said, were used to adjust the dynamic stiffnesses of a dam on the numerical model. She described results for two dams. The error between the first frequency measured and the one estimated on the model was important, she said. For one dam, the error would have led to underestimation of the dynamic amplification of dam displacements.

Stresses estimated by numerical modelling were linked to the deformation modulus of concrete considered, Bofferty noted. The validation of a numerical model only on displacements of a dam from monitoring could lead to an important over-estimation of the stresses. In-situ stress measurements made it possible to assess the actual stress state of the dam and validate the numerical model. EDF experience, Bofferty said, was that, as a simple numerical model could be representative of a dam's behaviour with a slow swelling rate, it was not applicable to dams with a high swelling rate.

Sam Johansson, of HydroResearch AB, Sweden, gave a presentation on the use of distributed acoustic sensing to detect changes in embankment dams related to seepage and internal erosion. He said that, in Sweden, about 100 dams were already equipped with optical fibres for seepage detection (based on distributed temperature sensing, DTS) or movement (based on distributed strain sensing, DSS). With complementary measurements using distributed acoustic sensing (DAS), Johansson said it may be possible to detect anomalous seepage flow in

dams without a drainage system, to detect this flow at some distance from the cable, and furthermore, provide information on the dam integrity. The potential capabilities of the technology had been tested in two research projects at embankment dams in Sweden, he said.

A passive seismic technique, known as ambient noise interferometry (ANI), is applied to DAS data to image the dams, and obtain absolute seismic velocities in the dam and foundations, Johansson explained, providing a snapshot of the structure. An extension of the method to dam monitoring could give relative temporal changes of the seismic velocities in the dam with respect to a pre-defined baseline. Temporal changes in seismic velocities could be a result of material changes in the dam, for example, caused by new seepage locations or ongoing internal erosion.

He told delegates that this feasibility study, combining DAS technology and ANI techniques, showed significant potential for the method to image and monitor dams, but further measurements were required to understand the advantages and limitations of the techniques fully.

Maraco Bersano, of HydroData, Italy, presented new approaches to risk assessment for the stability of rock slopes facing large reservoirs. He explained that the risk of rock slope instability and collapse was a serious phenomenon, especially as failure of the slopes would be sudden and rapid, and capable of mobilizing large masses. This could lead to abnormal wave formations in the reservoir, in addition to the structural damage.

The method he proposed was based on 3D point cloud analysis, and he described it taking the case study of application at the La Penna dam in Tuscany, Italy.

Among the advantages of the method, he said, was being able to focus on the analysis of specific spots, rather than a general area; it could calculate the size and volume of unstable blocks; making it possible to store and archive high resolution images as well as structural data, to detect



Pauline Bofferty, who stressed the importance of comparing in-situ measurements with numerical modelling

changes by using specific software; and, identifying zones where TinSAR (ground interferometric radar) monitoring could be focused subsequently.

Stefan Hoppe, of Ofiteco, Spain, discussed digital technology to manage dam safety records. He stressed that complete dam documentation was vital, in ensuring reliable safety evaluation and risk assessment studies could be undertaken. He felt that the use of modern tools such as digitization, asset management systems, BIM, virtual and augmented reality based on 3D models should be encouraged. This was vital, he said, in the case of dams, so that "living memory could be transformed to an efficient institutional memory", to transfer knowledge to future generations.

Guillaume Terrasse, of CNR, Paul-Henri Faure, of EDF and Vuillermet BRL Ingenierie gave a joint presentation on the automatic detection of surface deformations on an embankment dam. They described fast surface inspection technologies for hydraulic structures, using high resolution 3D scanning methods, mounted on autonomous underwater vehicles (UAVs). They explained that such technology allowed for more precise monitoring of the structure than classical point measurements. They presented two methodologies for 3D digitization, from UAVs using LiDAR, and photo-grammetric measurements (in one case a hybrid system using the two). As well as advantages, they drew attention to certain limitations, pointing out that while technological improvements in sensors and algorithms made it possible to track structures more easily and accurately, UAV acquisitions were subject to adverse weather conditions and flight authorization regulations, which could limit their use.

Russell Gunn, of the Swiss Federal Office of Energy, spoke of a new concept for swelling evaluations based on surveillance and monitoring data. He said that concrete core samples were often extracted from dams with the primary objective of identifying whether the structure was undergoing a phenomenon of concrete swelling as a result of alkali-aggregate/silicate reaction AAR/ASR, without necessarily any major concern about the numerical methods and constitutive models, which could be used to analyse and predict the effects of ASR on dam safety, and on possible rehabilitation works. The new approach he presented involved first assessing how, where and when core samples would be extracted from concrete dams based on in-situ humidity, thermal, stress and other conditions; and second, how to combine field observations derived from surveillance and monitoring data with laboratory test results.

He concluded that this could provide dam owners and operators with the information and tools necessary to investigate AAR-affected dams, in particular core sampling methods.



Russell Gunn spoke of a new approach to evaluating concrete swelling in dams

The work aimed to encourage early stage and continuous AAR investigations throughout the life of a structure, to improve safety evaluations and allow for appropriate time-based rehabilitation works if necessary.

Andri Puji Wahyudi of the Ministry of Public Works, Indonesia, described studies to assess seepage at the Jatiluhur dam in his country, comparing data from instrumentation with results of applying the FEM software SEEP/W. This is a powerful finite element software product for modelling groundwater flow in porous media. It can model simple saturated steady-state problems or more complex saturated/unsaturated transient analyses with atmospheric coupling at the ground surface.

The Jatiluhur dam has 829 instruments installed, but only 459 of them work. The paper presented a short-and long-term analysis of the piezometer and V notch instruments. Both analyses that use the SEEP/W application were then compared with the analysis of the instrument and V notch readings. The results of the short-term analysis had shown that the pore pressure reading on one of the piezometers did not correspond to the load obtained from the reservoir water level fluctuation, where the reservoir water level was high but the pore pressure was low. Meanwhile, SEEP/W had shown that as the reservoir water level increased, there was an increase in pore pressure. Long-term analysis showed that the maximum seepage discharge from the analysis, using SEEP/W, was still below the seepage that had occurred in the period 2004 to 2005. Observations from the piezometer showed that pore-water pressure did not fluctuate with a rise in the reservoir level, because the phreatic line in the core had not decreased.

Selim Sayah, of Lombardi Engineering, Switzerland, gave a talk, on behalf of his colleague Francesco Amberg, on advanced deterministic models to assess dam displacements, based on examples at three large dams in his country: Contra, Zeuzier and Emosson. He pointed

out that regular assessments of whether dam behaviour was normal might require the support of interpretative models, in particular in regions with significant seasonal variations, which would be a multidimensional problem.

He presented an approach on how to establish accurate deterministic models to analyse displacements, focusing especially on the pre-treatment of the demanding thermal part, and on the calibration procedure, based on the actual dam' behaviour.

In his conclusions he remarked that for dam monitoring, the use of deterministic models for the assessment of concrete dam displacements should be promoted and supported more than is generally the case today. He stressed the importance of developing comprehensive knowledge of the behaviour of large dams for future generations of engineers. He added that while statistical models were widely used and were simpler to develop, they provided only a limited contribution to the actual understanding of the static behaviour of concrete dams.

Juan Mata, of LNEC, Portugal, discussed Portuguese experience in the surveillance of large concrete dams, using automated monitoring systems and machine learning techniques. He said that the Concrete Dams Department at LNEC had been involved in the safety control of large dams, which today represented more significant risks since their design and construction stage. LNEC was involved in developing a management information system and some related methodologies aimed at improving the structural safety control in real time, using automated data acquisition systems. He summarized the aims as:

- evaluating the quality of instrument readings, taking into account the redundancy of measurement systems and using adequate identification tools for outliers;

- the analysis and interpretation of the structural behaviour using machine learning techniques, such as, among others, neural networks and short time Fourier transform.
- supporting decisions resulting from the structural safety assessment, for example, the emission of early warning messages caused by real-time classification of measurements based on thresholds previously defined. and the early detection of patterns related to dam failure scenarios.

Among his conclusions were that machine learning tools, which could certainly add value to the quality control of data, and to the analysis and interpretation of structural behaviour, could identify early signs of failure.

Theo Dezert, of NTNU, Norway, described tests undertaken at the university on riprap and rockfill dams prone to overtopping. He pointed out that there were 180 rockfill dams in Norway higher than 15 m, and many were to be upgraded as a result of increasing dam safety standards. He explained that overtopping was the main cause of embankment dam failures (accounting for more than 30 per cent of failures, according to ICOLD data). There was a need to equip the rockfill dams with improved defence mechanisms, particularly in view of the increasingly extreme flood events, associated with climate change. The research he described had focused on investigating the failure mechanisms of riprap, on a rockfill dam model subjected to throughflow and/or overtopping events.

He concluded that the results could be valuable in predicting and assessing the risk of rupture, as well as to improve construction and reinforcement techniques.

Marius Biiblmann, of Axpo Power AG, Switzerland, gave a paper on the multi-objective calibration of a dam behaviour analysis model for gravity dams. He began by explaining



Selim Sayah of Switzerland, speaking about advanced deterministic models to assess dam displacements.



Theo Dezert of NTNU, Norway gave a talk about research on failure mechanisms of riprap on rockfill dams prone to overtopping.



Harald Kling, of AFRY, Switzerland, chaired the Q107 session. While introducing the topic of climate change he emphasised the importance of the challenges facing the hydropower sector



General Reporter for the session, Denis Aelbrecht, of EDF, France, noted that global temperatures have been rising even more than the most pessimistic projections published by the IPCC

the function of such a model, used in conjunction with a monitoring system, for the early detection of deficiencies in a dam. Measured displacements could be linked with environmental conditions, such as water level and temperature distribution in the dam body.

The recently developed approach, he said, was to use a deterministic beam model to calculate displacements at various levels. The method had been applied to the Robiei hollow gravity dam in Switzerland, where a shift in displacements had been identified, which was concluded to have been caused by damaged measurement equipment. Displacements at the crest level also showed a slight trend, which was not present at all levels. He concluded that the research had shown the potential for using a deterministic beam model in combination with multi-objective calibration.

Q107 dams and climate change

Q107 General report

Harald Kling, of AFRY, Switzerland, chaired the first session for Q107. He introduced the topic by emphasising the potential huge significance of climate change impacts. Reflecting on the importance of the challenges faced by the hydropower and dams industry, Kling said that more than 20 papers had been accepted for presentation.

Kling then introduced the General Reporter for the session, Denis Aelbrecht, of EDF, France, who gave an overview of his General Report. He explained the report contained a synthesis of main conclusions drawn from the latest results of the IPCC assessment reports, a description of risk factors for dams, reservoirs and water resource systems, and a review of opportunities for dams and reservoirs to meet the challenges of water-energy. The full report concludes by listing ongoing activities of ICOLD Technical Committee Y, he added

Climate change was strongly related to the work of many other Technical Committees at ICOLD, Aelbrecht

said. Each of these could therefore benefit from the comprehensive assessment of climate science, impacts and mitigation aspects reported in the IPCC published Working Group reports released earlier this year and last year.

These documents state that by 2030, global temperatures are projected to increase by 1.2 to 1.9°C and by 2050 reach 1.6 to 2.4°C. Aelbrecht said the current temperature increases were about 1.1°C above pre-industrial levels: "This is significantly greater than the increase predicted only 20 years ago in the AR4 report", he said. Perhaps of even greater importance for dam, reservoirs and inland water infrastructure was, he continued, "average air temperature increases over terrestrial land are even greater than global average air temperature increases, because of the cooling effects of the atmosphere over ocean surfaces, which cover about 70 per cent of the earth's surface".

Aelbrecht noted that modelled precipitation changes were not as clear as they were for air temperature changes. "The global water cycle will intensify, and is expected to generate more precipitation in high latitudes and at the equator, while less precipitation is expected to fall at mid-latitudes. However, projections are subjected to high uncertainty when looking at regional or local scales", he said.

Aelbrecht said some of the impacts of these changes could lead to a fundamental shift in existing equilibriums with amplified 'positive feedback' and sometimes irreversible consequences. "Effects can be either direct or indirect, and include modification of flow regimes as a result of rainfall-evaporation-runoff and glaciers melting processes change, modification of flood regimes (frequency, intensity), modification of soil erosion and sedimentation processes, change of thermal loadings on structures and equipment, and systemic changes in the socio-economic environment that may indirectly affect

operating conditions", he said. Aelbrecht cautioned that the triple combination of sedimentation, climate change and groundwater overuse would combine to create extra challenges.

Despite these challenges, Aelbrecht noted that hydropower presented significant opportunities to combat global warming and support the energy transition towards net-zero CO₂ emissions. "At 24 gCO₂eq/kWh, hydropower has one of the lowest carbon intensity factors of all electric power generation technologies. It also has one of the highest energy return on investment ratios, while pumped storage schemes offer additional benefits to help balance the intermittency of other renewable energies", he said.

Debbie Gray of the THA, UK, described the IHA 'Hydropower Sector Climate Resilience Guide'. She said the guide offered a methodology for identifying, assessing and managing climate risks to enhance the resilience of hydropower projects. "It seeks to evolve from the default use of historical data and the assumption that hydrological variability will remain the same over the lifetime of a project and also addresses how best to access, use and interpret climate change modelling and observed climate data", she said.

Gray note that for hydropower operators, failure to consider climate risks adequately could lead to shortcomings in technical and financial performance, safety aspects, and environmental functions. "If schemes are not designed and managed appropriately or if climate change-related opportunities are not fully assessed, investment decisions may not adequately recognize the role of hydropower infrastructure in providing climate-related services. This includes hydropower's role in supporting the greater use of less flexible forms of low-carbon electricity generation", she said.

Marie-Claude Simard, of Hydro-Quebec, Canada, described a review undertaken by her company to analyse potential vulnerabilities at their assets and activities. "Vulnerability analysis is a complex and wide-ranging task that requires an integrated view of Hydro-Quebec's spheres of activity", she said. The size and diversity of activities carried out by the company made it difficult to apply a consistent approach across all business units. To address this, Simard reported that a multi-level decision-making structure had been adopted. "Until now, several critical and strategic business planning processes still rely on historical data to anticipate future conditions", she said. Simard added that this assumption was now challenged by climate change, which was a significant business risk and challenge to maintaining hydroelectric production.

Carmen Bernedo-Sanchez described some of the challenges when estimating inflow design floods during this period of climate change. "Developing accuracy for



Marie-Claude Simard, of Hydro-Quebec, Canada, reported on her organisation's work to understand better the potential impacts arising from climate change

inflow design flood (IDF) estimates is essential to evaluate dam performance, meet reservoir management objectives and protect downstream facilities from floods", she said. Because IDF and probable maximum flood (PMF) studies carried some degree of uncertainty, Bernedo-Sanchez said it has become critical to document the accuracy of these estimates, "especially given the changing climatic conditions which could potentially alter future IDFs and reduce the reliable supply of hydroelectric power".

The central valley and central Sierra Nevada regions of California had experienced several major floods events over the past century, he reported. In recent years, the effects of atmospheric river conditions on dam operations and facilities had become more prominent. To help understand flood event impacts, Bernedo-Sanchez reported a case study of the Moccasin dam, located on a tributary to Tuolumne river. She said a number of lessons had been learnt. adding that "Rainfall-runoff models typically used for estimation of PMFs and IDFs carry some degree of uncertainty, since these are used to predict conditions far beyond those used in the original models. It is critical to document and communicate the uncertainty of the IDF estimates to support the decision-making process for flood management and dam safety".

A delegate asked how climate change trends for dam safety were managed in California. Bernedo-Sanchez replied, "Measuring the PMF or PMP is tricky. It is a case of working with the best science, sharing information and updating work accordingly".

Another delegate suggested that future projections of relatively modest temperature increases seemed too optimistic and asked: "Which IPCC climate scenario do you use?" Bernedo-Sanchez replied that it was important to use multiple guidelines, as the future was uncertain.

Robert Boes, of ETH Zurich, Switzerland, described techniques to reduce sedimentation in bed load and suspended load reservoirs. His presentation included a

short video, which illustrated the deposition of different sized sediments. He said, each year, about 1 per cent of the global reservoir volume was lost as a result of sedimentation. "This loss is larger than the actual storage volume increase by new dam construction and by 2050, about 25 per cent of all reservoirs will be inoperable due to sedimentation, making reservoirs unsustainable in many cases", Boes said.

"For reservoirs where delta formation by bed load deposition is the governing sedimentation process, the intermittent routing of sediment through bypass tunnels or channels may be appropriate", he said. For reservoirs mainly affected by the deposition of fine sediment, Boes suggested that removal by hydrosuction or air lift and venting through low-level outlets or via power waterways may be appropriate. "The development of appropriate sediment management concepts requires an interdisciplinary approach, regular monitoring, learning from experience and, eventually, optimization measures", he added.

With additional pressures from climate change and a growing world population, there was an increased need for additional water storage, mainly for hydropower generation, drinking water supply, irrigation and flood protection, he concluded.

Following the presentation, a delegate asked what environmental considerations were given to sediment management. Boes explained that sediment venting was normally undertaken for only a few weeks a year best to access, use and interpret climate change modelling and observed climate data", she said.

Gray note that for hydropower operators, failure to consider climate risks adequately could lead to shortcomings in



Robert Boes, of ETH Zurich, Switzerland, describing the various options available for sediment removal and management with reference to limiting potential environmental damage

technical and financial performance, safety aspects, and environmental functions. "If schemes are not designed and managed appropriately or if climate change-related opportunities are not fully assessed, investment decisions may not adequately recognize the role of hydropower infrastructure in providing climate-related services. This includes hydropower's role in supporting the greater use of less flexible forms of low-carbon electricity generation", she said.

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Following the presentation, a delegate asked what environmental considerations were given to sediment management. Boes explained that sediment venting was normally undertaken for only a few weeks a year during non-fish spawning periods. In addition, he said "In Austria, the authorities are very strict on reservoir flushing regimes and threshold values are limited to 2.5 g/l, which is less than the concentration often found in natural systems". Another delegate asked how the concentration of sediment could be modified. "Screening is used in front of intake and may be 2 mm or even 0.5 mm, for example. The distance of the screening to the intake is under study and has implications for the build-up of coarse sediments that settle near the screen", Boes replied.

In a further comment from the audience, it was noted that in some cases dams were located in areas where trees could be planted to help control sediment, however,

in many alpine regions where reservoirs were sited at higher altitudes this was often not possible and therefore alternative measures would be needed.

It was noted that the cost of sediment management could deter some operators, "But as electric prices increase this may change and where it remains uneconomical to remove sediments, regulation might be needed to ensure they are passed down the river system", Boes said.

Luc Boutonnier of EGIS, France, described ongoing research concerned with cracking of embankment dams. He noted that shrinkage cracks could appear during dry periods in temperate climates, and depending on the initial moisture content and the initial dry density, they could contribute to various potential challenges. These included higher loading, increased hydraulic conductivity by several orders of magnitude, a reduction of the safety factor or slippage caused by rapid increase in pore pressures, and a concentration of flows leading to the development of internal erosion mechanisms, he said. To limit the risk of shrinkage at new structures using fine soils, Boutonnier recommended increasing compaction, while reducing the compaction water content. Climate change, and warmer climates, could lead to a greater number of larger cracks, he said, and these may penetrate to 2 m or more. It was also not clear if shrinkage cracking was reversible, he concluded.

In the discussion that followed, the view was expressed that while visual inspections might support safety assessments, their value depends on the depth of cracks. Also, it was stated "There is an issue of cost and when to carry out inspections. It was felt that perhaps the best time was in autumn, at the end of summer and again at the end of winter to see if the cracks remained open or if they had closed". If they remained open, it was suggested this might indicate a safety concern.

A delegate pointed out that old levees have generally not been compacted as much, and could therefore be more vulnerable to cracking.

Evangelos Rabias, of HydroPlus, Greece, talked of the need for environmentally friendly water management to supply increasing demand in Greece. The Dipotamos dam had started operating in 2005, he said. Since its commissioning, the population of the neighbouring city of Alexandroupolis had increased, and to help meet the extra demand this had generated, a pilot project ('Water for the City') had been created to promote an integrated approach to water management. Rabias explained the main pillar of the solution centred on optimizing existing water supply dam infrastructure and increasing the capacity to retain water, without increasing the environmental footprint.

The chosen solution included the implementation of a free-standing, fusegates system that increased reservoir capacity by about 14 per cent. Furthermore, Rabias said,

the fusegate system generated additional benefits, for climate resilience and flood safety, as well as alleviation of pressures in the coastal aquifers through decreased pumping, resulting in energy cost savings.

A delegate asked Rabias: "What is the annual probability for first tipping?" He replied that it was about 100 years for the first gates. "There was no loss of homes or land to nearby populations and the environmental foot print was not altered, as this was determined by the maximum water level; and the use of fusegates means the maximum water level does not change", Rabias added.

ICOLD Vice-President, D.K. Sharma, of India, spoke of the role of dams in mitigating the impacts of climate change. "The annual mean near-surface air temperature over India has warmed by about 0.7°C between 1901-2018, with the post-1950 trends attributable largely to anthropogenic activities", he said. Atmospheric moisture content had also risen during this period, while projections for further temperature increases by the end of the century were in the range of 2.4 to 4.4°C, he added.

Sharma noted that a key feature of regional climatic conditions in India was the summer monsoon. "With the resultant increase in temperature and atmospheric moisture, climate models project a considerable rise in the mean, extremes and inter-annual variability of monsoon precipitation by the end of the century", Sharma said. With reference to the Uttarakhand dam failure, in February 2021, he observed that increasing temperatures and changes to freeze-thaw cycles may have been contributing factors. To address these emerging challenges, he stressed that dams would play an increasingly important role in mitigating the impacts of climate change for water security, dam safety, and flood mitigation. "This will require formulation of new plans and strategies for the management and operation of existing, as well as future, water resources projects", he said.

Ezio Baldovin, of Geotecna Progetti, Italy, described the development and role of pumped-storage projects in Italy to help meet EU efforts for energy decarbonisation and increased diffusion of renewable energy. He noted the EU's National Energy and Climate Plan (NECP), presents a target for the electricity sector, to achieve renewable generation of 55 per cent by 2030 (compared with 36 per cent in 2020). Baldovin explained that the southern regions and major islands of Italy offer good potential for the development of new energy storage and pumped storage plants through the re-purposing and multiple-use operation of reservoirs that were currently exploited predominantly for irrigation. Such projects could be undertaken in conjunction with the development of photovoltaic and wind installations, Baldovin added. "Surveys for estimating sites with new potential and enhancement of existing schemes were commissioned by



ICOLD Vice-President, D.K. Sharma, of India, described some of the already experienced challenges climate change has presented in his country and also the need for appropriate management planning in the future

the Italian electricity network operator to identify possible opportunities for potential investors", he said.

Baldovin then described the methodological approach implemented for the study and the reported the use of GIS for identifying and classifying suitable sites for potential development.

Vincent Chanudet, of EDF, France, reported key findings from various studies undertaken by EDF and other organizations over the past 25 years in the field of GHG emissions at reservoirs. He presented both French and international examples with the first measurements and assessment made at the Petit Saut reservoir in French Guiana. Since that reservoir had been impounded in 1994, GHG emissions had been measured continuously, he said. "Analysis of these data and many other studies at this site were used during the development of the Nam Theun 2 project in Laos, where a detailed monitoring system with high temporal and spatial resolution had been implemented since reservoir impoundment in 2008", Chanudet said. He reported that, while measuring GHG emissions after reservoir impounding was important,

"It is also very important to estimate emissions before impoundment, particularly to establish mitigation measures". Chanudet explained that EDF used a range of approaches to facilitate and perform these evaluations, including simple comparisons with the Petit Saut and Nam Theun 2 reservoirs, to highly complex 3D deterministic modelling, using the IHA G-res tool, which made it possible to estimate the net emissions of a reservoir.

A delegate asked to what extent the G-res tool and other models captured uncertainties relative to empirical assessment. Chanudet said the modelling tools described were not necessarily designed to give definitive results, but rather to indicate the relative contributions, and then more precise modelling and on site investigations could

be done if necessary. He also commented that a large amount of the GHG emissions at reservoirs were a function of the underlying soil characteristics, rather than the above ground vegetation.

In his concluding comments for the session, General Reporter Denis Aelbrecht listed four key messages for delegates, as follows:

- Climate change will lead to new equilibriums and require new solutions to address the future scenarios. Collective action needs to start now as measures will take time to develop and implement,
- A multi-disciplinary approach is needed, as climate change is a cross cutting issue that cannot be addressed adequately with a silo mentality.
- There is now a window of opportunity for hydro-power and pumped-storage to play a leading role in facilitating a low carbon future, as adoption of intermittent renewable sources are increasingly pursued.
- A long term perspective of multiple decades, and not only 5 to 10 years, is needed. This time horizon will be challenging as it extends beyond typical shorter-term financial planning.

Technical Tour: rhone levees

A number of tours to hydraulic works in the region were offered during the ICOLD 2022 week.

About 40 delegates took part in a tour to visit the Rhone river levee system. A briefing by project engineers revealed that the delta is exposed to the impacts of flooding not only from the Rhone, but also from coastal storms. There have been eight major flood events recorded since 1840, with the most recent one occurring in 2003, during which the homes of 12 000 people were flooded and more than €700 million worth of damage was experienced.

Original flood defence structures were first erected during the 12th century, but were constructed with low compaction forces and located very close to the river. Subsequent upgrades were made, but, following the 2003 event, a new strategy was developed at a total project cost of €450 million. So far €210 million has been invested in the delta, of which € 195 million has been allocated for levee construction. The entire project was achieved through a robust public consultation with multiple stakeholders, including residents from various



ICOLD participants visiting the Rhone river levee system in Southern France, during a technical excursion on 31 May.

downstream and upstream areas, transport users and engineers. The chosen levee design was selected to facilitate safe overflow without breaching, until a flow of 14 160 m³/s is reached (equivalent to a return period of 1000 years). This is a key aspect of the programme, as it supports the decision not to heighten the levees, and thereby avoids uncontrolled transfer of water to other areas, including to a nearby railway embankment, running between the towns of Aries and Tarascon.

To increase resistance to overflow, the upstream side was reinforced with concreted riprap, and delegates had opportunity to see the construction of this in progress at one location. Constructed was undertaken after systematic dismantling of the multiple layers that had remained in place from pre-existing structures, and then been rebuilt to current standards. The compaction level required was 95 per cent, and the moisture content, before compaction, was between 0 and 3 per cent.

The project is expected to take approximately 15 years to complete, and includes the restoration and creation of wetlands, as well as the relocation of protected species. To support these environmental safeguarding programmes, it was decided to build the levees further back from the river and, where possible, use local and recycled materials from the existing levees.

Delegates could see completed sections of levees, as well as other areas still under construction. They also heard about a fibroptic system that has been installed on the downstream side of levees to provide early detection of leaks and their location, as well as to help identify potential failure warning signs.

Michael Rogers Completes his Mandate, and Reflects on the past Four Years as ICOLD President



The 27th Congress and 90th Annual Meeting of the International Commission on Large Dams (ICOLD) can be remembered as a great success, with more than 1500 delegates, exhibitors and guests coming together in Marseille, France, for the first meeting since June 2019. Congratulations are due to the French National Committee

of ICOLD (CFBR) for this success, and for so much hard work organizing the conference over the last four years in the most difficult of circumstances.

This ICOLD Congress closed an important chapter in my life, probably the most important chapter of my professional career: the completion of four years as ICOLD President. I am extremely grateful for the honour to have served as the 25th President of ICOLD since my election on 3 July 2018. I am very thankful to Aqua-Media for its support throughout my term on the ICOLD Board, as Vice President and then as President, and I am very pleased to provide a few reflections that I will carry with me from this very special adventure.

My term as ICOLD President has been the most rewarding professional experience of my life. As an organization, ICOLD has dutifully served the profession of engineering for dams since its founding in 1928. The name ICOLD carries instant recognition and respect around the world for the 104 member countries, and more than 15 000 individual members. ICOLD carries great responsibility to gather experts from around the world, and expertise, to share knowledge and lessons learned with the primary mission to make dams safe and to protect human life. My personal mission as ICOLD President has been to support these strong ideals of our founding, strengthen the organization with our national organizations and technical committees, and invest in the future as a mentor to our young professionals just starting their careers.

Vienna, Austria, 2018

I remember the euphoria of my presidential election and acceptance speech in Vienna in 2018. The excitement of reaching my life-long aspiration to serve as ICOLD President and the humble realization of the weight of this position. I was following a long line of highly respected and successful ICOLD Presidents: Prof Anton Schleiss (Switzerland), Mr Adama Nombre (Burkina Faso), Dr Jia Jinsheng (China), Dr Luis Berga (Spain) and many others who are recognized leaders in our profession, And, there was also the inspirational leader from my early years at Harza Engineering Company, Dr Jan Veltrop (USA). Harza Chief Engineer and ICOLD President (1988-1991).

The preceding three years as ICOLD Vice President had given me confidence and ambition to serve as President, in working with a Board of talented Vice Presidents from around the world and the dedicated, hard-working Secretary General Michel de Vivo, who would become my closest friend in ICOLD. On that day in Vienna, I remember clearly taking a deep breath and stepping up to the podium to outline my plan as the newly elected ICOLD President. I remember the room and the faces, some I already knew and many more I would come to know over the next four years, the faintly of ICOLD!

Over the next four years, I would solicit support from the ICOLD Board, asking individual Vice Presidents for their help with each priority, so that we could work together to make ICOLD stronger.

We have all worked together, along with the Secretary General and Central Office staff, to strengthen ICOLD while at the same time surviving our biggest challenge since World War II, a global pandemic.

dam Safety

My highest priority has always been dam safety. This has been a passion since my early days as a young engineer at Harza, learning under world-class engineers and scientists about the responsibility we hold for high quality design, to ensure the safety of the structures and protection of human life. I feel that one of my best accomplishments has been the ICOLD World Declaration on Dam Safety that was approved by the Board on 18 October 2019, at the HYDRO 2019 Conference in Porto, Portugal.

I feel that the Declaration is a strong statement by ICOLD that dam safety is our core value, and that, as engineers and scientists, we must always be diligent in our work, every day, to protect lives and the critical infrastructure that we build.

National Committees

ICOLD is an international organization that is strengthened by the active participation of each National Committee and each member from each country. I have been fortunate as President to represent our organization around the world, meeting colleagues and governmental representatives involved in water and power infrastructure. I have visited 12 countries meeting many of our friends and family, including many meetings, and memorable dinners. On these occasions, I have carried the message about the important role of ICOLD to unite the industry under a common and respected banner for technological quality and excellence for engineers from all nations.

Technical Committees

The hard work and heavy lifting of ICOLD is done by our Technical Committees. During my tenure as President, I will always remember a key success: the start of the new ICOLD Technical Committee for Levees. The inclusion of levees in our organization is especially important to me, primarily as a result of the terrible images in my memory of Hurricane Katrina, a huge destructive Category 5 hurricane that hit New Orleans, USA, in late August 2005, causing more than 1800 fatalities and more than US\$125 billion's worth of damage. I saw the vulnerability of levees to these catastrophic events, and I also know ICOLD's work on dam safety can make levee structures safer. I supported the initiation of a new levees committee in 2017 under the leadership of Remy Tourment (France), including the adoption of Question 103, Small Dams & Levees, for the ICOLD 2018 Congress in Vienna. I have seen this committee grow in stature and confidence, including the development of three Technical Bulletins during the pandemic years. There is a definitive place for levees in the ICOLD focus on safety and security of critical water and power infrastructure. Many lives have been and will be saved by ICOLD delegates committed to the safety and reliability of levees.

Capacity building

The need for sharing and training has been a cornerstone of ICOLD since its formation in 1928. The modern world sees soaring demand for reliable water and renewable energy in regions previously without the means to design and build such infrastructure, including Africa. In 2008, ICOLD issued its World Declaration for Dams and Hydropower for African Sustainable Development. ICOLD's Ad hoc TC-Z on Capacity Building was established in 2009, during the Annual Meeting held in Brasilia. The purpose of this committee was initially to handle the training programmes and coordinate workshops and technical tours, primarily offered by Turkey, Morocco, and China. It has since grown to look for supporting organizations for capacity building within and beyond ICOLD. This is a difficult mission when funding for training and technology transfer is often very limited.

As President, I have been fortunate to work with Hon President Adama Nombre, Chair of TC-Z, and Vice President Michael Abebe to look for opportunities to improve the situation of capacity building support within ICOLD and with our associated partners, including the World Bank. My hope is that the important work begun by ICOLD President Nombre and VP Abebe will be picked-up by other motivated ICOLD members to continue the commitment to African sustainable development made in our World Declaration in 2008.

Young professionals

As ICOLD President, I was asked to make many, many

speeches on many various topics on many different occasions. My favourite speeches were those to our ICOLD young professionals of engineers and scientists who are the future of ICOLD. I enjoy telling my own story from being a young student engineer, 18 years old, at Harza Engineering Company to attaining my goal to be ICOLD President. My 40-plus year professional career path in civil engineering for dams has been an amazing journey, and many of the highlights from that journey result from my participation in the United States Society on Dams (USSD) and ICOLD.

Concluding remarks

I will always look upon my time as ICOLD President as a grand adventure and the experience of a lifetime. During our ICOLD 2022 Final Dinner on 3 June, I took a brief moment of reflection on the patio looking over the beautiful city of Marseille and the gathered ICOLD family around me. I remembered the many faces of ICOLD I have met over the years, especially the dedicated colleagues who persevered to keep the mission of ICOLD moving during the isolation. Of the pandemic I remembered the friends that we have lost along this journey, and the joy of our annual gathering of the ICOLD family.

Now having completed my term as President, I remain full of optimism that ICOLD has emerged from the pandemic stronger than ever, because we have been tested in the cruel forge of despair and uncertainty. ICOLD has kept focus on our important vision and mission to build safer and more reliable dams by freely sharing knowledge and experience on a global scale. As engineers and scientists, we have a high calling to serve the basic needs of humankind for clean and reliable water and power, along with protections from floods, earthquakes, and other natural disasters. The important lesson of my time within ICOLD, especially the last four years as President, has been that this professional calling is about our important work and about the journey of our careers with the friends and family that we gather around us along the way.

I am grateful to my employer, Stantec, for its unwavering support to my participation in ICOLD, from the very beginning recognizing the importance of this organization to our profession. I am especially thankful to my wife, Kristin, as the First Lady of ICOLD, over four years, for her patience with my service and her unending support. I am warmed looking back at the memories from the many ICOLD experiences around the world that my wife and I have shared. We remember many beautiful places and smiling faces with our good friends, good dinners, and good wine.

I wish new ICOLD President, Michel Lino, all the best for success and excitement on his journey in this important role. Thank you to the ICOLD family for giving me this adventure of my life. God bless.

Michel Lino takes Office as ICOLD President and Reflects on his Mission Ahead



It is a great honour to be elected to the head of this magnificent organization that is ICOLD. It is a challenge to succeed President Michael Rogers, who has kept our ship afloat during the difficult journey we have just made. I will follow in the footsteps of his mandate.

I would like to thank the National Committees warmly for this election. I wish to thank Prof Luis Berga who encouraged me, Prof Anton Schleiss and Adama Nombre, whose traces are still very present and inspiring. With modesty, I follow in the footsteps of our great elders. First, Pierre Londe, my master, taught me both rigour and creativity. Then Giovanni Lombardi, with whom I also had the chance to work for a long time. I cannot fail to mention Francois Lemperiere and his tireless quest for innovation, to whom we owe so many inventions and new ideas.

At the beginning of this mandate, I would like to share with you the main lines of action that I wish to carry out for ICOLD.

Strengthening iCOLd's actions in favour of dam and dyke safety

Dam and dyke failures, although better documented than in the past, continue to be too numerous. The safety of dams is a primary condition for their sustainability and their acceptance by society. In continuity of the action initiated by Hon President Rogers, I will propose that the World Declaration on Dam Safety be completed by an operational action plan in favour of dam safety, a plan to be developed within ICOLD by relying on the national committees and by associating our traditional partners, such as the World Bank and other development banks.

dams as an instrument for energy transition and adaptation to climate change

Climate disruption was dramatically illustrated by the disasters of the summer of 2021, with exceptional floods in China and Europe, mega-fires in California and the Mediterranean basin, and the unprecedented heat wave that hit North America and the Arctic. Cyclone Ana, in January 2022, caused catastrophic flooding in Madagascar, Mozambique and Malawi. Floods occurred in Australia in February 2022, in South Africa in April 2022, in Bangladesh and India in May 2022. But also, dramatic drought in Ethiopia and an extreme heat wave were experienced recently in India and Pakistan.

The 2022 IPCC report, entitled 'Impacts, Adaptation and Vulnerability', paints a bleak picture of the consequences of climate change on water management. It states, with

a high degree of confidence, that "risks to physical water availability and water-related hazards will continue to increase in the medium to long term in all regions assessed, with a greater risk at higher levels of climate warming."

Reservoirs are essential tools for managing this precious and threatened resource and regulating extreme drought and flood events. Reservoirs are part of the solutions to be deployed to adapt to climate change, producing highly flexible and low-cost renewable energy, providing storage capacity for intermittent solar and wind energy through pumping stations, and creating storage capacity to cope with uneven water distribution in time and space.

In coordination with the relevant Technical Committees, I will propose actions to allow dams to play their role fully in the field of energy transition and climate change mitigation.

improving the acceptability of dams and promoting a fair distribution of project benefits

I am convinced that dams have played a major role in the history of humanity and remain an indispensable tool in the difficult times of transition. We must continue to work hard to convince stakeholders of their beneficial role, and their overall positive balance. To do this, we must work in particular on best practices for the design, construction and operation of structures that take into account environmental issues and maximize the expected socio-economic benefits.

Biodiversity is seriously threatened today, and constitutes, in the same way as climate change, a major challenge for our societies. Dams can have a negative impact on biodiversity if the ecological functions are not sufficiently taken into account at the project design stage. The preservation of biodiversity or its restoration must be taken as a priority in our projects. It must be a personal commitment for the designer of a dam, equivalent to his or her commitment to dam safety or efficient water management.

ICOLD must also act decisively in favour of the equitable sharing of project benefits. The issue of the relocation of people living in the reservoir areas, which has been the Achilles heel of many large projects, is essential for the acceptability of our reservoirs. ICOLD, through its specialized technical committees (environment and resettlement), must define and testify to good practices in resettlement and illustrate the socio-economic development that results from the construction of large hydraulic works. The rule that no one's standard of living should be affected by the construction of a dam must be strictly enforced.

ICOLD needs to take a strong position on these environmental and social issues, and encourage respect for these principles. I will encourage dialogue with

environmental NGOs to improve our knowledge of those impacts and guide the management of existing dams and the development of future ones accordingly.

developing the visibility of iCOLD

ICOLD is a respected organization, but its impact on the outside world remains limited. Our publications (bulletins, proceedings of congresses, proceedings of regional and national symposia) are well distributed within our community, but it is difficult to ensure that they reach beyond. For example, it is notable and somewhat distressing that the 2021 UNU report on the risks associated with the aging dam stock has no reference from ICOLD.

Developing the visibility of our organization will be one of the axes of my action.

I will propose that an assessment be made of the actions initiated by Hon President Schleiss to improve the publication, dissemination and international referencing of our publications, with an action plan to pursue this important initiative.

Strengthening the sustainability of iCOLD

Our organization has been severely impacted by the COVID 19 pandemic. Three years had passed since we last met in Ottawa in June 2019. The functioning of our technical committees has been able to continue, but with an undoubtedly reduced efficiency. The conviviality of the ICOLD family has been hit hard. The joy of our reunion in Marseille felt all the stronger and the high attendance testified to this.

The finances of ICOLD, which depend on revenues from annual meetings and congresses, have been affected. The national committees have also experienced pain during this period of uncertainty.

Together with the Secretary-General and the Vice-Presidents, we will reflect on the actions to be taken to support the National Committees, to ensure the sustainability of ICOLD and to emerge stronger from the pandemic, I will also encourage the initiatives of the Young Professionals Forum, which represents the future of our family.

ICOLD has been a great passion throughout my professional career, ICOLD National Committees have now brought me for three years to the head of this wonderful organization. I will devote myself, body and soul, to this magnificent task of steering the actions of ICOLD in this critical period for our profession, as well as for the planet and its inhabitants.

I call upon the mobilization and enthusiasm of all the active members of the ICOLD family, particularly the Young Professionals who are our future. The next three decades will be decisive for the future of the planet. The challenges are immense and we must act without delay.

Let's mobilize ourselves together and play our part in taking on the challenges of the 21st century!

Michel I ino President, International Commission on Large dams

Honorary Awards



Left: Bernard Reverchon, Head of the ICOLD 2022 Organizing Committee, who was awarded the title Hon Vice President, on completing his term as Vice President.

Switzerland; Reza Ardikianian of Iran (accepted by Ali NoorzadV, and Robin Charlwood (accepted by Michael Rogers).

In the closing session of the Congress, Michael Rogers received the title Honorary President, and the Vice Presidents who had completed their terms of office (Michael Abebe, Ali Noorzad, Jean-Pierre Tournier and Bernard Reverchon), became Honorary Vice Presidents

During the Congress in Marseille, eight individuals were awarded Honorary Membership of ICOLD for their services to the dam engineering profession.

Michel de Vivo (shown left) made the presentations during the Final Dinner on 3 June. (Three could not be present, and so colleagues accepted the certificates and medals on their behalf).

The new Honorary Members are: (from second on the left in the photograph): Alberto Scuero of Italy; Jean-Jacques Fry of France; Tony Bennett of Canada; Zhang Chaoran of China; A.K. Pandya of India (accepted on his behalf by D.K. Sharma); Martin Wieland of



The presentation of ICOLD Honorary Membership, during the farewell dinner in Marseille



Memories of Dr John J. (Jack) Cassidy

Our dear friend and colleague, Jack Cassidy, passed away on 31 July 2022. Jack was an active member of both USSD and ICOLD and a mentor to many members of USSD.

He was born in Gebo, Wyoming and moved to Roberts, Montana where he was raised. Jack often said that Roberts was so small that the sign that said 'Entering Roberts, Montana' also had 'Leaving Roberts' on the back.

After graduation from high school, he entered Montana State University where he earned a BS in Civil Engineering. He then worked the Coast & Geodetic Survey until he was drafted into the US Army. He served his time in service overseas in Korea. After his discharge from the army, he returned to Montana State University where he earned an MS in Civil Engineering. He then earned his PhD from the University of Iowa, specializing in Hydraulics. He continued his career at the University of Missouri at Rolla, where, as a Professor, he continued to specialize in hydraulics and hydrology. He left that position in the 1970s to join Bechtel in San Francisco as a Specialist Manager in the Hydraulics and Hydrology Department. At Bechtel, he worked on numerous projects, including nuclear and hydroelectric power, mining and refinery projects throughout the world.

He left Bechtel in the late 1970s to return to the academic world. He joined Washington State University to chair the Hydraulics Department and manage the hydraulic laboratory. However, the challenge of overseas work and the variety of projects lured him back to Bechtel, where he concluded his fulltime career as Manager of Bechtel's Hydraulics and Hydrology Department.

Among his activities for ICOLD, he was Chairman of the Hydraulics Committee and he attended many of the Annual Meetings and Congresses. Both USSD and ICOLD were an ideal opportunity for Jack to mentor engineers, both domestically and overseas. During his time at Bechtel, he was a member of the organizing committee for the ICOLD Annual Meeting and Congress, held in San Francisco in 1988.

He received numerous awards for his work, including being inducted into the National Academy of Civil Engineers, being named both a Bechtel Fellow and Fellow of The American Society of Civil Engineers, and receiving the USSD President's Award.

Jack was widely sought for the largest, highest risk and most complex consulting assignments, as a result of his exceptional theoretical knowledge, vast experience, and his practical application of engineering solutions. He had the ability to break down difficult engineering problems into simple terms that could be understood by all. Some of his last projects in California were those of the greatest dam safety consequence in the state. Jack most recently served on the boards of consultants for the Calaveras dam replacement project, Anderson dam seismic retrofit and the Oroville spillways replacement projects.

He did not limit his contributions to just engineering. For example, in 2001, he and his wife Alice volunteered and worked at 'ground zero', the site of the World Trade Centre terrorist attack.

We will miss him. May he rest in peace. – *Harry Blohm, Consultant, USA.*

INCOLD News

26.2 GW OF HYdro CAPACiTY CHANGES OWNErSHiP iN CHiNA

China Yangtze Power Company (CYPC) is to pay CNY 80.5 billion (approximately US\$ 12 billion) to acquire the 10.2GW Wudongde and 16 GW Baihetan hydro stations on the Yangtze river, thereby expanding its total installed capacity, as well as increasing and optimizing production at its downstream assets. CYPC will acquire the Three Gorges Jinsha River Yunchuan Hydropower Development Company, which owns the Wudongde and Baihetan stations, from its parent, China Three Gorges Corporation; it was reported on 30 June. CYPC said it plans to purchase 100 per cent of Yunchuan from its shareholders, including CTGC, Yunnan Provincial Energy Investment Group and Sichuan Energy Investment Development Company. The offer, which has been approved by its board, is valid for 12 months and is scheduled to close in early 2023, subject to a minority shareholder vote and approval from government bodies.

The two power stations have a combined capacity of 26.2 GW, and, on completion later this year, will produce around 100 TWh/year.

Wudongde and Baihetan are located upstream from CYPC's existing hydro stations, allowing their reservoir storage capacity to increase and stabilize overall power generation. The electricity generated will mostly be transmitted to Guangdong, Guangxi, Jiangxi and Zhejiang provinces, while some will be consumed locally in Yunnan and Sichuan provinces. The transaction will see CYPC increase its installed capacity by 57 per cent from 45.6 to 71.8 GW. After the acquisition, CYPC will own five of the world's 10 largest hydro projects by installed capacity: Three Gorges (22.5 GW), Baihetan (16 GW), Xiluodu (13.86 GW), Wudongde (10.2 GW), and Xiangjiaba (7.75 GW).

The Wudongde project was fully commissioned in June 2021 and the Baihetan project is expected to be fully commissioned later this year.

PAKISTAN COMMiSSIONS THE 720 mW KAROT PROJECT

The 720 MW Karot run-of-river project. The first hydro plant to be developed under the Cluna-Pakistan Economic Corridor (CPEC), began full commercial operation on 29 June. The project was described as "a bridge of friendship between China and Pakistan" by Wu Shengliang, Chairman of China Three Gorges International Corporation, at an inauguration ceremony held on 9 July. Impoundment of the reservoir began in

November 2021, and the First unit was connected to the grid in May this year. Located on the river Jhelum in Pakistan's eastern Punjab province, the run-of-river project was developed under a 30-year concession on a BOOT (build-own-operate-transfer) basis by Karot Power Company Limited (KPCL), a special-purpose vehicle majority owned by China Three Gorges South



Asia Investment Limited (CSAIL) with Associated Technologies of Pakistan.

The Silk Road Fund and CTGC signed an MoU with the Pakistan Private Power and Infrastructure Board to develop the project jointly in April 2015 and an implementation agreement mid power purchase agreement were signed in September 2016 by the federal Government and the government of the province of Azad Jammu and Kashmir with the Chinese-led consortium. Ground breaking took place in January 2016, and financial closure of the US\$ 1.7 billion project was reached in March 2017.

The project is being co-financed by the International Finance Corporation, China Export Import Bank, China Development Bank, and the Silk Road Fund, China. The project, located 74 km upstream of the Mangla dam, in the Rawalpindi district of Azad Jammu and Kashmir, comprises a surface powerhouse with four 180 MW units, a 95 m-high concrete-core rockfill gravity dam. Impounding a 27 km-long reservoir, four headrace tunnels, a spillway and a connecting 500 kV transmission line. It is expected to generate 3.2 TWh/year, for sale to the National Transmission and Dispatch Company of Pakistan under a 30-year PPA.

Karot is the fourth of a cascade of five hydropower stations that are planned to be built on the upper stretches of the river Jhelum, the largest river of the

Indus basin river system. The 1000 MW Mangla station was the first project to be commissioned on the Upper Jhelum, with a total of 10 units installed in four stages from 1967-69 to 1993-94. The remaining three projects are all being developed as independent power projects under the CPEC on the basis of 30-year BOOT concessions.

The 1124 MW, US\$ 2.4 billion Kohala and 700 MW, US\$ 1.6 billion Azad Pattan projects are close to financial closure. A consortium of CTG and CWE Investment Corporation is developing Kohala. Azad Pattan is being developed by a consortium of Laraib Energy and the China Gezhouba Group. Meanwhile, studies are continuing for the development of the 640 MW Mahl run-of-river project, which is to be developed by CSAIL.

PumpEd STORAGE STUdY GOES AHEAD FOR CANADA...

An alliance led by Stantec has been commissioned by WaterPower Canada to assess the potential for pumped-storage development across Canada. The alliance, with the Australian National University, CEATI, and Power Advisory, will help WaterPower Canada and the wider hydropower industry to understand the strategic value of pumped storage better, Stantec announced in June.

In response to the Canadian Government's commitment to achieve net-zero emissions by 2035 and a net-zero economy by 2050, WaterPower Canada has commissioned research to explore opportunities to support increased hydropower in Canada. The assessment report, known as the 'Technical and Economic Potential Assessment of Pumped Storage Hydropower in Canada', is one of those research projects. It will present the strategic advantages and role of pumped storage in a future decarbonized electricity supply-mix in Canada.

"We realize the significance this study can have for the hydropower sector community and the social, economic, and environmental landscape in Canada," said Michael Morgenroth, Stantec's principal investigator on the project and business leader for hydropower and dams in Canada. "That is why we have activated our network to form a study alliance that brings Stantec, CEATI, The Australian National University, and Power Advisory under one roof as a team that can do justice in this strategic study to position waterpower among leaders into a new era."

Carolina Rinfret, President and CEO, WaterPower Canada, commented "New clean energy projects and infrastructure must be rapidly advanced to achieve a net-zero electricity supply in Canada by 2035, and beyond. One of the most promising options for storing electricity

at scale and for long periods of time is pumped storage. Through this study, we intend to raise awareness about this proven and cost-effective type of energy storage, and to demonstrate the full potential that it holds in Canada, especially with the integration of more variable renewable into the grid, like wind and solar energy."

Stantec, which has designed more than 130 hydro projects with a total installed capacity of more than 150 GW, will act as principal investigator and study lead.

The Australian National University, Australia's highest-ranked university, created the 'Global Atlas of Off-River Pumped Hydro Storage'.

CEATI provides leadership in developing applied technology solutions for the electricity industry on a collaborative basis, with about 150 utilities participating from more than 18 countries.

Power Advisory offers extensive experience in North American electricity markets with a deep understanding of the power system, market design, and investment climate.

... as a new alliance is formed to support Canadian pumped-storage

Meanwhile, BBA, an energy and natural resources-focused engineering consultancy in Canada, and Lomhardi of Switzerland have created a strategic alliance to assist with the development of pumped-storage projects in Canada. "The agreement establishes a framework for collaborating on pumped-storage schemes for Canadian clients, while laying the groundwork for international growth", BBA announced on 10 June.

"No new pumped storage stations have been built in North America for more than four decades, but a significant resurgence of interest in this type of technology is underway," the company added.

"Pumped-storage is a proven technology that needs to be part of Canada's energy mix if we truly want to decarbonize our economy," said Francois Vitez, Director of Renewable Energy at BBA.

UK TO INVEST US\$ 200 MILLION IN AFRICAN HYDROPOWER

The UK Government's development finance institution (DFI) is to make the largest investment in hydropower in its 74-year history by taking a minority stake in a joint venture with Norway's DFI Norfund. The British International Investment (BIT) announced on 23 June that it would commit up to US\$ 200 million to construct at least three hydroelectric projects in Africa as part of the partnership. The two entities will hold a 49 per cent stake in a joint venture with Norwegian renewable energy

company. Scatec, with Norfund committing up to US\$ 100 million over the few several years. "Hydropower is critical for providing clean baseload and peaking power, especially in the landlocked countries in Africa, as the continent transitions away from fossil fuels towards a net-zero future," said Chris Chijitomi. The BII's head of infrastructure equity for Africa and Pakistan. The alliance will focus on various existing and new projects, including the planned 205 MW Ruzizi III hydro project on the border between DRC and Rwanda, This is Africa's first trilateral. Public private partnership laid will supply electricity to Rwanda, Burundi and the DRC. Other hydro projects in Scatec's African portfolio include 350 MW Mpatamanga project in Malawi and the 120 MW Volobe hydropower station on the river Ivoudro in Madagascar. The various pipeline projects will be designed and constructed over the next few years. BII estimates that in a decade, the clean electricity provided by the JVs new assets could support the creation of at least 180 000 further jobs, avoid at least 270 000 t CO₂e of GHG emissions annually, and meet the equivalent demand of more than 3 million people, BII's commitment to hydropower comes as it enters a new five-year strategy, in which at least 30 per cent of its planned annual investment of between UK£1.5 billion and UK£2 billion will be devoted to climate finance.

The joint investment extends and compliments BII's and Norfund's existing commitments and partnerships to powering Africa, through Globeleq, an independent power producer in which BII and Norfund are shareholders, and their joint investment in HI Capital, a South African renewables investment and development company. Norfund was instrumental in building SN Power into a hydropower developer in developing countries, which was then sold to Scatec in January 2021. The parties agreed to collaborate on SN Power's projects in Africa, under Scatec's ownership, with Norfund retaining a 49 per cent stake, which will now be shared with BII.

Currently around 600 million people in Africa, equivalent to slightly more than 40 per cent of the population, lack access to electricity. An International Energy Agency (IEA) study published in June predicted that Africa will need US\$ 25 billion of investment per year to achieve universal energy access by 2030. Renewables, including solar, wind, hydropower and geothermal power, will account for 80 percent of new power generation capacity by 2030. according to the IEA's proposed Sustainable Africa Scenario. By 2030, hydropower is set to be the second-largest source of flexible power under the proposed Sustainable Africa Scenario, fossil fuel power plants in 2020 accounted for 80 per cent of Africa's flexible sources for power systems, according to the IEA.

mosul dam REHABILITATION WINS 'OUTSTANDING PROJECT AWARD'

The Deep Foundations Institute (DFI in the USA) has selected the Mosul dam rehabilitation project in Iraq, carried out by Trevi SpA of Italy, for this year's Outstanding Project Award. The award will be presented at DFI's 47th Annual Conference on Deep Foundations, in October.



A view of the Mosul dam and spillway during the grouting work by Trevi, which was recently recognized as an outstanding project.

The Mosul dam, on the Tigris river, was constructed in the 1980s and is the largest in Iraq. It is 113 m-high and 3.65 km-long. During the construction phase, engineers were aware of the foundation's weak rock, and contractors encountered cavities during excavation. As a result of political and schedule pressures, the work continued. Despite extensive grouting efforts, seepage began immediately after commissioning of the dam.

In March 2016, Trevi took over the contract to perform maintenance grouting, along with training the owner's personnel and rehabilitating the bottom outlet tunnels through electromechanical work and diving operations.

From 2016 to 2019, Trevi completed about 403 000 linear metres of grouted boreholes, injecting about 41 000 m³ of grout (equivalent to 26 700 t of solids) into the ground. Trevi also created courses on modern equipment and techniques as part of its remit to engage and train the owner's personnel. (See also H&D Issue 2, 2016).

The company carried out work at the dam, 13 km away from the armed conflict against ISIS. The presence of the coalition forces, together with the Italian army, guaranteed the required security of the project area. Notwithstanding the strict security procedures, the works proceeded expeditiously, with no delays. The workforce numbered more than 700, and the project logged 8 million man-hours worked without accidents.

Established by DFI in 1997, the Outstanding Project Awards recognize the superior work of DFI members. A

committee selects the scheme based on their size, scope and challenges of the project: degree of innovation and ingenuity exercised; and, uniqueness of the solution to the difficulties of the job.

NHPC EXPLORES NEW PROJECTS WITH THE DAMODAR VALLEY CORPORATION

National Hydro Power Corporation (NHPC), India's state hydropower producer and developer, has signed an MoU with the Damodar Valley Corporation (DVC) to explore the setting up of a joint venture to explore and develop hydropower and pumped-storage projects. "The MoU heralds a new dawn in co-operation between the two power sector organizations in jointly harnessing hydropower and pumped-storage projects as energy storage solutions in line with the national energy transition objective of 500 GW of renewable energy by 2030 and net zero by 2070," a spokesman for NHPC said on 20 July.

The DVC, a government-owned power utility, plans to increase its current capacity by more than 100 per cent, through the development of both thermal and renewable energy. DVC's own generation capacity from all sources stands at 6901 MW, with an additional 1388 MW owned through joint ventures. It is also diversifying into new areas, such as pumped storage, integrated battery energy solar system, ground-mounted and floating solar, and green hydrogen. Around 3650 MW of renewable energy projects have been identified by DVC for completion by 2028.

DVC disclosed that the company has plans to develop a 1500 MW pumped-storage scheme at Lugu Pahar on the river Bokaro, a tributary of the river Damodar, in Jharkhand, by 2028, and has identified another prospective site for a 600 MW pumped-storage project at Panchet Hills.

NHPC, meanwhile, has secured pre-investment activities approval from the Union Power Ministry for the 1856 MW Sawalkot hydroelectric project in Jammu and Kashmir. NHPC, which owns and operates a combined capacity of 7071 MW that is predominantly hydro, has a further 6 GW of hydropower under construction. NHPC has secured board approval to raise debt amounting up to INR 63 billion (US\$788 million) during 2022-23 to fund its development programme through the issuance of secured/unsecured, redeemable, taxable, non-convertible corporate bonds on a private placement basis and also term loans and external commercial borrowings.

BAJOLI HOLI PROJECT COMMISSIONED IN HIMACHAL PRADESH, INDIA



The recently commissioned 180 MW Bajoli Holi scheme in India, which will help support economic activity in the country.

GMR Energy, a unit of the Indian multinational infrastructure company, has officially commissioned the 180 MW Bajoli Holi project in India's northern state of Himachal Pradesh. Three 60 MW units have been generating since the project was connected to the grid in March 2022, according to GE Renewable Energy, which was responsible for the design, supply and installation of the project's complete electro-mechanical equipment.

The 180 MW run-of-river station on the river Ravi, in Chamba district, is the group's first hydropower project, and will be operated for a period of 40 years on a BOOT (build-own-operate-transfer) basis under a concession awarded in 2007 by the Indian Government.

The contract for the electro-mechanical supply was awarded to GE Hydro Solutions in March 2015. The company was responsible for design and engineering, supply, transportation, erection, testing and commissioning of vertical Francis units, generators, penstock valve, main inlet valve, digital governing system, excitation system, control and monitoring, protection system, electrical and mechanical balance of plant equipment. GMR noted that GE Hydro Solutions had commissioned all three units within 11 days of water availability. This was despite a series of challenges created by the pandemic. In addition to providing the local population with sustainable and clean energy, the Bajoli Holi hydro plant actively contributes to the functioning of the country's infrastructure. For example, it generates 94 per cent of energy required by Delhi's Indira Gandhi international airport, which recently became the first in India to run entirely on hydro and solar power.

Forthcoming Events

Sr. No	description	date	Country/Organizer
1	IWA World Water Congress & Exhibition	Copenhagen, Denmark	11-15 September 2022
2	ANCOLD 2022 Dam Operator Forum	Strathgordon, Tasmania, Australia	12-14 September 2022
3	Dam Safety 2022	Baltimore, Maryland	18-22 September 2022
4	Hydropower Insight	Perth, Scotland	19-21 September 2022
5	Pan Africa Capacity Building Workshop on International Water Law and Water Governance	Entebbe, Uganda Africa,	19-23 September 2022
6	24th ICID International Conference and the 73rd IEC Meeting	Adelaide, Australia	03-10 October 2022
7	Business Hydro Grenoble	Grenoble, France	10-11 October 2022
8	6th International Conference Dam Safety Conference 2022	Jaipur, India	10-11 October 2022
9	14th International Symposium on Eco – Hydraulics	Nanjing, China	10-14 October 2022
10	ANCOLD NZSOLD Conference 2022	Sydney, Australia	26-28 October 2022
11	Vienna hydro 2022, the 21st International Seminar on Hydropower Plants	Vienna, Austria	09-11 November 2022
12	AFRICA 2022 Water Storage and Hydropower Development for Africa	Uganda Africa,	29 Nov- 01 Dec 2022
13	IWA Digital Water Summit	Bilbao, Spain	29 Nov- 2 Dec 2022
14	13th IWA International Conference on Water Reclamation and Reuse	Chennai, India	15-19 January 2023
15	ASIA 2023 Water Resources and Renewable Energy Development in Asia	Kuala Lumpur, Malaysia	14-16 March 2023
16	ICOLD-CIGB 2023-91st ICOLD Annual Meeting	Gothenburg, Sweden	11-15 June 2023
17	12th ICOLD European Club Symposium	Interlaken, Switzerland	05-08 September 2023
18	XX Technical Dam Control International Conference		12 -15 September 2023
19	Hydro 2023: New Ideas for Proven	The EICC, Edinburgh, Scotland	16-18 October 2023
20	XX Technical Dam Control International Conference		12-15 September 2023
	Hydro 2023: New Ideas for Proven	The EICC, Edinburgh, Scotland	16-18 October 2023

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Aims & Scope

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

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

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

A.k. dinkar

Secretary General

Indian Committee on Large Dams

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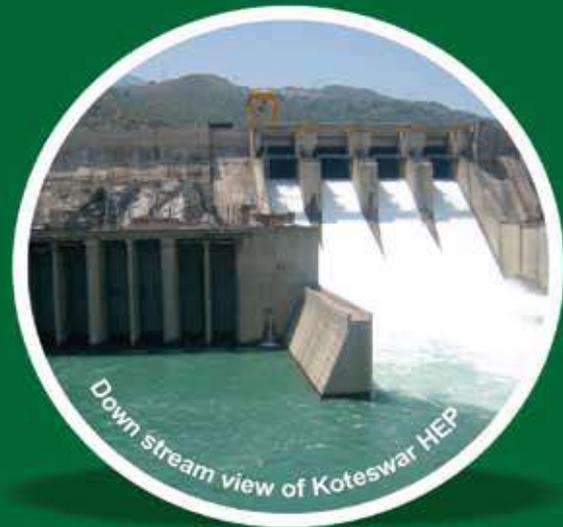
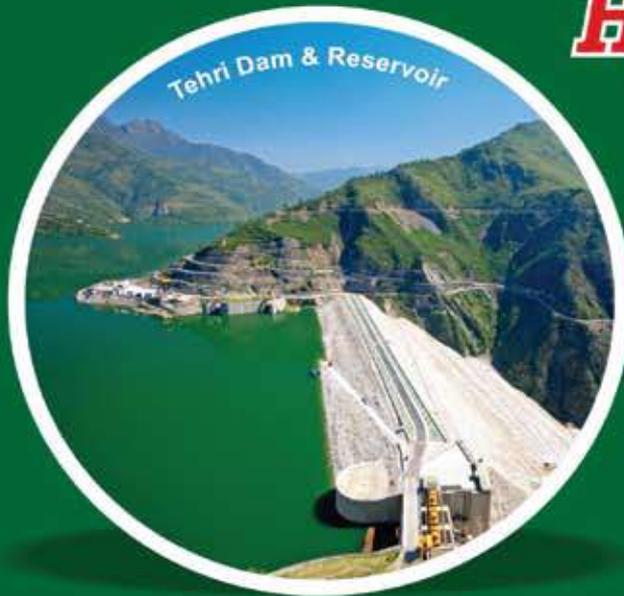


PrOGrAmME SCHEduLE

DAY	GENERAL PROGRAM	TECHNICAL EXHIBITION	SOCIAL PROGRAM	WORKSHOPS & COURSES
June 5-9	- Pre Conference Tours			
Saturday June 10	- Meeting of ICOLD Board			All day
Sunday June 11	- Meeting of ICOLD Board - Chairmen Tech Com - Regional Clubs & YEF - Techn. Com. WS	Opening	Welcome Reception	
Monday June 12	- Meeting of Tech Com	All day		
Tuesday June 13	- Symposium	All day	Cultural Evening	
Wednesday June 14	- Technical Excursions - Symposium or Workshops	Half day		Half day (WS only)
Thursday June 15	- General Assembly - Workshops		Farewell Dinner	Half day (WS only)
Friday June 16	- Post Conference Tours			

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