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INCOLD

INCOLD JOURNAL

A Half Yearly Technical Journal of Indian Committee on Large Dams

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INDIAN COMMITTEE ON LARGE DAMS
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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The original unpublished manuscripts that enhance the level of expertise and research in the various disciplines covered in the Journal are encouraged.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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ABOUT JOURNAL

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

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Secretary General

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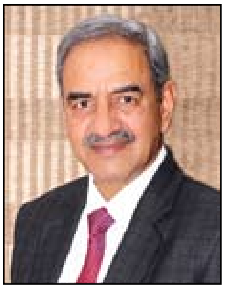
From the President Desk



Dear ICOLD and INCOLD Members, Colleagues, Ladies and Gentleman,

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

The global spread of COVID-19 coronavirus has infected millions of people around the world and is continuing at faster pace. At the moment, it's a challenge to contain the pathogen. This crisis calls for greater cooperation across the borders to turn the tide. Together we shall defeat the pandemic, together we can, we will. On behalf of ICOLD fraternity, we would like to offer our heartfelt condolences to the families of the victims around the world. It is hoped that soon we will be able to overcome this deadly virus after administration of vaccination and stay out of danger through international cooperation.

On behalf of the INCOLD and on my personal behalf, I wish to express our solidarity with the ICOLD and INCOLD Family Members during the outbreak of COVID-19. Our prayers and thoughts are with the families currently dealing with COVID-19. In view of the COVID-19 situationthroughout the Globe, based on the request of INCOLD, ICOLD Board has taken a decision to change the dates ofICOLD Symposiumfrom April to September then to November-December and finally it is now being organized from **24th- 27th February 2021** at New Delhi.

ICOLD Symposium will provide an excellent platform for researchers, scientists, engineers, policy makers and young professionals working in the field of energy and water resources management around the world. This event will definitely act as confluence of brilliant minds and provide an interactive platform to share path breaking ideas on the theme 'Sustainable Development of Dams and River Basins' besides Special Workshops being organized by ICOLD experts.

The Indian National Committee on Large Dam (INCOLD) has prepared an excellent program for ICOLD and APG Symposium. In view of our challenges to further develop dams and reservoirs worldwide and combating the effects of climate change, I invite the dam professionals from all over the Globe to join us for the ICOLD and APG Symposium, to discuss and deliberate on emerging professional issues along with meeting the National and International dam experts.

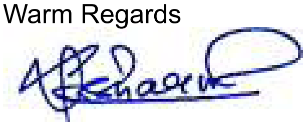
The Symposium would see convergence of renowned dam experts in academia, industry,utilities& research institutions and in other related disciplines from across the world. These expertsand participants would brainstorm and deliberate on various aspects of sustainable development of dams and river basins i.e., meeting the needs of the present without compromising the ability of future generations to meettheir own water needs.

The deliberations of the symposium would include presentations by national and internationalexperts who are involved in the planning, design, construction and operation & maintenance ofdams and associated structure and would share their experiences to tackle the various issues connectedwith the sustainable development of dams and river basins.

INCOLD offers heartfelt condolences to the families of the victims who lost their lives, to those untraced and to all those who have been impacted in the recent tragedy in Uttarakland, on 7th February, 2021 due to breaking of Nanda Devi glacier.

I am looking forward to welcoming the ICOLD and INCOLD family, old members as well as newcomers on Virtual Platform.

Warm Regards



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

Editorial

India has built 5334 large dams which includes dams like Bhakra, Tehri, and Sardar Sarovar and 411 dams are under construction. The Dam industry in India has contributed significantly towards meeting the water and power demand of the country, yet India is facing increasing pressure for additional water storage due to population growth, urbanization, change in use pattern and creeping effect of climate change.

To focus on the sustainable development of dams and river basins, INCOLD in collaboration with CWC, DRIP and NHP is organising Symposium on "Sustainable Development of Dams and River Basins" under the aegis of ICOLD at New Delhi as Hybrid event from 24th - 27th February 2021.The above symposium is being organised to provide an excellent opportunity to Indian Dam Engineering Professionals and Agencies to share their experiences, ideas and latest developments in new materials and construction technologies, advancement in investigation techniques, best engineering practices, dam safety issues etc. Besides opportunity to networking with the world renowned dam experts from different countries and global organizations involved in Dam Construction, management and operation and maintenance for mutual benefits.

The Symposium would provide an interactive platform for eclectic brainstorming and sharing pathbreaking ideas & case studies in respect of the theme which will be addressed through oral presentations on the topicsviz. Modern Technologies in Survey and Investigation for Sustainable Dam Development; Simulation Methodologies for Dam Analysis and Design; River Basin Development and Management including Optimization of Reservoirs Operation and InnovativeConstruction Methodology and Contracting Practices; Impacts of Climate Change – Sustainable Dams and Hydropower development including Pumped Storage and engineering challenges and safety of Tailing Dams and Advances in Dam Safety, Risk Assessment & Management and Rehabilitation of Dams to address vulnerable issues regarding Sustainable Management of Water Resources. I anticipate veryenlightening deliberations on these facets. Concurrent with symposium, an exhibition on virtual platform is also being organizedto showcase the latest productsand services in the dam engineering field besides the seven workshops to focus on the different aspects of dam engineering.

The delegates have the chance to participate in the deliberations of the Symposium on "Sustainable Development of Dams and River Basins" and APG Symposiumin "Water and Dams", which will focus on important topics such as Dam Safety, River Basin Development, flood management and extreme events, Tailings Dams - Life Extension and Rehabilitation Strategies, sedimentation management, and reservoir seismicity. The expected outcomes of ICOLD Symposium in India will certainly be indispensable for the global dam community.In view of the many opportunities and challenges in our industry, I advise you to attend ICOLD Symposium, and to discuss the emerging professional topics of the Symposium and Workshop, which will be of a high quality.

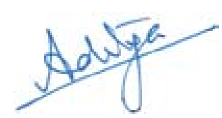
More than 800 delegates representing international experts, policy and decision makers from Centraland State Governments, officers of Irrigation and Water Resources Department, Agriculture, donoragencies, academician, consultants as well as NGO's are likely to participate in the event.

From 43 countries, 285 full text of technical papers received from dam professionals are incorporated in the Proceedings volume which would certainly add new dimensions to the body of knowledge on the subject.We are grateful to authors of the various papers for their efforts in preparation of abstracts, papers and their presentations. About 130 presentations will be made during the 27 technical sessions besides more than 30 presentations in the seven workshops are being organized on 27th February 2021 on virtual platform.

We are sure that the deliberations of the ICOLD Symposium would help the participants in better understandingof the various aspects of Sustainable Development of Dams and River Basins in the country.

In view of the many opportunities and challenges in our industry, I request you to attend ICOLD Symposium, to discuss the emerging professional topics of the Symposium and Workshops, which will be of a higher quality technical interest.

I am looking forward to welcoming and meeting the ICOLD and INCOLD family, old members as well as newcomers on Virtual Platform.



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

Effect of Reservoir-Triggered Seismicity on Safety of Large Dam Projects

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ABSTRACT

The first case of reservoir-triggered seismicity (RTS) was observed during impoundment of the reservoir stored by Hoover dam in 1935. Since then, over 100 cases of RTS have been reported from large storage dams worldwide. The strongest events suspected of being triggered by reservoirs with magnitudes up to 6.3 were recorded in India, China, Greece and Zambia. However, most of them are small events. Although RTS only affects a small number of dams, it has remained controversial and has become a key safety subject for groups opposing new dams. Reservoir-triggered seismic phenomena are seismic events which needed the incremental effects of reservoir load and the build-up of pore pressure to make them happen. The effect of RTS on the seismic design of large dam projects and on buildings, infrastructure and people living in the dam and reservoir region, are discussed. As RTS usually occurs within a few years after impounding of the reservoir, it has an effect on the seismic hazard and design criteria for appurtenant structures, buildings and infrastructure but not on the ground motion of the safety evaluation earthquake, used for designing and checking the seismic safety of dams and safety-critical elements such as spillways and low level outlets. The prediction of the largest RTS events is not possible today but by seismic monitoring, irrational concerns about dam safety can be greatly reduced. The different aspects of RTS are discussed from the solution-oriented viewpoint of dam engineers, which may be quite different from that of earth scientists. As dams are being built in seismic regions, there is great uncertainty, if strong earthquakes are actually triggered by reservoirs.

***Keywords** : Reservoir-triggered seismicity, Dam safety, Seismic design criteria, Earthquakes, Earthquake hazard, Reservoir impoundment*

1. INTRODUCTION

This paper gives an overview on the possible effects of reservoir-triggered seismicity (RTS) on the safety of large dam projects. The first case of RTS was observed in connection with the impounding of Lake Mead, the reservoir stored behind Hoover dam in USA, in 1935. Since then, over 100 cases of RTS have been reported from all over the world [1]. In the past, the term “induced seismicity” was used to describe these seismic phenomena, but as the seismicity is usually associated with tectonic processes, the correct term used in connection with large dams and reservoirs is “reservoir-triggered seismicity”. This is very important as dams and reservoirs cannot create earthquakes. The term induced seismicity would only be appropriate with, for example, the collapse of underground cavities formed by people (mining activities), hydraulic fracturing and others, which, in general, is less important for dams than RTS.

Hundreds of papers have been written on RTS and many more will be published in future as dam construction is going on in the foreseeable future. Because the largest RTS events cannot be predicted, which is a hard problem, similar to earthquake prediction, RTS has become the preferred dam safety topic for people opposing large dam projects. As dam engineers and owners were often not familiar with RTS, in the past, it was addressed by introducing a separate load case for dam design, which was called “induced seismicity”. This term is still used in some projects or old guidelines, but as mentioned above, this is an incorrect term. Sometimes it takes a long time until terms and methods, which are obsolete, are replaced. For example, the pseudostatic method introduced for the seismic analysis of concrete and embankment dams in the 1930s, is still used today by many dam engineers, although, based on the damage caused by the 1971 San Fernando earthquake in California, it was concluded that this method may give incorrect results and therefore, should no longer be used. This is also the recommendation of the ICOLD Committee on Seismic Aspects of Dam Design.

The state of knowledge on RTS phenomena, including the physical processes causing RTS and several case studies, is discussed in [1]. These scientific-oriented subjects are not discussed again. The present paper gives a rational assessment of RTS from the viewpoint of dam engineers and, hopefully, it will answer the main questions regarding the dangers of this hazard and how RTS problems can be solved, despite the very large uncertainties involved. RTS is an old phenomenon. However, interest in induced seismicity caused by fracking and liquid waste storage in the US as well as geothermal projects, has grown significantly in recent years. The underlying processes of these types of seismicity, i.e. cracking due to increase in pore pressure, are similar to that of RTS. However, the pore pressures applied in these projects are several orders of magnitude higher than those caused by the filling of a reservoir.

Strong earthquakes, which are suspected of being reservoir-triggered, have occurred in the reservoirs formed by the Koyna gravity dam (India), Hsinfengkiang buttress dam (China), Kremasta embankment dam (Greece), and Kariba arch dam (Zambia), so that the general interest for this phenomenon has sharply increased. The maximum magnitudes of the seismic events observed in these reservoirs were in the range of 6.0 to 6.3. As reservoir-triggered earthquakes tend to have shallow focus, the ground motion at the dam sites of Koyna (1967) and Hsinfengkiang dams (1962) was very severe and caused cracks in both dams. These two approximately 100 m high concrete dams were subsequently repaired and strengthened and are in operation today. The microseismic activity in the reservoir region of Koyna and Hsinfengkiang dams is still high. For example, in the Koyna dam region nearly 100 earthquakes with magnitude M>4 and about 10 events with M>5 have occurred since 1967. The ground motions caused by these earthquakes are of no serious concern for the safety of the strengthened dam.

RTS was mainly observed at large storage dams with maximum reservoir depth exceeding approximately 100 m and reservoirs with a volume of over 500 Mm3, which tended to decrease with time after the first filling of the reservoir.

In order to assess the implications of RTS on the safety of large storage dam projects, it is necessary to have a proper understanding of the current seismic design criteria. Unfortunately very few who question the safety of large storage dams under the effect of RTS know about it and therefore unrealistic scenarios, questioning the safety of dams, are brought forward.

The seismic design criteria and methods of dynamic analysis of dams have undergone substantial changes since the 1930s when earthquake actions have been introduced to the design of dams. Today we have a clear concept for the seismic design criteria to be applied when a dam is subjected to ground shaking and methods of dynamic analysis have been developed, which allowthe calculation of the inelastic seismic response of embankment and concrete dams.

However, we must recognize that earthquakes can cause multiple hazards in large dam projects including ground shaking, fault movements in the footprint of dams and in reservoirs, rockfalls, landslides, liquefaction, ground deformations, seepage, impulse waves in reservoirs etc. [3]. In the subsequent sections the modern seismic design criteria for dams, the possible effects of RTS on dam design, the possible effects during the first years of reservoir operation, the possible effects on the safety of existing and new buildings and infrastructure in the dam and reservoir region, and the possible psychological effects of people living in the region affected by RTS, are discussed. This is a more comprehensive approach than the one followed in the past, which focused on dam safety only.

2. OVERVIEW ON SEISMIC DESIGN CRITERIA FOR LARGE STORAGE DAMS

In order to assess the implications of RTS on the seismic safety of large dam projects, we must know what types of design earthquake ground motions are used for the seismic design and safety evaluation of the different structures and elements of a large storage project. The seismic design criteria for dams, which have been updated recently by the Committee on Seismic Aspects of Dam Design of ICOLD [2] cover the following structures and elements of large storage projects subjected to ground shaking:

(i) the dam body,

(ii) the safety-critical elements like low level outlets and spillways (hydro-mechanical and electro-mechanical equipment, motors, power supply, emergency power supply, control units, etc.), which must be operable after a strong earthquake,

(iii) appurtenant structures including powerhouse, penstocks, desilting basins, switchyard, transmission lines, hydro-mechanical and electro-mechanical equipment etc., and

(iv) temporary structures such as cofferdams, diversion facilities, retaining structures and critical construction stages of the dam and appurtenant structures.

In the discussion of dam safety, the importance of spillways and low level outlets (i.e. bottom outlets, sediment flushing outlets, irrigation outlets, low level spillways, etc.) in controlling the reservoir after a strong earthquake is often underestimated. These elements are also needed to lower the reservoir level if there are dam safety concerns or threats of increased RTS, or for repairing earthquake damage on the upstream dam face.

In the subsequent sections the different types of design earthquakes to be used for these structures and elements are discussed, i.e.

- Safety Evaluation Earthquake (SEE): The SEE is the earthquake ground motion a dam must be able to resist without uncontrolled release of the reservoir. The SEE is the governing earthquake ground motion for the safety assessment and seismic design of the dam and safety-critical components, which have to be functioning after the SEE.

- Design Basis Earthquake (DBE): The DBE with a return period of 475 years or 2475 years, depending on the seismic building code used, is the reference design earthquake for the appurtenant structures. The DBE ground motion parameters are estimated based on a probabilistic seismic hazard analysis (PSHA). The mean values of the ground motion parameters of the DBE can be taken.
- Operating Basis Earthquake (OBE): The OBE may be expected to occur during the lifetime of the dam. No damage or loss of service must happen. It has a probability of occurrence of about 50% during the service life of 100 years. The return period is taken as 145 years The OBE ground motion parameters are estimated based on a PSHA. The mean values of the ground motion parameters of the OBE can be taken.
- Construction Earthquake (CE): The CE is to be used for the design of temporary structures such as coffer dams and takes into account the service life of the temporary structure.

The SEE ground motion parameters can be obtained from probabilistic and/or deterministic seismic hazard analyses, i.e.

- Maximum Credible Earthquake (MCE): The MCE is the event, which produces the largest ground motion expected at the dam site on the basis of the seismic history and the seismotectonic setup in the region. It is estimated based on deterministic earthquake scenarios. According to ICOLD [2] the ground motion parameters of the MCE shall be taken as the 84 percentiles (mean plus one standard deviation).
- Maximum Design Earthquake (MDE) : For large storage dams the return period of the MDE is taken as 10,000 years. For dams with small or limited damage potential shorter return periods can be specified. The MDE ground motion parameters are estimated based on a probabilistic seismic hazard analysis (PSHA). According to ICOLD [2] the mean values of the ground motion parameters of the MDE shall be taken.

For major dams the SEE ground motion parameters (peak ground acceleration, acceleration response spectra, duration of strong ground shaking, spectrum-matched acceleration time histories) can be taken either as those of the MCE or MDE. Usually the most unfavorable ground motion parameters have to be taken. If it is not possible to make a realistic assessment of the MCE then the SEE shall be at least equal to the MDE.

It must be added that for the seismic design of dams ground motion parameters are used, which do not have the characteristics, the earth scientists feel are physically correct, i.e. duration of strong ground shaking, near field and directivity effects, spectrum shape of main shocks and aftershocks etc. However, the dam designer will use simplified models of the design earthquake ground motion and methods of dynamic analysis that lead to a safe design, even if the earthquake ground motion models do not comply with the real nature of the earthquake ground motion! This concept may be difficult to accept by seismologists and other experts, who are not familiar with the seismic design of dams. However, the use of load models for live loads etc., which do not represent reality, is standard practice in the design of buildings, bridges and other structures. The same concept is used for the seismic design of dams.

The ground motion parameters at the dam site, caused by the largest RTS events, may be determined by a deterministic hazard analysis in which different RTS scenarios are considered.

3. EFFECTS OF RTS ON DAM SAFETY

Today it is generally accepted that significant reservoir-triggered earthquakes can only occur in regions with high tectonic stresses in the earth crust, i.e. the causative fault that can produce the earthquake is already in near failure conditions, so that added gravity stresses and pore pressure propagation due to reservoir impounding, can trigger the seismic energy release. This means that triggering due to impounding cannot change the underlying tectonic processes and the long-term seismic hazard at the dam site, if the seismic potential at a dam site is correctly assessed.

The basic requirements for reservoir-triggered seismic activity are [1] and [5]:

- the existence of active faults in the reservoir region, or
- the existence of faults near failure limit (i.e. high tectonic stresses in reservoir region).

A large dam, which has been designed against earthquakes according to the current state of practice requiring that the dam can safely withstand the ground motions caused by the SEE, can also withstand the effects of the largest reservoir-triggered earthquake as the SEE ground motions are, per definition, larger than those caused by the strongest RTS events, i.e. RTS cannot trigger earthquakes, which are stronger than the MCE. Therefore, a dam, which has been designed according to modern seismic design guidelines [2], is safe against the worst-case RTS events. This is also true as most RTS events are much smaller than those used in the dam design. Accordingly, there is no need to consider an extra RTS load case in the design of dams.

As the magnitudes of reservoir-triggered earthquakes are decreasing with time, it is rather unlikely that such events will jeopardize the safety of existing dams, even if they were not designed according to the current state of practice. However, it is strongly recommended that the earthquake safety of dams, which have a continuing record of increased seismicity, be reassessed, especially when they have been designed against earthquakes using design criteria and methods of dynamic analysis, which are considered as outdated or even obsolete today, such as the pseudostatic seismic design method with a seismic coefficient of 0.1, which has been common practice in the past.

It is understood, based on the observation of dams during strong earthquakes, that well designed and constructed dams can withstand ground motions of near-field earthquakes with magnitudes of 5 or larger and remain functional, i.e. are undamaged.

The Koyna gravity dam and Hsinfengkiang buttress dam mentioned earlier, which were damaged during earthquakes, had unusual shapes that were vulnerable to earthquake shaking. Moreover they had been designed against earthquakes using the pseudostatic analysis method with a seismic coefficient, which was unrelated to the seismic hazard at the dam site. In other words, these dams were not designed according to the current seismic design practice for large dams as presented in the previous section.

4. EFFECTS OF RTS ON EXISTING STRUCTURES IN RESERVOIR REGION

Relatively strong reservoir-triggered earthquakes may cause damage to existing buildings and structures in the project region. During the magnitude 6.3 Koyna earthquake of 1967 about 100 people were killed in villages in the dam region. The damaged buildings were not designed for earthquakes as the region of the dam was not considered as a seismic area. Although the earthquake is referred to as a reservoir-triggered event in the literature, it is argued by dam engineers and the owner that it would have occurred anyway, even if the dam would not have been built. To prove that a strong earthquake has been triggered by a reservoir is very difficult, as the stresses fields and strength properties of faults at focal depths of over 10 km cannot be measured.

A reservoir-triggered earthquake with a magnitude of 6.3 (observed maximum RTS magnitude) can cause peak ground accelerations that may approach those caused by the SEE. However, the duration of strong ground shaking of RTS events, which contributes mostly to the observed damage in structures and not the peak ground acceleration, is usually much shorter than that of the SEE. Despite of that, short-duration reservoir-triggered earthquakes can still cause considerable damage to buildings and structures, which have not been designed for earthquake actions. The main difference between a reservoir-triggered earthquake and a natural earthquake is that RTS likely to occur within the first few years after impounding of the reservoir. These earthquakes have often a shallow focus and their epicenters are relatively close to the dam sites. Thus the short-term seismic hazard for moderate earthquakes may increase. However, prediction of the size, date and place of large RTS events, which can cause damage to dams or other structures, will still not be possible for quite some time.

5. EFFECTS OF RTS ON SEISMIC DESIGN OF LARGE DAMS, AND STRUCTURES IN RESERVOIR REGION

If RTS is possible then the DBE and OBE ground motion parameters, discussed in Section 2, should cover those from the critical and most likely RTS scenarios as such events are likely to occur within years after the start of the impounding of the reservoir. This means that these parameters must be increased if they are lower than those estimated for the largest RTS events. But as mentioned earlier, the RTS ground motion parameters are in most cases much smaller than those of the SEE.

As prediction of the strongest RTS events is still not possible, therefore the following solutions may be considered by the dam owner to minimize the risk of claims from damage caused by unpredictable RTS events:

(i) to conservatively design all new structures at the dam site and in the reservoir region;

(ii) to strengthen, seismically vulnerable structures;

(iii) to establish a photographic database of all existing buildings and structures in the project area, which could be damaged by RTS and to use this as a basis for the assessment of claims if RTS is observed, or

(iv) to wait with the construction of new structures in the reservoir region until RTS has diminished.

Other solutions are also possible. To cover any unforeseen claims, the dam owner should have a proper insurance. However, to abandon a dam project because of anticipated RTS, as put forward by dam opponents, would be an unjustified over-reaction, as there are structural and nonstructural solutions available for dealing with this hazard. Up to now no dam project, known to the author, has been abandoned because of RTS concerns. Moreover, in any dam and large infrastructure projects there are other hazards from the natural and man-made environment as well as site-specific and project-specific hazards, which have more severe implications on the safety of these projects than RTS.

Irrespective of these solutions, monitoring of the seismicity in the reservoir region, as discussed in the subsequent section, is strongly recommended for large storage projects.

6. RTS MONITORING

For settling any reservoir-triggered earthquake claims, a comprehensive monitoring of the seismicity before dam construction, and during and after impounding of the reservoir is strongly recommended. Such measurements help to dispel any doubts about what is actually happening as otherwise speculative interpretations of events may appear, which a dam owner may not be able to explain. It is very important that the project region is monitored a few years prior to the start of dam construction, in order to establish a record of the natural seismicity, which can be used as reference for the assessment of any RTS. If no instruments are placed or placed too late it is very likely that the observed activity will be attributed to the reservoir and its owner. The monitoring system should be capable to record the microseismic activity in the reservoir region and to record the strongest events, which can cause damage (mainly cracks and deformations) in buildings. The regional seismic networks may not be enough as the density of networks in remote areas, where dams are located, may be inadequate.

A project-specific network may include 4 to 6 seismic stations. These can be either geophones or sensitive accelerometers. Accelerometers are also used for the strong motion monitoring of dams, but this monitoring system is different from that of RTS monitoring.

As large dam construction has peaked off in many countries, it is unlikely that the number of new dam projects, which will experience RTS, is growing substantially in the near future. The dams where RTS was observed and is still taking place are not considered as a major risk as the seismicity and the maximum magnitudes of the shocks tend to decrease with time. However, it is strongly recommended to monitor continuously the ongoing seismicity in the reservoir region where RTS has been observed in the past and to install monitoring systems in the reservoir region of future dams (i) where reservoir-triggered seismicity is expected due to the size of the project and the seismotectonic setting, (ii) where many people are living in the reservoir area, or (iii) where important industries and infrastructures are located near a new reservoir.

7. EFFECT OF RTS ON LANDSLIDE AND ROCKFALL HAZARD

The main dam safety concern of RTS is the landslide and rockfall hazard as mass movements into the reservoir can cause impulse waves and overtopping of the dam or they may block intakes or damage gates or motors for operating spillway gates. Such mass movements can already be triggered by moderate to large RTS events. Of main concern are mass movements close to the dam, intake structures and spillways. Based on the damage caused by landslides to hydropower projects in the epicentral region of the May 12, 2008 Wenchuan earthquake in China, it is concluded that the landslide and rockfall hazards have been underestimated and not addressed in equal detail as the effect of ground shaking on dams and other structures. As the safety of natural slopes is around 1, mass movements can easily be triggered. Moreover, due to reservoir impounding and reservoir operation, the safety of slopes will be decreased.

In Fig. 1 landslides are shown, which occurred near the 152 m high Zipingpu concrete face rockfill dam during the Wenchuan earthquake. These shallow slides were not dangerous as they occurred when the reservoir was only about 30% full, i.e. impulse waves had no effect on the dam as the freeboard was very large.

Fig. 1 : Rockfalls in the Zipingpu reservoir area caused by the May 12, 2008 Wenchuan earthquake in China (photo taken from Zipingpu dam crest when reservoir was full, April 2009)

Slope failures triggered by RTS are also a great problem if they can cause damage to buildings and infrastructure (mainly roads) in the reservoir region. This damage can be more severe than that due to ground shaking. Therefore, in mountainous regions, it is not enough to focus on the seismic safety of structures against ground shaking only. It shall not be forgotten that the seismic hazard is a multi-hazard, which can affect large dam projects in different ways [3]. In the case of RTS the situation becomes even more complex as the buildings and structures in the reservoir region must also be included.

8. PSYCHOLOGICAL AND OTHER EFFECTS OF RTS

As discussed in Section 3, RTS is not a safety problem for well-designed and constructed dams; however, if unexpected seismic events occur more frequently, people living below a dam may start questioning its seismic safety. It may be difficult to dispel such safety concerns, because of mistrust in authorities and other reasons acceptance of scientific and technical arguments may be limited among the people living in the project area. These concerns may also promote irrational and superstitious beliefs especially when such noise is persisting and when former villages have been submerged by the reservoir.

Moreover, small magnitude RTS events and also cracking caused by the redistribution of stresses in the (brittle) foundation rock of arch dams with high in situ stresses can be accompanied by explosion-like noise. Close monitoring of the seismic activity in the reservoir region before, during and after reservoir impounding is still the best way for dam owners and authorities to respond to psychological concerns as well as to claims of physical damage to buildings and structures.

The magnitudes of RTS events are generally small and it is assumed that they do not cause any damage. However, in the case of the Katse arch dam in Lesotho RTS events with a maximum magnitude of 3.0 occurred during impounding of the reservoir and movements on shears were observed in an upstream village, which were not related to active faults but to high stresses in the basalt layer overlaying old sandstone formations. The fissures opening along a shear zone caused some damage to seismically weak local buildings and the depletion of wells. The damage had to be compensated by the dam owner.

9. WENCHUAN EARTHQUAKE OF MAY 12, 2008

Shortly after the Wenchuan earthquake, reports have appeared in the press, which claimed that this magnitude 7.9 earthquake was triggered by the impounding and operation of the Zipingpu reservoir. The main arguments were that (i) large reservoirs can trigger earthquakes, (ii) the epicenter of the Wenchuan earthquake was located 17 km from the Zipingpu dam, and (iii) a small part of one branch of the reservoir intersects the fault, which ruptured during the earthquake.

From March 29 to April 4, 2009 a joint mission of ICOLD, headed by the author, Chairman of the ICOLD Committee on Seismic Aspects of Dam Design, and the Chinese National Committee on Large Dams, led by ICOLD President Jia Jinsheng and Chen Houqun, member of the Chinese Academy of Engineering, visited dam sites and prepared a position paper on reservoirs and the Wenchuan earthquake, in which the issue of triggering of the Wenchuan earthquake by the Zipingpu reservoir was addressed. Thirteen foreign dam and earthquake experts and an equal number of Chinese experts (Fig. 2) participated in this mission. It was concluded that there is no evidence that the Wenchuan earthquake was triggered by the Zipingpu reservoir. Further studies by Chen et al. supported this conclusion [6]. This statement is still valid today.

The dam engineers are convinced that the Wenchuan is not a reservoir-triggered earthquake, but earth scientists still make contradictory statements without giving supporting evidence [4] and [5]. This example shows that the definition of RTS is not straightforward when an assessment of the triggering mechanisms of the strongest events near dams and reservoirs has to be made and justified by evidence. Moreover, if a tectonic fault is close to failure then it is almost impossible to determine the exact factors triggering a major earthquake. This is also the case for the Wenchuan earthquake.

Fig. 2 : Members of ICOLD-CHINCOLD delegation at the Zipingpu CFRD (April 2009)

10. CONCLUSIONS

In the seismic safety assessment of dams it is not necessary to treat RTS as a separate load case as the ground motion caused by the safety evaluation earthquake (SEE) is more severe than that of the largest reservoir-triggered earthquake.

Up to now, the maximum observed magnitude for reservoir-triggered earthquakes is about 6.3. It is almost impossible to prove that the occurrence of a strong earthquake has been caused or influenced by the impounding of a reservoir, as the focal depth is usually several kilometers and it is not possible to measure the in situ stress field and the strength properties along faults at such depths.

Reservoir-triggered earthquakes may cause mass movements (landslides, rockfalls, avalanches, debris flows, etc.) into the reservoir, resulting in water waves that could cause overtopping of a dam. An adequate freeboard has to be provided during the period of increased RTS and mass movement hazards.

Natural slopes in the reservoir region, which are prone to failure, may fail even under small magnitude earthquakes as those caused by RTS. Such slopes are a problem if they can cause damage to buildings and infrastructure (mainly roads in mountainous regions).

Buildings and structures in the reservoir region are normally designed according to seismic building codes. If the ground motion parameters of the design basis earthquake (DBE) for buildings and other structures in the reservoir area are lesser than those of the strongest RTS event, then the DBE ground motion parameters shall be increased to cover RTS events, which are likely to occur within a short period after impounding of the reservoir. The same adjustment will be needed for the ground motion parameters of the operating basis earthquake (OBE) used for the design of the dam and safety-critical elements. However, the safety of the dam and safetycritical elements (spillways and low level outlets) must be checked for the SEE, which is much more severe than the OBE.

Reservoir-triggered microseismic activity, which can be felt or heard, creates safety concerns among the people living below dams, which have to be taken up seriously by the dam owners.

Monitoring of the seismic activity prior, during and after impounding of a reservoir is highly recommended for large storage dams and dams located in tectonically stressed regions.

If a tectonic fault is close to failure then it is almost impossible to determine the exact factors triggering a major earthquake. The same applies to the largest events, which are assumed to have been triggered by the impounding of reservoirs.

The magnitude 7.9 Wenchuan earthquake in China does not have features of RTS and there is no evidence that it was triggered by the impounding of the Zipingpu reservoir.

Acknowledgements

The paper is an update of a paper on a similar topic prepared for the 16th World Conference on Earthquake Engineering, held in Santiago de Chile in January 2017[5].

REFERENCES

[1] ICOLD (2011) Reservoirs and Seismicity - State of Knowledge, Bulletin 137, Committee on Seismic Aspects of Dam Design, International Commission on Large Dams (ICOLD), Paris

[2] ICOLD (2016) Selecting Seismic Parameters for Large Dams, Guidelines, Bulletin 148, Committee on Seismic Aspects of Dam Design, International Commission on Large Dams (ICOLD), Paris.

[3] Wieland M (2009) Features of seismic hazard in large dam projects and strong motion monitoring of large dams, Int. Journal Front. Archit. Civ. Eng. China, December 2009

[4] Wieland M (2010) Seismic Aspects of Large Dams: Lessons Learnt from the May 12 2008 Wenchuan Earthquake, Proc. Int. Symposium on Dams & Sustainable Water Resources Development, 78th ICOLD Annual Meeting, Hanoi, Vietnam, May 20-26.

[5] Wieland M (2017) Reservoir-triggered seismicity and effect on seismic design criteria for large storage dams, Proc. 16th World Conference on Earthquake Engineering, 16WCEE, Santiago de Chile, Chile, Jan. 9-13.

[6] Chen H, Xu Z and Li M (2010) The relationship between large reservoirs and seismicity, International Water Power & Dam Construction, January 2010, 29-33.

Mohanpura Dam Rajgarh

Mohanpura Irrigation Project is the first such project in the country that will irrigate fields with pressure. This is the first long pipeline in the country, under this project costing 3800 crores, the underground canal with the longest pressure pipe will irrigate 1 lakh 35 thousand hectares of land. In the first phase, 25 hectares of rocky land will be irrigated in Kalipith area. Underground pipe laying work is going on in other areas. Mohanpura Dam is built on the Nevaj River, 8 km from Rajgarh.

The catchment area intercepted at the dam site is 3726 sq. km. The Mohanpura dam is provide water for irrigation (*irrigate about 35500 ha Kharif and 62250 ha of Rabi season*), domestic and industrial uses.

Sediment Management Practices in NHPC's Power Stations

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ABSTRACT

The problem of sedimentation is extremely serious for the dams positioned on Himalayan Rivers as they carry huge sediment load. More than 80% of annual sediment inflow comes during the monsoon. Efficient sediment management is therefore required in monsoon season to protect the economic life of the reservoirs. NHPC Limited, a Government of India Enterprise in India is maintaining 20 power stations in Himalayan region and has been successful in maintaining gross/live capacity of reservoirs of these power stations satisfactorily by adopting different site/project specific techniques of sediment management.

Drawdown flushing in small reservoirs along-with sluicing in large/medium size reservoirs, are most adopted techniques in NHPC for sediment management in reservoir. Desilting basins/chambers have been provided in most of the power stations to allow settlement and removal of significant portion of the coarse sediment entering into the intake, thereby reducing the impact of big size sediments into turbine and other parts. Silt excluders/silt ejectors have also been provided in some of the projects of NHPC. Site specific reservoir operation and flushing guidelines, prepared for every power station, have been proven to be very helpful in preserving the reservoir capacity and ensuring smooth running of power plant.

1. INTRODUCTION

It is a well know fact that sedimentation poses a significant threat to the long life, efficacy, and sustainable operations of both storage and run-off the river projects as enumerated below;

- Loss of storage capacity : It has a serious impact on water resources development by reducing water supply, hydropower production, the supply of irrigation water, and the effectiveness of flood control schemes.
- Growth of the delta deposits at the upstream end of the reservoir cause increased flooding in the backwater upstream.
- Abrasion of turbines, spillway and other dam/WCS components, decrease in efficiency of a turbine and can require expensive repairs.
- Apart from loss in energy generation, the shutdown of hydropower stations to avoid operating under such conditions leads to loss of peaking availability.
- Sedimentation at or near the dam face may tend to block the outlets causing difficulties in operation of the gates.

It is predicted that there shall be around 50% loss in the existing reservoir storage by year 2050 and almost all the storage shall be lost in 200-300 years. Concern over the long term viability and sustainable use of reservoirs has led to worldwide efforts to evaluate and develop techniques to minimize the impacts of reservoir sedimentation on the life of reservoir as also on the life of water conductor system and turbines. The World Bank in its RESCON (Reservoir Conservation) approach, call for adoption of "life cycle management" approach for designing dam. The RESCON approach is based on the following two messages:

- Whereas the last century was concerned with reservoir development, the 21st century will need to focus on sediment management; the objective will be to convert today's inventory of non-sustainable reservoirs into sustainable infrastructures for future generations.
- The scientific community at large should work to create solutions for conserving existing water storage facilities in order to enable their functions to be delivered for as long as possible, possibly in perpetuity.

2. RESERVOIR SEDIMENTATION PROBLEM IN NHPC'S RESERVOIRS

NHPC Limited (formerly known as National Hydroelectric Power Corporation) was incorporated on 7th November 1975 as a Schedule 'A' Enterprise of Government of India for development of Hydro Power in Central Sector. The company is mandated to plan, promote and organize an integrated and efficient development of power in all aspects through conventional and non- conventional sources in India and abroad. With an authorized share capital of 2.1 Billion USD, NHPC is a premier organization in India for development of hydro power. Along the journey of over 45 years, NHPC's total installed capacity has reached to 7071 MW from 24 projects including joint ventures (JV), Solar and Wind. Major power stations of NHPC are shown in Figure 1.

Fig. 1 : Location of Power Stations and Construction Projects of NHPC

As can be seen from Figure 1, most of the power stations of NHPC having small and medium size of reservoirs are located in Himalayas. The problem of sedimentation is serious for these hydropower plants as Himalayan Rivers carry huge sediment both as bed load and suspended load during monsoon. More than 80% of average annual sediment comes during the monsoon season. Efficient sediment management system is needed in monsoon season to protect the economic and useful life of the reservoirs. These techniques are required to be customized for different projects depending on their reservoir size, valley shapes as well as their unique design features. The present papers aims at showing the reservoir sediment management practices being adopted by NHPC in its existing power stations.

3. ASSESSMENT OF SEDIMENT LOAD INTO THE RESERVOIR BY NHPC

Estimates of the amount of sediment transported by rivers are important for evaluating the impacts of reservoir sedimentation and its management. The amount of sediment entering into the reservoir upto project site is broadly estimated on basis of:

- Sediment Observation at Project Location:

  It involves concurrent measurement of discharge and suspended sediment concentration. In NHPC's power stations, it is a regular practice to observe suspended sediment near dam/intake, upstream of reservoirs, TRT outlets, SFT outlet and other important locations on daily basis. Fractional distribution of sediment (coarse, medium & fine) is measured at important locations. Frequency of sampling is more during monsoon.

- Bathymetric Survey of Reservoir:

  Bathymetric surveys of the reservoir are carried out at regular intervals. Comparison of the bathymetry thus developed with respect to the original survey of the reservoir allows the volume of sediment that has been deposited over a certain period to be quantified. Bathymetric survey is carried-out annually (post monsoon) in all NHPC's reservoirs.

- Empirical methods:

  Empirical methods are used to estimate average annual sediment yield in circumstances when long term sediment data and bathymetric surveys are not available. These include using sediment yield maps of the area, empirical relations etc. This method is seldom used in NHPC except during planning stage of the projects in un-gauged catchments.

4. SEDIMENT MANAGEMENT TECHNIQUES BEING FOLLOWED IN NHPC

Sediment management techniques being adopted in NHPC are explained in detail as below.

4.1 Sediment Yield Reduction

Catchment area treatment, afforestation etc are generally adopted in NHPC's Project as a part of EIA/EMP study. Integrated approach is adopted under CAT plan which includes various biological, engineering, and bio-engineering measures. Afforestation (to compensate for the forest land submerged due to impoundment of reservoir and other structures) is an effective tool for arresting soil erosion and up-gradation of environment and it includes soil conservation and moisture retention measures. Also lots of protection works are done to stabilize hill slope in the vicinity of reservoir and adjoining hill road sides, which reduces sediment inflow into reservoir.

4.2 Sluicing

It is an international practice to maintain the reservoir at low level during monsoon so that majority of incoming sediment is passed in the downstream through the spillway. During sluicing, reservoir is maintained at lower levels (normally near MDDL), which decreases the effective capacity of the reservoir. The decrease in capacity causes reduction in the capacityinflow ratio, which in turn reduces the trap efficiency of the reservoir. The fine/cohesive sediment can be removed by drawdown sluicing thereby prohibiting consolidation of cohesive sediment particle which are difficult to scour once deposited.

Reservoir operation manuals have been prepared for all the power stations of NHPC in which it is advised to maintain the reservoir level at/near MDDL during monsoon period in all run-of-the-river projects/power stations. In case of high dams such as Chamera-I PS, low level undersluices have been provided in dam body for sluicing of sediment from the reservoir.

4.3 Flushing

Sediment flushing is a technique in which the flow velocities in a reservoir are increased to such an extent that the deposited sediments are remobilized and transported through bottom outlets. During draw down flushing the reservoir area takes the form of pseudo-river. Flushing is most effective if the reservoir is drawn down to the extent that the flow condition over the deposits approaches that of the original river (ICOLD Bulletin 115). In small size reservoirs of NHPC, generally reservoir flushing be carried out once in a month during monsoon period when river inflow exceeds a specified discharge. The discharge at which flushing is to be carried out is worked for each monsoon month on basis of 50% probability of occurrence of that discharge using inflow discharge data. Flushing in free flow condition is generally carried out for more than 12 hrs. Flushing is stopped when sediment concentration of inflow/outflow becomes almost equal for 2-3 hrs.

4.4 Desilting basins/Chambers

Desilting basins/Chambers are used for removing sediment of specific size and quantity. The main key is to provide a section wide and long enough so that the resulting reduced flow velocity will permit the sediment to settle out. Desilting basins have become an integral part of the water conductor system of ROR hydropower projects to minimize the impact of damage due to suspended sediment on water conductor systems, turbine and other underwater parts. Desilting basins are provided just after power intake and discharge is passed through them before entering into the head race tunnel. Generally, desilting basins are designed for 90% removal of suspended sediment particles of size 0.2 mm and above. However, basins may be designed to eliminate particles finer /coarser than 0.2 mm which will increase / decrease length of the basin and in turn adds / reduces cost of the project. In NHPC, desilting basins/chambers have been provided in Teesta V, Chamera-II, Chamera-III, Sewa-II, Dhauliganga, Tanakpur, Rangit, Dulhasti, Uri-I, Parbati-III, & Uri-II power stations.

4.5 Silt Excluder and Silt Ejector

Silt excluder is provided near river bed u/s of diversion work and silt ejector is installed in canal bed d/s of regulator work. Silt excluders have been provided in Uri-I and Tanakpur Power Station. Silt ejectors have been provided in Tanakpur Power Station.

4.6 Sediment Bypassing

In Baira Siul Power Station , diversion tunnel used for construction of Baira dam (53 high Rockfill dam) having intake about 200 m upstream of dam axis is being used as Sediment Bypassing Tunnel (SBT). This tunnel is also being used for drawdown flushing of Baira reservoir.

4.7 Dredging/Excavation

Dredging technique is used to remove deposited sediment from the reservoirs using dredging equipments, pumps or hydraulic suction. In Tanakpur power station reservoir capacity was regained by removal of accumulated sediment in the centre of reservoir through this technique. In TLDP III power station localized dredging is done during flushing to remove deposited sediment in front of intake.

5. LESSONS LEARNED

NHPC is operating 20 power stations and has gained a lot of experience from their operation. It has learned many lessons and improved its techniques of sediment management based on feedback from specific power stations, mathematical model as well as physical model studies.Lessons learned in some of the projects/power stations are explained below;

5.1 Tanakpur Power Station (94.2 MW) in Uttarakhand,Sharda Basin–No Pondage, Flushing, Silt ejectors and Silt Excluders

Tanakpur power station (commissioned in 1992) has 3 generating units coupled with Kaplan type turbines and the rated head is 24.25 m. Average annual sediment load entering into Tanakpur reservoir is around 42 MCM. Sediment management is done by flushing through 22 gates and limiting the sediment entry into the power house. Silt excluders are provided at undersluice bay adjoining the head regulator to reduce the entry of sediment in the head regulator . Silt ejectors have been provided in Power channel in between Head regulator and Forebay. When the sediment concentration is more than 5000 ppm and / or discharge crosses 2500 cumec for July to September and 1000 cumec in Jun, power house is shut down and flushing is carried out through spillway gates to pass the excessive sediment laden water.

The Tanakpur reservoir had initial reservoir capacity of 5.96 MCM. Till the year 2015 the reservoir lost its capacity to 2.85 MCM due to the sedimentation in the form of island in center portion of the reservoir. Since 2015, power station is trying to regain the capacity of the reservoir through intensive flushing and by dredging the accumulated sediment. Power station constructed a channel through the island (accumulated sediment) to activate the central flow channel as a result of which Power station has regained the reservoir capacity to 4.05 MCM as per post monsoon 2018 survey.

5.2 Baira Siul Power Station (198 MW) in Himachal Pradesh, Ravi Basin - with Diversion cum De-silting Tunnel

In Baira Siul power station (commissioned in 1982), water is fed to machines through 7.63 km long Head Race Tunnel from Baira reservoir. It has three units of Francis turbines with a net head of 259.5 m. Reservoir flushing is being done through a diversion-cum-desilting tunnel of size 5 m (W) x 7 m (H) located upstream of the Intake. The crest level of de-silting tunnel is 23.15 m below the crest of intake. In reservoir flushing, spillway also plays important role as crest level of spillway is 1.15 m below the crest of intake. A desilting basin (twin hopper type) 30 m long x 7m (W) x 12m (H) has also been provided in HRT to eliminate 0.2 mm and above particle size and efficiency of desilting basing is estimated to be 90%. When inflow sediment concentration exceeds 3000 ppm and/or discharge exceeds 100 cumec, the power house is closed and flushing of reservoir is carried out. By way of flushing through spillway and diversion tunnel, live storage of 0.6 MCM is generally maintained against the original capacity of 1.3 MCM.

5.3 Dhauliganga Power Station (280 MW) in Uttarakhand State, Sharda Basin: Low Level Outlet, Desilting Basin

Dhauliganga power station, commissioned in 2005, is in Sharda Basin, of India. Dhauliganga dam is a CFRD dam with two spillways consisting of low level outlets. Water is fed to the machine through 5.4 km head race tunnel. Two desilting chamber of size 13.0 m X 16.2 m with length of 314.40 m are provided. It has four units of Francis turbines with a net head of 297 m. Originally power station had the gross storage capacity of 6.20 MCM at FRL (EL 1345 m). During monsoon, the reservoir is being operated at MDDL (EL 1330 m) for discharge more than the design discharge. If the inflow in the river is less than design discharge, reservoir level is kept between EL 1330 m to EL 1340 m.

At present, 7 nos. of flushings per year have been recommended for effective management of sediment. Change in reservoir capacities of Dhauliganga Power Station after different years of operation are mentioned as below:

- During year 2008 -2012, the gross capacity was maintained nearly about 5 MCM.
- The reservoir lost its capacity majorly during 2013 Uttarakhand floods because of deposition of large amount of sediment in the reservoir thereby decreasing the gross and live storage by 34% and 45 % respectively.
- Afterwards, the gross capacity and live storage capacity was maintained nearly at 3 MCM and 2.3 MCM respectively from year 2014 to year 2016, by combination of drawdown sluicing and flushing.
- In 2017, power station could manage to conduct only 3 flushings and the reservoir level could not be lowered upto MDDL due to some project specific reasons, which resulted in decreased gross capacity from 3.08 MCM to 2.03 MCM.
- In year 2018, power station conducted all proposed flushing during the monsoon, thereby increasing the gross capacity from 2.03 MCM to 3.24 MCM, which proved the effectiveness of aggressive sediment flushing (in combination with sluicing) in removing the deposited sediment from the reservoir.
- Also, based on observed sediment data near intake and TRT outlet, sediment removal efficiency of

Desilting basin of Dhauliganga Power Station was found to be around 50% of total observed sediment and around 82% for coarse sediment as was also predicted in Physical Model Study.

5.4 Teesta-V Power Station (510 MW), Sikkim : With Low level outlet and desilting basin

Teesta V power station, commissioned in 2008, is in Teesta Basin, Sikkim State of India. It has a 17.2 km length head race tunnel with diameter of 9.5 m through which water is fed to the machines. It has 3 nos of desilting chambers of size 19.7 m X 24.5 m. The length of desilting chambers is 250 m. It has three units of Francis turbines with a net head of 197 m.It has small reservoir storage capacity (Gross - 13.5 MCM, Live-6.3 MCM, initially) and sediment management is though low level spillway, combination of reservoir flushing and sluicing and desilting chamber.

Sediment got deposited within first year and reduction in gross and live capacity was 21% and 10.3% respectively. This loss in capacity was majorly due to full deposition upto spillway crest as expected as there was no opening below this level.

Due to present practice, after 11 years of commissioning, the live capacity is maintained at 5-6 MCM as compared to initial live capacity of 6.3 MCM. Desilting basin/ SFT provided in the project also played effective role in reducing impact of sediment to turbines and other underwater parts. Sediment balance study showed that about 39 % of the incoming sediment has been flushed out during flushings, 10 % has been passed out through SFT, and around 23 % has been spilled out through spillway. Balance 28% of sediment passes through machines.

On river Teesta four projects namely Teesta III (1200 MW) and Teesta V (510 MW), TLDP- III (132 MW) and TLDP –IV (160 MW) have been commissioned and are in operation. Teesta III and Teesta V are in vicinity of each other whereas TLD- III is quite far from Teesta V. Flushing operations of Teesta V vis a vis TLD III and TLDP IV have been delinked.

5.5 Chamera Stage-I Power Station (540 MW), Himachal Pradesh, Ravi Basin : Under Sluices, no desilting basin

Chamera I power station, commissioned in 1994, is in Ravi Basin, Himachal Pradesh State of India. It has large reservoir capacity (around 391 MCM initially). It has 6.4 km head race tunnel with 9.5 m diameter. Power is being generated through 3 units of francis turbine with gross head of 207 m.

Sediment management is done by sluicing through low level sluice outlets (4 nos) and following reservoir operation rules. The low level sluice outlet helps in achieving better sediment environment in the vicinity of dam to the downstream channel. The level of reservoir is kept at near to lower operating levels during monsoon season so that sediment may be routed to the downstream. No sediment related problem has been reported in underwater parts from Chamera-I power station which was commissioned about 25 years ago, even though it does not have desilting chambers. The sediment management practice adopted in this project results only a loss of around 0.5% in live capacity per year. (Joshi et al, ICOLD-2018)

5.6 Chamera-II Power Station (300 MW), Himachal Pradesh, Ravi Basin : Low Level Outlet, Desilting Basin

Chamera-II power station, commissioned in 2003, has three generating units coupled with Francis type turbines and design head is 243.0 m. Four low-level spillways have been provided for reservoir flushing. Two de-silting chambers of 16 m width and 375 m length have been provided in HRT to eliminate 0.2 mm and above particle size. During peak water inflow, reservoir level is maintained at a level lower than FRL, to pass most of the silt laden water downstream of the dam. When sediment concentration increases above 5000 ppm and/or discharge exceeds 300 cumec, the power house is closed and flushing operation is carried out by opening all the spillway gates gradually. Four flushings, one in each monsoon month are carried out from June to September. After 15 years of commissioning of project the live capacity has been maintained at 1.4 MCM (post monsoon 2018 survey) as compared to original capacity of 1.8 MCM.

Chamera II power station is in cascade with Chamera III power station. Chamera III is located at 24 km upstream of Chamera II dam along the river Ravi. Reservoir flushing at Chamera II power station is carried out in tandem with flushing at Chamera III power station. Chamera III starts the flushing first and give prior intimation to Chamera II to plan its flushing accordingly.

5 .7 Mangdechhu Project (720 MW) in Bhutan: Low Level Outlet, desilting basin

Mangdechhu dam has been provided with an orifice spillway with 4 gates (10 m wide x 16 m high). The crest of the spillway is at EL 1702.2 m. Two Dufour type desilting chambers of size 14.0 m (W) x 17.7 m (H) are provided to remove 90% of 0.2 mm and above size sediment particles. The power intake is located just upstream of spillway on the left bank with invert level at EL 1720 m and comprises twin intake tunnels leading to a single power tunnel. The sediment laden water is removed through silt flushing tunnels.

Though free flow flushing in combination with sluicing with reservoir at low level, has been proved to be effective in reservoirs with small capacity. However for Mangdechhu Project reservoir operation and flushing guidelines has to be framed keeping structural safety in mind due to typical upstream geometry and river slope. As per physical model study, due to the distinctive site specific flow conditions, after carrying out many alternative physical model studies for a range of discharges, it has been decided to adopt controlled gate operation (orifice flow) for discharge rates more than 1200 m3/sec (i.e around 18% of PMF) to ensure safety of the structure. Moreover, during high flood events (above 1200 m3/sec), reservoir levels higher than MDDL, are recommended to arrest turbulent flow and adverse flow conditions. In addition, for better performance of Ski Jump Bucket during high flood events, it is proposed to avoid free flow condition. (Joshi et al, ICOLD-2019)

5.8 Projects/power stations in cascade

The sediment management techniques being followed in power stations in cascade are different than being followed in standalone projects. For projects in close vicinity to each other, it becomes essential to carry out flushing in tandem so that the sediment flushed out from the upstream reservoir is not allowed to settle in the downstream reservoir. In case of cascade projects having large distances in between, the in tandem flushing has to be analyzed depending upon the river slopes, travel time, sediment carrying capacity of the river, river inflow, reservoir capacities and loss in power generation.

Some of power stations of NHPC in river basins such as Teesta and Ravi are in cascade with each other. The reservoir operation in cascade run of the river projects is divided into two parts: (i) Sediment Management in monsoon period (ii) Optimization of peaking in period other than monsoon. NHPC has reviewed the operation philosophy for the power stations lying in cascade after commissioning of more than one power station in the basin and revised the reservoir operation manuals accordingly by coordinated and synchronized sediment management approach. In case of cascade projects having large intermediate catchment areas and distances the high sediment concentration flushed out from the upstream project does not reach up to the downstream project. In such projects, the reservoir flushings can be delinked with each other.

The summary of sediment management practices adopted for above power stations along with the gross and live capacities is given in Table 1.

6. SUSTAINABILE SEDIMENT MANAGEMENT: BEST PRACTICES

Sustainable sediment management seeks to maintain long-term reservoir capacity, retarding the rate of storage loss and eventually bringing sediment inflow and discharge into balance while maximizing usable storage capacity, hydropower production, or other benefits. Based on experience gained by NHPC, best practices for sustainable sediment management are as follows:

Table 1 : Sediment Management techniques being followed in NHPC Power Stations

Project	Tanakpur	Bairasiul	Dhauliganga	Teesta V	Chamera I	Chamera II
Installed Capacity	94.2 MW	180 MW	280 MW	510 MW	540 MW	300 MW
Year of Commissioning	1992	1982	2005	2008	1994	2003
Sediment Management Technique	Flushing, Silt ejectors, silt excluder, dredging	Desilting (bypass) tunnel, desilting basin, flushing	Low level outlet, desilting basin, sluicing, flushing	Low level Outlet, desilting chamber, flushing	Under sluices	Desilting chamber Low level outlet, Sluicing, flushing
Original Gross Capacity(MCM)	5.96	3.8	6.2	13.5	391.3	2.3
Present Gross Capacity (MCM)	4.05	0.7	3.2	9.3	195.1	1.7
Original Live Capacity (MCM)	Not Provided	1.3	3.2	6.3	109.6	1.6
Present Live Capacity (MCM)	Not Provided	0.6	2.3	5.6	87.9	1.4

(i) Prepare project specific guidelines and detailed standard operating procedures for management of sediments for each project/power station.

(ii) Observe sediment data regularly and accurately, maintain long term record.

(iii) Conduct bathymetric surveys at fixed locations soon after initial filling and thereafter at regular intervals.

(iv) Adopt low level outlets, operation of reservoirs at/near MDDL during high flow periods and free flow flushing, in run of the river schemes with small storage capacities in order to reduce filling of live storage capacity.

(v) Keep intake level sufficiently above spillway crest to reduce the entry of sediment into water conductor system.

(vi) Make arrangements for exclusion of sediments larger than a particular size (usually 0.2 mm) from the water entering into water conductor system and turbines.

(vii) Simulate long-term reservoir sedimentation by mathematical modeling, extending the modeling period until a stable longitudinal profile and sediment balance across the dam have been achieved. It assists in the evaluation and quantification of the effectiveness of operational rules for sediment management and provide an idea of the extent and geometry of sediment deposits, which helps designers to select the location and configuration of outlet works to best handle anticipated future sedimentation conditions.

(viii) Carryout physical model study for each project to understand the behavior of flow through spillway, flushing/sluicing operation, feasibility of proposed sediment management techniques, effect of reservoir operation on safety of structure etc.

(ix) Coordinated and synchronized reservoir operation and sediment management approach for projects in cascade in a basin

An effective combination of drawdown sluicing and flushing helps to maintain the useful and long life of the reservoir. Elaborate reservoir operation manuals have been developed for these power stations by NHPC. Due to this, NHPC has been successful in maintaining the live capacities of most of its reservoirs to a satisfactory extent thereby achieving the generation targets and other intended purposes of the plant even after almost more than 20 years of commissioning in many projects. The comparison of original and present live reservoir capacities of some of the reservoirs of NHPC is shown in Figure 2.

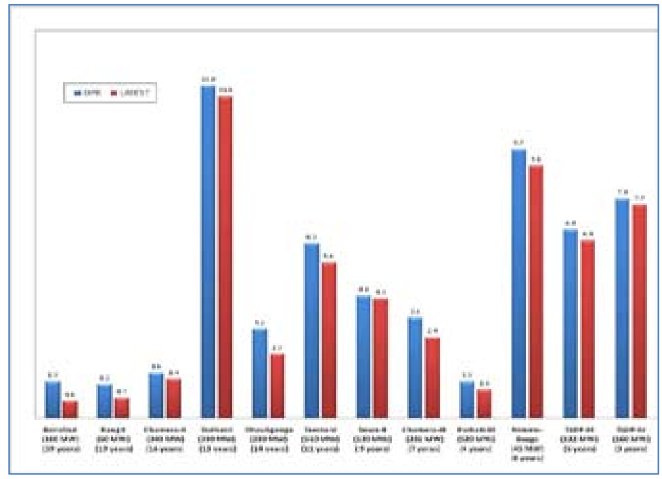

Fig. 2 : Change in Live Reservoir Capacities of Some of the Power Stations of NHPC

7. CONCLUSION

Sedimentation is threatening the existence of all kind of reservoirs. Himalayan rivers carry much more sediment load than the capacities available in the reservoirs of power stations located in this region. The annual loss in generation due to sedimentation has been estimated about 1% of the overall generation as per NHPC's experience. NHPC Limited is maintaining 20 power stations in Himalayan region and has been successful in maintaining gross/live capacity of reservoirs of these power stations satisfactorily by combination of providing low level spillways, drawdown flushing and sluicing. Desilting basins/silt excluders/silt ejectors have played their role in reducing the impact of sediments in water conductor system, turbines and other underwater parts. These techniques, are, however required to be customized for different projects depending on their reservoir size, valley shapes as well as their unique design features.

It has been observed that if proper reservoir operation and flushing guidelines are not adhered to, along with significant loss in reservoir capacity, the runner and guide vanes are required to be repaired every year. However, after following guidelines as proposed in the manuals, the repair cycle of runner and guide vanes has increased to 2-3 years and 3-4 years respectively.

These project specific guidelines have been extremely helpful in preserving the reservoir capacity and ensuring smooth running of power plant.

7. REFERENCES

• Guidelines for Sediment Management in Hydropower & Water Resources Projects by Design (N&W) Organization, Central Water Commission, Government of India, Sept, 2018

- Handbook for Assessing and Managing Reservoir Sedimentation, Doc. No. CDSO_GUD_DS_04_v1.0, February 2019, Central Water Commission, Ministry of Water Resources' River Development & Ganga Rejuvenation Government of India
- Standard Operating Procedures (SOP) for Management of Silt in Hydro Electric Projects, Central Electricity Authority, Govt. of India, Aug 2018.
- Research Article "Sustainable sediment management in reservoirs and regulated rivers: Experiences from five continents" by G. Mathias Kondolf1, Yongxuan Gao2, George W. Annandale3, Gregory L. Morris4, Enhui Jiang5, Junhua Zhang5, Yongtao Cao5, Paul Carling6, Kaidao Fu7, Qingchao Guo8, Rollin Hotchkiss9, Christophe Peteuil10, Tetsuya Sumi11, Hsiao-WenWang12, ZhongmeiWang5, ZhilinWei13, Baosheng Wu14, CaipingWu5, and Chih Ted Yang15 Earth's Future, 2,256–280, doi:10.1002/2013EF000184.
- Article "Sediment Management in Taiwan's Reservoirs and Barriers to Implementation" by Hsiao-Wen Wang, Mathias Kondolf ID , Desiree Tullos and Wei-Cheng Kuo, Water 2018,10,1034;doi:10.3390/w10081034
- Atkinson, E., 1996. The feasibility of flushing sediment from reservoirs. Report OD 137, HR Wallingford, Wallingford, UK.
- Morris, Gregory L. and Fan, Jiahua. (1998). Reservoir Sedimentation Handbook, McGraw-Hill Book Co., New York. Electronic Version, Ver 1.04, December 2010.
- ICOLD Bulletin 115, 1999, Dealing with Reservoir Sedimentation, CIGB ICOLD
- Balraj Joshi, Narendra Kumar, Rajeev Baboota & Manjusha Mishra (ICOLD 2018 at Vienna, Austria) Reservoir Sedimentation and Sustainable Development: Sediment Management Practice in Reservoirs of Two Power Stations Located on Himalayan Rivers of INDIA.
- Balraj Joshi, Narendra Kumar, Keshav Deshmukh, Rajeev Baboota & Manjusha Mishra (ICOLD 2019 at Ottawa, Canada), Reservoir operation of Mangdechhu Project and Safety of the Structure.
- The World Bank, Reservoir Conservation – The RESCON Approach , Vol. I & II.
- Impact of Silt on Hydroelectric Projects across the Country, Ministry of Power Publication.

WORLD'S LARGEST TWO HYDRO PLANTS SET NEW RECORDS IN 2020

Three Gorges, the world's largest capacity hydroelectric plant, has set a new world record for annual power generation from a single hydropower station. The 22.5 GW plant on the Yangtze river in Hubei province, central China, generated 111.795 TWh in 2020, breaking the previous record of 103 TWh set in 2016 by South America's Itaipu, its operator, China Three Gorges Corporation (CTGC), announced on 1 January.

The volume of electricity generated by Three Gorges in 2020 is estimated to have saved the use of 34.39 x 10^6 t of standard coal, and reduced emissions of $C0_2$, $S0_2$ and NO by 94.02 x 10^6t, 224 000 t and 212 000 t respectively. On the basis of estimates by economists that one kWh of electricity can produce 13.8 yuan of gross domestic product, its generation in 2020 supported 1.54 trillion yuan of GDP, (US $240 billion) CTGC added.

"With the strong support of relevant institutions and units such as China Yangtze Power, CTGC was able to implement risk management and control measures for the Three Gorges project during the flood season, to optimize its operation," the company said. "These efforts also helped CTGC enhance the accuracy of fore-casting water and rainfall in the river basin, and improved its ability to coordinate control of the cascade reservoirs, allowing for the power-plant to operate uninterrupted at full load. As a result, CTGC was able to mitigate floods and maintain smooth running of the equipment, keeping the Three Gorges project in a safe and stable operating condition".

The Three Gorges powerplant, which is equipped with 32 main generating units of 700 MW, as well as two 50 MW units, has been the world's largest hydro plant by in-stalled capacity since it began full commercial service in July 2012. The plant first began generating in 2003. The 14 GW Itaipu hydropower plant on the river Parana, on the border of Brazil and Paraguay, still holds the record for cumulative output by a single hydropower plant, its operator Itaipu Binacional, announced on 1 January. "At the end of 2020, Itaipu reached the record of total production of 2770 TWh over 36 years and seven months of operation. No other plant has generated so much in such a short time," it said. Itaipu Binacional also announced record productivity in 2020, registering annual production of 76.38 TWh in spite of the worst drought in its history. Despite an average inflow of around 7900 m^3/s, which is 30 per cent lower than the historical average, Itaipu Binacional said it achieved productivity of 1.087 MW on average per m^3/s, up from historical average productivity of 1.034 MW per mVs.

Sediment Yield and Depostion Pattern in Long Conical Tehri Reservoir

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THDC India Limited, Rishikesh

ABSTRACT

Tehri Storage Dam constructed across the mighty river Bhagirathi with a catchment area of 7511 km^2 is located at Tehri which is 85 km from the famous holy place Rishikesh, Uttarakhand, India. Tehri HPP (100 MW) is already commissioned and Tehri PSP (1000 MW) is in advance stage of construction. The long and conical shaped reservoir of the Tehri Dam with a gross storage of 35.40 billion m^3 and a live storage of 26.15 billion m^3 spreads in an area of approx. 42 km^2. Sedimentation of reservoirs is a matter of great concern as it not only occurs in dead storage but also encroaches the live storage capacity thus impairing the intended benefits from the reservoir.

Depositional patterns of sediment in reservoir vary with differences in hydrologic conditions, sediment grain size, and reservoir geometry. In reservoirs with fluctuating water levels like Tehri reservoir, previously deposited sediments may be extensively eroded and reworked by stream flow, failure of exposed slopes, and wave action. Also in long and narrow reservoirs like Tehri reservoir, the bathymetric profile commonly associated with delta deposits may be absent, but an area characterized by a rapid shift in grain size, marking the downstream limit of coarse material deposition, may still be present. Sediment deposition is initially focused in the deepest part of each cross section, creating deposits having a near-horizontal surface regardless of the original cross section shape. Because the upstream area of such long and narrow reservoir is shallow with little storage capacity, the longitudinal growth of the delta may initially be very rapid and sometimes sedimentation can also result in deltas becoming exposed above the reservoir pool.

Distribution of both fine- and coarse-grained sediment deposits in a reservoir can be predicted by both empirical and numerical techniques. The hydrographic survey is a direct method to find out the depth of sediment deposition, the pattern of sediment deposition and the loss of the reservoir capacity. Considering generally weak nature of Himalayan rocks and steep valley slopes in the catchment of the project, CWC has recommended bed load as 15% of the suspended sediment load for Tehri reservoir and accordingly total sediment load is assumed to be about 161.84 lac t /year for the reservoir. Periodic bathymetric survey since 2005 is being conducted at Tehri reservoir and based on the analyses of survey data collected so far, the overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year. The pattern of sediment deposited at different depth of Tehri reservoir after 2013 survey, plotted on the figure given by USBR for classification of reservoirs, shows that the current pattern of deposition lies reasonably close to type – III reservoir curve.

This paper provides an insight of the methodology adopted in the study and results of the analyses of survey data for deposition pattern of sediment in long conical Tehri reservoir.

***Keywords**: Reservoir, Sediment Yield, Reservoir capacity, Deposition pattern, Live storage.*

1. INTRODUCTION

Tehri Storage Dam built across the mighty river Bhagirathi with a catchment area of 7511 km^2 is located at Tehri which is 85 km from the famous holy place Rishikesh, Uttarakhand, India. Tehri HPP (100 MW) is already commissioned and Tehri PSP (1000 MW) is in advance stage of construction. The long and conical shaped reservoir of the Tehri Dam with a gross storage of 35.40 billion m^3 and a live storage of 26.15 billion m^3 spreads in an area of approx. 42 km^2. The reservoir at FRL of 830.0 m extends about 44 km along river Bhagirathi and about 25 km along the tributary river Bhillangana. The full reservoir level and minimum draw down level are fixed as El 830.0 m & El 740.0 m respectively.

Sedimentation of reservoirs is a natural phenomenon & is a matter of great concern. It occurs not only in the dead storage but also encroaches the live storage capacity, which impairs the intended benefits from the reservoir. Therefore the problem of sedimentation needs to be carefully addressed. Besides, the capacity surveys should be carried out at regular intervals to assess the volume of silt accumulated and its distribution pattern, rate of silting, updating the elevation-capacity curve for efficient management and operation of reservoir and to adopt the appropriate measures to prolong the useful life of the reservoir.

Periodical capacity survey of reservoirs in a basin is also necessary to arrive at a realistic siltation index for planning of future reservoir projects in the basin. The reports from CWC for the 23 reservoirs indicate that the actual rate of siltation is higher than the design rate. The annual loss in live storage capacity is 214.2 MCM that is 0.912% of the original live storage capacity. This has huge implications due to significant reduction in benefits from the reservoirs in terms of hydropower generation, irrigation, water supply and flood management.

In order to assess sediment yield and deposition pattern of sediment a study has been conducted for long conical Tehri reservoir. The location and layout of Tehri reservoir has been shown in Figure 1.

2. CATCHMENT AREA AND SEDIMENT CHARACTERISTICS FOR TEHRI RESERVOIR

The catchment area of Tehri dam covers about 7511 sq. km. and is spread over a length of 187 km. Out of total catchment area about 31 % is snow bound, 32% is reserve forest land and remaining 37 % comprises of cattle grazing and private agriculture land. The snow bound catchment contributes run off only in non-monsoon periods due to snow melt. The balance 69 % of the catchment receives about 100 to 263 cms average annual precipitation, 80 % of which is received during monsoon period only. Both the valleys feeding Tehri reservoir i.e. Bhagirathi and Bhilangna river valleys are quite narrow with steep side slopes and also the valleys receive heavy torrential rains causing floods in the rivers. The bed slopes of the rivers are quite high varying from about 50m / km in upper reaches to around 10m / km near the dam site. The valleys at certain places are prone to landslides and have deep deposits of debris, hillside wastes and colluvial talus. Furthermore, the rocks along the valleys are also susceptible to considerable weathering and erosion. Catchment area of Tehri reservoir is shown in Figure 2.

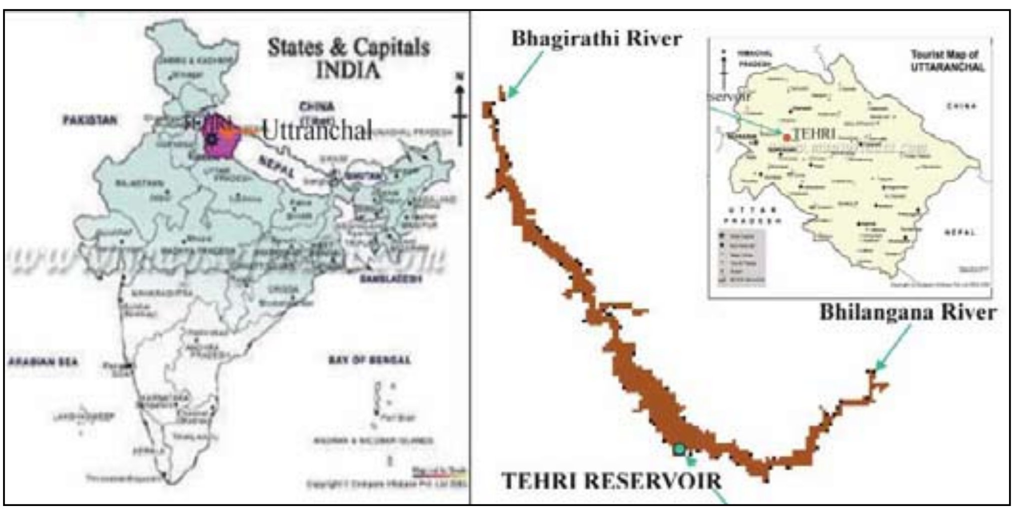

Fig. 1 : Location and layout of Tehri reservoir

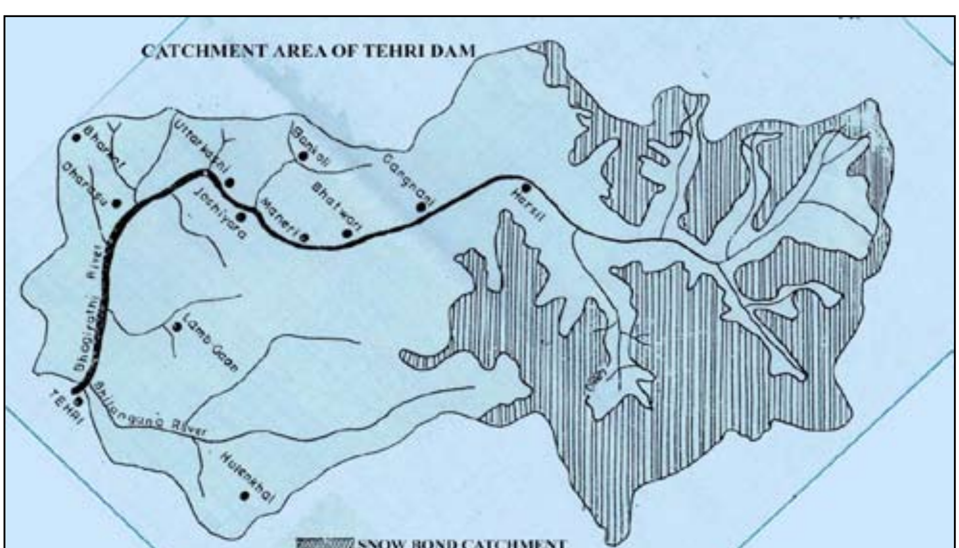

Fig. 2 : Catchment area of Tehri reservoir

3. SILT DATA FOR TEHRI CATCHMENT

Due to weaker rocks, steep river bed and steep side slope characteristics, river Bhagirathi carries sizable amount of suspended sediment and bed load. The most of the sediment is carried by the river during monsoons and the ratio of sediment transported by the river during monsoon and non- monsoon period is very large. Ganga Basin Water Resources Organisation of Central Water Commission (CWC) is collecting data for suspended sediment since 1972. Considering generally weak nature of Himalayan rocks and steep valley slopes in the catchment of the project, CWC has recommended bed load as 15% of the suspended sediment load for Tehri reservoir. Based on the CWC suspended silt data from year 1973 to 1993, total sediment load is assumed to be about 161.84 lac t /year for Tehri reservoir.

4. METHODOLOGY FOR DETERMINING CAPACITY OF A RESERVOIR:

4.1 Inflow-Outflow Method

In this method, the incoming and outgoing sediment load is estimated on the basis of observations for discharge and sediment samples taken on upstream and downstream of reservoir. The volume of the sediment retained in the reservoir is determined by establishing volume-weight relationship on the basis of analysis of undisturbed sediment samples collected from the reservoir bed. The loss in capacity by the method is determined from the observations in each flood season. This method is usually not much reliable due to following reasons:

- It is difficult to measure accurately the incoming discharge in high floods.
- Sampling of suspended load at varying depths is difficult.
- Sampling of bed load at high velocities is almost impossible.

4.2 Hydrographic Survey

The hydrographic survey is a direct method to find out the depth of sediment deposition, the pattern of sediment deposition and the loss of the reservoir capacity. To compute capacity of reservoir and volume of sediment deposit by this method, reservoir is surveyed for its topology with the help of echo-sounder by range line method along the prefixed range lines. The portion which is not under water is surveyed by ordinary ground survey methods. The depths of the reservoir are recorded with the help of echo sounders along a pre-determined range line across the reservoir. These range lines are normally spaced one to two kilometre apart along the length of the reservoir. With the help of data collected from the site by the above surveys, the volume of silt deposited in the reservoir is calculated between the two successive surveys.

4.3 Remote Sensing Technique

Satellites provide land surface imageries at regular intervals from which water spread areas of the reservoirs can be identified. The satellite imageries for various dates and corresponding gauge observations enable the development of the area-elevation relationship between the maximum and minimum reservoir levels. The relationship can be utilised for calculation of available reservoir capacities at various elevations and the current elevation–area-capacity curves can be obtained. The comparison of the current elevation-capacity curve with the earlier years enables computation of total volume of silt deposited.

The technique is being applied in sedimentation studies of 25 Reservoirs in India by Central Water Commission, NIH and other agencies and it has been reported that the difference between the water spread area measured by ground survey and satellite imageries were within 10 %. The only constraint in this technique is that the silting below minimum water level, is required to be measured using the conventional method of hydrographic survey.

5. SCOPE UNDER HYDROGRAPHIC STUDY FOR TEHRI RESERVOIR:

Scope of the present study consist of analysing the hydrographic and topographic survey data -2013 for Tehri reservoir w.r.t. pre impoundment survey in the following frame work :

- Preparation of upgraded X-sectional and L-section.
- To upgrade elevation area capacity curve of the reservoir.
- Estimation of sediment trapped after the last survey and its distribution in reservoir.
- To predict sediment distribution pattern with assessment of NZE
- Loss of storage and prediction of useful life of reservoir.

6. DATA ANALYSIS:

The analysis / calculation of data was performed by a tailored computer programme having capability to calculate area of cross section at each range line and submerged area at fixed/given interval of elevation with the help of Trapezoidal formula from the field data. The cross sectional areas and submerged areas are then used to calculate the capacity of reservoir at corresponding elevations. The basic data required for execution are as follows :

- Total number of range lines
- Distance between consecutive range lines
- Full reservoir level

- Bed level of reservoir
- Elevations corresponding to distances along the range lines.
- Interval of elevations on which capacity of reservoir is to be computed.

6.1 Elevation–Area Computations

On the basis of data, elevation area calculation for the reservoir were computed and the area of the reservoir at FRL (830.0M) is 43.37 Sqkm, 42.69 Sqkm and 41.97 Sqkm for the year 2005 (pre-impound survey), 2008 and 2013 respectively. The small difference in area for 2008 and 2013 may be attributed to small landslides encroaching into the reservoir at that elevation.

6.2 Elevation–Capacity Computations

The reservoir capacities at various elevations have been computed with the same methodology using trapezoidal formula. The capacity of the reservoir has been computed at an interval of 0.10 m up to El. 840.0 m. The capacity of the Tehri reservoir for pre impounding survey (2005), 2008 and 2013 was compared and is shown in Figure 3. The capacity of reservoir for respective surveys at MDDL, FRL and MWL is shown below in Table-1:

Table 1 : Capacity at different reservoir levels

Res. Elevation	Reservoir Capacity (MCM)		
	2005	2008	2013
740.00 (MDDL)	916.209	910.682	907.45
830.00 (FRL)	3548.51	3527.504	3505.85
840.00	3994.97	3976.272	3973.35

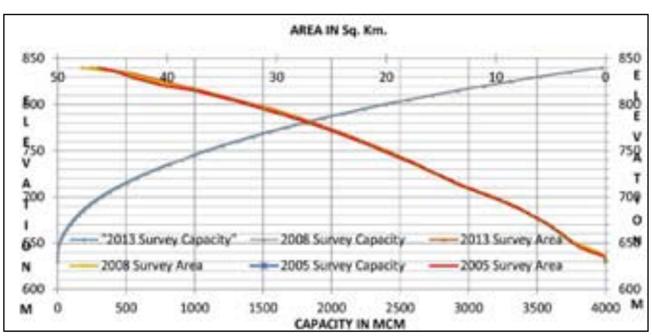

Fig. 3 : Elevation capacity curves 2005, 2008 & 2013 survey

It may be seen from the above Table-1 that live storage reduced at a rate of 5.16 MCM / year in a period from 2005 to 2008 while latter on from a period of 2008 to 2013(5 years), the rate of reduction of live storage was reduced to 3.68 MCM / year. The overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year. Similarly, the reduction rate in total reservoir capacity of the reservoir at FRL is 7.00MCM/Year from 2005 to 2008 and 4.33 MCM/ Year for a period of 2008 to 2013. The reduction in flood capacity (El.830.0 m to El.840.0 m) is very substantial from year 2008 to year 2013. The reduction may be summarized as below in Table 2 :

Table 2 : Reduction in reservoir capacity.

Time period	Reduction in reservoir capacity (MCM)		
	Live capacity	Gross capacity	Flood area capacity
2005-2008	15.48	21.01	18.65
2008-2013	18.42	21.65	2.92

6.3 Evaluation of Trapped Sediment

It may be seen from the above Table 2 that drastic reduction in sediment yield has occurred after 2008. It has been reported in many cases that for any reservoir more increase in sediment yield in the first five years is due to loosening of top soil by the activity of planting vegetation or other activities. A higher reduction in the next 3-5 years should follow, after which a slower rate would ensure until the rate stabilizes about the likely lower limit. The average volume of sediment trapped during the first 3 years (2005-2008) was 7.0 M Cum / year which is reduced to 4.33 MCM/Year from 2008 to 2013 (5 years).

7. SEDIMENT DISTRIBUTION PATTERN & CLASSIFICATION OF RESERVOIR:

Depending upon the percentage of sediment deposition with respect to depth of the reservoir, U.S.B.R. has classified the reservoirs into four standard types (Figure 4) The pattern of sediment deposited at different depth of Tehri reservoir after 2013 survey is also plotted on the same figure and it may be seen that the current pattern of deposition lies quite close to type – III reservoir curve, therefore, the Tehri reservoir under the present conditions may be classified as Type –III reservoir.

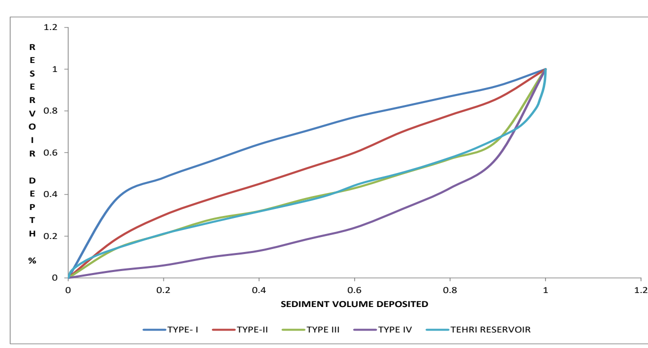

Fig. 4 : USBR classification of reservoirs and status of Tehri reservoir

Further the depth to capacity relationship also defines the shape of the reservoir. The standard curves adopted for determining the shape of the reservoirs are shown in Figure 5.

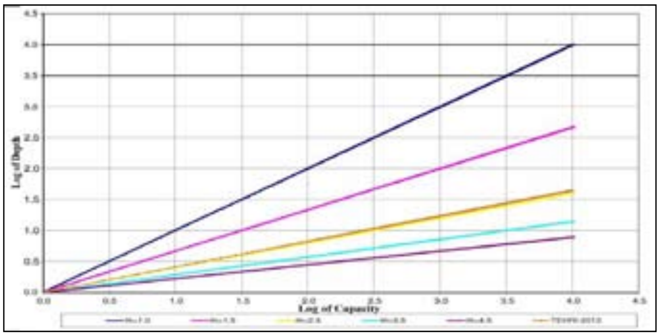

Figure 5 : Standard curves for determination of shape of reservoir

Utilizing the survey data of 2005, Nov-Dec 2008 and that of Jan-Feb 2013, the slope 'M' for Tehri reservoir has been computed and depicted in Figure 6. 'M' is the reciprocal of the slope of the line obtained by plotting reservoir depth vs reservoir capacity on log-log paper. The values of calculated 'M' for different surveys are given below in Table 3:

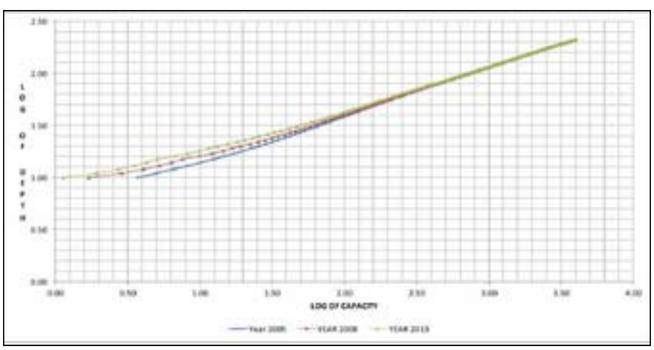

Fig. 6 : Log plot of reservoir depth vs reservoir capacity (slope "M")

Table 3 : Calculated 'M' for different surveys of Tehri reservoir

Year	M	Type
2005-Survey	2.21	III
2008-Survey	2.50	III
2013-Survey	2.43	III

It may be seen in Figure-5 that log of depth plotted against calculated value of M (2.433) lies almost on the line of curve with M=2.5 (Type –III reservoir), therefore, the present shape of Tehri reservoir is classified with type III reservoir.

8. PREDICTION OF SEDIMENT DISTRIBUTION

8.1 Empirical Area Reduction Method

8.1.1 *Design Curves for Tehri Reservoir and NZE Calculations:*

Using the surveys data of Tehri Reservoir, the design curves appropriate for Tehri reservoir have been developed for use in finding out the New zero elevation. The standard area design curves and the area design curve appropriate for Tehri reservoir has been plotted in Figure 7. The area design curve for Tehri reservoir resembles with reservoir Type-III curve.

Using the design curve of Type-III reservoir, new zero elevation (NZE) is computed as 634.0 m by empirical area reduction method. The New zero elevation has also been calculated by Area increment method which indicates the NZE to be 635.7. New zero elevation as per 2013 year survey is 634m. However, the capacity below El 635m does not significantly alter the subsequent area-capacity curves. Therefore, the NZE can be taken as 634.0m.

Vertical distribution of sediment volume (accumulated sediment volume as % of total sediment Vs relative depth) is plotted in Figure 8. Further, the Elevation-area-capacity curve for years 2005 and 2008 is shown in Figure 9.

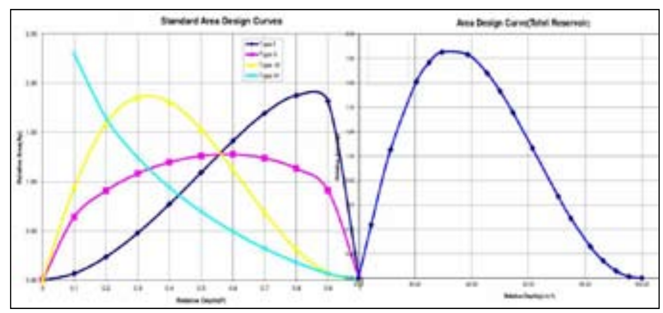

Fig. 7 : Standard and Tehri reservoir area design curves

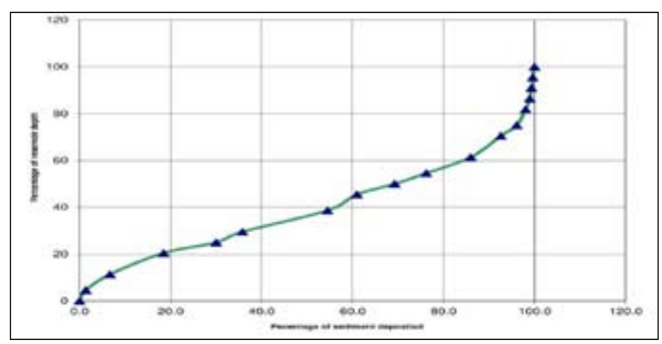

Fig. 8 : Vertical distribution of sediment volume

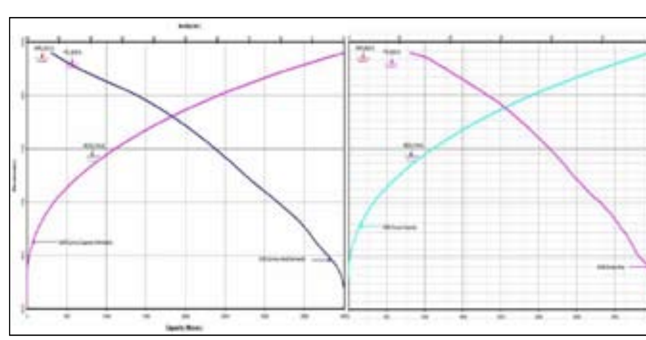

Fig. 9 : Elevation area capacity curve for 2005 & 2008 (Left & Right figures)

8.1.2 *Sedimentation in Different Zones and Loss of Storage*

In order to access the quantity of sediment deposited in different reaches of the reservoir, the reservoir survey area was divided into eight (8) zones as given below and marked in Figure 10.

(i) Zones – 1. 2 and 3 from entry of the Bhilanganariver into the reservoir.

(ii) Zones – 5, 6, 7 and 8 cover the Bhagirathi River

(iii) Zone – 4 confluence of Bhagirathi and Bhilangana Rivers nearest to Dam

Table 4 : Sediment deposit in different zones of reservoir

Zone	Capacity at FR: 2008-Survey (MCM)	Capacity at FRL: 2013-Survey (MCM)	Reduction of Capacity (MCM)	% Capacity Reduction
I	32.425	32.187	0.238	0.734
II	231.851	231.345	0.506	0.218
III	527.596	523.311	4.285	0.812
IV	982.456	975.913	6.543	0.666
V	896.607	893.802	2.805	0.313
VI	500.718	499.36	1.358	0.271
VII	280.055	276.159	3.896	1.391
VIII	75.796	73.773	2.023	2.669
Total	3527.504	3505.85	21.654	0.614

It may be seen from Table 4 that the siltation is mostly confined to the zones close to the reservoir namely, Zone III and IV. The situation is almost same as was in previous years of analysis.

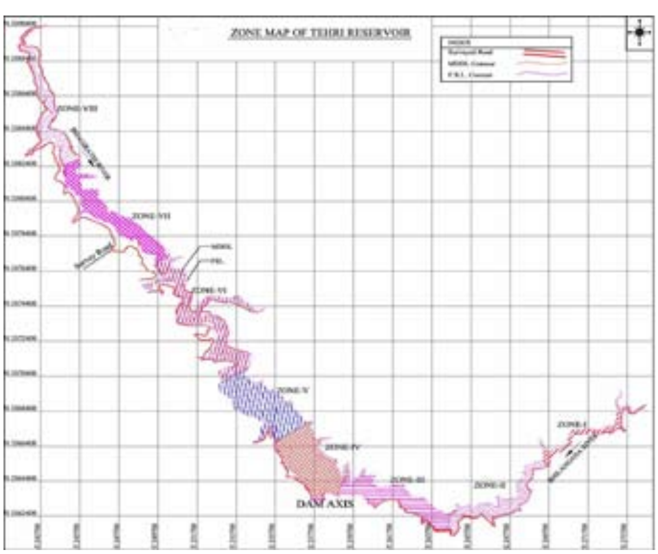

Fig. 10 : Zone map of Tehri reservoir

8.2 Loss of Storage from 2008 to 2013

Table 4 : Siltation of Tehri reservoir (loss of reservoir) from 2008-2013.

Levels	Total silt deposited (MCM)	% Loss of capacity	Rate of siltation MCum / 100 sq km / year
In MDDL storage	3.232	0.355	0.0086
In LIVE storage	18.422	0.704	0.0490
Total up to FRL	21.654	0.614	0.0576

8.3 Assessment of useful life of reservoir

Reservoirs formed by dams on natural rivers are invariably subjected to sedimentation. The term "life of reservoir", as loosely used denotes the period during which whole or a specified fraction of its total or active capacity is lost. As per the assessment criteria *"Useful capacity of reservoir = 70% of the original capacity (assumed)"*, useful life of the reservoir has been computed as 465.8 Yrs. As per the assessment criteria *"Useful capacity of the reservoir = Pre pounding storage up to MDDL (740 m)"*, useful life of the reservoir computed as 171.8 Yrs.

9. SUMMARY AND CONCLUSION OF THE REPORT

The computation and analysis of the survey data for the capacity of Tehri reservoir reveals that:

- Since impounding of the reservoir, loss of area up to MDDL is 0.313 Km^2 while at FRL the area loss is 1.4 Km^2.
- The overall reduction rate of the live storage of Tehri reservoir since the year 2005 comes to be 4.23 MCM / year.
- The pattern of sediment deposited at different depth of Tehri reservoir after 2013 survey, if, plotted on the figure given by USBR for classification of reservoirs, it may be seen that the current pattern of deposition lies quite close to type – III reservoir curve, therefore, the Tehri reservoir under the present conditions may be classified as Type –III reservoir.
- Using the design curve of Type-III reservoir, new zero elevation (NZE) is computed as 634.0 m by empirical area reduction method. The New Zero elevation has also been calculated by Area increment method. It indicates the NZE to be 635.7. However, the capacity below El 635m does not significantly alter the subsequent area-capacity curves. Therefore, the NZE can be taken as 635.0m.
- For more detailing and validation of results, the reservoir sedimentation study is recommended to be done through mathematical modelling.

Design and Planning of Large Diameter Underground Surge Shafts

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ABSTRACT

Two nos. of 20.92m diameter circular upstream surge shafts are designed to facilitate upstream surges of Tehri pumped storage project. The project site is located on the bank of River Bhagirathi in the state of Uttarakhand of India. The Project comprising 04 nos. reversible pump turbine units of 250MW each, involves construction of underground caverns and chambers along with the tunnels of left bank of the River. The Ground is composed of the Lesser Himalayan Phyletic rocks of Chandpur formation. The Shafts are generally 140m deep with a chamber at the top and bottom portion of shaft connected with the Head Race Tunnel. This paper presents the design and planning of support system and the construction sequence for different ground condition and the monitoring performance of shafts during construction. Due to a large shaft diameter, the shafts are planned to be excavated in parts with the pilot opening. Both the shafts are under construction and the paper will discuss the support system design, construction method, sequences of excavation and construction challenges in the complex Geological condition.

***Keywords** : Underground Construction, Shaft, Support design, Excavation method, Excavation sequence, Geological challenges.*

1. INTRODUCTION

The 2400MW Tehri hydropower project located in Tehri district of Uttarakhand state of India, is being constructed in three stages. The first 02 stages of 1400MW are already in generation stage, the 3rd stage of 1000MW pumped storage is under construction. This fully underground project involves construction of 02 upstream surge shafts, butterfly chambers, penstock assembly chambers, vertical penstocks, underground power house and transformer hall caverns and twin tail race tunnels. One of the rarest underground complexes of the country negotiating with fragile Himalayan rocks to accommodate multiple openings, caverns and vertical shafts.

02 nos each of 20.92m diameter upstream surge shafts have been provided at the end of the twin head race tunnels to dampen the water-hammer-effect resulting from the rapid start and closure of the turbine. Separate surge chambers have been provided at the top to facilitate construction and operation of both shafts.

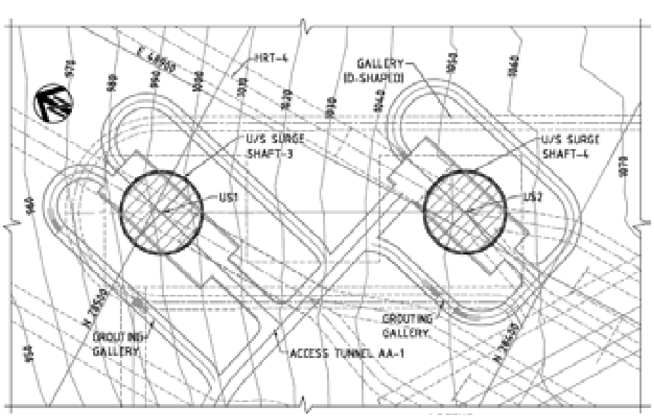

Fig. 1 : Layout of Upstream Surge Shaft

2. GEOLOGICAL SETUP

The Project is situated on the rocks of Chandpur formation of Lower Himalaya where the main rock units of project belong to Phyllitic Quartzite (PQM, PQM+PQT) and Quartizitic Phyllites (QP, QP+SP). The acronym PQM stands for Massive Phyllitic Quartzite, PQT for Thinly foliated Phyllitic Quartzite.The two others, QP and QP+SP stands for Quartizite Phyllities & Sheared Phyllites.

The better and stable ground was experienced with PQM (Type-1); where as fair rock conditions for tunnelling were found in PQM+PQT (Type-2) zone. The QP and QP+SP (Type-3) and SP (Type-4) categories belong to poor to very poor ground condition for tunnelling. A Geological model of both the surge shafts developed on the basis of subsurface investigations.

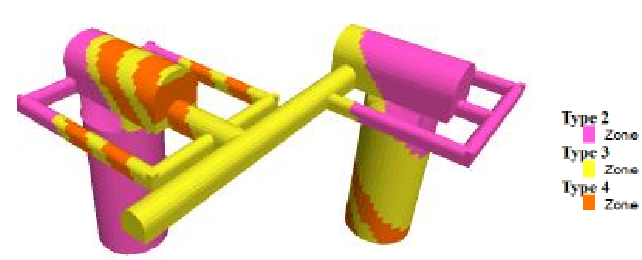

Fig. 2 : Geological model of surge chambers

3. ARRANGEMENT OF SHAFT LAYOUT

The tactical function of the two shafts is to facilitate the upstream surges. The internal diameter 20.92m of the shafts was necessary to facilitate and dampen the upstream water surges. A circular structure of shafts was designed to make them structurally stable and hydraulically suitable. Slight rearrangement of shaft- layout was carried out, away from the initial planning arrangements, in order make them compatible with the local geology.

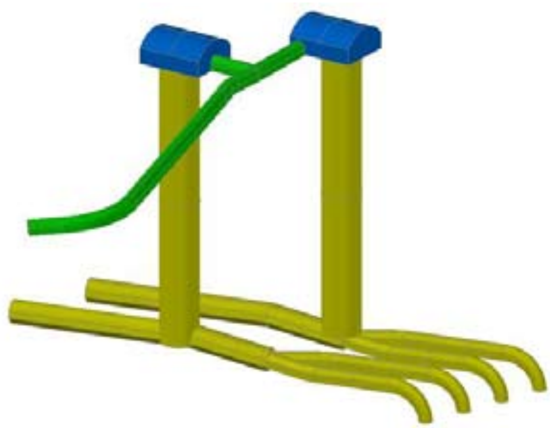

Fig. 3 : Arrangement of Shaft with Head Race Tunnel

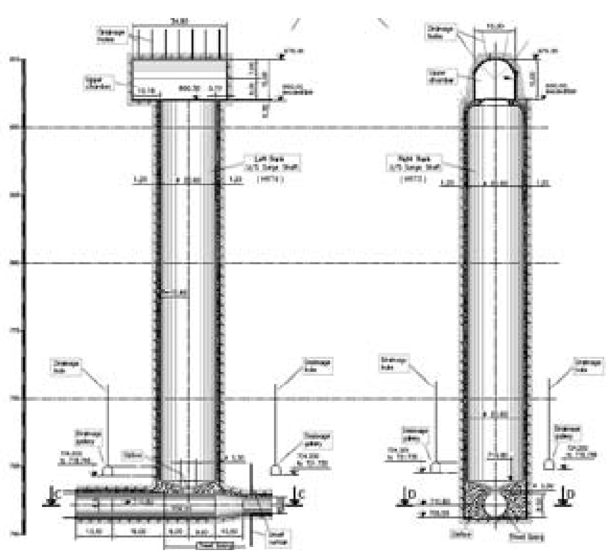

Fig. 4 : Sectional view of shaft

4. GEOLOGICAL MODEL OF SHAFT DESIGN

Assessment of Geological conditions, the in-situ stress- ,state, is always a crucial task for determination of the expected rock-behaviour vis-a-vis the hydraulic fracturing potential. In order to investigate Geological conditions vertical bore holes parallel to shaft alignment was drilled. The investigation focused on the identification of various rock units, assessment of permeability, the strength and deformability, as well as orientation and magnitude of the local stress field. Few Dilatometer, UCS, Triaxial & Hydro fracture tests were carried out to confirm the rock- mass strength, deformation modulus and in-situ stresses.

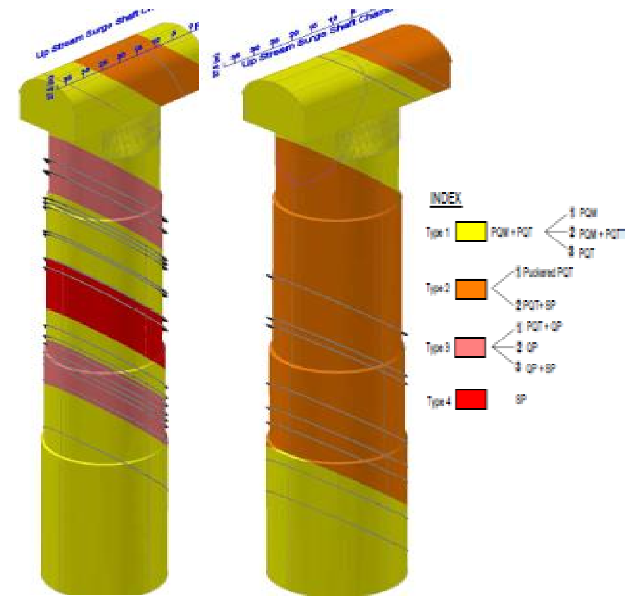

Fig. 5 : 3D Geological model of surge shafts

Based on Hydro fracture test results, two stress level considered in design analysis due to considerable height of the shafts.

Table 1 : Insitu stress

Particulars	Rock Cover 270 m	Rock Cover 350 m
Vertical Stress (σ_v) in MPa	7.29	9.45
Maximum horizontal stress ratio	1.2	
Minimum horizontal stress ratio	0.9	
Maximum horizontal stress in MPa	8.75	11.34
Minimum horizontal stress in MPa	6.56	8.51

The geotechnical parameters of various rock units were adopted, based on investigation results and empirical correlation.

Table 2 : Geotechnical Parameters for Design for D=0

Parameters		ROCK CLASS Type 2 (Homogeneous)	Type 3	Type 4
GSI_{mean}	[–]	40	30	25
m_i	[–]	10	10	10
UCS	[MPa]	35	25	20
Poisson's Ratio, ν	[–]	0.22	0.25	0.25
Bulk Density, γ	[kN/m³]	27	27	27
Disturbance Factor D	[–]	0	0	0
Elastic Modulus, E_m	[GPa]	6.0	3.0	2.0
Cohesion, c^{peak}	[MPa]	0.7	0.5	0.4
Friction Angle ϕ^{peak}	[°]	38	32	28
m_b^{peak}	[–]	1.173	0.821	0.687

Table 3 : Geotechnical Parameters for Design for D=0.3

Parameters		ROCK CLASS Type 2 (Homogeneous)	Type 3	Type 4	Ref
s^{peak}	[–]	0.0013	0.0004	0.0002	[1]
Disturbance Factor D	[–]	0.3	0.3	0.3	[1]
Elastic Modulus, E_m	[GPa]	6.0	3.0	2.0	[1]
Cohesion, c^{peak}	[MPa]	0.6	0.4	0.3	[1]
Friction Angle ϕ^{peak}	[°]	35	28	25	[1]
m_b^{peak}	[–]	0.804	0.528	0.428	[1]
s^{peak}	[–]	0.0006	0.0002	0.0001	[1]

5. DESIGN OF SHAFT

A comprehensive series of numerical analysis were performed for the initial support requirement and overall stability of the excavation. Both the shaft designed to stand the test of global stability and local stability. To assess the global stability of the shafts, a stress-deformation analysis was carried out using the 2D FDM program. The local stability test UNWEDGE revealed that due to different set of rock joints there was a formation of unstable rock wedges on the site.

The stress deformation led to the discovery that the rock mass surrounding the excavation are was homogeneous and isotropic in all directions, the rock mass runs in continuum, and the blast damage zone or disturbance zone comes out to be the first 03m of the rocks surrounding the excavation. The support installation is carried out after the one round excavation which generally results in relaxation of stresses upto 90%.

5.1 Wedge Stability Analysis

The analysis of Geometry and stability of the underground wedges is defined by intersection of joints of the rock mass surrounding the shafts, performed on the scale of UNWEDGE software. Four sets of joints planes were selected for wedge formation. Different combinations of all the joint sets were analysed. Support system of 350KN with fully grouted rock bolts, 10m long and 1.5m c/c, was adopted to assess stability of wedges after installation of the support. And all wedges were found stable with FOS more than 1.5.

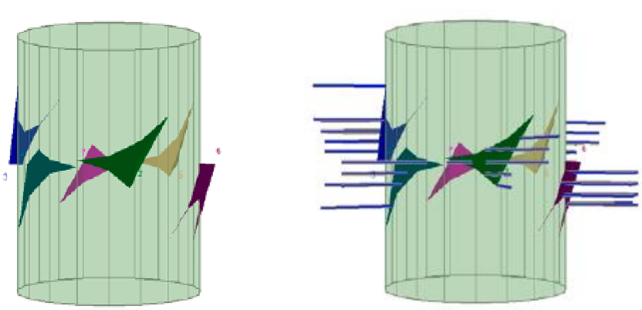

Fig. 6 : Wedge Analysis and support system

5.2 Stress Deformation Analysis

For the stress deformation analysis, 2D numerical modelling was done, using FLAC program. A model of 120m x 120m x 160m was crested to minimize the influence of the boundaries of excavation. The outer boundaries were kept at sufficient distance from the shafts to simulate the 'far field conditions'. The support system under analysis consists of a composite support, including the rock bolts of tensile strength 350KN, and the shotcrte with compressive strength of 25MPa. Depending upon the rock types and the rock cover. Different density of rock bolts and thickness of shotcrete were modelled.

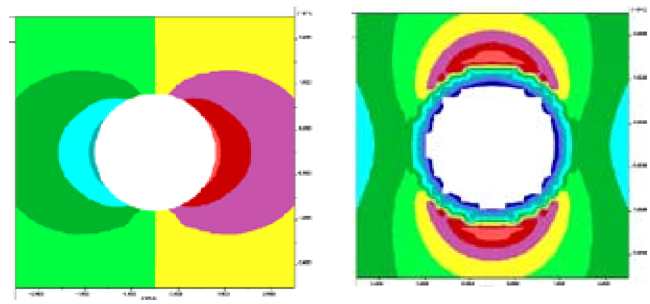

Fig. 7 : Stresses & displacement plot

Table 4 : support system for Analysis

Rock-Type	Rock Cover	350 kN Rock bolts	Shotcrete
Type-2	270 m	10 m long @ 1.5 m c/c	200 thick
Type-2	350 m	12 m long @ 1.5 m c/c	250 thick
Type-3	270 m	14 m long @ 1.0 m c/c	250 thick
Type-3	350 m	15 m long @ 1.0 m c/c	300 thick
Type-4	270 m	15 m long @ 1.0 m c/c	300 thick
Type-4	350 m	15 m long @ 1.0 m c/c	300 thick

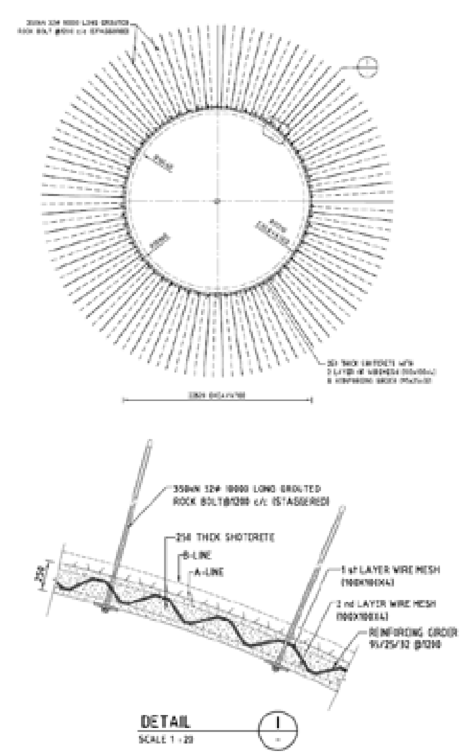

Fig. 8 : Typical Support system for Poor rock (PQT+QP, QP, QP+SP)

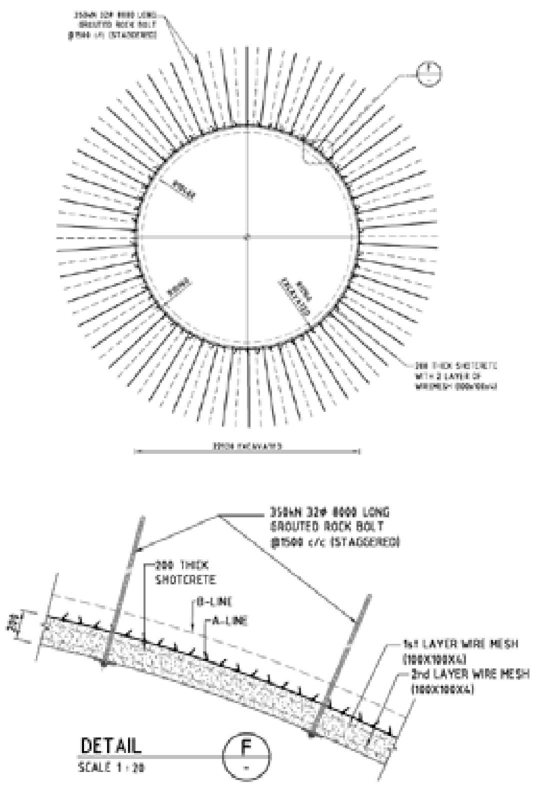

Fig. 9 : Typical support system for Fair rock (PQM+PQT)

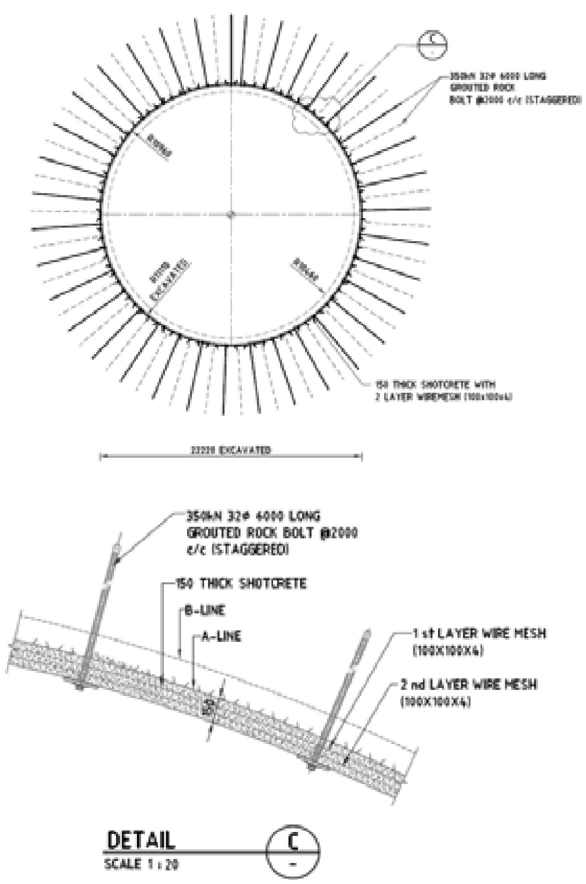

Fig. 10 : Typical support system for Good rock (PQM)

From the analysis it is found that the maximum rate of deformation was found in the weak and high rock cover zone.

Table 5 : Maximum displacement for different rock type

Rock-Type	Rock Cover	Max. Displacement in x [cm]	Max. Displacement in y [cm]
Type-2	270 m	3.3	3.1
Type-2	350 m	4.8	5.1
Type-3	270 m	7.8	8.3
Type-3	350 m	10.6	11.9
Type-4	270 m	13.6	17.5
Type-4	350 m	19.0	25.5

Based on the wedge-stability and stress-deformation analysis, the following support system has been recommended.

Table 6 : Support system recommended for shaft

Rock-Type	Rock Cover	350 kN Rock bolts	Shotcrete	Reinforcing Girder
Type-2	270 m	10 m long @ 1.5 m c/c	200 thick	-
Type-2	350 m	12 m long @ 1.5 m c/c	250 thick	-
Type-3	270 m	14 m long @ 1.0 m c/c	250 thick	95/25/32
Type-3	350 m	15 m long @ 1.0 m c/c	300 thick	130/25/32
Type-4	270 m	15 m long @ 1.0 m c/c	300 thick	130/25/32
Type-4	350 m	15 m long @ 1.0 m c/c	300 thick	130/25/32

6. CONSTRUCTION PLANNING

Construction of the twin vertical shafts for upstream surges, is a huge challenge because of its large diameter and complex Geological conditions. A raise-climber technique was adopted involving the opening of 3.0m dia- upward Pilot shaft with the help of Alimak Raise climber. Then widening of pilot shaft has been proposed taking in to consideration the sequential excavation and support system from the top to the bottom.

Separate chambers for each shaft have been constructed at the top of the shafts for widening of the pilot shaft and for operational manuvers.

Fig. 11 : Pilot shaft by Raise climber

To control shaft deformation and to restrict of explosive consumption, taking in view the vicinity of the shafts close to the already operating Power house of the THDC, the widening has been modelled as the 'half face excavation'. The controlled-blast, designed has been adopted to restrict Peak Particle Velocity and to delimit over excavation of the shafts in the poor rock conditions.

For monitoring the behaviour of the excavated face of the shafts, certain geotechnical instrumentation techniques have been proposed. One of them is use of Multipoint bore hole extensometers (MPBX), designed to depict the depth of deformation.Another is the rock bolt load shell which monitors the tension on the rock bolt. Yet another is the Bi Reflector Target, proposed to monitor 3D movement of the excavated face of the shafts.

6.1 Excavation & Support of Slant Portion of Shaft

A series of steps were taken to ensure the stability and effective excavation of Tehri PSP U/s Surge Shafts, mainly a crucial slant -portion -design and its Excavation and Support. The thirs major was casting of collar beams and for erection of truss girders and for movement of the gantry.

6.1.1 *Use of Equipment for safe operation of slant portion*

The Geometry of U/s Surge Shaft and its Upper Chamber connection was unique owing to the complex Geological Formations (Low Geotechnical properties of rock mass housing the excavation). The excavated dimensions of the Surge- Shafts just below the chamber (at chamber invert) are 22520x15600mm (the dimensions are not rectangular; in the plan they comprise of two parallel lines separated by 15600mm and their ends connected by arcs of 11260mm radius). The diameter of the Shaft is 20920mm. The maximum dimensions of the excavated-plan of the upper chambers are 37520(L) x15600 (W) mm. Therefore, the chamber- width is restricted to 15600mm, where as the Surge Shaft dia. below it is 20920mm. A change was proposed which was necessitated by the hostile geology and non-feasibility of the construction of the chamber- size in commensuration with Surge-Tank diameter. Therefore, a circular section of the shaft was tapered to oval shape at invert of upper chamber. The 10000mm height of shafts was needed for safe operations and optimum use of the equipments. The design process was evolved accordingly.

6.1.2 *Step taken to achieve stability of slant portion of shaft.*

The most critical portion of the Surge-Shaft is its slant and 10m high span below the chamber invert. The chamber was excavated to invert EL. 859.50m. Complete levelling concrete was laid at the chamber invert.

The excavation of the slant portion of the Surge Shaftswas done in two semicircular parts. The first part was excavated to EL. 854.50m; this has now allowed the working space (depth) of 2.4m below the bottom chord of the truss girders (gross depth 2.6m). During the downward excavation, the excavation of collar beam area around the periphery atop the Surge Shaft was undertaken and stabilized, depending on the type of the rock as per approved GFC drawings. The excavation of the second half was taken up and stabilized accordingly.

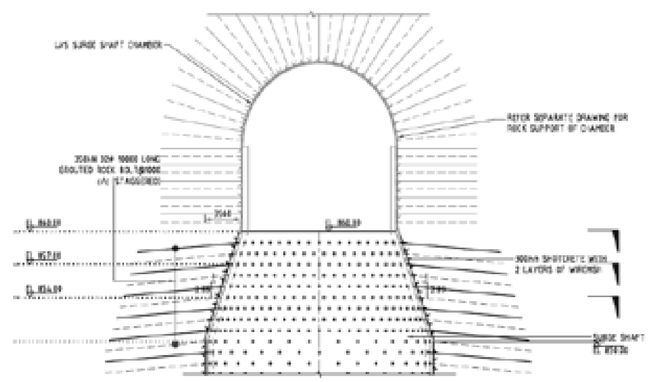

Fig. 12 : slant portion of shaft

Step 1 : The initial excavation below the chamber area up to EL. 856.50m, i.e., 3m was done in step by step of 1.0m with the help of hydraulic breaker mounted on the excavator. Thereafter up to EL. 854.50, excavation carried out with control blasting. The slant portion was worked out using chiseling method.

Step 2 : The step 1 was followed by first layer of 50mm thick shotcreting and then fixed with the help of a high strength cable-net, properly securing all the edges (full rock support as per approved drawings has to be provided after every round (1 m) of excavation}.

Step 3 : The final layer of supports was raised. Lattice girders at 0.5 c/c slant length on the first layer of wire mesh were fixed.

The 2nd layer of shotcrete was completed. For securing all the edges the second layer of high strength was fixed then the final layer of shotcrete was applied. Drawing on the final shotcrete surface, rock bolts as per approved GFC drawing, were installed. Until the excavation & support reached to EL. 854.50m, the measures of step 2&3 were followed. Care shall be taken to finish the balance supports in the previous bench, before the next bench round is excavated.

After completion of excavation and support upto EL. 854.50m, the collar beam were cast with reinforcement and concreting around the defined periphery atop the Surge Shaft. In the process, the provisions of base plate and bolts arrangement for support of truss girder (as per GFC drawing of collar beam and truss- girder) were followed and sufficient time to the collar beam to gain their strength was allowed.

Both the truss- girders were installed, one by one, at the defined positions. All the proper precautions to fix truss girders were taken. The struts and 20mm dia. 1.5m long rock bolts were fixed as per approved GFC drawing.

The excavator was positioned at the chamber invert. Any ramp in to enter in the Surge Shafts was strictly avoided.

In order to maintain the conical shape and to avoid over-break, careful excavation at the initial stages of the slant portion shall be done. Blasting was not to be carried out in the initial stage of excavation at least for an initial depth of 3m.

For the remaining slant area, a continued bench excavation was conducted from depth 5m to 10m, with each bench- round of 1 m depth, using the soft blasting with line drilling.

Chiseling method was followed in the slant portion in order to avoid over- breaks and to maintain the shape. Soft blasting was adopted below EL. 854.50m, in order to give negligible disturbance to the truss girder arrangement.

At each stage of working in the slant portion excavation, proper platform arrangements to cover the pilot hole were ensured.

Any rock fall, cracks, wedge failure etc. were recorded and informed immediately.

Fig. 13 : Excavated Portion of Both shaft with support

6.2 Excavation beyond slant portion

After achieving the construction of slant portion up to the depth of 10m below ring beam, we could achieve the required circular diameter of 20.92m and started shaft sinking in full swing. We achieved the consistent progress of 6m/month in each shaft. Presently we have proceeded with drilling and blasting with advance of 2m advance per cycle, followed by mucking, fixing of lattice girder @ 1.5m C/C, wire mess fixing,2 layers of shotcreting and fixing of 62 nos 10 m long grouted rock bolts. Photos of each shaft appended below show the clear picture of the progress achieved.

Fig. 14 : Excavated Portion of Both shaft with chamber

Fig. 15 : Support System Installation

7. CONCLUSION

Construction of surge shaft of the hydro power project is one such component which happens to be the most critical phase, as it involves multiple stages for its completion. It becomes more critical when it encounters adverse geology. Therefore, proper planning based on sound design is very much important for the safe and stable construction.

Due to inherent varieties of geological conditions and large diameter of the shafts, it has been proposed that shafts must be constructed with NATM method. The complete sequence of excavation was modelled using the finite element model to ascertain that the adequate safety factor is obtained for stresses in final lining. Based on the detailed geological and geotechnical data of the project, the shaft profile has been divided into three segments of similar rock types, where similar ground support can be applied. Excavation and initial ground support systems have been designed for each of the segments. The excavation options include dividing the shaft profile in two parts based on restricted ground vibration and controlled over break. Both the shafts have been constructed to the 28% depth, using sequential excavation and designed support measures. The excavated zone has been kept under monitoring of the Geotechnical Instrumentation, and it is found that both the shafts have been performing perfectly as per the designed assumptions.

8. REFERENCES

Reports on the analysis and design for Rock support system of upstream surge shaft (July 2015), Tehri Pumped Storage Plant.

Excavation sequences for slashing of upstream surge shaft No. 3 & 4. (May 2017), Tehri Pumped Storage Plant.

Barla, G (2016), Application of Numerical modeling in tunneling & underground excavation,

T.T Aye, M.S.Y Tong, K H Yi, E. Arunasoruban, Design & construction of Large Diameter Shaft. Amberg & TTE Engineering Pte Ltd, Singapore.

EDT-G&G-12-0250, Tehri PSP- General layout of main Geological features

EDT-GG- D309514008817A, Tehri PSP- Geological & Geotechnical input data for conduct calculations on the stability of upstream surge shaft.

EMM-1110- 2-2901. U.S. Army corps of Engineer, Engineering & Design – Tunnels & Shafts in Rock.

Bhawani Singh & Rajnish K. Goel, Tunnelling in Weak Rock- Elsevier Geo-Engineering Book Series, Volume-5.

THREE PROJECTS GO AHEAD ON INDIA'S ON CHENAB RIVER

Indian hydropower producer Satluj lal Vidyut Nigam (SIVN), a joint venture of the Government of India and the Government of the northern state of Himachal Pradesh, has been awarded a contract for three hydro projects totalling 501 MW by the Government of Himachal Pradesh.

"The Cabinet meeting, chaired by Himachal Pradesh Chief Minister Jai Ram Thakur, has allocated 104 MW Tandi, 130 MW Rashil and 267 MW Sach Khas hydroelectric projects on the Chenab river basin to SJVN," the company said in a filing on the Indian Stock Exchange, issued on 24 December.

The Sach Khas project, in the Pangi valley of Chamba district, about 54 km downstream of Udaipur, is to be built between the upstream Purthi and downstream Duggar schemes. It is planned to include a concrete gravity dam, with a height of about 77 m, impounding a reservoir with gross storage of 25.24 x 106m^3, and an underground powerhouse at the toe of the dam. The Rashil and Tandi projects, in the district of Lahaul and Spiti, are both designed as run-of-river plants. Tandi will be located upstream of Rashil. It will comprise a diversion barrage just downstream of Tholung, a 7.4 km-long headrace tunnel and a powerhouse equipped with three units of 34.66 MW to generate annual output of 430 GWh, under a gross head of about 69 m. Rashil will also comprise a diversion barrage located near Jabrang/Rashil and an 8.8 km-long headrace tunnel. The plant is designed to generate average annual output of 541 GWh, with a gross head of 82 m.

SJVN now has six projects, with a total capacity of 1279 MW, under development in the Chenab river basin. In addition to the latest award, me power producer is already devel-oping the 430 MW Reoli Dugli, 210 MW Purthi and 138 MW Bardang hydro projects.

SJVN is also developing the 210 MW Luhri Stage-I hydro scheme, in the northern state of Himachal Pradesh, on a build-own-operate-maintain (BOOM) basis. In November last year, India's Cabinet Committee on Economic Affairs approved INR 18.10 billion (US$ 244.5 million) in investment to sup-port the construction of the run-of-the river scheme, on the river Satluj river (see H&D Issue 6,2020).

Formwork for RCC Dam Construction at TLDP-IV

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Hindustan Construction Company Ltd.

1. PROJECT DESCRIPTION

Teesta Low Dam Project–IV (TLDP-IV) is a 160 MW (4×40 MW) run of the river scheme located at about 350 m upstream of Teesta-Kalijhora confluence on NH-31A and 18.3 Km downstream of Teesta Bridge in Darjeeling district of West Bengal. The gravity dam has a total length of 511 m out of which RCC portion is 195.6 m. The height of the dam is 43.70 m from the founding level. The designed cross-section with steps on both upstream and downstream sides is shown in Figure 1

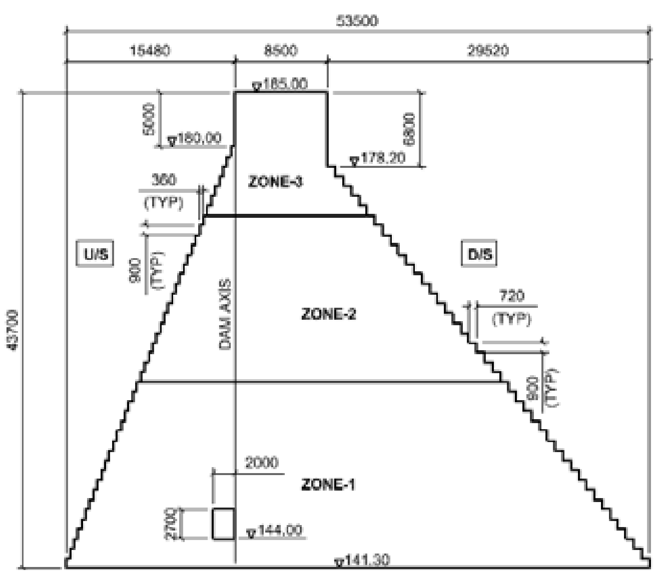

Fig. 1 : Cross-section of RCC dam at TLDP-IV

The total volume of dam concrete was estimated to be 1,65,000 cum. This 195.6 m long dam was constructed in 196 days. The construction planning was such that the entire dam was divided in different zones (refer Figure 2) while being cognizant of engineering, design and construction aspects. The dam cross-section narrowed down as it rose in height, with the width shrinking from both sides. Usually the steps are provided on the downstream side for better energy dissipation; in this case however the steps were provided on both the sides.

2. FORMWORK CONSIDERATIONS

Salient differences in RCC formwork when compared to conventional concrete formwork include:

(i) RCC formwork must meet the needs of continuous climbing in continuous type of construction activity;

(ii) Early strength is lower due too slow development of RCC strength, the cohering strength of concrete at the anchorage is minor and hence should be properly accounted for

(iii) Thirdly, the lateral pressure produced during the RCC construction is less due to drier nature of RCC

The key to designing RCC formwork is to resolve the contradiction of minor cohering strength in anchorage and rapid climbing, while making sure that it is easy and rapid to erect and detach formwork on spot. In general, there are various factors affecting the selection and design of formwork for RCC. These are listed below:

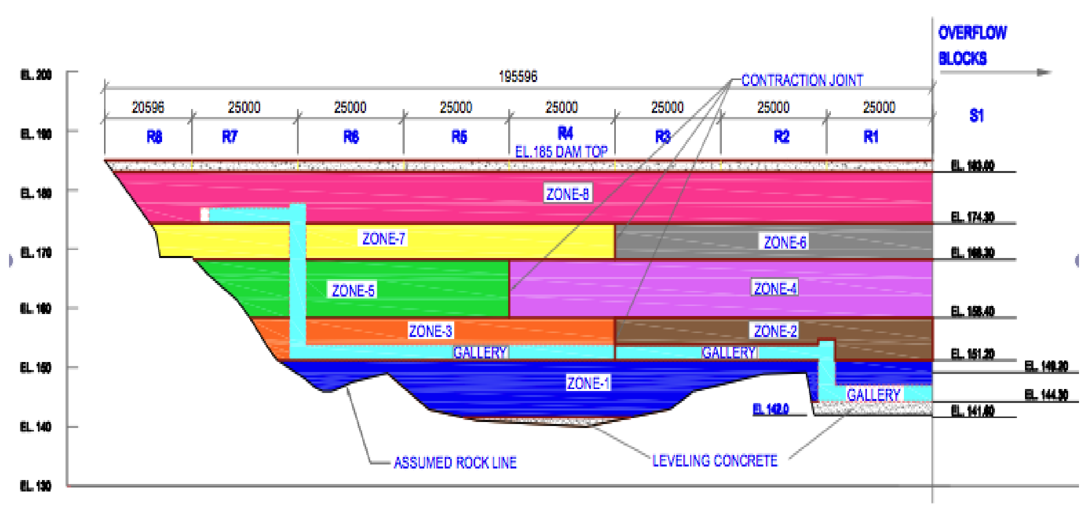

Fig. 2 : Zoning of RCC dam construction

A. Concrete Materials

(i) Rate of rise of concrete in forms - It means at what speed the concrete is being poured into the formwork. It is measured in m/hr. Rate of rise directly affects the pressure exerted by concrete on forms

(ii) Temperature of Concrete - If the concrete temperature is lower, then the pressure exerted on formwork is higher

(iii) Setting time of concrete - Longer the setting time of concrete, higher the pressure on formwork. This also means taking cognizance of the season in which RCC is planned to be constructed

(iv) Finish - A good and defects free finish of concrete surface is always desired. But in case of dams it is even more essential to prevent the erosion of concrete surface. In cases where the concrete is not visible, there formwork material with slightly rough finish may be accepted to save the cost

(v) Joints - Joints visible on concrete shall be less noticeable. Again, in case of dams it is critical to have smooth joints

(vi) Anchorage - Sometimes anchorages are left (sacrificial) in concrete being cast to support the formwork for next lift. Care needs to be taken that the anchorages are not loaded before the concrete gains enough strength

B. Design

(vii) Maximum Pour Height: - Maximum height that is going to be cast in one go is called as maximum pour height. Higher the pour height, higher the pressure

(viii) Deflection - Formwork must be designed so that it fits within the permissible deflection allowed for that structure

(ix) Shape Retention - It should retain its shape after number of repetitions

(x) Exposure to fatigue stresses - the formwork wears out faster if subjected to rapid fatigue loads

(xi) Support System - Where can the formwork be supported from? Ground or already cast pour of concrete; Internal or external support etc. are considered while designing the formwork

C. Construction

(xii) Handling ease - Depending upon the handling requirement of the activity (manually or by cranes etc.), the weight of the individual components of formwork must be restricted

(xiii) Number of repetitions – The required number of repetitions for satisfactory performance guides the selection of the material for formwork; longer life requirements necessitate better choice of material. It is trade-off that the designer must draw between the initial fabrication cost versus a holistic life-cycle performance

(xiv) Cost - It should be cost effective depending upon use and number of repetitions

(xv) Erection time – Since speed is of essence in RCC layer turnaround time, formwork should normally be quickly erectable, but it should not be expensive to achieve that. This is done while being cognizant of the required construction speed and methodology

(xvi) Ruggedness - It should be rugged enough to withstand some jerks and rough handling at site. This also includes considerations cognizant with the compaction equipment

xvii. Set Formation - One set of formwork can be defined as the complete unit of formwork which is enough to cast one lift or 1 entity of structure till concrete gains strength sufficient to stand freely

3. CONSIDERATIONS AT TLDP-IV

The formwork requirement for the entire dam was 540 square metres or 100 MT. besides satisfying the structural and aesthetic requirements, the formwork must satisfy the needs for continuous climbing. The key of the formwork design is whether the alternate climbing formwork can meet the needs of RCC rising rapidly during the low temperature season. The formwork design considerations at TLDP-IV involved four unique types of formwork sets viz.

(i) For upstream steps

(ii) For downstream steps

(iii) For block-to-block joints

(iv) For galleries

Each upstream step had a riser of 900 mm and tread of 360 mm while each downstream step had a riser of 900 mm and tread of 730 mm. The design methodology consisted of compacting each layer to a thickness of 300 mm. In accordance with the construction specifications and methodology, the following assumptions were made:

(i) Each riser is compacted in three layers of 300 mm lift thickness with concrete placement temperature of 15 degree C

(ii) The maximum rate of rise of concrete is 0.09 m/h

(iii) The initial setting time of concrete is 18-24 h and final setting time is 30-45 h

(iv) Expected in-situ strength gain of concrete is assumed at 1.5, 2.5 & 4.0 MPa respectively at the end of 48, 72 & 96 h

(v) The roller width is 2.1 m. The edge distance of the vibratory roller working from the formwork face is 0.5 m

(vi) The surcharge loads of the moving machineries were assumed commensurate to the available machines

The material used for formwork was as follows:

(i) Formwork panel was of 2000 x 900 mm

(ii) Skin plate was 3.15 mm thick

(iii) Horizontal stiffeners for panels were Flat 75 x 5 thick

(iv) Panel frame angle was ISA 75x75x6

(v) Soldier frame with bracing members in pipe cross section

(vi) Anchor bolts of 16 mm diameter

4. SCHEME FOR CLIMBING FORMWORK

4.1 General structure

There are four parts for a formwork:

(i) Faceplate – 3.15 mm thick faceplate of 2.1 x 0.9 m was standardized and modularized

(ii) Supporting structure – Girder frame was adopted as supporting structure steel frames. For the sake of convenient erection, special hanging point, position device and wedge were designed. By adjusting bolts which are located at the bottom of girder truss, erection and detachment of formwork were mainly fulfilled through wedges

(iii) Fixing structure – Bolts and jackets XXXX (describe briefly)

(iv) Operating platform and accessories – From the construction side, the working lift was used as a working platform, while on the steps side, the steps which were already casted were used as working platform

(v) Anchor bolts – steel reinforcement bars are been used as anchor bolts to take the lateral pressure of green concrete. These bolts are

4.2 General scheme

The general scheme for climbing type of framework is shown in Figure 3 through Figure 6. The scheme is detailed as follows:

(i) Stage-1 consists of erecting Frame 1 & 4 with panel welded to solider. The first step was casted in lift thickness, each of 300 mm. After completing first two layers, sacrificial anchor bolts were inserted and tightened

(ii) In Stage-2, Frames 2 & 5 are erected. Frames 1 & 2, 4 & 5 were then locked with plate and pin. Step 2 was then cast in 300 mm thick layers. Anchor bolts were inserted and tightened after completing the first two layers

(iii) Stage-3 consisted of erecting frames 3 & 6 and locking 2 & 3 and 5 & 6. Anchor bolt insertion followed like above sequence

(iv) After completing step-3, frames 1 & 4 were removed (deshuttering) and shifted for the fourth steps. Fixing, locking and anchor bolting procedures were followed like the above steps

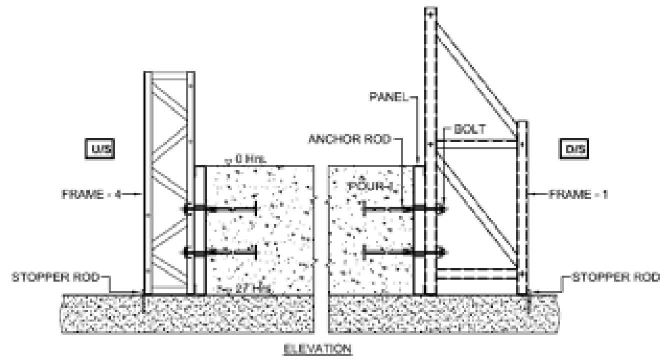

Fig. 3 : Stage - 1 of formwork scheme

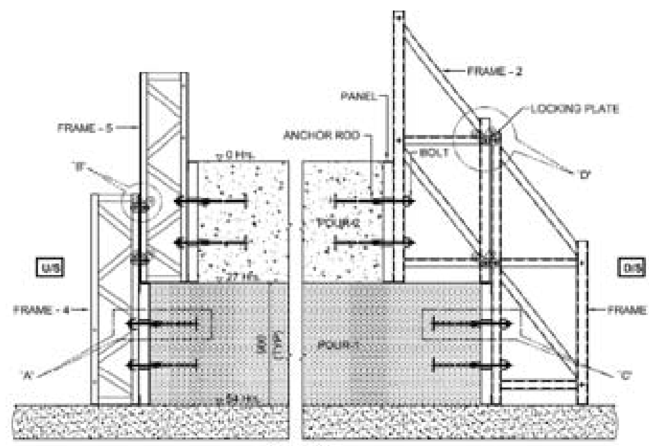

Fig. 4 : Stage - 2 of formwork scheme

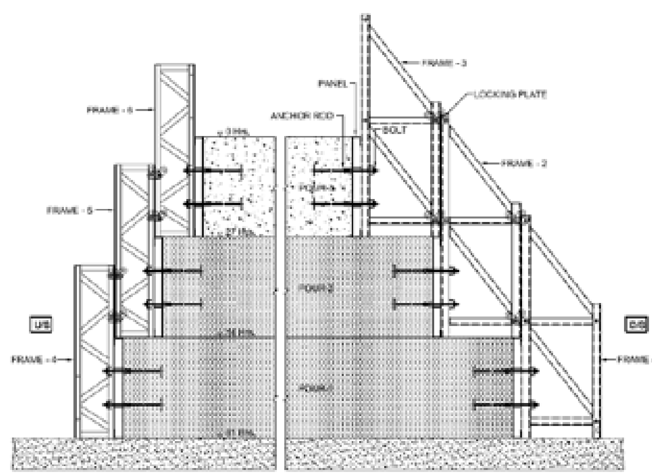

Fig. 5 : Stage - 3 of formwork scheme

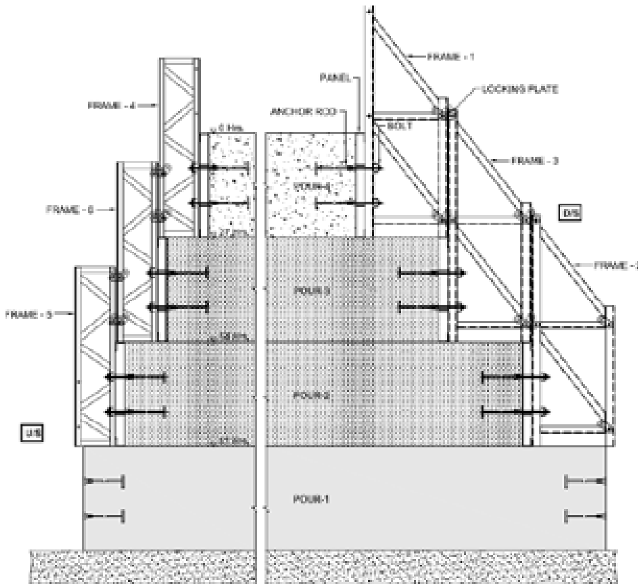

Fig. 6 : Stage - 4 of formwork scheme

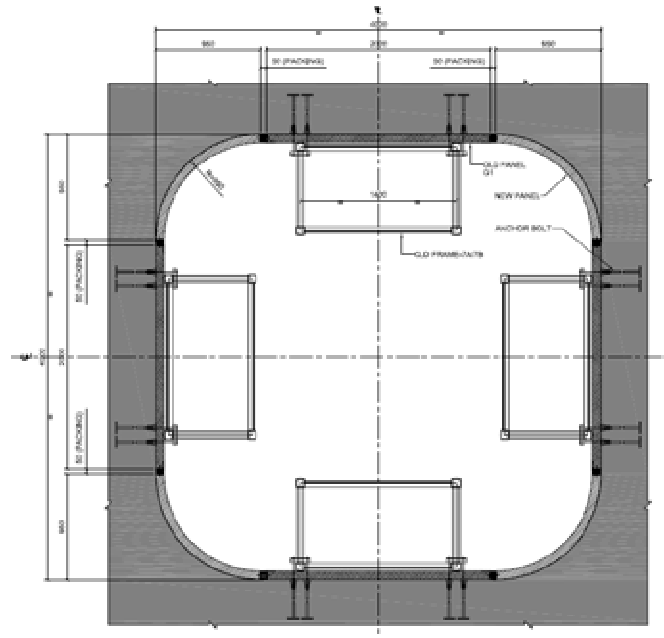

Fig. 7 : General arrangement drawing for vertical shaft

5. VERTICAL SHAFT

Similarly, the formwork and the construction scheme for the vertical shaft in the dam were arrived at. Figure 7 shows the general arrangement (GA) drawing for the vertical shaft formwork assembly used in the RCC dam construction.

6. LESSONS LEARNT

During the construction following lessons were learnt:

(i) A turn-buckle system of formwork would have proved to be a better alternative from ease in handling point of view

(ii) Monitoring of setting time of concrete is essential for appreciating the time windows for formwork removal

(iii) The space planning in a highly regimental RCC construction is pivotal as it decides the speed with which a formwork can be installed without hampering the RCC layer construction

(iv) Formwork removal must be very carefully executed, since RCC gains strength slowly. Special care must be taken during winter season

(v) The design and implementation of grout enriched vibratable RCC (GEVR), which is placed near the forms is another vital link for a defect-free formed surface.

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

Pumped Storage Projects: Climates Change and Clean Energy Transition

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ABSTRACT

Pumped Storage schemes are typical variant of conventional hydroelectric projects and have two reservoirs one in the upstream another in the downstream. Pumped Storage Schemes (PSPs) acts as a Grid ScaleBattery Storage and helps to improve system reliability. As the 21st century world is grappling with global warming due to increased greenhouse gas emissions, the world is focusing on electricity generation from renewable energy sources like solar and wind etc. India, too, has set up an ambitious target to achieve capacity addition of about 175 GW from renewable energy sources by 2022 to meet the emission reduction targets as committed in COP-21 under UNFCCC. However, renewable sources like wind & solar are variable and intermittent and would need large energy storages for their smooth integration into the grid and to avoid their curtailment. PSPs provide Balancing Power/Grid Stabilization and act as ancillary sources for improved frequency. Besides that, features like Large Grid Storage, Long discharge time in hours, Fast ramp rate, Frequency Regulation etc., Grid balancing/ stability & Voltage support against Demand/ Generation variations which Improve overall economy of power system operation by relative flattening of load curve are pushing the world for faster development of PSPs. The government of India has also come out with policy interventions to promote Hydro Power Development along with PSPs in the country.

Keywords *: Climate change, Renewable Energy Sources, Pumped Storage Projects, Hydro Projects, Policy Interventions.*

1. INTRODUCTION

The 21st Century World is grappling with the problem of climate change due to increased greenhouse gases emissions. Main greenhouse gases include carbon dioxide, methane, nitrous oxide, hydro fluoro carbons, per fluoro carbons and sulphur hexa fluoride. In the power sector, the coal based power plants are themajorcontributorsof increased greenhouse gases concentration in the atmosphere. Efforts to mitigate emissions of the greenhouse gases have shifted the focus of world towards deployment of more and more renewable energy sources for electricity generation on war footing andSolar &wind power are among the major sources of such renewable energy.

During 21st Conference of Parties (CoP) under United Nations framework Convention on Climate Change (UNFCCC), held in Paris in 2015, an agreement was signed with long term goal to keep increase in global average temperature to well below 2^0 C above pre-industrial levels and to peruse efforts to limit the increase to 1.5^0C. Under Paris agreement, India has made following International commitmentsto mitigate global warming which are to be achieved by 2030:

(i) Reduction of emissions intensity of its GDP by 33 to 35% from 2005 level.

(ii) Achieving 40% cumulative installed capacity from non-fossil fuel energy resources.

(iii) Creating additional Carbon Sink of 2.5-3 billion tons of CO2 equivalent.

In light of the same, Government of India has embarked upon an ambitious plan to attain Renewable Energy (RE) generation capacity of 175 GW by 2022. This includes 100 GW from solar, 60 GW from wind, 10 GW from bio-power and 5 GW from small hydro power.As per the Draft Report on “Optimal Generation Capacity Mix For 2029-30” ofCentral Electricity Authority, the projected energy mix of India by 2029-30 is given in Table 1.

Table 1 : Optimal Generation Capacity Mix For 2029-30

Fuel Type	Likely Capacity (MW) in 2029-30	Percentage Mix (%)
Hydro *	73,445	8.8
Coal + Lignite	2,66,827	32.1
Gas	24,350	2.9
Nuclear	16,880	2.0
Solar	3,00,000	36.1
Wind	1,40,000	16.8
Biomass	10,000	1.2
Total	8,31,502	
Energy Storage	34,000MW/ 136,000MWh	

*including small hydro of 5000 MW and hydro imports of 4356 MW.

It is observed that the major share of renewable energy has been planned to come from solar & wind. However, solar & wind plants, being the source of variable and intermittent power have the potential to destabilize the whole Indian power system if not balanced properly in real time. Pumped Storage Projects (PSPs) power are capable of balancing the grid for demand driven as well as generation driven fluctuations at a very high ramp up/ down rate. Accordingly, there is need to develop pumped storage plants on priority.

2. PUMPED STORAGE PROJECTS AND ITS IMPORTANCE

In the case of conventional Hydro Projects, water is impounded in a reservoir and the potential and the kineticenergy of this stored water is used to run turbines and generate electricity. This water, however, cannot be reused again. In Pumped Storage Projects,there are two reservoirs- Upper Reservoir and Lower Reservoir and these projects operates in two modes- Generating Mode and Pumping Mode.In the Generating Mode, waterflows from upper reservoir to lower reservoir and is used to run turbines to generate electricity. Thus, the potential and the kinetic energy of the stored water is converted to electrical energy. In the Pumping mode, water is pumpedback from lower reservoir to upper reservoir with the help of an electrical motor, which can be converted again to electrical energy via generating mode, when required. Thus, a PSP acts a storage battery which can be charged and then used to generate electricity, again and again.

In light of huge capacity additions from Solar and Wind, PSPs would be in high demandin the ancillary services market in the coming future for maintaining secure and stable operation of the power system and ensuring quality of voltage and frequency qualityetc. due to its following features:

(i) Frequency stabilization support

(ii) Peak saving during peak demand hours and load balancing

(iii) Voltage support by controlling reactive power

(iv) Quick ramping capabilities

(v) Black start capability.

3. APPLICATIONS OF PUMPED STORAGE PROJECTS

In this Section, some major applications of PSPs are discussed.

3.1 Integration of Renewables to the Grid

As discussed earlier, the Indian Power Sector is undergoing a major transformation with the planned large scale integration of Renewables such as wind and solar in the Power Mix. As per National Institute of Wind Energy (NIWE), the estimated wind power potential of India is 302 GW with Karnataka (11531 MW), Gujrat (10,645 MW), Andhra Pradesh (8,968 MW), Tamil Nadu (5530 MW) among the top wind energy rich states.As per Ministry of New & Renewable Energy, the estimated solar power potential of India is 748.98 GW with Rajasthan (142 GW), J&K (111 GW), Maharashtra (64 GW), Madhya Pradesh (61 GW) among the top solar energy rich states. Power Sector therefore needs to provide for flexible generation sources like PSP which can provide quick and efficient ramping capacity to support the variability and intermittency of the generation output of solar & wind power plants.

3.2 Spinning Reserve

As per existing National Electricity Policy, 2005, spinning reserve requirement is 5% of the installed capacity and projected installed capacity by 2030 is 843 GW. Spinning Reserve can be met through Conventional & Pumped Storage Hydroelectric Projects and through Gas - based Power Stations. Since Gas Reserves are limited and have competing demands from other sectors, development ofHydroelectric Projects including Pumped Storage projects is imperative. Pumped Storage Schemes suits better asfor spinning reserves as it provides large scale electricity storage, provides ancillary services well suited to complement intermittent generation, provides quick ramping, load following capabilityand provides assistance during Peak hours. Further PSP is mature/ dependable technology with service life of 30-40 years approx.

3.3 Flattening of Load Curve

The spinning reserve provided by Pumped Storage hydro projects also enable flattening of Load Curve and Improves Plant Load Factor (PLF) of Thermal Power Stations as depicted in figure-1. During low demand when load factor is low, Thermal Power Plant can be used to pump water in a PSP and this will improve the load factor of the Thermal Power plant. Similarly, during high demand, PSP can be operated in generating mode to reduce load on the thermal power plant.

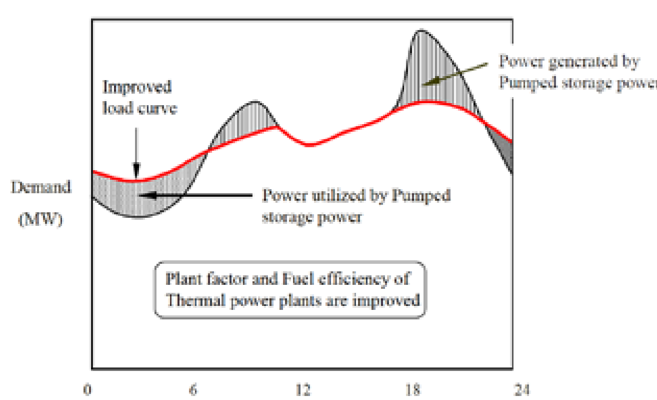

Fig. 1 : Flatting of load curve and improvement of PLF

3.4 Role of PSPs as Energy Storage Plants

PSPs represent about 96 per cent of global electricity storage by capacity. However, there are a range of other technologies on the market at various stages of development. As per the IRENA 2017 report, out of total global storage of 176 Giga Watts (GW), installed storage power capacity comprises 169 GW-96% of PSPs,3.3 GW-1.9% of thermal storage, 1.9 GW 1.1% of batteries and 1.6 GW-0.9% of other mechanical storage. Most notable is Lithium-ion (Li-ion) battery storage due to similar feature of fast ramping rate. However, PSPs have following advantages over Lithium-ion (Li-ion) batteries:

(i) PSPs can operate over a wide range of Power and Energy capacity in MW & MWh range from the huge volumes of energy (at Grid Scale) that can be stored in reservoirs and released through turbines. Li-ion batteries and other rapid response systems are traditionally suited to smaller scale localized grids in the kW to MW range.

(ii) In terms of discharge time, referring to how long power output can be maintained while releasing stored energy, PSPs can typically generate for at least about 6 hours, or more in some cases if the plant is being charged and discharged over a 24 hour period. In comparison, batteries typically provide relatively shorter duration storage, meaning charge and discharge cycling over small timescales rather than extended periods.

(iii) While PSPs can take several years from construction to commissioning, they last, perhaps, the longest in terms of project lifetimes of all storage technologies. On the other hand, the construction of a battery system is much quicker, however, they degrade quickly (their round-trip efficiency can fall from 85 per cent to below 70 per cent), with a lifetime of up to 10 years or lower depending on the conditions of operation such as cycling frequency, depth of discharge and temperature.

(iv) Both on the front of capital cost per unit of energy storage (kWh) and a levelised cost of storage, PSPs remain one of the most competitive and preferred energy storage options thanks to its economies of scale and long lifetime. According to Lazard, on a capital cost basis per kilowatt hour PSPs can fall in the range of USD 200 to USD 300, while on the same basis the value range of Li-ion batteries is USD 400 to USD 900.25.

PSP's advantage is in cost-effectively storing and releasing large amounts of energy, while batteries are more suited to short term incremental balancing due to their ability to dispatch stored energy in milliseconds. This highlights their complementarity and both technologies will have a part to play with increasing demand for electricity and achieving the best solution for a system will depend on its particular circumstances. Coupling PSPs with batteries is also a future avenue of potential growth.

4. PSP DEVELOPMENT WORLDWIDE

PSPs have been developed in different countries around the world. China with an installed capacity of 28,490 MW has the maximum developed PSPs potential followed by Japan, USA, Germany and India.As per IRENA Statistics, Installed Capacity of PSPs in some countries is given in Table 4.

Table 4 : Country-wise Globally Installed Capacity of PSPs

S. No.	Country	Inst. Cap. (MW) in 2018	Inst. Cap. (MW) in 2009
1	China	29 390	13 700
2	Japan	21 924	19 749
3	USA	19 102	22 160
4	Germany	5 493	5 898
5	India	4786	4786
6	South Korea	4700	3900
7	Italy	3 940	3957
8	Spain	3 337	2 449
9	South Africa	2732	1400
10	UK	2444	2 444

In India the first pumped storage plant was taken up at Nagarjunasagar in Andhra Pradesh in the year 1970 with an installed capacity of 700 MW (revised-705.6 MW). The Project got commissioned during 1980-85. However, it has started functioning in pumping mode since January, 2017, only after Tail Pool Damof the project was constructed.The pumped storage project potential of the country is more than 82GW, out of which 9 projects with aggregate installed capacity of 4,785.6 MW have so far been developed while another 8,700 MW of installed capacity from 11 projects is under development. The region wise breakup of this potential is given in Table 5. Out of 9 PSPs developed so far, 6 PSPs are operational and given in Table 6.

However, other 3 projects (1480 MW) are not able to operate in Pumping mode due to vibration problem in Kadana St. I & II (240 MW), Tail Pool dam construction in Sardar Sarovar (1200 MW) and land acquisition issue in Panchet Hill (40 MW). The growth of PSP has been slow and the next Section discusses the reasons for this slow growth. Further, there are 7 PSPs for an aggregate capacity of 6120 MW.

Table 5 : Region wise pumped storage project potential of the country.

Region	Potential (MW)	Developed (MW)	Under Constn. (MW)
Northern	8,185 (5 Nos.)	0	1000 (1 No.)
Western	32,209 (31 Nos.)	1840 (4 Nos.)	80 (1 No.)
Southern	12780.6 (13 Nos.)	2005.6 (3 Nos.)	125 (1No)
Eastern	12345 (12 Nos.)	940 (2 Nos.)	0
North Eastern	16900 (10 Nos.)	0	0
Total	82419.6 (71 Nos.)	4785.6 (9 Nos.)	1205 (3 Nos.)

Table 6 : State-wise operational PSPs in the Country.

S. No.	Project	State	Capacity (MW)
1	Kadamparai (2008)	Tamil Nadu	400
2	Bhira (1996)	Maharashtra	150
3	Srisailam LB (1981)	Telangana	900
4	Purulia PSS (2008)	West Bengal	900
5	Ghatghar (2006)	Maharashtra	250
6	Nagarjuna Sagar (1985)	Telangana	705.6
		TOTAL	3305.6

5. REASONS FOR SLOW GROWTH OF PSPS

Growth of PSPs in country is slow due to various reasons. Some important reasons are listed below:

5.1 Environment and Forest issues

Due to the considerable time taken in the process of Environment and Forest Clearances due to various issues relating to e-flows, free flow stretch requirement, Longitudinal Connectivity, EIA, EMP etc., commencement of construction works of Hydro projects often gets delayed. It is desirable that all the clearances relating to Environment & Forest, Wildlife etc. should be given in time-bound manner. The e-flows may be prescribed for hydro projects considering case-to-case basis and in a judicious manner and once prescribed, these should not be revisited for a project. Free flow stretch requirements should be based on river gradient and velocity. Moreover, it is often experienced that identification of land for compensatory afforestation takes a lot of time especially in the hilly states where majority of the hydro potential is identified. It is, therefore, important that a Land Bank is identified and created for the purpose.

5.2 Land Acquisition & Rehabilitation & Resettlement (R&R) Issues

In States like Arunachal Pradesh, land records are not available and, as such, timely land acquisition becomes an issue. Dislocation of the people from their houses/ workplaces etc. and their resettlement is a sensitive issue and involves a lot of time and money. Many times, this issue leads to court cases resulting in delay in project execution/ completion. State should play a pro-active role in updating/digitization of land records, land acquisition and R&R to mitigate the issues in time-bound manner. Land acquisition issues and Environment & Forest issues. 23 GW of potential PSP projects affected due to forest land/ wild life clearances.

5.3 Inadequate Infrastructural facilities

Hydro projects are often located in difficult terrains having poor accessibility. As such, substantial time is lost due to lack of adequate Infrastructural facilities at the project site allotted to a developer by the State Government. As such, States could be entrusted with development of required infrastructure facilities, matching with the schedule of development of hydro project to reduce their gestation period.

5.4 Law & Order / Local issues

Protests by the local people against the construction activities like blasting, muck disposal etc. and demands for employment, extra compensation etc. often create law and order problems, which often delays commencement of the project and affects progress of the works. State should play a pro-active role to provide a conducive environment for construction of hydro projects. Implementation of various Corporate Social Responsibility Plans and proper co-ordination with local bodies & State Authorities can minimize the issues.

5.5. Geological Surprises & Natural Calamities

A large number of hydroelectric projects has been delayed due to Geological Surprises as well as Natural Calamities like unprecedented rains / flash floods, cloud burst, earthquake etc. Use of latest technologies in Survey & Investigation and preparation of Bankable DPR, could help to reduce geological surprises to some extent. Further, efficient preparedness and Disaster Management Plan should be in place to tackle Natural Calamities.

5.6. Inter-State Issues

Delay in project implementation occurs due to Inter-State disputes between the States. Concerned State

Governments have to play active role in resolution of Inter-State matters. Pending resolution of Inter-State aspects, some of the projects could be taken up in Central Sector to avoid time and cost overruns.

5.7. High Tariff of Hydro Projects

Tariff from hydro projects has tended to be higher in initial years as compared to other sources of power (conventional as well as renewable sources) mainly due to following:

(a) Construction of complex structures having long gestation period,

(b) Non-availability of low interest bearing loans for longer duration,

(c) High R&R cost,

(d) High infrastructure (roads & bridges) cost etc. As such, some of hydro projects even after commissioning are facing financial distress due to dishonoring of PPAs / non-signing of PPAs.

5.8. Lack of price differential for peak and off-peak power tariff. PSPs have high tariffs and lack incentives for development.

5.9 Non-availability of off-peak power for pumping.

6. RECENT POLICY INITIATIVES FOR REVIVING THE HYDRO POWER CAPACITY

Realizing the need for faster development of Hydropower, the Government has also come out with certain policy interventions in March 2019 to promote hydropower. The salient features of the policy are listed below:

6.1 Declaring Large Hydropower Projects as Renewable Energy Source

Large Hydropower Projects (LHPs), i.e. projects with installed capacity greater than 25 MW, have been declared as Renewable energy source. But, LHPs would not automatically be eligible for any differential treatment for statutory clearances such as Forest Clearance, environmental clearance, NBWL clearance, related Cumulative Impact Assessment & carrying Capacity study, etc., available to Small Hydropower Projects (SHPs), i.e., projects of capacity up to 25 MW.

6.2 Hydro Purchase Obligation as a separate entity within Non-Solar Renewable Purchase Obligation

Hydropower Purchase Obligation (HPO) has been notified as a separate entity within Non-Solar Renewable Purchase Obligation (RPO). The HPO shall cover all LHPs commissioned after the declaration of new policy as well as the untied capacity (i.e., without PPA) of the commissioned projects. This HPO will be within the existing Non-Solar RPO after increasing the percentage assigned for it so that existing Non-Solar RPO for other renewable sources remains unaffected by the introduction of HPO.

6.3 Tariff Rationalization measures to bring down hydro power tariff

Certain tariff rationalisation measures as declared in the new policy include providing flexibility to the developers to determine tariff by back-loading of tariff after increasing project life to 40 years, increasing debt repayment period to 18 years and introducing escalating tariff of 2%.

6.4. Budgetary support for Flood Moderation/ storage Hydro Electric Projects (HEPs)

In-principle approval has been accorded for providing budgetary support through the budgetary grant of Ministry of Power for Flood Moderation component for Storage HEPs to be set up in future.

6.5. Budgetary support for cost enabling infrastructure, i.e., roads/ bridges

In-principle approval has been accorded for providing budgetary support through the budgetary grant of Ministry of Power for funding enabling infrastructure for hydropower projects i.e., roads/ bridges. The limit of this grant for such roads and bridges has been decided to be as follows:

(a) Rs. 1.5 crore per MW for projects upto 200 MW.

(b) Rs. 1.0 crore per MW for projects above 200 MW.

7. MEASURES REQUIRED TO ENCOURAGE PSP DEVELOPMENT

Following measures need to be taken to encourage PSP development in the country:

(i) Operationalizing recent policy measures by Govt. in Mar' 2019 for promoting hydro power sector and improving their economic viability and sale ability.

(ii) Allotting few hydro projects on the lines of Ultra mega projects for their faster implementation.

(iii) For expeditious development of PSPs at competitive costsinvolving minimal environmental, forests and R&R issues, development of PSP on existing Hydro Schemes, wherever feasible to be promoted/ incentivized.

(iv) Central Public Sector Units to be involved in big way in setting up PSPs.

(v) Promote development of Hybrid Plants comprising PSP, Solar and/ or Wind on large scale.

(vi) Pumped storage hydro plants (PSPs) be installed and operated as Regional or National asset and considered as a Grid Element for providing reliability service.

(vii) Separate regulations for peaking energy may beenvisaged for commercial justification of peak energy produced from PSPs.

(viii) Need to capture intangible benefits and services provided by Hydro stations including PSPs such as Spinning Reserve, Voltage Support to the Grid, Frequency Regulation, Load following, Black start, by suitable market design for their commercial viability.

8. CONCLUSION

To tackle the problem of Climate Change and reduce Global Green House Gas emissions, the World as well as Indian Power Sector is undergoing a major transformation with the planned large scale integration of Solar and Wind power in the Energy Mix. Power Sector, therefore, needs to provide for Energy Storage and flexible generation sources in the system which can provide quick and efficient ramping capacity to balance the variability and intermittency of the generation output of Solar and Wind. Pumped Storage hydro projects are best suited to cater to this specific demand of Power System.However, these need to be commissioned at a faster pace at comparable costs. Therefore, need of the hour is identify more and more projects utilizing either one or both the reservoirs of existing hydro stations in order minimize their project costs and completion time and at the same time involving minimal of environmental and forest and R&R issues. At the same time, there is also need to push few off-the-river PSPs like Pinnapuram, where land acquisition is relatively easier and complex civil structures like spillways, de-silting chambers etc. associated with conventional stations are not required resulting in a shorter time-frame for their completion. The recent measures announced by the Government of India relating to grants towards infrastructural works like roads and bridges and mandating Hydro Purchase Obligations and flexibility to developers in deciding the tariff is also likely to give a push to the development of hydro power sector including PSPs in India. Thus, PSPs have a major role to play in the power sector to combat climate change in the times to come.

Thermal analysis and design features of Muskrat Falls RCC North Dam

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ABSTRACT

The Muskrat Falls Hydroelectric Project being developed by Nalcor Energy is located on the lower reaches of the Churchill River, approximately 35 km west of the Town of Happy Valley–Goose Bay in North Central Labrador at latitude of 53° north. It comprises a four unit close-coupled four unit intake-powerhouse structure with a total capacity 824 MW, a gated spillway with a discharge capacity of 25,000 m³/s, a 39 m high overflow roller compacted concrete (RCC) dam and conventional gravity dams to retain the reservoir. The overflow RCC dam, referred to as the North Dam, was constructed over two seasons in a sub-arctic climate with a temperatures range from +30°C in the summer to -30°C in the winter. This paper focuses on the thermal analysis and design features of the North Dam. It presents the dam characteristics, thermal control plan and the thermal protection required during winter as well as temperature monitoring. A comparison of the results of the model and the actual field measurements will be made and variation between these will be discussed.

1. INTRODUCTION

The Muskrat Falls Hydroelectric Project being developed by Nalcor Energy is located on the lower reaches of the Churchill River, approximately 35 km west of the Town of Happy Valley–Goose Bay in North Central Labrador at latitude of 53° north. It comprises the overflow RCC North Dam, the gated spillway control structure (5 x 10.5 m bays), the four unit close-coupled intake-powerhouse structure, and a 243 m long 20 m high central core rock fill South Dam. The North Dam, the Spillway, Intake and the South Dam structures are connected by concrete gravity transition dams. SNC-Lavalin Inc undertook the design of the facility and now participates in engineering support to the construction of the facility. The general layout of the Muskrat Falls Generating Facility is illustrated in Figure 1.

Fig. 1 : Muskrat Falls generation facility – Water retaining structures.

The design and construction of the North Dam in a northern climate presents many challenges which necessitate a detailed thermal analysis, thermal control plans and thermal protection to ensure the long term integrity of the structures. This is particularly true for the Muskrat Falls North Dam which has been constructed over two seasons in a sub-arctic climate with a temperatures ranging from +30°C in the summer to -30°C in the winter. The development of thermal cracks in an RCC dam, as with conventional concrete dams, may require considerable rehabilitation and maintenance costs and therefore must be mitigated at the design stage and during construction. In this regard, contraction joints layout and the use of insulation become significant parameters to reduce the temperature difference within the dam, which in turn minimizes the potential for thermal cracking.

A comprehensive numerical thermal model was developed to study the effect of the temperature regime when evaluating thermal stresses in the dam during the construction phase due to the hydration heat and the subsequent cooling. Contraction joints were introduced at a specified distance along the dam axis to relieve the thermal restraint effects and for the control of cracking in the North dam.

This paper focuses on the thermal analysis, thermal control plans and the thermal protection required during winter as well as temperature monitoring. Additionally, since the North Dam structure was built during two construction seasons, with a break in construction over intermediate winter, it was necessary to consider the thermal impacts of a partially constructed dam over the first winter period. A comparison of the results of the model and the actual field measurements will be made and variation between these will be discussed.

2. DESIGN FEATURES - NORTH DAM

2.1 Dam characteristics

The Muskrat Falls North Dam is a 450 m long, 39 m high overflow gravity dam constructed primarily of RCC, with an exterior face comprised of conventional vibrated concrete (CVC) totaling approximately 243,000 m^3 of concrete. The dam is divided into a 330 m long overflow section and a 120 m long non-overflow abutment section, with crests at el 39.3 m and 45.5 m, respectively. Energy dissipation is achieved using a stepped downstream face at a slope of 0.8H:1.0V and an 8m-radius flip bucket to redirect the flow away from the rock surface at the toe of the dam. The North Dam is founded on unweathered gneiss bedrock and it has a drainage gallery over 374 m long with two accesses, one at each end, to allow for the installation of a grout curtain, foundation drains, internal drains and instrumentation. Figure 2 provides a general cross-section of the North Dam.

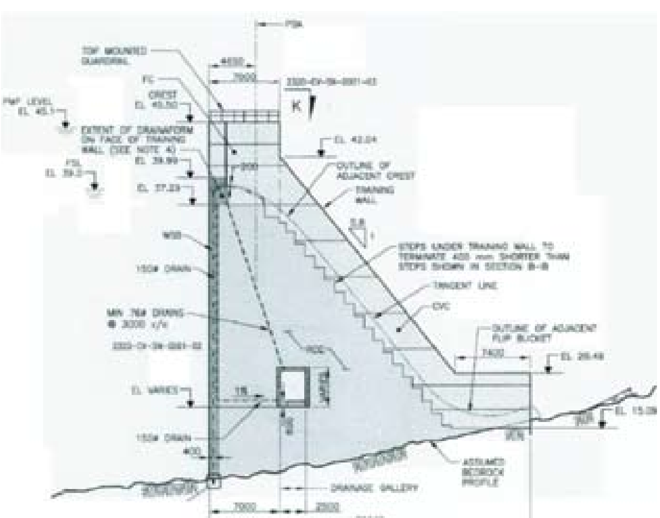

Fig. 2 : General cross-section of North Dam

2.2 Climatic Conditions

Figure 3 presents the meteorological data at Happy Valley-Goose Bay, in the proximity of the Muskrat Falls Generating Facility. The average annual temperature is 0°C and the recorded extremes are respectively -39°C and 38°C. The warmest month is July with an average temperature of 15°C and the coldest is January with an average temperature of -18°C.

2.3 Design considerations for cold climate

The design must consider site conditions, construction schedule and temperatures variation effects when evaluating potential of thermal cracks and stresses in the North dam. During setting and hardening of fresh concrete, the heat of cement hydration increases the temperature of the mass concrete and induces non-uniform volumetric changes when the concrete cools at varying rates throughout the dam over time. Thermal behaviour of the North dam is highly dependent on the initial placing temperature of RCC, the speed of lift placement and the ambient temperature at site. This is particularly important when the dam construction continues late into the fall or early winter period.

To understand the thermal behaviour of the North Dam structure, a thermal finite element model (FEM) was developed during the design phase to determine initial locations of the contraction joints, the required placement temperatures and other thermal related criteria. The evolution of temperature within the body of the dam and stresses induced by thermal conditions were assessed at various stages of construction over a two-year period, including the winter pause.

For the North Dam, the original schedule planned to complete construction in a single year, namely 2017. Construction was due to begin mid-May and completed by end of October. The reservoir impoundment was to follow soon thereafter. However, schedule changes necessitated the construction of the dam over two years, 2017 and 2018. In both scenarios (i.e. single and two season construction), internal temperatures remain high during the winter, as there is no time for heat to dissipate from the dam before the onset of winter. The high internal temperatures have the potential to create higher thermal differentials and stresses within the dam. Surface insulation can reduce the thermal differentials and stresses - the insulation does not increase the maximum concrete temperature appreciably, but it can decrease the rate of surface cooling significantly. However, removing the insulation too soon in northern temperatures can

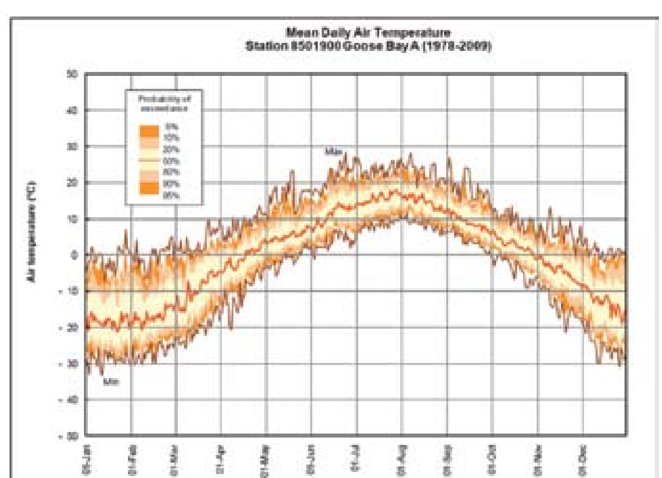

Fig. 3 : Mean daily air temperature - Goose Bay airport (1978 to 2009).

cause the mass concrete to cool quickly, which may lead to thermal cracking of the dam.

To assess such effects, a thermo-mechanical model was developed assuming the dam will be built over two construction seasons (2 phases). The aim of the thermal analysis is to: (1) determine the temperature evolution in the North Dam during construction and after impoundment, (2) assess the risk of thermal cracking and (3) determine the type of protection required, if any, during the cold winter pause. The first phase of construction was assumed to begin 15 Jun 2017 and end 31 Oct 2017, while the second phase was assumed to begin 15 May 2018 and end 31 Oct 2018. Impoundment was assumed to begin soon after. At the time of model study, the progression of construction at the end of the first phase was unknown, and thus for design purposes two work stoppage elevations were considered for the first phase, namely el 12.69 m and el 21.69 m - only the results for 21.69 have been presented herein.

2.4 RCC mix, compressive strength and thermal properties

The design mixture proportions of the RCC used to construct the North Dam are as follows: 80 kg cement, 140 kg fly ash, 134 kg water, 729 kg fine aggregate, and 1237 kg coarse aggregate.

Table 1 provides the evolution of the compressive strength for the RCC used for the construction of the North Dam. Adiabatic testing was performed which provided the heat of hydration curve for the RCC as shown in Figure 4 and the other thermal properties used in the thermal analysis are presented in Table 2.

Table 1 : Design Compressive Strength

	7 days	28 days	56 days	91 days	182 days
Strength (MPa)	5.9	9.6	13.7	18.0	21.4

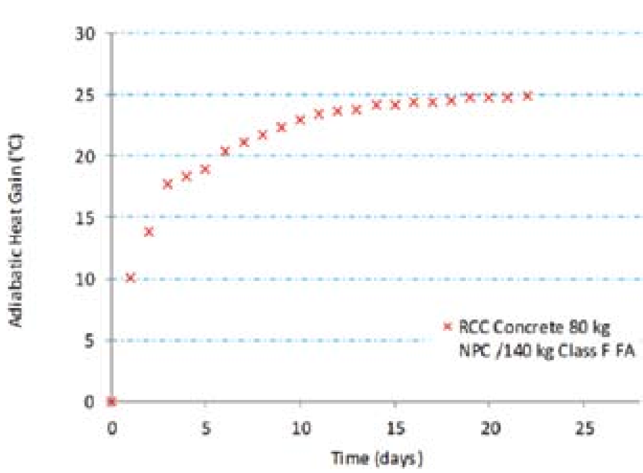

Fig. 4 : Adiabatic heat curve for the RCC dam mixture.

Table 2 : Thermal Properties of RCC

Thermal conductivity:	118	J/m/day/°C
Specific heat capacity:	782	J/kg/°C
Thermal diffusivity:	7.31×10^{-7}	m^2/s
Coefficient of thermal expansion:	7.72×10^{-6}	1/°C

3. TRANSIENT THERMAL ANALYSIS

3.1 Finite Element model

The Finite Element analysis was performed using Abaqus FE software provided by "Dassault Systèmes". Figures 5a and 5b show an isometric view of the 3D model developed for the thermal analysis at the design phase. The model was set up in layers to simulate the RCC placement sequence. For the sake of simplicity of the 3D FE model, the upstream and the downstream concrete facing (which are CVC in the dam) were treated as an RCC material. The ogee crest and the flip bucket were made of conventional concrete (CVC).

Formwork was maintained during the placement of the lift and then removed enabling diffusion to occur in the air, a surface convection coefficient of 10 W/m^2/°C was assumed. After the impoundment, the boundary condition at the upstream face of the dam was set equal to the water temperature and a convection coefficient of 100 W/m2/°C was utilized. The initial RCC temperature at placement was set at 15°C.

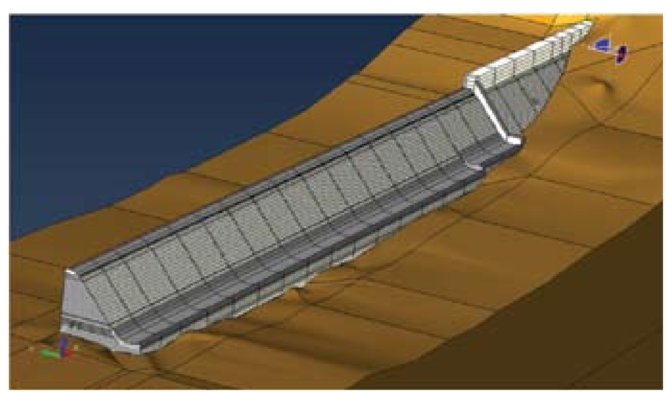

Fig. 5a : Isometric view of the 3D model of the North Dam.

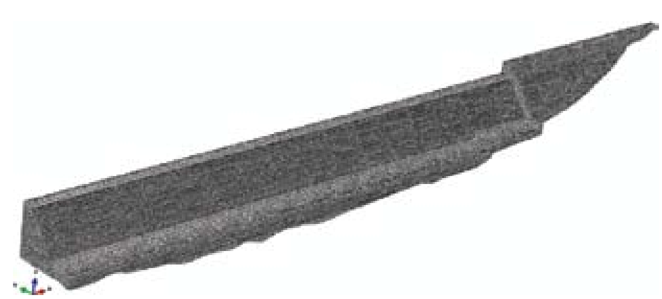

Fig. 5b : FE Model used for thermal analysis.

3.2 Temperature distribution in the North Dam without thermal protection during winter

Figure 6 presents the temperature distribution in a typical overflow section of the North Dam, just prior to the winter pause (31 Oct 2017), approximately 138 days after the start of RCC placement. As shown in Figure 6, the maximum temperatures attained are approximately 32° C in the core of the dam and near 0ºC at the exposed faces of the dam. The maximum temperature differential between the core and the facing concrete exceeds 20 ºC, the limit below which the risk of thermal cracking of the concrete is considered negligible by CSA A23.1.

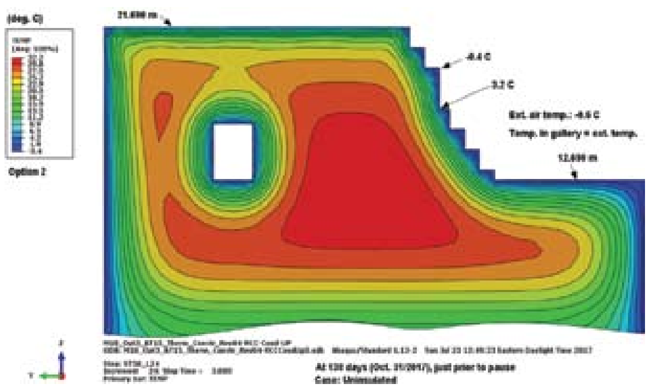

Fig. 6 : Temperature distribution just prior to winter pause (31 Oct 2017).

Figure 7 shows the temperature distribution in the North Dam at the coldest winter day (21 Jan 2018), without any thermal protection. The results indicate that the core temperature remains high at 28ºC while the temperature at the concrete surface drops to -18ºC. The temperature differential of 46ºC within the RCC is very high and could be a potential for thermal cracking, particularly for the top RCC layers which would not have attained full strength by that time.

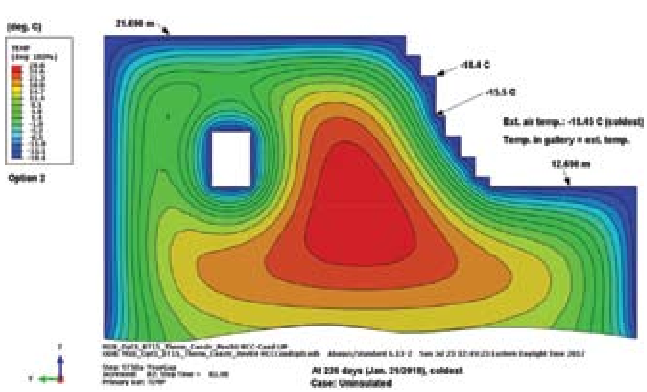

Fig. 7 : Temperature distribution at the coldest winter day (21 Jan 2018) without thermal protection

The second construction phase of the North Dam was assumed to begin on 15 May 2018 and end 31 Oct 2018. Figures 8 to 10 present, respectively, the temperature evolution within the dam after the winter pause (15 May 2018), at the completion of the RCC placement (30 Sep 2018), and at the completion of CVC ogee (31 Oct 2018). As shown in Figure 10 at the end of the dam construction, the maximum temperatures attained are approximately 35°C in the core of the dam and near 0ºC at the exposed faces of the dam.

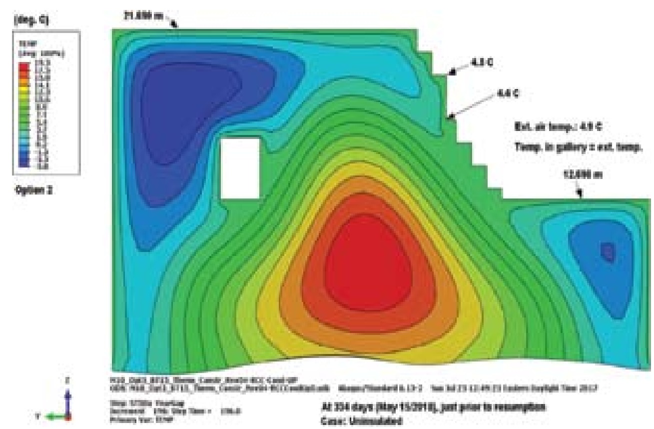

Fig. 8 : Temperature distribution after winter pause (15 May 2018) without protection.

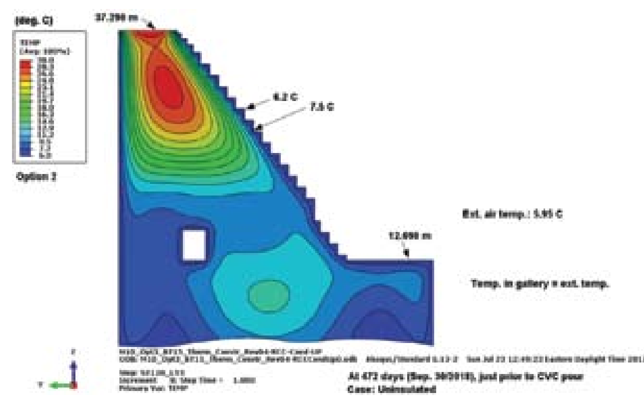

Fig. 9 : Temperature distribution at the completion of the RCC (30 Sep 2018) without protection.

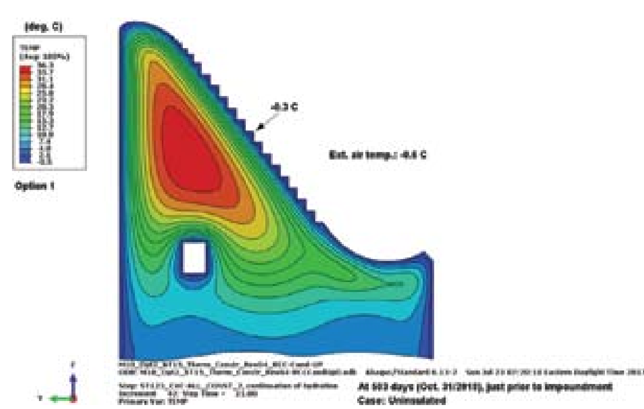

Fig. 10 : Temperature distribution after the completion of CVC ogee (31 Oct 2018) without protection.

4. THERMAL STRESS ANALYSIS

4.1 Thermal stress model

A thermo-mechanical finite element analysis was performed to evaluate the stresses in the North Dam and also to determine if thermal protection, in the form of insulation blankets, was required during the winter pause. The temperature fields calculated from the thermal analysis above were applied in the FE model as nodal temperature loads. The FE model includes both the dam and the rock foundation. The initial placement temperature of the RCC was assumed to 15°C. The self-weight of the RCC was also applied, simultaneously.

For RCC, typical splitting tensile to compressive strength ratios range from 8% to 15%. For the design purpose, a ratio of 8% was selected. Also, to consider the stress relieving effects due to creep relaxation, the temporal development of the Young's modulus during the RCC hardening is an important factor in terms of the prediction of restrained thermal stresses. An effective Young's modulus was used in the FE stress analysis, considering a restraint coefficient (Kr) of 0.42 and a creep coefficient (Kc) of 0.65. The calculated thermal stress is compared to design tensile strength of the RCC based on compressive strength of the RCC at a specific date (as estimated based on Table 1).

4.2 Thermal stress results

Figure 11 presents the maximum principal stress iso-contours in the dam section without a protective insulation during winter pause, for an RCC at elevation 21.69 m. The grey area in this figure represents the zone where stresses are below 1352 kPa, which is considered as the allowable RCC tensile strength limit. The colored iso-contours indicate the area where the tensile strength is exceeded and cracking will likely occur. From the top (el 21.69 m) of the RCC block this represents a depth of approximately 1.8 m to the 1352 kPa iso-contour or grey zone. The extent of the cracking zone shown in Figure 11, jointly with a temperature differential of 46 ºC between the dam core and surface as shown in Figure 7, suggests that thermal protection is likely required.

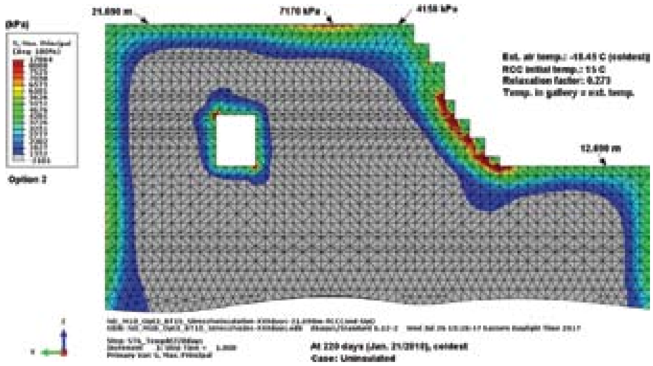

Fig. 11 : Principal stress at coldest external air temperature with no insulation cover.

Figures 12, 13 present, respectively, the maximum principal stress iso-contours and thermal temperatures distribution with a protective insulation value of R1.8. As shown, the cracking zone is reduced substantially by providing an insulation cover. The cracking zone is reduced to a small band on the top surface having a depth of approximately 0.6 m. As indicated in Figure 13, the maximum temperature is approximately 28°C in the core and 3°C at the exposed faces of the dam, with a maximum temperature differential of 25°C.

Based on the thermal results above, as shown in Figures 12 and 13, it was determined that winter protection measures would be required to prevent excessive thermal gradients and stresses due to rapid heat loss from the dam's surface over the winter shutdown period. Insulated tarps having a minimum total insulation value of R1.8 were specified. Some portions of the dam were covered by thermal tarps having an insulation value of R5. The tarps were removed when ambient conditions were acceptable in early May prior to the start of construction in 2018.

Figure 14 presents the evolution of the temperature within the North Dam at the completion of CVC ogee (31 Oct 2018) with insulated covers. The maximum temperatures attained, as shown in Figure 14, are approximately 35°C in the core of the dam and near 0ºC at the exposed faces of the dam.

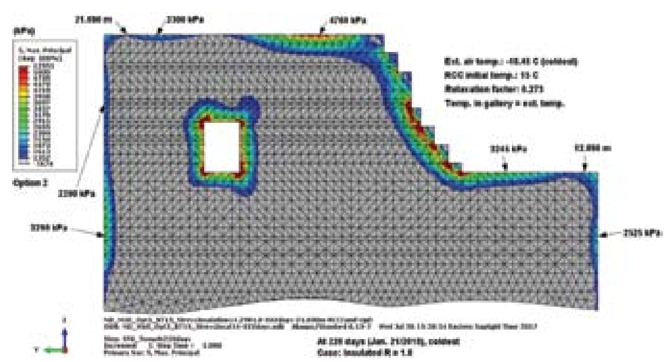

Fig. 12 : Principal stress at coldest external air temperature with insulation covers R1.8

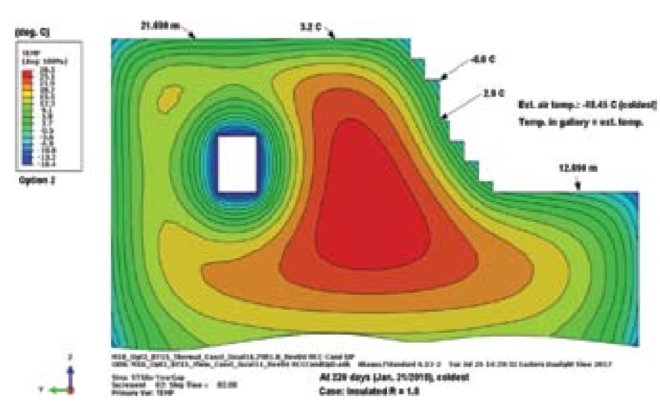

Fig. 13 : Temperature distribution at the coldest external air temperature with insulation covers R1.8

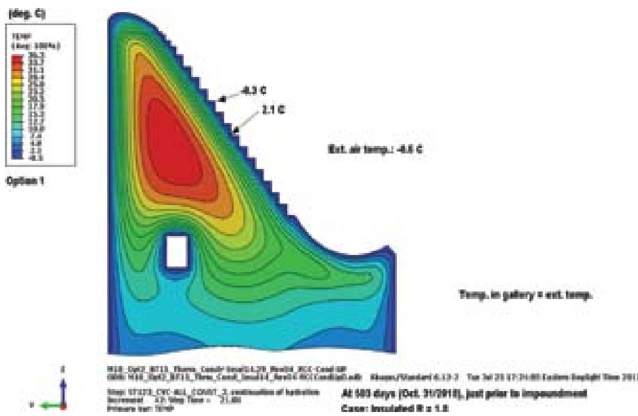

Fig. 14 : Temperature distribution at the completion of CVC ogee (31 Oct 2018) with insulation covers.

5. COMPARISON OF THERMAL RESULTS WITH ACTUAL FIELD MEASUREMENTS

5.1 Construction of the North Dam

Construction of the North Dam began in mid-2017. The contractor for the North Dam elected to use the slope layer method (SLM) to construct the dam. In the lower elevations, 3 m lift heights were utilized, while the higher elevations used 1.5m lift heights to coincide with the height of the downstream steps above the flip bucket. As is typical with a RCC dam, construction began with dental and levelling concrete as necessary to prepare the foundation for the start of RCC placement. Following this, RCC progressed during the first construction season for five 3 m lifts and concluded on 21 October 2017.

As is typical for large construction projects, the actual progression by the contractor during construction varied from the assumptions made during the design. Whereas the model assumed the construction would reach elevation 21.69 m during the first phase, the construction actually stopped at an uppermost level of el. 15.69 m. The lower portion, under the flip bucket, was constructed to the design elevation of 12.69 m (Figure 15). At the end of season one (i.e. 2017) approximately 100,000 m3 of concrete was placed within the North Dam.

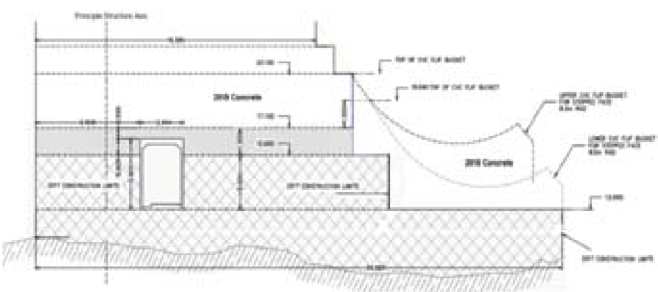

Fig. 15 : North Dam construction progress 30 Sep 2018 (cross-hatched area).

Insulated tarps were placed on the partially completed structure at the end of the first construction season in October 2017 (Figures 16 and 17). Two types of tarps were used based on availability: (1) a single layer of tarp having an insulation value of R5, and (2) multiple layers of tarps having an insulation value of R0.7 each. Additionally, snow accumulation on the dam contributed some insulation value as well.

Construction resumed in May 2018, with mass concrete placement continuing until October 2018. Other associated works (i.e. drilling, gallery floor, instrumentation, etc.) continued into 2019. Approximately 243,000m^3 250,000m^3 of concrete (dental, levelling, RCC and CVC) were placed.

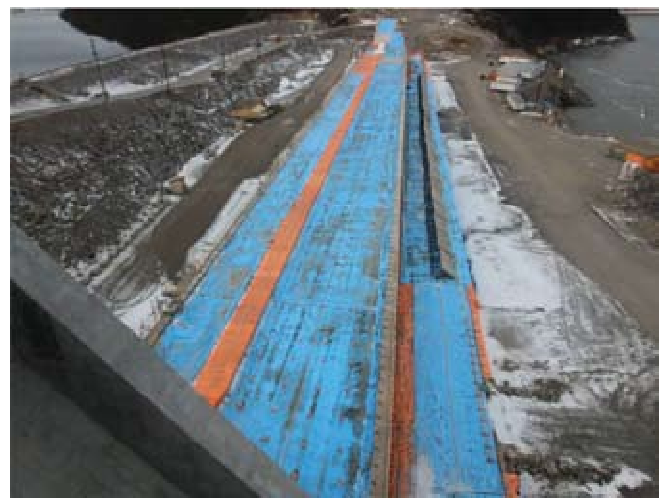

Fig. 16 :. Insulated tarps on the North Dam October 2017

Fig. 17 : Insulated tarps on the North Dam at elevation 15.69 m

5.2 In-situ temperature monitoring

Monitoring of the interior and surface temperatures was undertaken by installation of both thermistors within the body of the dam and thermocouples at the surface. The thermocouples were installed underneath the insulated tarps. Five thermistors, TS-01 to TS-05, were installed in the dam during the 2017 season at approximately elevation 9.69 m as shown in Figure 18. Thermistors TS-06 to TS-10 were installed during the 2018 construction season – TS-09 and TS-10 were installed near elevation 16.0 m, and the remainder near elevation 27.69 m. The recorded temperatures are illustrated in Figure 19.

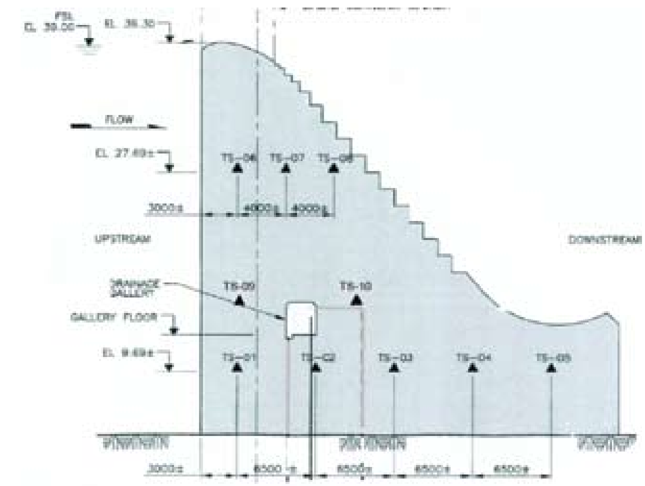

Fig. 18 : Thermistors in the North Dam.

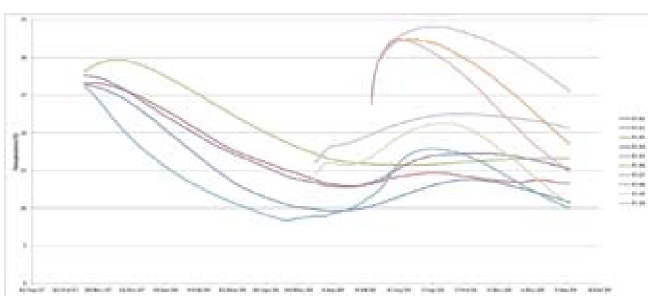

Fig. 19 : Recorded temperatures from within the dam

5.3 Comparison of thermal results with actual field measurements

Table 3 provides the predicted and measured temperatures for the various thermistor locations for each of the dates output from the model in the figures above. In general, there is a good correlation between the predicted and recorded temperatures. There are, however, some exceptions. It appears the thermistors near the surface of the dam (i.e. TS-01 and TS-05) did not cool as quickly as the model predicted – the measured temperatures were notably higher than the predicted temperatures as time progressed. There are several factors which may have contributed to this. The higher R-value of the tarps used on the sides and surface of the dam over the winter period, combined with the snow pack, likely prevented heat loss from the dam, whereas the model assumed lower thermal protection.

The temperatures measured by thermistors TS-06 to TS-10, which were placed in concrete during the second construction phase, are very close to the predicted values. The thermal impact of winter condition of a partially constructed dam over the first winter period (Phase 1) is also well predicted by the thermal model. As shown in Table 3, the predicted and measured temperatures for the TS-01 to TS-05 are very close at the end of the dam construction (31-Oct-2018).

6. CONCLUSION

The finite element thermal models, in conjunction with the thermal stress model, were very valuable for evaluating the requirement and efficiency of thermal protection on the North Dam over the winter pause in construction. The models demonstrated that the temperature differentials without the insulated tarps would be significant and would likely result in high thermal stresses and cracking of the concrete. The models further demonstrated that the insulation would reduce the potential for thermal cracking. Actual recorded temperatures in the core of the structure were similar to the predicted values, for the two construction phases. The recorded temperatures closer to the surface were higher than the thermal model predicted – this was likely due to the fact that tarps of higher insulation value were available to the contractor and installed. However, the use of numerical simulation was an indispensable aid for understanding the relevant thermal behavior the Muskrat Falls North dam, which was constructed in a harsh northern environment with a temperatures range from +30°C in the summer to -30°C in the winter. The thermal protection planned and implemented based on the model for the winter pause of 2017-2018 proved successful, and the inspection in the Spring 2018 revealed very little cracking, validating the predictions from the modelling that had been carried out.

Table 3 : Comparison of model prediction and measured temperatures

Date / Location	31-Oct 2017		21-Jan 2018		15-May 2018		31-Oct 2018	
	Predicted	Measured	Predicted	Measured	Predicted	Measured	Predicted	Measured
TS-01	25	26	11	19	2	10	13	14
TS-02	25	27	18	22	11	14	13	14
TS-03	32	28	27	27	18	18	15	16
TS-04	32	28	21	21	13	14	17	17
TS-05	25	26	11	14	0	9	17	15
TS-06							28	27
TS-07							34	32
TS-08							22	24
TS-09							17	19
TS-10							24	22

Recent Remote Underwater Surveys: Advances in Methods and Rechnologies for Structural Assessments of Dams and Spillways

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ABSTRACT

This paper examines recent advances in technologies and methods for remote underwater structural surveys of dams. Various inspection cases are included to show how imaging and multibeam sonar, photogrammetry, underwater laser, and HD video can be used to bolster a facility's permanent record while adding an invaluable contribution to risk assessment data. Processes for calculating volumes are discussed, be they loss of eroded material or debris and sediment accumulation. The presentation covers issues such as sonar range and resolution, positioning and navigation, hydro-acoustic and other methods for leak detection, as well as new technology such as GPR for void detection behind penstock and tunnel liners and concrete condition assessments. Examples of sonar renderings, multiple and disparate types of date sets stitched together, and other reporting methods are included.

1. REMOTE UNDERWATER ROBOTICS

1.1 Safety Aspects of Robots vs Divers

In the not-so-distant past, most underwater structural assessments of dams were completed by divers. This practise continues today, in spite of safer and more effective remote inspection alternatives. Diver deaths are often associated with Delta P incidents - a diver working upstream of the dam is pulled against (or through) an underwater gap between stop logs or into bypass vents or piping. Sometimes there are significant openings between construction joints, and the dangers around these can be hard to predict because observed leakage coming through the lower face of the dam can be expressed over a much larger area than is found at the inlet. This can result in a sense of complacency about the seriousness, in terms of risk to divers, of an upstream leak. Logic dictates that if the dive inspection is driven by the desire to locate known leaks, safety related incidents are more likely to occur.

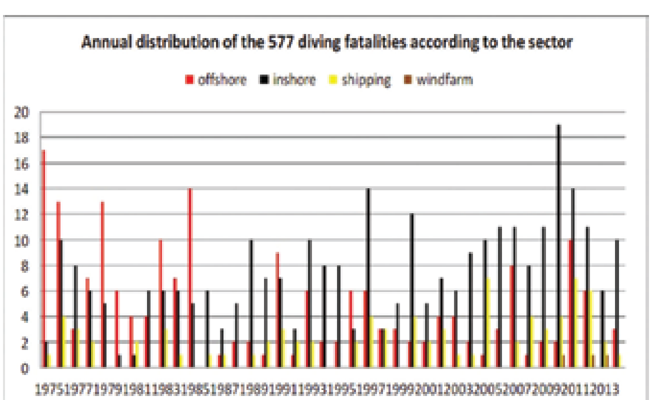


Fig. 1 : Commercial diver deaths by sector. Note the increased prevalence of inland sector deaths (black bars). Source: Survey And Analysis of Fatal Accidents in ihe Commercial Diving Sector, Francis Hermans, 2016

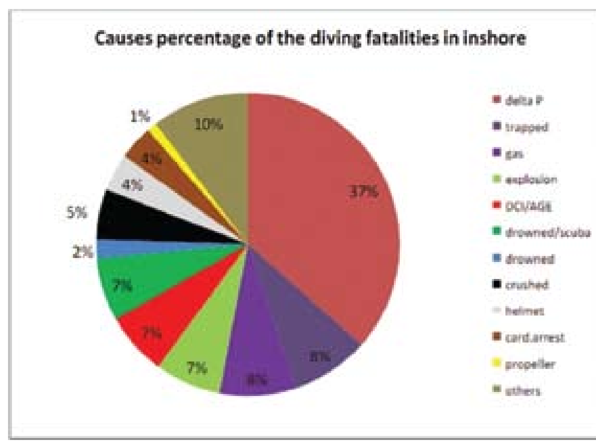


Fig. 2 : Breakdown of inshore diver deaths by cause, Delta P being the most common. Source: Survey and Analysis of Fatal Accidents in the Commercial Diving Sector, Francis Hermans, 2016

To surmise the reasons for the historic increase in prevalence of inland diver deaths as indicated in Figure 1, the graph in Figure 2 (from the same study) is probably a good place to start. Delta P is the clear front-runner for inshore deaths, and all indications point to upstream zones around dams and spillways as the zone of risk.

Studies on this issue are not common, comprehensive studies rarer still. There is an informed suspicion that a significant number of deaths go under-reported (i.e., causes or contributing factors 'not known'). The CDC (Centers for Disease Control and Prevention) concluded that the annual fatality rate was about 181 per 100,000 which, at that time (1998), was about 40 times higher than that of all the other sectors. Incredibly, though studies vary and are often muddled by the inclusion recreational scuba death data, these statistics have more or less held to the present day.

1.2 Repeatability

Compared to remote technology, diver effectiveness can also be limited by other conditions. In downstream areas, spillway currents can be significant. Visibility can be poor, and even when it is good, the diver's field of view is severely limited. Depending on depth and water temperature, effective bottom time for the diver can be extremely limited, sometimes to only a few minutes of working time. The inspection report, which is arguably the most critical part of the exercise, is either based only upon anecdotal observations or is supplemented by helmet-mounted or hand-held video. These can be unstable and difficult to follow when viewed later, such that certainty about tagged locations is often be suspect. In that sense, the most troublesome aspect beyond diver safety is the issue of repeatability. This factor is arguably the most significant when comparing reports that rely on anecdotal diver observations vs. those resulting from ROV surveys that produce measurable data (see Reporting, Section 4 below).

1.3 Just Another Sensor Platform

Remotely Operated Vehicle (ROV), Automomous Underwater Vehicle (AUV), Autonomous Surface Vehicle (ASV), pole-mounted, float-through, no matter what the system or its acronym, it is easy to forget that it is first and foremost a delivery platform for sensors (Figure 3).

Remote platforms should therefore be chosen and fielded with one intent: to deploy the sensor(s) to desired underwater locations so that they can acquire the required data. It makes sense, therefore, to work backwards from what the suspected structural issues are, to what sensors will best delineate them. Only then should platform, method and operational parameters be considered.

For example, identifying concrete slab displacement on the upstream face of a dam might be more effectively accomplished by a simple tripod on a wheeled trolley with an imaging sonar transducer mounted atop (Figure 4). The advantage of maintaining a constant elevation, and therefore angle of incidence with the dam face surface produces a rendering that allows for a level of analytical clarity that would be difficult to achieve with a free swimming ROV. Each has it's ideal application.

2. UNDERWATER STRUCTURAL ISSUES AROUND DAMS

2.1 As-Built Survey

The most logical reason for an underwater survey is often the simple fact that, for many older structures, no

Fig. 3 : ROV readied for deployment on the Hugh L Keenleyside dam spillway survey (l), AUV launch in NYC's Rondout Pressure Tunnel (c), and ASV deployed at OPG Sir Adam Beck feeder canal (r).

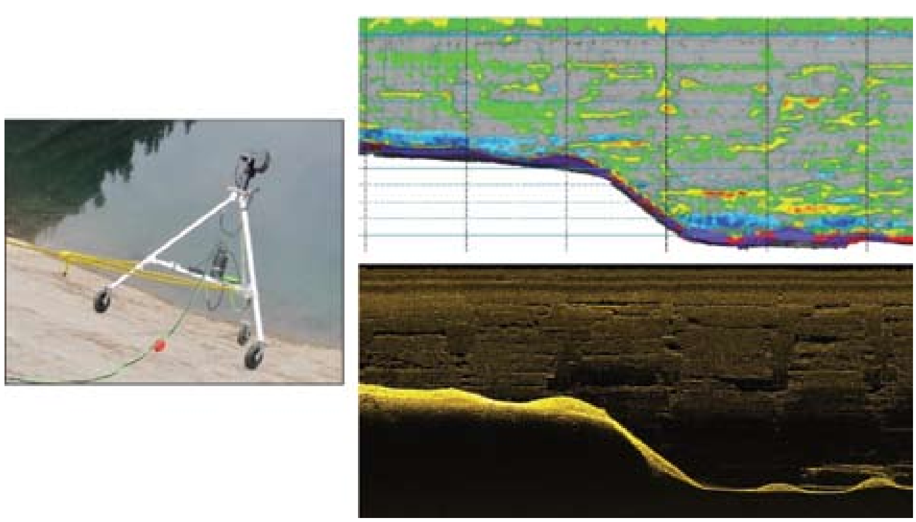


Fig. 4 : Sonar inspection of dam face. Tripod trolley (l) and detail of relief map (tr) with section scan (br) of the same location.

as-builts exist, leaving owners with concerns associated with reliance on construction drawings and anecdotal knowledge. A very useful resource in contemporary underwater surveys of these facilities is original construction photographs. These can be combined with design drawings and software that can even extrapolate 3D models from what was formerly thought to be quite limited data.

For new-builds, many of these concerns would already seem to be alleviated. But even for new facilities, there are very good reasons to conduct a post-commissioning underwater survey, especially on sites where the geology has been challenging and when internal structures like penstocks and headrace tunnels are subject to high water pressures. As some have discovered, a very large, newly filled reservoir may affect the local topography, and even the dam itself, through subsidence or in other unforeseen ways. For these reasons, as-built underwater surveys of new facilities (and older ones that have undergone repair or refurbishment) are increasingly seen as essential to responsible longterm asset and risk management.

2.2 Priorities - Dam Structure: Condition of Concrete and Location of Leaks

Most underwater inspection programs around dams are focused on assessments of concrete condition and the detection of leaks. If visibility permits, video of surficial areas is a good way to quickly assess concrete conditions by noting the appearance of cracks, spalling, scour and erosion, protruding re-bar and slab displacement at construction joints.

The correlation between suspect concrete conditions and the presence leaks can be anywhere from strong to non-existent, depending on the structure, but large cracks or displacements are obvious sites for further investigation. For example, Figure 4 above also shows preliminary sonar survey data collected in support of what was primarily a leak detection survey.

2.3 Spillway Priorities: Condition of Concrete, Erosion, Subsidence.

Spillways of all types have historically received less attention than other features. This may be because in many instances it is easier and less costly to isolate and repair downstream structures than it is to repair, say, a leaking dam from the reservoir side. Concrete erosion is an expected fact over time, especially where local conditions make this more of a probability, so interest lies in determining the actual rates of erosion. Suspended sharp fines in the water column, pH, ice, sudden fluctuations in spillway water depth, all can contribute to what might be expected over time to contribute to deterioration, possibly unevenly distributed over a large area (Figure 5).

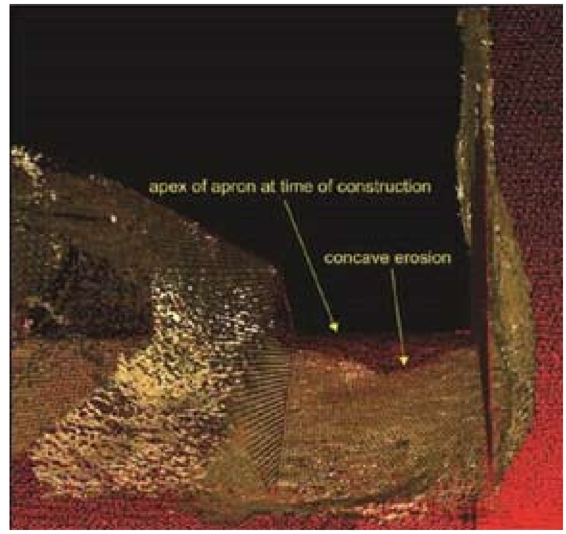


Fig. 5 : Hugh L. Keenleyside spillway - 3D sonar rendering of apron erosion between dissipators.

The recent Oroville spillway failure did more to change complacent attitudes about the criticality of structures separate from the dam itself than perhaps any other spillwayrelated event. In terms of inspections, the type and function of a given spillway will dictate the best means of remote inspection. Sonar, as discussed below, requires submergence in water to work, so open channels, side channels and shaft spillways, water cushions and stilling basins, dissipator piers, etc., are the best candidates for underwater surveys. It is important to keep in mind that, operationally, two common detrimental factors are frequently encountered. High currents can negatively affect the operation of the remote system and thereby degrade the quality of data acquired, and the presence of entrained air in the water column impedes sonar signals and blocks the intended target from being detected by the sensor.

2.4 Penstocks, Headrace and Tailrace Tunnels

For dams associated with hydroelectric production, internal surveys of confined underwater spaces are a common requirement. When remote underwater technology is used, we can subtract the risks and expense of dewatering and add real time metrology through sonar. Underwater UT and acoustic leak detection can also be used in penstocks. Dewatering, especially for pressure tunnels and penstocks, is best avoided, not only due to loss of generating revenue:

Lemonthyme Tunnel Rock Fall (Figure 6), Tasmania 1969: ‘2000 m^3 loose volume rockfall conditions were probably aggravated by hydrostatic pressure within the fault zone during dewatering.’[1] A 2008 walk through had to be limited to the downstream 1.8 km of the total 6.5 km due to safety concerns associated with rockfalls due to dewatering.

Snowy – Geehi Tunnel Rock Fall, 2002: '50-80 m^3 rock and sand mass failure most likely that the failure was triggered by the tunnel drain for the inspection.'[2] Safety concerns about confined space entry and other physical issues surrounding worker entry into penstocks and tunnels should also be discussed in terms of efficacy. Typical walkthrough reports are often anecdotal, based on observations illuminated by flashlight, while walking on slippery and/or uneven ground. In larger structures it is impossible to gain proximity to the crown, limiting the effective range of useful observations.

1. S. J. Patterson, A Note On Lemonthyme Tunnel Rockfall, Tasmania, 1969.
2. S. Rosin, Geotechnical Risk Assessment and Management for Maintenance of Water Conveyance Tunnels in South Eastern Australia.

The whole argument of the relative benefits of manned vs unmanned entry in such cases can largely be dispensed with since only one option, the robotic, unmanned one, provides repeatable metrology. Anything less is simply not up to modern standards.

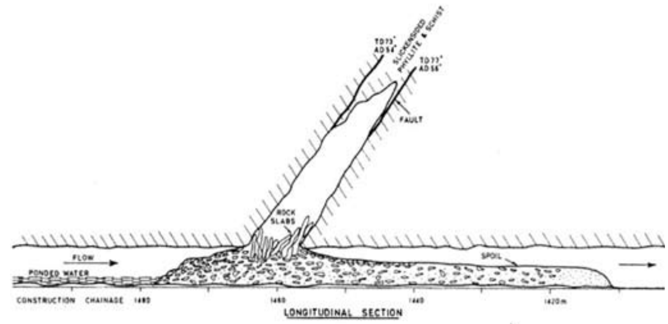


Fig. 6 : Lemonthyme tunnel collapse, determined to be exacerbated by dewatering for inspection

2.5 Reservoir and Spillway Bathymetry

Bathymetry surveys of reservoirs are used for monitoring silting trends and embankment slump. Due to the minimum depth requirements of most survey systems (>1 m), care needs to be taken when determining overall volume as near-shore zones will have been omitted. Volume calculations for reservoirs with steep shore contours are likely to be more accurate than those with shallow shore contours, since more of the near shore zones can be captured in the survey. Figure 7 shows the limits of near shore data acquisition.

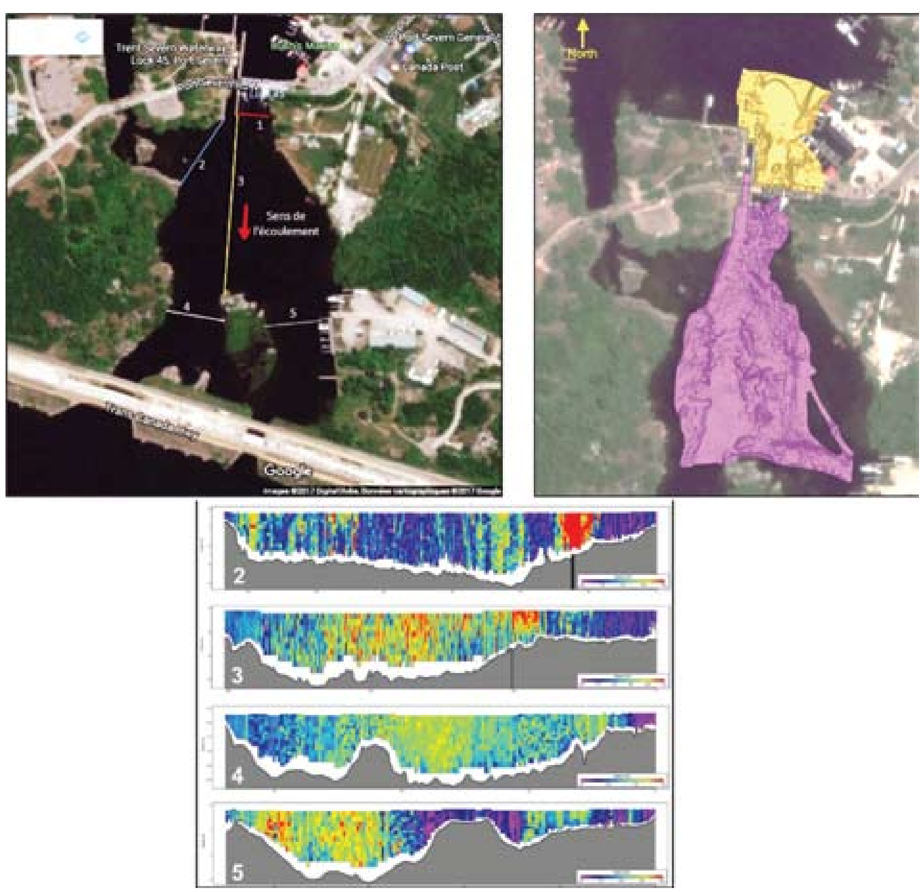


Fig. 7 : Port Severn, Ontario, Hydraulic Velocity Survey Transects. Note the near-shore areas (white) in the heat map in the image on the right, indicating shallow zones that could not be included and therefore omitted from the data set.

3. PROVEN SENSOR TECHNOLOGIES

3.1 Video

With all the excitement about newer sensors and their increasing value as additional tools in the inspection kit, it is easy to forget the power of quality underwater video imagery. The most obvious factor is water clarity, or, conversely, turbidity. Much effort has been expended over the years in development of low light cameras that allow for use of very low illumination. This is important because designing effective underwater lighting for remote systems is a challenging task. Of necessity, lights must be mounted near the camera, and this produces all manner of problems such as hotspots, distracting shadows, and, generally, less than ideal conditions for good video imagery. When there is little or no ambient light, reliance on vehicle lighting often means compromising video quality.

That said, underwater video is seeing a renaissance because of software – 3D imaging that provides a photogram of an area that has been viewed from multiple angles (Figure 8). Measurements derived from quality underwater photograms can accurately be rendered on a scale of millimeters, but only where enough lighting and visibility are present and the camera path is smooth and well-controlled. With ROV deployments, this technology is useful for observing fine features and perhaps qualified extrapolation of assumptions based on a very limited survey area but is generally impractical for surveying large structures. This is true for field operations and post processing time, which would both need to be extensive and costly. That said, there are many scenarios where an upstream dam face could be efficiently rendered photogrammetrically with a dedicated tripod trolley system launched and controlled from the dam crest.

3.2 Sonar

Sound Navigation and Ranging – SONAR, uses a series of sound pulses in water to measure the time of travel from the sonar 'head' (called a transducer because it both transmits and receives), to the 'target' (a solid object in its path that reflects sound) and back. Many different types of sonar systems exist and are used according to their specific capabilities. For water conduits, two systems are typically used. One is called an imaging sonar and is used for both for pilot navigation and survey data. Figure 9 below shows multibeam bathymetry rendering of a dam with sections derived from the same data set.

Fig. 8 : Photogram of dissipator pier erosion

One of the best features of a sonar record is that it can be queried in different ways depending on the information desired. Or any portion can be accessed for processing on an as-needed basis, meaning that post-processing costs can be spread out over months or years after the fact. This has been the case with the Keenleyside Dam in BC, Canada, owned and operated by BC Hydro (Figures 8 and 10). Spillway field surveys have been going on in stages since 2015, with all data archived, and the as-built, as/found record has been steadily expanding in volume and detail, in accordance with the priorities and schedule set by the client. This allows a reporting budget to be used efficiently and spread over a period of the client's choosing.

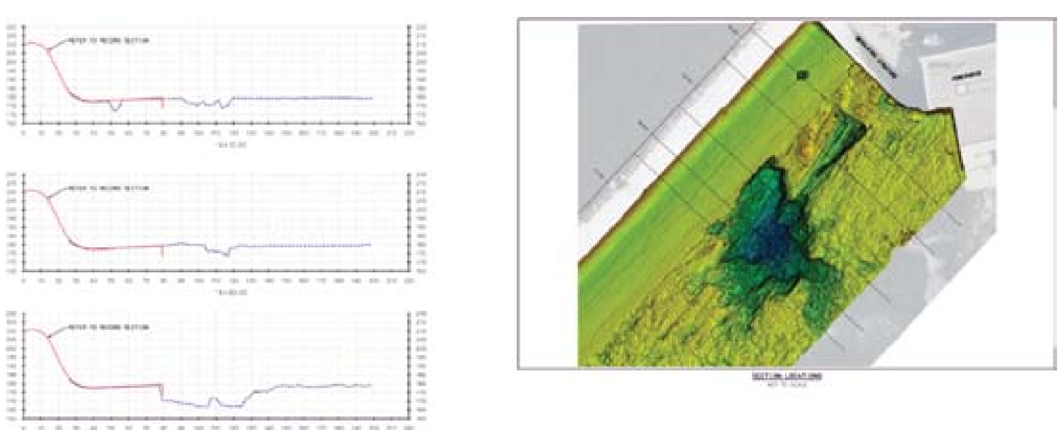


Fig. 9 : Multibeam rendering of upstream dam toe and reservoir (r), with sections (l)

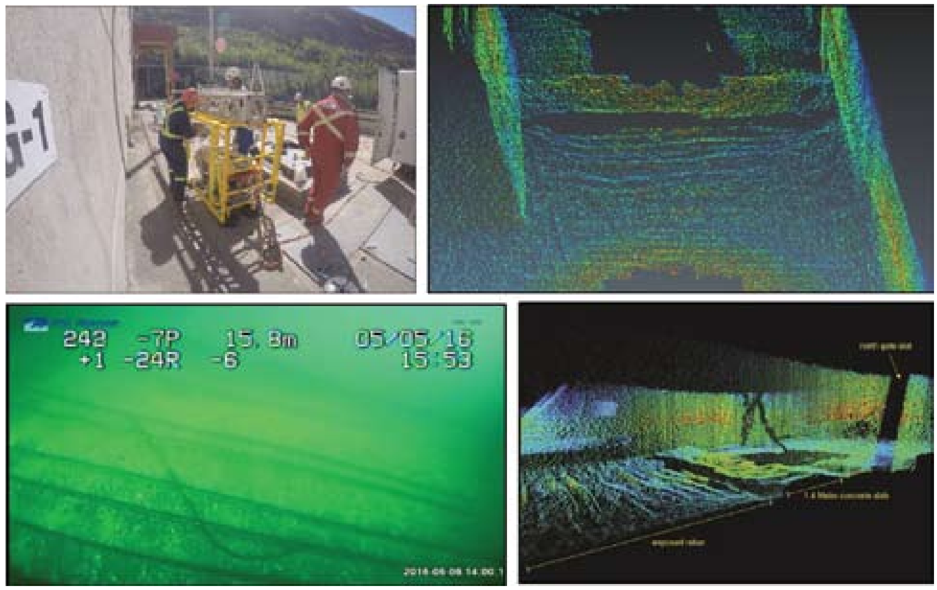


Fig. 10 : Keenleyside Dam Spillway Surveys in BC, Canada. Clockwise from upper left: Site operations, 3D sonar rendering of exposed rebar on slab, same location from a different angle, and video

The most common questions about sonar usually concern accuracy and/or resolution. Simply put, are directly related to range, frequency (of the sound pulse the unit emits), and sensor settings (such as the 'firing' rate, or number of sound pulses per unit of time). For higher frequency units (e.g., 2.25 MHz), a good rule to remember is one-halfof-one-percent-of range. This means that at 10 meters, the range accuracy would be approximately 5 cm. Better accuracy is achieved simply by reducing the distance between sensor and target.

3.3 NDT

UTS sensors are commonly deployed on ROVs, with devices and operational methods like the hand-held units operated by divers. As with diver operations, surfaces to be tested need to be prepped, an ROV task easily accomplished with a small manipulator and a rotating wire brush. All data can be logged automatically according to the master timestamp and correlated with other data (such as leak detection) later.

3.4 Hydrophone

A simple microphone, when adapted for submerged applications and combined with powerful filtering software and the correct operational conditions, can be a very powerful tool for detection of underwater leaks (Figure 11). Ideal conditions are sites where there is little or no ambient noise, as any outside sounds (e.g., an open valve) can acoustically mask a leak and make it impossible to find. The same is true for the deployment platform, where ROV thruster noise can produce abroad spectrum of acoustic interference. For this reason, a passive trolley is again useful on a dam face since there are no drive motors to interfere with acoustic data. This also means that the hydrophone will always be at the same relative distance from the dam face, so it is important to calculate the best offset for the site. This is largely dependent on the time available. A lower offset will provide a closer and more sensitive 'listen', but also require more time overall since swath width for each pass will be necessarily small.

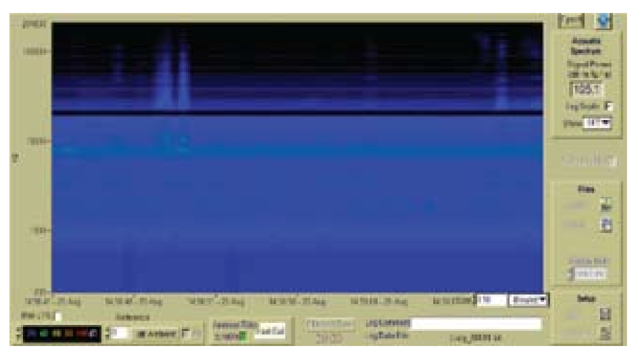


Fig. 11 : Hydrophone screen capture. Vertical bands indicate noise generated from leaks

3.5 Visual Leak Detection

Although acoustic detection has been proven to work well in exceptionally quiet environments, it is not yet known how this technology performs at a 'noisy' site, such as a reservoir that is also used for motorized water recreation vehicles, especially jet skis and speed boats. Leak sources, especially low-velocity leaks on the upstream face of the dam can be extremely difficult to detect, so a combination of methods usually works best. Sonar can be used to identify construction joint misalignment, voids, large cracks and other suspect features. With enough visibility, tell-tales and dye injection can help verify locations (Figure 12).

Fig. 12 : Leak detection by dye injection (l) and telltales (r).

3.6 Laser

Underwater laser scans can be very effective for determining fine detail (Figure 13 - r), with accuracy (under ideal conditions) in the sub-millimeter range. Conditions required are the same as photogrammetry – good visibility and a sensor path that eliminates blind spots. Similarly, this technology is only useful for small areas, since the survey swath width at close range is far too narrow to be productive over a significant area.

3.7 Ground Penetrating Radar (GPR)

The potential for proven above-ground GPR technologies to be applied to void detection in underwater environments is great, but to date remains unrealized. This seems about to change, with client interest driving the innovation that needs to occur to bring this technology into the underwater survey toolbox. The road forward is as expected, beginning with a set of assumptions and development of a research framework, then controlled experimentation in lab and tank tests, mockups and, finally, field trials. The payoffs of a successful GPR research program are significant, given the concerns surrounding washouts behind penstock, headrace and tailrace tunnel liners, spillway slabs, etc.

3.8 Inertial Navigation System

Essential to any dimensioning survey taken from a moving platform is a position compensating device called an Inertial Navigation Sensor (INS). ROV motion data from underwater gyro sensor is combined with dedicated software that continually redraws the real-time image and correlates ROV movement with stationary targets such as pier or dissipator.

4. REPORTING

4.1 Data Integration: Past and Future

It may seem redundant to continually emphasize the importance of the final report in any inspection exercise, but it bears repeating if only to help manage expectations of an underwater survey project from the outset. The first thing to note is that final reports are rarely that – they merely constitute an addition to an existing body of knowledge about a given facility. The first task should be to gain an understanding of what that body of knowledge consists of, in what format(s), how will new data be integrated with past and, for true forward thinkers, how the current exercise will integrate effectively with future inspection data. Sometimes this is as simple as ensuring that, regardless of proprietary program data which may

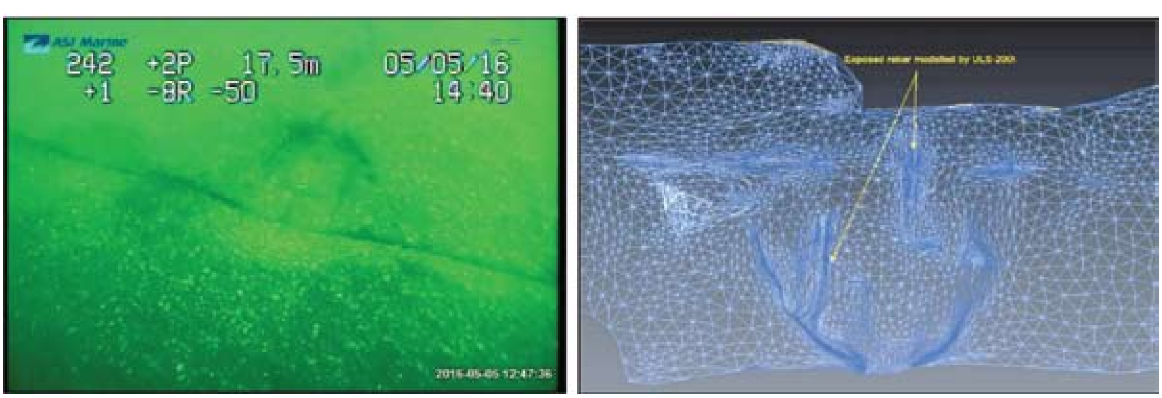


Fig. 13 : Video capture of eroded pocket in spillway (l) and the same location scanned with underwater laser (r).

or may not mesh smoothly with future software releases, the data is also captured and archived in simple formats such as ASCII. This can easily be done with any xyz data set.

4.2 Non-linear Reporting

Non-linear reporting has finally entered the realm of normalcy (Figure 14). Gone are (or should be) the problems of the not-too-distant-past, when reviewing a video of a trash rack inspection by diver deployed camera meant spending hours looking for that 2 minutes of critical imagery one remembers viewing in the control cabin during field work. Today, all inspection data can be recorded and synchronized using a timecode generator. Using a simple ranking system (say, severity of observed anomaly on a scale of 1-5), reports can be queried according to whatever hierarchy or criteria has been adopted as the basis for assessment.

4.3 Field Notes

Essential to the post-editing process (and even more important in the old linear reporting world) are the field notes of the operators. ROV control room pilots have their hands full and long tunnels can take a day or more to survey, so ease of use and automation are the key to a practical field notes protocol. This can be done by flagging (the elapsed time) by severity of observed anomaly as previously mentioned. Typed notes (auto timestamped) can be kept brief and these can make use of key search words like 'void', 'debris' 'erosion', as well as important excursion and location information (e.g., 'max. excursion out at 9820 m, crew break for 10 min, begin to retrieve and inspect north spring line, visibility gradually improved to est. 2 NTU'. Voice recognition software can now produce a searchable text generated from by ROV pilot audio. Since other topside personnel (such as the winch operator) are also equipped with headsets for operational communications, all can become part of the field record with multiple uses when converted to searchable text. Incidentally, this method has the added benefit in that it also helps keep needless chatter off operations communications systems and maintains focus on the deliverable objective.

5. FURTHER THOUGHTS

5.1 Focus on Minimizing Workplace Risks

Dimensioning capabilities alone would seem to make remote inspections standard over traditional 'touch and feel', anecdotal, after-the-fact-reporting by divers (Figure 15). Add to that the obvious benefits of avoiding unnecessary dewatering of penstocks, reservoirs, spillways, headrace and tailrace tunnels, and yet in certain sectors these old ways die hard. Many countries in Europe, including Norway (noted for early adoption of strict diver safety codes and reliance on ROVs in the offshore petroleum industry), still routinely use divers to conduct dam inspections

Perhaps the most convincing practical arguments (should the moral ones fail us) for remote interventions in such facilities should come from insurers, those who are monetarily liable for risk, be it for diver deaths from working around intakes and gates, or structural failure due to undetected undermining of a spillway apron. Many owners are finally taking on responsibility for remaining informed about remote inspection capabilities through conferences, trade journals and association bulletins, so the hope is that the number of diver deaths while working around dams due to Delta P continues to drop.

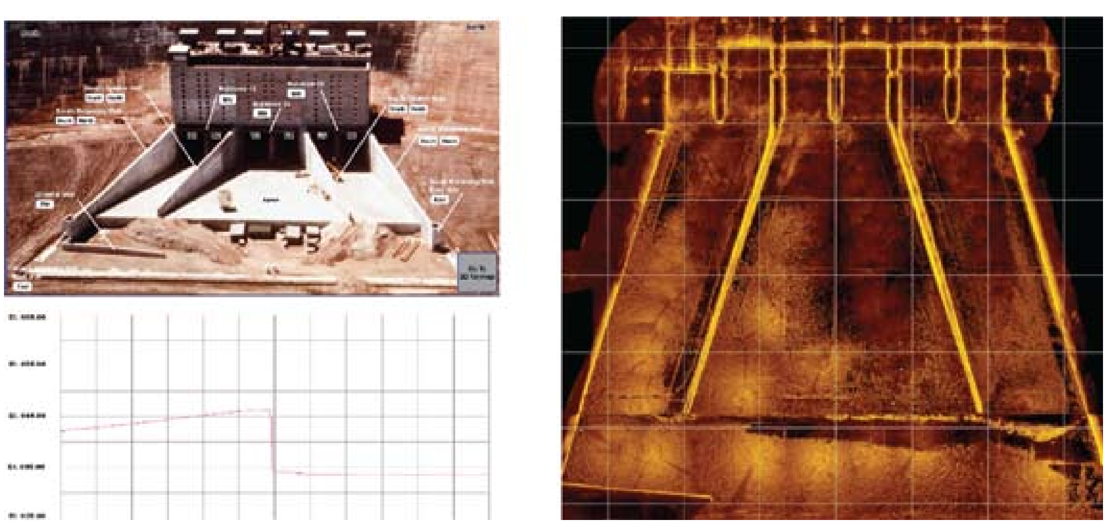


Fig. 14 : Interactive graphic of spillway inspection showing master page derived from construction photo (top l) linked to scan renderings by location

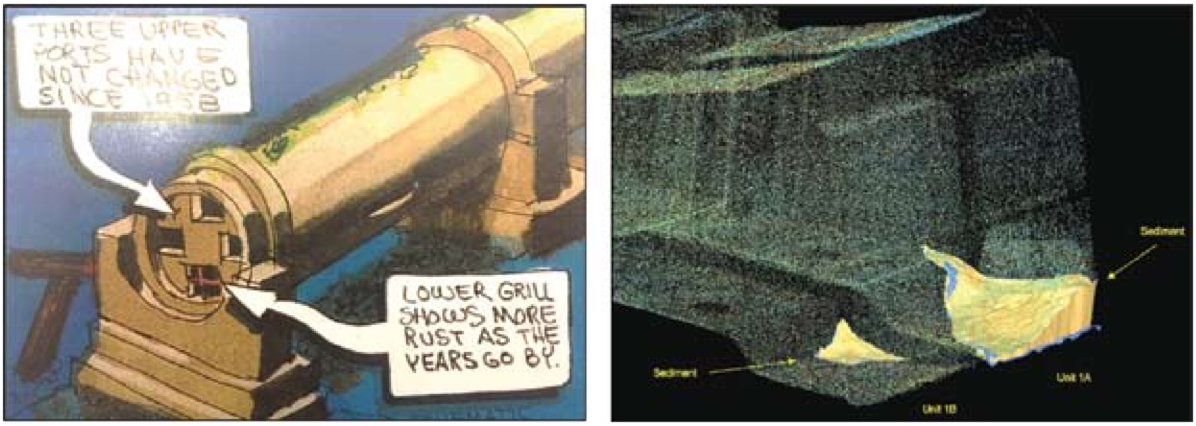


Fig. 15 : The old way (anecdotal) inspection drawing of an outfall pipe (l), vs the new way, where metrology derived from the sonar signal allows determination of the actual volume of debris adjacent to an outfall structure (r)

5.2 An After-Note on Self-Performance

Self-performance - the purchase of in-house remote inspection assets and internal hiring and retention of qualified personnel - is gradually becoming a bigger factor in underwater asset inspections for dams. Any client-owned ROV program has both benefits and risks. Benefits include on-demand inspections, highly detailed control of reporting processes and outcomes, and, within the personnel pool, retained knowledge about the facility that outside vendors would not have. Risks to self-performance are usually associated with technical inexperience and lack of personnel training that can result in unsatisfactory reporting results and sometimes a direct loss of the ROV asset. Training and retention of qualified personnel become an ongoing battle. Another factor is the ever-shortening cycle of obsolescence in a rapidly changing technological landscape. This increases maintenance costs and legacy incompatibility.

More than one owner has had to warehouse what has been generously called a ‘stranded asset’, ROV gear that is either essentially worthless due to depreciation, lack of maintenance and obsolescence, or inoperable, because the company’s resident expertise has moved on to other employment. Still, the cheapness and availability of basic systems that require little training to operate and, under ideal circumstances, produce good underwater video in a timely manner, may be worth the effort.

Current capabilities of owners to handle massive amounts of underwater point cloud sonar data and produce meaningful reports are commonly less than adequate. This is primarily because of two things. The first is related to the field component – trained in-house expertise is essential to proper interpretation and presentation of the massive data set, and there is no small element of artistry involved especially where stitching edges of survey swaths is required to complete the big picture. The second is that there can be three to five software programs involved in handling and presenting data, each with its own peculiarities, upgrade and integration issues. Add to this that ROV service company personnel tend to have a lot more recent and varied experience with both field and report work than their counterpart would with a self-performing owner.

These decisions should be based on the same long-term cost/benefit considerations other potential self-performance issues receive. Safety training, HR, payroll, maintenance, cafeteria and building services, many types of services are outsourced for the same good reasons – they promote the right kinds of specialization, efficiency, and, importantly, value and innovation driven by healthy competition between experienced, qualified service entities.

World Declaration

Water Storage for Sustainable Development

IN 2050 WORLD POPULATION WILL LIKELY EXCEED NINE BILLION INHABITANTS

The global increase in population, both rural and urban, and the socio-economic development with increasing living standards for all, will continuously raise the requirement for water, food and energy consumption. Populations will continue to concentrate in cities where the need for water, food and energy will be most acute. The rapid population growth and socio-economic development means that by 2050:

The continuously increasing demands of water, food and energy will challenge the natural resources. We need to face this exceptional situation because at the same time:

- Due to climate change, water distribution may become more irregular, and disasters related to floods and droughts will worsen.
- Energy sources are limited:
  - Fossil energies are polluting and emitting greenhouse gases and their reserves are limited;
  - Nuclear energy is restricted to industrial countries which have the technology and the security of nuclear energy has aroused people's wide concern;
  - Variable renewables such as wind and solar sources are valuable and should be developed as much as possible; however, they need back up. Hydropower can play this role, but policies and markets are not encouraging this.

Water is precious and water storage infrastructure will become increasingly important!

Water storage infrastructure, providing multiple water services, is vital for human development. Out of the 40,000 km^3 of freshwater available each year, only 9,000 km^3 is accessible. Through the construction of more than 50,000 large dams and millions of small reservoirs throughout the world over the past 5,000 years, many communities are able to enjoy reliable water services. These water storage facilities regulate about 4,000 km^3/year.

The role of dams and reservoirs in sustainable development has already been acknowledged in various declarations: World Summit on Sustainable Development (2002), Beijing Declaration on Hydropower and Sustainable Development (2004), World declaration “Dams and Hydropower for African Sustainable Development” (2008), and the Ministerial Declarations of the Fifth and Sixth World Water Fora (2009/2012).

Humanity is facing a more severe water situation than it has ever faced in the past.

To face this century’s greatest challenge – to managewater sustainably –we need to strengthen existingwater systems and further develop new water storage infrastructure. This will require adequate legislation and funding. It must also include the optimization of the use of water by combining multiple purposes:

- Flood management and drought mitigation
- Irrigation for food production
- Energy production
- Drinking water and sanitation
- Industrial water supply
- Navigation
- Environmental services, etc.

There is need to improve the maintenance and operation of existing water storage infrastructure.

Taking into account the aging process, improved knowledge, and the effects of climate change, there is a need to increase efforts to maintain the existing water storage infrastructure. For example, modern monitoring and engineering can improve the safety of structures against extreme earthquakes and floods. Climate change is likely to make reservoir regulation more difficult as hydrological patterns change. Reservoir regulation must be optimized to store more floodwater, while considering the requirements of both upstream and downstream areas. With the latest forecasting systems and real-time acquisition of data, dynamic operations to control water levels in reservoirs can achieve the best balance between infrastructure safety and the wise use of water resources.

There is need to accelerate the development of new water storage infrastructure formultiple purposes.

- *Flood Management and Drought Mitigation*

Floods and droughts are the greatest water management problem for many countries with insufficient water storage infrastructure. Every year, more than 200 million people are affected by flood damage. Due to climate change, floods and droughts will become more frequent and severe. Water storage infrastructure is a key component of water disaster mitigation, especially in developing countries.

- *Irrigation for Food Production*

Irrigated agriculture covers about 277 million hectares, about 18% of the world’s arable land. This makes this land remarkably more productive, providing about 40% of the world’s crop output. Irrigated lands also concentrate agricultural employment, with nearly 30% of the rural population working in these areas. Much of the world’s food production must be in regions with long dry seasons. Since arable land area is limited, the additional production will require efficient use of existing irrigation facilities and extending the area under irrigation through increased water storage facilities. It is estimated that 80% of additional food production by 2025 will need to comefrom irrigated land.

- *Energy Production*

Hydropower supplies about 16% of the world's electricity today. Hydro supplies more than 50% of national electricity in about 65 countries, more than 80% in 32 countries and almost all of the electricity in 13 countries. The flexibility of this renewable resource is fundamental in matching electricity services with demand and contributes to the development of other intermittent sources of electricity production such as solar and wind, which are less flexible. Consequently, the energy stored in water, converted through pure hydropower and pumped storage, improves the reliability of power systems in a clean and efficient manner. Only 30% of the world's identified hydropower potential has been developed. Transforming the undeveloped hydropower potential into reality would save extraordinary amounts of fossil fuel, reduce greenhouse gas emissions substantially and improve the management of water resources.

- *Drinking Water and Sanitation*

One in eight people in the world do not have access to safe water for drinking, cooking and sanitation. With the expected population growth, and without investment in storage, the number of people who could not have access to water will reach 4.2 billion by 2025. One of the Millennium Development Goals calls for halving, "by 2015 the proportion of the population without sustainable access to safe drinking water and basic sanitation". Investment in sustainable water storage infrastructure in developing countries would help achieve this goal.

- *Industrial Water Supply*

Every manufactured product uses water during its production process. Industrial water use includes purposes such as processing, washing, diluting, cooling, or transporting a product as well as for sanitation needs within the manufacturing facility. Industries that use large amounts of water produce food, paper, clothing, chemicals, refined petroleum, or primary metals, all of which would aid developing countries to increase the value of their natural resources. However, sustainable and reliable water supply is a precondition to encourage establishment of such productive industries.

- *Navigation*

Inland navigation for goods transportation, compared with land and air freight, has many environmental and economic advantages. Inland navigation is also well suited for handling large quantities of cargo and items with large dimensions. For those reasons, nations have encouraged inland navigation on canals and natural river courses. The control of levels in water courses for navigation requires water storage, and this can be an important role for multipurpose reservoirs and infrastructure.

- Environmental Services

Water storage infrastructure can keep the healthy life of rivers through ecological operation and serve wider environmental services. They can allow upkeep of minimum flows during dry seasons which enable the preservation of many aquatic animals and plants during droughts. Moreover, dams and reservoirs contribute to stabilizing ground water levels in adjacent land areas. Reservoirs can also be used to create new and biologically desirable habitats and to irrigate wetland biotopes or wetland forests.

We, therefore, call for joint efforts to develop water storage infrastructure in a sustainable way.

Today, water and energy schemes can be built in a safe, economic, and eco-friendly way. Water, food and energy services are intricately linked and need to be developed in an integrated approach. Based on the multi-faceted and cross-boundary nature of water issues in the present world, we call for:

- Continued cooperation among various stakeholders, government authorities, research institutions, businesses, civil societies, local communities and so on, to speed up the development and implementation of effective and sustainable water solutions.
- Development of sharing rivers with win-win cooperation to better serve regional requirements on water, food and energy.
- Improved policies, guidelines and protocols to evaluate and mitigate environmental and social impact of various storage options and to address the concerns of affected communities.
- Funding agencies to effect action in countries which need water storage, promoting national and regional development, with innovative financing mechanisms.

In conclusion

- Water is life andwater storage infrastructure is an indispensable tool for society.
- Investment in water storage infrastructure is investment in the green economy.
- The services they provide will be crucial in the mitigation of, and adaptation to, climate change.
- To meet growing demands for water, food and energy, it is time to develop solutions for better use of water resources, especially for developing countries, and to match political commitments with action.
- A balanced approach, combining large, medium and small reservoirs, is required; one that takes into account sustainable development, with full commitment to minimize negative impact.
- The organizations signing this declaration commit to collaborate with all partners and stakeholders that share this common vision.

Approved on 5th June 2012 in Kyoto, by:

The International Commission On Large Dams (ICOLD), The InternationalCommission on Irrigation andDrainage (ICID), The International Hydropower Association (IHA), and the InternationalWater Resources Association (IWRA).

CIGB ICOLD ICID•CIID INTERNATIONAL HYDROPOWER ASSOCIATION IHA IWRA

World Declaration
Dam Safety

The construction, operation and maintenance of dams and their storage reservoirs have provided significant benefits to humankind throughout history. Storage of water behind dams regulates natural streamflow, provides benefits resulting from increased water availability, renewable energy production and reduction of adverse impacts caused by nature's extremes of flooding and drought. This document addresses the importance of the dam safety, which encompasses water dams, mining tailings dams and levees.

Growing population in our fragile world is causing steady increases in demand for water, food, energy, minerals and flood control. Dams are critical infrastructure to meet these basic human needs as well as rising standards of living. At the same time, however, dams create new hazards involving potential risks to downstream communities, including potential adverse impacts on life, property and the environment. The potential for dam safety incidents, possibly resulting in an uncontrolled or catastrophic release of stored water is of the highest concern.

The profession of dam engineering has a profound ethical responsibility to carry out its professional duties so that dams and reservoirs are designed, constructed and operated in the most effective and sustainable way, while also ensuring that both new and existing dams are safe during their entire lifespan, from construction to decommissioning.

ICOLD AND DAM SAFETY

For almost a century, the International Commission on Large Dams (ICOLD) has made dam safety one of its highest organizational commitments, as stated in the ICOLD Mission statement:

ICOLD leads the profession in setting standards and establishing guidelines to ensure that dams are built and operated safely, efficiently, economically, and are environmentally sustainable and socially equitable. Before the creation of ICOLD in 1928, knowledge on dam safety was disparate, while the need for building water storage infrastructure was very high and growing. It therefore became a priority of ICOLD to disseminate the understanding of the design and operation of dams based on experience within the global dam engineering community. And along with this dissemination came a strong focus on dam safety that has permeated up to the modern era.

ICOLD has played a key role in improving dam safety through its work in collecting and analyzing information on the lessons learned from past successes and failures. Since the very beginning, ICOLD and its thousands of professionals within the member countries have continuously contributed to the improvement of dam safety through publication of technical papers and exchange of experience during Annual Meetings and Congresses. ICOLD's Technical Committees develop Bulletins for publication that summarize the current state of the practice.

Since the creation of ICOLD, the number of failures compared to the total number of dams in operation has been reduced significantly, which is a positive achievement that reflects the worldwide influence of ICOLD in raising dam design and management standards. Nonetheless, constant vigilance and commitment to dam safety is still required in order to continue the global trend towards safer dams. Any dam incident is a matter of the gravest concern for dam professionals. It is our ICOLD Declaration that Dam Safety is our highest priority.

CHANGING CONDITIONS OF DAM SAFETY

Due to the vital need for water, food, energy, minerals and flood control, the total number of dams worldwide continues to grow. Maintaining the present trend of a decreasing incidence of dam failure is a never-ending challenge for the profession. ICOLD's role in knowledge transfer and capacity building through the dissemination of the best practices is as pertinent as ever. The science, technology and human roles in dam safety are in constant evolution with many changing conditions:

- *Ageing of existing infrastructure*, creating new concerns related to the longevity of construction material and equipment, including infilling of reservoirs with sedimentation.
- *Lack of experience in dam safety management and operations* in some countries engaged in building dams, requiring the need for capacity building.
- *Retirement of experienced personnel in all countries,* leading to a deficiency in qualified engineers trained in dam design.
- *Increasing participation of the private sector* in the development of dams as well as increasing cost and time pressure on developers, designers, contractors and operators, creating a need for new governance conditions for dam safety.
- *Climate change causes changes in extreme precipitation* and drought events, resulting in

increased hydrological risks. It is critical to consider changes in climate during planning and management, including resilient design and adaptive reservoir operation of dams. In some regions, this results in a need to increase the height of dams, expand spillway capacity, modify reservoir operating procedures, and/or construct new dams. There may also be a need to assess and address other hazards created by climate change as part of the planning, design and operational phases.

- *The most suitable sites for dams have largely been utilized*, thus new dams must be built in more and more challenging locations, especially regarding geological conditions.
- *Changing local, regional and national governance* can have a significant impact in regulatory authority for dams.

As a recognized international organization of experts in dam engineering, ICOLD calls upon governmental authorities and financing institutions to promote an awareness of the subject of Dam Safety. The goal of this ICOLD World declaration on Dam Safety is to restate the fundamentals of dam safety that have been learned over time. Furthermore, all involved entities should be reminded to ensure, through the fulfillment of their responsibilities, that these fundamentals are respected in order to minimize risks associated with dams and reservoirs.

PILLARS OF DAM SAFETY

With almost a century of commitment to dam safety, and knowing that the zero risk does not exist, ICOLD recognizes several overarching pillars of dam safety:

- *Structural integrity of dams is the keystone to dam safety*. Best current practices of dam design and performance during the occurrence of hazardous events such as extreme floods and earthquakes have been largely documented by ICOLD bulletins in order to create a sound basis on which existing and future dam structures should be designed, built and operated in safe conditions.
- *A routine surveillance and maintenance programme is necessary for early detection*. Inspection and upkeep are of high importance to minimize the risk and to ensure dam safety in the long term. Periodic safety review by qualified engineers that are highly experienced in dam safety assessment is mandatory. Supervision of dams should be based on both the operator´s self-supervision and periodic external safety reviews by an independent and competent authority or institution.
- *An instrumentation and monitoring programme is essential throughout the life of a dam*. A comprehensive dam monitoring programme is necessary to: (a) determine behavior during construction; (b) assess performance during first reservoir filling; (c) compare actual performance with design; (d) characterize long-term behavior; (e) provide early warning of abnormal conditions; (f) capture & analyze response to events, such as large floods, earthquakes, etc.; (g) predict future performance of dam; and (h) demonstrate safe management of the dam to regulatory authorities.
- *Design-Intrinsic risks need to be adequately addressed*. These risks are based on dam type, materials, ageing, foundations, hydraulic structures, etc., in which good practices and surveillance are the keys for safety.
- *Natural hazard risks change with time, thus should be regularly reviewed and updated*. These hazard risks like floods and earthquakes are external threats, for which risks are accepted based on known science and likelihood of occurrence.
- *Emergency planning is of utmost importance for all dams.* Emergency plans should be developed with the objective of avoiding loss of life and reducing damage to property, infrastructure and the environment resulting from a dam failure. The first filling of the reservoir being a critical period during which the emergency plan must be ready for implementation in a timely manner. Periodic review, updates and practice of the emergency plan is mandatory.
- *Adequate training of operators is part of a comprehensive dam safety programme.* Those placed in charge of dams bear an important responsibility to maintain their training and understanding of their dam. Mis-operation of a dam, especially of spillway gates, can lead to accidents, downstream flooding or potential overtopping of the dam.
- *Sharing lessons learned benefits the entire industry, making all dams safer.* The experience of ICOLD has shown that sharing lessons from dam incidents and failures is crucial to improve state-of-the-art practices. For all involved parties, it is thus imperative that any documentation on dam incidents, including independent expert reports on the root causes of such incidents, be made freely accessible to the international community.
- *A comprehensive dam safety approach will allow minimization of risks.* This is done through collaboration of national organizations to support dam safety: structural measures for strengthening

the structure's integrity and stability; measures to minimize the consequences of failures as well as education and public awareness about dams. A comprehensive dam safety approach should also consider the fact that river basins, many of which are transboundary basins, often include several dams, or systems of dams and levees.

- *A dam owner has the ultimate responsibility for its dam.* ICOLD recognizes that the safety of all dams is primarily the responsibility and liability of owners and operators. Adequate personnel and financial resources as well as relevant know-how are essential conditions to meet this responsibility.
- *The role of regulatory authorities is paramount for safety.* Regulatory authorities should take a strong role in ensuring adequate site investigation, best practice design standards, quality construction, contractual frameworks, emergency preparedness and operational compliance within accepted guidelines and standards. Developing norms, standards and safeguards is a key factor to proper dam safety surveillance.
- *An international perspective to dam safety can be enlightening.* International organizations such as ICOLD, which provide guidelines based on worldwide experience, can provide important guidance to designers, owners and government authorities to better understand the current state of best practices for design and safety of dams.

SUMMARY DECLARATION

With the aspirational goal of working towards continuous reduction of dam safety incidents, ICOLD, as the leading international organization committed to dam safety, calls upon all involved professionals and companies to make a firm commitment safety improvements and risk reductions at all dams.

Furthermore, Governments, Financial Institutions and other Developers, in their contribution to the development and regulation of dam infrastructure, are called upon to make a similar political and financial commitment so that the all-important safety recommendations for dams outlined in ICOLD Bulletins, will be disseminated to the relevant entities and followed to completion.

This common effort will contribute immeasurably to the overarching ICOLD vision:

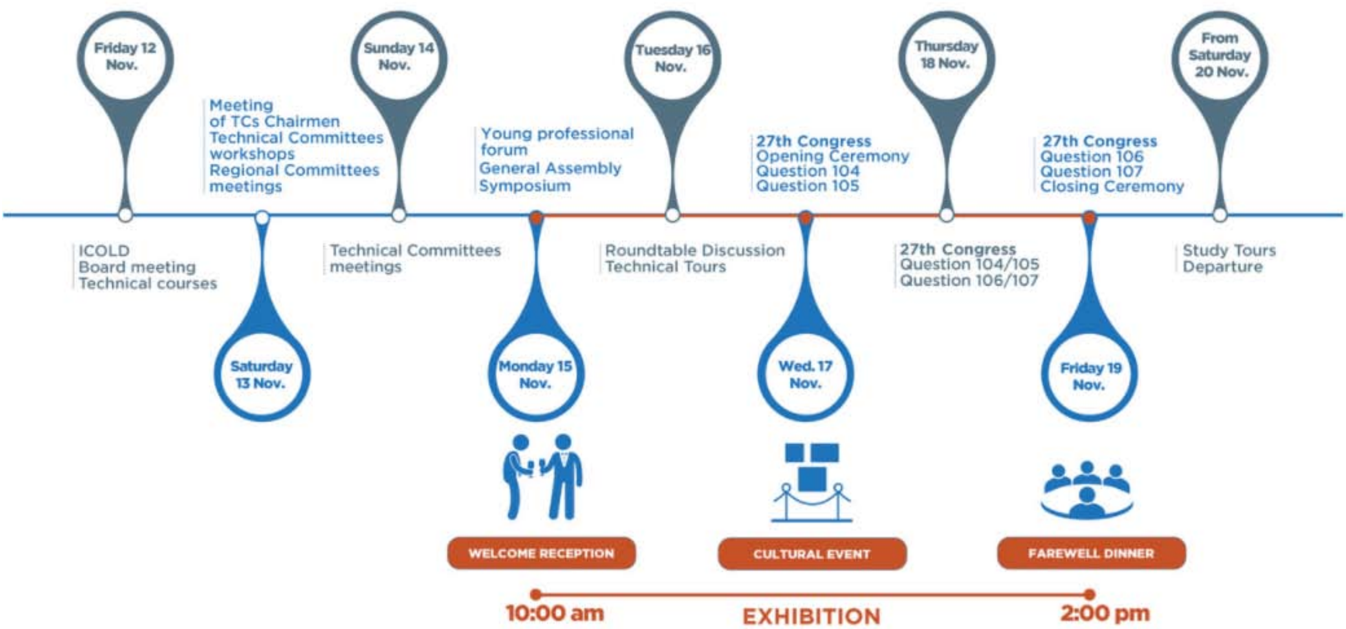
CIGB ICOLD

"Better Dams for a Better World"

Approved on October 18th 2019, in Porto.

International Commission On Large Dams

PROGRAMME



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Scientific Program and abstracts Symposium submission
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HYDROPOWER & DAMS (NEWS)

MYANMAR SEEKS CONSULTING SERVICES FOR LARGE-SCALE REHABILITATION PROJECT

October 26, 2020

Expressions of interest are invited by 19 November for an international consultant on the rehabilitation of five large hydro schemes.

The Ministry of Energy and Electricity (MoEE) of the Republic of the Union of Myanmar seeks to engage an international consultant to assist with the preparation and implementation of the rehabilitation of five large hydropower plants.

Expressions of interest are invited by 19 November from qualified consultants to provide technical assistance to the MoEE, in charge of the project execution with: preparation of the works (reviewing of workstream, planning, revision of the operational manual; assistance to Electric Power Generation Enterprise (EPGE) for the procurement of materials and equipment (terms of reference, support during procurement procedures); supervision of works, and enforcement of Agence Française de Développement's E&S guidelines; and, coordination of the various stakeholders, reporting and ad hoc assistance to the EPGE project team. The assignment is expected to last approximately three years. The project and the services of the consultant will be financed by the Agence Française de Développement (AFD). Eligibility criteria to AFD financing are specified in the "Procurement Guidelines for AFD Financed Contracts in Foreign Countries", available online on AFD's website: http://www.afd.fr.

The applicant should submit only one application, either in its own name or as a member of a joint venture. Subconsultants may participate in several applications. The MoEE will shortlist a maximum of six applicants, to whom the request for proposals to carry out the services will be sent.

Expressions of interest must be submitted by email to the address below.

Interested applicants may obtain further information and the appendix to the request for expression of interest by sending an official request via email to Aung Kyaw Thant, Project Director, Rehabilitation of 5 Hydropower Plants, Ministry of Electricity and Energy, Electric Power Generation Enterprise, Building 27, Nay Pyi Taw, Myanmar; Email: epge.afd@gmail.com.

FINANCIAL ADVISORY SERVICES SOUGHT FOR PROJECT IN INDONESIA

September 23, 2020

Infunde Development is co-developing the unnamed project in South Sumatra together with a local partner, according to a tender notice published on its website on 7 September.

Infunde Development invites expressions of interest (EOIs) by 12 October from qualified consultants to provide Financial Advisory Services for a hydropower project in Indonesia.

Infunde acts on behalf of InfraCo Asia Development as its exclusive developer in various Southeast Asian markets, including Indonesia, to originate and develop infrastructure project opportunities. IAD is a donor-funded infrastructure fund, headquartered in Singapore and a member of the Private Infrastructure Development Group.

Infunde Development lists one hydropower project in its project portfolio in Indonesia. The 36 MW Endikat hydropower project would supply clean, low-cost electricity to the west coast of the island of Sumatra, according to its website, and would help diversify the South Sumatran grid, which is dominated by fossil fuel-powered plants. The project is planned to be developed as a run-of-river cascade on the river Endikat, which extends down the Dempo Mountain in the Pagar Alam Regency, in the province of South Sumatra. It is expected to comprise two plants with a preliminary capacity of 19 MW upstream and 17 MW downstream, with an estimated total capex of US$ 92 million.

Consultants should also attach the project references and credentials for conducting such work, along with the EOI. Interested suppliers will be contacted upon receipt of the EOI. After receipt of the EOI and execution of a non-disclosure agreement (NDA), the terms of reference and associated documents will be provided to qualified consultants. The request for proposal (RfP) and Terms of Reference will be sent to shortlisted consultants after review of their technical qualifications and relevant work experience.

For more information on the project and scope of work, please fill out the online form expressing an interest in responding to RfP #94. The tender notice can be viewed at: infundedev.com/eoi-financial-advisory-services-of-a-hydropower-project-in-indonesia.

DEADLINE APPROACHING: CONSULTING SERVICES SOUGHT FOR MATENGGENG PUMPED-STORAGE PROJECT IN INDONESIA

September 2, 2020

The proposed project, with a generating capacity of 943 MW, is planned to be built in the province of West Java, approximately 300 km southeast of Jakarta, with an upper dam on the Cimancing river and a lower dam on the Citeuteul river, one of the tributaries of the Citanduy river.

Indonesia's state utility PT Perusahaan Listrik Negara (PT PLN) invites expressions of interest by 15 September from qualified consulting firms to prepare detailed design and tender documents for the proposed Matenggeng pumped-storage project in Indonesia.

The main features of the project include: an upper RCC dam with a maximum height of 88 m and a crest length of 279 m; a power waterway consisting of two intakes, two 0.7 km-long headrace tunnels, two 200 m-long buried penstocks, two 350 m-high vertical penstocks, and two 1.6 km-long tailrace tunnels; an underground powerhouse with four pump-turbine units; and, a lower CFRD with a maximum height of 57 m and a crest length of 388 m. A feasibility study, including topographical mapping of the project area through LiDAR survey and extensive geological investigations, was completed in 2018.

The consulting services are to be financed from two loans from the World Bank: Pumped Storage Technical Assistance, and new financing, which is currently being finalized, from the under-preparation Development of Pumped Storage Hydropower in Java Bali System Project. Because of separate financing sources, the consulting services have been divided into two phases. Phase I will entail a review of the feasibility study and scope of works for additional investigations, and Phase II will cover detailed design, preparation of tender documents and assistance through the entire procurement process. The consultant will also assist PLN with the procurement of all contract packages: civil Works including access road (FIDIC's Red Book); electromechanical Equipment (FIDIC's Yellow Book); Hydraulic steel structure Equipment (FIDIC's Yellow Book); and, transmission line (FIDIC's Yellow Book). The consultant will also carry out (through sub-consultants) and manage the following additional investigations: geological investigations including drilling, seismic survey, excavation of exploratory adits, and plate load and block shear tests; topographical survey of the proposed access roads and transmission line route; and, meteorological and hydrological surveys.

A consultant will be selected in accordance with the Quality-and Cost Based Selection (QCBS) method set out in the consultant guidelines.

UZBEKISTAN'S MINISTRY OF ENERGY ANNOUNCES LOAN FROM FRENCH DEVELOPMENT AGENCY FOR HYDRO SECTOR

August 28, 2020

The Ministry of Energy of Uzbekistan announced on 27 August that a 20-year loan agreement, worth €55.8 million, has been signed with the French Development Agency (FDA). The loan facility will finance a series of projects in Uzbekistan's hydropower sector.

The loan agreement complements Uzbekistan's ambitious national energy strategy to generate a quarter of all electricity from renewable sources by 2030, including 3.8 GW of hydro energy.

Uzbekistan is implementing several ongoing investment projects to construct new hydropower plants and modernize existing ones.

The €55.8 million loan will be used as follows:

€46.5 million will contribute to a €52.5 million project to construct a small hydro plant in Tashkent and assist construction of two small hydro plants in the Southern Fergana Canal.

€9.3 million will contribute to a €33.95 million project 'Safety of HPPs' to be implemented at the Charvak hydro plant.

Successful completion of these projects will yield production of additional cheap and environmentally friendly electricity, increase hydropower's share in the country's energy balance, save fuel resources and meet the growing demand for electricity.

With the support of international partners such as the FDA, Uzbekistan is making great strides towards its ambitious renewable energy goals for 2030. The Ministry of Energy would like to place on record its thanks to the FDA for their support and their public vote of confidence in its ongoing efforts to reform and modernize the country's energy sector.

Feasibility studies for the projects were developed by a consortium of consultants: ISL, IED and R-plus, on behalf of the FDA. Loan contributions will support the purchase and construction of modern technological equipment through a tender process in line with FDA procedures.

The FDA part-financed projects are part of an ongoing initiative by JSC Uzbekhydroenergo, the state hydropower producer and developer, called "Project Factory" promoting the development and implementation of new investment projects based on modern technologies. The 23 projects, with projected capacity of 907.5 MW, worth $1.37 billion, are currently underway.

By the end of 2020, it is expected that seven projects with additional capacity of 118.3 MW will have been commissioned.

PROJECT IMPLEMENTATION CONSULTANT APPOINTED FOR BAKARU I AND II IN INDONESIA

July 30, 2020

A joint venture of Tractebel, NEWJEC, and PT Connusa Energina has been appointed for the upgrading and expansion project.

A joint venture led by Tractebel Engineering with Japan's NEWJEC, and local consultancy PT Connusa Energindo, has been appointed project implementation consultant for the Bakaru I and II hydropower projects on the river Mamasa on the island of Sulawesi by Indonesia's state utility PT Perusahaan Listrik Negara (PT PLN).

The project involves the rehabilitation of the 128 MW Bakaru I plant and its extension by 144 MW (referred to as Bakaru II) with the construction of a new headrace tunnel, pressure shaft/tunnel and powerhouse parallel to the existing structures. The existing switchyard also has to be modified. The Bakaru I run-of-river plant, which was commissioned in 1991, is capable of generating 1030 GWh/year under an operating head of 320 m.

The 60-month contract, which is valued at around US$ 14.2 million, covers the preparation of the detailed design and procurement of the civil and E&M contractors, and supervision of the contractors through to commissioning, according to a contract award notice published on 15 July on the website of Germany Trade and Invest (GTAI). The consultant will also support PLN in project execution in line with international best practice and World Bank guidelines with respect to social, environmental, and health and safety aspects. The consultancy services will be financed from a special grant fund provided by the German Federal Ministry for Economic Cooperation and Development.

FEASIBILITY STUDY AND EIA TO BE CONDUCTED FOR KALIGANDAKI PROJECT IN NEPAL

July 30, 2020

SMEC will carry out a feasibility study and environmental impact assessment for the 844 MW Kaligandaki hydropower project in Nepal's central province of Gandaki Pradesh, under a contract awarded by the Department of Electricity Development.

SMEC's services will include updating the feasibility study, detailed engineering surveys and design and preparation of tender documents, the global engineering, management and development consultancy announced on 15 July.

The multipurpose storage hydropower project, on the border between the districts of Parbat and Myagdi, is designed to use river discharge flowing into the Kaligandaki river to generate close to 380 GWh annually, according to a desk study report by the Department of Electricity Development. Output will be transmitted through the Koshi Corridor transmission line. The planned location of the project is 1-2 km upstream from the confluence of the Kaligandaki and Seti rivers, with an elevation of around 530 m. The reservoir volume has been calculated at approximately 2.043 x 109 m^3.

Late last year, SMEC, in a joint venture with local consultancy Jade Consult, was contracted to carry out detailed engineering survey and design and prepare tender documents for the proposed Simbuwa Khola project (70.34 MW) in the Taplejung district of Nepal. The run-of-river plant, which will harness the flow of Simbuwa Khola, a tributary of the Arun river, is being developed by Remit Hydro, a sister organization of Hydroelectricity Investment and Development Company (HIDCL).

MOUS SIGNED FOR 4 GW OF HYDROPOWER IN JAMMU AND KASHMIR

The National Hydroelectric Power Corporation (NHPC), India's state hydropower producer and developer, has signed MoUs with Jammu and Kashmir State Power Development Corporation Ltd (JKSPDCL) and J&K Power Development Department (PDD) for the development of five hydro plants, totalling 4134 MW, in the northern state of Jammu and Kashmir. The agreements, which were signed on 3 January, are de-signed to transform Jammu and Kashmir from a state with a power supply deficit into a power surplus region, over the next four years. One MoU was signed by NHPC and JKSPDCL for the development of the Kirthai-II (930 MW), Sawalkot (1856 MW), Uri-I Stage II (240 MW) and Dulhasti Stage II (258 MW) hydro projects, and a supplementary one was signed by NHPC with JKSPDCL and the Power Development Department of the Government of Jammu and Kashmir for implementation of the 850 MW Ratle project. The Ratle scheme is to be undertaken by a joint venture company in

The MoU signing ceremony for 4134 MW of new hydro capacity in India which NHPC will hold 51 per cent and JKSPDCL will hold 49 per cent. Under a previous MoU signed in February 2019, JKSPDCL was to have purchased NHPC's equity from the end of the fifth year of operation over a period of 15 years.

This clause has now been rescinded. Under the current MoUs, the projects will be handed over to J&K after 40 years of operation. At the signing ceremony, Manoj Sinha, Lieutenant Governor of Jam-mu and Kashmir, said the projects would ensure a 24 h power supply to the population.

"J&K is taking a quantum leap from being power deficient to having a surplus over the next four years", he said. "Only 3504 MW is being generated at present. The works now going ahead will ensure that another 3498 MW is installed over the next four years. The capacity installed over the last 70 years is to be doubled within the next four years". He added that the MoUs that have been signed will attract major investments for Jammu and Kashmir's power sector, ensuring energy security and 24-hour power supply.

NHPC and JKSPDC are already developing three hydropwer projects totalling 2164 MW in the Chenab river basin in Jammu and Kashmir. Chenab Valley Power Projects, a joint venture of NHPC, JKSPDC and PTC India, was established in 2011 by the Government of Jammu and Kashmir and by the Central Govern-ment. Its mission is to harness the hydropower potential of the Chenab river basin. It is developing the 1000 MW Pakal Dul, 624 MW Kiru and 540 MW Kwar projects on a build, own, operate and maintain (BOOM) basis.

ADB TO FINANCE THE 120 MW LOWER KOPILI PLANT IN ASSAM, INDIA

The Asian Development Bank (ADB) has approved a US$ 231 mil-lion loan to construct the 120 MW Lower Kopili hydropower plant (LKHEP) in India's northeastern state of Assam. The loan, which is the third and largest tranche of the US$ 300 million Assam Power Sector Investment Programme ap¬proved by the ADB in 2014, will double the hydro capacity of the Assam Power Generation Corp¬oration (APGCL), the Bank announced on 19 December. ' "This project will produce clean energy and help address the growing demand for electricity in the state of Assam. It will also help state power companies reduce their dependence on expensive electricity from fossil fuel sources," said ADB Principal Energy Specialist Len George.

"Providing reliable power supply will promote economic growth, cre¬ate employment opportunities, and attract investments", he added.

The Lower Kopili project is to be built on the river Kopili near Longku, in the east of Karbi Anglong district, downstream of two operating plants: 75 MW Khandong, which is served from Khandong reservoir on the Kopili, and 200 MW Kopili, supplied from the Umrong reservoir on the river Umrong. It will comprise a 65 m-high concrete gravity dam, a 3.6 km-long headrace tunnel, a main powerhouse equipped with two 55 MW Francis turbines, and an auxiliary 10 MW powerhouse. The project is designed as a hybrid run-of-river and storage plant.

During the high flow season, the main plant will operate for base load on a run-of-river basis, but in the low flow season it will store water during the day and then release it and generate power during the evening peak demand period. The auxiliary power plant, which is to be located at the toe of the dam, will use water released to maintain the minimum river flow. LKHEP will receive water from the tailrace outlet from the existing Kopili powerplant, as well as incremental flow from the river catchment area between Khandong and LKHEP dam near Longku, and any releases from the Khandong and Umrong reservoirs.

The two plants are expected to produce a total of 511 GWh/year, reflect-ing an annual capacity factor of 48.6 per cent. The main plant is designed to produce 456 GWh/year under a net head of 108 m. The auxiliary plant is estimated to produce 55 GWh/year under a net head of 47 m.

L&T Construction is to carry out the civil and hydromechanical works under an EPC contract. The subsidiary of the Indian company Larsen &Toubro (L&T) began mobilizing re-sources on site in August (see H&D Issue 5, 2020).

The loan will finance APGCL's enterprise resource planning system, and will support measures to improve financial management. It will also plan for special measures to mitigate acidity concerns in the Kopili river on the project. In addition, a US$ 2 million grant from ADB's Japan Fund for Poverty Reduction will finance community-based disaster resilience initiatives and resource management.

EQUIPMENT ORDERED FOR THE POLAVARAM PLANT, INDIA

Bharat Heavy Electricals Limited (BHEL), India's state-controlled power engineering group, has been contracted to supply the electro-mechanical equipment for the 960 MW Polavaram hydropower plant, in the southeastern coastal state of Andhra Pradesh.

Under the contract, awarded by the project's EPC contractor Megha Engineering & Infrastructure Ltd (MEJL), BHEL will be responsible for the design, engineering, manufacturing, supply and supervision of erection, testing and commissioning of the equipment, including 12 Kaplan units with a rated capacity of 80 MW each, and associated

The 960 MW Polavaram scheme in India, for which electro-mechanical equipment has recently been ordered.

auxiliaries. BHEL announced on 31 December that the turbines will be the highest rated Kaplan turbines to have been manufactured domestically.

Major equipment for the project will be manufactured at BHEL's production units in Bhopal, Jhansi, Rudrapur and Bengaluru, while .supervision of erection and commissioning on site will be undertaken by the Southern Region division of BHEL's Power Sector subsidiary in Chennai.

The hydro plant is being developed by Andhra Pradesh Power Generation Corporation Ltd (AP-GENCO), as part of a multipurpose irrigation project on the Godavari river in the West Godavari district and East Godavari district of Andhra Pradesh.

The Polavaram project has been accorded National Project Status by the Union Government of India and will be the last to be accorded this status.

WORLD BANK SUPPORTS THE NEXT STAGE OF INDIA'S DRIP INITIATIVE

The World Bank has approved a US$ 250 million loan to help continue improvements in the safety and performance of large dams across various states of India. The Second Dam Rehabilitation and Improvement Project (DRIP-2), with an estimated total cost of US$ 713.4 million, will strengthen dam safety by establishing dam safety guidelines, bringing in global experience, and introducing newer technologies, the World Bank announced on 15 December. "A major innovation envisaged under the project, that is likely to transform dam safety management in the country, is the introduction of a risk-based approach to dam asset management which will help to allocate financial resources towards dam safety needs more effectively," the Bank added.

The project will be implemented at approximately 120 dams across the states of Chhattisgaih, Gujarat, Kerala, Madhya Pradesh, Maharashtra, Manipur, Meghalaya, Odisha, Rajasthan, and Tamil Nadu, and at the national level through the Central Water Commission. Other states or agencies may also be included in the project during the implementation. The $250 million loan from the International Bank for Reconstruction and Development has a maturity period of 13 years, including a grace period of six years. The Asian Infrastructure Investment Bank will also provide a loanof US$ 250 million, with the balance to be covered by the Government of India.

"This is the world's largest dam management programme. Its objective is to break the costly cycle of 'build-neglect-rebuild' which characterizes the operation and maintenance of infrastructure across sectors," said Junaid Ahmad, World Bank Country Director in India. "The expected outcomes will be game-changing: sustaining the livelihoods and food security of millions of Indians who depend on irrigated agriculture, and enabling farmers to avoid the need to pump groundwater, thereby, reducing energy consumption and greenhouse gas emissions. This programme can act as a lighthouse for other countries tackling the challenge of managing hydraulic infrastructure."

Since 2012, the Government of India has been implementing the World Bank-supported DRIP-1 scheme. The World Bank approved financing totalling US$ 350 million in 2010 for the DRIP to improve the safety and sustainable performance of more than 220 dams in the states of Karnataka, Kerala, Madhya Pradesh, Odisha,

Tamil Nadu and Uttarakhand. In March 2019, it approved additional funding of US$ 137 million forDRIP-1, as well as for the construction of an additional spillway on the Hirakud dam in Odisha, and to strengthen the institutional, legal and technical framework for dam safety assurance within the Government of India, and in participating states. "The ongoing DRIP-1 project is helping to set-up institutions, build capacity, and put in place procedures for dam safety. To build on these achievements, further measures are needed to channel scarce funds towards the dams at highest risk," said Chabungbam Rajagopal Singh, Senior Water Resources Management Specialist and Halla Maher Qaddumi, Senior Water Economist and the task team leaders for DRIP-2. "The project will introduce risk-informed dam safety management, establish sustainable mechanisms for financing dam safety, and enhance the capabilities of institutions to manage dam assets."

Other important measures that DRIP-2 will support include flood forecasting systems and integrated reservoir operations which will contribute to building climate resilience; the preparation and implementation of emergency action plans to enable vulnerable downstream communities to prepare for and enhance resilience against the possible negative impacts and risks of climate change; and the piloting of supplemental revenue generation schemes such as floating solar panels.

Forthcoming Events

Sr No	Description	Date	Country/Organizer
1	WEBINAR: Modernising the Hydropower Fleet in Latin America and the Caribbean	July 19-2020	www.epri.com/events/AE9482BD-C...
2	EVENT POSTPONED: PowerGen India	23 Jun –25 June-2020	New Delhi, India Clarion Events URL: www.powergen-india.com
3	BHA Hydro Network 2020	2 Jul - 2 Jul-2020	Shrewsbury,UK Organizers: British Hydropower Association www.british-hydro.org/hydro-ne...
4	EVENT POSTPONED: The International Sustainable Energy Summit	12 Aug - 13 Aug-2020	Shah Alam, Malaysia Organizers: SEDA https://ises.gov.my
5	PowerGen Australia	18 Aug - 20 Aug-2020	Melbourne, Australia Organizers: Talk2 www.powerandutilitiesaustralia...
6	28th Meeting of the European Working Group on Internal Erosion	1 Sep - 4 Sep-2020	Sheffield, UK Organizers:University of Sheffield https://onlineshop.shef.ac.uk/...
7	EVENT POSTPONED: Energy Storage Forum	3 Sep - 3 Sep-2020	Adelaide, Australia Organizers: Clean Energy Council www.cleanenergycouncil.org.au/...
8	BDS 21st Biennial Conference	16 Sep - 19 Sep-2020	Nottingham, UK Organizers: The British Dam Society URL: https://britishdams.org/assets...
9	21st Biennial British Dam Society Conference	16 Sep - 19 Sep-2020	Nottingham, UK Organizers: British Dam Society URL: https://britishdams.org
10	Dam Safety 2020 Virtual Conference	20 Sep - 24 Sep-2020	Online Organizers: Association of State Dam Safety Officials (ASDSO) https://damsafety.org/training...
11	XVII World Water Congress	21 Sep - 25 Sep-2020	Daegu, Republic of Korea Organizers: The XVII World Water Congress Secretariat URL: www.worldwatercongress.com
12	4th International Dam World Conference	21 Sep - 25 Sep-2020	Lisbon, PortugalOrganizers: LNEC URL: http://dw2020.lnec.pt
13	Enlit Asia (formerly PowerGen Asia & Asian Utility Week)	22 Sep - 24 Sep-2020	Jakarta, Indonesia Organizers: Clarion Events URL: www.enlit-asia.com/welcome
14	24th ICID International Congress + 71st IEC Meeting	22 Sep - 28 Sep-2020	Sydney,NSWAustralia Organizers: Encanta Event Management URL: www.icid2020.com.au

15	8th International Conference on Green Energy & Expo	23 Sep - 24 Sep-2020	Edinburgh,Scotland Organizers: Conference Series LC URL: https://greenenergy.conference...
16	Waterpower Canada 2020	5 Oct - 9 Oct-2020	Online Organizers: Canada Hydro URL: www.conference.waterpowercanad...
17	IEEE PES T&D Conference & Exposition	12 Oct - 15 Oct-2020	Chicago, IL, USA Organizers: IEEE URL: www.ieeet-d.org/IEEE20/public/...
18	ICAAR 2020 (16th International Conference on Alkali Aggregate Reaction in Concrete)	13 Oct - 15 Oct-2020	Lisbon, Portugal Organizers: LNEC URL: http://icaar2020.lnec.pt/index...
19	All-Energy Australia 2020	21 Oct - 22 Oct-2020	Melbourne, Australia Organizers: Reed Exhibitions www.all-energy.com.au/en-gb.ht...
20	Offshore Energy Exhibition & Conference	27 Oct - 29 Oct-2020	Amsterdam, The Netherlands Organizers: Navingo BV URL: www.offshore-energy.biz/offsho...
21	Enlit Europe (formerly European Utility Week & PowerGen Europe)	27 Oct - 29 Oct-2020	Milan, Italy Organizers: Clarion Energy Netherlands www.enlit-europe.com
22	Power & Electricity World Africa 2020	4 Nov - 5 Nov-2020	Johannesburg, South AfricaOrganizers: Terrapinn www.terrapinn.com/exhibition/p...
23	The Water Show Africa	4 Nov - 5 Nov-2020	Johannesburg, South AfricaOrganizers: Terrapinn www.terrapinn.com/exhibition/w
24	Business Hydro	10 Nov - 10 Nov-2020	Grenoble, France Organizers: Hydro21 www.hydro21.org
25	Viennahydro 2020	11 Nov - 13 Nov-2020	Vienna, Austria Organizers: Vienna Hydro www.viennahydro.com
26	HydroVision 2020	17 Nov - 19 Nov-2020	Minneapolis, MN, USA Organizers: Clarion Events URL: www.hydroevent.com
27	BHA Annual Conference, Exhibition & Dinner	25 Nov - 26 Nov-2020	Glasgow, Scotland Organizers: British Hydropower Association URL: www.british-hydro.org/bha-annu...
28	ICOLD 2020 , 88th Annul Meeting/ Symposium	28 Nov- 3 Dec -2020	New Delhi-India Organized by INCOLD www.icold2020.org

29	ASIA 2020	8 Dec - 10 Dec-2020	Kuala Lumpur, Malaysia Organizers: Aqua-Media International Ltd URL: www.hydropower-dams.com
30	Enlit Australia (formerly Australian Utility Week & Power Utilities Australia)	10 Mar - 11 Mar 2021	Melbourne, Australia Organizers: Talk2ME URL: https://enlit-australia.com
31	Africa 2021: 4th International Conference & Exhibition on Water Storage and Hydropower Development for Africa	13 Apr - 15 Apr-2021	Lake Victoria, Uganda Organizers: Hydropower & Dams URL: www.hydropower-dams.com/Africa...
32	IWA World Water Congress & Exhibition	9 May - 14 May-2021	Copenhagen, DenmarkOrganizers: IWA URL: https://worldwatercongre
33	Power of Water Canada	25 May - 27 May-2021	White Oaks, Canada Organizers: Ontario Water Power Association URL: www.owa.ca/conference
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35	ICOLD 27th Congress - 89th Annual Meeting	5 Jun - 11 Jun-2021	Marseille, France Organizers: MCO Congrès SAS URL: http://cigb-icold2021.fr/en
36	Seanergy 2021	8 Jun - 11 Jun-2021	Nantes, France Organizers: Bluesign URL: www.seanergy-forum.com/en/sean...
37	24th International Congress on Irrigation & Drainage	6 Jul - 12 Jul-20201	Sydney, Australia Organizers: Irrigation Australia URL: www.irrigationaustralia.com.au
38	HydroVision 2022	12 Jul - 14 Jul-2022	Denver, CO, USA Organizers: PennWell Corp URL: www.hydroevent.com/future-even.

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Anthony T.Hincks

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