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INCOLD

INCOLD JOURNAL

A Half Yearly Technical Journal of Indian Committee on Large Dams

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Tehri Dam

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The original unpublished manuscripts that enhance the level of expertise and research in the various disciplines covered in the Journal are encouraged.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

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

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

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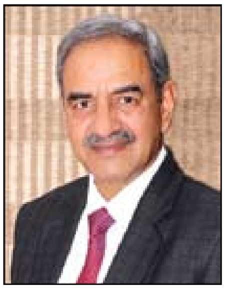
From the President Desk



Dear INCOLD Members, Colleagues, Ladies and Gentleman,

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

The Omicron variant of the corona virus has been detected in 89 countries, and COVID-19 cases involving the variant are doubling every day in places with community transmission and not just infections acquired abroad, as indicated by the World Health Organization. At the moment, it's a challenge to contain the pathogen. This crisis is experienced directly by some and indirectly by all of us. We have to fight together this pandemic and come back stronger as this is the need of the hour. In this new COVID-19 situation, skill enhancement and training of professional has emerged as a very important aspect and a challenge.

On behalf of the INCOLD and on my personal behalf, I wish to express our solidarity with the INCOLD and ICOLD 'Family Members' during this hour of crisis. Our prayers and thoughts are with the families currently dealing with COVID-19.

We are happy to inform that ICOLD Board has agreed to organize the 92nd Annual Meeting of ICOLD and Symposium on "Dams for People, Water, Environment and Development and workshops and Special Sessions on the different aspects of dam engineering to be organized by ICOLD experts during the event from **18-24 October 2024 at New Delhi**. ICOLD-2024 International 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 of the symposium besides Special Workshops

In view of the challenge to develop new dams and reservoirs worldwide and combating the effects of climate change, I invite dam professionals from all over the Globe to join us for the ICOLD- 2024 Symposium, to discuss and deliberate on emerging professional issues. This would be an excellent opportunity to meet 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 experts and participants would brainstorm and deliberate on various aspects of Dams for People, Water, Environment and Development i.e. meeting the needs of the present without compromising the ability of future generations to meet their own water needs.

The deliberations of the Symposium would include presentations by national and international experts who are involved in the planning, design, construction and operation & maintenance of dams and associated structures and would share their experiences to tackle various issues connected with the sustainable development of dams and river basins.

I am looking forward to welcoming the ICOLD and INCOLD family, old members as well as newcomers to the ICOLD event in October 2024 at New Delhi.

Warm Regards

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

Editorial

Dear Readers,

Greetings from INCOLD, New Delhi.

Dams were the first structures designed against earthquakes, on a worldwide basis, starting in the 1930s. At that time, the ground shaking was the main seismic hazard and was represented by a seismic coefficient of typically 0.1, almost irrespective of the seismic hazard at the dam site, which was often unknown. The seismic analysis was done with the pseudo-static method, ignoring the dynamic characteristics of dams. Because of its simplicity, this method is still in use today, although it has become clear that this method is obsolete following the observations made during the 1971 San Fernando earthquake. The pseudo-static method is also not compatible with current seismic guidelines (ICOLD Bulletin 148) and, therefore, this obsolete method shall no longer be used for the safety checks of large storage dams. Using the pseudo static concept, the seismic load case was very seldom the governing one. This has changed by using today's rational concepts for seismic hazard analyses and dynamic analyses of dams. The earthquake load case has become the dominant one for most dams. Since the 1930s considerable developments in the seismic analysis and design of large storage dams have taken place. The main developments, documented in several ICOLD Bulletins.

Today, a modern dam safety concept includes the elements like Structural safety; Dam safety monitoring; Operational safety and maintenance, and Emergency planning. Earthquakes play a role in all these safety elements, which are being addressed in the training course. If we use modern seismic design criteria for large dams (ICOLD Bulletin 148), the following, very general, performance criteria apply for the effects of the strongest ground motion at a dam site:

1. to retain the reservoir and to protect people from the catastrophic release of water from the reservoir,
2. to control the reservoir level after an earthquake as a dam could be overtopped and destroyed if the inflowing water into the reservoir cannot be released through damaged spillways or low-level outlets, and
3. to lower the reservoir level after an earthquake – for repair of works or for increasing the safety of a damaged dam where there are doubts about the safety of dam

A dam must be able to withstand the strong ground shaking from even an extreme earthquake, which is referred to as the Safety Evaluation Earthquake (SEE) or the Maximum Credible Earthquake (MCE). Large storage dams are generally considered safe if they can survive an event with a return period of 10,000 years, i.e. having a one percent chance of being exceeded in 100 years. It is very difficult to predict what can happen during such a rare event as very few earthquakes of this size have actually affected dams. Therefore, it is important to refer to the few such observations that are available. The main lessons learnt from the large Wenchuan and Chile earthquakes will have an impact on the seismic safety assessment of existing dams and the design of new dams in the future. Large dams are required to be able to withstand an earthquake with a return period of about 10,000 years, whereas buildings and bridges are usually designed for an earthquake with a return period of 475 years. In many parts of the world the earthquake safety of existing dams is reassessed based on recommendations and guidelines documented in bulletins of the International Commission on Large Dams (ICOLD).

To create awareness amongst engineers, scientists, dam professionals, and contractors etc. about the procedures in working out the appropriate seismic design parameters, different seismic hazards affecting storage dams, such as fault movement in the footprints of dams and dam safety, utilizing the State-of-the technology/practices followed globally. In this effort, Indian Committee on Large Dams (INCOLD) organized the Virtual Workshops for two days durations on the subjects relevant to different aspects of dam safety engineering development on the following topics:

1. Reservoirs and Seismicity: September 23-24, 2021
2. Earthquake and Dam Safety: October 21-22, 2021
3. Seismic safety of Existing Dams: November 18-19, 2021
4. Seismic Aspect of Dam Design: December 16-17, 2021

The 5th in the series, Workshop on the topic "Multiple Hazards Caused by Strong Earthquakes to Dams and Appurtenant Structures" is being organized on January 20-21, 2022 (Thursday and Friday)

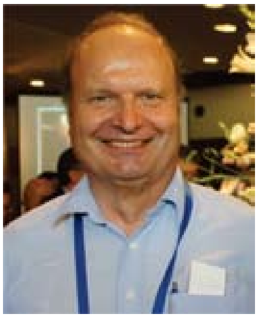
The Virtual Workshops gives an overview on the possible effects of Reservoir-Triggered Seismicity (RTS) on the safety of large dam projects; different seismic hazards affecting storage dams such as fault movements in the footprint of dams and reservoir triggered seismicity, seismic design criteria and multiple hazards caused by strong earthquakes to dams and appurtenant structures. These virtual workshops will offer a good scope for interchange of experiences, to facilitate exposure of state of art technology in all aspects of seismic design, dam safety and earthquake, especially considering participation of eminent dam expert Dr. Wieland Martin, Chairman, ICOLD Committee on Seismic Aspects of Dam Designs from Switzerland as expert faculty.

We thank all the authors for their contributions. I also take this opportunity to thank all the members of the Editorial Board for helping us in our endeavour and providing us with their valuable suggestions in bringing out this journal.

We request all the water and dam professionals' readers to contribute technical papers/articles news etc. which would be of interest for publishing in the subsequent issues of the journal.

We also request for the comments /suggestions of the readers so as to improve the utility of the journal.

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



Damage of Sefid Rud Buttress Dam Project in Iran Caused by the Magnitude 7.4 Manjil Earthquake of June 21, 1990

M. Wieland[1]

ABSTRACT

There are only few case histories of concrete dams that have suffered damage during strong earthquakes. The June 21, 1990 Manjil earthquake resulted in the loss of over 35,000 lives and the total destruction of the town of Manjil. Some 100,000 structures, including dams and irrigation canals, were destroyed or severely damaged. The epicenter was in the town of Manjil. The focal depth was 19 km and the magnitude Mw = 7.4. The nearest strong motion record available is from the town of Abbar, about 40 km from the dam site, where the horizontal components of the peak ground acceleration (PGA) were 0.65 g and 0.62 g and the vertical one was 0.52 g. The PGA at the dam site was estimated as 0.7 g. Sefid Rud Dam is a buttress dam with a maximum height of 106 m and a crest length of 417 m. There are twentythree 14 m wide buttresses, with a web thickness of 5 m, and two gravity type abutment blocks. Construction of the dam took place from 1958 to 1962. Damages to the dam structure consisted mainly of cracks along horizontal lift joints and of spalling of concrete along the vertical joints between buttress heads. These damage features affected the central buttresses at the level of the kink in the slope of the downstream face. On the dam crest, slabs of the carriageway suffered cracking and spalling. The dam was subjected to ground shaking, faulting and rockfalls. The different features of the damage of the dam and appurtenant structures including the gate of the intermediate level spillway are described. Very limited information can be found in the literature on this dam, which up to now is the concrete dam that has experienced the strongest ground shaking of any large concrete dam in the world. The author was a member of the official reconnaissance team inspecting the dam shortly after the earthquake. The repair works carried out after the earthquake, which included epoxy grouting of the cracks and the installation of rock anchors in all blocks are also described.

Keywords *: buttress dam, earthquake damage, 1990 Manjil earthquake, strong ground shaking, dam rehabilitation*

1. INTRODUCTION

There are only few case histories where a concrete dam has suffered severe damage due to earthquake action as reported in [1]. The best-known examples are the Hsinfengkiang buttress dam in China, the Koyna gravity dam in India, and the Sefid Rud Buttress Dam in Iran. The damage pattern due to ground shaking was similar, i.e. cracks appeared near the kink at the downstream face of the dams. The structures could be repaired and strengthened and they are in operation today. Furthermore, two spillway openings of the Shih-Kang concrete weir in Taiwan were destroyed by large fault movements during the 1999 Chi-Chi earthquake.

The above dams are gravity-type structures. Pacoima dam in California, a 116 m high arch dam, was subjected to very strong ground shaking during the 1971 San Fernando earthquake and the 1994 Northridge earthquake and has experienced joint opening and limited cracking, but as the reservoir level was relatively low during these events nothing can be said about its performance under full reservoir condition.

The 21 June, 1990 Manjil earthquake that occurred in the Alborz Mountains in the Caspian Sea region of Iran was one of the most devastating seismic events. It resulted in the loss of over 35,000 lives and the total destruction of the town of Manjil. Some 100,000 structures, including public and residential buildings, dams, industrial facilities, water tanks, irrigation canals either collapsed or were severely damaged. The macroseismic epicenter coincides with the town of Manjil. The focal depth was 19

1. Chairman, Committee on Seismic Aspects of Dam Design (International Commission on Large Dams), Poyry Switzerland Ltd., Zurich, Switzerland

km and the moment magnitude Mw = 7.4 (Ms = 7.7). The main shock was associated with nearly 80 km of fresh faulting. There were also several strong aftershocks with magnitudes up to about 6.0. No strong motion data was recorded at the dam site. The nearest record is from the town of Abbar, about 40 km from the dam site, where the the peak ground acceleration (PGA) of the horizontal components were 0.65 g and 0.62 g and the vertical one was 0.52 g. The horizontal PGA-value estimated for the dam site was about 0.7 g [1, 2].

Sefid Rud Buttress Dam, located in the epicentral region of the Manjil earthquake, is the concrete dam, which up to now has experienced the strongest earthquake ground shaking of any concrete dam in the world (Fig. 1). This case is hardly known among dam and earthquake engineers, because in 1990, when the earthquake occurred, only few foreign engineers and earthquake experts were able to visit the devastated region. Sefid Rud dam and also hydraulic structures of the downstream irrigation scheme were among the main damaged infrastructure projects.

The author was among a team of four Swiss dam engineers and a seismologist, who inspected Sefid Rud dam a few days after the earthquake and was the main earthquake and dam engineer among this team. The team also included one Iranian engineer from Mahab Ghodss Consulting Engineers in Tehran. The dam safety inspection was initiated by the then Iranian President Akbar Hashemi Rafsanjani. The safety of this dam was essential for Iran as it is part of large irrigation scheme, where most of the Iranian rice is grown. A Swiss team was appointed because at that time the Swiss Joint Venture Stucky-Electrowatt in cooperation with Mahab Ghodss was involved in the safety evaluation of all major dams in Iran.

Other Iranian engineers have also visited and inspected the dam afterwards. Most of the photo documents available on this important case study are those from the Swiss team, and are kept in Iran, as at that time we were requested to hand over all photos to our Iranian partner Mahab Ghodss. There was also a camera team of Mahab Ghodss, who made videos and after completion of all repair works a video on the Sefid Rud dam and the Manjil earthquake was assembled, but is hardly known outside of Iran. The main publications describing the effect of the Manjil earthquake on Sefid Rud dam are [1, 2]

Thirty years have passed since the Manjil earthquake has happened. It was the worst earthquake in the last decade of the 20th century and it had a major impact on site-specific seismic hazard studies and the dynamic analysis of large dam projects in Iran.

2. SEFID RUD BUTTRESS DAM

Sefid Rud Buttress Dam, located about 200 km NW of Tehran and about 2 km from the town of Manjil, has a maximum height of 106 m and a crest length of 417 m. There are 23 buttresses, 14 m wide, with a web thickness of 5 m, and two gravity type abutment blocks. The gravity block on the left bank accommodates an intermediate level spillway of 2000 m^3/s capacity. The dam is part of a multi-purpose storage project with irrigation and power production as main purposes. The powerhouse at the downstream toe of the dam has five 17.5 MW units. The dam stores a reservoir with a volume of 1.8 km^3. The right-hand side of the dam is founded on competent andesite rock while the left part rests on andesite breccia and pyroclastic rock. Construction of the dam took place from 1958 to 1962. The layout of the project is shown in Fig. 2.

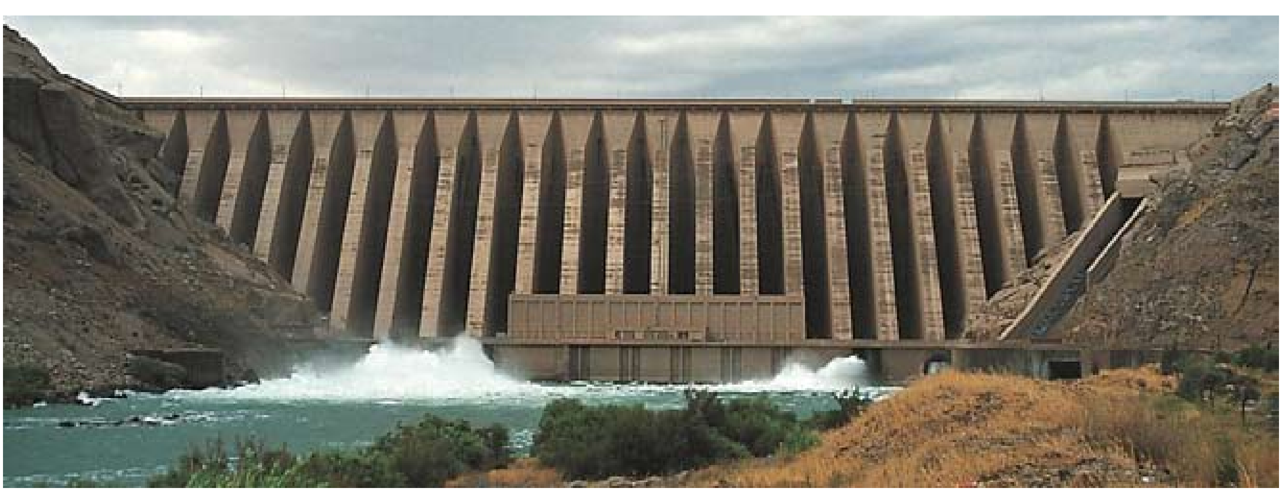


Fig. 1 : Sefid Rud Buttress Dam in Iran with irrigation outlets in operation for lowering the reservoir immediately after the 1990 Manjil earthquake; the powerhouse is at downstream foot of the dam.

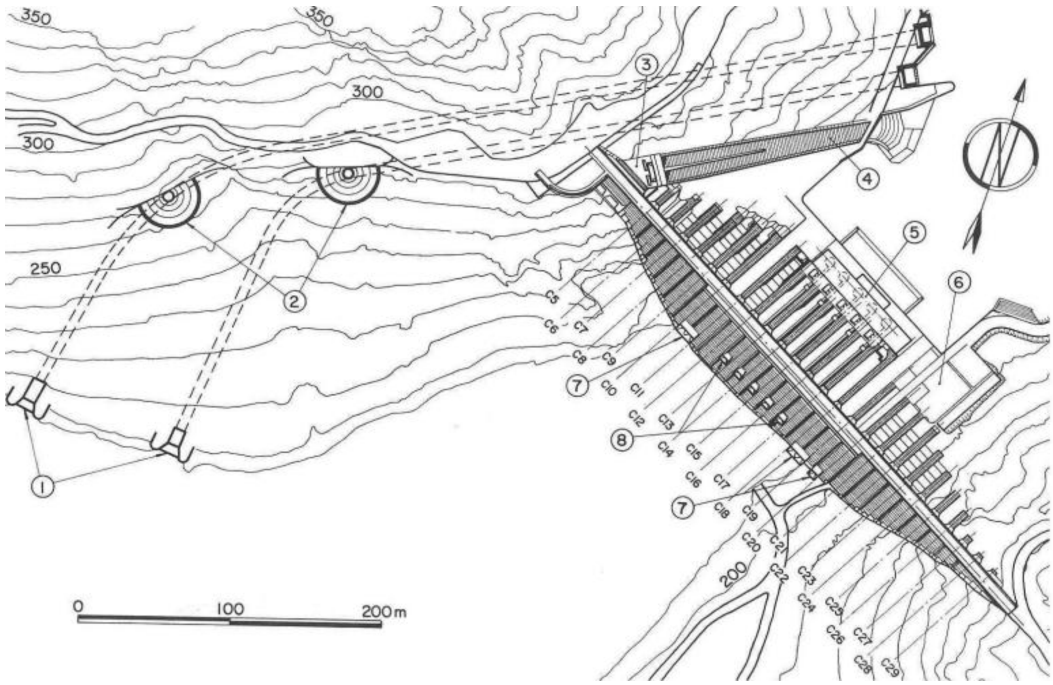


Fig. 2 : Layout of Sefid Rud Dam: (1) Intakes for diversion tunnels, (2) Morning glory spillways connected to diversion tunnels, (3) Orifice spillways, (4) Chute of intermediate spillway, (5) Powerhouse, (6) Switchyard platform, (7) Bottom and irrigation outlets left and right bank , (8) Intakes for penstocks [2]

The seismic design was done by the pseudo-static analysis method using seismic coefficients of 0.1 and 0.25. No tension was allowed at the upstream face under static and seismic loads for a seismic coefficient of 0.1. For a value of 0.25 the allowable concrete stresses were specified as 7 MPa for compression and 0.7 MPa for tension. The dynamic analyses carried out after the Manjil earthquake gave much higher stresses than the original pseudo-static analysis [3]. This was expected as the pseudo-static analysis method used in the past has severe deficiencies, and shall no longer be used today for large dam projects, especially for those located in seismic areas [4].

3. EARTHQUAKE DAMAGE OF SEFID RUD BUTTRESS DAM

Damages to the dam structure consisted mainly of cracks along horizontal lift joints, which were spaced at 2 m (Figs. 3 and 4). Cracks appeared also in central buttresses that were located at the level of the kink in the slope of the

Fig. 3 : Crack at kink location in buttress (left) and horizontal crack along lift joint (right)

Fig. 4 : Horizontal crack at upstream dam face through several buttresses along lift joint (left) and horizontal crack and spalling of concrete above intake gates (right)

downstream face. There was at least one major horizontal crack along working joints in all of the buttresses (Fig. 4). In one buttress, the cracks formed a wedge in the buttress web, which displaced by about 20 mm. On the dam crest, slabs of the carriageway suffered cracking and spalling (Fig. 5).

Typical damages of concrete parapet walls are shown in Fig. 6. The rockfall hazard above the intakes of the morning glory spillway can be seen from Fig. 7, and Fig. 8 shows the inelastic deformations of the arm of a radial gate of the intermediate level spillway, which was caused by high hydrodynamic pressures.

In Fig. 9 different types of damage to the downstream irrigation scheme is displayed. Multiple gates installed in long weirs are critical elements as all of them are of the same type. If one fails, the others are very likely to fail in the same way. The main seismic safety problem of gates of existing older projects is that they have been designed for seismic loads acting in river direction but not in cross-river direction.

Fig. 5 : Cracks on dam crest due to high compressive stresses: Longitudinal crack (left) and compression shear crack at block joints (centre and right) (Note: Relative movements occurred between some of the block joints)

Fig. 6 : Tilting of concrete parapet wall on downstream crest (top left) and secured tilted wall after the earthquake to protect it from falling on the powerhouse (top right), damage at upstream face parapet walls above intake gates (bottom left and right)

Fig. 7 : Rockfalls at intakes of morning glory spillways on left dam abutment: main rocks could be withheld by horizontal platform above intake (right)

Fig. 8 : Damage of radial gate of intermediate level spillway causing leakage (left and centre) and deformed portion of spillway arm due to high hydrodynamic pressures (centre and right)

Fig. 9 : Damage of lining of downstream irrigation canal (left) and several counter weights for gate lifting of diversion structure of irrigation scheme were falling down (right)

In Fig. 10 a reactivated old fissure in the foundation gallery is shown, which was leaking after the earthquake as fine material was washed out due to seismic fissure displacements. Cracks and fissures in concrete dams indicate that uplift pressures exist, which have a negative effect on the post-earthquake stability of concrete blocks. In the same figure a segment of the main fault of the Manjil earthquake can be seen, which passes through the footprint of the dam. The related movements were very small.

In mountainous regions the seismic hazard is a multi-hazard, which besides ground shaking (Figs. 11 and 12), the hazard considered by all dam engineers, we must also taking into account faulting in the dam foundation and the reservoir, landslides, rockslides and rockfalls as well as ground movements (Fig. 13).

During the Manjil earthquake, thousands of rockfalls could be observed; many of them were located very close to the dam site (Figs. 7 and 11).

Electro-mechanical equipment installed in the powerhouse and switchyard are vulnerable to ground shaking, because some have high centres of gravity and are not properly anchored to the foundation or structural walls and, therefore, are vulnerable to overturning (Figs. 14 and 15). But more important is the fact that electrical and mechanical engineers are often not familiar with the overall seismic safety concept used for large dam projects and some of the design guidelines may have to be revised. Furthermore, transmission towers can easily be destroyed by rockfalls. This has also happened with the first transmission tower in Sefid Rud, which caused the shut-down of the power plant.

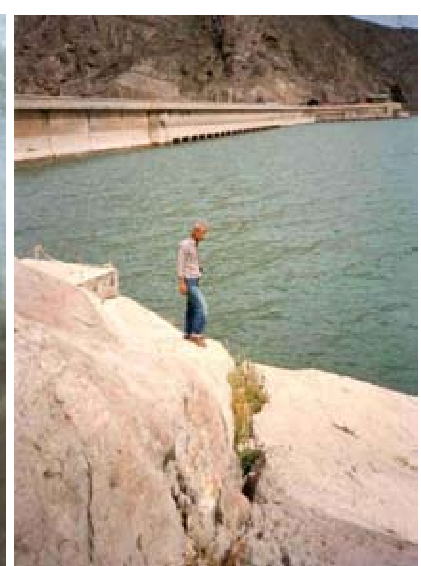


Fig. 10 : Leaking fissure in foundation gallery (left) and trace of fault of Manjil earthquake (right)

Fig. 11 : Rockfall at the dam site: Large displaced rocks above the spillway intake on left bank (top left)

Fig. 12 : Damage in the control room of the hydropower plant caused by ground shaking
(Note: The sandbags at the left were placed as protection from missiles as the dam and power plant were attacked by fighter planes during the Iran-Iraq war of 1980-1988)

Fig. 13 : Collapsed buildings at dam site caused by strong ground shaking

Fig. 14 : Damage of switchyard equipment due to ground shaking and ground movements

Fig. 15 : Derailed transformers that were not properly anchored

4. REHABILITATION OF SEFID RUD DAM

Immediate repair of the damage was of high priority and started in November 1990 and was completed in 1991 [5].

The seismic rehabilitation work was based on the following concepts [2, 5]:

(i) Re-establishing watertightness of the cracked buttresses by epoxy resin grouting. Initial estimates based on water testing arrived at about 80 cracks that had to be treated by grouting.

(ii) Re-establishing the shear strength of the cracked horizontal lift joints by post-tensioned rock anchors passing through the fractured joints (Figs. 16 and 17).

The objectives of the post-tensioned rock anchors were to increase the sliding resistance of the cracked surfaces, and to improve the sliding and overturning stability of the top portion of the dam The design of the strengthening works called for a post-tensioning force of 100 MN per buttress for buttresses 8 to 23 and of 50 MPa for buttresses 5 to 7, and 24 to 27. With this normal force applied to the sheared lift joints, it was expected to restore the shear strength in the block joints that had moved during the earthquake [1, 2]. High capacity strand anchors of 8.4 MN working load were selected. Twelve anchors or six respectively were required per buttress to match the design force (Figs. 16 and 17).

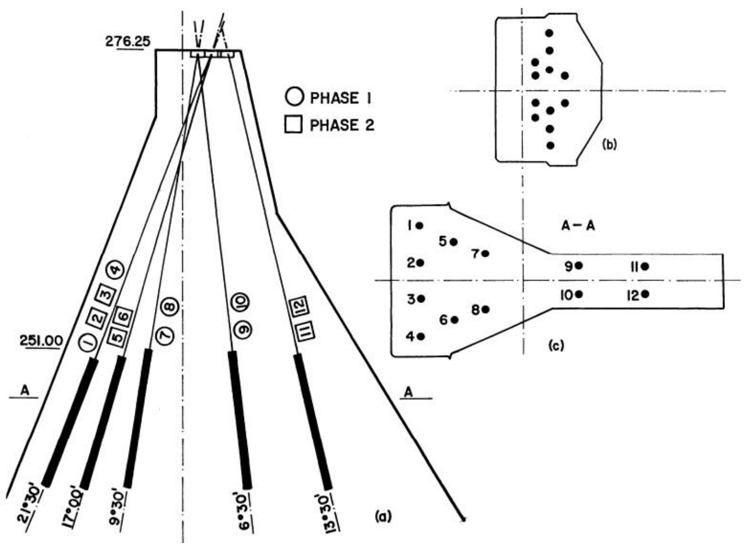


Fig. 16 : Arrangement of post-tensioned anchors in damaged buttresses: (a) cross-section of buttress, (b) top elevation, (c) Section A-A [1]

In the region of the downstream kink, the post-tensioned anchors cause an additional vertical stress of approximately 0.8 MPa. This amount of prestress is not sufficient to prevent future cracking during similar earthquakes. However, the dynamic stability of the detached upper portion of the dam is improved substantially.

As the tendons are anchored in concrete and not in rock, the extra corrosion protection typical for permanent rock anchors was not considered a necessity and, therefore not specified [2].

In addition, some grouting works were carried out in the dam foundation.

5. MODERN SEISMIC SAFETY CRITERIA FOR LARGE STORAGE DAM PROJECTS

Today, the following seismic safety and performance criteria must be checked for large storage dams subjected to the so-called safety evaluation earthquake ground motion (SEE), which is the strongest ground motion at the dam site [6, 7] (Note: The SEE ground motion parameters can either be obtained from a deterministic seismic hazard analysis, assuming worst-case earthquake scenarios, or from a probabilistic seismic hazard analysis for a return period of 10,000 years [6]):

(i) Dam body and foundation: The reservoir must be retained safely, structural damage (cracks, deformations, leakage etc.) are accepted as long as the stability of the dam is ensured and no large quantities of water are released from the reservoir causing flooding in the downstream region of the dam.

(ii) After the SEE the reservoir level must be controlled and it must be possible to release a moderate flood by the spillway or low-level outlet(s), which must remain functioning.

(iii) After the SEE it should be possible to lower the reservoir for repair of earthquake damage, and/or to increase the safety of a dam, if there are doubts about its static or seismic safety after an earthquake or other incidents.

(iv) Safety-critical components and equipment (gated spillways, bottom outlets) must be fully operable after the SEE. Minor distortions and damage (e.g.

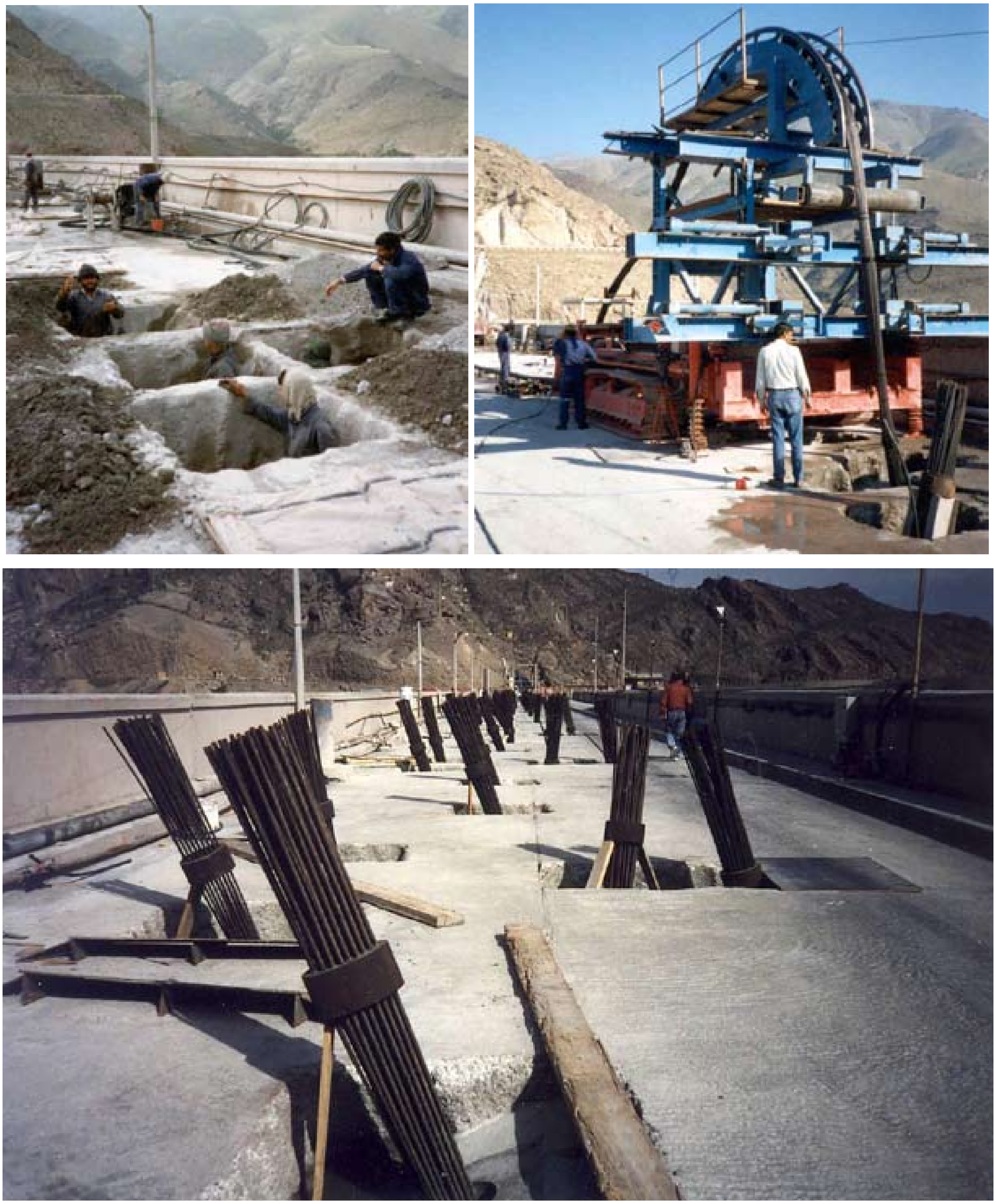


Fig. 17 : Repair work at Sefid Rud dam: Excavation for placement of anchor heads (top left), placement of anchor by homing device mounted on a crawler chassis (top right) and installed rock anchors before stressing (working load of each tendon: 8.4 MN) and final placement of anchor heads (bottom)

leakage of seals of gates) are accepted as long as they have no impact on the proper functioning of the components and equipment. This means that all gates, valves, motors, control units, power supply and emergency power generators for the spillway and low-level outlets must withstand the SEE ground motions and they must be functioning after the SEE, i.e. the equipment shall be properly anchored etc. This is a new requirement [6, 7], which concerns hydro-mechanical and electro-mechanical engineers, who may not have been fully aware of their importance in the seismic safety of dams.

6. CONCLUSIONS

Sefid Rud Dam was damaged by a very strong earthquake, which corresponds to the worst ground motion expected at the dam site. The dam was repaired and strengthened after the 1990 Manjil earthquake and is in full operation. The following conclusions may be drawn based on the observations made at Sefid Rud Dam:

1. Earthquake hazard is multi-hazard: rockfall hazard has been underestimated in most places. Access to dams is a problem after strong earthquakes, especially in mountainous regions.
2. Earthquakes affect all components of storage dams at the same time and all of them must be able to withstand different levels of earthquake shaking.
3. Cracks in concrete dams are discrete cracks developing along lift and construction joints and at locations with sudden changes in stiffness and/or mass (kinks and corners are locations with stress concentrations).
4. It must be possible to lower the reservoir after a strong earthquake in order to increase the safety of a damaged dam. Furthermore, to control the reservoir level after a strong earthquake, spillways and low level outlets must be operable.
5. Hydro-mechanical and electro-mechanical equipment of spillway gates and low-level outlets must be capable to withstand the ground motion of the safety evaluation earthquake. Hydrodynamic pressures may damage gates.
6. The power plant of hydropower projects is most likely out of operation after a strong earthquake.
7. Many people were killed in buildings in the region of the dam, which were not designed against earthquakes or only for much weaker earthquake actions than the dam.
8. Post-tensioning of the top portion of a cracked gravity dams or dams with low strength lift joints is suitable for improving the sliding stability of detached concrete blocks.
9. Although, buttress dams are considered vulnerable to strong earthquake shaking, the Sefid Rud dam performed rather well with damages that were amenable to repair without interfering with its operation.

Acknowledgements

The post-earthquake inspection team of Sefid Rud dam included T. Arasteh and M. Wieland and the late R. P. Brenner, W. Indermauer, J.-P. Stucky, and J. Wagner. J.-P. Stucky had overseen the monitoring of the dam since its construction.

REFERENCES

[1] Wieland M, Brenner RP, Sommer P (2003): Earthquake resiliency of large concrete dams: damage, repair, and strengthening concepts. Proc. of 21st Int. Congress on Large Dams, ICOLD, Montreal, Canada, June 2003.

[2] Indermaur W, Brenner RP, Arasteh T (1992): The effect of the 1990 Manjil earthquake on Sefid Rud Buttress Dam, Dam Engineering, 2(4):275-305, 1992.

[3] Ahmadi MT, Khoshrang G (1992): Sefid Rud dam's dynamic response to the large near-field earthquake of June 1990, Dam Engineering, 3(2):85-115, 1992.

[4] Wieland M (2018): Application of pseudo-static sliding stability analysis in seismic design and safety evaluation of embankment dams, Proc. 16ECEE, Thessaloniki, Greece, June 17-21.

[5] Arcangeli E, Ciabarri P (1994): Menjil dam rehabilitation by resin grouting and high capacity anchors, Int. Water Power & Dam Construction, February, pp. 19-25.

[6] 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.

[7] Wieland M (2020): Changes to expect in seismic safety assessment of large storage dams in future, Proc. Symposium on Proc. Symposium on Sustainable and Safe Dams around the World, ICOLD Annual Meeting, New Delhi, India, April 4-10, 2020

Sediment Management in Hydro Power Reservoirs

J.S. Bawa[1], Manoj Tripathi[2] and Dr. Veepin Kumar[3]

1. INTRODUCTION

Hydro Power is a Green, Sustainable, and Environmental Friendly source of electricity. Hydro Power Plants are among the Temples of modern India (a term coined by India's first Prime Minister Jawahar Lal Nehru while starting the construction of the Bhakra Nangal Dam to describe scientific research institutes, steel plants, power plants, dams being launched in India after independence to jump-start scientific and industrial progress).

The first Hydro development in India commenced with the commissioning of 130 KW hydropower station at Darjeeling in 1897 by the Darjeeling Municipal body. The electrical power generation capacity at the end of 1950 was only 1712 MW comprising about 1000 MW of Thermal, 560 MW of Hydro and 152 MW of Diesel plants. The present total installed capacity of the country as on 29-02-2020 is about 368989.77 MW comprising 230189.57 MW in Thermal, 45699.20 MW in Hydro, 6780 MW in Nuclear and 86321 MW in other non-conventional sources of energy, viz., wind, biomass, etc. Out of this, In Operation installed capacity as on 29-02-2020 is 45699.20 MW. The category wise operational installed capacity is given in Table 1.1.

The Hydro Power Plants, unlike the other resources of power, provide a number of benefits not only to the energy grid but also to the environment and society. Some of the well known benefits of hydropower plants are as follows:

(i) Flexibility in operation.

(ii) Carbon emission reduction

(iii) Longer Life

(iv) Benefits of Flood Moderation, Irrigation, Navigation and drinking water.

(v) Socio-Economic benefits of education, employment, infrastructure development and economic upliftment of the people.

2. WATER SECURITY ISSUES- SOME FACTS

India has 4% of world's water resources but 18% of world population. The country receives around 4,000 BCM Annual Rainfall out of which 6% (250BCM) is stored in dams. Our water requirement will be around 1093 BCM for the year 2025 and 1447 BCM for the year 2050. In 1951, the annual per capita availability of water of India was 5177 m^3, which reduced to 1342 m^3 by 2000. The fact indicates that India is expected to become 'water stressed' by 2025 and 'water scarce' by 2050. India has 200 m^3 of water storage capacity per person, compared to 2,200 m^3 per person in China and 6,000 m^3 per person in the United States. India's accessible, reliable supply of water amounts to 744 billion m^3, or 29 per cent of its total water resources.

The total live storage capacity of the 120 reservoirs in India is 170.328 BCM which is about 66.06% of the live storage capacity of 257.812 BCM which is estimated to have been created in the country. As per reservoir storage bulletin dated 09.01.2020, live storage available

Table 1.1 : Installed Capacity (Hydro > 25 MW) - Operational category-wise

Sector	**RoR**		**RoR (P)**		**Storage (S)**						**Total**	
	No.	**MW**	**No.**	**MW**	**S(P)**		**S(MPP)**		**PSS**		**No.**	**MW**
					No.	**MW**	**No.**	**MW**	**No.**	**MW**		
Central	8	2115	19	6963	6	1725	9	4503	1	40	43	15346
State	14	781	50	7590	32	6434	43	7557	7	4595	146	26958
Private	1	400	13	2547	3	297	0	0	1	150	18	3394
Total	23	3296	82	17100	41	8456	52	12060	9	4785	207	45699
% (Total)	11.5	7	41	38	20.5	19	26	27	4.5	10	100	100

Abbreviations : RoR - Run of River, RoR(P) – Run of River with Pondage, S(P) – Storage (Conventional) for Power Generation purpose only, S(MPP) – Storage (Conventional) for Multipurpose Project, PSS – Pumped Storage Scheme

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in these reservoirs is 130.282 BCM, which is 76% of total live storage capacity of these reservoirs. More Storage dams are needed for water security and management of storage volume is required for existing dams and future dams. However, Siltation is causing Loss of storage volume. Storage sites are limited and objective should be to convert non-sustainable reservoirs into sustainable infrastructure for future generations.

3. SEDIMENT- SOURCE AND ASSOCIATED PROBLEMS FOR HYDRO POWER PLANTS

Sedimentation embodies the process of erosion, transportation, deposition and the compaction of sediments. Erosion and sedimentation are part of the natural evolution of landscape. Most alluvial rivers have experienced increased sedimentation or bed load deficit; both due to natural processes and series of human interventions in the river catchment or on river itself. Rapid urbanization in flood plains, encroachment of river beds, changes due to human activity and deforestation in catchment area of rivers are causing sedimentation in rivers. Sediment or the silt comprises of solid particles of mineral and organic material that are transported by water. The “suspended sediment load” refers to the fine sediment that is carried in suspension and this can comprise the material picked up from the bed of the river (suspended bed material) and material washed into the river from the surrounding land (wash load). The wash load is usually finer than the suspended bed material. In contrast, the “bed load” comprises larger sediment particles that are transported on the bed of the river by rolling, sliding or saltation. Himalayan rivers carry huge sediment during monsoon seasons with nearly 60 to 65% quartz or Feldspar contents having angular & sub angular structure and hardness of 6 to 7 moh.

High concentration of silt load in water passing through turbine hits the underwater parts at high velocities like bullets thus detaching the parent metal of the components causing high hydro-abrasive erosion due to gouging or hammering by the coarse silt particles. Additionally, silt also acts like a grinding paste on these under water metallic surfaces causing low hydro-abrasive erosion due to rolling or sliding of medium & fine silt particles over the surface thus causing metal loss/ thinning of components. Thus, water with high silt content, if allowed to pass through underwater components of hydro power stations including turbines, cooling water system, etc., would not only reduce the operating useful life of such equipment and component but also reduce operational efficiency and regularly cause high recurring cost on maintenance of these items. However, the rate of hydro abrasive erosion caused by silt particles largely depends on the silt characteristics i.e. concentration, size, shape and hardness as well as the velocity and angle of impact of the silt particles.

The gravity of problems associated with silt varies depending upon the type of the hydro project and the extent of sediments carried by the river. In case of projects with large storage reservoirs, the silt tends to settle down quickly and relatively clear water is available for generation. Moreover, these projects are often designed taking into consideration the New Zero Level after 70/ 100 years of sedimentation. However, dam construction creates an impounded river reach characterized by extremely low flow velocities and sediment trapping. The impounded reach will accumulate sediment and lose storage capacity. Declining storage reduces the capacity for flow regulation and with it all water supply and flood control benefits, besides benefits that depend on releases from storage such as hydropower, navigation, recreation and environmental.

On the other hand, the ROR projects have negligible storage compared to the river flows and management of the silt is a bigger challenge in such projects. The suspended sediment load in these reservoirs is trapped in the desilting chambers and relatively clear water is available. However, during the flood seasons, some rivers carry extensive sediment load which may damage the runner and other under water parts and a number of measures are taken to reduce the silt load as well as to mitigate its impact on the project operation.

During high silt periods, generating units are shut down to protect them from silt damages which leads to loss of generation. The average loss in generation on account of such shutdowns has been estimated to be around 1% of the overall generation. Apart from loss in MU generation, the shutdown of hydro power stations to avoid operating under such conditions also leads to loss of peaking (MW) availability. It also indirectly impacts the power grid and involves issues of grid security in handling such operational matters arising out of big capacity at single location or in cascade operation going out of operation.

In the next Section, various techniques for silt management adopted in Hydro Electric Projects are discussed.

4. SILT MANAGEMENT TECHNIQUES

Silt management in hydropower project needs to be done both at ‘Planning and design stage’ as well as ‘Operational stage’. We discuss them, one by one, in subsequent sub-sections.

4.1 Silt management techniques at Planning and Design Stage

These techniques are applied during the design of the Hydro Electric Project and its components. Various techniques during planning and design stage are given below.

(i) In case of reservoir based projects, to fix the reservoir levels and corresponding storage capacity such as Active Storage Capacity, Live Storage Capacity, Dead Storage etc. amount of silt in the water needs to be taken into account to estimate new zero elevation of the reservoir for 50/70 years of operation. This can be done by collecting long term silt management data and then calculating average sediment load from the catchment and using it in determining the different reservoir levels mentioned above.

(ii) In case of ROR and canal-hydel projects, necessary arrangements are normally provided for exclusion of sediments larger than a particular size (usually 0.2mm) from the water entering into turbines. In such projects, when silt load is very heavy, sediment exclusion should be done by sediment excluders and ejectors, which form part of the head works in the river. At present, devices like sediments excluders and extractors are designed using thumb rules and model studies which give only qualitative information. As a result, even though some excluders and extractors are working satisfactorily, the performance of others is unsatisfactory. Hence, there is need for rationalizing their design procedures taking into account the theory of sediment transport. Desilting Chambers, also known as Silting Tanks, Settling Basins, Sediment Traps, Decantation Chambers are also used for removing sediments larger than the required size, which enter into the water conductor system wherever, the silt issues are envisaged during operation of the project. Further, desilting chambers could, however, be made more effective by automatic operational flushing valve by placing load sensors etc.

(iii) The chemical analysis of water and silt data including the petrographic analysis needs to be taken into consideration while designing the turbine, main inlet valve and other auxiliary equipment susceptible to abrasive effects of silt.

(iv) To minimize effect of damage to underwater parts of HE station due to high silt content in the river water, suitable materials, protective hard coating (i.e. Tungsten Carbide) by High Velocity Oxy Flame (HVOF) spray method or any other state of the art technology should be employed to resist silt abrasion, wherever required, as per the site conditions. The abrasion resistant coating on the underwater parts of turbine, often, gets eroded due to water silt content of abrasive nature during the course of operation. As such, this coating needs to be reapplied in case it is found eroded during visual inspection or according to established maintenance practice of the utility based on operational experience. This technique has been applied in SJVN project Nathpa Jhakri (1500 MW) and JSWHEL project Karcham Wangtoo (1000 MW).

(v) Gates at desilting arrangements require appropriate features suitable for exclusion of silt and control of discharges under high heads. These gates require sealing and bearing arrangements such that constant flow of silt loaded water has no long term detrimental effects on the gate components. These gates are quite often of small size and are required to be operated under partial open conditions. Due to heavy silt load, these gates require frequent operation. Considering these, hydraulic hoists for the operation of various gates in power station including desilting chambers should be encouraged, wherever possible since drum hoists are often found inconvenient and modern installations adopt hydraulically operated gates for maintaining partial operation.

(vi) The need for installation of sediment removal system at hydro projects using a Hydro Suction System could be envisaged/ suitably explored at planning and design stage. The system allows sediment dredging in reservoir by hydro-suction without input of power of any kind and utilizes excess water during monsoon season, so no water is lost for production.

(vii) The possibility of providing low level sluices needs to be explored in the new projects since it is an effective solution for carrying out flushing of reservoir in run-of-the-river projects.

(viii) In case of the projects planned in the high silt-affected areas, provision for providing requisite blank panels during monsoon at the intake crest level should be made based on hydraulic model studies to restrict silt ingress in water conductor system. This technique has been successfully applied in projects like Nathpa Jhakri Hydro Electric Project.

In the next sub-section, we discuss various techniques for silt management, which could be applied at operational stage.

4.2 Operational Stage silt management Techniques

Every hydroelectric project is a unique entity and has different set of problems. Generation utilities should prepare project specific guidelines and standard operating procedures for management of sediments for each of the project based on their operational experience. Various techniques that could be used for silt management during operational stage are given below.

(i) Sediment rating curves, discharge v/s suspended sediment load, should be prepared for every medium and major hydroelectric project on monthly basis for the monsoon season. Rating curves may also be prepared for non-monsoon period. Based on the above and the operational experience of the developer, plant should be shut down if the silt content measurement in water upstream of power house increases beyond pre-defined limit of silt content in the river which is for example 5000 ppm in case of Nathpa Jhakri. Efforts should also be made by the utility for forecasting of the flows in the upstream for planning in advance of the operational measures in the eventuality of the shutdown of the station due to high level of silt.

(ii) Wherever, hydroelectric projects having diversion structure with small storage capacity or projects where live storage capacity has been reduced considerably due to sedimentation, utilities should prepare detailed instructions for carrying out flushing operations during monsoon season to prolong the useful life of the project and for its desired performance.

(iii) In order to reduce siltation of live storage capacity in case of run-of-the river schemes or projects having small storage capacities, operation of reservoirs at/ near MDDL during monsoon/ high flow periods, while discharges are more than the design discharge, could be considered. This would ensure sediment free environment in front of power intake as well as sediment balance between upstream and downstream of dam/barrage is maintained and thus natural river regime remains close to original profile. This practice is being used in the HEPs in Himalayan region.

(iv) For projects in cascade lying in close vicinity of each other, flushing could be carried out to the extent possible in tandem so that the sediment flushed out from the upstream reservoir are not allowed to settle in the downstream reservoir. A co-ordinated and synchronized silt flushing approach should be studied based on river slope and its sediment carrying capacity and the flushing/guildlines need to be prepared for the project accordingly. The last reservoir flushing shall normally be carried out at the end of high flow seasons with coordination of upstream project to avoid any accumulation of silt in the reservoir so that it does not affect the performance of the machines during the balance month of entire lean season. Such an arrangement has been made between Naptha Jhakri and Karcham Wangtoo HEPs. A joint protocol for reservoir flushing has been signed between JSWHEL, NRLDC and SJVNL for regulating generation and shut down of the units followed by reservoir flushing.

(v) Depending upon type and size of deposited sediments in the reservoir and tributaries meeting the river/reservoir, dredging could be carried out.

(vi) For effective operation of the Desilting chambers in existing stations, the possibility for automation of the operation of flushing valves, depending upon sediments deposition inside the desilting chambers by placing the load sensors, should be examined by the utilities, which would minimize choking of the desilting chambers and would also optimize water requirement for flushing operations. The frequency of the operation of the desilting chamber valves would, however, depend on the incoming sediment load during the monsoon and non-monsoon period and need to be estimated by the utility based on their operational experience.

(vii) Wherever possible, efforts could be made for real-time coordination among different hydro generating utilities, in order to have effective regulation and to supplement the peak generation from projects having diurnal storage or large volume storage especially during the period of closure of plant(s) due to heavy silt load.

(viii) For effective management of sediments, feasibility of lowering of spillway crest and converting them into low level sluices, in the existing dams, by cutting body of the dam or any modifications by suitable techniques (wire-line cutting technology etc.) could be explored on case-to-case basis.

(ix) A temporary channel may be excavated through which the sediment can be poured into dead storage using force of inflow. This technique has been applied in the Takase Dam of Japan. Especially when flood is forecasted, the water level of the Takase Dam is set near Minimum Water Level before the flood occurs. The stronger the flood, the more effective this technique is, i.e., more effectively the sediment is poured into the dead storage.

(x) Hydrographic survey of the reservoir should be carried out every year at fixed locations, which shall permanently be marked along the reservoir length by constructing concrete pillars duly marked with reach lengths. Power utilities should carry out systematic and quantitative budgeting of sediments by taking into account, inflow sediment load, sediments deposited in the reservoir, flushing of sediments, dredging of sediments and sediments passing through the turbines.

The effectiveness of Catchment Area Treatment Plans need to be assessed from time-to-time by the generating utility and requisite works identified to restore the old treatment works as well as new ones should be taken up on priority to reduce the sediment yield. Efforts should be made to reduce the sediment yield from catchment area of the project. Generation utilities need to follow the methodology of catchment area treatment, including construction of small check dams, plantation/ forestation along river embankments to check soil erosion, embankment protection works to check landslide debris at identified/ prone weaker geological zones, etc. The effectiveness of these treatment plans needs to be assessed from time to time.

In the next Section, we discuss a new model, which may be used to forecast sediment in the reservoir.

5. A NEW MODEL FOR SEDIMENT FORECASTING

The proposed model incorporates forecasting both the weather system and land structure as given below:

(i) **Weather Forecasting System**: It predicts the quantum of rainfall in the upstream catchment area of the river on which the HEP is located. The sediment created out of the erosion is directly related to the amount of rainfall. Thus, amount of sediment can be anticipated by a better weather forecasting system located on the upstream of the river. For this a localized weather model needs to be developed.

(ii) **Inflow Forecasting System**: To get an estimate of the amount of inflow at the project site 'Automatic Weather Stations (AWS)' on the catchment of the River and Gauge site on its upstream may be installed. AWS will measure the amount of precipitation on the catchment of the River and Gauge sites on the upstream of the river at suitable locations will measure the amount of inflow at the site of its installation. Suitable mathematical models developed on the basis of the data will help predict the inflows at the Dam site.

(iii) **Rock Structure Forecasting**: The forecasting of rock structure will help in understating the stiffness/ hardness of rock on the upstream of the river. This information will help in predicting the amount of erosion by the river which forms the sediment. For this an inventory of the landslides happened in the area needs to be created and the existing land use and soil data needs to be reviewed and updated by using the satellite images. The rock cutting activities that have occurred in the area also needs to be looked into. The run-off that will occur in the catchment area of the Dam also needs to be reviewed by driving the inputs received from the satellite images.

The combined forecasting model incorporating the above discussed models may help in predicting the amount of sediment in the river in advance which would further help in better silt management in the hydro power plants in terms of generation forecasting/scheduling of power by generating utilities/load despatchers. To make it economically viable, the cost of developing the localized silt prediction model can be shared by all the project proponents operating in cascade in the river. One similar kind of model is being presently developed by NRSC, ISRO for NHPC Project TEESTA IV, a 520 MW run of the river project located in Sikkim on river Teesta.

REFERENCES

1. "Standard Operating Procedure for Management of Silt in Hydro Electric Project", by Central Electricity Authority, Ministry of Power.
2. "Executive Summary on Power Sector" by Central Electricity Authority, Ministry of Power.
3. Article on "R&M in Hydro Power Plant- Historical Background, Present & Future", by Sanjay Srivastava, Rakesh Kumar, K.K. Neema and Deepak Choudhary, Published in CEA Technical Papers on Renovation, Modernization, Uprating & Life Extension of Hydro Power Plants in December 2016.
4. Various data from official site of CEA.

Simulation of Flows at Tehri Dam during Various Storm Events using HEC-HMS

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ABSTRACT

Reliable prediction of storm runoff from rainfall and snowmelt are important for flood hazard mitigation and resilience. In this study, the HEC-HMS software of U.S. Army Corps of engineers was used to simulate the flows at Tehri Dam during various storm events. The Tehri dam is the 4th highest dam in the world in earth and rock fill category. The catchment area of Tehri dam is 7293 km², out of which 2042 km² is covered with permanent snow. Eight storm events from monsoon of 2016-2017 and two events from monsoon of 2018 have been selected for calibration and validation respectively. Model parameters were calibrated and performance of the model was evaluated by comparing the six hourly flows at Tehri dam. Maximum and minimum Nash and Sutcliff efficiency (NSE) for 8 events during calibration were 90.7% and 72.6 % respectively. While during the validation of two monsoon events of 2018 the NSE were 85.3% and 85.1%. Model performs satisfactorily to reproduce the runoff induced from rainfall as well as snowmelt. The paper discusses delineation of sub-catchments, selection of storm events, sensitivity analysis, calibration of parameters and validation of six hourly flows at Tehri dam.

1. INTRODUCTION

The Hydrologic Modelling System (HEC-HMS) is a physically based, semi-distributed model developed by Hydrologic Engineering Centre of the United States Army Corps of Engineers HEC-HMS is very flexible application software that allows the user to select combinations of different models for runoff simulation of a watershed. Furthermore, a number of parameters required by different models can also be estimated automatically by optimization trials using observed input and output data. HEC-HMS software has been applied in watersheds as small as an elevated highway interchange to as large as 20,000 square miles. Hydrographs produced by HEC-HMS are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanisation impact, reservoir spillway design, flood damage reduction, floodplain regulation, and real-time systems operation. For Himalayan basins also, some studies have been reported in the literature, see, e.g. Gautam (2014), Prajapati (2015) and Khatri (2017).

However, for the Bhagirathi basin, only one study by Sah (2018) using gridded data has been carried out and reported in the literature. The main reason for the same has been the non-availability of hydro-meteorological data for the basin. The present study is the first study for the application of the HEC-HMS model for the entire Bhagirathi basin at Tehri using the observed hydro-meteorological data of eleven stations.

2. STUDY AREA

Tehri dam is situated in the district Tehri of Uttarakhand state of India, Tehri dam catchment is bounded between longitude 78°9'15''E to 79°24'55''E and latitude 30°20'20''N to 31°27'30''N (Fig. 1). The catchment area up to the dam axis is 7293 km². River Bhagirathi Bhilangana and Balganga are the three major rivers which contribute to Tehri reservoir. Bhagirathi River originates from Gangotri glacier near Gomukh at an elevation of 4255 m and traverses a distance of about 145 km to its confluence with river Bhilangana at 1.5 Km upstream of Tehri dam. River Bhilangana traverses a distance of 72 km before meeting with river Bhagirathi. Some minor tributaries like Mangad, Nilapani, Jadganga, Garunganga, Ganeshganga, Asiganga, Dharshugad, Jalkurgad also meet with river Bhagirathi. River Balganga is a major tributary of river Bhilangana, and it meets at Ghansali, 3 Km downstream of Sarasgaon at EL 818 m, falling directly into the reservoir. Different tributaries of Bhagirathi and Bhilangna are shown in Fig.2.

There are two run-of-the-river hydropower projects namely Maneri Bhali I and Maneri Bhali II situated in the

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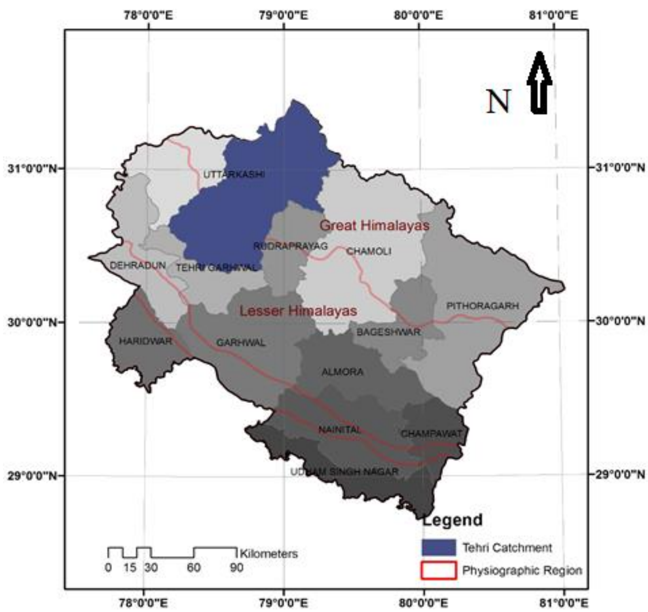


Fig. 1 : Showing Location Map

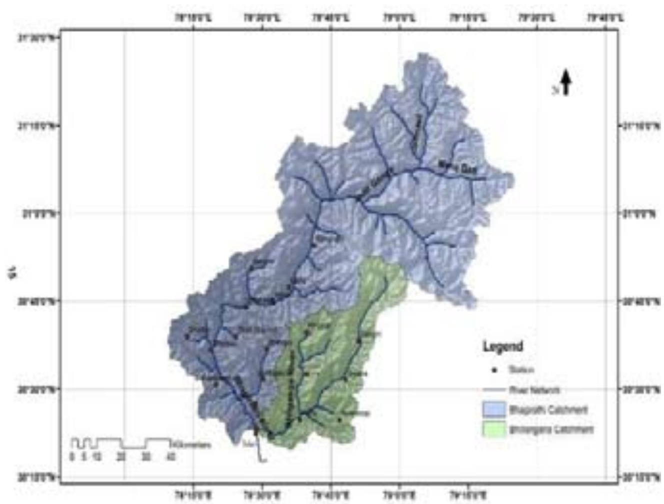


Fig. 2 : Showing location map and major rivers and tributaries of Tehri Catchment

upstream of Tehri Project on river Bhagirathi. The releases from these projects affect the inflows to the Tehri reservoir. These power schemes play a major role in the regulation of the inflows to the reservoir.

Tehri dam is 260.5 m high rockfill earthen dam. It is the fourth highest rock-fill earthen dam in the world after Rogun dam (335 m) in Russia, Nurek dam (300 m) in Tadzhikistan and Chicoasen dam (261 m) in Mexico. It is a multipurpose project. The first phase of the project was commissioned in 2006. In its first phase, four Francis turbines of 250 MW capacity each, have been installed. Another 1000 MW capacity is to be added after completing the third phase by 2020.

It is a major source of irrigation for Rabi crop to various canals of Uttar Pradesh and Uttarakhand State. Seven million peoples get drinking water from this dam. Dam's FRL (Full Reservoir Level) is at 830.2 m above mean sea level, and MFL (Maximum Flood Level) is at 835m. The PMF (Probable Maximum Flood) for the dam is 15540 cumecs. To handle the PMF, a chute spillway, having 5500 Cumecss discharging capacity and four shaft spillways, each having 1900 cumecs discharging capacity have been provided. The gross and live storages of the reservoir are 3540 and 2615 MCM (Million Cubic Meters) respectively. Mean annual flow volume of river Bhagirathi is 8000 MCM. Dam and its reservoir are shown in Figure 3 and Figure 4 respectively.

Fig. 3

Fig.4

Fig. 3 & 4 : View of Tehri dam, its Chute Spillway & Tehri Reservoir

3. METHODOLOGY

Digital Elevation Model (DEM) is used as input for partitioning of the basin into some sub-basins. HEC-HMS can be used to simulate an individual storm event or can be used in continuous simulation mode. The model has three components viz. basin model, meteorological model and control specifications. The basin model deals with the physical characteristics of the watershed. The inputs like precipitation, temperature, evaporation are handled by the meteorological model. The control specifications are used to provide the simulation time of a process. The HEC-HMS software models overland flow and interflow, base-flow and channel flow separately. In the HEC-HMS model, six different models can be used to model the runoff volume. There are six models for estimating the temporal distribution of runoff, three different models for modelling of base- flow and eight different models for channel routing. However, keeping in view the data availability, the following combinations were selected, Initial and constant loss rate method, SCS-UH for the time distribution of run-off, Constant monthly base flow, and Muskingum-Cunge for channel routing. For the meteorological setup, different rain gauges were used, and the gauge weights were setup. The snowmelt runoffs from different catchments have been computed using the Temperature Index method. Thiessen weights for different gauges have been computed using the ARC-GIS. The temperature index method is used to calculate the snowmelt contribution to the basin. Snow generally occurs when the temperature is below the freezing point over the land surface, and the snow will accumulate on the land surface as long as the temperature remains below the freezing point. In some basins, snow accumulates to the snowpacks during the winter season. The snowpack melting starts when the atmospheric condition transfers sufficient energy to raise the temperature above the freezing point of the snowpack. The most common means of measuring the water content from the snowpack is the snow water equivalent (SWE).

The snowmelt method is only required when the temperature of the basin is going below the freezing point during the simulation, or if there is already available snowpack within the basin at the beginning of the simulation. The temperature index method is generally an extension of the degree day method used for modelling snowmelt in the study. Hourly temperature data of Dhopardhar and Bishan have been used for snowmelt modelling for Bhilangana and Balganga catchments respectively. Hourly rainfall data of Ghansali, Bishan and Dhopardhar have been used to model the runoff of these sub-catchments. For computation of snow melt contribution, Bhilangana and Balganga catchment have been divided into six and five elevation bands respectively. Model parameters such as lag time, temperature index, critical temperature, base temperature, initial snow water equivalent and time weight of automatic weather stations have been calibrated.

The flow of Bhilangana at Ghansali, Balganga at Sarasgaon, regulated flow, i.e. spill, flush and turbine discharge of Maneri Bhali II and DSRO of all the sixteen ungauged tributaries were routed up to Tehri dam through twenty-one reaches using Muskingum-Cunge method. Bhagirathi River from Joshiyara barrage to Tehri dam has been divided into twelve reaches, Bhilangana River from Ghansali to Tehri dam has been divided into 8 reaches. For Balganga at Sarasgaon, there is one additional reach. Cross-section of each reach has been obtained from the hydrographic survey of Tehri reservoir, which was done by THDCIL in 2013. Dimensions like bottom width, top width, side slopes and invert levels of each cross-section were used. The flow of each tributary and MB II outflows are taken as a source. Every reach is connected with a junction and Bhilangana at Ghansali and Balganga at Sarasgaon are taken as sub-catchments. The flow chart of the intermediate catchments from Bhagirathi side and Bhilangana side is presented in Fig 5 and Fig 6 respectively. For validation of the flows, Tehri reservoir levels and turbine discharges were used to calculate the inflow at the dam site.

4. RESULT AND DISCUSSIONS

Ten storm events during 2016, 2017 and 2018 were selected for event-based modelling. The catchment area has been divided into four parts, i.e. (i) Bhagirathi up to MBII, (ii) Balganga up to Sarasgaon; (iii) Bhilangana up to Ghansali and (iv) intermediate catchment area. The outflows from MB II, being regulated flows, are taken as source and Bhilangana, and Balganga flows are modelled using HEC-HMS as snowfed catchments. The contributions of the intermediate catchment are obtained using HEC-HMS considering these catchments as ungauged and rainfed.

4.1 Modelling of Balganga at Sarasgaon

For this catchment hourly rainfall data of three stations namely Bishan, Dhopardhar and Ghansali were used. Thiessen weights of Bishan, Dhopardhar and Ghansali are 0.45, 0.3 and 0.25 respectively. Hourly temperature data of Bishan AWS were used for snowmelt modelling. Before the calibration of the model sensitivity analysis was performed for Event-1

4.2 Sensitivity Analysis

Sensitivity analysis is performed to understand how the model results react to change in model parameters. Some of the parameters have more impact on model results than others. The knowledge of sensitive parameters is useful in model calibration. To perform the sensitivity analyses

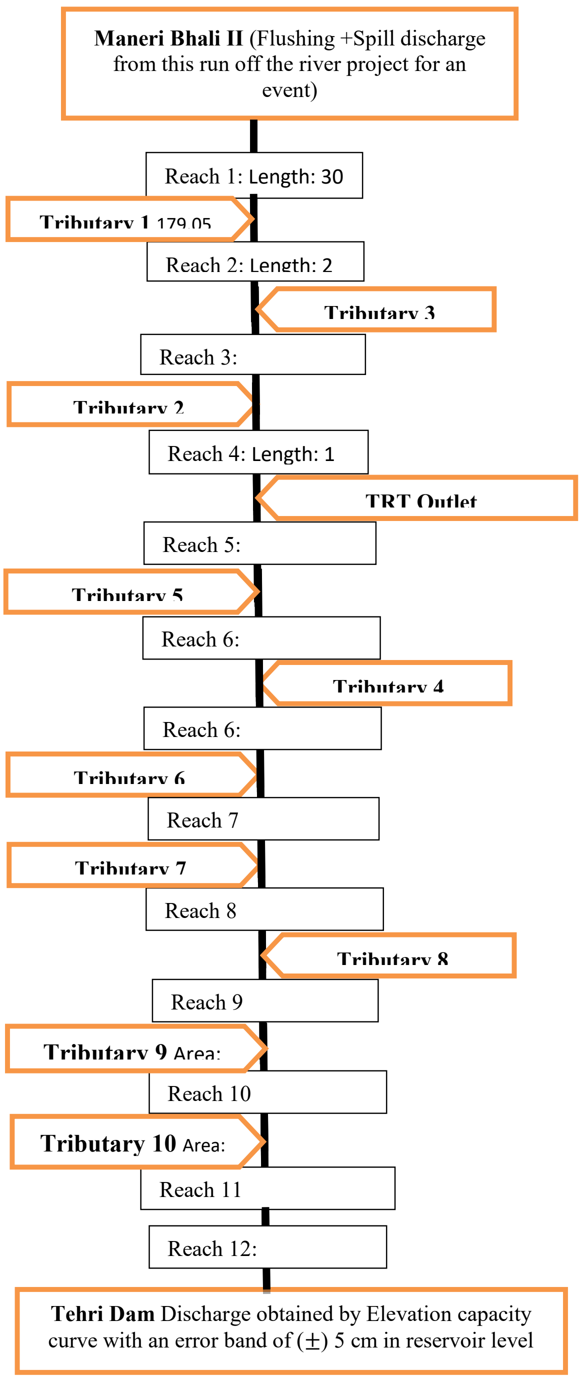


Fig. 5.

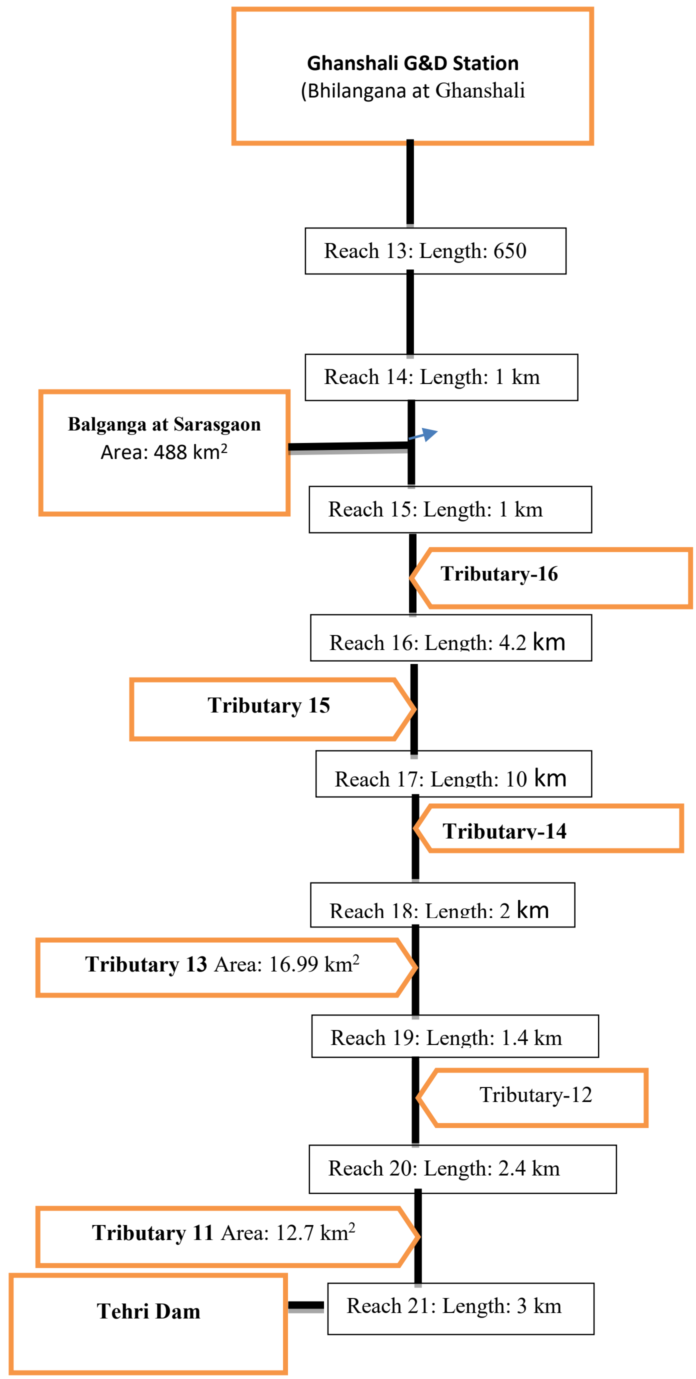


Fig. 6.

Fig. 5&6 : Flow Charts of the intermediate catchment, Bhagirathi and Bhilangana side

the parameters whose sensitivity is to be analysed are changed and other parameters are kept constant. It is found that unmeasured parameters like ATI melt rate coefficient, wet melt rate, lapse rate, and constant loss rate are highly sensitive. Other parameters such as initial loss, critical (PX) temperature, rain rate limit and cold limit do not have much effect on the results.

4.3 Calibration and Validation

The calibration of the parameters in HEC-HMS, i.e. initial loss rate, constant loss rate, lag time, temperature lapse rate and parameters of different elevation bands etc. has been done These calibrated parameters have been obtained after a number of iterations to maximize the efficiency. Based on these calibrated parameters of eight events, the average parameters of July and August separately were obtained and using these average parameters, same eight events of 2016 and 2017 were validated. The plots of one typical event in calibration and validation are shown in Fig. 7 to 10 It can be seen from these figures that during calibration and validation the peak flows are matching quite closely. The NSE of eight events of 2016 and 2017 during calibration and validation with averaged parameters are given in Table1. It may be seen from this table, that average, maximum and minimum NSE of all the eight events during calibration are 81.4%, 94.2% and 61.2% respectively. During validation, using the averaged parameters, the same get deteriorated to 72.8%, 90.8% and 50.5% respectively. The validation of the model has also been done for two events of July 2018. The results of validation of two new events no. 9 and 10 shows that NSE of the model is 88% and 89.4% respectively. From Fig 7&8 and 9&10, it can be seen that peeks of the flows are matching. The model is predicting the runoff generated due to rainfall quite effectively.

Table 1 : Nash-Sutcliffe efficiency for Balganga sub-catchment using HEC-HMS event based modelling

Event No.	Efficiency	
	Calibration	Validation
1	75.8	75.1
2	87.6	86.8
3	75.7	69.8
4	94.2	90.8
5	87.2	86.6
6	61.2	48.5
7	88.5	67.6
8	81.2	57.5
9	-	88.0
10	-	89.4

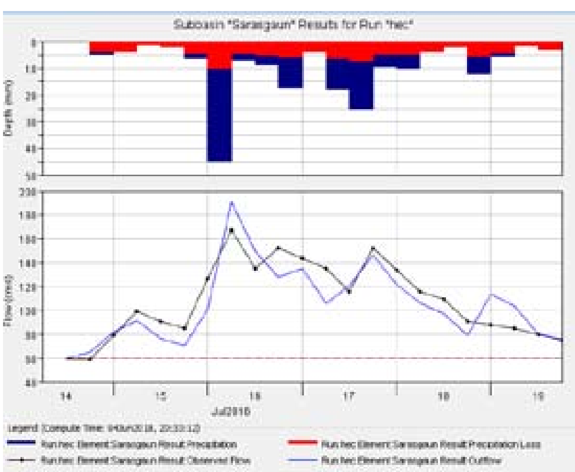


Fig. 7.

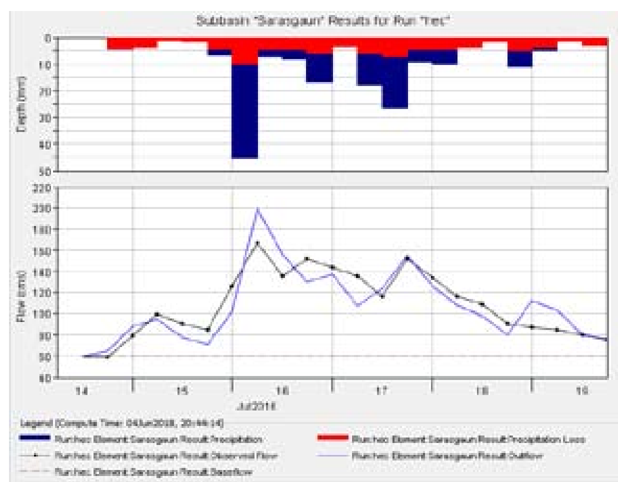


Fig. 8

Figure 7&8 : Hydrographs for event-1, during calibration and validation

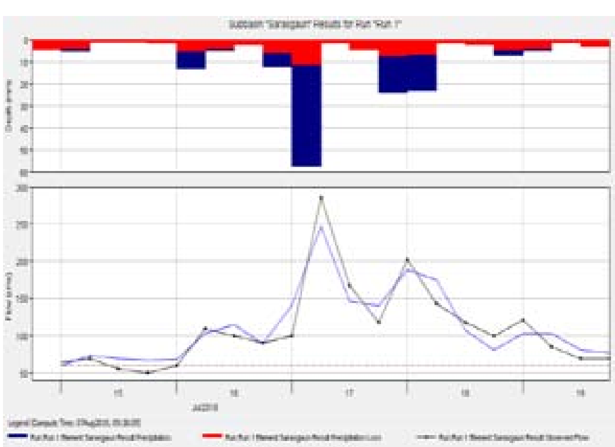


Fig. 9

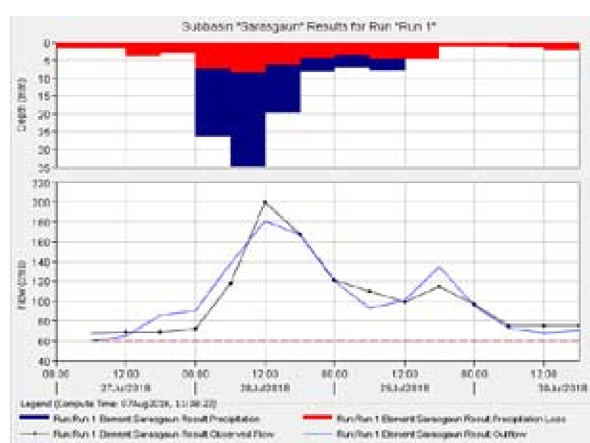


Fig. 10

Figure 9&10 : Hydrographs for event-9 and 10 during validation.

4.4 Modelling of runoff of bhilangana at ghansali

For this catchment hourly rainfall data of three stations namely Bishan, Dhopardhar and Ghansali were used. Thiessen weights of Bishan, Dhopardhar and Ghansali are 0.3, 0.45 and 0.25 respectively. Hourly temperature data of Dhopardhar AWS were used for snowmelt modelling.

The calibration of the parameters in HEC-HMS, i.e. initial loss rate, constant loss rate, lag time, temperature lapse rate and parameters of different elevation bands etc. has been done These calibrated parameters have been obtained after a number of iterations to maximize the efficiency. Based on these calibrated parameters, separate average parameters of July and August were obtained and using these averaged parameters different events of 2016 and 2017 were validated. The plots of two typical events in calibration and validation are shown in Fig. 11 to 14. It can be seen from these figures that during calibration and validation the peak flows are matching quite closely. The NSE of eight events of 2016 and 2017 during calibration and validation are given in Table 2. It may be seen from this table that average, maximum and minimum NSE of all the eight events during calibration are 83.8%, 93.2% and 56.4% respectively. During validation, using the average parameters the same get deteriorated to 70.5%, 90.4% and 45.1% respectively. The validation of the model has also been done for two new storms of July 2018. The NSE of these two events no. 9 and 10 are 83.6% and 79.2% respectively. From Fig 11&12 and 13&14, it can be seen that peaks of the flows are matching closely.

Table 2 : Nash-Sutcliffe efficiency for Bhilangana sub-catchment using HEC-HMS event-based modelling.

EVENT NO	EFFICIENCY	
	Calibration	Validation
1	81.9	76.6
2	91.4	89.5
3	88.2	49.2
4	91.0	90.4
5	81.8	78.6
6	93.2	49.4
7	56.4	45.1
8	86.3	85.2
9	-	83.6
10	-	79.2

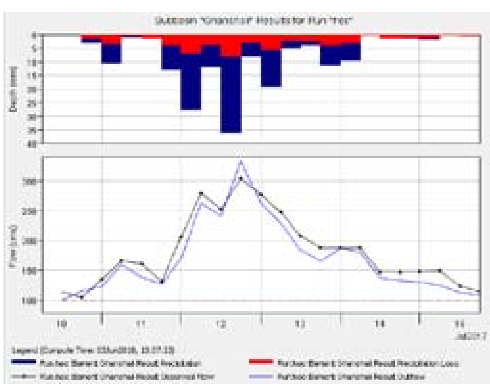


Fig. 11

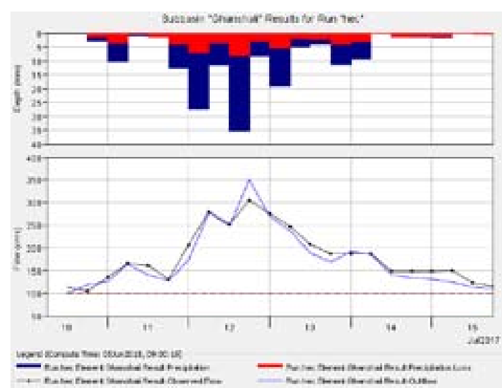


Fig. 12

Figure 11&12 : Hydrographs for event-4 during calibration and validation

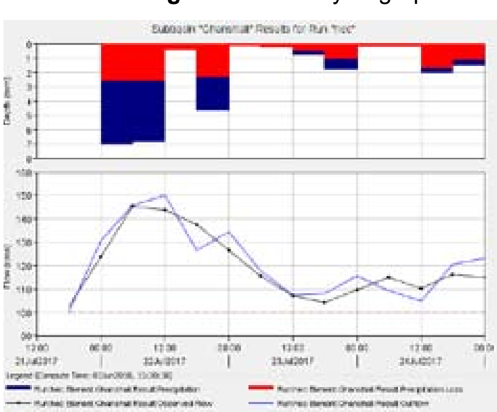


Fig. 13

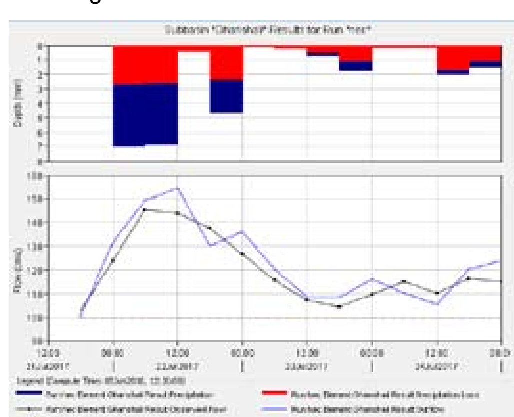


Fig. 14

Figure 12&13 : Hydrographs for event-5, during calibration and validation

Fig. 15

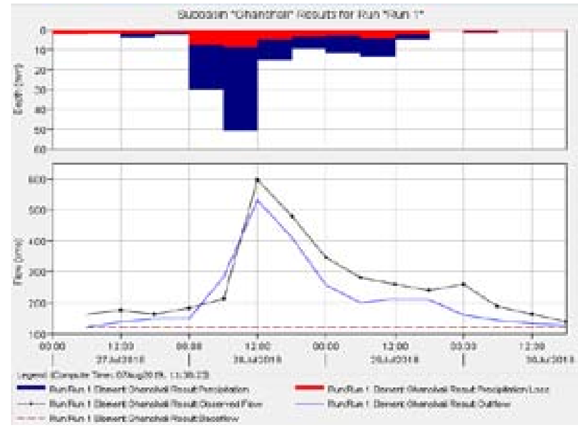


Fig. 16

Figure 15&16 : Hydrographs for event-9 and 10 during validation.

4.5 Modelling of ten events of intermediate catchment using HEC-HMS

For this sub-catchment hourly rainfall data of Dharasu, Lambgaon, Tehri and Ghansali have been used. Thiessen weights of Dharasu, Lambgaon, Tehri and Ghansali, are 0.25, 0.35, .25 and 0.15 respectively. The maximum elevation of this sub-catchment is 2826m hence there is no snowmelt contribution in runoff from this sub-catchment. There is no G&D site is available in this part of catchment, therefore, validation of the flows was done at Tehri dam itself.

4.6 Results of event-based modelling of flows at Tehri dam

The runoff contribution of different segments is routed up to the Tehri dam and added together to compute the Tehri flows. The observed and simulated flows at Tehri using HEC-HMS model for the eight events in calibration and validation are plotted in Fig 17 to 32 are compared on the basis of NSE, the percentage difference in peak discharge and percentage difference in flow volumes entering into the reservoir. The results are presented in Table 3 to 5.

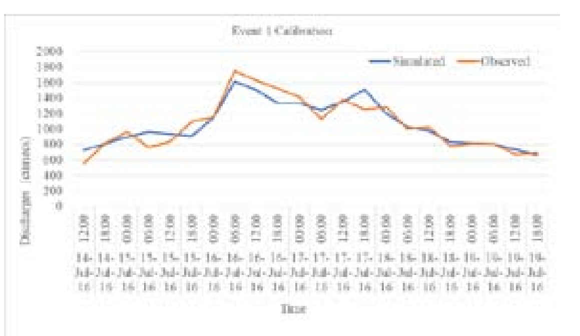


Fig. 17

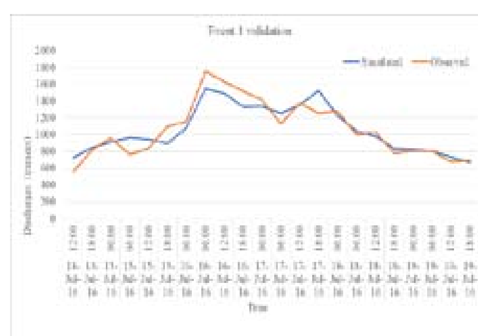


Fig. 18

Figure 17&18 : Observed and simulated flows of Bhagirathi at Tehri for event no.1 from July 14, 2016, to July 19, 2016, during calibration and validation

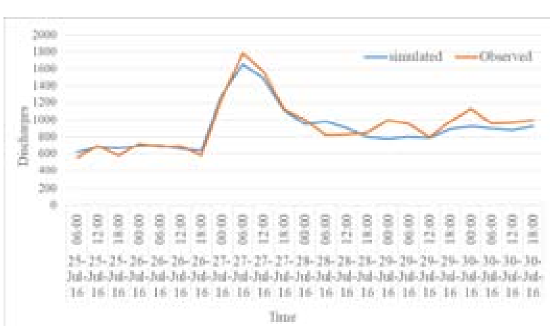


Fig 19

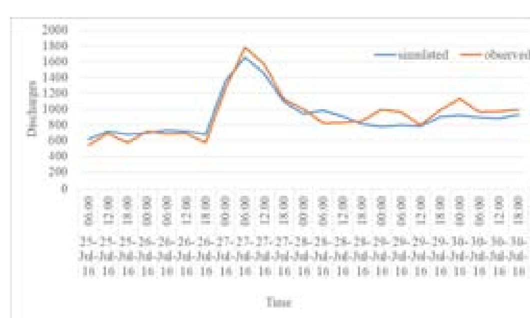
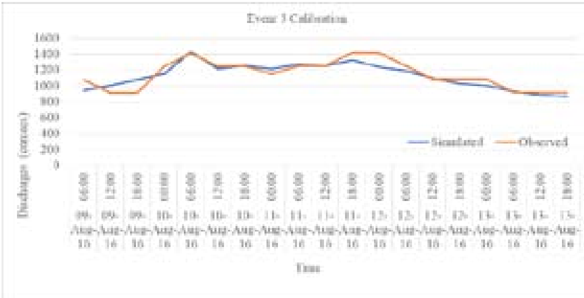


Fig. 20

Figure 19&20 (a) : Observed and simulated flows of Bhagirathi at Tehri for event no 2 from July 25, 2016, to July 30, 2016, during calibration and validation



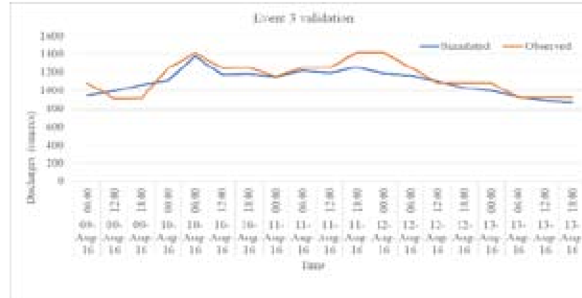


Fig 19 **Fig. 20**

Figure 19&20 (b) : Observed and simulated flows of Bhagirathi at Tehri for event no 3 from August 09, 2016, to Aug 13, 2016, during calibration and validation

The maximum NSE is for the event no 2 during calibration and validation as 90.7% and 89.5% respectively. During calibration the minimum NSE for the event no. 5 is 72.6%. During validation, the minimum efficiency is for event no.7 as 56%. It may be seen from Table 4 that the percentage difference in observed and simulated peak flows varies from -11.6% to +9.6%, which is considered to be satisfactory. Table 5 shows that the percentage differences in flood volumes vary from -4.34% to +7.4%, which may also be considered as satisfactory. However, NSE's are not satisfactory for some of the events.

The validation of the model has also been done for two new storm events of July 2018. The NSE of these two events no. 9 are 10 during validation are 85.3% and 85.1% respectively. The percentage volume entered in to the reservoir for these two events are 0.31% and -8.89% respectively. Fig 31 shows that peaks of simulated flows are under estimated by the model in the event no 9, while the overall flows were under predicted by the model during the validation of the event no 10 as shown in Fig 32.

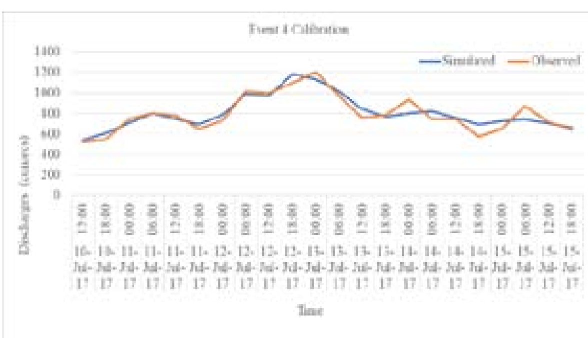
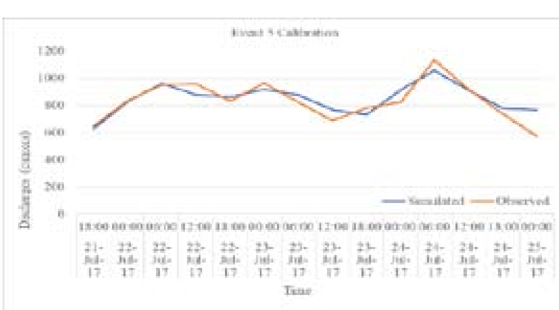


Fig. 21 **Fig. 22**

Figure 21&22 : Observed and simulated flows of Bhagirathi at Tehri for event no. 4 from July 10, 2017, to July 15, 2017, during calibration and validation



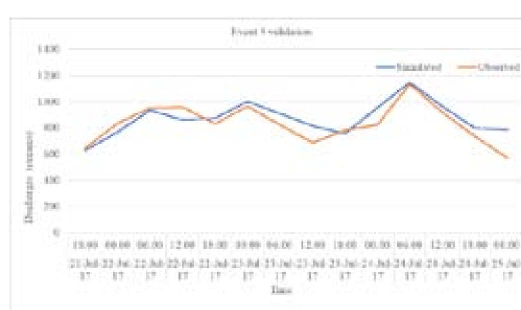


Fig. 23 **Fig. 24**

Figure 23&24 : Observed and simulated flows of Bhagirathi at Tehri for event no. 5 from July 22, 2017, to July 25, 2017, during calibration and validation.

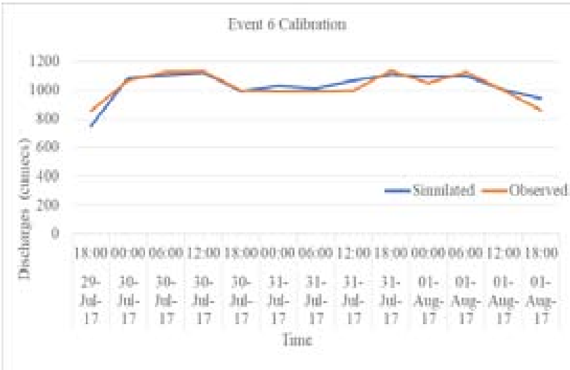


Fig. 25

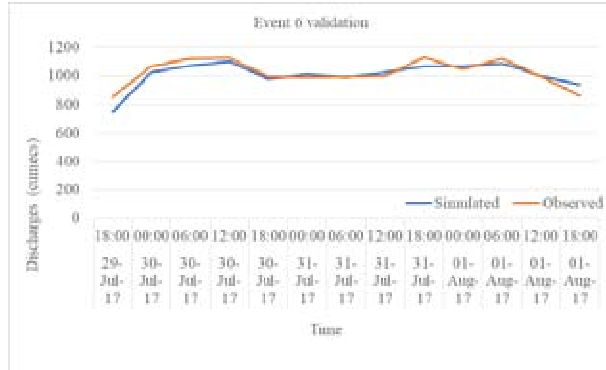


Fig. 26

Figure 25&26 : Observed and simulated flows of Bhagirathi at Tehri for event no. 6 from July 29, 2017, to Aug 01, 2017 during calibration and validation.

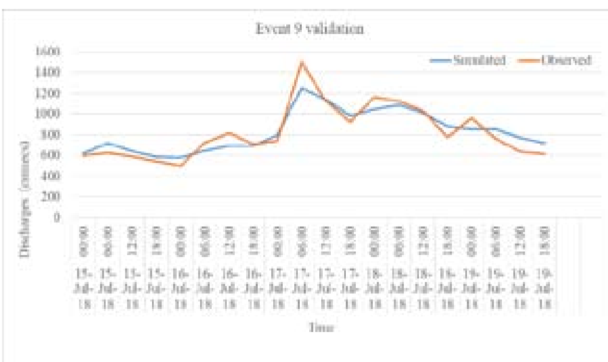


Fig. 27

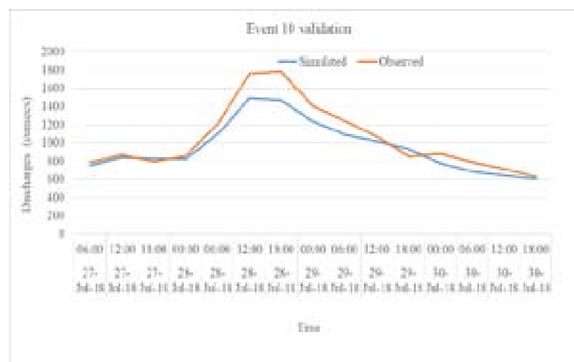


Fig. 28

Figure 27&28 : Observed and simulated flows of Bhagirathi at Tehri for event no. 7 from Aug 04, 2017 to Aug 06, 2017 during calibration and validation

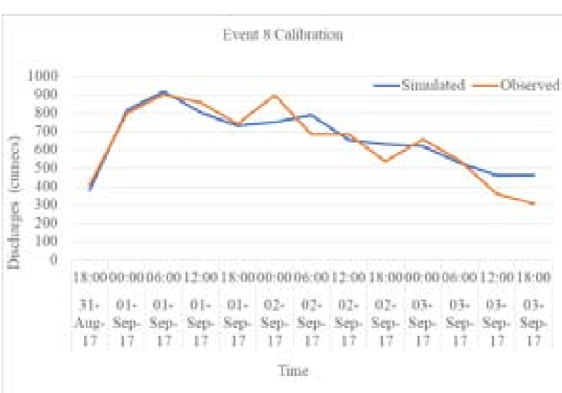


Fig. 29

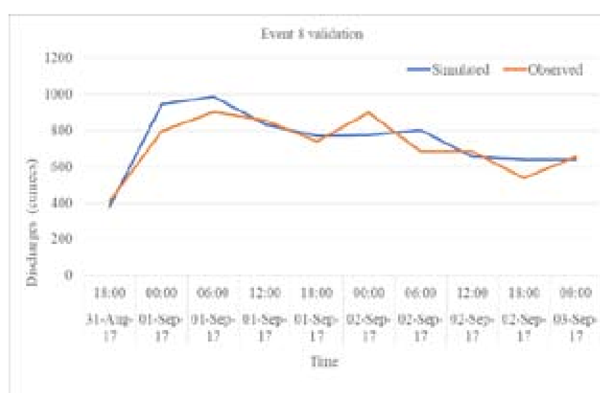


Fig. 30

Figure 29&30 : Observed and simulated flows of Bhagirathi at Tehri for event no.8 from Aug 31, 2017, to Sep 03, 2017 during calibration and validation

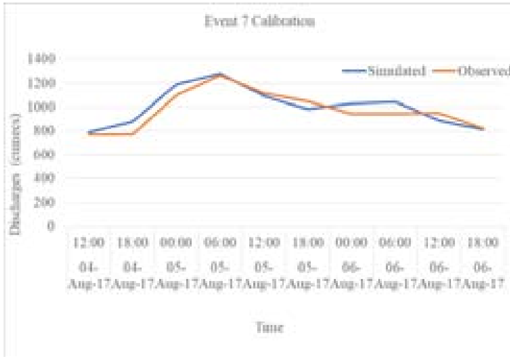


Fig. 31

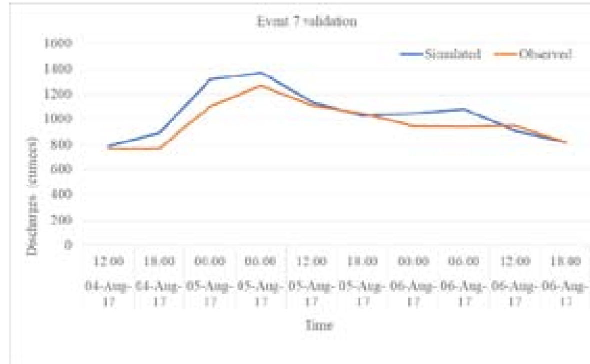


Fig. 32

Figure 31&32 : Observed and simulated flows of Bhagirathi at Tehri for event no.9 and 10 from July 15, 2018, to July 20, 2018 during validation.

Table 3 : Nash-Sutcliffe efficiency for Tehri catchment during event-based modelling.

Event No.	Efficiency in %	
	Calibration	Validation
1	87.7	85.3
2	90.7	89.5
3	77.1	67.0
4	85.8	82.8
5	72.6	60.5
6	73.4	72.3
7	80.4	56.0
8	83.1	77.9
9	-	85.3
10	-	85.1

Table 4 : Observed and computed peak discharges at Tehri.

Event No.	Peak Discharge observed (cumecs)	Peak Discharge computed (cumecs)	Difference in peak discharge (cumecs)	Percentage difference
1	1753.6	1550.6	-203	-11.6
2	1783.0	1634.0	149.0	8.36
3	1420.6	1378.9	-41.7	-2.9
4	1206.8	1155.5	-51.3	-4.3
5	1136	1147.1	11.1	1.0
6	1132.4	1104.8	-27.6	-2.4
7	1267.3	1371.6	104.3	8.2
8	902.7	989.3	86.6	9.6
9	1501.2	1253.6	-247.6	-16.49
10	1786.9	1490.3	-296.6	-16.60

Table 5 : Observed and computed volume entered in to the reservoir.

Event No	Observed volume entered in Tehri reservoir (MCM)	Modelled volume entered in Tehri reservoir (MCM)	Difference in volume (MCM)	Percentage difference
1	491.23	489.42	-1.81	-0.37
2	452.8	439.16	-13.64	-3.01
3	450.64	431.08	-19.56	-4.34
4	365.77	363.07	-2.7	-0.74
5	239.15	248.46	9.31	3.89
6	269.25	265.4	-3.85	-1.43
7	192.9	207.17	14.27	7.40
8	173.28	182.71	9.43	5.44
9	342.652	343.698	1.046	0.31
10	322.96	294.237	-28.723	-8.89

5. CONCLUSIONS AND RECOMMENDATIONS

ATI Cold/Melt rate functions and Index (mm) value are highly sensitive to the model. While, the first one is important to run the model the second one is important to simulate the model. Runoff estimation is mandatory to sustain the water resources. Event-based rainfall-runoff modelling using HEC-HMS model gives good result for Tehri dam catchment. Sufficient warning time may be available by using this event based model to evacuate the flood prone area of Rishikesh and Haridwar.

REFERENCES

Gautam, N. P. (2014). Flow routing with Semi-distributed hydrological model HEC- HMS in case of Narayani River Basin. Journal of the Institute of Engineering, 10(1), 45–58.

Prajapati, R. N. (2015). Delineation of Run of River Hydropower Potential of Karnali Basin- Nepal Using GIS and HEC-HMS. European Journal of Advances in Engineering and Technology, 2(1), 50–54.

Khatri, H.B. (2017), ‘Comparative Evaluation of HEC-HMS and SRM Model in Simulating Rainfall-Runoff Behavior of Budhigandaki Catchment’, M.Tech. Thesis, Department of Hydrology, Indian Institute of Technology Roorkee.

Sah, S.K. (2018). Geomorphological analysis and Hydrological Modelling of Three Himalayan Catchments of Nepal and India. M.Tech, Thesis, Department of Hydrology, Indian Institute of Technolgy, Roorkee

Seismic Design and Safety Criteria for Tailings Dams : A Comparison with Water Storage Dams

M. Wieland[1]

ABSTRACT

There exist up-to-date seismic design and safety criteria for water storage dams and guidelines for the conceptual design of large dams in seismic regions, published by the International Commission on Large Dams (ICOLD). Tailings dams store waste from mining activities, which is often classified as hazardous. They are mainly embankment dams, and the way of construction differs from that of water dams. Water dams are usually completed before the reservoir is filled, whereas in tailings dams the construction of the dam and the filling with the waste material proceed stepwise at the same time, leaving an adequate freeboard to protect the tailings dam from overtopping. Thus, because of the incremental construction and reservoir filling, embankment dams are built in which consolidated tailings form also part of the embankment. In general modern dams that can resist strong ground shaking are earth core rockfill dams, where seepage through the dam body is controlled by an impervious core, which is protected from internal erosion by filters, Moreover, seepage through the foundation is controlled by a grout curtain or cut-off walls, depending on the type of foundation. Large water dams are usually founded on rock but this may not be the case for smaller embankment dams. If no sediment flushing is provided, the reservoirs formed by water dams will eventually fill up with sediments and their final state may not be too different from that of tailings dams. The difference being in the properties of tailings and in the way these tailings are placed. In water dams there is no control on how the sedimentation process occurs. Most sediment deposition will be during large floods. Both the sediments and tailings materials are assumed to liquefy under strong ground shaking. Therefore, the stored materials are basically liquids during strong earthquakes. If we take this into account, then certain types of tailings dams cannot be safe. Some recent failures of tailings dams in Brazil and Australia have shown that they failed due to static liquefaction. Therefore, it is obvious that they would have also failed under seismic action. Based on this comparison, the seismic safety requirements for tailings and water dams should be the same for the same risk classes of projects. In the case of tailings dams, the hazardous materials remain in the reservoir for hundreds of years and in the case of safety concerns the reservoir cannot be lowered as in the case of water dams, which would allow a fast increase in dam safety. Thus, the seismic safety of tailings dams should be even larger than that of water storage dams. These seismic aspects of water and tailings dams are discussed in the paper.

Keywords *: tailings dam, embankment dam, earthquake safety, seismic design criteria, liquefaction*

1. INTRODUCTION

Storage dams can be classified into water storage dams and tailings dams. In water dams the storage (called reservoir) can be used for water supply, irrigation, power generation, navigation, tourism, fishery and others and the storage may serve as flood protection or for regulating the flow of rivers. There are single-purpose dams, mainly smaller projects, which are used for water supply, irrigation, hydropower generation and flood protection. The large storage dams, however, are mainly multi-purpose projects. Tailings dams are singlepurpose dams and serve for long-term storage of tailings mainly from the mining industry and others. The height of these dams is generally small, but there are tailings dams, which are among the highest dams in a number of countries.

Until March 11, 2011 no people have died from the failure or damage of a large water storage dam due to earthquake. However, during the magnitude 9.0 Tohoku earthquake in Japan in 2011 an 18.5 m high embankment dam failed, and the flood wave created by the release of the reservoir caused the loss of eight lives. A large number of dams have been damaged during recent earthquakes, as, for example, during the May 12, 2008 Wenchuan earthquake in China about 1580 dams and reservoirs were damaged. Most of them were small earth dams for water storage, but also some large dams were damaged.

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The statistics does not look that favorable for tailings dams, as a considerable number of people were killed due to the failure of tailings dams during earthquakes as reported in [1]. Accordingly, there are about 52 tailings dams that have failed during earthquakes. Several tailings dams failed in 1965 during the La Ligua earthquake in Chile. The flow slide caused by the failure of the 35 m high El Soldado tailings dam of the El Cobre Copper Mine killed more than 200 people and 2.3 Mm^3 of liquefied tailings was released catastrophically that flowed 12 km.

The following tailings dam failures have occurred very recently: (i) the instantaneous failure of the Brumadinho tailings dam in Brazil of January 25, 2019 killed 270 people, (ii) the Mariana tailings dam failure of November 5, 2015 in Brazil killed 27 people and 44 Mm^3 of tailings were released polluting a 688 km long stretch of rivers, and (iii) the failure of a tailings dam of the Cadia gold mine in Australia of March 9, 2018. In all three cases the tailings were liquefied and in the damage analysis small earthquakes with magnitudes of less than 3, were mentioned as possible triggers. As any well-designed and constructed dam would be able to survive such small earthquakes undamaged, it must be assumed that these dams were not designed against earthquakes like water dams and must have experienced other safety problems.

Different designs of embankments for tailings dams are used that are not employed in water dams. Some of these designs are less favorable in resisting strong ground shaking than conventional dams for water storage [2]. Another factor is that dam construction is not the core business of mining companies, who are also constructing their own tailings dams.

That tailings dams are different from water storage dams is reflected by the fact that there are different technical committees of the International Commission on Large Dams (ICOLD), which are concerned with the safety of water storage and tailings dams, which, from the point of view of dam safety, is not logical as the same safety standards should apply. However, there are often different government agencies, which are in charge of the safety of these two types of storage dams, using different safety standards.

In terms of dam safety the following qualitative ranking may be established: (i) large dams for hydropower generation (multi-purpose projects), (ii) large irrigation dams and dams for water supply, and (iii) small dams and tailings dams (most tailings dams are small dams). The earthquake safety of tailings dams needs greater attention to bring the seismic standards up to those of large hydropower dams, where the highest standards are used. This will have an effect of the design of tailings dams as some designs are no longer feasible. Moreover, the fact that tailings have to be stored for very long periods of time, calls for even higher seismic safety standards than for water storage dams. This is accepted for nuclear waste storage facilities but must also be implemented in tailings storage facilities. Therefore, it is obvious that earthquake will become the governing load case for long-term storage of tailings even in areas of low to moderate seismicity. This has also been the case for nuclear power plants.

2. MAIN ELEMENTS OF LARGE WATER STORAGE DAMS

A large storage dam consists of a concrete or fill dam with a height exceeding 15 m (definition of large dam according to ICOLD), a grout curtain or cut-off to minimize leakage of water through the dam foundation, a spillway for the safe release of floods, a bottom outlet (or low-level outlets) for lowering the reservoir in emergencies, and a water intake structure to take the water from the reservoir for commercial use or power production. Spillway and low-level outlets are called safety-critical elements.

As tailings dams are generally fill dams with different types of watertight elements, only earthfill or rockfill dams (embankment dams) are discussed in this paper.

If low-level outlets are missing and sediment flushing is not possible, reservoirs are eventually filled up with sediments. Close to the dam the sediment level may reach the lowest levels of the water intakes or the sill of the spillway. In industrialized areas the sediments deposited in the reservoirs may also contain hazardous substances, and therefore sediment flushing would not be allowed today, as, for example, contamination of the sediments with PCBs is not uncommon and has only been realized with the availability of very sensitive measuring equipment. The allowable levels of PCB contamination are also very low. Therefore, such substances are kept in the sediments in the reservoirs and the water dams – in terms of storage of contaminated sediments - may be like tailings dams.

3. SEISMIC DESIGN AND PERFORMANCE CRITERIA FOR LARGE WATER STORAGE DAMS

3.1 Seismic Design Criteria

The seismic design and performance criteria of large dams are given in ICOLD Bulletin 148 on the Selection of Seismic Parameters for Large Dams [3]. Accordingly, the two levels of earthquakes to be considered in the design and safety assessment of large existing dams are as follows:

- 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 [3]. The OBE ground motion parameters are estimated based on a probabilistic seismic hazard analysis. The mean values of the ground motion parameters of the OBE can be taken.

- 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 elements (gates and valves of spillways and bottom outlets, motors, emergency power supply, hydraulic pistons, etc.), which have to be functioning after the SEE in order to control the water level in the reservoir. The SEE ground motion parameters may be obtained from a probabilistic or deterministic seismic hazard analysis [4].

The main issue related to the seismic design criteria, which are specified for three types of dams [3], i.e. extreme or high consequence dams, moderate consequence dams, and low consequence dams, is the risk classification of dams. There are significant differences in the risk classification used in different countries and organizations. If the same dam is, for example, classified as a high risk dam in one country which must resist the ground motion of an earthquake with a recurrence period of 10,000 years [3] and in another country, it is classified as a moderate consequence dam, the recurrence period is reduced to 3000 years or even 1000 years for low consequence dams. Future developments must address this issue for both water storage and tailings dams.

3.2 Seismic Performance Criteria

Today, the seismic performance criteria of dams are given in a rather general way for both the OBE and SEE [4].

The following performance criteria apply for the OBE:

(i) Dam body and foundation: No structural damage in dam is accepted; the safety-critical elements must remain functioning.

(ii) Safety-critical components and equipment (gated spillways, bottom outlets) shall be fully operable after the OBE and therefore should behave elastically during the OBE.

The following performance criteria apply for the SEE:

(i) Dam body and foundation: The reservoir must be retained safely, structural damage (cracks, deformations, leakage etc.) are accepted as long as the stability of the dam is ensured and no large quantities of water are released from the reservoir causing flooding in the downstream region of the dam.

(ii) After the SEE the reservoir level must be controlled and it must be possible to release a moderate flood by the spillway or low-level outlet(s), which must remain functioning.

(iii) After the SEE it should be possible to lower the reservoir for repair of earthquake damage, and/or to increase the safety of a dam, if there are doubts about its static or seismic safety after an earthquake or other incidents.

(iv) Safety-critical components and equipment (gated spillways, bottom outlets) must be fully operable after the SEE. Minor distortions and damage (e.g. leakage of seals of gates) are accepted as long as they have no impact on the proper functioning of the components and equipment. This means that all gates, valves, motors, control units, power supply and emergency power generators for the spillway and low-level outlets must withstand the SEE ground motions and they must be functioning after the SEE, i.e. the equipment shall be properly anchored etc. This is a new requirement, which concerns hydro-mechanical and electro-mechanical engineers, who may not have been fully aware of their importance in the seismic safety of dams.

The OBE performance criteria can be verified by dynamic linear-elastic stress and deformation analyses - usually time history analyses -, and by rigid body sliding (and overturning) stability analyses using the peak acceleration acting in the center of gravity of the sliding mass. The safety criteria are given in terms of allowable stresses, deformation (e.g. crack width) and allowable sliding stability safety factor for the OBE load combination. For the check of the sliding stability, where a safety factor of larger than one is required, a conventional slope stability analysis can be used in which residual strength properties and the peak acceleration acting in the center of gravity of the sliding mass are required as input. The latter is obtained from a dynamic analysis of the dam.

The SEE performance criteria for the dam body will require a nonlinear dynamic analysis, which must all be done in the time domain, requiring the seismic input in the form of acceleration time histories. The main results required for the safety checks are the inelastic deformations of the dam after the earthquake. The basis of the safety checks are the failure modes of embankment and concrete dams as discussed below. The main structural failure modes can be checked based on dynamic stability analyses of slopes of embankment dams, sliding blocks of concrete dams or wedges in the dam abutments.

3.3 Seismic Failure Modes of Embankment Dams

The main seismic failure modes of embankment dams are as follows :

- Overtopping of rockfill dam due to (i) malfunction or blockage of spillway gates (overtopping will occur after the earthquake), (ii) excessive seismic settlements of embankment dams, causing overtopping, or (iii) mass movements into the reservoir, causing impulse waves and overtopping of the dam crest.
- Internal erosion due to (i) insufficient protection of core of earth core rockfill dams, (ii) sliding movements of slopes or fault movements in the dam footprint that exceed the thickness of the fine sand filter, or (iii) damage of the contact between the core, abutment rock, concrete structures or conduits through the dam body (due to settlements, poor compaction etc.).

For the seismic safety checks, time history analyses have to be carried out, which require the seismic input in form of acceleration time histories. These time histories are not physically correct earthquake records but models of the earthquake ground motion [5]. Using ground motion models will result in a safe dam design. It is important that this is also understood by earth scientists involved in seismic hazard studies for large dams.

4. MAIN ELEMENTS OF TAILINGS DAMS AND LONG-TERM DAM SAFETY ASPECTS

The main difference between tailings and water storage dams is the hazardous material stored by tailings dams. Tailings dams are mainly embankment dams and they are typical for the mining industry. There are different types of sequentially raised tailings dams. The method of construction (upstream, downstream and centerline construction methods) is different from that of water storage dams as the stage-wise construction proceeds normally simultaneously with the impounding of the reservoir with tailings. Therefore, depending on the progress of the mining activities, the design of the tailings dams may be modified during its construction. This is a rare case for water dams, but heightening of water dams is also done.

Moreover, tailings dams are often raised repeatedly throughout their lives, they store a mixture of water and minerals in their reservoirs, and when they are full or mining operations cease they are left in place.

Therefore based on this general discussion, it may be concluded that in terms of the seismic safety, there should be no difference between these two dam types. However, due to the stage-wise construction, the seismic safety must also be checked for critical dam construction stages, as tailings could be released during dam construction.

The main difference from water dams is that tailings dams are single-purpose dams and that the hazardous tailings must be stored safely for very long periods of time, which exceed, for example, the lifespan of water dams. It is expected that well-maintained modern earthfill or rockfill dams could have a lifespan of several centuries. As the storage period of hazardous tailings could be "infinite" if the hazardous materials remain unchanged, earthfill or rockfill dams are most suitable for long-lasting tailings dams. Therefore, as the lifespan depends on maintenance and compliance of the dam with current safety criteria, it is required that "someone" takes care of tailings dams when, e.g., mining activities have ceased. This is a challenge for the definition of the recurrence period of the SEE ground motion, if a probabilistic seismic hazard analysis is carried out. In water dams a return period of 10,000 years has been recommended[3,4]. But for tailings dams, if we assume a probability of exceedance of the ground motion of 10% in 10,000 years, then we will arrive at a return period of the order of 100,000 years or more. This has an effect on the dam safety, if probabilistic safety analyses are carried out. However, in water dams, the concept of the ground motion from the worst-case earthquake scenario still holds, which is questioned by people doing probabilistic safety analyses as the worst-case scenario is not related to any return period. In a deterministic seismic analysis, the worst-case earthquake ground motion is the same for the critical construction stages and the ultimate storage phase. Therefore, using the deterministic worst-case earthquake scenario concept, it would be straightforward to confirm the seismic safety of tailings dams during the very long storage phase. In a probabilistic safety analysis, fragility or vulnerability curves of the tailings dams would be required, which may only be feasible for long levee-type embankments of small height.

As we cannot assume that the safety of a tailings dam (or any other type of structure) will remain unchanged during its very long service life. Therefore, for tailings dams it is proposed to review the seismic safety periodically like in water dams, i.e. every five years. When we talk about earthquake safety then we talk about the technical safety of the project and the safety of the people, who would be endangered when the tailings were released catastrophically. Another aspect is environmental safety, which is subsidiary to technical safety of the dam. Sometimes, because the environmental safety criteria are getting stricter and stricter, the technical safety is given less attention, which would be a wrong development. But this may happen as there are usually different government agencies in charge of the safety of tailings and water dams.

In general, tailings dams do not have low-level outlets and no grout curtain or cutoff walls in the foundation. Watertightness may be provided by special types of (flexible) watertight linings of the storage area. Similar linings are also provided in some water storage projects.

5. SEISMIC ANALYSIS OF TAILINGS DAMS

Depending on the risk classification of tailings dams, different methods of seismic analyses must be employed. For small embankment dams the simplified deformation analysis proposed by Bray et al. [6] may be used.

For large dams or dams with liquefiable soils or foundation materials, a dynamic analysis is required. The seismic input for the dynamic analysis of the dam-tailings storage-foundation system must be provided in the form of acceleration time histories, which represent models of the earthquake ground shaking rather than real ground accelerations [5]. This is an important aspect in practical problems as for seismic safety checks recorded acceleration time histories are only used in exceptional cases. The inelastic seismic analyses are carried out using direct time integration methods.

The use of the simple pseudo-static analysis method is outdated and shall no longer be used [7]. This is not new, as following the observations made during the 1971 San Fernando earthquake in California, it has become clear that with the pseudo-static analysis the behavior of the failed San Fernando dam, which experienced liquefaction, could not have been predicted. Although, the limitations of the pseudo-static method have been known for almost 50 years, this method is still used by some engineers and organizations, even in countries of high seismicity. This method is still defended by people and countries, who like the method! Eventually, proper analysis methods must be used everywhere.

6. CONCLUSIONS

Based on the comparison of the seismic design and safety aspects of water storage and tailings dams, the following conclusions may be drawn:

1. Most tailings dams are fill dams. Several standard dam designs and construction methods used for tailings dams are not used for water storage dams. These dams are less costly than water dams, but the fact that these designs are not used for water dams shows that they may be less safe.
2. The seismic design and safety criteria of tailings dams and water dams must be the same during the operation phase of the projects, if they belong to the same risk class.
3. Tailings must be stored safely for many centuries after ending the mining operation etc. This calls for higher seismic safety standards if probabilistic safety concepts are used. In a probabilistic seismic hazard analysis the acceptance levels may be defined similar to those used in seismic building codes, i.e. a probability of exceedance of the ground motion parameters of 10% during the lifespan of the project, which for the long-term storage may exceed 10,000 years, i.e. this will result in return periods of 100,000 years.
4. To improve the long-term seismic safety, the water table in the tailings must be lowered. However, in low permeability tailings such processes may take a very long time or it may not be possible to lower the water table, therefore, the tailings may be liquefied due to strong ground shaking, even centuries after terminating mining operation.
5. To keep the tailings dams safe, they must be maintained after closure of mining operations. Periodic seismic safety assessments are required. Unlike water dams, where the reservoir level can be lowered to improve the safety of the dam and the safety of the people living in the downstream flood plain, this is more difficult and very costly for tailings if they have to be re-excavated or the dam has to be strengthened.
6. The seismic safety check of tailings dams with the pseudo-static analysis method is an outdated concept. For small dams empirical relations published in the literature may be used to estimate the inelastic seismic deformations; however, for larger dams, dynamic analyses have to be carried out, using acceleration time histories as input.
7. It is important to note that the seismic hazard is a multi-hazard, which, besides ground shaking, includes mass movements into the storage facilities, liquefaction of soils and tailings, and ground deformations, which must be taken into account in the seismic design and safety assessment of the tailings dams [8].
8. The risk classification of both water storage and tailings dams, which governs the seismic design criteria, is ambiguous as in different countries and organisations different classifications are used. Therefore, for the same dam different seismic design and safety criteria may be specified.

REFERENCES

[1] Lyu Z, Chai J, Xu Z, Qin Y, Cao J (2019) A Comprehensive Review on Reasons for Tailings Dam Failures Based on Case Histories (Review Article), Hindawi, Advances in Civil Engineering, Volume 2019, Article ID 4159306, https://doi.org/10.1155/2019/4159306.

[2] ICOLD (1995) Tailings dams and seismicity – Review and recommendations, Bulletin 98, International Commission on Large Dams (ICOLD), Paris.

[3] 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.

[4] Wieland M (2016) Safety aspects of sustainable storage dams and earthquake safety of existing dams, Journal of Engineering, Elsevier, 2016, Vol. 2, Issue (3): 325 -33, DOI: 10.1016/J.ENG.2016.03.011.

[5] Wieland M (2018b) Models of earthquake ground shaking used in seismic design and safety checks of large dams, Int. Journal of Civil Engineering, https://doi.org/10.1007/s40999-018-0339-3, June 2018.

[6] Bray JD, Travasarou T (2007) Simplied Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements. Journal of Geotechnical and Geoenvironmental Engineering, ASCE 133(4), 381–392.

[7] Wieland M (2018) Application of pseudo-static sliding stability analysis in seismic design and safety evaluation of embankment dams, Proc. 16ECEE, Thessaloniki, Greece, June 17-21.

[8] Wieland M (2009) The many features of the seismic hazard in large dam projects and strong motion monitoring of large dams, Proc. 2nd Int. Conf. on Long-term Behaviour of Dams, Graz, Austria, Oct. 12-13, 2009.

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Analysis of Artificial Lake formed on River Phutkal, J&K and Management of Outburst Flood at Nimmo-Bazgo Dam

Balraj Joshi[1], Narendra Kumar[1], Keshav Deshmukh[1], Rajeev Baboota[1] and Bharti Gupta[1]

ABSTRACT

The landslide lakes are temporary lakes in the river valleys formed by landslide debris and commonly form in mountains of high relief and mass movement activity such as Indian Himalayas. Breaching of such temporary lakes with huge amount of accumulated water and sediments can create devastating floods in the downstream areas. On 31 December 2014, a large landslide in the Zanskar Himalayas, India created a 50m high natural blockade on the Phuktal river, a tributary of Zanskar which is further a tributary of Indus river, resulting in formation of around 15 km long impounded lake upstream of blockade. NHPC has a hydroelectric power project, namely Nimmo-Bazgo power station (45 MW) in the downstream on Indus river about 220 km from Phutkal and about 20 km d/s of Indus-Zanskar confluence. After the blockade a study was carried out for possible landslide breach to estimate the flood peak, its travel time and rise in river water level at various locations along the reach upto Nimmo-Bazgo project. The landslide dam finally breached on 7th May 2015 and in this study, a comparison of simulated and actual event parameters have been presented. Results of the study indicate that parameters estimated through hydrodynamic simulation using river cross-sections from open source DEM provided a reasonable assessment of the situation which helped in formulation of effective reservoir operation plan for passing the flood safely in the downstream.

1. INTRODUCTION

The combination of extremely high mountains, high seismic activity, and steep slopes in the Himalayan region causes a wide range of natural hazards, including landslides, flash floods, avalanches etc. Landslide dam lakes are created as a result of a broad range of mass movements in different geomorphologic settings. Dams form most frequently as a result of rock and earth slumps and slides, debris and mudflows, and rock and debris avalanches in areas where narrow river valleys are bordered by steep and rugged mountain slopes. A lake then forms behind the dam as a result of the continuous inflow of water from the river. This type of activity is common in geologically active areas such as the Himalayas. These areas contain abundant landslide source materials such as sheared and fractured bedrock materials. The lakes formed as a result of such damming of the river can breach at timescales varying from days to years after their formation (Li et al., 1986), producing some of the largest known catastrophic floods (O'Connor et al., 2013). The resulting dam geometry and the hydrogeomorphic characteristics of the upstream catchment area are primary factors determining the stability and longevity of landslide dammed lakes.

A large landslide on 31 December 2014 blocked the Phuktal river (a tributary of Zanskar river which is further a tributary of Indus river) in Leh district, Jammu and Kashmir state of India. Blockage of Phuktal river gorge by the landslide created a temporary lake behind the accumulated debris thereby reducing the flow of river in the downstream.

2. STUDY AREA

Leh district is a part of union territory of Ladakh which lies between 320 17'N to 36015' N latitude and 750 15' E to 800 30' E longitude and is one of the remotest district in India. It has got land route connectivity only during summer whereas during winter because of heavy snow fall in Zozilla Pass and Rohtang pass, it remain cutoff from rest of the world with only aerial route available as connectivity. The region is bounded in north and east by Tibet and on the north-west by Pakistan. Ladakh is cut diagonally by Indus river forming a huge basin. The Indus River rises from the lofty mountains of Himalayas around Mansarovar Lake in Tibet at an elevation of 5,182 m. The total length of Indus from origin to its outfall in Arabian Sea is 2,880 km, out of which 1,114 km flows through India. It follows a north-westerly course through Tibet and enters the Indian Territory. The main tributaries of Indus are Zanskar, Shyok, Nubra and Hunza. The study area is shown in Figure 1.

1. NHPC Ltd., Faridabad, Haryana, India

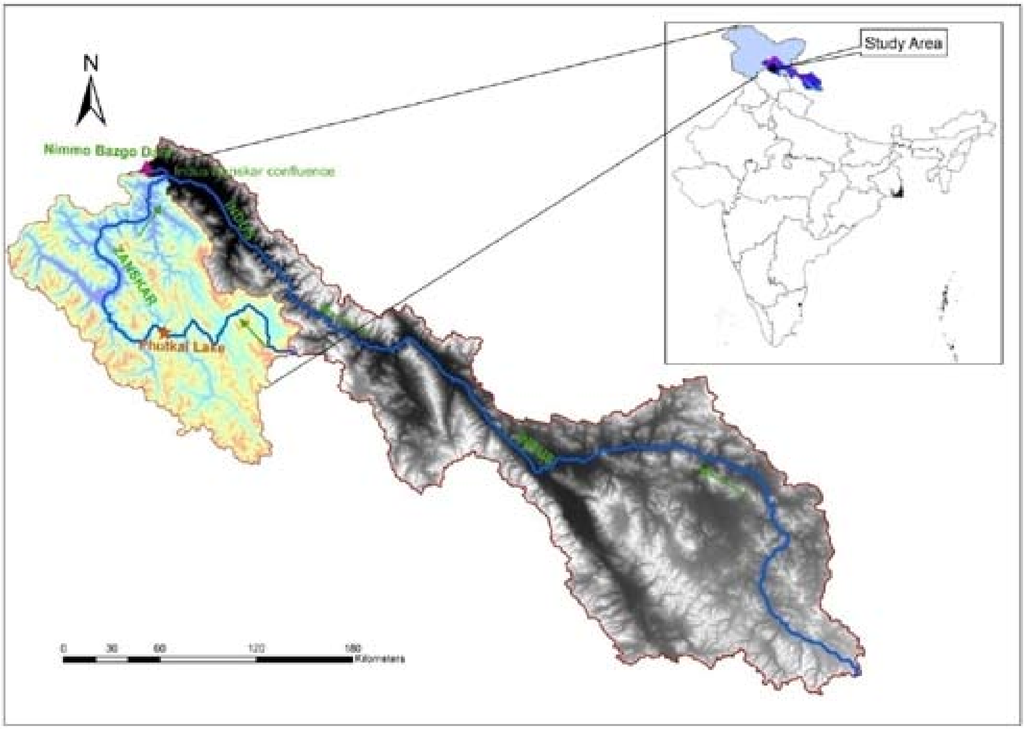

Fig. 1 : Study Area of the Landslide

2.1 Brief Description of the Event

An artificial lake was formed on River Phutkal a tributary of River Zanskar due to landslide about 200 km upstream of Indus-Zanskar confluence probably on 31st Dec 2014. The slide debris thereafter blocked the flow of Phutkal and Zanskar river due to natural damming of the river. The latitude and longitude of land slide blockage is about 330 17' 57" N and 770 17' 23" E respectively.

Discharge of river Phutkal and further of river Indus suddenly decreased on 31 st Dec 2014 and subsequently it came to the notice of Kargil district administration that the flow of river Phutkal has reduced due to the landslide over the river near village Marshum. The location of landslide is shown in Figure 2. A pre and post landslide image as per NRSC satellite data is shown in Figure 3.

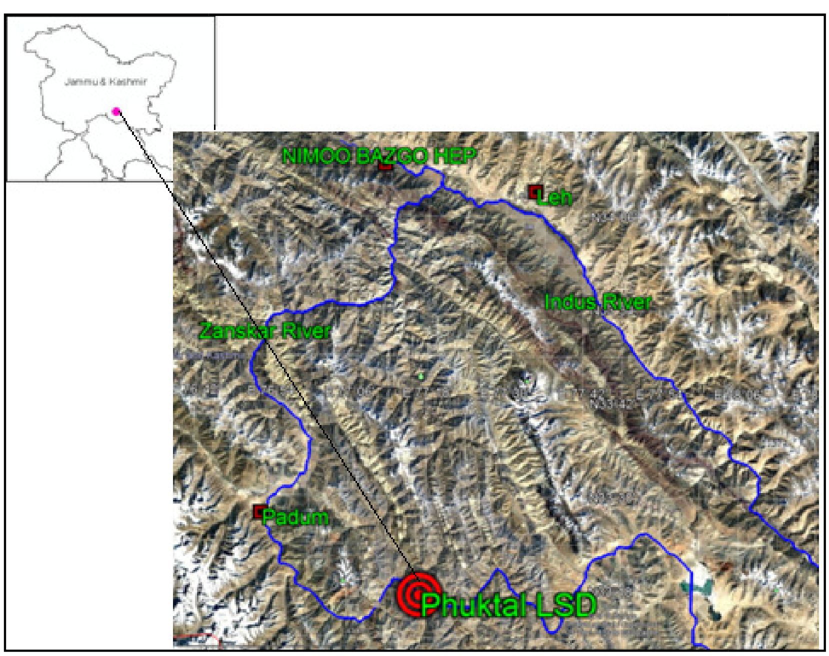

Fig. 2 : Location map of the Landslide

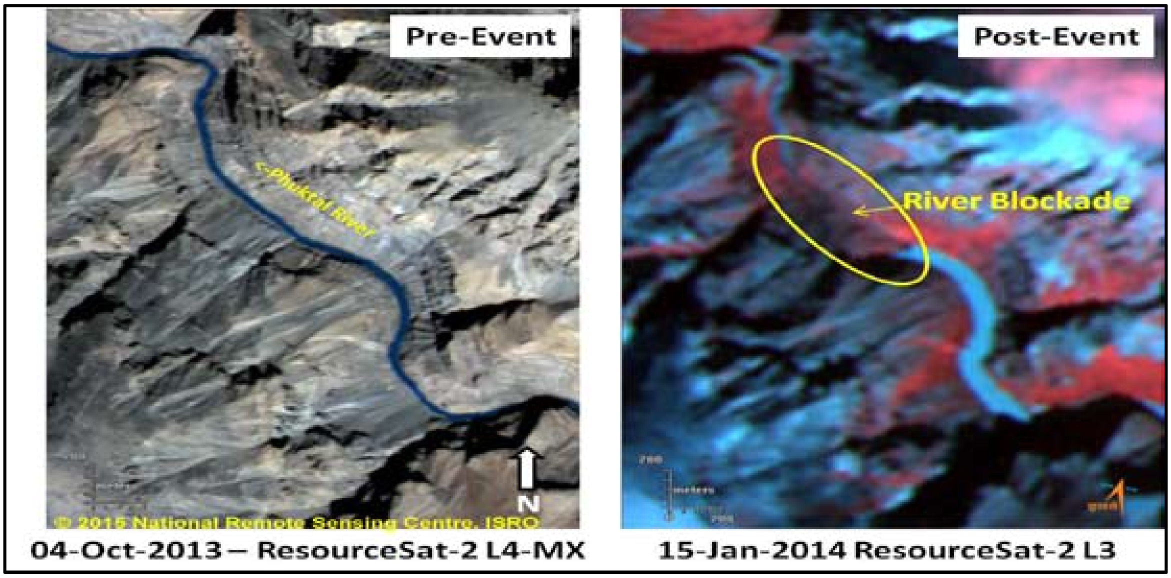

Figure 3 : Pre and post landslide image of the Zanskar river

2.1.1 *Dimensions of Landslide*

Using multi date satellite data, NRSC provided necessary information on the landslide to the concerned government authorities. NRSC analyzed the high resolution (1 m) CARTOSAT-2 data of 20th January 2015 along with the DEM data of CARTOSAT and provided the satellite image of the landslide area. A High resolution satellite image showing detailed view of landslide and water impoundment is shown in Figure 4. The dimensions and some features of the landslide as well as impounded area are mentioned below and shown in Figures-5 (a) to 5(d):

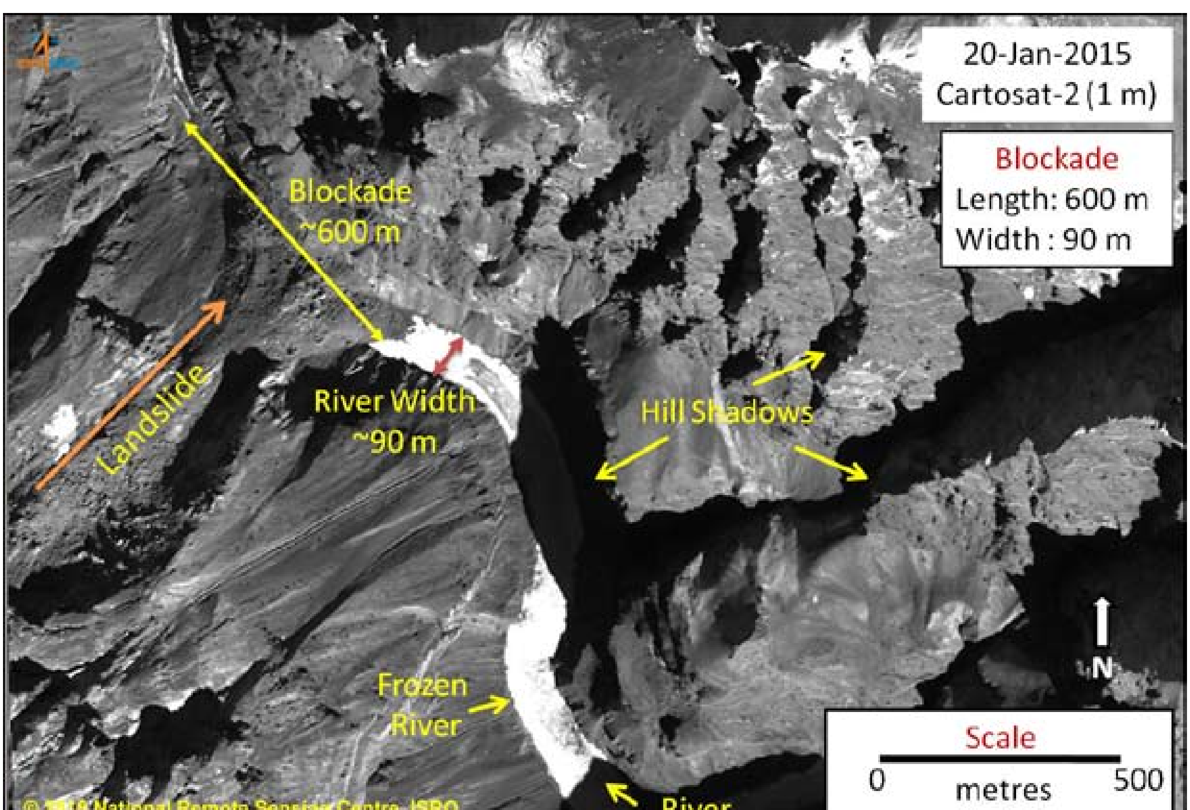

Fig. 4 : Satellite image showing detailed view of Landslide

Fig. 5(a)

Fig.5(b)

Fig. 5(c)

Fig. 5(d)

Figures 5(a) to 5 (d) : Dimensions of the blockade and artificial lake formed

- The landslide scar is observed and the length of the blockade created has a length of about 600 m and width of about 60 m.
- The length of the lake formed due to impoundment of water as per initial information was about 15 km with a surface area of about 55 Ha. Surface of the artificial lake formed was completely frozen.

As per preliminary analysis based on the dimensions of blockade coupled with differential discharge at Nimmo-Bazgo dam site due to blockade, the estimated volume of the artificial lake was worked out as 40 Mcum during Jan 2015.

2.2 Breach Analysis

For the estimated volume of 40 Mcum in Jan 2015, the possible critical landslide breach analysis was generated to estimate the flood peak, its travel time and possible rise in river water level at various locations along the reach. Zanskar river meets Indus river at about 200 km d/s of the location of artificial lake and NHPC has a hydroelectric power project, namely Nimmo-Bazgo power station (45 MW) in the downstream on Indus river about 220 km from Phutkal and about 20 km d/s of Indus-Zanskar confluence. A preliminary study was carried out considering the following input data and limitations:

(i) The cross-sections along Zanskar river have been developed using 30m ASTER DEM from site of landslide upto Indus-Zanskar confluence at an interval of 4 km.

(ii) The breach parameters i.e. breach depth, breach width and breach time have been assumed on basis of some dimensions given by NRSC and also as per committee visit at site and others as used in similar studies. The breach depth, breach width and breach time have been estimated as 40 m, 60 m and 1 hour respectively.

Based on the above data dam break study was carried out to estimate the possible discharge reaching in the downstream reaches and expected water levels corresponding to those discharges using 1-D mathematical model MIKE-11. In this tentative study, it was estimated that in case of outburst of this artificial lake a discharge of about 1460 cumec shall be reaching at Indus-Zanskar confluence (approx near tail end of Nimmo-Bazgo reservoir) after a lag of about 11 hours. Thus it was expected that Nimmo-Bazgo power station may experience a discharge of 1460 cumec in addition to regular discharge coming from river Indus. The approximate depth of water along travel reach would vary from 2.0 m to 15 m depending upon the river geometry along the reach. A plot showing the travel time and possible rise in water level with respect to distance from blockage site is shown in Figure 6.

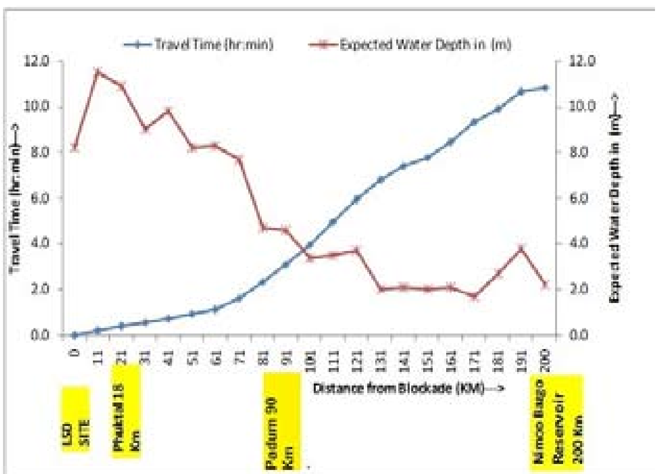

Fig. 6 : Plot showing the travel time and possible rise in water level with respect to distance from blockage site

After two months in Mar 2015, the analysis was revised considering some increase in lake volume as the lake had not breached by that time and the water level behind the lake was increasing. Breach analysis considering the volume of lake as 50 Mcum was carried out and it was estimated that in case of outburst, a discharge of about 2142 cumec shall be reaching at Indus-Zanskar confluence after a lag of about 10 hours.

In the eventually of outburst of this artificial lake, there would have been sudden increase in discharge at Nimmo-Bazgo power station and therefore, suitable reservoir operation guidelines were being followed at the power station. The FRL and MDDL of Nimmo-Bazgo power station are EL 3093.0 m and EL 3090.0 m respectively and the live capacity of the reservoir as per Sep 2014 survey was 9.67 Mcum. The flood hydrograph reaching at Indus-Zanskar confluence due to outburst of artificial lake was routed through the reservoir for passing the flood safely in the downstream. Power station was advised to maintain the reservoir level at MDDL and for carrying out reservoir routing, the flood hydrograph was impinged at MDDL i.e. EL 3090.0 m and the spillway outflow curve was assumed in such a manner so as to contain the maximum water level within FRL i.e. EL 3093.0 m. As a precautionary measure, NHPC along with local administration had been monitoring the water level at various locations enroute Zanskar river, ever since the news of blockage first appeared.

In the month of February, an expert committee having members from CWC, SOI, NHPC, SASE, BRO & local administration was constituted under the aegis of National Disaster Management Authority (NDMA) who decided on a creation of a channel through the landslide blockade to drain out water from the artificial lake in a controlled manner. In March 2015, after a series of blasting and manual digging the team NDMA was able to create a narrow channel which resulted in controlled release of impounded water in the downstream.

However, in Apr 2015, the flow through channel was reduced due to marginal collapse of debris into the created channel.

3. LAKE BURST AND FLOOD MANAGEMENT

During summer, when the temperature started rising to about 15 degree, due to pressure induced by melting of snow, water finally started coming across the channel which was created earlier and on the morning of 7th May (about 5:00 AM) the artificial lake appeared to have busted and water started coming from the lake in an uninterrupted manner. The district administration sounded an alert in the area and villagers were asked to move to safer places in view of the possibility of heavy flow of water from the lake. NHPC also sounded alert in the areas falling in the vicinity of the dam and alerted people living near the banks of the river to move to safer places. Special teams were sent for announcement in nearby downstream area to alert people not to go near the river. A satellite image showing the landslide site before and after lake burst is shown in Figure 7.

3.1 Flood Management at Nimmo-Bazgo dam

The inflow of water in the river was closely monitored at our Dam Control Room round the clock taking information from various locations in Padam, Chilling, Sangam and at dam site area. It was informed that water level at some locations rose upto 10 m due to sudden burst of lake. Accordingly, as a precautionary measure, reservoir level was kept low so as to accommodate the water coming from Zanskar river. The Power station was shut down at 2:00 PM and the complete system was kept on backup. The discharge kept on rising and the water reached Chilling (about 40 km upstream of the dam) at 4 PM where the water depth was about 6 m. Severe damage was caused to bridges and buildings in the upstream of

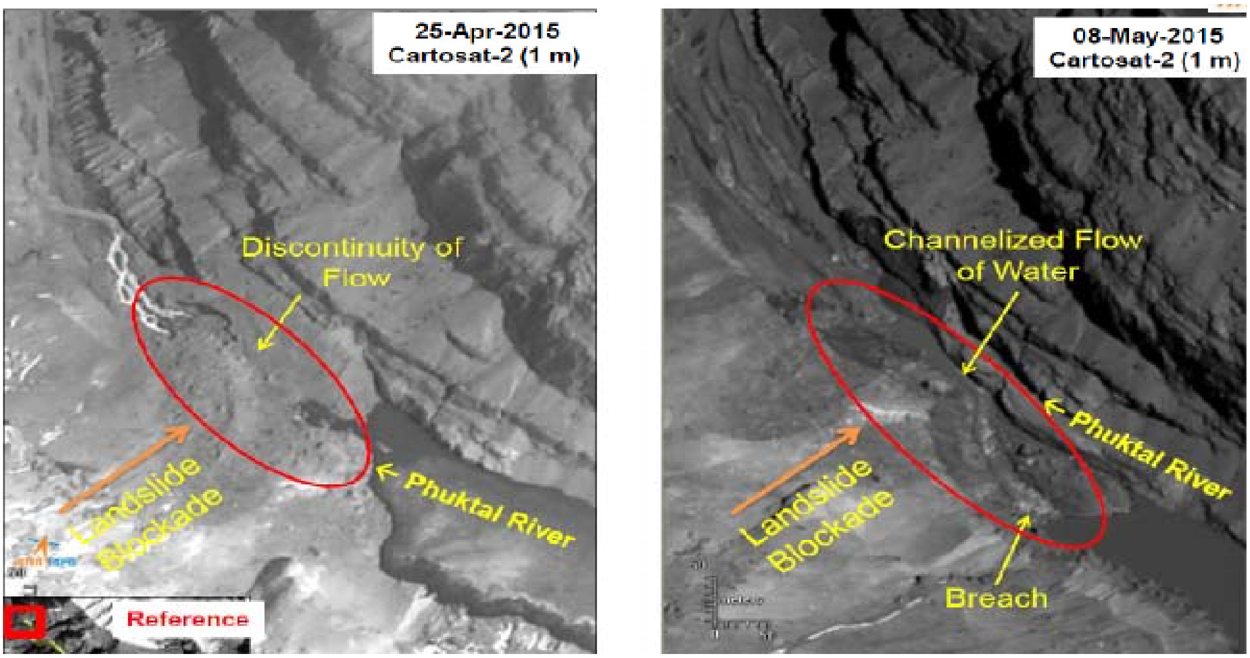

Fig. 7 : Satellite image of landslide location before and after lake burst

Zanskar area and some motorable bridges were also washed away in flash flood.

Keeping in view the estimated volume of the lake and a lead time of about 11 hours, it was decided to lower down the reservoir level at Nimmo-Bazgo dam by 3 m below MDDL, which provided a capacity of about 16 Mcum. The peak inflow of about 2757 cumec received at Nimmo-Bazgo dam was moderated to around 1650 cumec which did not cause much damage in the downstream area. Since our initial estimates were based on volume stored over a period of about one month, the estimated figures of volume and peak discharge were on a little lower side. However, at the time of actual event as the water level was continuing to rise at a much faster pace it was decided during the rising limb of the hydrograph, which was very sharp, to increase the outflow through the dam in comparison to that envisaged earlier, so as to avoid the overtopping thereof. A plot showing the outflow hydrograph, reservoir levels and normal river discharge at Nimmo-Bazgo dam during the flood event is shown below in Figure 8.

As per the above hydrograph, the total amount of water that was released by the artificial lake worked out to be around 49 Mcum upto 8:00 AM on 8th May where as the volume of water released through the dam after impinging of the flood hydrograph till the reservoir level reached upto EL 3092.5 m was about 34.2 Mcum. Timely action by NHPC by regulating the water level and round the control monitoring by our staff at various locations averted the major disaster and saved various villages and downstream areas. The flood volume was absorbed effectively by the reservoir such as the maximum outflow downstream reduced to 1648 cumec.

3.2 Effectiveness of advance disaster management plan at Nimmo Bazgo dam site

- Due to regular monitoring and advance warning systems in place there was no casualty. No loss of human life has been reported.
- Only inevitable damage was reported to low and small bridges and few small buildings near the river banks.
- Nimmo Bazgo dam helped in absorption of flood volume to an extent so as to pass a safe discharge in the downstream areas.

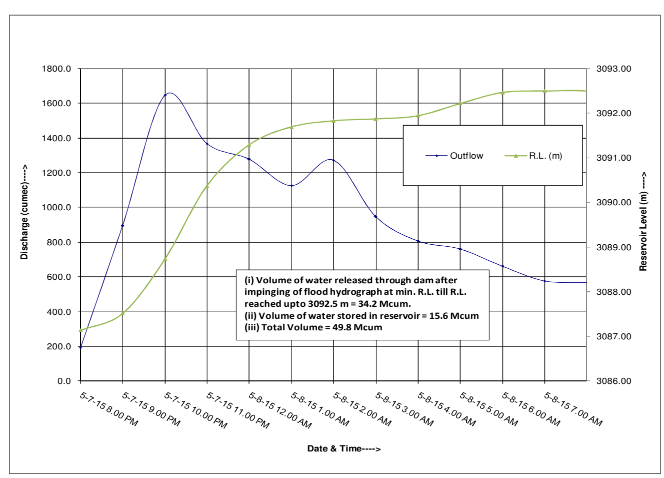

Fig. 8 : Plot of outflow hydrograph, reservoir level and normal river discharge

- It is worthwhile to mention here that during the cloud burst of August 2010 in Leh, a discharge of almost similar magnitude (around 2500 cumec) was observed at Nimmo-Bazgo dam site during its construction and it caused widespread devastation in the areas around the project. The debris and mudflows generated during this cloudburst caused extensive damage to life, property and infrastructure.
- During the lake breach event also, the mudflows and debris flows accumulated boulders, trees as the flow travelled along the Indus river and caused major destruction rather than the flooding itself in the reach between lake breach site and Nimmo-Bazgo dam. Severe damage was reported to bridges and buildings in upstream of dam.
- By absorbing the flood volume at Nimmo-bazgo dam, a major portion of the accompanying debris and mudflow was also accumulated in our reservoir at the cost of loss in reservoir storage capacity, thereby averting a major disaster in the downstream areas and villages.

4. CONCLUSION

Landslide lakes are temporary lakes in the river valleys formed by landslide debris blocking the natural flow of river. Breaching of such temporary lakes with huge amounts of accumulated water and sediments can create devastating floods in the downstream areas. To reduce risk posed by breaching of such landslide dams, it becomes important to monitor the impounded lake continuously and assess parameters such as accumulated volume of the lake and maximum discharge released in the downstream along with its corresponding travel time.

Due to presence of Nimmo-Bazgo dam it was possible to report the sudden decrease in the river flow at dam site and the same was brought to the notice of Kargil district administration and subsequently the occurrence of landslide in upstream reaches of Zanskar river was reported. Remote sensing techniques using satellite images were helpful in monitoring of this landslide dammed lake and estimating the lake width near the blockade, length and area of the impounded lake. Flood peak due to landslide lake burst and its travel timed estimated through 1-D hydrodynamic simulation using river cross-sections from open source DEM provided a reasonable assessment of the situation in case of lake burst which helped in formulation of effective reservoir operation plan for passing the flood safely in the downstream. The estimated peak discharge by NHPC of about 2200 cumec at Nimmo-Bazgo dam site after a lag of about 10 hours was reasonably close to the actual discharge observed at Nimmo-Bazgo dam after the lake burst. Regular monitoring and advance warning systems helped in reporting the breach of landslide dam as sudden increase in water level was reported along the river. Proper co-ordination by the project authorities among different agencies and regular monitoring of the landslide area made it possible to take timely action to avoid any serious disaster. Nimmo-Bazgo dam also accommodated the large inflow released due to lake burst by absorbing about 30% of the flood volume and 40% reduction in flood peak majority of the mud and debris flow which could cause much of the destruction more than that due to flooding. The discharge downstream of the dam was regulated through dam gates in a controlled manner and the river water level was closely monitored so as to avert damages to the life, bridges and houses in downstream areas which are densely populated. Timely action by NHPC by regulating the water level and round the clock monitoring by our staff at various locations averted major disaster and saved villages in the downstream.

5. REFERENCES

- Report on the Phutkal blockage flood and effect on Nimmo-Bazgo power station – report submitted to Indus Commission, MoWR by NHPC Ltd.
- Resource Manual of flash flood risk management, Dec 2012, ICIMOD.
- Press Release- Operation Phutkal, May 2015, National Management Disaster Authority.
- Mass movement events in the Himalaya: The impact of landslides on Ladakh, India, Sian Hodgkins, Geology for Global development.

Tehri Dam – A Savior from Climate Change Led Extreme Events

Atul Singh[1], Muhar Mani[2] and R.K. Vishnoi[3]

ABSTRACT

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

1. CONTEXT

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

Sudden high-intensity rainfall (exceeding 100mm per hour) over a small area is termed as cloudbursts which mainly depend on geography of the area. Himalayan region is prone to rapidly changing weather at micro levels due to its topography, geology, tectonic activities and ecological fragility. It is being reported by scientists that cloudburst-like events in the Himalayas saw a steep increase from an average of five days per year between 2001 and 2005 to over 15 days per year between 2006 and 2013. While high-intensity rainfall events have increased, there has also been a fall in the annual number of days with rainfall in India. The average number of rain days has fallen from around 80 per year in early 2000s to 65 in the past 10 years. In recent years, anthropogenic factors such as population, deforestation, land-use change and emissions due to urbanization have been implicated in extreme weather events in the Himalayas.

The Intergovernmental Panel on Climate Change says glaciers in the Himalayas are receding faster than in any other mountain range. Glacial lakes formed by melting glaciers are constrained by ice dams. Since the Indian summer monsoon coincides with the melting of glaciers, ice dams are weakened by the additional stress of the monsoons and are prone to bursting. A

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flash flood in Kargil in May 2016 was attributed to this. While global temperature is recorded to have increased by about 0.8°C in recent decades, the increase has been greater in regions at higher altitudes. This is especially ominous considering that mountains are not only affected by climatic patterns but also contribute to the changing climate owing to the enormous deposits of water they hold in the form of glaciers, ice and snow. Nowhere is this situation truer than in the Himalayan-Tibetan massif, the world's highest region, where warming of 0.15-0.6°C per decade has been observed in the past three decades. The warming, according to some scientists, has wreaked havoc on the monsoonal patterns in the Himalayas.

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

2. INTRODUCTION TO TEHRI DAM PROJECT

Tehri dam project (Tehri HPP) is a multipurpose scheme designed for providing water for irrigation and drinking purposes along with generating 1000 MW of peaking power. At Tehri, a 260.5 M high with its crest at EL 839.5m, Earth and Rockfill Dam has been constructed across river Bhagirathi, just downstream of its confluence with river Bhilangana. The gross storage of dam is about 3540MCM at Full Reservoir Level (FRL, EL 830m). The live storage i.e. usable storage between FRL and Minimum Draw Down Level (MDDL, EL 740m) below which no power generation takes place is 2615MCM. The basic purpose of constructing such a big dam at Tehri is to store surplus water of floods during monsoon and thereafter releasing the same during non monsoon for irrigation and drinking purposes through power plant when river flow becomes lean. River Bhagirathi while traversing down joins river Alaknanda at Devprayag after 42 kms and river Ganga is formed. Thereafter, river Ganga traverses down towards Indian Ocean through Gangetic plains having major cities like Rishikesh and Haridwar in Uttarkhand; Kanpur, Allahabad and Varanasi in UP; Patna in Bihar, and Kolkata in West Bengal. So, the consequences of river Ganga floods could be disastrous for millions of people living along the river.

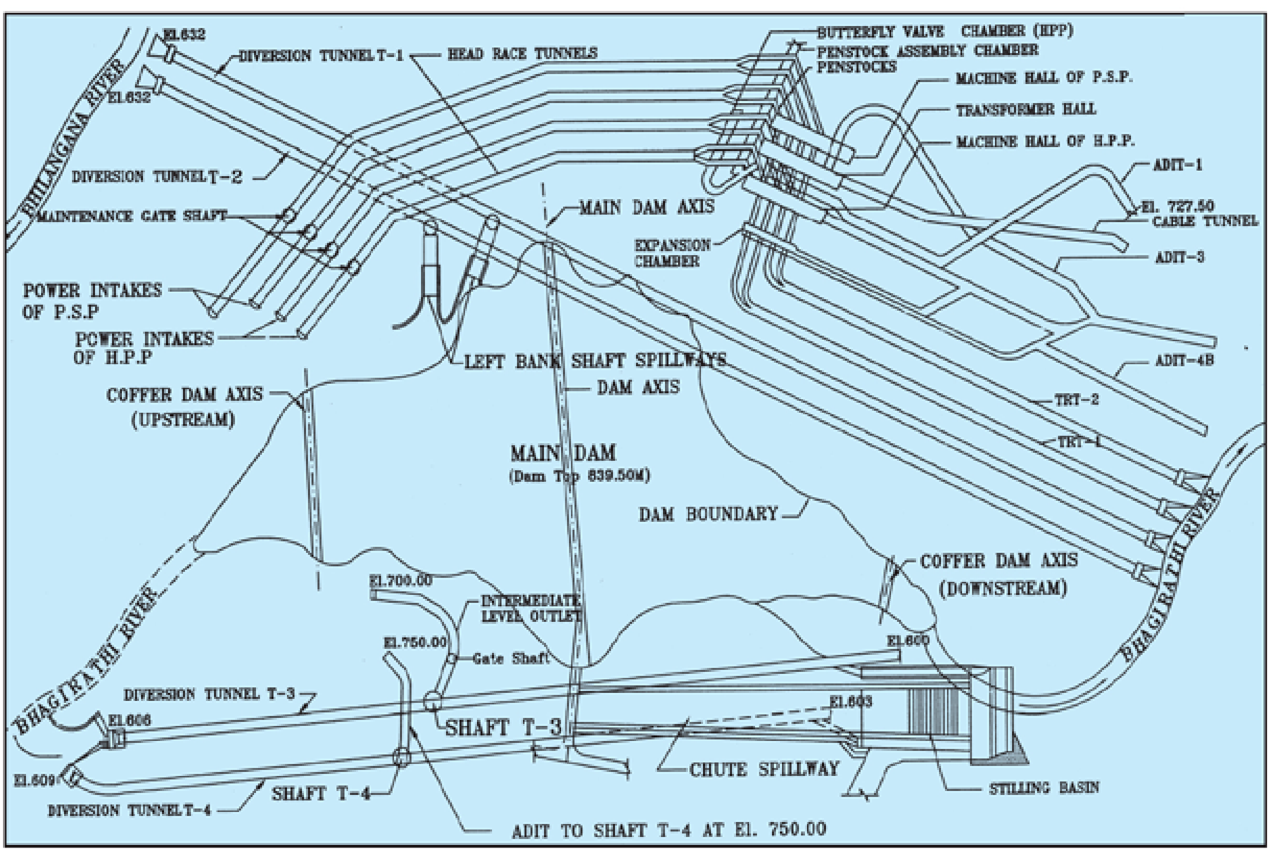


Fig. 1 : Layout of Tehri Dam Project

Fig. 2 : A View of Tehri Dam Project

3. RESERVOIR MANAGEMENT AT TEHRI DAM

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

4. RELEASE OF WATER FOR IRRIGATION, DRINKING AND OTHER PURPOSES

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

5. ARRANGEMENTS FOR FLOOD REGULATION

The spillway system of Tehri dam has been designed to cater a PMF (1 in 10,000 years return period flood) of 15540cumes whereas the peak flood discharge of about 7500 cumecs has been observed so far in river Bhagirathi at Tehri. Its flood regulation system consists of gated chute spillway having 3 bays of 10.5m each with crest at EL 815m, gated left bank shaft spillway (LBSS) having 2 bays of 10.5m each with crest at EL 815m and 2 nos. un-gated right bank shaft spillways (RBSS) with crest at EL 830.2m. The routed flood discharge of complete spillway system (Chute Spillway, LBSS & RBSS) is 13043cumecs by allowing a lift of 5m in reservoir level above FRL (i.e water level rises to MWL EL 835m).

6. OPERATION OF SPILLWAYS FOR PREVENTION OF FLOOD

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

Fig. 3 : Chute (U/s & D/s), Right Bank & Left Bank Shaft Spillways (clockwise from top)

7. PREVENTION OF FLOOD

One of the important roles of Tehri dam is to store flood water in the reservoir and safeguarding the downstream population from its devastating effect. Tehri dam, even in the worst scenario (1 in 10,000 years return period flood) is capable to store the peak of flood and thereafter passing the same to the downstream in a regulated manner when the flood recedes in river Alaknanada to mitigate the impact of flood. Since Tehri dam came into operation, maximum observed outflow has been about 1400 cumecs whereas maximum observed inflow has been about 7500 cumecs. Tehri dam has stored water of almost every flood event so far. It is not out of context to mention here that during the floods of 2010 and 2011, Tehri dam played a crucial role in averting the flood of higher order in the river Ganges by storing high flood inflows of Bhagirathi and Bhilangana and mitigated flood impacts on habitation along river Ganges in Rishikesh and Haridwar towns.

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

In the flood of river Ganga during 16th & 17th June, 2013, discharge at Haridwar rose up to around 15,000cumecs (5,25,000 Cusecs) and water level reached 295.90m in the evening of 17th (i.e. 1.90m above danger mark of 294.00m). In fact, this flood was the contribution of river Alaknanda and tributaries of river Ganga in between Devprayag and Haridwar only as the flood of the order of about 7,500Cumecs (2,62,500Cusecs) peak discharge in river Bhagirathi had been stored in the Tehri reservoir by releasing only 500Cumecs (17,500Cusecs). Had the Bhagirathi flood not been stored in Tehri dam, the peak discharge could have gone up to around 22,000Cumecs (7,70,000Cusecs)

Fig. 4 : Spillways in Operation during 2010 Flood

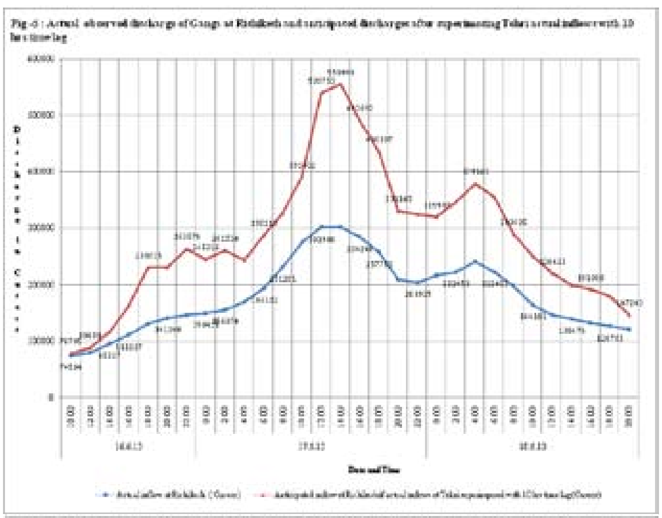
and devastation by this flood, not only at Haridwar but above and below Haridwar also, would have been beyond imagination with anticipated rise of 2.5 to 3.0m in water level above the observed highest level. It is gathered from the available records that June-2013 flood in Ganges would have been of the order or even higher which had happened in the year 1924, had Bhagirathi flood not been hold by Tehri dam.

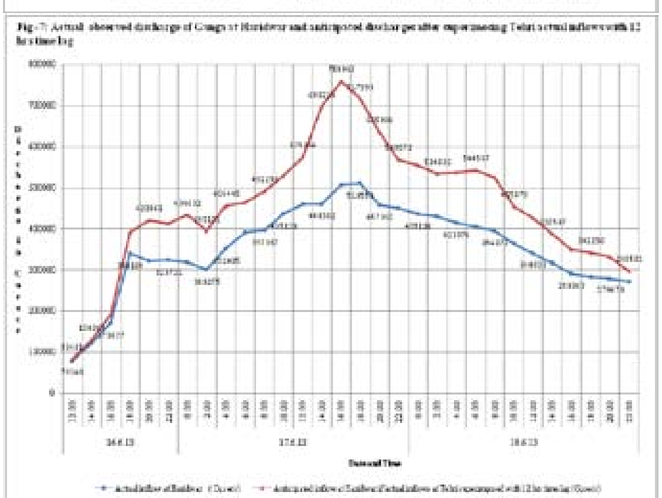
This phenomenon can be easily imagined with the Tehri and non-Tehri scenarios. The actual observed discharge data of Bhagirathi at Tehri and Ganga at Haridwar from 16-18 June has been analyzed to understand this phenomenon. As velocity of water increases with the increase in discharge, the travel time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

Graphs have been plotted to depict the probable impact of Bhgirathi flood on the flood of river Ganga at Rishikesh and Haridwar. In Fig-5, graphs showing inflow and outflow at Tehri have been plotted from 0.00hrs of 16th which depicts the discharge stored in the Tehri reservoir. In Fig-6, graphs showing observed discharge at Rishikesh from 10.00hrs of 16th and anticipated discharge at Rishikesh after superimposing the stored discharge of Bhagirathi at Tehri over the observed discharges of Ganga at Rishikesh with 10hrs time lag have been plotted. The same procedure is adopted for plotting anticipated discharge at Haridwar (Fig.-7) after superimposing the stored discharge of Bhagirathi at Tehri over the observed discharges of Ganga at Haridwar with 12hrs time lag.

8. LEVERAGING TECHNOLOGIES FOR ENSURING SAFETY OF DOWNSTREAM POPULATION

The safety of habitation and infrastructure in the downstream of dam is paramount for which dam owner need to make all out efforts for the safe operation and maintenance of dam. Unsafe operation of dam could be disastrous instead of saving the downstream habitation. Realizing this fact, THDCIL is taking all the measures





suggested by CWC for safety of dam. Real Time Inflow Forecasting System for Tehri dam and Advance Early Warning System for downstream areas are among such measures taken by THDCIL.

8.1 Real Time Inflow Forecasting System

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

8.2 Advance Early Warning System

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

9. CONCLUSION

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

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

REFERENCES

- Report in Down to Earth on 03 July' 2018 - Uttarakhand cloudburst: Urbanisation, Warming continue to intensify the impact
- Report in SANDARP on 11 Dec. 2019- Uttarakhand Cloud Bursts in Monsoon 2019: No Doppler Radars Six Years Since 2013 Disaster

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

Activity of INCOLD

Indian Committee on Large Dams (INCOLD) is involved in to disseminate the information about the latest development of the techniques, new trends and experience gained by the professionals to update the knowledge of dam professionals in the country. It has always been our endeavour to promote accelerated dam engineering development in India through its activities like organization of regular Training programs/ Workshops etc., which has greatly helped involvement of maximum dam professionals with INCOLD.

In this present COVID-19 situation where skill enhancement and training of professional is emerged as an important aspect and a challenge, CBIP and INCOLD propose to organise virtual Workshops for two days durations on the subjects relevant to different aspects of dam safety engineering development.

1. Earthquake and Dam Safety: September 23-24, 2021 (Thursday and Friday)
2. Reservoirs and Seismicity: October 21-22, 2021 (Thursday and Friday)
3. Seismic safety of Existing Dams: November 18-19, 2021 (Thursday and Friday)
4. Seismic Aspect of Dam Design: December 16-17, 2021 (Thursday and Friday)
5. Multiple Hazards Caused by Strong Earthquakes to Dams and Appurtenant Structures: January 20-21, 2022 (Thursday and Friday)

Out of the above 5 workshops, four have been organized to create awareness amongst engineers/designers, scientists, dam professionals, contractors etc about the procedures in working out appropriate seismic design parameters utilizing the State-of-the technology/practices followed globally. In this effort, Indian Committee on Large Dams (INCOLD), Central Board of Irrigation & Power, under the aegis of ICOLD propose to organize the above five workshops on virtual platform. The Virtual Workshops gives an overview on the possible effects of reservoir-triggered seismicity (RTS) on the safety of large dam projects; different seismic hazards affecting storage dams such as fault movements in the footprint of dams and reservoir triggered seismicity, seismic design criteria and multiple hazards caused by strong earthquakes to dams and appurtenant structures. The virtual workshop will offer a good scope for interchange of experiences, to facilitate exposure of state of art technology in all aspects of dam safety and earthquake, especially considering participation of eminent dam expert Dr. Wieland Martin, Chairman, ICOLD Committee on Seismic Aspects of Dam Designs from Switzerland.

About 100 participants are expected from various Govt. as well as private dam/hydropower building agencies, CPSUs, hydropower Corporations etc. to participate in the deliberations of the virtual workshops which will be enrolled on first-cum-first served basis.

Virtual Lecture on
Risk Analysis Applied to Dam Safety Management

14th October, 2021

ABOUT THE PROGRAMME

This course aims at providing basic concepts on the application of risk analysis techniques to dam safety management, presenting available tools for risk analysis and lessons learned from real cases worldwide during the last decade.

The recently published "DRIP Guidelines for assessing and managing risks associated with dams" (Central Water Commission, India, 2019) will be the main technical reference of the program, which will include practical cases and the use of quantitative risk analysis free software.

During the course, the benefits of risk-informed dam safety governance will be exposed and discussed as well as the practical implications of risk outcomes in terms of dam safety investments decision making.

SUB-TOPICS

- Overall view to dam safety risk governance, including worldwide examples.
- Risk framework: screening, qualitative and quantitative phases, as per DRIP Guidelines.
- Risk indicators & prioritization of dam safety investments.
- Risk models: practical cases using iPresas HidSimp software tool
- Risk outcomes and dam safety decision making, including open discussions.

More than 40 professionals from Govt. organisation and private agencies participated in the deliberation of the virtual lecture.

RESOURCE SPEAKER

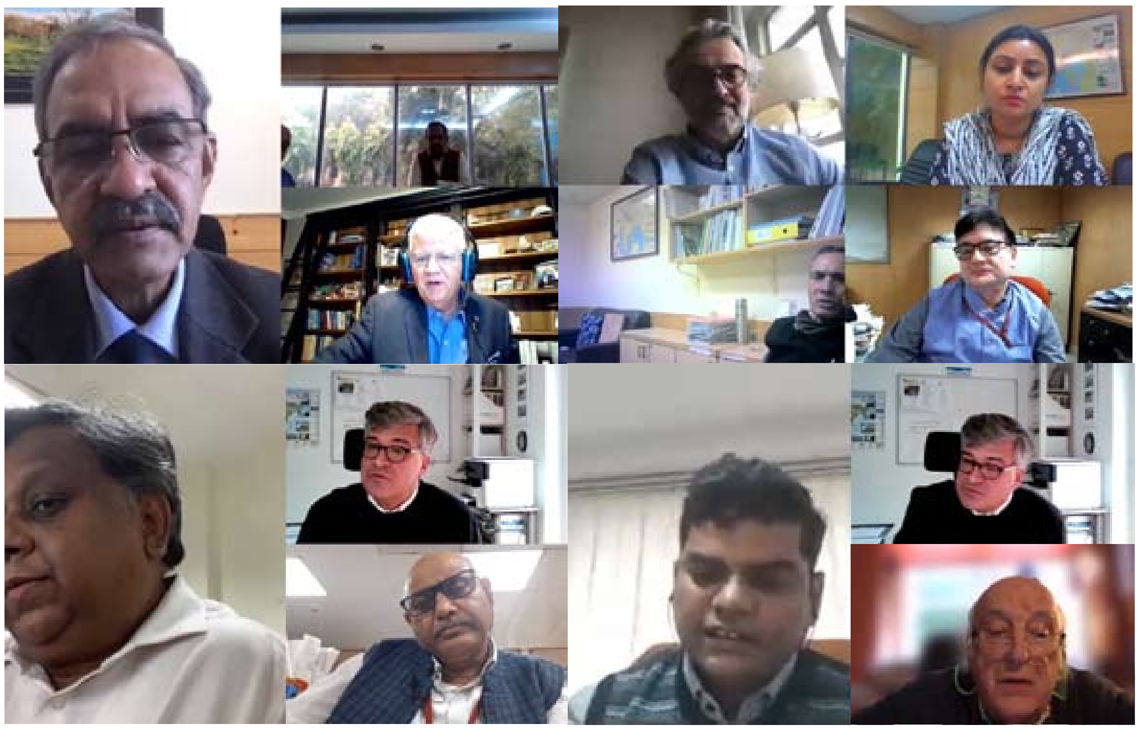
Professor IGNACIO ESCUDER BUENO holds a 6-Year (Bachelor plus Master's) Degree in Civil Engineering from the Universidad Politécnica of Valencia (UPV, Spain), a Master of Science in Civil Engineering from University of Wisconsin – Milwaukee (UWM, USA) and a PhD in Civil Engineering from UPV. He is member of the Spanish Institution of Civil Engineers (Registered Professional Engineer since 1996). He is a University Professor at UPV as well as promoter and associate founder of iPresas (a technology based SPIN-OFF company of UPV). He has been Visiting Professor at University of Maryland (USA, 2014) and Utah State University (USA, 2006) and Teaching Assistant at UWM (USA, 1995-1996).

He is President of SPANCOLD since December 2017. He has been Chairman of the International Committee on Dams Computational Aspects of the International Commission on Large Dams (ICOLD) 2011-2017, and Secretary-General of ICOLD European Club since 2010-2017.

In the last 20 years, he has worked as a consultant in areas related to safety studies, risk analysis and design projects concerning more than 150 dams and hydropower facilities in Europe, Asia and America. He currently serves as member of the Independent Expert Panel for reviewing US Army Corps of Engineers Dam Safety Program and has leaded the team that developed the "Guidelines for Assessing and Managing Risks Associated with Dams" for the Central Water Commision, Government of India, in 2019 (visit www.ipresas.com for updated information).

Virtual Training Programme for NHPC Officers on Roller Compacted Concrete Dams

10th - 12th November, 2021



ABOUT THE PROGRAMME

Indian Committee on Large Dams (INCOLD) is involved in to disseminate the information about the latest development of the techniques, new trends and experience gained by the professionals to update the knowledge of dam professionals in the country. It has always been our endeavour to promote accelerated dam engineering development in India through its activities like organization of regular Training programs/ Workshops etc., which has greatly helped involvement of maximum dam professionals with INCOLD.

In this present COVID-19 situation where skill enhancement and training of professional is emerged as an important aspect and a challenge, INCOLD propose to organise virtual Workshop 3 days (two lectures each day) on Applicability and Feasibility of Roller Compacted Concrete Dams.

RCC dams have the virtues of saving a great deal of concrete, building quickly, bringing project cost down, early completion of the project and so on. Hence, this technique of constructing dams has quickly spread and applied since it came out. Today, there are more than 700 RCC dams in more than 40 countries where great successful experiences have been observed. There appears a need to create awareness about RCC technology including planning, design, construction, equipment, cost aspects, O&M etc. especially highlighting the scope for utilization of bulk quantity of fly ash being produced annually in thermal power stations in the country. The following presentations were made by the resource speaker during the virtual training session:

Day 1 – Wednesday 10th November, 2021

- Brief about the Programme and introduction of the Resource Speaker - *Mr. Devendra Kumar Sharma, INCOLD President & ICOLD Vice President*
- Brief about the topic – Indian Scenario – *Dr. R.K. Gupta, Vice President, INCOLD & Member (Design & Research), Central Water Commission, Govt. of India*
- World Trends in RCC - *Dr. Malcolm Dunstan*
- An introduction to ICOLD Bulletin 177 - *Dr. Quentin Shaw*
- RCC Dam Design – *Dr. Quentin Shaw*

Day 2 – Thursday 11th November, 2021

- RCC Dam Rehabilitation & Raising – *Mr. Michael F. Rogers*
- Materials & mix proportioning - *Mr. Francisco Ortega*

Day 3 – Friday 12th November, 2021

- RCC dam construction – *Mr. Rafael Ibanez de Aldecoa*
- RCC Quality Control – *Mr. Marco Conrad*
- RCC dam performance - *Mr. Tim Dolen*
- RCC construction systems & Automation – *Mr. Christopher Hicks*
- Summary - *Quentin Shaw*

The valuable experience, ideas, technological advancement in Roller Compacted Concrete Dams and interaction with the Indian dam professionals and policy makers during the workshop is useful to create awareness about the various aspects of dam surveillance. It will help INCOLD dam community as well as Indian dam building agencies in further steering the country with more confidence to deal with matters related to construction and maintaining of RCC dams in safe and healthy conditions.

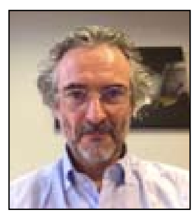
RESOURCE SPEAKERS

Mr. Michael F. Rogers, P.E., P.ENG. is a Principal Civil Engineer and Senior Project Manager at Stantec Consulting Services, Inc. He serves as Stantec's Global Practice Leader for Dams with responsibility for corporate management and quality in the dam practice of dam engineering. His experience includes technical and management participation for more than 200 dam projects worldwide, including dam safety, design, and construction. His experience includes management of multi-disciplinary teams for design of dams and cofferdams with construction, including technical scope direction, senior technical review, consulting review board roles, and project controls oversight. He is a recognized technical expert in the field of dam safety engineering at the domestic and international levels with a specialty in roller-compacted concrete (RCC) structures.

Mr. Rogers currently serves as President of the International Commission on Large Dams (ICOLD, 2018-2022). Previously, he served as ICOLD Vice President (2015-2018) and Chairman of the Technical Committee on Concrete Dams. He also served as President of the United States Society on Dams (USSD) and Chairman of the USSD Technical Committee on Concrete Dams. He is also a past member of ASCE's Hydraulic Structures Committee, including a term as Chairman.

Mr. Rogers has contributed to documentation of the state-of-the-practice through his professional engagement in USSD, ASDSO, and ICOLD for more than 30 years. He has contributed to more than 50 technical papers and technical articles for professional magazines. As Chair of the USSD and ICOLD Technical Committees on Concrete Dams, he contributed to several technical White Papers and ICOLD Bulletins, including the recent ICOLD Bulletin 177 on Roller-Compacted Concrete Dams.

Mr. Francisco Ortega is a Consulting Engineer, specializing in the design and construction of RCC dams. He graduated in Civil Engineering from the Polytechnic University of Madrid, Spain, and throughout his career he has gained large experience as a contractor and as consultant. Since 1999 he has been running Fosce Consulting Engineers based in Germany. He has extensive experience relating to concrete mix design optimization and logistics of RCC production, transportation and placement on major RCC dam projects. Mr Ortega has successfully developed first time in the world the application of Immersion Vibrated RCC (IV-RCC) mixes bringing significant improvements and economy to modern RCC dam projects. He is member of the Spanish and the German National Committees on Large Dams, and during the last 30 years has been directly involved in the design and construction of more than 50 RCC dams throughout the world.



Dr. Quentin Shaw, PhD MSc BSc (Hons) CEng PrEng FICE FSAAE, Quentin is a consulting dam engineer specialising in the design, analysis, materials, construction and safety of concrete and RCC dams. Additionally, he has extensive experience in all dam types. He is currently serving his second term as Chairman of SANCOLD, he is Vice-Chairman of ICOLD's Committee on Concrete Dams and was the lead author for ICOLD Bulletin 177 on RCC dams.

During his 37 year career, Quentin has worked on more than 150 dams in 34 countries, the highest being the 275 m Yusufeli double-curvature concrete arch dam completed in Turkey in 2021, for which he was the chief design engineer. He has worked as an RCC specialist on 18 projects to date, being responsible for more than 9 million m^3 of RCC. Quentin has acted as a specialist and Panel of Experts member on numerous large international projects.

Dr. Quentin has published extensively and has been a keynote speaker and invited presenter at several international symposia. In July 2018, he received the ICOLD Innovation Award for his ground-breaking work on the early thermo-mechanical behaviour of RCC in large dams. He is a Fellow of the Institution of Civil Engineers (UK) and a Fellow of the South African Academy of Engineering.

Dr Malcolm Dunstan obtained his first degree from Birmingham University and his PhD from Surrey University, both in the UK. He is the Chairman of Malcolm Dunstan & Associates. He has been involved with more than 140 RCC dams in 53 different countries during the past

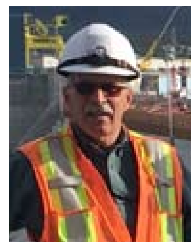
40 years. He is the longest serving member (38 years) on the ICOLD Concrete Committee and was Chairman of the Committees that drafted ICOLD Bulletins 109: Concrete dams – Control and treatment of cracks and 126: Roller-Compacted Concrete dams – State of the art and case histories. He is the author of many papers and maintains a database of all the RCC dams in the World, a summary of which is published annually in the Hydropower & Dams World Atlas and Industry Guide. At the Ottawa ICOLD 2019 Annual Meeting he was awarded an Honorary Membership of ICOLD.

Mr. Christopher Hicks, B.S. Civil Engineering, Colorado State University, Chris has experience at many different levels of Heavy Civil construction, including both trade and managerial positions. Substantial RCC (Roller Compacted Concrete) and hydropower construction experience on projects throughout North America, as well as South and Central America, Africa, Europe, Middle East and Asia, both unit rate as well as EPC method of project delivery. RCC Dam and Hydropower experience with generation capacities in excess of 1,800 megawatts.

Chris has been an integral part of two RCC projects, both planning and on-site construction, that have won ICOLD (International Committee on Large Dams) International Milestone RCC Project Award. This award has been given to a total of 12 projects to date, out of over 600 eligible. Authored several published papers regarding RCC dam construction and is application from a contractor's perspective.

Current role is Managing Director for Simem MegaProjects with duties that include leading the R&D of Industry 4.0 efforts and their application to Dam and Hydropower constructability improvement. Simem MegaProjects offers consultancy services for RCC Dam and Hydro projects to Financers, Owners, Engineers, and Contractors for BIM (Building Information Modeling) and other services to plan, illustrate, qualify, and quantify major aspects of the construction process. These services include BIM applications for construction simulation and modeling, including 4D and 5D scheduling, as well as Virtual and Augmented Reality as well as on site work. Chris is a member of ACI (American Concrete Institute) and USSD (United States Society on Dams).

Mr. Rafael Ibáñez-de-Aldecoa is the Head of Hydraulic, Underground and Environmental Projects of the Technical Department of Dragados Construction Company. He graduated in Civil Engineering from the Polytechnic University of Madrid, Spain. Rafael is Chairman of SPANCOLD's Technical Committee on Concrete Dams and a Member of ICOLD and USSD's Technical Committees on Concrete Dams. He has been involved in the design and construction of more than 40 large hydraulic projects in Europe, Africa, and North, Central and South America, 10 of which have been RCC dams. He has published and presented over 50 papers, most of them in the field of RCC dam design, construction, materials and mixtures.



Mr. Tim Dolen is a Civil Engineer and concrete technologist with Dolen and Associates in Loveland, CO, specializing in mass and roller compacted concrete materials and construction quality control. He is the past chairman of ACI Committee 207 on Mass Concrete and has published many articles on concrete mixture proportioning, RCC, mass concrete, long-term materials properties, and durability of concrete. Tim worked 33 years with the US Bureau of Reclamation concrete laboratory. For the past 10 years, Tim has worked on site for the construction of several RCC dams including the 240 m high Gibe III Dam in Ethiopia, the 1 million cubic yard Trung Son Dam and Hydropower Project in Vietnam, the Shah wa Arus Dam in Afghanistan, and was the RCC construction engineer for the Muskrat Falls RCC Dam in Newfoundland-Labrador, Canada completed in 2018. He is a member of ASTM Committee C 9, Concrete and Aggregates, and led the development of the first international standards for RCC consistency testing and test specimen fabrication.

Dr. Marco Conrad has 22 years of experience in dam engineering. His main activities are in the design, construction planning and supervision, surveillance, condition assessment and rehabilitation of dams and concrete structures for hydropower plants. Marco is specialized in RCC dams with experience in the different RCC philosophies, methodologies and their specifics. He was involved in assignments during design, tender, contractor bidding, construction and operation stages of more than 30 large RCC dams between 40 and >200 m high.

Marco obtained his Civil Engineering M.Sc. from Technical University of Munich / Germany in 1999 and his doctorate in the field of RCC dams from the same university in 2006. He is member of ICOLD's Technical Committee on Concrete Dams since 2007 and serves as its chairman since 2018. He is co-founder of ICOLD's Young Engineers Forum (ICOLD-YEF) and member of the Technical Commission of the Swiss Committee on Dams. Marco works as Principal Dam Engineer and Project Manager with the Switzerland based Hydropower unit of AFRY, a merger of former AF and Pöyry.

Virtual Training Programme on Dam Surveillance

25th & 26th November, 2021

ABOUT THE PROGRAMME

Dam surveillance is one of the cornerstones and the foundation upon which dam safety is built, and its main activities include different types of inspections visual inspections, monitoring with instruments, control of discharge operations and hydro-meteorological networks, plus data recording and dam behaviour monitoring. The goal is to detect any phenomenon that can compromise the structural and operational safety of our dams.

The state-of-the-art of dam surveillance is adequate both in terms of policies and best practice, also in terms of the available technology. However, many dams are not properly inspected and monitored due to multiple reasons. Most dam surveillance systems are developed in the design stage and implemented during construction, though it is necessary to review and improve them on the basis of the observed behaviour and the dam safety operation needs. Visual inspections constitute the most relevant component of dam surveillance, and they allow for a comprehensive qualitative evaluation of the condition of the structure and its surroundings. Dam monitoring is a control action that involves measuring physical parameters to assess their development, either by means of geotechnical and structural monitoring or by other methods, such as topographic monitoring, satellite radars, GPS, geophysics, etc.

To accomplish a thorough and comprehensive assessment of a dam's condition and behavior, dam instrumentation must be oriented to monitor the potential failure modes of the dam. With a good understanding of the dam's potential failure modes, attention can then turn to whether there is evidence of initiation or development of any of the potential failure modes from the surveillance system

SUBTOPICS

- Dam Safety Management and Dam Surveillance
- PFMA and Dam Surveillance
- Dam Surveillance fundamentals
- The power of visual inspections
- Dam Monitoring: sensors, campaigns, software, new technologies
- Data collection, cleaning, validation, and reduction
- Dam Surveillance Data Analysis
- Real case examples

ABOUT THE SPEAKER

Louis Hattingh, M.Eng. is Managing Director of a small consultancy, Hattingh Anderson Associates CC, based in South Africa since January 1999. He joined the Department of Water Affairs of South Africa in 1992 doing dam safety evaluations using risk analysis under the mentorship of Dr Chris Oosthuizen.

During the past 29 years, he has focused on dam safety evaluation and behavioural engineering as well as numerical modelling techniques. He has been a member of Expert Panels for the Safety Evaluations of large dams in Ghana and Lesotho. Recently he has provided technical assistance for dam safety programs in several African countries including Zambia, Ethiopia, Egypt, Sudan and South Sudan.

He is current chairman of the ICOLD Technical Committee on Dam Surveillance as well as a co-opted member of the ICOLD Technical Committee on Dam Safety. He also is a past vice-chairman of SANCOLD (South African National Committee on Large Dams). He has lectured and published widely on dam engineering related topics since the early nineties, authored and co-authored more than 60 papers at international and national Symposia, Conferences and Congresses.

Dr. Manuel G. de Membrillera is currently an Expert Consultant at Typsa, Spain. During his 20 years of experience, he has worked as an international consultant, with holistic and hands-on expertise on dam safety, dam monitoring and surveillance, dam risk analysis, dam construction, new and rehabilitation dam designs, numerical and physical modelling at 287 dams (133 hydropower dams).

He has worked in Spain, Peru, Costa Rica, Colombia, Panama, Guatemala, Ecuador, Uruguay, Brazil, Venezuela, Nicaragua, El Salvador, Algeria, Morocco, Tunisia, Italy, Austria, Poland, Turkey, and Ethiopia. He is Co-Chairman of the ICOLD Technical Committee on Dam Surveillance, and he also serves as a part-time professor at post-graduate and master programs, and as a coach in engineering training and capacity building events. He has been a university/college Professor for 15 years and is the author of 2 full-length books, and co-author of chapters in 2 other books, 7 research journal articles, and 53 conference papers and communications.

More than 70 professionals from Govt. organisation and private agencies participated in the deliberation of the virtual lecture.

INCOLD News

RAJYA SABHA PASSES THE LANDMARK 'DAM SAFETY BILL (2019)'

The Dam Safety Bill Was Passed By Lok Sabha In August, 2019

The safety and security of our dams is a matter of great concern as it is not just about infrastructure but also the question of thousands of lives around and affected by them – Sh. Gajendra Singh Shekhawat

The Rajya Sabha today passed the landmark Dam Safety Bill (2019), paving the way for enactment of the Dam Safety Act in the country. The Union Minister of Jal Shakti Shri Gajendra Singh Shekhawat had introduced the bill in Rajya Sabha on 1st December, 2021. The Dam Safety Bill (2019) was passed by the Lok Sabha on 2nd August 2019.

After China and USA, India is the 3rd largest dam-owning nation in the world. There are around 5,700 large dams in the country, of which about 80% are already over 25 years old. Nearly 227 dams that are over 100 years old are still functional. Although India's track record of dam safety is at par with that of the developed nations, there have been instances of unwarranted dam failures and of poor maintenance issues.

The Dam Safety Bill provides for adequate surveillance, inspection, operation, and maintenance of all the large dams in the country so as to prevent dam failure related disasters. The Bill provides for an institutional mechanism at both Central and State levels to address structural and non-structural measures required for ensuring the safe functioning of dams.

As per the provision of the Bill, a National Committee on Dam Safety (NCDS) will be constituted to help evolve uniform dam safety policies, protocols, and procedures. The Bill also provides for the establishment of a National Dam Safety Authority (NDSA) as a regulatory body for ensuring the nationwide implementation of dam safety policies and standards. At the State level, the Bill prescribes for the constitution of State Committees on Dam Safety (SCDS) and the establishment of the State Dam Safety Organizations (SDSO).

The Dam Safety Bill also addresses in a comprehensive manner, critical concerns related to dam safety on account of emerging climate change related challenges. This Bill provides for regular inspection and hazard classification of dams. It also provides for drawing up of emergency action plans and comprehensive dam safety reviews by an independent panel of experts. There is provision for an emergency flood warning system to address the safety concerns of downstream inhabitants.

Through this Bill the Dam owners are required to provide resources for timely repair and maintenance of the dam structure, along with related machinery.

This Bill looks at Dam Safety holistically and provides for not only structural aspects, but also operational and maintenance efficacy through prescription of strict O & M protocols.

This Bill has penal provisions, involving offences and penalties, for ensuring compliance of the provisions.

Definite timelines have been provided in the Bill for the establishment of a robust institutional framework, with the support of both the Centre and the States. The Bill also focuses on implementation of mandatory dam safety actions by the dam owners within a defined timeline. The passage of this Bill heralds a new era of dam safety and water resources management in India.

FLOODS AND DROUGHT FORECASTING

Central Water Commission (CWC) issues flood forecasts as a non-structural measure of flood management throughout the country. CWC also issues inflow forecasts to identified reservoirs for proper reservoir regulations during floods. Flood forecast formulation methodology used by CWC includes gauge to gauge correlation technique for short range (up to 24 hours) forecasting and numerical modelling technique for 5 days advisory forecasts. Presently, flood forecasts are issued by CWC at 331 stations (132 Inflow Forecast Stations + 199 Level Forecast Stations) in the country as per Standard Operating Procedure.

India Meteorological Department (IMD) supports flood warning services of CWC by providing observed and forecasted rainfall. CWC is working in close association with IMD and State Governments for timely flood forecast whenever the river water levels rise above warning level. In order to meet specific requirements of flood forecasting by CWC, IMD operates Flood Meteorological Offices (FMOs) at fourteen locations viz., Agra, Ahmedabad, Asansol, Bhubaneshwar, Bengaluru, Chennai, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Patna, Srinagar and Thiruvananthapuram. Apart from this, IMD also supports Damodar Valley Corporation (DVC).

In order to cater to the services of hydro-meteorological events occurring in short duration of time, IMD is issuing Flash Flood Guidance (FFG) by which a diagnostic value within a watershed required to produce flooding at the outlet of the catchment is estimated, to support the flood warning services. IMD provides actual and forecast rainfall information in different spatial and temporal scales like districts, States & meteorological subdivisions level and daily, weekly & seasonal scale to the Ministry of Agriculture for drought monitoring.

North Eastern Space Applications Centre (NESAC)/DOS has developed and operationalized Flood Early Warning System (FLEWS) for Assam since 2012 till date, with funding from Assam State Disaster Management Authority (ASDMA).

CWC has taken up the work of Early Flood Warning System in Ganga Basin, including inundation forecast under National Hydrology Project (NHP) covering 11 states of Ganga basin.

Under NHP, National Remote Sensing Centre (NRSC)/ ISRO has developed medium range spatial flood early warning models for Tapi and Godavari river basins, using space based inputs in collaboration with CWC.

POLICY ON FLOOD MANAGEMENT

Flood management schemes are formulated and implemented by concerned State Governments as per their priority. The Union Government supplements the efforts of the States by providing technical guidance and also promotional financial assistance for management of floods in critical areas. Ministry of Jal Shakti with an objective to take cognizance of the existing water situation has come up with National Water Policy (NWP) in the year 2012. For flood control, NWP-2012 has emphasized flood mitigation through structural & structural measures, integrated operation of reservoirs with sound decision support system, rehabilitation of natural drainage system, Integrated farming systems and non-agricultural developments creation of storage projects with dedicated flood storage as the long term solution to the devastating floods occurring every year, etc.

The issue of including water in the concurrent list has been under discussion at various for a. The proposal to bring water in the Union/Concurrent list has earlier been examined by the two Commissions on Centre-State Relations chaired by Justice R.S. Sarkaria and Justice M.M. Punchhi respectively. This proposal did not find favour with either of the two Commissions.

The Government of India has been making continuous efforts to assist the State Government in effective flood management. During XI Plan Government of India had launched Flood Management Programme (FMP) for providing Central Assistance to States for works related to flood management and erosion control which continued during XII Plan and thereafter, as a component of “Flood Management and Border Areas Programme” (FMBAP) for the period from 2017-18 to 2020-21 and later extended to December, 2021. As per the extant guidelines for release of central assistance under FMP, the State Governments which adopt Flood Plain Zoning Bill are given priority over the other States.

DAMS WITHSTAND THE RECENT INTENSE FLOODING IN GERMANY

Large parts of Germany, Belgium and the Netherlands were affected by a severe flood event in mid-July. The following report has been prepared for Hydropower & Dams by Univ-Prof Dr-Ing. Holger Schiit-trumpf, Institute of Hydraulic Engineering and Water Resources Management, RWTH Aachen University, Germany.

The storm, with precipitation levels of up to 200 mm in 48 hours, hit the low mountain regions of North Rhine-Westphalia and Rhineland-Palatinate particularly hard. For comparison, the typical annual mean rainfall in the region is about 800 mm (in the City of Aachen). Because of the mountainous landscape with relatively short and steep valleys, the rivers rose rapidly, creating enormous floods.

Water depths of up to 8 m above normal water levels caused considerable devastation to buildings, roads and other infrastructure in the affected valleys. The most severe damage was recorded in the Ahr valley, in Rhineland-Palat-inate, and along the Erft and Vicht rivers in North Rhine-Westphalia. More than 180 people in Germany lost their lives during the flood. The economic damage is still uncertain, but probably in the order of several billions of Euros. This flood is therefore considered the worst natural disaster in Germany since the storm surge in 1962 and the Elbe flood in 2002.

Dams and reservoirs in the Eifel mountains reached their design limits, and in some cases the design values for a return period of 1 in 10 000 years were even exceeded. For example, the Urft dam, one of the oldest dams in the northern Eifel, completed in 1905, experienced an event with a return period of more than 10 000 years (see: https://wver.de). But many other dams in the northern Eifel also experienced their design event. This demonstrated that the planning, design, construction and maintenance of these dams has been very effective, and that a high level of resilience is guaranteed even in the case of very extreme events. Some dams were even able to withstand an event which was greater than the design event.

A preliminary comparison between valleys with dams and valleys without dams also shows the protective effect of the dams, even during such extreme events. The severe damage along the Ahr, Vicht and Erft occurred on rivers with no large dams in their upper reaches. Nevertheless, the event was so strong that some damage even occurred in areas downstream of the dams and in regions of flat land.

The towns affected by the flood in the low mountain regions are characterized by an intensive use of the valleys. Town development has historically resulted from the use of the clean and clear water of the low mountain rivers for various purposes (for example, metal processing, textile and paper industries, tourism, agriculture, old grain mines and mining). Nowadays, cities, roads, industry and agriculture are still located along the rivers and consequently narrow the river courses to a minimum. Even during small flood events, these rivers frequently overflow their banks and flooding is not uncommon. But during an extreme flood, like the one in July, water levels rise even higher than the buildings in some areas. The consequences of such floods are dramatic. One of the key challenges in future will be to keep the most affected areas free from any future intensive human activity (buildings and infrastructure).

An obvious challenge during the flood event was warning the public. Although there were indications regarding heavy rainfall by the German weather forecast service (DWD), the transfer of the precipitation

information into a recognizable hazard on site was not sufficient. It was impossible to evacuate people in time. This demonstrated the obvious and significant difference between a flood event on a large river, with several days' warning time, and the short warning times on the low mountain range rivers, which develop into raging torrents within a very short time. This aspect should be ad-dressed in the near future.

Clean-up work is currently taking place in the affected regions, which will probably take many years. Many people have lost everything and have to start from scratch. The willingness to help and donate for the affected people is extremely high. Many private and public activities have been launched to help the affected region financially or through hands-on assistance.

One of the main challenges will be to transfer the lessons learned from this extreme event into a sustainable improvement of future flood protection in low mountain regions

GEOTECHNICAL SPECIALIST STARTS WORK AT THE CHALLENGING TEESTA VI SITE IN INDIA

A contract for specialist foundation engineering and geotechnical work has recently been awarded to Bauer Engineering India Pvt Ltd, a sub-sidiary of Bauer Spezialtiefbau GmbH. Germany, for the 500 MW Teesta V] run-of-river hydro project in Sikkim. northern India.

The contract was awarded by Jaiprakash Associates Ltd, the contractor for the scheme, which is being developed by M/s Lanco Teesta Hydro Power Ltd, a wholly owned subsidiary of NHPC.

The project is under construction on the Teesta river, near the town of Singtam. The 300 km-long Teesta river rises from the Pahunri glacier at an elevation of more than 7000 m in the eastern Himalayas, and flows through the states of Sikkim and West Bengal, and then joins the Jamuna river at Fulchhari in Bangladesh. The site presents a number of challenges, according to Harish Agarwal, Vice President of Jaiprakash. The area is prone to erratic Hooding, and geotechnical conditions arc complex, with boulder strata in the area; also the work site space is limited, because of the relatively narrow valley and steep slopes, as well as the proximity of an existing barrage.

The scope of the work to be carried out by Bauer includes the construction of an anchored pile wall, with about 10 000 m of piles with a diameter of 800 mm, as well as about 60 000 m of anchors. The anchored pile wall will allow for 40 m-deep excavation for the intake structure on the right hank.

Along the upstream cofferdam, a 4700 m2 grout curtain wilt be constructed, using the jet grouting technique. Then in two stages, on ihe upstream side of the barrage, a total of 4600 m^2 of diaphragm wall will be built, with a trench cutter being used through the boulder alluvium after pre-treatment.

The work by Bauer began in April, and is expected to be completed in late 2024.

Main features of the scheme include: a 26.5 m-high concrete bar-rage equipped with five radial gates; two headrace tunnels and surge shafts; four pressure shafts and penstocks; and an underground power cavern to be equipped with four vertical axis Francis units.

The Teesta VI project is part of a major cascade development on the Teesta river.

HEADRACE TUNNEL COMPLETED FOR NAITWAR MORI, INDIA

The Indian hydropower producer Satluj Jal Vidyut Nigam (SJVN), a joint venture of the Government of India and the Government of the northern state of Himachal Pradesh, has completed the excavation of the headrace tunnel for the 60 MW Naitwar Mori hydro project on the river Tons, in the northern Indian state of Uttarakhand. At a ceremony held on 6 July. Shri Nand Lai Sharma, Chairman and Managing Director of SJVN, triggered the last bhisl to mark the completion of the tunnel's excavation.

The 4330 m-long headrace tunnel will supply a powerhouse equipped with two 30 MW units, to be supplied by Voiih Hydro. The civil works, including a 30.5 m-high barrage, are being undertaken by JP Associates, and the hydro-mechanical works are being carried out by GMW. The project, which is scheduled to be completed by April 2022, is designed to generate average annual outpm of around 266 GMh of which 12 per cent will be supplied free of charge to the state of Uttarakhand as a royalty SJVN, which was awarded development rights for the project in October 2017, began construction works in March 2018. The diversion works for the river Tons, which is a major tributary of the Yamuna river in the Ganga basin, were completed in January 2019.

MOU SIGNED TO IMPLEMENT THE DAGMARA SCHEME IN BIHAR, INDIA

National Hydroelectric Power Corporation (NHPC). India's state hydropower producer and developer, has signed an MoU with the Bihar State Power Holding Company (BSHPC) for implementation of the 130 MW Dagmara run-of-river project in the northeastern state of Bihar. The MoU was signed by Shri Biswajit Basu. Director of Projects at NHPC and Sliri Alok Kumar, Managing Director of BSHPC, in the presence of Shri R.K. Singh, Minister of State of Power and New and Renewable Energy.

The multipurpose project, which will be built in Supaul district, about 22.5 km downstream of the Bhini-nagar barrage on the trans boundary Kosi river, envisages the construction of a 945.5 m-long concrete barrage. as well as an earth fill dam with a length of about 5750 m across the Kosi to create gross storage of about 255.8 x 10* m\

Because of the large discharge variations in die river, a surface powerhouse on the left side of the barrage is currently designed to house seventeen 7.65 MW units with pit-type bulb turbines, rather than a smaller number of larger units, to maximize water utilization and enhance the economics,

The project, which will generate under a gross head o! about 5.87 m, is designed to generate power for the Eastern Regional Grid, which comprises the states oF Bihar, Jharkhand, Orissa. Sikkim and West Bengal. In addition to power generation, the Dagmara project will provide Hood protection in northern Bihar and increase irrigation water supply.

FIRST PRODUCTION AT NEPAL'S LARGEST HYDRO STATION

The first of six 76 MW units at the 456 MW Upper Tamakoshi hydropower project in north-central Nepal

began generating in test mode on 5 July, at a ceremony intended by the Prime Minister K..P, Sharma Oli. The project, which has taken a decade to complete after suffering earthquake damage and cost overruns, will be the country's largest hydro plant when fully commissioned later this year, with a design output equivalent to two-thirds of Nepal's current power generation. Located on the Tamakoshi river, a tributary of the Sun Kosi, near the border with Tibet, the run-of-river project has been developed by Upper Tamakoshi Hydropower Ltd (UTKHPL). majority-owned by four public entities, Including the slate power utility Nepal Electricity Authority, as well as Nepal Telecom, Citizen Investment Trust and Rastriya Beema Sansthan; it is entirely financed from domestic financial institutions and companies.

"This is a historic achievement," said Hitendra Dev Shaky a, Managing Director of the Nepal Electricity Authority. "This makes Nepal a power surplus country, capable of exporting electricity." The Upper Tamakoshi hydro project is considered to be of high economic importance to Nepal as it will not only make it a surplus producer and contribute to the national gross domestic product, but it will also reduce electricity imports from India during the dry season. The peaking run-of-river project will have a live storage volume sufficient for four hours daily peaking operation in the driest month. The project is designed to generate average annual output of 2281 GWh under a gross head of 822 m and a design discharge of 66 m3/s. With an installed capacity of 1385 MW and peak demand of around 1350 MW, Nepal will have nearly 500 MW of surplus energy in the wet season, when all units of Upper Tamakoshi begin full commercial production.

Energy Minister Bishnu Paudel, speaking at the inauguration, said the full operation of the project is expected to contribute around 1 per cent to national GDP. "It will help boost industrial production," he said. "This project shows that we can collect the fragmented capital within the country and invest in projects like Upper Tamakoshi."

Premier Oli added: "The project has boosted our confidence, and we can now develop this type of project through our own resources and man-power".

The run-of-river project, in Dolakha district, Bagmati Province, about 200km from Kathmundu, was built by a consortium of Chinese, Indian and Austrian contractors. Civil works including a 22 m-high, 60 m-long diversion dam. with an integrated with a 225 m-long. 35 m wide intake: an 8 km-long headrace tunnel, a 1.16 km-long penstock, an underground powerhouse and transformer cavern and a 3 km-long tailrace tunnel, were carried out by Sinohydro Corporation.

Electro-mechanical equipment, consisting of six vertical Pelton turbines and six 90 MVA synchronous generators, were supplied by Andritz Hydro. Hydro-mechanical works and equipment were supplied by Texmaco Rail & Engineering of India, and transmission works, including a 47 km-long double circuit 220 kV transmission line from Gongar to the New Khimti substation was undertaken by KEC International of India.

While the project is a milestone for a country like Nepal, facing significant infrastructure gaps, it is also a reminder of how cost and time over-runs impact the country's development aspirations, die Prime Minister said during the inauguration. "If we do not complete projects on time, we have to face losses. We have to learn from this project."

Construction of this priority project began in February 2011 and was originally scheduled to be completed in July 2018. It has. however, taken further three years at a cost of more than 60 per cent more than its original estimated budget owing to a combination of the damage caused by the 2015 earthquake, problems with the installation of the penstock pipes, security concerns and worker strikes, as well as finally the impact of the COVTD-19 pandemic.

As a result of this, the total cost has risen to Rs85 billion (US$ 708 million) from an initial cost of Rs35 bil-lion (US$ 456 million) according to the Chief Executive of UTKHPL.

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, totaling 4134 MW, in the northern state of Jammu and Kashmir. The agreements, which were signed on 3 January, are designed 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 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 hydropower projects totaling 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 Government. 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.

THE MINISTRY OF PUPR AIMS TO COMPLETE THE CONSTRUCTION OF NINE DAMS BY 2022.

Infrastructure projects to be completed in 2022 include nine dams: Ciawi, Sukamahi, Margatiga, Sadawarna, Lolak, Semantok, Tamblang, Beringinsila and Kuwil Kawangkoan.

Jakarta (ANTARA)-The Ministry of Public Works and Public Works (PUPR) aims to complete the construction of nine dams by next year.

“Some of the infrastructure projects targeted to be completed in 2022 include nine dams, Ciawi, Sukamahi, Margatiga, Sadawarna, Lolak, Semantok, Tamblang, Beringinsila and Kuwil Kawangkoan. Zuna said here during the webinar on Wednesday.

Zuna mentioned the construction of a highway with a total length of 421 km. The 64km Section 1 at the Indraraya-Muara Enim intersection, the 16km Section 2 at Semarang-Demac, and the 12km Section 2 at Siawi-Sukabumi were also scheduled to be completed next year.

In 2022, the ministry will also begin work on several strategic projects.

Forthcoming Events

SR. No	Description	Date	Country/Organizer
8	24th International Congress on Irrigation & Drainage	6 Jul - 12 Jul-20201	Sydney, Australia, Organizers: Irrigation Australia, URL: www.irrigationaustralia.com.au
9	HydroVision 2022	12 Jul - 14 Jul-2022	Denver, CO, USA, Organizers: PennWell Corp URL: www.hydroevent.com/future-even.
10	World Future Energy Summit	17 Jan - 19 Jan 2022	Abu Dhabi, UAE
11	DistribuTech International	26 Jan - 28 Jan 2022	TX, USA
12	Power Gen International	26 Jan - 28 Jan 2022	TX, USA
13	ASIA 2022	15 Mar - 17 Mar 2022	Kuala Lumpur, Malaysia
14	IEEE PES T&D Conference & Exposition	25 Apr - 28 Apr 2022	New Orleans, LA, USA
15	24th ICID International Congress + 73rd IEC Meeting	30 May - 6 Jun 2022	Adelaide, Australia
16	ICAAR 2021 (16th International Conference on Alkali Aggregate Reaction in Concrete)	31 May - 2 Jun 2022	Lisbon, Portugal
17	Hydro Vision 2022	12 Jul - 14 Jul 2022	Denver, CO, USA
18	IWA World Water Congress & Exhibition	11 Sep - 15 Sep 2022	Copenhagen, Denmark
19	Vienna Hydro 2020	9 Nov - 11 Nov 2022	Vienna, Austria
20	Valve World Expo 2022	29 Nov - 1 Dec 2022	Dusseldorf, Germany

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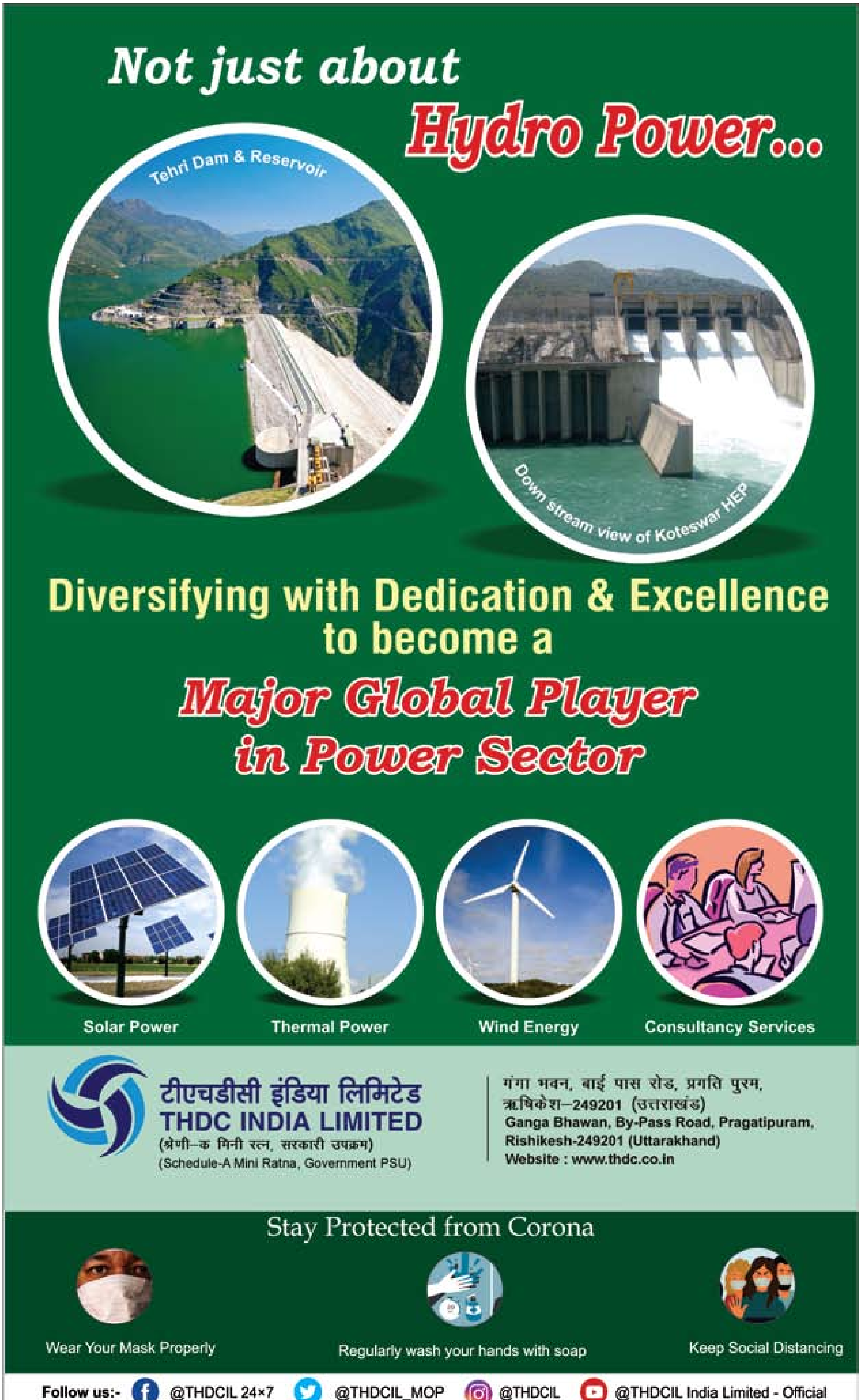
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