THE NEED FOR DAM SAFETY MANAGEMENT IN NEPAL

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ABSTRACT

In Nepal, the plan to achieve economic development through hydropower expansion is driving a new era of dam construction. Nepalese dams are, however, exposed to a broad spectrum of natural hazards which increases potential dam safety risks. A structured dam safety management program is commonly used around the world to help reduce the likelihood and potential consequences of failure.

While efforts by the Government of Nepal and other organizations are being made to improve dam safety, the nation currently has a relatively weak dam safety management program with no national dam safety regulation nor mandated requirements for the effective implementation of consistent dam safety best practices. In this paper, the evolution in dam safety management practices is discussed, emphasizing the need for robust dam safety programs and stringent regulations to improve public safety. It explores why effective dam safety management program become even more relevant and critical in mountainous countries such as Nepal and discusses how dam safety management "best practices", can help Nepal to develop resilient hydropower to achieve the nation's goals.

Keywords *: Hydropower, Dam Safety, Natural Disaster, Dam Incidents, Residual Risks; Emergency Management; Public Safety*

1. INTRODUCTION

Water is one of Nepal's most precious resources, one that can be used as a powerful economic engine, if safely developed and wisely utilized. However, while dams provide considerable economic and societal benefits, a dam failure can pose significant risks to the public, the environment, and cultural heritage. While the actual lifespan of well-maintained dams can be almost indefinite if an owner implements an effective dam safety management program dams can, and do, still fail at a somewhat consistent rate of about 10-4 dam failures per dam year per year according to information reported by Donnelly (2015) and others. As such, the development of a modern national dam safety management program that is implemented throughout a project's life cycle has become a well-accepted approach to help minimize the likelihood and impacts of dam safety incidents

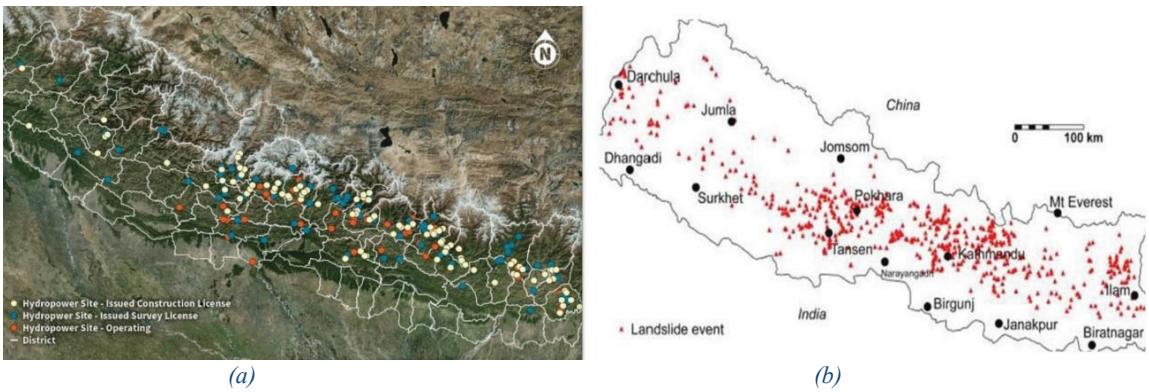
In this paper, some thoughts and recommendations on how Nepal and Nepalese dam professional can work to develop their capacity to guide the nation's dam safety practices in this direction are discussed.

2. NATURAL HAZARDS OF NEPAL AND INCREASED DAM SAFETY RISKS

2.1 Dams in Nepal and Related Risks

As is illustrated in Figure 1, there are a significant number of existing dams and dams that have been or are planned to be constructed as part of Nepal's growing hydropower industry. All of these dams are located in a seismic region of the world where natural hazards represent a real risk.

Unfortunately, formal dam safety management programs designed to address the full range of potential risks that these existing and new dams may pose do not yet exist which results in inconsistent dam safety design and management practices. In addition, Nepal's ability to efficiently deal with the impacts of these hazards is reduced because many dam sites are remote with poor access and, in many river valleys, little opportunity to attenuate flows making downstream populations and infrastructure considerably more vulnerable.



(a) *(b)*

Figure 1a : Existing and planned hydropower power plants in Nepal and 1.b: Historic Landslide Events showing increased geohazard risks to dams (data from the GoN)

2.2 Climate Change Impacts on Dam Safety Risks in Nepal

Climate change science indicates that there is a strong likelihood of an increasing occurrence of severe events in the next century (Ouranous 2015). Therefore, a means to estimate these impacts represents one of the most important questions facing dam industry and utility owners (Dick et. al. 2019). While, currently, the impacts of climate change remains uncertain, the available evidence indicates that the rate of global warming is higher in the Himalayan Range and can be expected to result in more frequent extreme climatological events leading to more frequent and severe geohazards. In this regard, Bhatta (2017) projected that the economic costs of climate change including hydropower, agriculture and water-induced disasters could be 2–3% of current GDP/year by mid-century. The potential for changing climate variables likely represents one of the most significant dam safety hazard in countries such as Nepal due to more pronounced seasonal precipitation imbalances increasing the potential for extreme flood events as well the po-tential for severe landslides and Landslide Dam Outburst Floods (LDOFs), Glacial Lake Outburst Floods (GLOF's) and debris flows.

Recently, Nepal's Climate Change Policy promoted the development of more clean energy to reduce greenhouse gas emissions, and to build climate resilient infrastructure that can adapt to climate change impacts in Nepal. These policies encourage the development of hydropower projects to help meet the region's energy demand (Bhatta 2017). To meet this goal the impacts of natural hazards, climate change, and the associated risks needs to be one of the considerations accounted for in the design and maintenance of hydropower projects in Nepal.

3. THE GLOBALLY EVOLVING DAM SAFETY REGULATORY LANDSCAPE

Jensen 1980 highlighted the potential risks a dam can pose to the public, noting that there has been about 200 notable reservoir failures globally in the 20th century alone with more than 8,000 fatalities. Within the last five years, dam safety incidents including the Mount Polley tailings dam failure in Canada (2014), the Fondao dam failure in Brazil (2015), the Oroville Dam Spillway incident in the USA (2017), the Xe-Pian Xe-Nam Noy hydroelectric facility that impacted Laos and Cambodia (2018) and the Feijao project located near Brumadinho, Brazil (2019) indicate the need for the dam safety industry to rededicate efforts to improve the safety of the worlds dams to avoid eroding public confidence and trust in the dam industry. Morgenstern 2018 recognized that this recent series of failures that have occurred in jurisdictions such as Canada, the US and Brazil, that have modern dam safety management programs in place represents a dam safety crisis that requires immediate attention.

In Nepal, the devastating 2015 Gorkha earthquake and aftershocks (Sharma & Deng 2017), coupled with monsoon rains, resulted in debris flows impacted dozens of Nepalese Hydropower dams (e.g. Upper Bhotekoshi, Kulekhani, Sunkoshi, Upper Trishuli). Overall, about 115 MW of hydropower facilities were severely damaged with another 60 MW impacted, representing over 20% of the nation's available capacity (Donnelly et al. 2018).

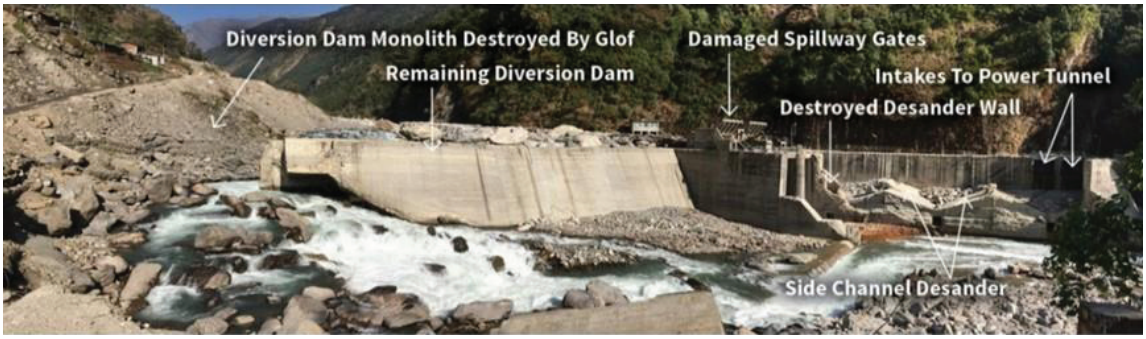


Figure 3. Impact of a rainfall induced Debris Flow at the Upper Bhote Koshi HPP

3.1 Dam Safety Management – A Global Outlook

The general philosophy of the world's evolving dam safety regulations is more or less consistent. Dams and hydropower projects should not present an unacceptable and unreasonable hazard to the public, environment or to significant cultural heritage sites. The implementation of evolving dam safety regulations, directives, and guidelines designed to achieve these goals have had a marked impact on dam and public safety. For example, following the enactment of dam safety legislation in the USA in 1996 and the subsequent adoption of risk informed strategies in 2000, the occurrence of dam safety incidents declined significantly, dropping from an average of about 39 per year between 1995 and 2000 to about nine incidents per year after dam safety management programs began to be implemented (Figure 4) . The success of the evolving dam safety management methods and increased regulatory oversight is also highlighted in the International Committee on Large Dams Bulletin 99 (ICOLD 1995). In this bulletin, it is reported that the percentage of failures of large dams has shown a remarkable decrease, from 2.2% of dams built before 1950 to less than 0.5 % of dams built since 1950. Foster Fell 2000 noted failure rates before 1950 as 8.6x10-4 and after 1950 as 2.7x10-4 and gives the credit for improvement to the modern dam safety practices.

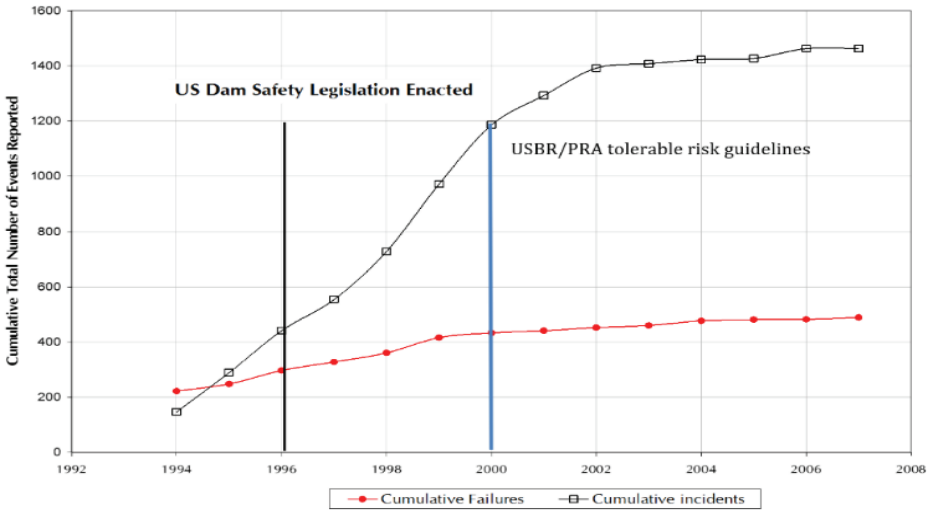


Figure 4 : Effect of sound dam safety management practice on dam incidents

Given a dam owners responsibility for protecting the public from the effects of dam failure, maintenance of comprehensive dam safety management programs and up to date emergency plans have become a dam owner's legal and moral responsibilities (Acharya and Wog 2010).

3.2 Recent Evolution from Standards-based Approach towards Risk Informed Approaches

Standards-based approaches are commonly used in dam safety industry to assess the safety of a dam and are what is normally required by regulators. Unfortunately, many dam failures occur as a result of an unusual combination of a chain of usual events that are not easily accounted for in a traditional standards-based assessment. As was reported by Regan, 2004 and others, risk-informed approaches used in combination with traditional standards-based assessments have proven to help owners better understand the complete range of dam safety vulnerabilities that may not be apparent using only deterministic methods. In this way, the hazards can be better identified and appropriate barriers put in place put in place to reduce the likelihood or the consequences of adverse events in accordance with the "Bow-tie" principle (CDA, 2007, 2013 revision). Simplified risk assessment tools such tools such as "Failure Modes and Effects Analyses" (FMEA), "Event Trees", Potential Failure Mode Analyses (PFMA) and "Multiple Account Analyses" can be used to help identify events or combinations of events that were often previously not recognized or dismissed as being of little consequence allowing for better dam safety management and increased societal and professional confidence (Donnelly et al.(2019)). Lacasse (2019) noted the increasing need for "risk informed decisions" for the society and engineering standards. She highlighted the benefits of implementing reliability and risk concepts in dam engineering as a complement to conventional deterministic analysis. Morgenstern (2018) summarized the evolution of risk-based techniques and standards, its merits, limitations and recent trends. He noted that this approach has helped dam professionals in critically assessing the way dams could fail along with the relative likelihood of the different failure modes which ultimately serves to enhance the dam safety decision-making process. He concluded that decisions affecting public policy require the use of all available information and consideration of "feasibility, fairness, and affordability".

4. A DISCUSSION OF THE NEED FOR DAM SAFETY MANAGEMENT IN NEPAL

4.1 Dam Safety Management – A Canadian Perspective

The Canadian Dam Association developed dam safety guidelines in 1995 along with subsequent revisions in 1999, 2007, and 2013 as well as supporting technical bulletins (2007; 2016; 2019) designed to improve dam safety management

practices in Canada. As with many other countries around the world, dam safety begins in Canada begins with ensuring that the dam owner is fully responsible for the safety of the structure and that a well-structured dam safety management system is in place. Dam safety classification, based on the consequences that might occur on the event of a dam failure is a key component of and management system. This is used to develop the standard of care for each dam serving as a proxy for addressing the risk a dam poses. Throughout the life-cycle of a dam, a sound dam safety management systems involve fundamental elements of the "plan-do-check-act-report" cycle as explained in Figure 5 with clearly identified roles and responsibilities.

Figure 5 : Simple Schematic Showing the Elements of Dam Safety Management System (Adopted from CDA 2013)

4.2 Dam Safety Management in Nepal

Currently, Nepal does not have a national dam safety regulation of dam safety requirements. Nepal also lacks integrated emergency management programs, despite the fact that the dam safety hazards that exist in Nepal are unique, and significant, compared to many other jurisdictions around the world. Instead, the management of dam safety risks is left to the discretion of the designer, owner and operator of each individual dam with limited accountability for public safety and economic consequences of dam failure. Most of the major dams in Nepal are designed using the international standards or standards of consultant's country of origin. As such, the hazards unique to Nepal are not always well accounted for (Donnelly et al., 2018) and designs can vary significantly depending on the judgment and experience of the practitioner, the standards with which they are familiar and the risk tolerance of the owner of the facility.

4.3 Assessing Dam Safety Ricks in Nepal

4.3.1 *The Need for Integrated Risk Assessment as Part of the Dam Safety Management System in Nepal*

Nepal is geographically situated in a location vulnerable to earthquakes, landslides, debris flows and flooding that increase the risk of a dam incident or failure (Sharma & Deng 2017). The first documented earthquake event, with a suspected magnitude of 7.8, dates back to 1255. Since then, M8 earthquakes have occurred every century, often in close proximity to each other following a period of quiescence. This is supported by Rajendran et al., 2018 who reported that a review of historical major earthquakes in the region indicates that there is increasing strain developing that portends at least one earthquake of magnitude 8.5 or more in the western part of Nepal in the relatively near future. While earthquakes can pre-condition mountainsides and glacial lake dams to destabilize, they are seldom the cause of a dam safety incident. In the steep Himalayan valleys, it is prolonged monsoon rains on pre-conditioned slopes that are augmented by cloudbursts that may increase in intensity and frequency due to climate change, that cause destructive landslides and debris flows (Reynolds et. al. 2018). Therefore, it is critical that these natural hazards be considered in throughout the life-cycle of a hydropower facility. The tradition approach of studying individual loading conditions in isolation (e.g. earthquake, hydrology, geotechnical, glacial hazards) is insufficient to ensure the resiliency of dams in mountainous regions. In Nepal dam safety management practices must consider the potential for natural hazards to act alone and in combination. Therefore, comprehensive integrated risk assessment is essential for resilient (safer) hydropower development (Reynolds et. al. 2018).

4.3.2 *Sedimentation Considerations*

In Nepal as the natural hazards discussed above can yield a significant amount of sediment. Kaini and Annandale (2019) have identified sedimentation control and management as one of the most overlooked area in planning and design of hydropower projects in Nepal. As shown in Figure 6, developing regions of the world (e.g. China, South America, Northern India and Nepal), that stand to benefit most from production of hydroelectricity, are often those that have the highest sediment yields (Grummer, 2009).

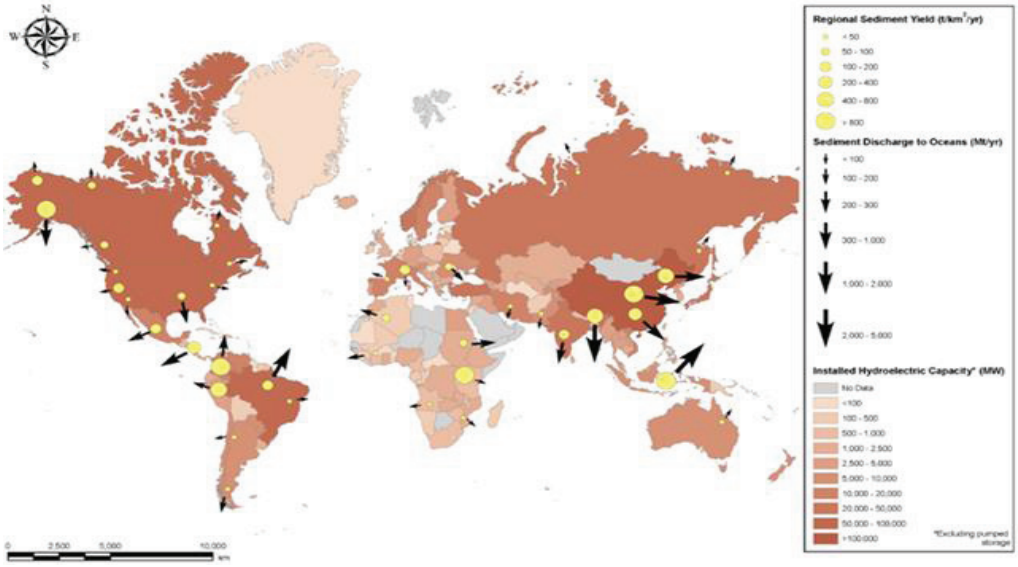


Figure 6 : Comparison of hydroelectric potential and sediment production (Schelenberg et. al, 2017)

While no dam has ever failed as direct result of sedimentation issues, sedimentation can alter reservoir routing, complicate the management of seasonal flood inflow, reduce spillway discharge capacity, alter reservoir ice formation and increase loads on the dam and components of the dam such as gates. Given these circumstances, the implementation of a dam safety management program tailored to the specific needs of Nepal that includes integrated hazard assessment and management becomes one of the most effective and essential vehicle to help minimize the likelihood and consequence of dam failure, and to increase public safety.

4.3.3 *Emergency Management Program – a Vital Strategy to Reduce Residual Dam Safety Risks*

The impacts of Natural Disasters within a dam safety management program can be managed, as conceptually illustrated in Figure 7, if an effective emergency management program is in place, integrated into an owner's business practices and shared with first responders within the communities (Bennett and Spektor 2013). A key component of any residual risk management strategy is an effective emergency management program to ensure that practicable measures are taken to minimize life safety hazards from reasonably foreseeable incidents (ICOLD 2017). A first step in defining the potential consequences and developing an emergency management plan is undertaking a hypothetical dam breach assessment in which flood wave routings are performed, inundation mapping developed, and potential impacts are assessed for a range of failure and flood scenarios. A wide range of methods may be applied in each of these steps depending on the purpose of the assessment (CDA 2013).

Figure 7 : Strategies for Managing Residual Risks of Dam Incidents (CDA 2019)

The emergency management program represents a low cost but very effective strategy to reduce the residual risks of dam incidents. As is illustrated in Figure 8, an effective emergency management program, an element of a robust dam safety management system, typically consists of four elements: (1) a Prevention and Mitigation Plan, (2) an Emergency Preparedness Plan (EPP), (3) an Emergency Response Plan (ERP) and/or Flood Action Plan (FAP) and (4) a Recovery Plan.

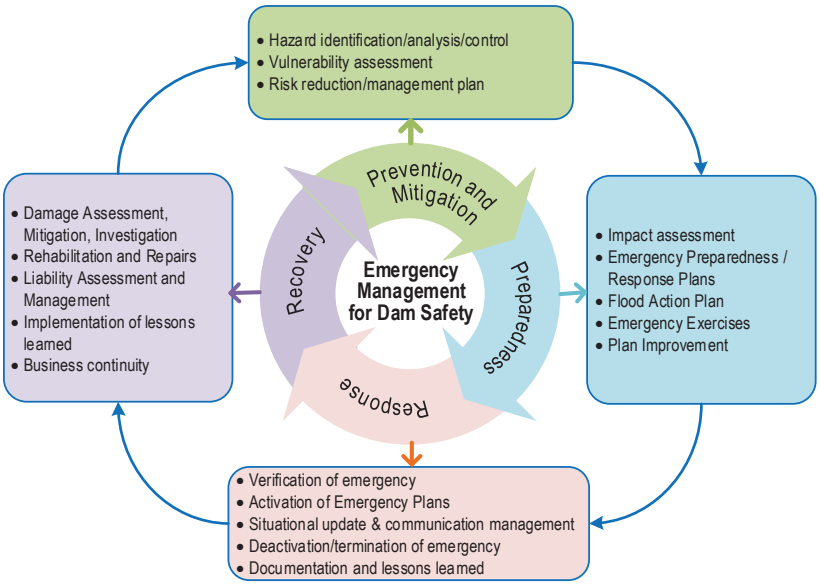


Figure 8 : The key Elements of an Effective Emergency Management Program

4.3.4 *The Need for Improved Dam Safety Risk Communication*

Bosewell at el. 2019 identified risk communication as a major gap in modern dam safety management practice. They noted that the recent high-profile dam failures have demonstrated the need for clearly communicating dam safety risks which can only be effectively achieved by a collaborative approach involving all stakeholders. While Morgenstern, 2018 recognized that communicating risks to inform public policy is a challenging task, to manage risk effectively, stakeholders must be included in risk management and decision-making processes during the planning, design, construction and subsequent operational phases of the project. This needs to include communication of the possible emergencies that could occur and the mitigation strategies being employed (MAC 2016). Involving stakeholders early, and often, helps to establish and maintain the owners social license to operate the facility and gets ahead of potential misleading statements and perceptions that can be communicated through social media.

In Nepal, community engagement and appropriate public consultation sessions will become increasingly important to enhance public awareness of the potential risks, and benefits, of hydropower development. Developing these effective community engagement strategies needs to be performed in parallel with the development of Nepal's national dam safety standards and regulations. This will include regular communication and collaborative emergency response plan exercises with national, sub-national and local government response agencies that will help to ensure all parties fully understand what resources may be available and the roles each needs to play to manage the dams and associated risks they pose. These actions will also assist decision-makers and incident commanders in keeping high-hazard dams in mind when considering response resource allocations. Bosewell 2019 emphasized that it is time for dam engineers to rethink the societal acceptability, and the professional acceptability of the current ways we think about and talk about risks. He argues that the concept of "extreme consequences" needs to gradate towards "unbearable consequences". While engineers cannot solve this alone, the dam safety community can invite and facilitate the needed conversation between engineering experts, corporate decision-makers, regulators and the public.

5. CONCLUSIONS

In Nepal, water has the potential to become one of the nation's the most powerful economic engine, if it is safely developed and wisely utilized. However, in a mountainous, seismically active region like Nepal, natural hazards that can initiate a dam failure are varied and significant. The current lack of a modern national dam safety management program increases the risks that hydropower projects pose to the environment, the public and the nations rich cultural heritage and dams and downstream communities. With the construction of new and larger dams to facilitate economic growth, the impacts of climate change, continued population growth and increased development downstream of dams, dam safety risks in Nepal can be expected to increase. The implementation of a modern national dam safety management program tailored to specific needs of Nepal that includes integrated hazard assessments, risk informed decision making and improved risk communication represents an effective and essential vehicle to help minimize the likelihood and consequence of dam safety incidents now and into the future.

A robust dam safety program will increase public awareness and safety and would strengthen societal and professional confidence that the inherent risks of these large engineered structures are appropriately addressed and managed during all phases of their life cycle. This will, ultimately, help to create an attractive investment climate in Nepal for national and international investors on major hydropower development project in a safe and sustainable manner.

6. RECOMMENDATIONS

Nepal would significantly benefit from:

(1) Implementing the recently developed (2018) Dam Safety Guidelines so that consistent design standards and practices are applied across the nation

(2) Developing a suitable capacity building program with opportunities for continuous improvement.

(3) Supporting the development and implementation of a modern dam safety regulation, policy and program tailored to the unique needs of Nepal.

(4) Establishing a dam safety section within the appropriate government agency to ensure continuous improvement in the capacity of individuals and institutions to develop, implement and promote the consistent dam safety management standards and best practices.

(5) Incorporating adequate public participation and consultation during planning, site selection, design, and developing sustainable and effective operational strategies for new dams to minimize risks and maximize resiliency.

(6) Offering introductory level educational seminars and courses in high schools and universities for dam safety, and emergency management to enhance education, and awareness and risk communication.

(7) Collaborating with other governments, international dam safety organizations and regulatory agencies to accelerate the learning.

Professional engineering organizations and academia also need to take a lead role in connecting the Nepalese engineering community to the national and international dam safety industry in order to introduce international best practices such as emergency management for dams (CDA 2019), conducting failure modes and effect analysis (FMEA) at the design stage and throughout the life-cycle of a hydroelectric facility, the use of risk informed decision-making systems and the establishment of independent review boards for major hydropower projects.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the review and comments of Pravin Karki, Global Lead Hydropower & Dams, World Bank Group and Dr. John Reynolds, Reynolds International Ltd., Mold, Wales, UK.

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