



<https://doi.org/10.64211/oidaijsd190419>

Strengthening Documentation and Field Implementation of Dam Safety Guidelines in Sri Lanka

G.K.P. Wickramasinghe ¹, A.P.N.P. Chandrasena ², A.G. Jayasinghe ³, S.W. Seneviratne ⁴

^{1,2,4} Department of Civil and Environmental Engineering, Faculty of Engineering,
University of Ruhuna, Hapugala, Galle, Sri Lanka.

³ Department of Civil Engineering, Faculty of Engineering Technology,
The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

Corresponding author: gkalanaprabhath97@gmail.com

© Author (s)

OIDA International Journal of Sustainable Development, Ontario International Development Agency, Canada.

ISSN 1923-6654 (print) ISSN 1923-6662 (online) www.oidaijsd.com

Also available at <https://www.ssrn.com/index.cfm/en/oida-intl-journal-sustainable-dev/>

Abstract: The extensive dam network in Sri Lanka plays a pivotal role in water resource management in the country. Despite substantial socio-economic benefits offered by dams, the failures around the world have caused disastrous consequences, stressing the importance of dam safety management as a global concern. Having identified the significance, the Irrigation Department of Sri Lanka as the primary custodian of dam safety management in the country, has drafted local dam safety guidelines. Acknowledging the efforts to enhance safety practices in the country, the present study was carried out to assess the status of drafted local dam safety guidelines against the international standards, focusing on the level of documentation and the field implementation. The study utilized an expert questionnaire survey that targeted two audiences: 1) experts involved in dam safety guidelines and 2) on site-field engineers, to assess six technical aspects related to dam safety namely, geotechnical, structural, hydro technical, seismic considerations, risk assessment and management, and public involvement and emergency preparedness. The expert questionnaire survey was developed referring to the “Maturity matrix method” for institutional benchmarking in dam safety. The results of the survey revealed that documentation of the majority of aspects performs well compared with the international guidelines, whereas seismic considerations demonstrate a notable deficiency. Notably, the overall maturity levels obtained for the aspects during field implementation indicated clear room for further improvement, reflecting the need not only to maintain robust documentation of dam safety guidelines, but also to effectively translate the same into field implementation. Additionally, “Key informant interviews” were conducted to obtain insights from the field engineers which revealed crucial concerns and challenges to the field implementation of local dam safety guidelines such as, gaps in accessibility at the bottom level, ambiguity of dam ownership, concentrated responsibility and oversight, lack of records of the historical performance and dam surveillance data etc. Furthermore, the responses from the field engineers emphasized that dam safety regulation through a designated, legally empowered body, lifecycle-based dam safety guidelines, multidisciplinary organizational collaboration, sustained capacity building, and the involvement of downstream community as pivotal in enhancing the field implementation of dam safety guidelines. Overall, a periodic benchmarking approach as utilized in the study is recognized as a sustainable tool for the dam owners and governing authorities to self-assess the performance and effectiveness of their dam safety program, which ultimately contributes to strengthening documentation and field implementation of the local dam safety guidelines in Sri Lanka.

Keywords: Dam safety guidelines; Documentation; Expert survey; Implementation; Sri Lanka

Introduction

Dams play a pivotal role in water resource management by essentially supporting the irrigated agriculture, flood protection, and hydropower generation in the country [1,2]. Despite substantial socio-economic benefits offered by dams, the failures have caused devastating disasters resulting in loss of life and severe damage to the environment and the infrastructure [1,2,3]. Historical instances such as the Banqiao dam failure in China in 1975, and almost 50 years later, the Derna disaster in Libya in 2023 are crucial reminders of the longevity and the gravity of catastrophe of dam failures [4]. Notably, dam safety management practices have had progressive development through technological advancement over the years; however, it is evident that a zero-risk guarantee in dam safety is not practically feasible [5].

The International Committee on Large Dams (ICOLD) acts as the central custodian of the development and implementation of dam safety guidelines in the world [6]. Recognizing the significance of ensuring the integrity of dam infrastructure and the safety of the downstream community, developed countries such as the United States, China, Canada, the United Kingdom, and Australia etc. have strengthened their local dam safety guidelines and practices complementing with ICOLD guidelines [6,7]. These international guidelines have mainly highlighted the importance of local regulatory frameworks to oversee the implementation of dam safety practices [6].

Sri Lanka's dam network consists of about 350 medium to large dams and over 12,000 small dams according to the classification of ICOLD, and the vast majority of these dams are earthen embankment dams [8]. Dam ownership and the responsibility for dam operation vary from farmer organizations through provincial councils to national level organizations such as the Irrigation Department, Mahaweli Authority, and Ceylon Electricity Board [8]. Being a country that heavily relies on irrigated agriculture, the extensive dam network in Sri Lanka is a crucial component in the country's water infrastructure, which primarily supports the livelihood in the dry zone [9]. However, the majority of the earthen embankment dams in the country, which were built in the ancient era have been subjected to ageing and deterioration, and have demonstrated seepage related deficiencies to date. Hence, ensuring the continued safety and integrity of these crucial water infrastructures has become a major challenge to the local dam authorities, specially in light of climate change [10,11].

Having identified the importance, the Irrigation Department of Sri Lanka, as the primary responsible authority of dam safety management in the country, has drafted dam safety guidelines for local practice. While acknowledging the efforts to enhance dam safety management practices in the country, the present study was carried out to assess the current level of documentation of the local dam safety guidelines compared to the international standards, and their level of field implementation in the country. The study adopted a "Maturity matrix based expert questionnaire survey" and "Key informant interviews" as the research methodology to obtain critical insights on local dam safety guidelines from the experts and engineers involved in guideline development and field practice. By employing a maturity matrix based benchmarking approach, the ultimate aim of the research study is to identify the areas for improvement, and enhance the quality of documentation and field implementation of local dam safety guidelines to align with international best practices.

Materials and Methods

Maturity Matrices for Institutional Benchmarking in Dam Safety. Maturity matrix model based institutional benchmarking is defined as a self-evaluation process of how well-developed an institutional program is and its effectiveness compared to the international best practices and standards [12]. These Maturity matrix models have been widely used in institutional benchmarking processes over the past few decades and have been identified as an effective tool in supply chain management to assess a company's performance against the best industrial practices. Given the competitiveness in the growing industry, maturity models have been of great help for the management body to evaluate the effectiveness of the management hierarchy, identify strengths and areas for improvement and ultimately enhance the company's performance to cope with the field competition [12].

Similarly, the maturity matrix method for institutional benchmarking in dam safety was developed by CEATI International's Dam Safety Interest Group (a multinational consultancy organization) for the assessment of worldwide dam safety programs in 2015 [13,14]. Later, the method was extensively utilized by the Dam Safety Unit in Indonesia for institutional benchmarking of dam safety management in 2018, as a World Bank funded project [13]. These studies described the maturity matrix method for institutional benchmarking as a periodic self-assessment process for the dam owners to evaluate the effectiveness of their dam safety program over the years, compared to international standards and guidelines [13,14]. This method not only provides an understanding of the varying maturity levels across different aspects to identify the areas for improvement, but also provides a valuable means to communicate the effectiveness of the dam safety program to wider audiences [12,13,14].

In the maturity matrix method, each dam safety related activity is assessed against a set of defined maturity levels (as indicated in Table 1), and corresponding maturity scores are assigned based on the self-evaluation of the dam owner. The activities are clustered into different aspects (ex: geotechnical, hydro-technical, risk assessment, etc.), and an average maturity score is obtained to identify the corresponding overall maturity level for each aspect based on the maturity scale [13,14].

Table 1: The Maturity Matrices Scoring System [13, 14]

Maturity Level	Verbal Descriptive		Definition	Maturity Score (%)	Maturity Scale (%)
	Local Documentation	Local Field Practice			
1	Needing development	Needing development	Lacks conformance to international guidelines and best practices	20	$20 \leq X < 36$
2	Elementary address	Elementary practice	Slightly conforms to international guidelines and best practices	40	$36 \leq X < 52$
3	Average address	Average practice	Generally conforms to international guidelines and best practices	60	$52 \leq X < 68$
4	Good address	Good practice	High degree of conformance with international guidelines and best practices, with a good understanding of deviations to account for local conditions	80	$68 \leq X < 84$
5	Very good address	Very good practice	Highest degree of conformance with international guidelines and best practices, with a very good understanding of deviations to account for local conditions	100	$84 \leq X < 100$

Expert Questionnaire Survey. To benchmark local dam safety guidelines against the established international standards, an expert questionnaire survey was prepared referring to the well-established international dam safety guidelines of the International Committee on Large Dams (ICOLD), Canada, the United States, Australia, the World Bank, and India. The questionnaire survey addressed six technical “aspects” related to dam safety: 1) geotechnical considerations, 2) structural and mechanical integrity, 3) hydro technical considerations, 4) seismic considerations, 5) risk assessment and management, and 6) public involvement and emergency preparedness.

As mentioned in Table 2, each technical aspect consists of “components” which divide a particular technical aspect into several sub elements. Each component is consisted of dam safety related “activities”, which are the simplified technical concerns ultimately evaluated for their maturity level. The expert selects the maturity level that best describes the level of maturity for each activity supported with their justifications. The typical structure of the expert questionnaire survey considering the hydro-technical aspect is shown in Table 3.

As aforementioned, the ultimate objective of the expert questionnaire survey was to assess 1) the level of documentation, and 2) the level of field implementation of local dam safety guidelines compared to the international standards. Accordingly, the questionnaire survey targeted two types of audiences: 1) experts involved in the preparation of guidelines, and 2) on-site dam engineers. The Head Office of the Irrigation Department of Sri Lanka, and Seven dam sites in Polonnaruwa and Matara regions, namely Girithale, Kaudulla, Minneriya, Parakrama Samudraya, Denagama, Lenabatuwa and Ellakanda were covered during the data collection for the expert questionnaire survey. Eighteen experts including the experts involved in the development of local dam safety guidelines and on-site dam engineers participated in this questionnaire survey. During the response collection, the experts were asked to assign a maturity level for each activity related to dam safety (supported by justifications) based on the key definitions as mentioned in Table 1. Consequently, by analyzing the obtained responses, the average maturity score and the corresponding overall maturity level were determined for each technical aspect.

Table 2: Technical Aspects and Components Evaluated in the Expert Questionnaire Survey

Aspect	Components
Geotechnical considerations	<ul style="list-style-type: none"> Seepage control measures Slope stability assessment Ageing and deterioration of earthen embankment dams
Structural/mechanical considerations	<ul style="list-style-type: none"> Structural integrity of the dam and appurtenant structures Functionality of mechanical equipment (ex: gate mechanisms) Inspection, maintenance and rehabilitation practices
Hydro technical considerations	<ul style="list-style-type: none"> Reservoir inflow and flood routing Adequacy of spillway and outlet structures Dam breach modelling and flood hazard mapping
Seismic considerations	<ul style="list-style-type: none"> Seismic hazards and site specific ground motion assessment Liquefaction potential assessment and mitigation Seismic retrofitting
Risk assessment and management	<ul style="list-style-type: none"> Dam safety governance and regulation Dam surveillance, instrumentation and monitoring Periodic dam safety reviews
Public involvement and emergency preparedness	<ul style="list-style-type: none"> Dam owner- downstream community interaction Community awareness and Early Warning systems Emergency Action Plan

Table 3: Typical Structure of the Expert Questionnaire Survey

Aspect	Components	Activity	Maturity level					Remarks (Justification)
			1	2	3	4	5	
Hydro-technical considerations	Reservoir inflow and flood routing	Availability of reservoir inflow hydrographs and flood routing studies			x			Expert justification for the maturity levels and comments or suggestions regarding the activities.
		Incorporating climate impact forecasting in flood routing studies			x			
	Adequacy of spillway and outlet structures	Spillway and sluice capacity is adequate to safely withstand the Probable Maximum Flood				x		
		Outlet structures are maintained in good condition				x		
	Dam breach modelling and flood hazard mapping	Controlled breach potential in decommissioning is addressed		x				
		Site-specific flood hazard maps are available at the dam office			x			

Key Informant Interviews

In parallel to obtaining responses for the expert questionnaire survey, key informant interviews were carried out with the field engineers as the qualitative component of the present study, to discuss the concerns and challenges regarding the field implementation of dam safety guidelines in Sri Lanka. Fourteen field engineers from seven dam sites in the North Central Province and the Southern Province of Sri Lanka (Girithale, Kaudulla, Minneriya, Parakrama Samudraya, Denagama, Lenabatuwa and Ellakanda) participated in the KII.

The open-ended questions which were asked from the field engineers at the interview are,

1. How accessible are the local dam safety guidelines to the field technical staff?
2. Can you describe the current situation of your dam site, regarding the adherence to the standard field practices aligning with the local dam safety guidelines?
3. What are the significant challenges you face during the implementation of dam safety guidelines at the field level?
4. What is your opinion on the engagement of the downstream community in the implementation of dam safety guidelines?
5. What are your suggestions to enhance the field implementation of local dam safety guidelines in the country?

The present study employed “Purposive sampling” technique for the selection of target respondents in both expert questionnaire survey and the key informant interviews. The responses were obtained from the experienced engineering professionals associated with local dam operation and maintenance (from large dams to medium and small scale dams), who most likely to yield most appropriate and useful information on their own field experience, specifically related to dam safety management. Thus, a relatively small and purposively selected sample is employed in the present study, with the aim of increasing the depth of understanding (as opposed to breadth), focused on local dam safety management practices specifically. Furthermore, prior to the on-field assessment, a “Pilot Expert Survey” was carried out independently with two experienced professionals in local dam safety management and their comments and suggestions were incorporated to the final survey. The present research study was conducted in collaboration with the Irrigation Department of Sri Lanka, (an industry-academia collaborative project), having the objective of deriving the practical insights of local dam safety management concerns as a collective effort. Hence, the KII interview sessions were detailed, in-depth and transparent to represent the actual condition of dam safety field implementation in the country. Furthermore, the transparent two-way communication in open-ended questions was useful to mitigate the influence of the researcher’s preconceptions.

Results and Discussion

Maturity scores for the documentation of Sri Lankan dam safety guidelines

The average maturity scores and the corresponding overall maturity levels obtained from the responses of the experts involved in guideline development is indicated in Table 4. The overall maturity level is based on the maturity scale as defined in Table 1.

Table 4: Overall Maturity Levels for Documentation of Dam Safety Guidelines

Documentation Technical Aspects	Average Maturity Score (%)	Corresponding Overall Maturity Level
Geotechnical considerations	93.3	Very good address
Structural/mechanical considerations	84.0	Very good address
Hydro technical considerations	81.4	Good address
Seismic considerations	40.0	Elementary address
Risk assessment and management	72.2	Good address
Public involvement and emergency preparedness	73.3	Good address

The results expressed that Sri Lankan drafted guidelines perform well in the majority of aspects when compared with the international standards, demonstrating ‘very good and good address’ maturity levels. Geotechnical and structural aspects indicate the highest maturity level (very good address) in documentation. The experts mentioned that as the majority of dams in Sri Lanka are earthen embankment dams, greater attention is directed towards the geotechnical and structural integrity of dams, emphasizing the importance of seepage control measures, improving slope stability, periodic inspection and monitoring procedures, and mechanical equipment integrity etc., hence extensively addressed in local dam safety guidelines.

Hydro-technical aspects denote a ‘good address’ maturity level in documentation. The experts mentioned that reservoir flood routing and adequacy of outlet structures are addressed well in the local guidelines, however the importance of dam breach modelling and flood hazard mapping has not been adequately addressed. It was suggested by the experts that by recognizing the potential climate change impacts and extreme rainfall events, proactive tools such as hypothetical dam breach modelling and flood hazard mapping should be included in the hydro-technical chapter of the local guidelines.

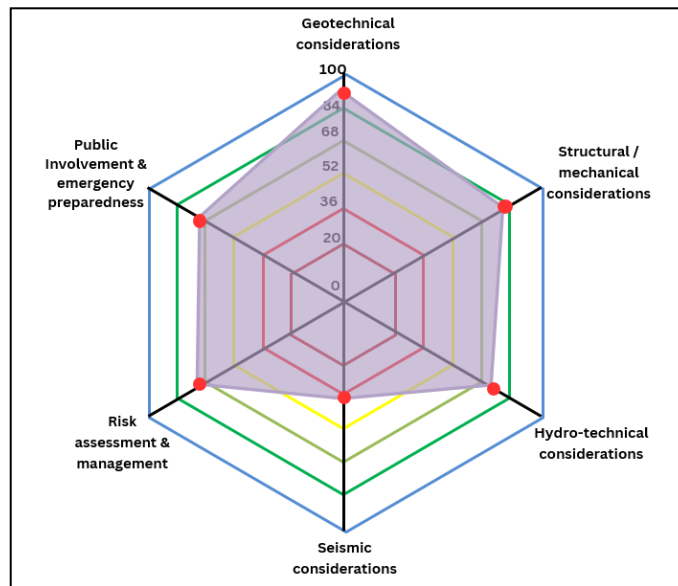
Comparing the overall maturity levels of the technical aspects in documentation, there is a notable deficiency when addressing the seismic considerations, denoting an ‘elementary address’ maturity level. As the experts explained, relatively less seismic concerns and related historical experiences in the country could be a possible reason for this exception; however, it is noteworthy to mention that seismic considerations must not be considered lightly in the face of climate change impacts in the future.

The aspect of risk assessment and management has been rated as ‘good address’ maturity level. As explained by the experts, local dam safety guidelines have adequately addressed the considerations of regulatory compliance, dam surveillance, instrumentation and monitoring procedures, and the frequency of the periodic safety reviews and the responsible personnel have also been clearly defined. Hence, when compared with the international guidelines, the risk assessment and management aspect has denoted a good address maturity level.

As per expert judgment, the public involvement and emergency preparedness aspects have been rated as ‘good address’ maturity level. The local dam safety guidelines have highlighted the importance of dam owner-downstream community relationship, the need for enhancing community awareness on dam safety and emphasized that a carefully conceived emergency management plan is crucial for the dam organizations. Despite having a good address maturity level, experts encouraged the potential room for further improvement to reach a ‘very good address’ maturity level related to the documentation of public involvement and emergency preparedness aspects.

A maturity spider diagram is developed as shown in Figure 1, based on the average maturity scores obtained for the technical aspects documentation in dam safety guidelines. It serves an effective communication tool indicating the overall image of the level of documentation, enabling a balanced evaluation rather than looking at each aspect in isolation. As Figure 2 represents, the plotted values show higher ratings in documentation of local dam safety guidelines having good and very good level address maturity levels (while improvement is needed in seismic aspects), acknowledging that the local documentation is overall at a good maturity level compared with the international guidelines.

Figure 1: Maturity Spider Diagram for Documentation of Local Dam Safety Guidelines



Maturity scores for the field implementation of Sri Lankan dam safety guidelines

The average maturity scores and corresponding maturity levels obtained from the responses of the field engineers regarding the level of field implementation of dam safety guidelines are indicated in Table 5.

Next page

Table 5: Overall Maturity Levels for Field Implementation of Dam Safety Guidelines

Field Implementation Technical Aspects	Average Maturity Score (%)	Corresponding Overall Maturity level
Geotechnical considerations	61.6	Average practice
Structural/mechanical considerations	69.1	Good practice
Hydro-technical considerations	78.4	Good practice
Seismic considerations	35.7	Needing development
Risk assessment and management	67.7	Average practice
Public involvement and emergency preparedness	66.4	Average practice

Overall, the obtained average maturity scores indicate that the field implementation of dam safety guidelines mainly falls under good and average level practice, essentially highlighting the room for further improvement.

When considering the geotechnical aspects, the field engineers highlighted that despite local engineering expertise, unavailability or lack of historical data of the earthen embankment dams built in the ancient era has been a major setback to implement the dam safety guidelines. Another reason identified from the responses is the inconsistencies of periodic inspections and the deficiencies in monitoring instruments. The majority of the earthen dams suffering from seepage issues in Sri Lanka have malfunctioning seepage monitoring instruments which pose significant challenges to the decision making process, ultimately resulting in false interpretations or neglect of the periodic inspections. These concerns have caused the geotechnical aspects to fall in the average practice maturity level in field implementation, despite having a very good address level in documentation.

Structural and mechanical aspects denote a ‘good practice’ maturity level. As stressed by the field engineers, the structural and mechanical integrity of the dam appurtenant structures is held paramount during the field implementation of dam safety guidelines. Maintenance and remedial measures of the outlet structures and mechanical components have been regularly taken place with established maintenance schedules.

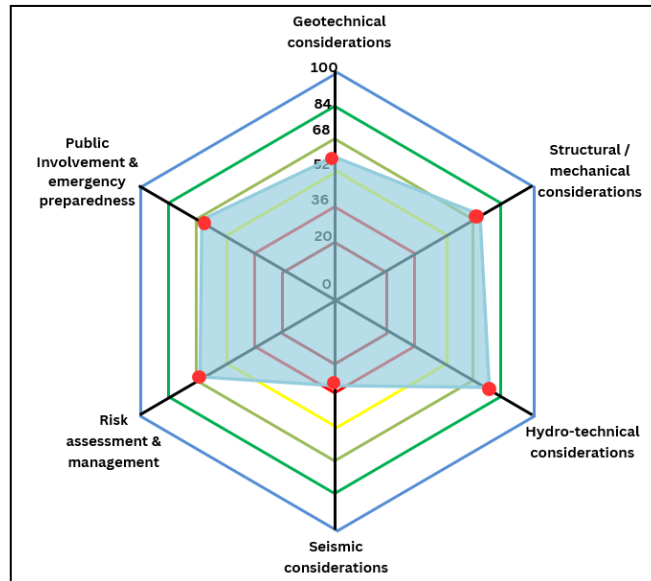
Hydro-technical aspects also denote a ‘good practice’ maturity level for field implementation. As the engineers highlighted, reservoir flood routing is effectively carried out at the dam offices and hydro-technical considerations have been given prompt attention, regularly evaluating the spillway adequacy and the performance of outlet structures over the years.

Similarly to the assessment of documentation, the lack of attention towards seismic considerations is clearly observed in the field implementation as well. As the experts mentioned, seismic loading has not been carefully accounted for during the implementation of local dam safety guidelines given the less seismic cases in Sri Lanka. Consequently, the limited practice of the field implementation of seismic considerations has resulted in ‘needing development’ maturity level.

The risk assessment and management aspects demonstrate ‘average practice’ at field implementation highlighting that despite a good maturity level in documentation, dam surveillance, periodic safety reviews and instrumentation and monitoring have not been practiced adequately in the field, necessitating prompt attention towards encouraging the field practice.

Public involvement and emergency preparedness aspect also demonstrate average maturity level of practice, emphasizing that the downstream community engagement is infrequent, lack of early warning systems or site-specific emergency management plans, and dam safety related community awareness programs not being practically implemented. The average practice maturity level obtained stresses that public involvement and emergency preparedness aspects should be enhanced with greater attention during field implementation.

A maturity spider diagram is developed as shown in Figure 2, based on the average maturity scores obtained for the field implementation of dam safety guidelines. As the maturity spider diagram denotes, there is clear room for further improvement to all the technical aspects in order to reach the desired ‘good and very good practice’ maturity levels of field implementation of dam safety guidelines.

Figure 2: Maturity Spider Diagram for Field Implementation of Local Dam Safety Guidelines

In summary, the field implementation practices fall behind the level of documentation in every aspect and notably, while documentation of geotechnical considerations demonstrates the highest maturity level, a considerable disparity is observed during the field implementation of the same, necessitating further attention. While structural and hydro-technical considerations demonstrate a good level of address in documentation and a good level of practice in field implementation, the seismic considerations significantly lag in both documentation and field implementation, when compared with the other aspects. The aspects of risk assessment and management, and public involvement and emergency preparedness demonstrate good alignment with documentation and field implementation, yet denote room for further improvement to reach a very good maturity level. Overall, the obtained results reflect the need not only to maintain strong documentation of dam safety guidelines, but also to effectively translate the same into field implementation to reach a very good maturity level compared with the international guidelines.

This expert questionnaire survey was carried out primarily targeting the technical aspects of local dam safety guidelines, however, the assessment of management, socio-economic and environmental aspects can also be carried out as improvement for this benchmarking study. Furthermore, as a positive facet, dam owners could conduct a site-specific maturity matrix benchmarking process periodically to evaluate the performance of their dam organizations over the years.

Expert Insights from the key informant interviews

The insights and perspectives of the field engineers who participated in key informant interviews were reviewed, and the crucial concerns and challenges to the field implementation of local dam safety guidelines were identified.

1. Accessibility of dam safety guidelines to the ground level field implementation

The field engineers pointed out that there is a certain gap in accessibility of dam safety guidelines at the bottom levels of the management hierarchy, in contrast with the government regulated dam organizations. In particular, medium to small-scale dams (mainly governed by provincial councils and farmer organizations) have not been adequately informed about the best practices of dam safety. The need to effectively translating the importance of implementing dam safety guidelines to the rural dam owners is identified as a timely concern by the field engineers, emphasizing that the majority of rural tanks in the country have been suffering from inadequate attention to dam safety. Hence, it was suggested to conduct island-wide capacity building programs and awareness sessions at regional dam offices involving the bottom level dam owners of the management hierarchy (ex: farmer organizations and provincial councils) to improve their awareness on dam safety guidelines.

2. Challenges for the implementation of local dam safety guidelines

The ambiguity of dam ownership is identified as a major challenge for the field engineers to implement dam safety guidelines in the field, as the lack of clear institutional responsibility often leads to unfavourable outcomes such as

disputes in policy-level decision-making, conflicts in institutional coordination, resource constraints, delays in maintenance, and gaps in accountability, etc. Consequently, it takes great effort and effective organizational collaboration at regional and national levels to enhance the implementation of local dam safety guidelines in the country.

As the field engineers highlighted, the implementation of dam safety guidelines becomes a challenging task in Sri Lanka, particularly when the dam ownership and regulation are not dispersed, as responsibility and oversight are concentrated potentially leading to neglect or conflict of interest. Hence, it was stressed that rather than being concentrated to accept self-assessment of the organization by itself, dam owners should consider the perceptions of all the stakeholders with great attention to detail, as neglect or failure to do so may lead to false interpretations.

The lack of records of historical performances and dam surveillance (ex: instrumentation and monitoring) is a recurring setback to effectively implement dam safety guidelines in practice, as the historical records with field engineers' timely recommendations are invaluable for the revisions of current safety practices at the site. During the interview sessions, it was strongly suggested to establish a designated national level system to facilitate documentation of the dam's performance throughout the lifespan.

3. *Downstream community involvement*

Encouraging the relationship between the dam owner and the downstream community is another key highlight captured at the interviews. The field engineers emphasized that the local experiences and insights are crucial to implementing the dam safety guidelines, acknowledging the fact that a supportive downstream community is an important asset to the dam owner. The engineers further highlighted that providing room for downstream community engagement not only supports the dam owner in decision making, but also improves the trust and relationship between the dam owner and the community.

4. *Way forward in enhancing local practice of dam safety guidelines implementation*

When considering the way forward in enhancing the implementation of the local dam safety guidelines in the country, the engineers highlighted that a centralized, legally empowered body to ensure regulation of dam safety guidelines is a timely requirement. Despite the ambiguity of dam ownership and responsibility, the designated body should be the custodian of documentation and implementation of dam safety guidelines in the country, empowering institutional strengthening and capacity building, thus effectively transferring the latest dam safety knowledge to the technical staff in the field. Furthermore, it was pointed out that the dedicated body should oversee the periodic assessment of dam safety guidelines implementation island-wide, while support budgeting and resource allocation at the policy level for strengthening the dam organizations.

The field engineers highlighted that each dam owner should take responsibility to develop and implement a set of site-specific safety guidelines, complementing the local dam safety guidelines which have been introduced by the Irrigation Department to a broader audience. For instance, site-specific periodic dam safety reviews and emergency management plans are vital to implement dam safety guidelines in the field more efficiently and conducting site-specific benchmarking processes periodically is identified as an ideal method to assess the performance of the particular dam.

It was a key highlight of the key informant interviews that dam safety guidelines should be developed with careful attention to the entire life stages of dams; from conceptual and design stages through construction and operation until the rehabilitation and decommissioning stages. The field engineers pointed out that it is a great reference for them during the decision making process.

Multidisciplinary organizational collaboration at regional and national levels to enhance the implementation of local dam safety guidelines is a timely requirement in the country, as identified by the field engineers. Rightfully so, as mentioned in ICOLD dam safety guidelines, safety of the dams must be held paramount by the dam owners even though it takes great effort and organizational collaboration among multidisciplinary professionals.

In summary, the respondents of key informant interviews complimented the effort of the present research study to benchmark local dam safety guidelines. The field engineers acknowledged that a periodic benchmarking approach as utilized in the study is a sustainable tool for the dam owners and governing authorities to self-assess the performance and effectiveness of their dam safety program, and it was recommended that an integrated approach involving multidisciplinary professionals while acknowledging the continued support of the downstream community as an integral component is the need of the hour to strengthen documentation and field implementation of local dam safety guidelines in the country.

Conclusion

The present study which was carried out to assess the status of the drafted local dam safety guidelines against the international standards, while focusing on the level of documentation and the field implementation. The study utilized a maturity matrix based expert questionnaire survey and key informant interviews to obtain insights from the experts involved in developing local dam safety guidelines and the field engineers responsible for dam operation and maintenance. By employing “Purposive sampling” technique for the selection of target respondents in both expert questionnaire survey and the key informant interviews, the responses were obtained from the experienced engineering professionals, who most likely yield most appropriate and useful information on their own field experience, specifically related to dam safety management. The study assessed six technical aspects related to dam safety namely, 1) geotechnical considerations, 2) structural and mechanical integrity, 3) hydro technical considerations, 4) seismic considerations, 5) risk assessment and management, and 6) public involvement and emergency preparedness. The average maturity scores for the six aspects considered in the present study revealed that the documentation of the majority of aspects performs well compared with the international guidelines, whereas seismic considerations demonstrate a notable deficiency. Most importantly, despite the good and very good maturity levels in documentation, the maturity scores obtained for field implementation of dam safety guidelines highlight clear room for further improvement, in order to obtain a very good field practice maturity level. As the present research study was conducted in collaboration with the Irrigation Department of Sri Lanka, the KII interview sessions were detailed, in-depth and transparent to represent the actual condition of dam safety field implementation in the country. The results of the key informant interviews revealed crucial concerns and challenges to the field implementation of local dam safety guidelines such as, gaps in accessibility at the bottom level, ambiguity of dam ownership, concentrated responsibility and oversight, lack of records of the historical performance and dam surveillance data etc. Furthermore, the responses from the field engineers emphasized the importance of dam safety regulation through a designated, legally empowered body, lifecycle-based dam safety guidelines, multidisciplinary organizational collaboration, sustained capacity building, and the involvement of downstream community as pivotal in enhancing the field implementation of dam safety guidelines.

Overall, a periodic benchmarking approach as utilized in the study is recognized as a sustainable tool for the dam owners and governing authorities to self-assess the performance and effectiveness of their dam safety program, which ultimately contributes to strengthening documentation and field implementation of the local dam safety guidelines in Sri Lanka.

Acknowledgement

The research study is funded by the National Science Foundation of Sri Lanka under the Research Grant No: RG/2024/EA&ICT/03. Furthermore, the authors are sincerely grateful for the support provided by the Irrigation Department of Sri Lanka during the expert questionnaire survey response collection phase and the key informant interviews.

References

- [1] Bharath, A., Shivapur, A. V., Hiremath, C. G., & Maddamsetty, R. (2021). Dam break analysis using HEC-RAS and HEC-GeoRAS: A case study of Hidkal dam, Karnataka state, India. *Environmental Challenges*, 5(August), 100401. <https://doi.org/10.1016/j.envc.2021.100401>
- [2] Awal, A., Bhattarai, U., Pandey, V. P., & Bhattarai, P. K. (2024). Downstream impacts of dam breach using HEC-RAS: a case of Budhigandaki concrete arch dam in central Nepal. *Environmental Systems Research*, 13(1). <https://doi.org/10.1186/s40068-024-00358-3>
- [3] Abdulrahman, K. Z., Faris, M. R., Ibrahim, H. M., Yousif, O. S. Q., Ghafoor, A. A., Othman, L. S., & Karakouzian, M. (2022). Hypothetical failure of the Khassa Chai dam and flood risk analysis for Kirkuk, Iraq. *Natural Hazards*, 113(3), 1833–1851. <https://doi.org/10.1007/s11069-022-05371-2>
- [4] Ahmad, I., Waseem, M., Ashraf, A., Leta, M. K., Ahmad, S., & Wahab, H. (2023). Hydrological risk assessment for Mangla Dam: compound effects of instant flow and precipitation peaks under climate change, using HEC-RAS and HEC-GeoRAS. *SN Applied Sciences*, 5(12). <https://doi.org/10.1007/s42452-023-05579-2>
- [5] Viseu, T., & de Almeida, A. B. (2009). *Dam-break risk management and hazard mitigation*. 211–239. <https://doi.org/10.2495/978-1-84564-142-9/06>
- [6] Wieland, M. (2020). *Draft Icold Bulletin: General Principles and Framework for Dam Safety General Principles and Framework for Dam Safety Draft Icold Bulletin: General Principles and Framework for Dam Safety*. 1–36.

- [7] Zhang, S., Hou, W., Yin, J., & Lin, Z. (2022). A Review of Research and Practice on the Theory and Technology of Reservoir Dam Risk Assessment. *Sustainability (Switzerland)*, 14(22), 1–21. <https://doi.org/10.3390/su142214984>
- [8] Fernando, N. (2008). Banking on dam safety in Sri Lanka. *International Water Power and Dam Construction*, 60(8), 22–24.
- [9] Wickramasuriya, S. S., & Fernando, W. C. D. K. (2012). Challenges in Dam Safety and Extreme Rainfall Estimation about Sri Lanka. *Engineer: Journal of the Institution of Engineers, Sri Lanka*, 45(1), 39. <https://doi.org/10.4038/engineer.v45i1.6948>
- [10] Rankoth, C. K. (2011). *Geotechnical Investigations on Earth Dams in Sri Lanka Unnichchai Dam as a Case Study*. 125–127.
- [11] Dolage, D. A. R., Elakanda, D. C. S., & Leelaratne, P. D. (2015). Beneficiary Participation in Formulating Social Safeguard Management Programmes – Experience from Dam Safety and Water Resources Planning Project of Sri Lanka. *Engineer: Journal of the Institution of Engineers, Sri Lanka*, 48(2), 15. <https://doi.org/10.4038/engineer.v48i2.6830>
- [12] Leeuw de, S. (2011). Supply Chain Process Benchmarking Using a Self-Assessment Maturity Grid. *Supply Chain Management*.
- [13] World Bank. (2018). *Maturity Matrices*. 1–41.
- [14] Knott, R., & Smith, L. (2019). Using maturity matrices to evaluate a dam safety program and improve practices. *Sustainable and Safe Dams Around the World*, 2171–2183. <https://doi.org/10.1201/9780429319778-196>

About the authors

Name: G.K.P. Wickramasinghe

Mailing address: G.K.P. Wickramasinghe, Research Assistant, Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Sri Lanka.

Tel: (+94)71 993 8484

E-mail: gkalanaprabhath97@gmail.com

Name: A.P.N.P. Chandrasena

Mailing address: A.P.N.P. Chandrasena, Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Sri Lanka.

Tel: (+94)75 944 5278

E-mail: piyumnalaka4@gmail.com

Name: Dr. A.G. Jayasinghe

Mailing address: Dr. A.G. Jayasinghe, Senior Lecturer, Department of Civil Engineering, Faculty of Engineering Technology, The Open University of Sri Lanka, Nawala, Nugegoda, Sri Lanka.

Tel: (+94)76 434 3614

E-mail: anjay@ou.ac.lk

Name: Dr. S.W. Seneviratne

Mailing address: Dr. S.W. Seneviratne, Senior Lecturer, Department of Civil and Environmental Engineering, Faculty of Engineering, University of Ruhuna, Hapugala, Galle, Sri Lanka.

Tel: (+94)76 068 2167

E-mail: samanthi@cee.ruh.ac.lk

