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Photo Courtesy of Ir. Fong Chew Chung

Command room of Itaipu dam on river Parana on the border of Brazil and Paraguay

Deficiencies of Current Dam Safety Management Practice

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There are currently 106 dams constructed in the country for various purposes - water supply, irrigation, flood mitigation, hydropower generation and recreation. The standards and practices of dam safety management adopted by dam owners/operators vary. The resources, knowledge and skills available also vary widely. Significant effort is required to bring the dam safety management systems of dam owners in line with current international practice on dam safety.

The current legislations on dam matters at both federal and state levels are not specific. There is no regulatory body to enforce dam safety requirements. The responsibilities and liabilities of dam owners/ developers have not been established.

Majority of the dam owners have no established dam safety management programme. There is a lack of a policy framework; allocation of resources to carry out safety programmes; training of personnel; information management and public consultation. In most cases the dam safety programmes do not cover the whole life cycle of the dam.

There is an urgent need to improve the dam safety management practice in the country to bring it into line with good international practice so that the risks of dam failure can be controlled to a level that is as low as is reasonably practical.

This article discusses deficiencies of the current dam safety management practice and dam safety issues in Malaysia. The risk of dam failure increases as more dams are built and they are subjected to natural hazards such as earthquakes, floods and landslides. Some of the dams are old. Any development of the downstream environment of existing dams increases the hazard of dam failures. Upgrading of old dams may be required due to the change in design criteria related to changes in catchment conditions, climate and seismic activities. A dam safety review is necessary to assess the performance and/or the response of dams during extreme events such as floods and earthquakes. The concrete structures of some older dams have deteriorated due to weathering and flow control equipment such as flow control valves have also deteriorated due to corrosion.

The current dam safety management practices in the country are not in line with good international practice. The risk of dam failure and impact of dam failure can be minimised by implementing and maintaining an appropriate dam safety programme.

State / Federal Territory	Total No.	Water Supply	Irrigation	Flood Mitigation	Hydropower	Silt Retention	Recreation
Johor	17	13	1	3			
Kedah	7	2	5				
Kelantan	2		1		1		
Negeri Sembilan	9	8	1				
Melaka	5	4					1
Pahang	10	3	2		2	3	
P. Pinang	6	6					
Perak	10	2	1		6	1	
Perlis	1		1				
Selangor	10	7	2	1			
Terengganu	6	3	1		2		
Sabah	10	8			2		
Sarawak	9	6			3		
Labuan	3	3					
Putrajaya	1						1
TOTAL	106	65	15	4	16	4	2

Table 1: Distribution of Dams in State/Federal Territory & Functions of Dams in Malaysia
Note : For multi-purpose dams only the primary function of dam is stated and their secondary functions are not indicated.

Period	No. of Dams Built	Period	No. of Dams Built
≤ 1900	3		
1901 – 1910	1	1961 – 1970	10
1911 – 1920	0	1971 – 1980	6
1921 – 1930	2	1981 – 1990	28
1931 – 1940	9	1991 – 2000	12
1941 – 1950	2	2001 – 2010	18
1951 – 1960	3	2011 – 2016	12

Table 2: Dams Built In Various Periods

Distribution Of Dams According To Function, Age, Dam Type and Hazard Rating

Table 1 shows the distribution of 106 dams built by various Government agencies and private developers for various purposes throughout the country. The owners of most dams are federal ministries and state statutory bodies. Private developers and mining companies are also involved in dam development.

Besides the 106 dams listed in Table 1, there are around 10 dams built by private companies for various purposes, such as storage of mining waste (tailing dams) and water supply in agriculture plantations. There are also dams built for storage of sludge from water treatment plants and storage bunds built for water supply and storm water detention.

Distribution of Dams According to Function

Over 60 % of the dams in the country were built for water supply purposes. There are 65 water supply dams out of a total 106 dams in the country. There are 15 (14.1%) irrigation dams, and 16 (15.1%) hydropower dams. There are four (3.8%) dams built for flood mitigation purpose, four for silt retention and two for recreational purposes.

Distribution According to Hazard Ratings of Dams

There are 48 dams which fall under the category of significant and higher hazard rating based on the current guidelines. At least 20 dams are located close to urban centres mostly due to downstream development.

Distribution of Dams According to Age

There are four dams over 100 years in age, which is generally taken as the design life span of dams. There are 20 dams over 50 years old. There are a few dams that have been decommissioned, e.g. Asahan Dam in Melaka and Berapit Dam in Penang. There are also dams where their functions have changed, for example Ayer Keroh Dam in Melaka, changed from water supply to recreational purposes. The distribution of dams built in various periods is shown in Table 2.

Distribution of Dams According to Dam Type

Table 3 shows the distribution of dams according to the type of design. Seventy (66%) of the dams built in the country are of the earth fill type. In recent years there is an increasing number of Roller Compacted Concrete Dams being built.

Item	Dam Type	No.	Percentage %
1	Earth fill	70	66
2	Rock fill	14	13.2
3	Concrete gravity	18	17
4	Others	4	3.8

Table 3: Distribution of Dams According to Dam Type

Referable Dams

Out of the 106 dams, there are 99 which are classified under referable dams (dam to be regulated) i.e. dams that are 10m or higher with storage capacity of 20,000m^3 or dams that have storage capacity of 50,000m^3 or more and are over 5m high.

Privately owned dams such as tailing dams are least known to the public and they are mostly located in isolated areas. There have been incidences of contamination to downstream areas due to stored toxic substances, including heavy metals, escaping from the tailing dams. There is a real need to bring the tailing dams under Government regulation due to the potential threat to the environment and people.

Existing Laws Related To Dam Safety

The siting of dams within the state is subject to State Government approval. Such approval may be given subject to conditions imposed by the State pursuant to various state laws including those related to town and country planning, land code, environment and natural resources, water resources, local Government and street buildings and drainage.

The Federal Government also has jurisdiction over dams, particularly in relation to the safety of workers, machinery and construction. However there is no specific federal legislation which adequately covers safety management of dam development and operation. To-date there are no specific regulations, guidelines or procedures made under Federal Legislation related to dam safety in the country.

Existing Dam Safety Management Guidelines

The current guidelines on dam safety management of dams in Malaysia i.e. Guidelines for Operations, Maintenance and Surveillance of Dams by Inter-Departmental Committee on Dam Safety was published in 1988. There is a lapse of over 27 years without any updating of the guidelines. The guidelines are merely advisory in nature and have no legal standing and lack any clout in implementation.

The Guidelines only cover operation, maintenance and surveillance of dams. A dam safety programme should cover whole life cycle of activities for a dam from planning, investigation, design, commissioning, construction, surveillance, operation and maintenance, safety review, remedial action, and emergency preparedness.

Responsibilities and Liabilities of Dam Owners, Operators and Dam Practitioners

The responsibilities and liabilities of dam owners, operators, designers and contractors and key stakeholders such as regulators, private property owners and communities downstream from dams are not defined in the existing legislation.

There are also state regulators, for example BAKAJ which has jurisdiction on dam matters and is also the owner of a numbers of water supply dams in Johor state.

Why an established dam safety management system is necessary

Dam failure can be catastrophic from which the owner, and others, would never recover as shown in such incidents over the world. It should be emphasised that dams are not ordinary structures. Dam failures can entail great financial loss to owners, disruption to public services, loss of life and extensive economic losses to downstream communities and major environmental damage.

Dams are subject to natural hazards such as earthquakes and floods that can affect the safety of dams and cannot be controlled by dam owners. Other risks, such as human error in design, construction, and operation of the dams that can affect the safety of dams, can be controlled by the dam owner.

There is a conflict of interest: it is not possible to enforce the dam safety regulations if the Regulator is also the dam owner.

Geology greatly influences structural safety, water retention and reservoir slope integrity. The quality of construction materials and dam design affect the resilience of the dam. The flood risks, seismic risks and earthquake loads may weaken the integrity of the dam. Safety issues associated with dams may be complex.

Oroville Dam, with damaged spillway.
Picture by William Croyle, California Department of Water Resources (Public Domain, wikimedia.org)

Dams age and deteriorate through on-going geological and chemical processes. If the foundations and abutments are structurally weak and subject to internal erosion, then dam safety issues can arise. Dam safety deficiencies in the foundations and abutments can include weaknesses (e.g. joints, shear zones, faults) that are susceptible to instability, erosion or liquefaction, and long-term weathering and chemical degradation of materials.

The consequences of a catastrophic dam failure are enormous. At stake are not only lives and property, but communities, their economic well-being and the natural environment.

Malaysia has experienced several dam incidences involving the loss of life and economic losses as follow:

- In October 2013, four illegal squatters who encroached onto the spillway outlet area of the Sultan Abu Bakar Hydro Power Dam drowned when excess water was released from the dam during a monsoon.
- In 1981, Batu Arang Dam, Selangor, an earth fill dam failed due to a classical slip on the upstream slopes during a prolonged wet spell with evidence of the extensive softening of the compacted materials on the upstream slopes.
- Collapse of the spillway at Anak Endau Dam in 1986 during its first over-spilling.
- Damage of Ayer Keroh Dam in November 1993 due to construction at the downstream toe of the dam.
- Collapse of the cofferdam at Paya Peda Dam in 2012 due to over topping by flood waters during construction of the dam.
- Bukit Panchor Dam, Penang, an earth fill dam failed due to a classical slip on the upstream slopes following an extremely wet and then a prolonged dry period in 1970.

With increasing population density the probability of loss of life and property damage is increasing. Vigilance is also necessary because

of the increasing number of large dams being constructed on less than ideal foundations. In addition, historical evidence indicates that effective dam safety programmes could have prevented the majority of dam incidents progressing to dam failures.

Dam failures continue to occur worldwide emphasising the need for on-going vigilance. Examples of recent dam failures include Shih-Kung Dam, Taiwan which suffered extensive damage in an earthquake in September 1999 and Zeyzoun Dam in Syria which failed in June 2002. Details of dam incidents are contained in "Dams and Public Safety" (*Jansen, 1983*), "Deterioration of Dams and Reservoirs *(ICOLD, 1983*) and "Lessons from Dam Incidents" (*ICOLD 1974).*

Current Dam Safety Management Practice

The current dam safety management practice in the country is largely by self regulation. There is no specific law on dam safety. There is no regulatory body to regulate activities on dam development and operation. Majority of the dam owners practice a limited number of elements of the Dam Safety Management System (DSMS). The standards and resources employed by dam owners vary considerably. There is a lack of an overall management system to implement dam safety activities, decision making processes and capacity building among dam owners in the country.

Dam safety management should cover both the assurance of quality in design, construction, surveillance and safety review throughout the life of a dam. The primary objective is preventing dam failure. It also involves preparing to respond to unusual conditions so that hazardous situations can be brought under control. The DSMS should reflect the owner's dam safety policy and provide a structured framework for conducting dam safety activities and addressing dam safety issues. A DSMS should incorporate:

- A dam safety policy, dam safety statement or dam safety standard.
- A description of the elements of the DSMS, dam safety management activities and resources for completing these activities.
- Responsibilities and procedures for implementing the DSMS
- Procedures for checking and reviewing the performance of the dam and the DSMS.
- Procedures for implementing corrective actions on deficiencies and non-conformance.
- Procedures for regular reporting of the performance of the dam and the adequacy of the DSMS to the owner and where appropriate, the regulator.
- Supporting systems for management, staff training, communications, information management and continuous improvement.

The DSMS should incorporate arrangements for governance, a good internal organisational structure, a clear decision-making process, competent staff, and key project data and records. An example of a DSMS is presented in Figure 1.

Deficiencies Of Current Dam Safety Management Systems

The key elements in a DSMS should include the following:

- Accountability
- Personnel competencies
- Operation and maintenance
- Surveillance
- Dam safety reviews
- Special inspections and dam safety reviews
- Emergency preparedness
- Identifying and managing dam safety issues
- Information management
- Audits and reviews

Countries with dam safety regulations typically stipulate the elements that must be included in the dam safety assurance programme. An effective DSMS not only provides a framework for a dam owner to assure safe dam operation, but also supports asset management and allows owners to maximise the value of the asset.

Currently, most dam owners do not have an established DSMS or practice a limited numbers of the key elements. Common cases of non-conformances or deficiencies of local DSMS which are not in line with good international practice include:

- The dam safety management system does not exist or is inadequate.
- The dam safety management processes, procedures or plans are not documented or followed.
- Appropriate dam safety governance, oversight and enabling arrangements do not exist.
- Roles and responsibilities are not adequately defined and understood.
- Lacking experienced and qualified personnel to implement appropriate dam safety management programmes.
- Surveillance inspectors are not adequately qualified and trained.
- Dam safety issues are not resolved within a time frame to reduce risk.
- Dam safety management system record-keeping is inadequate, e.g. design, construction, operation, maintenance, surveillance or testing records are limited or unavailable.
- Emergency action plan does not exist, is inadequate, or is not tested.
- Dam safety regulatory requirements are not met.

Accountability

The overall accountability for a DSMS remains with the dam owner and senior management of the organisation whether a public authority or private company. The DSMS should have a dam safety policy statement which provides the organisation's directive to its personnel who are responsible for implementation of the dam safety management system. Effective dam safety requires responsibilities to be fulfilled at all levels in the owner's organisation, from senior management to field personnel. A clear line of authority and accountability for dam safety in an owner's organisation is needed to ensure effective dam safety management.

Personnel Competencies

The effective management of dam safety generally involves a wide range of skills. On the ground routine surveillance and monitoring is commonly completed by the owner's permanent staff. Evaluation of the surveillance and monitoring results, the assessment of performance, and the completion of dam safety reviews should be undertaken by people competent in the evaluation of surveillance and monitoring results.

Operation and Maintenance

In most cases operators do not understand the parameters within which their reservoirs are to be operated for normal, unusual (e.g. flood) and extreme (e.g. earthquake) and emergency conditions (i.e. conditions that could result in dam failure if appropriate actions are not taken).

From the dam safety perspective the operation of a reservoir should not present undue risk to the people and their property and the environment downstream of the dam in the river system. There must be a sufficient margin to ensure safety of the dam under all loading conditions and foreseeable operational scenarios. Sufficient freeboard must be available to prevent overtopping or flooding during extreme weather events. There may be a need to limit the rate at which the reservoir level is lowered to ensure the stability of the dam and that the reservoir shoreline is not affected.

Operating personnel should be able to recognise significant threats to the safe performance of the dam and signs for the development of its potential failure modes, and understand how to initiate appropriate response actions and when to seek specialist technical advice.

Surveillance

A sound surveillance process is the owners' first line of defence for the safety of their dams. It includes routine visual inspections, instrument monitoring, data reviews and evaluation, and reporting on the safety of the dam. The United States Federal Guidelines for Dam Safety (FEMA 2004) includes the following statement:

> *Monitoring existing dams and reacting quickly to inadequate performance or to danger signals is a continuing critical aspect for dam safety. Careful monitoring and quick response can prevent failures, including those caused by poor construction.*

In most cases, the surveillance exercise is hampered by lack of records such as 'as-built' drawings, design reports, construction reports

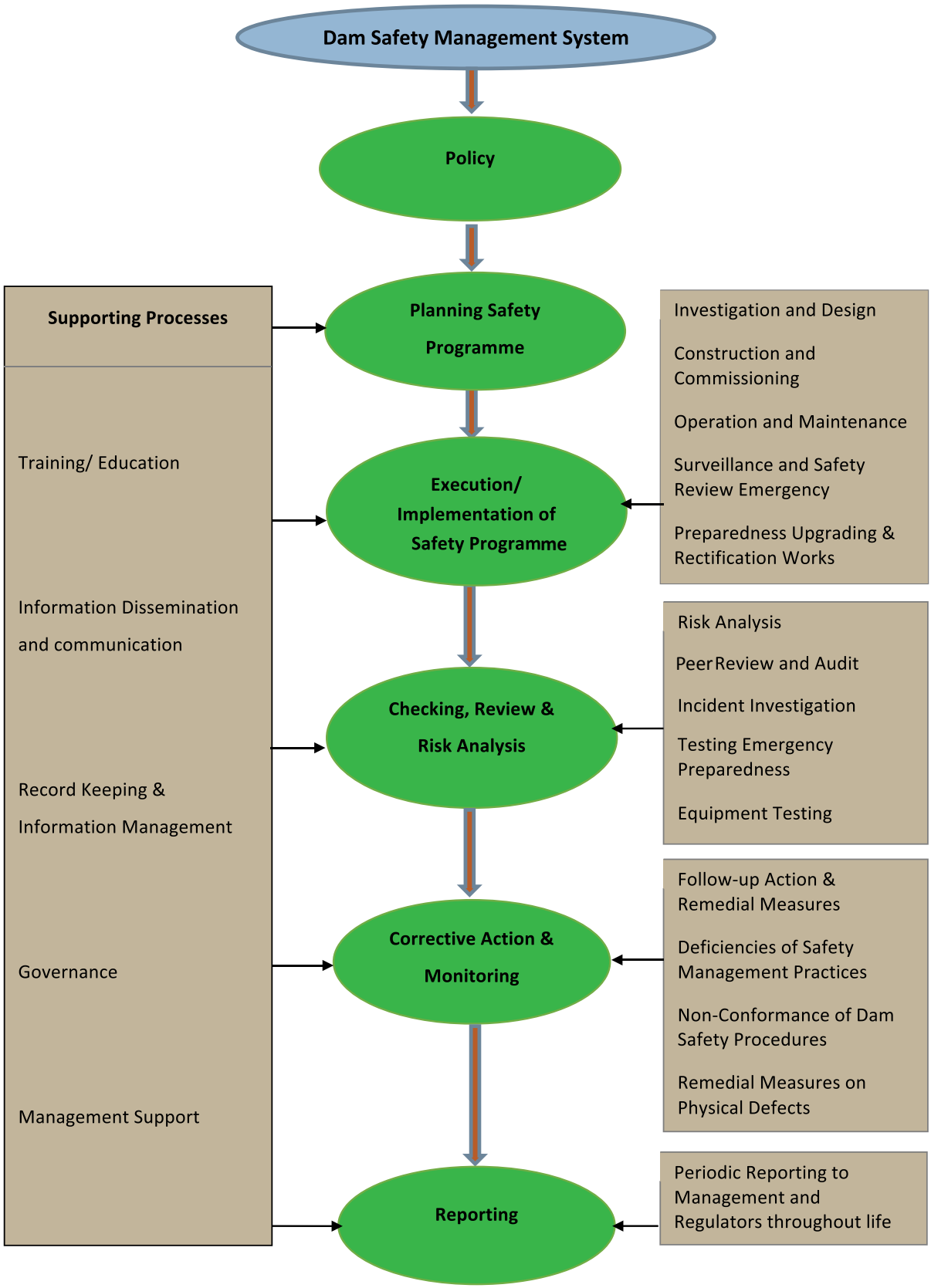

Figure 1 : Dam Safety Management System of Dam Owner

etc. As such, it is difficult to obtain a good understanding of the historical performance, inherent condition, characteristic behaviour and potential failure modes of the dam. In some cases, the dam instrumentations are damaged and the instrumentation data is not available.

The causes and processes of dam failure are varied. Case histories of dam failures reveal many remarkable similarities in antecedent conditions and processes of deterioration. Often deficiencies have developed over extended periods of time, yet these conditions have either gone undiscovered or were incorrectly interpreted. Surveillance programmes should be capable of detecting such conditions and processes early enough for corrective action to be taken.

Safety Reviews

Dam owners must recognise that there are uncertainties associated with natural destructive forces, material behaviour and construction processes associated with their dams. These must be balanced with competent technical judgement to deal with the uncertainties.

Dam safety reviews are required for assessing the safety of a dam, and comprise where relevant, detailed structural, hydraulic, hydrologic, geological and geotechnical design aspects and the records and reports from surveillance exercises.

A safety review should assess the integrity of a dam against known failure modes and mechanisms for the various types of dams in terms of safe acceptance criteria such as engineering standards and dam safety guidelines in order to recommend remedial or maintenance works.

Special Safety Review

A special safety review may be required on short notice if any inspections, monitored results or unusual events such as flooding, earthquake or landslide indicate that an adverse trend or condition exists. A safety review should also be undertaken to update the risk profile of a dam (See figure 1).

Emergency Preparedness

The standards used for design, construction, operation, maintenance and surveillance of dams minimise the risk of dam failures. However, unusual circumstances could result in dam failure. Dam owners should establish a formal internal emergency action plan that describes the procedures that operation staff should follow in the event of an emergency at the dam.

Two types of emergency plans might be required:

1. A dam safety Emergency Action Plan (EAP) developed by dam owner; and
2. A separate Disaster Plan, developed by State or local disaster management agency to provide protection for downstream communities in the event of a dam safety emergency.

It is important that these two plans be linked in a compatible manner.

An EAP is a formal plan that:

- Identifies emergency conditions which could endanger the integrity of the dam and which require immediate action;
- Prescribes procedures which should be followed by the dam owner and operating personnel to respond to, and mitigate, any emergency conditions at the dam; and
- Provides timely warning to State or local disaster management agencies for implementation of their protection measures for downstream communities.

It is essential that an EAP be tested periodically by conducting a drill simulating emergency conditions. For high hazard rating dams, an annual in-house review should be conducted and, at least once every five years, a drill should be conducted that is co-ordinated with all State and local disaster management agencies.

Identifying and Managing Dam Safety Issues

The identification and management of dam safety issues is an essential part of dam safety management by dam owners. Dam safety issues include physical infrastructure issues, dam safety deficiencies and non-conformances.

Information Management

In the context of dam safety in a dam's lifetime, the importance of careful record keeping and preservation of all dam information cannot be overstated.

Removal of the Marmot Dam, Sandy River, Oregon
By NOAA (Public Domain, wikimedia.org)

Audits and Reviews

Audits and reviews of a dam safety management system allow owners to maintain continuous improvement and provide assurance that dam safety risk is being appropriately managed.

Life Cycle Management

Dams typically have life expectancies that span over a 100 years. It is almost inconceivable that the environment within which a dam is situated, its use, operational requirements, technology and society's expectation of dam safety remain unchanged over the life of a dam. Dam owners must take note of such changes over time and their impact on dam safety.

There are many changes that can occur over a dam's lifespan that may require dam safety management including:

- Lifetime changes that may necessitate dam safety management such as changes to upstream catchment land use and downstream environment changes.
- Management of dam safety issues.
- Sediment accumulation in reservoirs and its effects on dam safety.
- Changes in use, where the function of a dam is required to be different from its original function.
- Decommissioning of a dam and decommissioning procedures.

Due diligence should be exercised during all stages of a dam's life cycle. Owners may need to consider the necessity for rehabilitation works in order to ensure the dams remain safe and in operable condition.

CONCLUSIONS

1. The current dam safety management practice in the country is not in line with good international practice.
2. There are serious deficiencies in the dam safety management system of dam owners.
3. There is no specific Federal Law to deal with dam safety matters.
4. Dam owners/ operators practice self-regulation, this is not effective in management of dams to a desirable standard. There is a general lack of public awareness on the hazard of dams.
5. There is a real need to establish a Government body to regulate development and operations of dams.
6. National dam safety management guidelines are needed to assist dam owners and all parties in understanding the legal obligations and liabilities of those associated with the development, ownership and operation of dams in Malaysia. ■

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