GOVERNMENT OF MALAYSIA

MALAYSIA DAM SAFETY MANAGEMENT GUIDELINES

(MyDAMS)

2017

MALAYSIA DAM SAFETY MANAGEMENT GUIDELINES (MyDAMS)

2017

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FOREWORD

The Cabinet on 29th August 2012 had given directive to KeTTHA in collaboration with Performance Management and Delivery Unit (PEMANDU) to discuss issues pertaining dam safety management practices in Malaysia. On 29th October to 9th November 2012, a special lab session headed by PEMANDU had come to conclude and endorse the need to establish a Special Committee to regulate all dam safety management practices and to set up a Dam Technical Centre (DTC).

The Government of Malaysia via Drainage and Irrigation Department (DID) under the purview of Ministry of Natural Resources and Environment (NRE) has appointed Angkasa Consulting Services Sdn. Bhd. (ACS) to produce the Dam Safety Management Guidelines and to draft the Dam Safety Management Act. Six meetings were held with the Dam Owners, Operators, State and Federal Agencies.

Malaysia Dam Safety Management Guidelines (MyDAMS), is a national guidelines aimed to serve as a source of information and to provide guidance pertaining to the latest dam safety best management practices (BMPs) for entities involve in local dam industry. MyDAMS, quite extensive in its entirety so as to cover the whole life cycle of dams.

MyDAMS is developed through contributions from the Government and private sectors. This is one of the many initiatives undertaken by the Government to further enhance its services parallel with ongoing transformations taking place in Government Department and private sectors. On the other hand, the public expects that measures to protect safety will be in line with best international practice.

It may be relatively difficult for engineers and professionals to get use of it for the first time. It is highly recommended that MyDAMS will be reviewed when knowledge and practice have developed to the point where an update is required.

Last but not least, there are many to name and congratulate individually for those involved in preparing MyDAMS. Most of them are my fellow professionals who are well-respected within their fields. I wish to record my sincere thanks and appreciation to all of them and I am confident that their contributions will be truly appreciated by the users in many years to come.

Ir. Hj. Ab. Qahar bin Osman
Chairman of Steering Committee

PREFACE

The Government of Malaysia intends to establish the Dam Safety Management Guidelines for safety management of dams in Malaysia.

This Malaysia Dam Safety Management Guidelines (MyDAMS) has been prepared based on the dam safety guidelines and technical bulletins published by International Commission on Large Dams (ICOLD) and other internationally recognised references on dam engineering. It outlines appropriate practices that should be considered during the investigation, design, construction, commissioning, maintenance, operation, safety surveillance, safety review, emergency preparedness, rehabilitation and the life cycle management of dams.

MyDAMS is applicable to all dams that are:

- 10 meters or more in height with a storage capacity of more than 20,000 cubic meters or
- dams with storage capacity of 50,000 cubic meters or more and are higher than 5 meters.

However, this term are not intended to be applied to tailings dams, aquifer recharge dams and check dams.

The absence of a proper best management practices on dam safety may increase the risk of dam failures which cause loss of life, properties, economic and environmental damage. MyDAMS is established with the purpose to ensure that the dam safety management in Malaysia is in line with the international recognised practices.

MyDAMS outlines technical procedures required for dam safety management and the roles and responsibilities of the key players involved. This includes the importance of a Dam Owner's commitment to safety programs, risk management, and the provision of adequate financial and human resources. Dam Owners are encouraged to view proper dam safety management as a key element of their overall risk and asset management strategies. Dam safety management should encompass throughout the life cycle of a dam from planning and investigation to decommissioning of the dam.

MyDAMS is not intended as design standards or an instruction manual. Specialists experienced in the design, construction and operation of dams are best qualified to judge the suitability of MyDAMS for a particular purpose.

It is recommended that MyDAMS has to be revised as and when required.

ACKNOWLEDGEMENTS

MyDAMS have been deliberated by representatives of Dam Owners, Operators, government agencies involved in dam matters and dam practitioners in Malaysia. This document would not have been possible without their time, efforts and facilities towards the completion of MyDAMS and their contributions are gratefully acknowledged. The Steering Committee and Working Group are listed below.

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Exhibit A list all the organisation involved in development of MyDAMS.

Exhibit A:

Kementerian Kemudahan Awam Sarawak

Kementerian Pembangunan Infrastruktur Sabah

Kementerian Pertanian dan Industri Asas Tani (MOA)

Kementerian Sumber Asli dan Alam Sekitar (NRE)

Kementerian Tenaga, Teknologi Hijau dan Air (KeTTHA)

Jabatan Air Kelantan

Jabatan Air Negeri Sabah

Jabatan Air Terengganu

Jabatan Alam Sekitar

Jabatan Bekalan Air, KeTTHA

Jabatan Mineral dan Geosains Malaysia (JMG)

Jabatan Pengairan dan Saliran, Malaysia

Lembaga Air Perak (LAP)

Lembaga Kemajuan Pertanian Muda (MADA)

Lembaga Sumber Air Negeri Kedah (LSANK)

Lembaga Urus Air Selangor (LUAS)

Badan Kawalselia Air Negeri Johor (BAKAJ)

Badan Kawalselia Air Negeri Melaka

Badan Kawal Selia Air Pahang

Badan Kawal Selia Air Negeri Pulau Pinang

Badan Kawal Selia Air Negeri Sembilan

Pasukan Projek Penyaluran Air Mentah Pahang – Selangor (PPAMPS)

Perbadanan Putrajaya

Sarawak Energy Berhad

Sarawak Hidro Sdn Bhd

Tenaga Nasional Berhad (TNB)

Angkasa Consulting Services Sdn. Bhd.

Document History

Original	2017	Parent with Appendices (A-F)

ACRONYMS AND ABBREVIATIONS

AEP	Annual Exceedance Probability
ALARP	As Low As Reasonably Practicable
ANCOLD	Australian National Committee on Large Dams
CDA	Canadian Dam Association
CFRD	Concrete Face Rockfill Dam
CIDB	Construction Industry Development Board
DID	Department of Irrigation and Drainage, Malaysia. Also abbreviated as ‘JPS’
DOC	Designer Operating Criteria
EAP	Emergency Action Plan
FERC	the Unites States Federal Energy Regulatory Commission
FEMA	Federal Emergency Management Agency, US Department of Homeland Security
FMA	the Factories and Machinery Act 1967
FMEA	Failure Modes and Effects Analysis
FSL	Full Supply Level
ICODS	Inter-departmental Committee on Dam Safety
ICOLD	International Commission on Large Dams
IDF	Inflow Design Flood
MCE	Maximum Credible Earthquake
MNCOLD	Malaysian National Committee on Large Dams
MyDAMS	Malaysia Dam Safety Management Guidelines
NADMA	National Disaster Management Agency
NPL	Normal Pool Level
NZSOLD	New Zealand Society on Large Dams
O&M	Operation and Maintenance
OBE	Operating Basis Earthquake
OSHA	Occupational Safety and Health Act 1994
PAR	Population at Risk
PLL	Potential Loss of Life
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RCC	Roller Compacted Concrete
RTS	Reservoir Triggered Seismicity
SCADA	Supervisory Control and Data Acquisition
SEE	Safety Evaluation Earthquake
USACE	United States Army Corps of Engineer
USBR	United States Bureau of Reclamation

GLOSSARY OF TERMS

Abandonment of Dam: The dam is not to be used and adequate dam structures has been removed or altered, hence making it unable to impound a storage, in present or future, and constitutes no risk to the public and environment. It does not require any continual dam safety actions such as operation, maintenance and surveillance.

Abutment: The undisturbed natural material part of the valley side or bank, excavated to acceptable foundation surface, against which the dam is constructed. An artificial abutment is sometimes constructed, as a concrete gravity section, where there is no suitable natural abutment.

Acceptable Risk: A risk which, for the purpose of life or work, everyone who might be impacted is prepared to accept assuming no changes of risk control mechanisms. Such a risk is regarded as insignificant or adequately controlled. Action to further reduce such risk is usually not required unless reasonably practicable measures are available at low cost in terms of money, time and effort.

Active Fault: A fault, reasonably identified and located, known to have produced historical earthquakes with epicentre nearby or showing evidence of movements, one or more times in the last 10,000 years.

Active Storage: The volume of a reservoir that is available for its purposes (e.g. water supply, irrigation, etc.). Active storage excludes flood surcharge. It is the reservoir capacity less dead storages.

ALARP (As Low As Reasonably Practicable) Principle: Principle which states that risks, lower than the limit of tolerability, are tolerable only if further risk reduction is impracticable, or if its cost is grossly disproportionate (depending on risk level) to the benefit gained.

Annual Exceedance Probability (AEP): The probability of a specified magnitude of a natural event being equalled or exceeded in any year.

Appurtenant Structures: All ancillary structures, components and equipment functionally pertaining to the dam including, but not limited to, spillways, inlet and outlet works, water conduits, tunnels, pipelines, penstocks, power stations and diversions.

Auxiliary Spillway: A secondary spillway designed to operate only when normal floods are exceeded. Also referred to as Emergency Spillway.

Base of Dam: The general foundation area of the lowest portion of the main body of the dam. It excludes seepage barriers below foundation area and any piled foundation.

Breach: The uncontrolled release of the contents of a reservoir through failure of a dam or appurtenant structure (see also 'Failure'). The final stage in development of a dam failure, where the preceding stage are initiation, continuation and progression.

Breach Outflow Hydrograph: A graph of discharge versus time describing the rate that the storage volume is released from an upstream reservoir through a dam breach as the breach forms over time.

Breach Parameter: Parameters that described the nature of dam breach (e.g. shape, width, depth, rate of growth, time to breach).

Cascade Failure: The 'domino' effect of the failure of an upstream dam that cause overtopping and the consequential failure of downstream dams.

Catchment: The land surface area which drains to a specific point, such as a reservoir.

Consequence: Effects of an action or event that have impacts on downstream or upstream area of a dam as a result of failure of the dam or its appurtenances. In MyDAMS, the term '*consequences'* refers to the damage above and beyond the damage that would have occurred in the same event or conditions had the dam not failed. See also '*incremental'*.

Contractor: The primary construction entity appointed to the dam works (e.g. dam construction, upgrading, raising, rehabilitation, decommissioning, etc.).

Controlled Document: A document subject to managerial control over its content, distribution and storage. It may have legal or contractual implications.

Crest of Dam: The elevation of the uppermost surface of a dam proper, not taking into account any camber allowed for settlement, kerbs, parapets, crest walls, guardrails or other structures that are not a part of the main water retaining structure. This elevation may be a roadway, walkway or the non-overflow section of a dam.

Dam: All man-made barriers, together with appurtenant works, constructed for storage, or control of water or other fluids. This classification normally excludes canals and levees, but MyDAMS may be used as a basis for developing safety management plans for these structures, if the need exists.

In MyDAMS, the term '*dam'* includes '*appurtenances'* and systems incidental to, necessary for, or connected with the barrier.

The Guidelines is applicable to all dams that are 10 meters or more in height and have a storage capacity of more than 20,000 cubic meters; or dams which have a storage capacity of 50,000 cubic meters or more and are higher than 5 meters. However, this term are not intended to be applied to tailings dams, aquifer recharge dams and check dams for debris flow control.

Dam Break Study: A study of the hazard of a potential dam break flood to downstream people, property and the environment (e.g. extent of inundation, depth of inundation, velocity, flow, time to peak flow, duration of inundation).

Dam Crest Flood: The flood event which, when routed through the reservoir, results in a still water reservoir at the lowest crest level of the dam.

Dam Designer: A primary engineering entities appointed to design a new dam, to design any rehabilitation, raising or upgrading work of an existing dam, or to design any works to decommission an existing dam.

Dam Engineer: A professional engineer who is suitably qualified and recognised by the engineering profession as experienced in the engineering of dams and its various subfields.

Dam Hazard Rating: A classification system that categorizes dams according to the degree of adverse incremental consequences of a failure or mis-operation of a dam. The dam hazard rating does not reflect in any way on the current condition of the dam (e.g., safety, structural integrity, flood routing capacity).

Dam Inspection: A careful and critical viewing and examination of all visible aspects of a dam.

Dam Instrumentation: Instruments installed on or near dams for the purpose of dam safety performance monitoring.

Dam Owner: The person, organisation or entity legally deemed to be the owner of a dam and reservoir. The dam owner is responsible for the safety of a dam.

Dam Safety Inspector: A technical person suitably trained to undertake dam safety inspections.

Dam Safety Management System: A framework and programme of actions and activities to manage the safety of a dam for its entire life cycle.

Database: An abbreviated convenient source of information summarising all pertinent history and records related to the safety of a dam that is required to assess the performance and safety of a dam.

Dead Storage: The storage that lies below the invert of the lowest intake that cannot be released by gravity flow from the reservoir.

Decommissioned Dam: The dam that has reached the stage in its life cycle when both its construction and its intended use have been taken out of service permanently and which has been rendered adequately safe in the long term according to its decommissioning plan.

Designer Operating Criteria (DOC): Comprehensive operating criteria which state the dam designer's intentions in the use and operation of equipment and structures in the interest of safe, proper and efficient use of the facilities.

Deterministic: A term applied to a process whose outcome is always the same for a given set of inputs. Contrast with '*probabilistic'*.

Disaster Plan (Dam Crisis Plan): A plan developed by emergency management agencies to provide community protection in the event of emergencies (e.g. floods).

Discontinued Dam: The dam where the storage is no longer in use and is impractical to remove the dam, but still impounds water during normal and flood period. It still poses a downstream hazard and must be maintained in a safe condition at all times.

Emergency: A condition which develops unexpectedly and endangers the integrity of the dam or downstream life, property and environment; and requires immediate action.

Emergency Action Plan (EAP): A document prepared by Dam Owner which contains predetermined plan of action to be taken to reduce the potential for loss of life, environmental damages and economic losses affect by dam breach. It is a continually updated set of instructions and maps, with reference to the dam break study, that deal with possible emergency situations or unusual occurrences at or related to a dam or reservoir.

Failure: The uncontrolled release of the reservoir of a dam through breach of the dam or some part of it, or the inability of a dam to perform its design functions, such as water supply or water containment.

Failure Mode and Effects Analysis (FMEA): An inductive method of analysis where particular faults or initiating conditions are postulated and the analysis reveals full range of effects of the fault or the initiating condition on the system.

Filter: A band of granular material which is incorporated to dam and its appurtenant structures so as to allow seepage to flow through and prevent migration of fines.

Flood Mitigation Dam: A dam which temporarily stores or controls flood runoff and includes dams used to form flood retarding basins.

Flood Routing: The propagation of a dam break flood wave downstream in order to evaluate the extent of flood inundation.

Foundation: The undisturbed material on which the dam structure is placed.

Freeboard: The vertical distance between a stated water level and the lowest level of the non-overflow section of a dam.

Full Supply Level (FSL): The maximum normal operating water surface level of a reservoir when not affected by floods. See also *'Normal Pool Level'*

Hazard: The threat or condition which may result from either an external cause (e.g. flood, landslide, earthquake, sabotage) or internal vulnerability (e.g. internal erosion, piping, large deformation) with the potential for creating failure or adverse consequences.

Headwater: The water upstream from a structure or point on a stream.

Height of Dam: Normally the maximum height from the lowest point of the general foundation area to the top of the dam.

Incident: An event which develops naturally or unexpectedly, but does not endanger the integrity of the dam and downstream property or life. Incident is a deviation from the expected dam performance but is not an emergency.

Incremental: Under the same conditions (e.g., flood, earthquake, or other event), the difference in impacts that would occur due to failure or mis-operation of the dam over those that would have occurred without failure or mis-operation of the dam and appurtenances.

Inflow Design Flood (IDF): The most severe inflow flood (volume, peak, shape, duration, timing) for which a dam and its associated facilities are designed.

Inundation Map: A map showing the estimated extent of flood inundation area.

Maintenance: The routine work required to maintain existing works and systems (civil, hydraulic, mechanical and electrical) in a safe and functional condition.

Maximum Credible Earthquake (MCE): The largest reasonably conceivable earthquake magnitude that is considered possible along a recognised fault or within a geographically defined tectonic province, under presently known or presumed tectonic framework.

Monitoring: The observing of measuring devices that provide data from which can be deduced the performance and behavioural trends of a dam and appurtenant structures, and the recording and review of such data.

Normal Pool Level: For a reservoir with a fixed overflow, the lowest crest level of that overflow. For a reservoir whose outflow is controlled wholly or partially by movable gates, siphons or other means, it is the maximum level to which water may rise under normal operating conditions, exclusive of any provision for flood surcharge. See also *'Full Supply Level'*.

Operating Basis Earthquake (OBE): A level of ground motion at the dam site for which the dam, appurtenant structures and equipment should remain functional and minor damage should be repairable following the earthquake event, for the occurrence of earthquake shaking not exceeding the OBE.

Dam Operator: The personnel, organisation, or legal entity which is responsible for the control, operation and maintenance of the dam and/or reservoir and the appurtenant works.

Outlet Works: The combination of intake structure, conduits, tunnels, flow controls and dissipation devices to allow the controlled release of water from a dam.

Population at Risk (PAR): All persons directly exposed to inundation greater than 0.5m in depth within the dam breach affected zone, if they took no action to evacuate.

Potential Loss of Life: A subset of the PAR – the number of fatalities that would be highly likely due to a dam failure.

Potential Failure Mode: A mechanism or set of circumstances that could result in the uncontrolled release of all or part of the contents of a reservoir. Generally, potential failure modes include overtopping, erosion, excessive seepage, instability and structural failure.

Probabilistic: A term applied to procedures that are based on the application of mathematics of probability and take explicit account of random variations in natural and other events and properties. Probabilistic design is based on an assessment of the probabilities of failure for specific design points.

Probability: The likelihood of a specific event or outcome.

Probable Maximum Flood (PMF): An estimate of a hypothetical flood (peak flow, volume and hydrograph shape) that is considered to be the most severe "reasonably possible" at a particular location and time of year. The estimate is based on a relatively comprehensive hydrometeorological analysis of critical runoff-producing precipitation and hydrological factors favourable for maximum flood runoff.

Probable Maximum Precipitation (PMP): The theoretical greatest depth of precipitation meteorologically possible for a given duration that is physically possible over a particular catchment area, based on generalised methods.

Project Manager: The person accountable for management of a project.

Rainy Day Failure: A dam failure which occurs under conditions of a coincidental flood, typically caused by the spillway capacity of a dam being exceeded or inappropriate operation of spillway during the passage of flood.

Regulatory Body/ Regulator: The entity or organisation empowered by law to regulate dam safety.

Remedial Action: Any action required to rectify a deficiency to an adequate safety standard (e.g. dam rehabilitation).

Reservoir: The body of water or fluids that is impounded by a dam.

Reservoir Capacity: The total or gross storage capacity of the reservoir at full supply level or normal pool level.

Residual Risk: The remaining level of risk at any time before, during and after a programme of risk mitigation measures has been taken.

Retarding Basin: A type of flood mitigation dam used to temporarily store some, or all, of the stormwater runoff from an urban catchment.

Return Period: The reciprocal of the AEP. Over the long period of record, the return period equals the average elapsed time between occurrences of an event equalling or exceeding a specified magnitude.

Reviewer: An individual, or a panel of individuals, engaged by a client to complete an independent review of work completed by others.

Risk: A measure of the probability and severity of an adverse effect to life, health, property, the environment or business concerns.

Risk Assessment: The process of deciding whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates risk analysis and risk evaluation.

Safety Evaluation Earthquake (SEE): The earthquake that would result in the most severe ground motion for which the dam should be designed or analysed. It will be required at least that there is no uncontrolled release of water when the dam is subjected to the seismic load imposed by SEE.

Safety Review: The assessment of dam safety by methodical examination of all design and surveillance records and reports, and by the investigation and analysis of matters not addressed previously or of items subject to new design criteria or possible deterioration.

Seepage: The unregulated escape of reservoir water through, under or around the dam.

Seismicity: Geographic and historical distribution of earthquakes and it includes reservoir triggered seismicity (RTS).

Spillway: A weir, channel, conduit, tunnel, gate or other structure designed to permit discharges from the reservoir normally under flood conditions or in anticipation of floods.

Spillway Crest: The lowest portion of the spillway overflow section.

Standard-Based Approach: The traditional approach to dam engineering, in which risks are controlled by following established rules for defining design events and loads, structural capacity, safety coefficients and defensive design measures.

Stilling Basin: A basin constructed so as to dissipate the energy of fast flowing water e.g. from a spillway or bottom outlet and to protect the riverbed from erosion.

Sunny Day Failure: A dam failure which occurs under conditions of normal dam operation without a coincidental flood and is typically initiated by events such as uncontrolled embankment or foundation seepage, an earthquake, or inappropriate operation of a dam.

Surveillance: The continuing examination of the condition of a dam and its appurtenant structures by close monitoring of dam behaviour including systematic collection, analysis and interpretation of data through visual inspections and instrumentation in order to determine whether an adverse trend is developing or appears likely to develop.

Tailings Dam: A dam constructed to retain tailings or other waste materials from mining or industrial operations.

Tailwater Level: The water level in the discharge channel immediately downstream of a dam/ outlet structures.

Technical Adviser: An individual or organisation engaged by the Dam Owner to provide discernment relative to ongoing dam engineering services including analyses, designs, evaluations or rehabilitations, in order to provide counsel and advise to the Dam Owner on alternative course of action.

Technical Specialist: An individual who has the training and qualifications necessary to practice in their area of expertise, and is widely recognised for his/her specialist capability and experience.

Toe of Dam: The junction of the downstream (or upstream) face of dam with the ground surface (foundation). Sometimes "Heel" is used to define the upstream toe of a concrete gravity dam.

Tolerable Risk: A risk within a range that society can live with so as to secure certain net benefits. It is a range of risk that we do not regard as negligible or as something we might ignore, but rather as something we need to keep under review and reduce it still further if and as we can.

Uncertainty: Result of imperfect knowledge concerning the present or future state of a system, event, situation or population under consideration. The level of uncertainty governs the confidence in predictions, inferences or conclusions. In the context of dam safety, uncertainty can be attributed to (i) inherent variability in natural properties and events, and (ii) incomplete knowledge of parameters and the relationships between input and output values.

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FIGURES

TABLES

1 INTRODUCTION

1.1 OBJECTIVE OF GUIDELINES

This Malaysia Dam Safety Management Guidelines (MyDAMS) are intended for use in Malaysia and therefore must be read in association with relevant legislation, regulations and standards that are in place. The purpose of MyDAMS is to provide a framework for the management of dam safety, and guidelines for the development and implementation of appropriate dam safety practices throughout Malaysia. These include dams used for water supply, irrigation, hydroelectric power, flood mitigation, water quality control, sediment retention and recreation.

The objective of dam safety management is to protect life, property and the environment from the failure of any dam. This objective can be achieved by establishing an appropriate dam safety management system and implementing the necessary dam safety program. MyDAMS represents the recommended practice for dam safety management covering the complete life cycle of dams i.e. planning, investigation, design, construction, commissioning, operation, maintenance, surveillance, safety review, rehabilitation, emergency preparedness and abandonment.

MyDAMS is relevant to owners, operators, consultants, dam engineers, contractors, regulatory bodies and others who have a responsibility and a duty of care for dam safety. All parties share responsibilities for attaining safe dams but the Dam Owner is ultimately responsible for dam safety management throughout the entire life cycle of the dam. Reasonable skill and care is required when applying MyDAMS proportionates with each dam’s size, hazard rating and complexity.

There is a wealth of technical bulletins and literatures available from International Commission on Large Dam (ICOLD) and other internationally recognised agencies that provides guidelines for the investigation, design, construction, operation, maintenance, surveillance, rehabilitation, risk assessment ,emergency action plan (EAP) and other aspects regarding dams. MyDAMS is well aligned to similar documents from comparable jurisdictions and have been developed 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.

Each dam and dam site is unique and should be treated on a case by case basis. Dam Owners should gain an appreciation of what these features are and how to prioritise the effort and resources necessary to maintain an acceptable standard of dam safety. However, careful heed must be paid to the experience, ability and expertise, which is an essential requirement of a dam engineer.

1.2 COMMITMENT TO DAM SAFETY

The Cabinet on 29th August 2012 had given directive to KeTTHA in collaboration with Performance Management and Delivery Unit (PEMANDU) to discuss issues pertaining dam safety management practices in Malaysia. On 29th October to 9th November 2012, a special lab session headed by PEMANDU had come to conclude and endorse the need to establish a Special Committee to regulate all dam safety management practices and to set up a Dam Technical Centre.

In 2016, a series of meetings and workshops were held among government agencies, dam owners, operators and dams designers in Malaysia (Exhibit A) to discuss issues on development of MyDAMS and legislation on dam safety in line with international best practice in dam safety.

Dam owners are encouraged to provide funding and resources to undertake dam safety programme that are essential to minimise the risks posed by dams.

1.3 SCOPE OF GUIDELINES

MyDAMS provide recommended dam safety management practices for dams in Malaysia that are 10m or more in height and storage capacity of 20,000m^3 or more or Dams which have a storage capacity of 50,000 m^3 or more and higher than 5 meters.

The Guidelines cover the planning, investigation, design, construction, commissioning, operation, maintenance, surveillance, safety review, rehabilitation, emergency preparedness and abandonment of dams. The Guidelines do not constitute a design, construction or operations manual.

In all cases, the determination of what material included in MyDAMS is relevant to a particular project should be established by the Dam Owner in consultation with his/her Technical Adviser.

During the development or safety evaluation of any dam project or others aspects of life cycle management, reference must be made to appropriate technical publications and professional advice from qualified and experienced technical personnel. MyDAMS will not cover every conceivable circumstance.

1.4 CONTENTS OF GUIDELINES

An outline of the content included within the parent document and each supporting Appendix is as follows:

Chapter 1: Introduction

Outlines the objective of dam safety management, purpose and scope of the Guidelines and the contents of this document.

Chapter 2: Legal Requirements

Outlines Malaysia's legislative framework as of 2016 for the safety management of dams.

> Appendix A – Outlines the legal obligations and liabilities of those associated with the development, ownership and operation of dams. The Guidelines are subject to updating when the proposed Federal Legislation on dam safety is established.

Chapter 3: Potential Hazards of Dams and Safety Principles

Defines dam safety objectives and principles that are applicable to the investigation, design, construction, commissioning, assessment, rehabilitation and operation of dams in Malaysia.

Chapter 4: Dam Safety Management System

Outlines the guidelines for establishing and implementing a dam safety management system.

> Appendix B – Outlines the guidelines for the consequence assessments and hazard ratings of dams in Malaysia.

Chapter 5: Investigation and Design

Provides guidelines for the investigation and design of new dams, the assessment of existing dams and the design of rehabilitation works for existing dams. It includes an outline of the scope of investigation and design activities, and design documentation for risks and safety management.

> Appendix C – Outlines dam types and issues that should be focus on during their design, qualification and experience of personnel, quality assurance and control for the design, assessment of risks and hazards to the dam safety, and appropriate safety level criteria for flood, earthquake and other hazards.

Chapter 6: Construction and Commissioning

Provides guidelines for the construction and commissioning of new dams and rehabilitation works for existing dams. It includes an outline of personnel responsibilities, quality control measures, construction issues and commissioning issues.

Chapter 7: Operation and Maintenance (O&M)

Outlines the guidelines for O&M as one of the key elements in dam safety management. The importance of Dam Owners to understand the parameters within which their dams are to be operated for normal, unusual and extreme conditions is highlighted. The competence, training and capability of operating staff to recognize the threats and symptom of failures are outlined.

> Appendix D – Outlines the structures and contents of a typical dam O&M manual. The background information, operating procedures, maintenance procedures, responsibility, accounting, reporting, documentation and maintenance of records critical to dam safety are outlined.

Chapter 8: Surveillance and Safety Review

Outlines procedures for the surveillance of dams including detection of development of problem or unsafe trends and information on the dam's performance, safety actions to be taken and prevention of oversight. The principles of safety reviews for assessing the integrity of a dam against known failure modes and mechanisms for various types of dams are outlined.

> Appendix E – Outlines the principles and procedures of surveillance covering safety inspection, monitoring and surveillance evaluations.

Chapter 9: Dam Rehabilitation

Outlines the principles and procedures for management of upgrading and rehabilitation of dams and its remedial measures to address dam safety deficiencies, the conditions that necessitate the rehabilitation of concrete dams, embankment dams and appurtenant structures.

Chapter 10: Emergency Action Plan

Outlines emergency preparedness planning processes and guidelines for EAPs, review and training to ensure effectiveness of EAPs.

Appendix F – Outlines emergency preparedness planning and processes and recommended procedures for the development of EAP that is consistent with the National Disaster Management Agency (NADMA) for the crisis management of emergencies.

Chapter 11: Changes and Decommissioning

Outlines the guidelines for addressing dam safety issues and deficiency management, changes of dam use and decommissioning of dam. The guidance on the management of public safety around dams is also provided.

A glossary of terms relevant to dam safety is provided at the beginning of this document.

2 LEGAL REQUIREMENTS

2.1 INTRODUCTION

This Section will cover aspects related to laws pertaining to dam safety. “Dams” in so far as almost all of them are sited on rivers, may be considered a subset of water resources. A dam could be variously identified as an embankment on a river or lake, an obstruction, a structure, mechanism or even a factory producing power, reservoir for supply of water, irrigation, flood mitigation or even for aesthetic purposes. All dams will be classified under MyDAMS into appropriate categories and classified according to hazard ratings. In accordance with international practice, dams of the prescribed size will be regulated whilst those which are considered too small and of low risk may be self regulated. Dam owners and operators must also take cognizance of the fact that the Federal system of governance in Malaysia has resulted in both federal as well as state laws which they will have to comply with.

This Section:

- Outlines the legal obligations and liabilities of those associated with the development, ownership and operation of dams.
- Outlines statutory requirements for the development and operation of dams.
- Provides comments on interpretation of the legislative requirements for the development and operation of dams.

It is worth noting that this Section is an outline of legislative obligations, liabilities and requirements, and should not be considered complete. To ensure compliance with all legal requirements, Dam Owners should refer to the relevant legislation and seek appropriate professional legal advice where necessary.

2.1.1 Federal State Regulatory Regime

A typical dam is sited on a river and has a reservoir with a large land area of catchment. There will be catchments and buffer zones upstream and safety/security zones at the dam site as well as downstream. Within these zones there may be restrictions on rights of access, types of activities, resource utilization and land/slope management. Under the current separation of powers between Federal and State governments, much of the ancillary matters related to the development and operations of dams such as land, rivers, lakes, wetlands, town and country planning, buildings and local government are within the jurisdiction of State Governments. The siting of any dam 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 streets buildings and drainage. In Sabah and Sarawak this will include licensing for electricity generation. It would be necessary that the proponent of a dam is aware of such state legislative requirements and adopts measures to comply with these requirements. MyDAMS contains an overview of State legislation and listing of relevant state legislation in **Appendix A**. The project proponent is advised to ensure that adequate legal advice is obtained on the appropriate state legislation that would apply to a dam in which ever state the dam is sited.

The Federal Government also has jurisdiction over dams particularly in relation to the safety aspects of dams. Most of the large dams are also built by Federal agencies. However, at this juncture there is no specific Federal law that regulates dam safety. There are legislations which apply to particular aspects of dam operations particularly in relation to safety of workers, machinery and construction. The Factories and Machinery Act 1967 (FMA), Construction Industry Development Board Act 1994 (CIDB) and Occupational Safety and Health Act 1994 (OSHA) are laws applicable throughout Malaysia and on all dams (Federal, State or private). In addition, the Environmental Quality Act 1974 would apply when there is a proposal to develop any new dam or expand the capacity of existing dams to ensure sustainable practices are adopted by the dam proponent. Security within the immediate dam site may be prescribed by the Protected Areas and Protected Places Act 1959. A short description of the obligations of Dam Owners in relation to these laws is contained below and in **Appendix A**. Other than these laws, there are no Federal laws that would govern the safety aspects of dams.

2.2 LAWS, PRACTICES AND PARTIES INVOLVED[1]

2.2.1 Status of the Dam Safety Guidelines

The Guidelines outlines best practices in dam safety. It is not mandatory for dam owners to adopt and implement MyDAMS but there are strong and valid reasons for them to do so. As mentioned earlier currently there is no specific legislation which regulates dam safety. However, various licensing or permit conditions imposed on individual dams under the provisions of state enactments (such as the Lembaga Urus Air Selangor (LUAS) Enactment), may require such dams to comply with the Guidelines. The relevant state authority may "call up" or make reference to the Guidelines or parts of it (such as preparing an EAP) as a condition of such permit or licensing. In such circumstances the Guidelines would acquire

[1] Adapted from Part II, New Zealand Guidelines on Dam Safety

"legal status" and require the dam owner/operator to comply with the stipulated requirements failing which the provisions of the state laws and legislations would apply. It is also possible that currently, some dam owners may have their own in-house guidelines or abide by international codes (such as ICOLD). The Guidelines represents the end result of a comprehensive, inclusive and structured national effort. It is consistent with international best practices, at the same time including local content necessary to make it relevant and practical for Malaysian dam owners and regulatory authorities. In appropriate circumstances, a court of law will give due consideration to such valid reasons as opposed to the status of an in-house guideline (or an international code adopted with adaptations) which may not have been sanctioned by similar due process.

2.2.2 Common Law

Dams fulfil an important role in our society comprising an essential component of the nation's infrastructure. However, the failure of any regulated dam can have significant consequences ranging from loss of life or injury to economic loss and damage to property and the environment. Whilst Malaysia may claim to have a relatively good dam safety record, recurring dam failures around the world highlight the need and importance of dam safety management programs. As mentioned above, there is currently no specific legislation that regulates dam safety. Under common law[2], which is applicable in Malaysia, responsibility for the safety of a dam rests with the Dam Owner. Dam Owners may be liable for loss and damage caused by the failure of a dam or the escape of water from a dam. For operators and subsequent owners of dams, the principles of negligence apply, rather than strict liability under the Ryland v. Fletcher principle.[3] The basic principle is that in operating a potentially dangerous structure such as a dam, **reasonable care** must be exercised to ensure that damage to others is not caused by a failure of the dam. The focus will be on whether action taken during design, construction and operation of the dam was reasonable in the circumstances to ensure against such a failure occurring. A formal set of guidelines emphasising accountability and review of all aspects of dam design, construction and operation is required by the Dam Owner, to ensure there is the strongest chance of picking up any mistake before it can contribute to a dam failure. The Guidelines can be used as the minimum standards for conforming. The owner of a dam could also be civilly liable for damage caused by natural events and processes which arise as a consequence of the

[2] "Common law" is law based on precedence set by decisions made by Courts. Precedents could be from courts throughout the Commonwealth and accepted and applied by courts in Malaysia. Common law is accepted and practiced by courts in Malaysia.

[3] Rylands & Fletcher *"the person who for his own purposes brings on his lands and collects and keeps there anything likely to do mischief, must keep it in at his peril, and if he does not do so, is prima facie answerable for all damage which is a natural consequence of its escape"* 3 HL 330, (1868) LR 3 HL 330, [1868] UKHL 1

existence of the dam. If the damage was the reasonably foreseeable result of the activity of damming the river, then the Dam Owner could be held liable. The Dam Owner needs to undertake comprehensive studies regarding the natural effects of the construction and operation of the dam. All reasonable steps then need to be taken to eliminate or minimise such risks.

2.2.3 Best Practices in the Dam Safety Guidelines

The aim of MyDAMS is to obtain the compliance of all dam owners and operators to the safety practices enshrined within it. The Guidelines is based on international best practices including the FEMA, ICOLD, Australian, New Zealand and Canadian Guidelines on Dam Safety. Adoption and implementation of the Guidelines by dam owners will minimise the risk of a dam failing and protect life and property from the effects of such a failure should one occur. Evidence that the dam owner had adopted and actively implemented the Guidelines may mitigate their liability in the event they are faced with an action for damages.

2.2.4 Parties Involved and Responsibility / Liability

MyDAMS should be used by:

- Owners of dams and its operators / employees
- Approving and Administering Authority
- Consultants/Contractors/ Technical Advisors
- Public

2.2.4.1 Dam Owners

The Dam Owner occupies the most important role. It is the Owner who holds the various statutory approvals for the dam and is legally responsible for maintaining and operating the dam in a safe condition. The Dam Owner may rely on technical advisers for investigations, design, safety reviews and the like, and on suitably qualified construction contractors for construction, upgrading, raising or rehabilitation. In such situations, the advisers and contractors are considered as agents for the Dam Owner. They may carry an appropriate level of responsibility and liability for their actions as determined by the terms of the contract for their services. The Dam Owner must recognise that in the event of a problem arising, the Authorities will hold the Dam Owner responsible and fully liable. The Dam Owner must understand his liabilities and the limits of liability which the agents have contracted for. The Dam Owner is legally liable for damage after a dam failure and may be criminally culpable. A responsible attitude towards safety by Dam Owners is essential to protect others and avoid negligence situations. By understanding and requiring the Guidelines to be implemented, the Dam Owner will be taking positive initiatives to ensure that the dam is safely developed, maintained and operated. Further, the Dam Owner may face significantly reduced negligence risks and liability if evidence is produced to indicate that the Guidelines was fully complied with and implemented.

2.2.4.2 Approving and Administering Authorities

Apart from the Police and National Disaster Management Agency who may take control of a disaster, there are other authorities who administer legislation relating to dam safety. These are:

- the relevant State Authority
- the relevant Municipal Council
- the relevant Federal Authority

There is a more detailed section on the State/Municipal/Federal legislation that applies and the authorities that may be involved. State Governments are responsible for granting consents and the application of constraints and approvals through the planning and land/water alienation process. Municipal Councils may be responsible for granting permits for earth works, buildings and drainage approvals. The Land Administration (District Land Office) is responsible for alienation, utilisation and reservation of land for various purposes associated with the dam and its surrounds. Dam Owners must note that practices are not uniform in all States and they will be required to comply with differing conditions and requirements as stipulated by the State authorities. In considering environmental issues, the Department of Environment (or Natural Resources and Environment Board in Sarawak and Environment Protection Department in Sabah) will be concerned with the impact of dam safety on the environment in relation to potential environmental impact assessment. The Department of Occupational Safety and Health and Construction Industry Development Board (CIDB) will be involved in safety of workers and machinery. The National Security Council, Prime Ministers Department will be concerned with security within the premises of the dam (declaring it as a Protected Place to deter trespassers) whilst the National Disaster Management Agency will coordinate the setting up of an appropriate EAP.

2.2.4.3 Technical Advisers and Contractors

Technical Advisers and Contractors cover a wide scope of activities in the dam industry. Typical skills and related roles include geology and geotechnical engineering, hydrological and hydraulic engineering, seismological, environmental assessment, structural, electrical and mechanical, evaluating and managing construction risk particularly floods during construction, project management and quality assurance skills, specialist construction and peer review and appraisal capability. These roles or services are generally obtained from outside the Dam Owners in house capability. The parties filling these roles carry heavy responsibilities for their advice or services and are considered to be an agent of the Dam Owner. It is vitally important that the Dam Owner and Agent fully understand and acknowledge the exact scope of their roles, boundaries of their responsibilities and limits of their liabilities. It is best that these are contractually defined. Dam Owners must be aware that the authorities will hold them fully responsible for any dam incident and vest full liability on them and not the Agent. It is also usual practice and a recommendation of the Guidelines, that continuity of key Technical Advisers be maintained through design, construction and commissioning.

2.2.4.4 Public

Public interest is cared for in the broader sense by environmental, planning and building legislation and its enforcement by the Authorities. The Public has the opportunity for involvement through the EIA and Planning approval processes particularly for new development of dams. Members of the public most likely to become involved are those directly affected by the dam and its operation and wider interest groups advancing a particular environmental, social, cultural, or political perspective. Members of the public with a direct interest often include those to whom the dam (or more appropriately the stored contents), represents a potential hazard to life and property. Public safety is of primary importance and one of the reasons behind MyDAMS. Public participation should also be ensured in EAPs and simulation exercises. The other participants in the dam industry must at all times recognise their duty of care to the Public and act de facto as agents for the well being of the Public.

2.3 FEDERAL STATUTORY OBLIGATIONS

2.3.1 Street, Drainage and Building Act 1974 (SDBA)

This Act applies only to Peninsular Malaysia. The whole of Peninsular Malaysia comes within the jurisdiction of municipal authorities. The definition of "building" in the SDBA may not specifically include "dams" within its ambit.[4] In practice municipal authorities may not

[4] "building" includes any house, hut, shed or roofed enclosure, whether used for the purpose of a human habitation or otherwise, and also any wall, fence, platform, staging, gate, post, pillar, piling, frame, hoarding, slip, dock, wharf, pier, jetty, landing-stage or bridge, or any structure support or foundation connected to the foregoing; SDB 1974

therefore regulate dams within the scope of this Act. However, due to the fact that most dam sites often contain associated buildings such as power stations, workshops and workers quarters, the current practice is for dam owners to submit to municipal authorities for approval all works to be processed like a building work. The application by dam owners for approval for dam construction or rehabilitation works should be accompanied by sufficient detailed drawings, specifications, design reports and review reports to demonstrate compliance with the Act, Regulations, Codes of Practice or guidelines as stipulated by the municipal authorities. The dam owner may also not commence full operations until a Certificate of Completion and Compliance is issued by the municipal authority.

In the event of a breach of any of the relevant provisions of this Act, the municipal authority is empowered to take appropriate action including prosecution for offences which may result in the imposition of fines and or conviction. The municipal authorities may also issue stop work orders and compound offences. Dam owners and operators are therefore well advised to obtain a detailed appreciation of the prescribed requirements of the relevant municipal authorities and take proactive action to comply with their stipulations. (Similar legislation is in force in Sabah and Sarawak (see **Appendix A**). Owners should verify whether the jurisdiction of municipal authorities extends to their dam site, particularly those dams which are located in remote sites).

2.3.2 Akta Suruhanjaya Perkhidmatan Air Negara and Water Services Industry Act 2006

The restructuring of the water supply industry in Peninsular Malaysia resulted in two laws namely the Suruhanjaya Perkhidmatan Air Negara Act 2006 (SPAN) and the Water Services Industry Act 2006 (WSIA). WSIA established a regulatory framework for the water supply and sewerage industries with rules and licensing for the regulation of these industries. Together the two Acts cover the whole process of construction, operation and maintenance of water supply services and systems from the harvesting of raw water, storage, treatment, distribution and supply of water to the discharge of waste water. All infrastructure associated in this process, including dams, are regulated by SPAN pursuant to provisions in WSIA. WSIA requires those engaged in "water supply services"[5] to be licensed and to provide relevant information pertaining to "water supply systems"[6]. Owners of dams built for the

[5] "water supply services" means the treatment of water abstracted from watercourses and the distribution and supply of treated water to consumers and includes the operation and maintenance of the water supply system; "Dams" are included in the definition of "watercourses". WSIA 2006

[6] "water supply system" means the whole of a system incorporating public mains, pipes, chambers, treatment plants, pumping stations, service or balancing reservoirs or any combination thereof and all other structures,

purposes of public water supply should therefore generally take note of the requirements for licensing (for water supply services in general) which will include associated infrastructure works including dams within such requirements. The Act provides for various penalties, compounding of offences, fines and jail terms upon conviction under the Act. Besides SPAN and WSIA, it must be noted that almost all states in Peninsular Malaysia have state legislation on the management of water resources within the respective states which may require licensing of dams. Sabah and Sarawak also have laws on the regulation of water resources and water supply and dams in Sabah and Sarawak are largely regulated under these laws. Please refer to Appendix A for details of such laws.

2.3.3 Occupational Safety and Health Act 1994

The objectives of the Act are primarily directed at "securing the safety, health and welfare of persons at work and to promote an occupational environment for persons at work in accordance with their physiological and psychological needs"[7]. The Act empowers the Department of Occupational Safety and Health to enforce the provisions of the Act. Owners of dams in general would be required to abide by the requirements of this Act as it applies to all industries including construction, agriculture, manufacturing, mining and utilities including water and electricity. The Act applies throughout Malaysia. The Act imposes on all employers a duty to take appropriate measures that will ensure the safety, health and welfare of all persons at work in the premises. This includes in general the "provision and maintenance of plant and systems of work that are, so far as is practicable, safe and without risks to health". It also includes provision of adequate information, supervision, training and instruction to employees. The definition of "employees" includes an independent contractor engaged by an employer or a self employed person and any employee of the independent contractor;[8] The Act also imposes a duty of care on dam owners to persons other than employees (in other words third parties) who may be impacted by the activities carried out by the dam owner.[9] The Act provides for various penalties, compounding of offences, fines and jail terms upon conviction under the Act.

2.3.4 Factories and Machinery Act 1967

This Act regulates factories (where manual labour is employed) with respect to matters relating to the safety, health and welfare of persons therein and the registration and

installations, buildings, equipment and appurtenances used and the lands where the same are located for the storage, abstraction, collection, conveyance, treatment, distribution and supply of water; WSIA 2006

[7] OSHA, section 4.

[8] OSHA, section 15(3)

[9] OSHA, section 17.

inspection of machinery at any premises. A dam may not be classified as a "factory". However the Act may still apply to dams particularly as various machineries are normally used at dam sites. Machinery (as defined in the Act) used at dam sites must be certified fit under the Act prior to operation of the machines.[10] The occupier of the dam must maintain all safety appliances and machinery. The Act requires every person employed at any machine or in any process, being a machine or process liable to cause bodily injury, to be fully supervised, instructed and trained. Dam sites which has engineering construction works will also be subject to this Act. The Act defines **"**work of engineering construction**"** to include the construction, extension, installation, repair, maintenance, renewal, removal, renovation, alteration, dismantling, or demolition of any dam. Periodical inspections may be carried out by the Inspector of Factories and Machinery and dam operators are obliged to facilitate such inspections. Whenever there is any serious incident resulting in bodily injury, loss of life or serious damage to property or machinery, it is a requirement that the incident is immediately reported to the Inspector who may initiate an inquiry and take subsequent actions as provided in the Act. The Act provides for various penalties, compounding of offences, fines and jail terms upon conviction under the Act. The Act is in force throughout Malaysia.

2.3.5 Environmental Quality Act 1974

The Environmental Quality Act (EQA) defines "environment" to mean physical factors of the surroundings of the human beings including land, water, atmosphere, climate, sound, odour, taste, biological factors of animal, plants and the social factor of aesthetics. This Act confers powers on the Director General of the Department of Environment (DOE) to control and prevent pollution throughout Malaysia. The EQA prohibits any person from discharging or depositing pollutants or wastes into any inland waters unless licensed to do so. The definition of inland waters includes any river, stream, canal, drain or any other body of natural or artificial surface or subsurface water. Section 34A of the EQA and the accompanying Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 2015 also impacts major dam projects (see definition of major dams in footnote below).[11] Proponents of major dams are required to undertake and submit an

[10] FMA, section 3, "machinery" includes steam boilers, unfired pressure vessels, fired pressure vessels, pipelines, prime movers, gas cylinders, gas holders, hoisting machines and tackle, transmission machinery, driven machinery, materials handling equipment, amusement device or any other similar machinery and any equipment for the casting, cutting, welding or electro-deposition of materials and for the spraying by means of compressed gas or air of materials or other materials, but does not include—
(a) any machinery used for the propulsion of vehicles other than steam boilers or steam engines;
(b) any machinery driven by manual power other than hoisting machines;
(c) any machinery used solely for private and domestic purposes; or
(d) office machines;
[11] EQA, EIA Order 2015 includes:

Environmental Impact Assessment (EIA) Report to the DOE. The report shall be prepared in accordance to the EIA Guidelines established by the DOE. Primarily the report shall identify the anticipated environmental impact and appropriate measures to mitigate them. DOE is empowered to ensure that all approved actions and measures shall be implemented by the project proponent. The project proponent is required to submit an Environmental Management Plan (EMP) before commencement of construction. Local authorities are increasingly requiring major projects (even when it is not a prescribed activity) to undergo the EIA process. The Act provides for various penalties, compounding of offences, fines and jail terms upon conviction under the Act. In so far as the construction of dams in Sabah and Sarawak is concerned the EQA does not apply. Similar environmental laws are however in force in Sabah and Sarawak (See **Appendix A**).

2.3.6 Construction Industry Development Board Act (CIDB)

The Act applies generally to the construction industry including construction of any dams. The Act defines construction industry to mean industry concerning construction works and construction works, inter alia, includes any bridge, viaduct, dam, reservoir, earthworks, pipeline, sewer, aqueduct, culvert, drive, shaft, tunnel or reclamation works and includes any works which form an integral part of, or are preparatory to or temporary for the works described above, including site clearance, soil investigation and improvement, earth-moving, excavation, laying of foundation, site restoration and landscaping.[12] Only a person registered with the Lembaga and holds a valid certificate of registration issued by CIDB shall undertake and complete any construction works. CIDB shall keep and maintain a Register which shall contain the names, business addresses and other particulars of contractors who are registered as registered contractors. Contractors are required to notify and submit to the CIDB any information and documents, including any supporting documents relating to the construction works. They must also ensure the construction works are carried out in a safe manner and in accordance with the provisions of this Act including any terms and conditions imposed by the CIDB. The CIDB has powers to issue stop work orders, investigate any incidents and undertake any inspections at any time. A levy is also imposed on construction contracts worth over five hundred thousand which must be paid to the CIDB. The Act applies throughout Malaysia. The Act provides for various penalties, compounding of offences, fines and jail terms upon conviction under the Act.

(a) Construction of dams, impounding reservoirs with a surface area of 200 hectares or more;
(b) Construction of dam and hydro-electric power scheme with either or both of:
   (i) dam of 15 metres or more in height and ancillary structures covering a total area of 400 hectares or more;
   (ii) reservoir with a surface area of 100 hectares or more;

[12] CIDB Act, Section 2

2.3.7 Other Requirements on Dam Safety – MKN ARAHAN NO. 20

Major dams pose a significant risk to life and property in the event of a dam failure. Dam failures continue to occur worldwide and it is accepted practice that dams must have an Emergency Action Plan (EAP) for management of disasters. MyDAMS also requires the establishment of an EAP as a key component of dam safety and detailed instructions are contained herein. Essentially the EAP must comply with the requirements of the National Directive on Policy and Management of Disasters (Arahan Mengenai Dasar dan Mekanisme Pengurusan Bencana – MKN ARAHAN NO. 20) issued by the National Security Council. The National Disaster Management Agency (NADMA) is part of this organisational structure and is tasked with operationalising the MKN ARAHAN NO. 20. The declaration of a “Disaster Emergency" is decided by the Prime Minister. A Disaster Emergency is declared to ensure safety of life, property and public health. The declaration will be based on the complexity and magnitude of the disaster, level of destruction, the requirement for resources including financial, equipment, expertise, safety and security deemed appropriate to manage the disaster. Whilst the MKN ARAHAN NO. 20 is not a statutory requirement dam owners are strongly advised to comply with and take action to implement the Directive as it has established an elaborate response mechanism and organisational structure commencing at the National level cascading down to the local level. Dam owners who can produce evidence that they have taken action to comply with the MKN ARAHAN NO. 20 and MyDAMS may be able to mitigate their liability in the aftermath of a dam disaster.

3 POTENTIAL HAZARDS OF DAMS AND SAFETY PRINCIPLES

3.1 POTENTIAL HAZARDS OF DAMS

Dams pose potential hazard to communities, the environment and property often well beyond their locations. On the other hand dams are subject to natural hazards such as earthquakes and floods that can affect the safety of dams and cannot be controlled by the Dam Owner. 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.

3.1.1 Special Nature of Dams

The nature of dams is special. Dams are often built from a combination of natural and engineered materials, usually store large volumes of fluids, and are very dependent on foundations and abutments for support. All dams have unique characteristics that usually include site geology, construction materials and structural form. The variations in geology, building materials, geometry, and flood and earthquake hazards mean that it is not practicable to develop a standard code-type design, or standard analysis or evaluation procedures, for dams. Each dam is unique and must be treated individually, taking all relevant factors into account.

3.1.2 Safety Issues

The site topography influences how the dam will fit into or modify the topography. The regional and local geology greatly influences structural safety, water retention and reservoir slope integrity. The qualities of construction materials available at the project site and dam arrangements affect the resilience of the dam during construction and operation. The flood risks at the dam and how floods are managed and passed through the structure during construction and operation affect the safety of the dam. The seismic risks and earthquake loads which the dam, with its stored contents, and the reservoir shoreline may experience weaken the integrity of the dam. Safety issues associated with dams, particularly large dams, may be complex.

Dams age and deteriorate through ongoing geological and chemical processes and also may be found to be less safe than is desirable through technological advances which improve knowledge of dam and foundation behaviour, and earthquake and flood risk. Dam failures can be catastrophic and preservation of safe conditions requires never ending vigilance. Furthermore, dams typically have expected life spans well in excess of other engineered works and, as such, need to demonstrate resilience over time.

3.1.3 Safety Deficiency Due to Weaknesses in Foundation and Abutments

The area of ground on which the dam is located and the abutments form part of the total water barrier. If the foundations and abutments do not adequately support the basic dam structure, or are themselves structurally weak, subject to internal erosion, or prone to high seepage flows and forces, 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, liquefaction, long-term weathering and chemical degradation of materials.

3.1.4 Safety Deficiency in Appurtenant Structures

Appurtenant structures are required to fulfil functions necessary for the safety of dams and may include, but are not limited to, spillway, intake, outlet and sluice facilities together with their associated gates, valves and control equipment. Spillway facilities enable the management of flood flows and intake, outlet and sluice facilities enable reservoir lowering or dewatering in response to a dam safety emergency. Depending on the specific requirements of a site, other conduits or structures (e.g. tunnels, pipelines, surge chambers, penstocks, power stations) may fit the appurtenant structure definition if they fulfil dam safety functions. Dam safety deficiencies in appurtenant structures can include insufficient spillway capacity, susceptibility to spillway and sluice blockages, erosion and abrasion damage, and scour.

3.1.5 Safety Deficiency Due to Ageing

Ageing can lead to dam safety deficiencies that are not apparent at commissioning. Inappropriate operation of mechanical and electrical equipment installed in appurtenant structures can also affect dam safety and, as such, operational procedures and personnel training must be in place to ensure the equipment is appropriately operated during normal, unusual and emergency loading conditions.

3.2 WHY DAM SAFETY MANAGEMENT SYSTEM AND PROGRAMME ARE NECESSARY?

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

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

- In October 2013, four people located at the downstream of the spillway outlet channel (illegal squatters encroached into spillway outlet area) were drowned at the Sultan Abu Bakar Hydro Power Dam when excess water were released from the dam during monsoon.
- In 1981, Batu Arang Dam, Selangor, the earthfill dam failed by 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. No serious damage occurred downstream.
- Collapse of the spillway at Anak Endau Dam in 1986 during its first overspilling.
- Damage of Ayer Keroh Dam in November 1993 due to construction at the downstream toe of the dam.
- Collapse of the cofferdam due to overtopping by flood during construction at Paya Peda Dam in 2012.
- Bukit Panchor Dam, Penang, the earthfill dam failed by a classical slip on the upstream slopes following an extremely wet and prolonged dry period in 1970. No serious damage occurred downstream.

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 programs could have prevented the majority of dam incidents progressing to dam failures.

Lessons to be learnt from past dam incidents and failures include:

(a) Dam failure incidents led to the introduction of dam safety legislation to manage the risk of dam failure.

- St Francis Dam in California failed in 1928 killed 450 people. The Coroner of Los Angeles formed a jury which asserted that "a sound policy of public safety and engineering judgment demands that the construction and operation of a great dam should never be left to the sole judgment of one man, no matter how eminent, without checking by independent experts". In 1929 the State of California enacted legislation with this intent.
- The failure of Eigiau Dam in Walesin in 1925 resulted in the failure of another dam downstream and the flooding of Dalgarrog 1.6km further downstream killing sixteen people. In 1930 the United Kingdom passed dam safety legislation by way of the Reservoirs Act.

- Dam failures at Malpasset (France—foundation defect caused arch dam failure killing 421 people in 1959) and Vaiont (Italy—landslide into reservoir and dam overtopping killed 2600 people in 1963) resulted in the governments of several countries enacting new or revised laws for the supervision of the safety of dams and reservoirs.

(b) Design and construction defects can be unrecognised for many years and then suddenly cause serious problems.

- Lawn Lake Dam, Colorado, built in 1903, failed in 1982 releasing 800ML of stored water, killing three people. Failure was caused by corrosion failure of the outlet pipe.
- San Luis Dam, California, built in 1966, suffered partial failure of the up-stream shoulder after drawdown in 1981.

(c) Deficiencies in dams engineering during investigation, design and construction can lead to failures.

- Teton Dam, Ohio, failed during first filling in 1976 killing 11 people. Design and construction deficiencies were not recognised. Poor management was also involved.
- Carsington Dam, United Kingdom, failed at completion of construction before initial filling. This was caused by embankment instability due to non recognition of adverse geological features.

(d) Surveillance programs and vigilant dams personnel can provide early warning of disasters and reduce the loss of life.

- Baldwin Hills Dam, Los Angeles, built in 1951, failed in 1963. At 11.15 am, the caretaker noticed high seepage flows. When the dam failed at 3.38 pm, 1,600 people had been evacuated from the downstream area. Only five people died.
- Fontenelle Dam USA nearly failed on 6 May 1965 due to excessive seepage. Quick action by operations personnel in drawing the reservoir down and placing rockfill over the seepage area averted a disaster.
- Zeyzoun Dam, Syria, failed in June 2002. Early warnings of the impending failure allowed evacuation of hundreds of people downstream reducing the loss of life.

(e) A disaster can result if surveillance programs are not effective or are "non existent".

- A mine tailings dam near Starva, Italy failed on 19 July 1985, killing 279 people. No surveillance program existed. No warning of the failure have been conducted.

(f) The size of a dam does not necessarily indicate the hazard rating of a dam. Small dams can place the population, environment and/or the economy at risk

- Lawn Lake Dam in Colorado, USA, was only 8m high but its failure in 1982 killed three people and caused millions of dollars of damage to the town of Estes Park downstream.

(g) Dam failures continue to occur worldwide emphasising the need for ongoing vigilance.

- Gouhou Dam, China failed in 1993.
- Los Frailes Iron Pyrite Mine Tailings Dam, Spain failed in April 1998.
- Shih-Kung Dam, Taiwan suffered extensive damage in an earthquake in September 1999.
- Zeyzoun Dam, Syria failed in June 2002.
- USA experienced over 4000 dam incidents in the period 1994 to 2001 (US National Performance of Dams Register).

Further details of dams' incidents are contained in "Dams and Public Safety" (Jansen, 1983), "Deterioration of Dams and Reservoirs (ICOLD, 1983) and "Lessons from Dam Incidents" (ICOLD 1974).

3.3 PRINCIPLES OF DAM SAFETY

The dam safety principles presented below provide an overarching management framework for the achievement of dam safety objective in line with international practice. Dam Owners should consider the dam safety principles and satisfy themselves that appropriate systems and procedures are in place for the management of dam safety.

The justification of building a dam must be answerable by the Dam Owner. The purpose of building a dam may include water supply, irrigation, hydroelectric power generation, flood mitigation, sediment control and recreation. By building a dam, the retained water/fluid imposes risks on society, property and environment. The risks posed by dams and reservoirs vary on each dam, so as the benefits. Comprehensive assessment must be made on benefits and risks, considering all consequences of the dam operation. The benefits that the dam and reservoir operations produce should override the risks that they creates, thus, leading to building of a dam considered justified.

3.3.1 Fundamental Dam Safety Objective

Principle 1: The people, property and the environment, present and future, should be protected from the harmful effects of a dam failure or an uncontrolled release of the reservoir contents.

To achieve a desirable level of safety, measures must be taken to:

- Control the release of discharge downstream of a dam that would result in undesirable consequences.
- Reduce the likelihood of events that might lead to uncontrolled loss of stored water/fluid from a reservoir to a level as low as practicable through resilient design, construction and operational criteria adopted for dam and its associated appurtenant structures.
- Mitigate through incident management and preparedness of the consequences of such events if they were to happen.

The dam safety management should provide transparency on all risk factors considered, thus reassuring the stakeholders and the public that risks to people, property and the environment are being properly addressed.

3.3.2 Investigation, Design, Construction and Commissioning

Principle 2: All natural hazards, loading conditions, potential failure modes and any other adverse effects to the safe design, construction, commissioning, operation and rehabilitation of a dam should be identified.

Hazards that can affect dam safety include high rainfall, severe wind events, flood events, earthquakes, landslides and lightning strikes. The magnitude, frequency and possible occurrence of the hazard cannot be precluded, but the Dam Owner must ensure that the dam is engineered and managed to keep the risks of dam failure as low as reasonably practicable. Other human factors that can affect dam safety and usually can be controlled by the Dam Owner may result from errors and deficiencies in design, construction, O&M. These include:

- Design and construction of the civil works is insufficient.
- Dam safety elements of the design and construction of mechanical and electrical equipment are insufficient.
- Testing and commissioning procedures, O&M manuals, surveillance of dams and EAP are inappropriate.
- Violation of security and vandalism that affect dam safety.

Principle 3: Dams and appurtenant structures should be designed, constructed, commissioned, operated and rehabilitated in a way that they meet the performance criteria.

Design criteria should always be commensurate with the consequences of dam failure. The design criteria must not be affected by subsequent construction, commissioning and operation practices. This principle is achieved as follows:

- The competency and experience of the dam owner's agents must be adequate in managing the special nature of the dam and commensurate with the consequences of dam failure.
- The Dam Owner must provide adequate funding for investigations, design and construction to allow sufficient assessment and protection on vital aspects (e.g. dam foundation and treatment).
- Dam Owner should not compromise safety due to financial pressure or programme accomplishment.
- There must be trusting and cooperative relationship among Dam Owner, Designer and Contractor. The Designer must be appropriately consulted on matters that affect dam safety.
- Continuity of key technical advice should be maintained throughout the entire life cycle of the dam to minimise possibility of contradicting or misinterpreting the design intent and philosophy.
- Dam safety risks and controls should be fully understood and evaluated. They form a significant part of the dam design and dam rehabilitation design. Resilient features should be incorporated in the design to cope with uncertainties in future loading conditions and variance in properties of construction materials.
- Dam records relating to the investigation, design, construction, commissioning and maintenance should be well kept and updated throughout the life span of a dam.

- Quality assurance and control should be established and retained relating to investigation, design, construction, commissioning, operation, maintenance and rehabilitation of dam.

3.3.3 Responsibility of Dam Safety Management and Operational Integrity

Principle 4: The responsibility for the safety of the dam and its operational integrity rests with the Dam Owner.

The Dam Owner is directly responsible for the dam safety; this is both a moral and legal obligation. The dams in Malaysia are largely owned by governments or government agencies. In recent times there is an increase in number of dams owned by private mining companies. NADMA plays a role for the safety of the public, either directly or indirectly through an oversight crisis management in the event of dam failure.

The Dam Owner is responsible, but not limited to, for:

- Establishing and maintaining the necessary competencies for the executing dam safety management including provision of sufficient information and training.
- Establishing appropriate procedures and arrangements to upkeep safety of the dam under all conditions.
- Verifying appropriate design, construction and quality of the dam and appurtenant structures is carried out in compliance to acceptable current dam safety practices and resiliency to commensurate with the consequences of dam failure.
- Ensuring the safe control of the reservoir operations (i.e. inflows, outflows and stored volumes).
- Ensuring the safe control of all sediments and deleterious materials that result due to the operation of dam and reservoir.
- Ensuring the completion of periodic dam safety inspection and reviews.
- Ensuring that EAP, commensurate with the consequences of dam failure, is in place and updated periodically.

Dam can span many human generations. Provision must be made for continuity of dam records and database for future reference.

3.3.4 Role of Government

Principle 5: The legal and governmental framework for all industrial activities, including operation of dams, provides the overarching structures for operational integrity and safety assurance.

The government of Malaysia has the responsibility to address the issues on dam safety; no other organisation have these role and responsibility to protect the people, property and environment.

Generally, the legal framework, specific laws and regulations is established, but not limited to, for:

- Protecting against mis-operation or failure of dams and reservoirs.
- Provision of management of dams, reservoirs and operations that cause possibility of dam breach or other inundation risks.
- A clear framework that typically includes dam safety management and roles for operational integrity and safety assurance.
- Enforcement of related legislation, regulations and any other measures by governments, within the national laws system, to efficiently carry out their national responsibilities and any other international obligations.

3.3.5 Leadership and Management for Safety

Principle 6: An established and efficient leadership and management for safety should be sustained over the life cycle of the dam.

The top management in an organisation should lead in dam safety matters, manifest through an established efficient management system. A culture of dam safety conscious in an organisation and individual involved in the dam safety management system has to be promoted and practiced. Regular safety assessment on performance and the application of knowledge and lesson learnt from the past should be conducted.

To ensure an efficient leadership and management in all levels of the organisation, the following factors that govern include:

- Good performance and effective practices must be considered to prevent human and organisation failures.
- All ranges of interactions amongst individuals at all levels, with organisations and with technology in a management system is recognised and considered.

- Accident may happen although all measures are taken. Lesson learnt sessions should be carried out, documented and acted on which includes analyses and findings (e.g. root causes, operator's knowledge and experience, initiating events, accident symptoms, near misses, accident and unintended acts).

3.3.6 Dam Safety Management

Principle 7: A dam safety management system, commensurate with the consequences of dam failure and incorporating policies, procedures and responsibilities should be in place for all dams.

Effective dam safety management is essentially achieved through establishment and implementation of procedures commensurate with the consequences of dam failure. Dam Owners should show their commitment to dam safety and provide a structured framework for conducting dam safety operations, addressing identified dam safety issues and deficiencies. Dam safety management system includes:

- Establishment of a dam safety policy / mission statement / standard that reflects the Dam Owner's pledge to dam safety.
- A descriptive constituents of the dam safety management system, e.g. action plans and resources for carrying out dam safety works.
- Incorporating responsibilities and procedures for executing the constituent management system of dam safety. Procedural system involves safety inspection, instrumentation monitoring, safety reviews and alerts if symptoms of deficiencies or exceeding safety thresholds are observed.
- Incorporating assessment on performance of the dam.
- Incorporating identification with sufficient information on any safety issues and potential symptoms in the performance of the dam and dam safety management system.
- Provision of necessary facilities, communication system, training and education for staff and knowledge and information management.

As part of the efficient management, the dam safety has to be categorised using a hazard rating. The hazard rating should be determined by the worst potential consequences, based on the failure modes This classification is useful for setting appropriate level of dam safety programme as well as oversight management with relevant authorities.

Principle 8: Protection should seek to achieve the highest level of operational integrity and safety that can be reasonably obtained.

Throughout the entire lifecycle of the dam, the safety protection applied should yield the highest level of safety that can be reasonably obtained to the public and environment, with no unnecessary compromise on the benefits from the dam. In pursuit of this objective the following elements should be considered:

- Population that makes them susceptible to potential dangers of dam.
- Potential loss of life.
- Environmental, social and economic factors.
- Hazards from recognised harmful event that affects dam safety.

Appropriate funding and resources should be allocated by Dam Owners to ensure sustainable safe operation of dam.

Principle 9: No risks of dam safety impose on any persons and society should exceed the permissible level of tolerable risk.

Steps have to be taken to ensure that no inappropriate risk of hazard is imposed on any persons and society. Limit of dam risks usually correspond to utmost extent on bearable and permissible hazard. Tolerable risk in dam safety management involved evaluation of benefits and risks towards reaching a consensus of sufficient protections; with supports of legal requirement. Dam safety management is established by the Dam Owner with legal supports of regulatory framework set up by the governments. In managing risks, these include:

- Ensuring that protection of public interest gained from dam outweighs the hazard and risk posed by dam and reservoir.
- Reduction, if not elimination of failure modes to the extent that is tolerable.
- Control risks of foreseeable hazard, if not eliminate to as low as reasonably practicable.
- Ensuring that effective dam safety procedures and EAPs are able to mitigate any harmful incidents or dam failures.
- Drills on crisis response program in preparation of the dam failures to create public awareness of the affected population.
- Preparation of financial aids (e.g. insurances, Dam Owner’s compensation, societal resources) as a contingency plan in case of dam failure.

The dam safety management should include managing risks to overall affected people, property and environment are within the standards normally accepted by society.

3.3.7 Sustainability of Dams and Reservoirs

Principle 10: Dams and reservoirs must be sustainable to yield a long lasting societal worth asset by ensuring all failures and harmful incidents are negated as reasonably practical as possible.

The dam safety management should endure the whole life time of the dam. Any actions taken at every present moment will affect the future being of the dam. Likewise, the ageing of the dams, with recurring inclement weather and changes of the surrounding environment over time, this eternal risks imposed on dams and reservoirs have to be assessed thoughtfully.

The ongoing safety management decision making must evaluate the sufficiency of protections against the possible resulting risks due to the actions taken. Some recommendations consisting of safety mechanism are as follow:

- At the feasibility study stage, thorough dam site selection should be carried out with sufficient information acquired.
- During design and construction, robust design and engineering practices should be applied. This includes appropriate safety margins, state of the art technologies, good quality materials that enhanced the reliability of the engineering features.
- An effective blend of inherent and constructed dam safety features.
- Throughout the operation, maintenance and surveillance of the dam, an efficient and competent dam safety management with unrelenting pledge on safety should be cultivated, besides routine checks and regulating requirements.
- Crisis management plan should be established for preventing any mis-operation consequences.

Also, provision of recovery plan especially to bring back into normal operation, should any mis-operation incident occurs.

3.3.8 Emergency Preparedness and Action Plan

Principle 11: Emergency preparedness and action plan should be in place for dams.

Every dam should have an emergency preparedness that commensurate with its hazard rating and should be updated throughout the entire lifecycle of the dam. The EAP should commence prior to first filling of the reservoirs and crisis protections should be instilled from then onwards, giving consideration to all reasonably foreseeable dam incidents and failures.

Any absence of legal requirements does not negate the Dam Owner from providing emergency preparedness and action plan.

The EAP should incorporate:

- Efficient arrangement necessary at dam site, local, state, national and as concurred between neighbouring countries is established.
- Advance arrangements of the crisis management actions (e.g. identification of emergencies, adopted EAPs, communication plans, and remedial actions).

Having developed the EAPs, drills should be carried out accordingly to ascertain the preparedness of the relevant parties involved.

4 DAM SAFETY MANAGEMENT SYSTEM

4.1 INTRODUCTION

The primary objective of management of dam safety is preventing dam failure. It also involves preparing to respond to unusual conditions so that hazardous situations can be brought under control.

The consequences of a catastrophic dam failure are enormous. At stake are not only lives and property, but the community, its economic well-being and the natural environment. With increasing population density the probability of loss of life and property damage is increasing. In addition, historical evidence indicates that effective dam safety programs could have prevented the majority of dam incidents progressing to dam failures. Lessons to be learnt from past dam incidents and failures are described in “Deterioration of Dams and Reservoirs (ICOLD, 1983) and "Dam Failures – Statistical Analysis” (ICOLD Bulletin 99) and “Dams and Public Safety” (Jansen, 1983).

This section describes the need for an overall management system to provide a framework for dam safety activities, decisions, and supporting processes. The key elements of a dam safety program are outlined. Decision criteria, practices and procedures should be developed in the establishment of a dam safety management system.

The standard of care applied to management of safety at a dam and the extent of application of the management system as described in this document should be commensurate with the hazard rating of the dam.

4.2 RESPONSIBILITY AND ACCOUNTABILITY

4.2.1 The Role of Government

The role of government is to enact legislation to protect the community. Legislation should establish regulatory authorities that ensure Dam Owners, and potential Dam Owners, are taking appropriate actions in regard to dam safety.

4.2.2 Responsibility for Dam Safety and Liability for Dam Failure

A Dam Owner has a legal and moral responsibility to take all necessary measures to prevent a dam failure and to mitigate the effects of a failure should one occurs. The prime responsibility for the safety of a dam rests with the Dam Owner. When a dam failure causes loss of life or property damage, the Dam Owner can expect the injured parties to sue for damages. The Dam Owner's professional advisers, contractors and other involved parties may also be caught up in such action.

The Dam Owner is responsible for ensuring that adequate funds are available to provide an appropriate dam safety program, as outlined in MyDAMS.

The risk of adverse legal outcomes can be reduced by following a dam safety program that would ensure dam safety and by adopting defensive engineering in the development and management of a dam (Federal Emergency Management Agency, US Department of Homeland Security (FEMA) 1987 and ICOLD 1987).

4.2.3 Dam Owner

The owner of each dam is responsible for its safety. This responsibility requires the provision of sufficient resources to meet its safety program requirements.

Dam Owners should ensure that for each of their dams:

- They are operated and maintained in a safe manner;
- Dam Hazard Ratings are known and regularly reviewed;
- Appropriate surveillance programs are implemented;
- EAPs are prepared and tested; and assist relevant government agencies in downstream emergency planning ;
- Suitably qualified and experienced personnel are engaged on dam works and during inspections;
- Suitable corporate governance structures and internal reporting processes are in place.
- Dam safety reviews are undertaken at the appropriate time; and
- Dam risk profiles are available and risks are being addressed on a priority and urgency basis.

4.2.4 Regulatory Authorities

Regulatory authorities should maintain a register of the dams under their jurisdiction and have the power to ensure that those dams are designed, constructed, operated and maintained in accordance with currently accepted standards. They should at least require Dam Owners of Significant or higher Hazard Rating dams, and other dams with Population at Risk (PAR), to be conscious of the condition of their dam at all times and ensure that a dam safety program is in place.

4.2.5 Dam Engineers and Operators

Dam safety requirements should be identified and documented by suitably qualified and experienced dam engineers. These requirements will occur during all phases of the life of a dam, particularly during design, construction, operational life and decommissioning.

Dam operators should be aware of the damage potential of the dam and be able to recognise and report deficiencies, or adverse trends that could lead to failure, to a dam engineer.

4.3 DAM SAFETY MANAGEMENT PROGRAMME

An overall dam safety management programme provides the Dam Owner with a framework for dam safety management activities, decision making and supporting processes. Dam safety management responsibilities should be allocated to an individual or team within the Dam Owner's organisation and the organisation as a whole should be committed to meeting its dam safety objectives.

The dam safety management programme should incorporate arrangements for governance including oversight, enabling, delegated authorities and resourcing. An example dam safety management programme is presented in **Figure 4.1**.

A dam safety management programme should incorporate:

- A dam safety policy, dam safety statement or dam safety standard.
- A description of the dam safety management programme and its elements including dam safety management activities and resources for completing these activities.
- Responsibilities and procedures for implementing the dam safety management programme.
- Procedures for checking and reviewing the performance of the dam and the dam safety management programme.
- Procedures for identifying and addressing any dam safety issues, including deficiencies in the performance of the dam and the dam safety management programme.
- Procedures for regular reporting on the performance of the dam and the adequacy of the dam safety management programme to the Dam Owner and, where appropriate, Regulators.

- Appropriate supporting systems for management, staff training, communications and information management.

Figure 4.1: Dam Safety Management Programme

Dam safety incidents and dam failures do not necessarily correlate with complexity or improbable loadings. Technical issues or errors under normal operating conditions have been the cause of many dam incidents and dam failures, including combinations of small factors which together have resulted in dam safety incidents and dam failures.

To assure dam safety appropriate measures should be taken to prevent:

- The occurrence of abnormal conditions or incidents that could lead to an uncontrolled release of part, or the entire reservoir.
- The escalation of any such abnormal conditions or incidents to dam safety emergencies.

The primary means of preventing abnormal conditions or dam incidents is effective dam safety management (e.g. diligent visual inspection and monitoring, good communication practices, proper training, and regular maintenance and testing). The primary means of mitigating the consequences of incidents, should they arise, is resilience. This is achieved through an appropriate combination of effective management, operational processes and robust engineering features that provide safety margins, diversity and redundancy.

4.3.1 Governance

a. Dam Safety Policy/Statement/Standard

Dam Owner and senior management, whether an individual, public authority or private company is accountable for an effective dam safety management programme. Any Owner of a dam should have a dam safety policy, statement or standard.

A dam safety policy, statement or standard articulates a Dam Owner's commitment to dam safety management including the linkage of its dam safety objectives to:

- Applicable regulations.
- Industry practice.
- Public safety.
- The protection of third party property, public infrastructure and the environment.
- The Dam Owner's organisational goals and values.

The organisation's directive to its personnel responsible for implementation of the dam safety management programme should be stated in the policy statement.

b. Dam Owner Actions and Priorities

A Dam Owner's actions and priorities should promote the recognition of, and commitment to, the safe operation of its dams and reservoirs. Effective dam safety management requires responsibilities to be fulfilled at all levels in the Dam Owner's organisation, from senior management to field personnel. Senior management should take all steps to remain aware of the key activities and decisions relating to the safe management of their dams.

The implementation of a dam safety management programme, including the resolution of dam safety issues that may arise during the lifetime of a dam, should be in line with the organisation objectives.

c. Delegated Authority and Enabling

A clear line of authority and accountability for dam safety in a Dam Owner's organisation should be clearly stated.

Adequate resources (financial and personnel) and delegated authority should be provided to the responsible personnel to effectively fulfil their responsibilities. Allocation of resources should allow for the timely completion of all dam safety management activities including the investigation and resolution of any dam safety issues that may arise during the lifetime of the dam and authorities requirements.

d. Communication

Dam Owners should have effective communication processes in place that ensure important dam safety issues are promptly reported to the appropriate responsible personnel, and escalated appropriately to key decision makers and, where necessary, to external authorities. The organisational culture should promote upwards communication of dam safety information.

A Dam Owner's dam safety policy, statement or standard and its dam safety achievements should be communicated throughout the Dam Owner's organisation.

e. Review

Internal and external reviews of the effectiveness and appropriateness of a Dam Owner's dam safety management programme is an important part of governance. Such reviews ensure that the stated dam safety objectives are appropriate and are being met, and that a pathway towards continuous improvement is being maintained.

4.3.2 Competency of People

The Dam Owner is responsible for ensuring that appropriately competent personnel are engaged to implement all elements of the dam safety management programme, and their roles and responsibilities are fulfilled.

The Dam Owner should ensure that the technical advice is sort from competent and qualified personnel in dam engineering and dam safety. Designers and Technical Advisers play key roles in ensuring dam safety. The Dam Owners and their Designers and/or Technical Advisers should understand the extents of their roles and the boundaries of their responsibilities.

On-the-ground routine surveillance and monitoring is recognised as the first line of defence in dam safety and is one of the most important aspects of a dam safety management programme. Evaluation of the surveillance and monitoring results, the assessment and reporting on dam performance, and the completion of intermediate dam safety reviews should be undertaken by people competent in the evaluation of surveillance and monitoring results.

All people with dam safety responsibilities should understand the conditions and hazards that can affect dam safety, the potential failure modes for the dam, the early signs for the development of each of the potential failure modes, and the surveillance and monitoring procedures relevant to each of the potential failure modes.

Typical competencies required for personnel involved in ongoing dam safety management are listed in **Table 4.1**.

Table 4.1: Competencies for People involved in Dam Safety Management

Role	Principal Areas of Competence
Dam Owner / Manager / Administrator	Legal, regulatory and duty of care responsibilities relating to dam safety Understanding of dam safety hazards and risks Understanding of dam safety management programmes, principles and practices, and emergency planning and response procedures Understanding of quality assurance principles.
Technical Adviser	Structural, geotechnical, engineering geologist, mechanical, electrical, seismic, hydrologic and hydraulic design specialist. Dam construction techniques. Understanding of dam safety management programmes, principles and practices. Operation, maintenance and testing procedures. Surveillance and performance assessment. Response to and managing dam safety issues. Emergency action planning. Gates and valves including associated power supplies, control and protection systems, and communication systems
Operation & Maintenance Personnel[1]	Safe operation of gates and valves. Maintenance and testing practices. Dam safety and surveillance principles and practices. Emergency response.

Dam Safety Field Surveillance Inspectors[1]	Dam safety and surveillance principles including visual recognition of the onset of potential failure modes and dam safety deficiencies, e.g. erosion, crack. Potential failure modes. Emergency response procedures including escalation process for alerting others. Safe operation of gates and valves (if appropriate).
Key Emergency Personnel[1] (Dam Owner)	Understanding of the potential effects of a dam failure. Emergency response. Emergency planning and drills.
Dam Engineer	Competency requirements to be established by an appropriate authority.
Regulators	Understanding of the implications of legislation relating to dam safety.
Public at Risk	Understanding of safety around dams and reservoirs. Emergency awareness and response.

Note 1: Depending on the dam, Dam Hazard Rating and the Dam Owner, these roles may be performed by the Dam Owner in some cases and, in other cases, by a single person or team of people.

4.3.3 Training and Education

Training and education programmes for all personnel with responsibilities for dam safety should be geared towards developing and maintaining appropriate awareness and competencies, and should take into account:

- The organisational structure and governance arrangements.
- The characteristics of the dam, reservoir and appurtenant structures.
- The potential failure modes for the dam and appurtenant structures.
- The gate and valve systems that fulfil dam and reservoir safety functions.
- Site-specific issues including any potential or confirmed dam safety deficiencies.
- Changes in the facilities or operating procedures.

The personnel involved must be trained and know how to fulfil their respective roles. Training records should be maintained for all personnel with dam safety responsibilities.

4.3.4 Form and Content

A dam safety management programme should:

- Detail requirements and frequencies for routine surveillance and monitoring, data evaluation, and reporting to the Dam Owner.
- Detail requirements and frequencies for the routine inspection and testing of gate and valve systems that fulfil dam and reservoir safety functions.
- Assign routine surveillance, monitoring, inspection, testing, data evaluation and reporting tasks to ensure they are carried out by appropriately qualified and experienced people.
- Contain requirements for intermediate dam safety reviews and comprehensive dam safety reviews.
- Contain an EAP or, if appropriate, a reference to a separate EAP.
- Contain procedures for the identification, evaluation, and resolution of dam safety issues.
- Include appropriate governance, management, communication, training and information management programmes.

4.3.5 Documentation

A dam safety management programme, including all relevant operation, surveillance, maintenance, testing and emergency procedures, should be well documented and available at all times for those responsible for its implementation and review. The documentation should be clear, user friendly and easy to interpret.

Documentation of the dam safety management programme should be controlled and managed. The documents should be stored at separate main and back-up locations and in both hard copy and electronic formats.

4.3.6 Information Management

Careful record keeping and preservation of all dam information must be carried out throughout the dam's life time. The records must be filed and managed for easy retrieval. A sound information management programme will safeguard a Dam Owner against lost through staff turnover and save the Dam Owner time and money in obtaining the information require in future. For example, when investigating a dam safety deficiency, historic records may avoid the need for intrusive and unnecessary risk in drilling and investigation.

4.3.7 Audits and Reviews

Audits and reviews of a dam safety management programme allow a Dam Owner to maintain a pathway of continuous improvement and provide assurance that dam safety risk is being appropriately managed. Audits and reviews provide the best value when they are undertaken as a complementary mix of introspective self-assessment and external assessment.

4.4 DAM HAZARD RATING

The Hazard Rating is a measure of the extent to which the dam poses a potential threat to life, environment and property. The amount of effort and resources that a Dam Owner should put into a dam safety program is determined by each dam's hazard and risk.

The Hazard Rating of a dam may change during the life of a dam. Therefore, the basis of hazard rating of the dam should be documented and retained for the life of the dam. The guidelines for determining the Hazard Rating of dams are described in **Appendix B**.

Table 4.2 shows the summary of the categories of dam hazard rating for dams in Malaysia.

Table 4.2: Dam Hazard Rating

Dam Hazard Rating	PAR[1,2]	Environmental and cultural values[2]	Infrastructure and economics[2]
Low	0	Minimal short-term loss; No long-term loss	Low economic losses; Area contains limited infrastructure or services
Significant	1 – 10	No significant loss; Marginal deterioration of important flora and fauna habitat; Restoration is highly possible	Significant economic losses involving recreational facilities, infrequently used workplaces and transportation routes
High	11 – 100	Significant loss or deterioration of critical flora and fauna habitat Restoration is possible but impractical	High economic losses affecting infrastructure, public transportation and commercial facilities
Very high	> 100	Major loss or deterioration of critical flora and fauna habitat Restoration is impossible.	Very high economic losses affecting important infrastructure or services (e.g. hospital, highway, industrial area, storage facilities for dangerous substances)

Note 1: Definitions for Population at Risk (PAR):

The number of people who would be directly exposed to inundation greater than 0.5 m in depth within the dam break affected zone if they took no action to evacuate.

Note 2: Inference for PAR, environment and cultural values, and infrastructure and economic losses:

Losses or damages stated above are incremental, which dam failure might inflict on, are over and above any losses which might have occurred for the same natural event or conditions, had the dam not failed.

5 INVESTIGATION AND DESIGN

5.1 INTRODUCTION

MyDAMS provides a framework for the investigation and design of new dams, the analysis of existing dams, the design of upgrading and rehabilitation works of existing dams. Natural hazards that can affect dam safety need to be considered in the investigation and design of dams include floods, earthquakes, landslides, extreme storm and wind events, lightning strikes and hydrothermal activities. Other threats to dam safety related to human activities may arise from errors and deficiencies in design, specification, construction and operation, inadequate maintenance and surveillance.

Design criteria should always be commensurate with the consequences of dam failure. In addition, care should always be taken to ensure that the design is not posing difficulty to subsequent construction, commissioning and operational practices.

All designs must consider dam safety risks and measures to control them and resilient backup features to support primary works component should be provided. Dams engineering frequently involves handling uncertainties and risks beyond prevailing knowledge. It draws heavily on experienced judgement and known safe practices. Critical uncertainties must be identified, investigated and resolved to acceptable risk levels.

Appendix C provides the guidelines for investigation and design of new dams, the analysis of existing dams, the design of upgrading and rehabilitation works of existing dams.

5.2 ISSUES CONCERNING DAM OWNERS

Dam Owner must ensure that competence and experience personnel are engaged and adequate funding are provided to address all critical issues in the investigation and design activities.

A Dam Owner should also be satisfied regarding the following:

- Proposed dam satisfy its intended purpose.
- Design brief adequately and fairly cover the requirements of the Dam Owner, the Designer and the Regulator.
- Designer and Contractor engage suitably qualified and experienced dam engineers to undertake their work.

- Risks and consequences of failure of the dam are adequately addressed by the appropriate disciplines.
- Hazard rating of the dam and the standard of dam safety require.
- Whether an independent review of critical decisions is warranted for dam with Significant Hazard Rating or higher; independent review of critical decision is recommended.
- Investigation and design reports been adequately prepared.
- Statutory requirements need to be met and person who can advise on them.
- Relevant local or other environmental impacts been considered.
- Operations and maintenance requirements been incorporated into the dam.

5.3 ISSUES TO BE ADDRESSED BY DAM ENGINEERS

A dam engineer engaged on any aspect of the investigation and design of a dam should be familiar with all the necessary basic principles and the existence of technical guidelines, memoranda, articles and manuals.

The dam engineers should include, but not limited to, the following points during the dam development process:

- The regional and site geology should be understood and engineering geology models developed to form the basis for design.
- The foundations must be capable of supporting the dam, controlling the seepage and resisting erosion;
- The reservoir basin and rim should be sufficiently impermeable to prevent excessive losses of water. Seepage should be controlled and instability should not occur at any stage of reservoir operation;
- Construction materials should be identified to meet site and design requirements economically;
- Spillway size should be established on the basis of accepted guidelines and requirements given the capacity and locality. The hydraulic, hydrological and meteorological input should be appropriate;
- The design should be established on the basis of the loadings, including seismic effects, strengths, and erosion resistance of the available materials and the need to control seepage and internal erosion to ensure the long-term integrity of the dam;
- The outlet works should meet the requirements for robust, flexible reservoir operation and have provisions for safe operation, maintenance, drawdown, upstream/down-stream flood implications and any necessary environmental releases;

- Provision should be made for both the short term and long term monitoring of the structural performance;
- Adverse environmental effects should be minimised;
- Continuing investigation and the possible need for design changes during construction are addressed ; and
- An appropriate quality assurance program should be developed and adhered to through the investigation, design and construction processes to ensure all matters are properly attended to and recorded.

5.4 PERSONNEL AND QUALITY ASSURANCE

5.4.1 Introduction

Dam engineering is a mixture of science and art. Experience and engineering judgement play an important part.

Dam Owners should seek advice on current dam engineering practice to avoid making decisions that compromise on dam safety. Dam Owner should appoint a Dam Engineer to assist in all decision making relating to the dam project.

The continued involvement of design personnel during construction and commissioning is strongly recommended to ensure that any site conditions that are different from the design assumptions are addressed.

Dam Owners should allocate sufficient funds for the investigation and design of a dam to ensure dam safety is not compromised by inadequate funds. The Dam Owner has legal responsibility for the dam, so inadequate funding will reflect on the Dam Owner in the event of a dam safety incident or dam failure.

Dam Owners must be realistic about the time necessary for the completion of investigation and design activities. Experiences show that dam projects which do not include a thorough investigation have a much higher likelihood of unexpected or adverse conditions arising during construction. Any adverse conditions discover at a later stage of dam construction will be difficult to be resolved and often leads to delay and cost overrun.

5.4.2 Personnel and Quality Assurance Procedures

The Lead Designer should have had prior experience as a Lead Designer for a similar or higher hazard rating dam, or should have been a major contributor to the design of a similar or higher hazard rating dam. The design team should include specialist personnel with appropriate qualifications and prior experience in all areas of investigation and design as shown in **Table 5.1**.

Table 5.1: Responsibilities of Specialist Personnel

Specialist Personnel	Roles
Hydrologist	Flood analysis
Geologist	Geological assessment of dam site geology and the investigation of quarry, borrow area, tunnel and powerhouse area.
Geotechnical Engineer	Design of dam foundations and treatments The design of construction materials in dams
Structural Engineer	Design of concrete structures (e.g. draw off tower, spillways, outlet structures) Design and placement of concrete materials (concrete mix design, aggregate quality, durability and temperature control)
Hydraulic Engineer	Design of hydraulic structures (e.g. spillways, intake structures)
Mechanical Engineers	Design of gates, penstocks, lifting equipments, mechanical ventilation, fire protection system, etc.
Electrical Engineers	Design of power supply, instrumentation and control systems, general lightings, lightning protection system, and etc.
Civil Engineers	Design of infrastructures, roads and drainages etc.

5.4.2.1 Independent Review

A formal review of the investigation, design and construction by an independent experienced engineer should be a mandatory requirement for high and very high hazard rating dams. There are some basic tenets which should be followed for review. They include:

- Appointing a panel of reviewers where the dam includes a number of features that cannot be effectively addressed by a single reviewer in complex dam site conditions.
- Commencing review early in the design process to ensure that the design concept and investigation are appropriate for the proposed site and available construction materials.
- Ensuring that the Reviewer does not become the ‘Designer’ of the dam.
- Having a mechanism agreed between all parties for resolving any areas where the Reviewer and Designer have strongly opposing views.
- The design must remain the Designer’s responsibility.

5.4.2.2 Quality Assurance and Control

Formal in-house systems for the planning, checking and reviewing of all investigation and design work in accordance with a Quality Plan of a quality system (e.g. ISO 9001:2008) should include:

- A detailed investigation and design brief setting out objectives, data sources and assumptions, engineering design criteria, standards, methods of analysis, and the like.
- Statements of personnel responsibilities and interdisciplinary interfacing.
- A means for handling design changes that arise during design and construction.
- Communication and documentation requirements.

5.5 INVESTIGATION

Investigations should be thoroughly planned to ensure that all aspects, which may create a potential dam safety problem are identified so that they are investigated and appropriate solution can be determined by the dam designer.

Besides the dam site itself, the storage and surrounding areas topography, geomorphology and geology should be investigated to provide adequate information to allow the dam design to address the risks of major leakages, slope instabilities and significant reservoir induced seismicity, which could post risk to the safety of the dam.

All investigation work should be properly recorded and presented in a comprehensive report, which will enable the dam designer to define the extent of any further work required prior to finalising the design.

The feasibility study and concept design report should be reviewed before approval to proceed with detailed design. The feasibility study report should present sufficient documentation to prove the technical feasibility of the proposed dam project.

The main aspects of the feasibility study and concept design that should be considered, but are not limited to:

- Determination of the Hazard (consequence) Category
- Foundation investigations
- Hydrology and flood capacity
- Stability (static & seismic)
- Erosion resistance (internal and external)

- Reservoir sedimentation
- Availability and properties of construction materials
- Environmental issues
- Adequacy of proposed reservoir operations
- Designer's Operating Criteria
- Stakeholder issues
- Project options, risks and mitigation measures
- Cost estimates
- Cost-benefit analysis
- Construction methodology/ contract strategy

Investigations are generally also on going through the construction period, which is when the foundations become fully exposed, or the extent of grouting work becomes known. As such, reports will need to be amended (and updated) as construction proceeds, so that, by the time construction is completed, a full and comprehensive report is available as a reference for on-going surveillance of the dam.

5.6 DESIGN

The Designer's objective is to design a dam and its associated structures, or a dam rehabilitation, in a manner that suitably reflects the characteristics of the site, the loading conditions applicable to the site, and the consequences of dam failure. To obtain authority approval for construction, the Designer must demonstrate that the design has considered all hazards at a level appropriate to the consequences of dam failure, and that the hazards are accounted for and their effects satisfactorily mitigated. The Designer must also demonstrate that the completed structure will meet durability requirements and achieve the specified intended life for the structure.

The Designer needs to recognise that not all elements of dam structures requiring design are adequately covered by design manuals or standards. The Designer is required to assess all realistic risks and demonstrate how the design will reduce risks to as low as reasonably practicable (i.e. to the point that risk reduction is impractical or its cost is grossly disproportionate to the improvement gained). Attention needs to be directed not only towards extreme event loads of very low probability but also unforeseen combinations of usual events that could affect dam safety.

MyDAMS promotes the use of robust and resilient features to reduce the risk of dam failure from unexpected and unpredictable events. Resilience means the capacity of the structure or system to withstand changing conditions caused by sudden shocks, gradual stresses and cumulative change.

Dams typically have a long operational life. Interventions and upgrades at later stage can be expensive and result in increased dam safety risks. Robust design and resilient features enhance dam safety assurance. The elements or components with shorter design lives should ideally be readily replaceable.

Instrumentation should provide a means of comparing design assumptions and parameters with actual conditions, and of monitoring performance, during the construction and operating life of the dam.

Features of a dam often need to be specially instrumented to check the operational performance or to provide, or enhance, emergency warning capability. To avoid this being overlooked by surveillance personnel, the dam designer should highlight the concern in the report and drawings.

The ICOLD "Dam Safety Guidelines" Bulletin 59 (1987) gives a detailed listing of areas where potential safety problems can arise in dam design. Dam designers should consult this and other references for further guidance.

It is the dam designer's responsibility to achieve an overall design, which will satisfy accepted standards of safety whilst meeting the Dam Owner's and Regulator's needs. The designer should consider the maintainability, ease of replacement and redundancy of critical elements in the dam. At the same time the dam designer should be aware of new technology and methods being adopted elsewhere. The more that is known about the site conditions, foundation materials and construction methods the more confidence can be placed in the design.

5.7 DESIGN PROCESSES

5.7.1 Feasibility Studies and Design of New Dams

The dam design process is typically undertaken in a series of stages as per **Figure 5.1**.

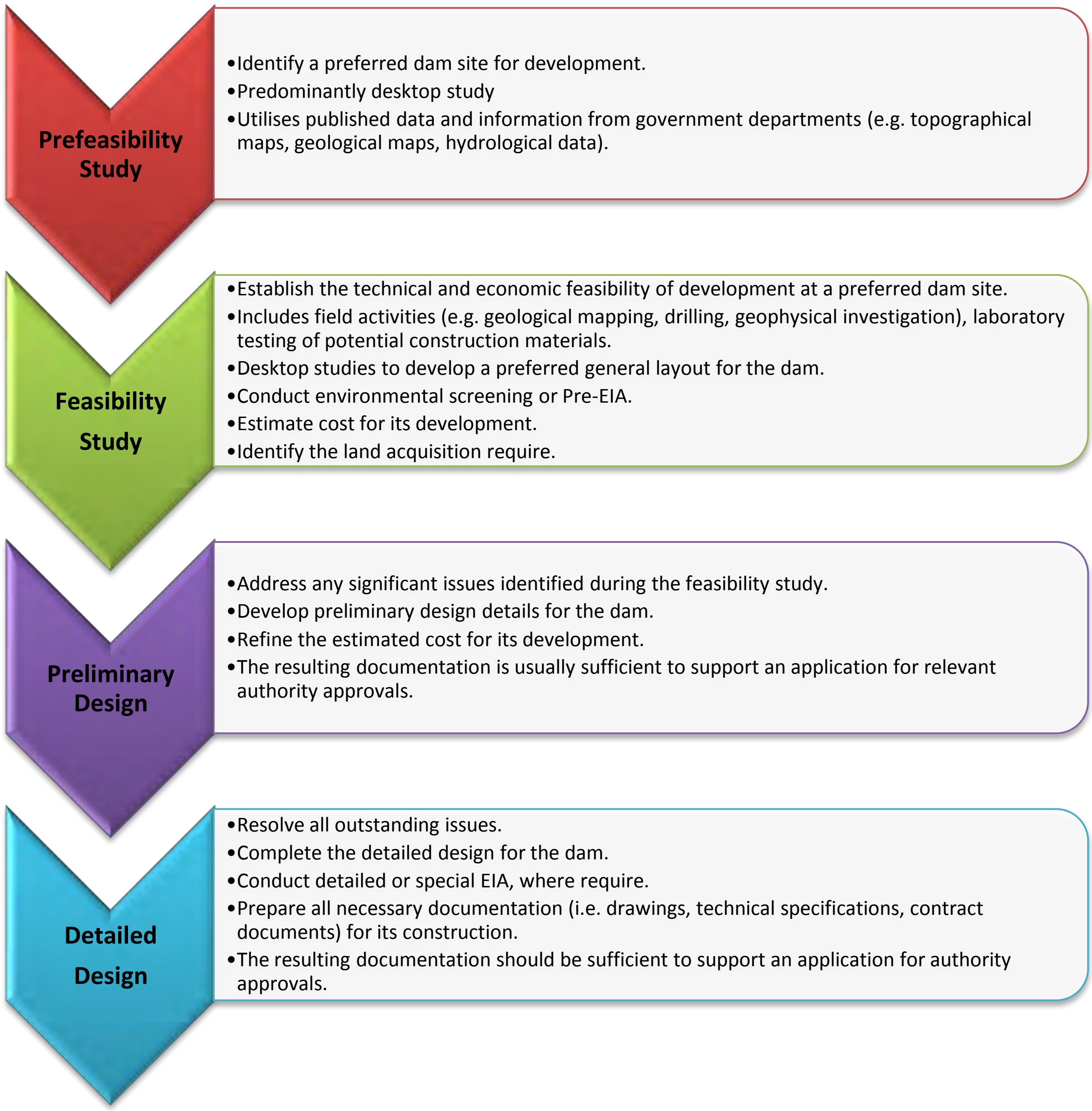

Figure 5.1: Design Processes for New Dams

As outlined in section **5.4**, each stage of the design process should be undertaken by personnel with appropriate backgrounds of experience. Significant benefits can result from the early engagement of peer review services for the design of Significant and higher hazard rating dams, and the later engagement of experienced contractors to assist in the identification of construction issues and risks, the assessment of construction methods (e.g. diversion arrangements) and the estimation of construction costs.

The design of a dam usually reflects precedent designs, the results of analytical studies, and the experience and personal preferences of the Designer. While alternative dam designs are often possible for a particular dam site, it is most important that the adopted design reflects the characteristics of the project and the dam site. Project and dam site characteristics that can strongly influence the design include:

- The function of the dam and its proposed operating regime. The reservoir for a hydroelectric scheme usually has a small operating range while the reservoir for a water supply scheme usually has a wide operating range. Impoundment upstream of a flood detention dam only occurs during large flood events.
- A requirement for staged construction to reflect a projected growth in water demand.
- The length of the season available for dam construction. Embankment dams typically have shorter construction seasons than concrete dams.
- The availability and quality of local materials for the construction of a dam. Some sites may have large resources of materials suitable for dam construction, while at other sites the resources may be limited.
- The size and shape of the dam site. Narrow dam sites with steep walls may necessitate special design provisions for an embankment dam or, if other site characteristics are appropriate, the development of a concrete dam.
- The local geology and the quality of the dam foundation. A site with a shallow rock foundation may require little foundation treatment in comparison to that necessary for a site with a deep alluvial foundation.
- The climate and likely weather conditions during the construction of the dam. Fine grained soils require dry weather for construction while coarser grained soils and rockfill can usually be placed during wet weather.
- Diversion requirements during construction. If diversion capacities are exceeded by a flood during construction, embankment dams present a far greater hazard to downstream communities and infrastructure than concrete dams.

5.7.2 Design of Rehabilitation, Raising and Upgrading Works

The design of rehabilitation works to address identified potential failure modes or dam safety deficiencies would typically be undertaken in a series of stages which include:

- A thorough evaluation of the existing risks and the necessity for the proposed rehabilitation works.
- A preliminary design to identify and consider rehabilitation alternatives, develop preliminary design details for the preferred remediation alternative, and complete an estimated cost for its completion. The resulting documentation should be sufficient to support any necessary applications for variations to existing water permits and land use consents.

- A detailed design to provide the necessary risk reduction, complete the detailed design for the works, and prepare all necessary documentation (i.e. drawings, technical specifications, contract documents) for their construction. The resulting documentation should be sufficient to support an application for authority approvals.

It is most important that the final rehabilitation works design properly addresses the identified dam safety deficiency, and that the solution is compatible with the characteristics of the existing dam and the dam site. Issues that can strongly influence the design of rehabilitation works for any dam include:

- The effects of the rehabilitation works on existing consents for scheme operation. For example, the completion of the rehabilitation works may necessitate a reduction in the consented reservoir level and variations in the consented discharges to the downstream river.
- The ability of the dam to fulfil its intended function during the completion of the rehabilitation works. For example, the lowering of a reservoir level may have a significant impact on the ability of a Dam Owner to meet bulk water supply targets, or may significantly reduce the head available for electricity generation.
- The risk to the safety of the dam during the completion of the rehabilitation works. For example, the rehabilitation of toe drainage facilities in an embankment dam could affect the stability of the downstream shoulder, and the rehabilitation of a spillway facility could markedly reduce the ability of the dam to safely manage flood events during the construction period.
- The time and cost required for completion of the rehabilitation works. To minimise the effects of rehabilitation works on normal business operations, a Dam Owner may consider a rehabilitation option that results in partial reduction of the risk rather than an option that results in full mitigation of the risk.
- The availability and quality of local materials for the construction of the rehabilitation works. Material shortages at some dam sites could significantly influence the scope and characteristics of the rehabilitation works.

5.8 DESIGN LOADS

Design loading conditions for various dam types are presented and discussed in various Australian National Committee on Large Dams (ANCOLD) guidelines, Canadian Dam Association (CDA) (2007), the United States Army Corps of Engineers (USACE) and the United States Bureau of Reclamation (USBR) engineering manuals. It is commonly accepted internationally that two extreme loading conditions do not need to be considered to occur at the same time. However, it is important to establish that the dam would not fail due to the effects of a combination of realistic loading conditions. Therefore, the Designer should consider the effects of one type of hazard occurring closely followed by perhaps a moderate event of the other type of hazard. For example, a dam damaged by a major earthquake may experience a significant aftershock or moderate flood before repairs can be completed. The dam should be able to withstand the second hazard in a damaged condition without failure.

5.9 POTENTIAL FAILURE MODES

A potential failure mode is a mechanism or set of circumstances that could result in the uncontrolled release of all or part of the contents of a reservoir. Avoidance of a potential dam failure mode, or mitigation to prevent or reduce the likelihood of a potential dam failure mode occurring, is a cornerstone of effective dam design.

Potential failure modes are a key element of risk informed approach to reduce the risk of dam failure; particularly those aspects not generally covered by standards based design. Identified potential failure modes provide valuable information about a dam which should be shared across design, surveillance and monitoring, safety review and rehabilitation activities.

Identifying, describing and evaluating site-specific potential dam failure modes are the most important steps in evaluating the safety of a dam.

Where required, reviews of design aspects of all new, or any major modifications should be carried out by an appropriate review team consisting of members with relevant, recognised, in-depth experience in the various fields of dam engineering.

5.10 DESIGN AMENDMENTS DURING CONSTRUCTION AND COMMISSIONING

Design details should be complete and constructible, areas of uncertainty should be identified and contingent details in place before construction commences.

Dam design is never complete until the dam or dam rehabilitation has been constructed and all facilities have been commissioned.

The Designer must remain alert throughout construction for any changes in conditions or properties from those assumed in the design. For example, foundation excavation may expose important foundation features that were not identified during the site investigation, the quantities and qualities of the borrow materials may be more variable than anticipated in the design, groundwater inflows during construction may necessitate modifications to the designed seepage control measures, and design changes may be necessary to suit a

Contractor's preferred construction method. A dam design or rehabilitation must be continuously reviewed and re-engineered during construction to ensure the final design is compatible with the conditions encountered during construction. This is especially true for dam rehabilitation projects where the actual as built conditions found during construction may be different than those presented on available drawings for the original construction.

Any changes to the design necessary to address observed site conditions or Contractor preferences must be completed to the same standards as the original design but, most importantly, must be addressed in a thorough manner to ensure that any changes do not inadvertently create a risk elsewhere. Even small design changes must not be considered in isolation as significant reductions in dam safety can result from a sequence of relatively minor seemingly unrelated modifications. Design changes that materially alter an authority approval issued for the construction of a dam or rehabilitation works will require the approval of the Regulator responsible for administering the authority approval process.

Design support is also essential during the commissioning of a dam and its associated hydraulic structures, and the commissioning of any rehabilitation works. The Designer should be responsible for planning the commissioning sequence, preparing all necessary commissioning documentation, ensuring all commissioning personnel are aware of their roles and responsibilities during the commissioning process, monitoring the commissioning process, and reviewing the performance of the dam and its associated hydraulic structures, or the completed rehabilitation works, during and following commissioning. The responsibility for dam safety should remain with the Designer until he/she is satisfied that all structures are safe and performing as intended.

It is essential that the Dam Owner understands the likelihood of design changes during construction and the need for design support during commissioning, with their associated costs, and has appropriate funding in place to support both activities.

5.11 DESIGN DOCUMENTATION

The dam designer should provide appropriate documentation as part of their design function for the Dam Owner. The level of documentation should be commensurate with the hazard and risks posed by the dam. This should cover all relevant details on the investigation, the design of the dam and include relevant commissioning requirements to validate design criteria. This provides a basis for ongoing dam safety management practices. It should include design changes and any matters of concern during the construction of the dam.

5.11.1 Documentation Procedures

A proper procedure should be established for the documentation of design process. The Design Report and associated documentation should be provided to the Dam Owner. They should be easily available for reference to assist in the analysis of any future dam safety problem that may arise, or to assist in the development of any major future modifications to the dam.

A design report and operations and maintenance manual should be prepared as part of the design function of the dam designer:

The parameters adopted, assumptions made , methods and results of analyses should be fully recorded and in such detail that should any safety problems arise during the life of the dam, quick and direct information can be obtained from the report to assist in whatever decisions need to be made to make the dam safe.

5.11.2 Construction Drawings and Specifications

The design should be translated into clearly understood construction drawings and specifications. An appropriate design report should be completed which records all design data, philosophies and assumptions, and defines areas requiring re-evaluation or confirmation during construction. Such documentation is required to accompany an application for authority approval for developing a dam.

Construction drawings and specifications must clearly describe any particular requirements to be achieved in areas critical to dam safety. For example, for an embankment dam specific fill materials and compaction requirements may be required adjacent to conduits and concrete structures to minimise the potential for erosion along concrete/embankment interfaces. The same applies to concrete dams. For example, specific foundation treatment may be necessary to minimise the potential for erosion along a shattered zone that trends across a rock foundation. The construction reports should highlights areas critical to dam safety, the reasons for their specified treatments, and the possible consequences of failing to meet the specified requirements.

5.11.3 Final Design Report

The final design report, which should be completed towards the end of construction, should be appropriate to the dam hazard rating. It should clearly document all assumptions, criteria and methods adopted for the design of the dam and its associated hydraulic structures or, as appropriate, the design of the rehabilitation works. The final design reports should include details as shown in **Table 5.2**.

Table 5.2: Details of Final Design Reports

Title	Details
Project Background	A description of the background to the project, the purpose of the dam, and the characteristics of the dam site.
Hazard Rating of Dam	An assessment of the hazard rating for the dam and its associated appurtenant structures.
Hazards Analysis	An assessment of the hazards that can affect the safety of the dam (e.g. floods, earthquake ground motions, reservoir landslides).
Site Characteristics	The characteristics of the site geology, the dam foundation, and the materials utilised for dam construction.
Design Philosophy and Approach	The philosophy adopted for the design of the dam and its associated hydraulic structures, and the criteria and methods adopted for their design.
Expected Performance	The expected performance of the dam and its associated hydraulic structures during normal, unusual and extreme loading conditions.
Instrumentations	The rationale for and a description of any instrumentation installed for the monitoring of dam performance.
Safety Surveillance	Surveillance and monitoring proposals for ongoing dam safety assurance.
Project Data	Relevant appendices (e.g. hydrological data, geological maps, seismic hazard studies, field investigation records, drilling logs, geophysical profiles, laboratory investigation results).

The final design reports for rehabilitation work should include details as shown in **Table 5.3**.

Table 5.3: Details of Final Design Reports for Rehabilitation Work

Title	Details
Project Background	A description of the purpose and characteristics of the existing dam, and the objectives of the rehabilitation works. A description of the risks associated with the identified dam safety deficiencies,
Site Characteristics	A description of any site specific considerations (e.g. site geology, available materials) or constraints (e.g. timing, flood management during construction, Dam Owner requirements) that influenced the selection and design of the rehabilitation works.
Design Approach	The philosophy adopted for the design of the rehabilitation works, and the criteria and methods adopted for their design.
Site Conditions	A description of the conditions encountered during the construction of the rehabilitation works.

Expected Performance	The expected performance of the rehabilitated dam during normal, unusual and extreme loading conditions.
Instrumentations	The rationale for and a description of any instrumentation installed for monitoring the performance of the rehabilitated dam.
Safety Surveillance	Surveillance and monitoring proposals for ongoing dam safety assurance.
Project Data	Relevant appendices (e.g. hydrological data, geological maps, seismic hazard studies, field investigation records, laboratory investigation results).

Copies of all key design records, drawings and documentation should be provided to the Dam Owner at the end of the project.

5.12 PERFORMANCE MONITORING

5.12.1 Instrumentations

Extensive instrumentation are require for the monitoring of dam performance, where particular design assumptions need to be validated, potential failure modes have been identified that require monitoring, or the consequences of failure are high. The need for instrumentation to check the validity of design assumptions and monitor the performance of a dam or appurtenant structure, and the limitation to monitor dam performance (e.g. difficulty to monitor seepage at dam toes inundated by tailwater conditions), should always be considered in the design of a new dam or the rehabilitation of an existing dam.

Where instrumentation is installed:

- It should not be used as a replacement for regular visual inspections but as an aid to augment the ongoing assessment of dam performance.
- It should be appropriate to the dam type and enable the monitoring of identified potential failure modes.
- It should be simple, reliable, robust and, where warranted, sensitive with sensors that are easy to install, calibrate, maintain and operate.
- Its installation does not adversely affect the integrity of the dam (e.g. the drilling within a dam core for piezometers may weaken the core if incorrect techniques are used).
- It should include sufficient instrumentation for the measurement of parameters critical to dam safety, and incorporate some redundancy to allow for instrument failures and the cross-checking of results.

- It should include, where appropriate, an automated monitoring system for the more frequent monitoring of key dam safety parameters such as reservoir water level, piezometric levels, and seepage flows and turbidity levels. Where automated monitoring systems are included, manual monitoring backup systems should be available to provide calibration and enable the monitoring of performance in the event of system failure.
- It should include the establishment of warning and alarm levels for the items being monitored, beyond which action is taken to review and ensure the continued integrity of the dam.

ICOLD Bulletins 104, 118, 129, 138, 141 and 158 discuss instrumentation objectives and various instrumentation techniques for monitoring dam performance.

The measurement of reservoir or pond level and, where appropriate, earthquake ground motions is common for embankment dams and concrete dams. The following subsections provide an overview of typical instrumentation systems that can be installed to verify design assumptions and assist in monitoring the long term performance of embankment dams, concrete dams and tailings dams. Guidelines for the monitoring of long term performance and the interpretation and reporting of monitoring results are included in **Appendix E** (Dam Surveillance).

5.12.2 Embankment Dams Instrumentation (Earthfill Dam and Rockfill Dam)

Instrumentation typically installed for monitoring the behaviour of embankment dams includes:

- Observation wells and piezometers for the measurement of groundwater levels in the abutments, and piezometric pressures in the embankment and its foundation.
- Weirs and other measurement facilities for the monitoring of seepage flows.
- Surface monuments for the monitoring of horizontal movements and settlements.

Dual piezometers, or individual piezometer installations, isolated in the core and in the foundation beneath the core (upstream and downstream of any impermeable cut-off) provide information which can be used to establish general seepage behaviour through and beneath a dam. Where these instruments connect directly with a seepage path, recorded piezometric pressures will provide an insight into hydraulic gradients and may indicate the occurrence of internal erosion.

Surface monuments are usually established on the abutments, along the crest and on the downstream slope of an embankment dam for the monitoring of dam deformations. Care needs to be taken to ensure that the monuments are founded on materials that are not susceptible to shrinkage and swelling.

Additional instrumentation should be installed for the monitoring of foundation settlement and embankment consolidation during and following construction (e.g. internal settlement gauges, borehole inclinometers), deformations and joint openings in concrete face slabs and plinths during construction and commissioning (e.g. joint meters), and seepage water characteristics following the identification of increased seepage flows (e.g. seepage turbidity levels, seepage water temperatures).

5.12.3 Concrete Dams Instrumentation (Concrete Gravity Dam and RCC Dam)

Instrumentation typically installed for monitoring the behaviour of concrete dams includes:

- Observation wells and piezometers for the measurement of groundwater levels in the abutments, uplift pressures at the dam/foundation contact and, if necessary, uplift pressures beneath potential failure surfaces in the foundation and blocks or wedges in the abutments.
- Weirs for the monitoring of seepage flows from internal and foundation drains.
- Survey points for the monitoring of dam deformations.
- Internal deformation instruments to measure tilt, rotation and horizontal deformation.

Piezometers installed from within drainage galleries or from downstream toes of concrete gravity dams enable the confirmation of uplift assumptions adopted during the design of the dam, the provision of uplift pressures for incorporation in stability studies, and the identification of any reductions in the efficiency of drainage systems.

In existing concrete gravity dams where piezometers are not installed, uplift pressures can be measured at selected drains. The monitoring of uplift pressures beneath thin arch and buttress dams that are not founded on slabs is not normally necessary as uplift pressures usually have a minimal effect on dam stability.

Weirs and calibrated containers are commonly used for the monitoring of seepage flows. In concrete gravity dams it is good practice to divide the seepage monitoring system into separate catchments to enable the location of any seepage increases or decreases. Reductions in seepage flow may indicate reductions in the efficiency of under-drainage systems.

In concrete gravity dams any loss of structural integrity will usually manifest itself at the vertical contraction joints between adjacent dam blocks. Because of the monolithic behaviour of concrete arch dams, any loss of structural integrity will usually manifest itself as horizontal displacements along the arch. In recognition of the above, deformation systems usually include:

- Survey points along the crests or in the galleries of concrete gravity and buttress dams for the monitoring of upstream/downstream deformations and vertical deformations. Alignment surveys are usually adopted for the monitoring of upstream/downstream deformations, and levelling surveys are usually adopted for the monitoring of vertical deformations.
- Joint meters across vertical contraction joints in concrete gravity dams. Simple scribe marks can be made across all monoliths at the surface or in galleries in concrete gravity to detect differential foundation displacements that may develop gradually under static loading or in response to earthquake or high flood loadings.

Additional instrumentation may be required for the monitoring of dam performance which includes plumb lines for the measurement of a dam's response to variations in reservoir level and temperature, inclinometers and extensometers for the measurement of movements within the dam foundation, and instruments for the measurement of concrete and reservoir water temperatures.

6 CONSTRUCTION AND COMMISSIONING

6.1 INTRODUCTION

MyDAMS provides Dam Owners, Regulators, Dam Operators, Designers and Contractors with dam safety management guidelines for the construction and commissioning of dams. The focus of MyDAMS is on issues and activities that can affect dam safety. MyDAMS address:

- Roles and responsibilities of personnel during construction.
- Dam safety risks associated with alternative types of construction contracts.
- Planning and programming of construction works which can affect dam safety.
- Quality control procedures to ensure dams are constructed in accordance with the design requirements.
- Management and authorisation of design changes that occur during construction.
- Importance of good construction records.
- Roles and responsibilities of personnel during commissioning.
- Procedures and practices for the commissioning of dams.
- Management of commissioning activities.
- Importance of good commissioning records.

6.2 DAM SAFETY RISKS DURING CONSTRUCTION

All parties should recognise that dam construction entails many risks and has many requirements that differ from other projects such as road or building construction. Dam safety risks during construction or arise at a later stage, may be due to causes such as:

- inadequate capacity of river diversion works,
- inappropriate construction methods and sequencing of works
- dam foundation defects, geological weaknesses and geotechnical problems not identified or rectified,
- unauthorised changes to the design during construction, and
- construction defects not rectified.

The dam safety risks during construction can be largely managed by:

- Engaging a Contractor who has capability and relevant experience to cope with the challenges of constructing the dam project, and is committed to achieving the standards of workmanship specified in the contract documents.

- Ensuring that on-site construction supervision resources, quality assurance procedures, Designer representation on-site, technical design support, and peer review services are appropriate to the complexity of the dam.
- Ensuring that an appropriate form of contract is adopted for the completion of the project.
- Identifying all aspects of construction risks, and ensuring that the risks are mitigated. Risks management workshops with representatives of the Dam Owner, Dam Operator, Designer, Contractor and other stakeholders are useful exercise to address the construction risks.
- Recognising that construction will often reveal site characteristics that were not anticipated during the design and having sufficient funds and procedures in place to properly address any necessary additional work or changes that may affect the design.

6.3 PERSONNEL – ROLES, RESPONSIBILITIES AND EXPERIENCES

Depending on the size, type and hazard potential rating of the dam, the following key personnel are involved in construction:

- Dam Owner and Dam Operator.
- Designer supported by Technical Specialists and Reviewers.
- Project Supervising Engineer and supporting personnel.
- Contractor supported by construction and supervision personnel.
- Regulator.

This section discusses the roles, responsibilities and experiences of the personnel involved in construction.

6.3.1 Dam Owner

Generally the Dam Owner delegates construction supervision and contract administration to a Supervising Engineer.

Dam Owner responsibilities related to dam safety are:

- Accepting industry advice as necessary, to ensure that all parties engaged to investigate, design, construct, commission and operate the dam are suitably qualified and have their roles and authorities properly defined.
- Complying with all regulatory requirements, including any requirements specified in conditions attached to consents issued by Regulators.

- Providing the necessary funding and decision in a timely manner.

6.3.2 Designer and Technical Specialists

The roles of the Designer, Supervising Engineer with the assistance of Technical Specialists and, if warranted, Peer Reviewers are to:

- Assure that the dam is built in accordance with the approved design and specifications; and any changes implemented during construction do not affect the safety of the dam.
- Review all Contractor submittals relating to the design to ensure that the proposed materials and methodologies are consistent with the design intent.

The continuity of Designer, Technical Specialist and Reviewer inputs from the design process should be maintained through construction stage. It enables actual site conditions to be evaluated against design assumptions, and the determination of whether any design changes are necessary for the actual site conditions. The Designer should provide a programme of on-site supervision to the Dam Owner in advance of construction works beginning.

The Supervising Engineer, the Contractor, and the support team must have a good understanding of the critical design issues. While the specifications and drawings need to identify and address all the key issues, the Designer should:

- Explain the key issues to all site personnel in a contract meeting and provide any necessary personnel training prior to the commencement of construction.
- Attend all subsequent and relevant construction meetings to ensure that changes are not being made without the Designer’s knowledge.
- Provide design criteria for, and approve, all engineering design work completed by the Contractor for the permanent works and temporary works
- Approve the decommissioning of any temporary works that could affect the quality of the permanent works.

6.3.3 Supervising Engineer

The Supervising Engineer is defined here as the person responsible, on behalf of the Dam Owner, for ensuring that the construction work is carried out in accordance with the contract design and specifications. While the Designer is the Dam Owner’s technical representative, the Supervising Engineer is the Dam Owner’s administrative representative on the project.

In terms of dam safety, the Supervising Engineer's role will be to:

- Provide an effective administrative link between the Dam Owner, Contractor and Designer, provide advice on any changed conditions, manage a change control process, and ensure that the dam is constructed in accordance with the design intent.
- Provide construction supervision and contract administration and also fulfilling his technical responsibilities that relate to the safety of the dam.

The Supervising Engineer may be an appointee of the Designer's company to provide the highest possible level of continuity and communication. In design and build contracts the Owner's Engineer should have sufficient technical expertise to liaise with the Dam Owner, Designer and the Contractor.

The Supervising Engineer should have the following attributes:

- Experience in the construction management of a similar dam.
- Communication skills and ability to deal co-operatively with the Contractor.
- Ability to diffuse confrontational situations to avoid risks of conflicts.
- Ability to understand and follow design specifications.
- Ability to recognize any features or changes which may impact on design assumptions or criteria and bring them to the Designer's attention.

6.3.4 Contractor

The Contractor has a vital role in achieving a safe dam. In all cases the Contractor must be suitably qualified in terms of personnel, resources, attitude and relevant experience.

The Contractor should demonstrate that his nominated personnel have the necessary generic attributes to carry out the works in accordance with the contract requirements.

The Contractor should have an understanding of the design and able to detect when special attention is required to address a potential dam safety deficiency (e.g. foundation treatment, material selection and placement, filter processing and testing, concrete supply and testing).

6.3.4.1 Construction Method Statements

Contractor should prepare method statements to demonstrate an understanding of the design and construction requirements. These should be stated in the construction contract specifications for all important elements of the project and should be reviewed by the

Designer to enable any non-compliant methods, equipment or materials to be corrected prior to work commencing.

6.3.4.2 Approach and Commitment to Construction

The objectives of the Dam Owner can only be achieved with a Contractor who adopts a professional and responsible approach to the construction and participates as part of the overall project development team. This requires an open and active working relationship with the on-site representative of the Designer and making a conscious effort in resolving all dam safety issues which is critical to the overall success of the project.

6.3.5 Regulator

Regulators are responsible for administering the requirements of the legislation in relation to dams. To satisfy themselves that dams are being constructed in accordance with the requirements of the legislation and any conditions that accompany consents to construct dams. Regulators are likely to require site access for inspections during construction and/or verification from Dam Owners and Designers that specific construction activities have been completed in accordance with the specified design requirements.

Inspection and reporting requirements during construction are matters for each Regulator. Consents issued by Regulators may incorporate specific hold points to enable Regulator representatives and their consultants to inspect and sign-off particular construction activities.

6.4 CONSTRUCTION CONTRACTS

6.4.1 Contractual Arrangement

Dam Owners should ensure that the administrative and contractual arrangements for the construction of a dam, do not adversely affect dam safety. Dam projects typically include a number of uncertainties (e.g. flood protection during construction, foundation conditions, suitability of available construction materials and construction methodologies). Contract provisions to cover the uncertainties may range from “full recovery by the Contractor of all additional costs and time to meet changes” to “all construction risks being recognised and met entirely by the Contractor without increase in price or time”.

There are obvious challenges in both of the above extreme positions. The Dam Owner should be aware that commercial pressures might govern the response to the conditions found, to the detriment of dam safety. To minimise the potential conflicts between the interests of the parties to a contract and to ensure that those that remain do not adversely affect dam safety, all contracts should incorporate an element of construction risk sharing.

6.4.1.1 Construction Risk Sharing

Turnkey and lump sum fixed price contracts where all construction risks are usually carried by the Contractor are not appropriate for the construction or rehabilitation of dams where there can be many uncertainties relating to foundation conditions, diversion requirements and material characteristics.

Forcing a Contractor to accept a fixed price may not reduce uncertainty in completion of the project. Experience has shown that supposed safeguards, such as guarantees, can be illusory and the Dam Owner may then face a significant additional cost to complete the project.

Broadly speaking, the most cost-effective form of contract is likely to be one where risk sharing is based on each party's ability to control the construction risk. The best approach for risk sharing is that the Contractor should carry the construction risks over which he has control (e.g. his own resources, plant, equipment, any design for which he is responsible, construction activities) and the Dam Owner should carry the construction risks inherent in the project itself (e.g. the hydrology of the catchment, foundation conditions, foundation treatments, general project design).

The simplest form of risk sharing is for the Dam Owner and Designer to identify the areas of construction risk and uncertainty and set tender baseline conditions for the pricing of tenders. The Contractor can then be paid at the tendered rates up to the baseline conditions and, if conditions deteriorate beyond the baseline, variation claims are justified. This concept can be applied to many conditions (e.g. groundwater conditions, weather conditions, foundation conditions, material characteristics, foreign exchange rates).

The Dam Owner should be aware that he is always exposed to some construction risks that can lead to delay and cost overrun. The Dam Owner should maintain an active monitoring role during the contract to measure progress and identify any issues that could affect the cost-effectiveness of the project.

6.4.2 Contract Organisation and Administration

Dam construction involves multi-disciplinary activities. The Contractor's team should have personnel with the skills to match the range and complexity of the activities. The Contractor's team should be well structured with both field technical and management staff to ensure:

- The project engineer has sufficient knowledge and experience to meet the needs of the project and has adequate authority within the Contractor's organisation to control the work activities to ensure the specified quality standards are achieved.
- The senior site managers are fully familiar with the contract, the drawings and the specifications. Any anomalies and doubts over the interpretation of requirements or achievability of the specified requirements should be raised with the Designer.
- Experienced field supervision personnel are appointed to control the work and aware of the construction activities that affect dam safety.
- Experienced personnel to assist with key early tasks such as training, planning, programming, temporary works design and site infrastructure establishment. Early effort in getting the job up and going and on a sound footing will help significantly in achieving a successful result.
- The project team is continuously monitored by the Dam Owner's Engineer throughout the contract to ensure that performance is meeting expectations. Working and living conditions are often harsh and the early identification of problems is essential if poor quality performance or time delays are to be avoided.
- The control of documents including drawings, site instructions, meeting minutes, contract correspondence, variation orders and the like are important. It is important to maintain drawing registers and to ensure that obsolete or superseded drawings are removed from use.
- Materials and components incorporated in the works must comply with the specifications and drawings.
- The demonstration of compliance with the specifications and drawings, including verification and signoff by the design support personnel. A Quality Management Plan, Inspection Test Plans and test data should be produced to demonstrate compliance.
- Subcontractors are often major contributors to a dam project and proper selection and management procedures must be adopted if their contribution is to be successful. The Contractor must actively manage and control the activities of subcontractors to ensure they fully understand and fulfil their responsibilities.

Regular liaison and meeting between the Contractor's project engineer, the Contractor's senior site managers, the Designer and the Supervising Engineer should be carried out to provide a forum for clarification and the development of a spirit of cooperation.

6.5 CONSTRUCTION PLANNING

6.5.1 Construction Tasks

Dam construction usually involves multidisciplinary activities, and thorough planning and programming are essential to achieving a safe dam. Construction tasks which affect dam safety and require special consideration during construction planning include:

- River diversion and cofferdam design and construction.
- Foundation preparation and treatment.
- Embankment materials selection, processing, placement and testing.
- Concrete mix design, production, placement and testing.
- Scheduling and sequencing of construction activities.
- Quality control testing.
- Reporting and documentation.

It is often necessary to conduct additional work activities to provide a more reliable information base for construction planning, for example, completion of additional investigation and laboratory testing to select and fully characterise foundation conditions and construction materials.

6.5.2 Temporary Works

It is normal practice for the Contractor to design all temporary works necessary for the construction of the project. This usually includes dewatering facilities, and can include cofferdams and diversion works.

Any engineering design work completed by the Contractor for temporary works (e.g. diversion facilities), must satisfy design criteria provided by the Designer and be approved by the Designer.

Dewatering is often necessary during construction. Inappropriate treatment of dewatering facilities can have significant effects on dam safety, particularly in embankment dams. As such, all proposed dewatering facilities and their final treatments must be approved by the Designer.

6.5.3 Construction Programming

Construction programming is vital to the success of a project and must be used as a management tool to assist in achieving a quality product. Inappropriate programme may lead to delay and often affect quality and standards, adversely affect the Contractor’s costs and cash flow.

Regular short-term programmes should be produced for sections of the work. Issues and remedial actions should be implemented before they become irreversible. Regular updates to the project’s master programme are essential and must highlight all critical activities which impact on work quality. Sufficient lead times must be allowed for appropriate planning and preparation by the Contractor to ensure the orderly and controlled progression of the work.

6.5.4 Emergency Action Planning

Large flood events represent the most significant hazards during the construction of a dam as they can result in overtopping and failure of cofferdams and embankment dams under construction, damage to downstream infrastructure and the environment, and possible loss of life.

EAPs should be prepared for the construction of all large dams, particularly if they are embankment dams.

6.6 QUALITY CONTROL

6.6.1 Objective

The objective of quality control is to ensure that all construction is completed in accordance with specified design requirements. Without an appropriate level of quality control, through a quality management system or plan, there is the potential for design requirements and/or standards not being met which will adversely affect dam safety.

6.6.2 Quality Planning

6.6.2.1 Key Requirements

The scope of a quality control system during construction will vary with the hazard potential rating of the dam and the degree of protection built into the design. All quality control systems during construction should include:

- Continued application of the requirements of ISO 9001 (Quality Management Systems – Requirements) by the Designer.
- Establishment of a system complying with the intent of ISO Standards. Additional key requirements that should be incorporated within quality control systems for the construction of Significant or higher hazard rating dams.
- Designer and independent review continuity throughout construction.
- An appropriate Contractor selection process which focus on the Contractor’s track record and the availability of key personnel. This may be by a formal prequalification process involving specific questions and a formalised evaluation system, or by the direct selection of potential bidders.
- Members of the Contractor and Designer site teams should be thoroughly briefed on their duties and responsibilities in full recognition of the characteristics of the project, particularly issues that are critical to dam safety.
- On-site inspection and testing procedures, throughout construction, to verify that all construction is in accordance with the design.
- Appropriate design change procedures should be established. Any change, departing in any way from the approved initial design must be checked and approved by the Designer before its construction.
- Construction contracts must give the Designer authority to make design changes as are necessary during construction to achieve the required level of dam safety and performance, particularly during foundation work.
- Quality control system must include appropriate procedures for confirming the quality of off-site manufacture, including the effects of transportation. Appropriate quality control records should be provided by the supplier and verified by the Designer.
- Comprehensive record keeping is essential for future diagnosis and to enable any necessary certification to meet legislative requirements.

6.6.2.2 Construction/Design Interface

Close coordination between design and construction personnel, both on-site and off-site, is an essential component of any quality control system. Close coordination ensures that:

- construction personnel are aware of the design intent,
- new field information acquired during construction is assimilated into the design,
- the design assumptions are confirmed, and
- the dam is constructed according to the design intent.

6.7 QUALITY PLAN

All construction work should be completed in accordance with a Quality Plan which sets out the scope of the quality control system and the quality control procedures that will be implemented to demonstrate compliance with the specified requirements. The Quality Plan, which should be developed by the Contractor, should include:

- Overall scope of the quality control system for the project.
- Quality control personnel, including their roles and responsibilities.
- Visual inspection procedures and records.
- Field and laboratory testing procedures and records.
- Independent testing authorities and their testing and reporting responsibilities.
- Verification, signoff and recording procedures for each element of the works.
- Compliance and non-compliance criteria and procedures for logging and dealing with non-compliances.
- Hold points for inspection and signoff by the Contractor and Designer.
- Schedules, forms and check sheets for the inspection, testing and reporting of all quality control activities.

The Designer should approve the Quality Plan and monitor its effectiveness throughout construction.

Test records should be reviewed by the Designer's site personnel for compliance with the specifications and the design assumptions.

6.8 ON-SITE QUALITY CONTROL

6.8.1 On-Site Organisation and Responsibilities

The size and composition of the on-site quality control team should be sufficient for the inspection of construction activities, completion of field and laboratory tests, review of inspection and test results, identification of non-compliances, documentation of inspection and test records, and completion of quality control reports. On large projects a Quality Control Manager and a team of support staff should be appointed by the Dam Owner and Contractor for the completion of inspection and testing activities.

The Contractor should understand the scope and importance of the quality control function which involves inspection and testing of the work to verify its compliance with the contract requirements for the completion of a safe dam.

The Designer is normally responsible for quality assurance and, as such, reviews and approves the Contractor's Quality Plan. The Designer should have the ability to undertake additional independent inspections and tests considered necessary to confirm that the construction is completed in accordance with the design intent.

6.8.2 Visual Observations

Inspections are necessary at various stages of construction particularly when foundation conditions are exposed, foundation treatments are completed, material trials are completed and initial dam construction gets underway. Full time supervision of construction should be provided for Significant or higher hazard rating dams.

Visual inspections and signoffs determine whether the requirements of the drawings and technical specifications are being met. Experienced inspectors with the ability to identify acceptable and unacceptable construction work are essential for effective quality control.

The Contractor's quality control procedures should include inspection sheets for the particular element of the project, date, the type of work, tests carried out and verification by the Contractor's supervisor that the work has been completed and checked. Finally, the Supervising Engineer should sign the inspection sheet.

6.8.3 Field and Laboratory Testing

The extent and frequency of testing should be adequate to verify that the physical characteristics of the materials meet design requirements and the adopted construction methods are acceptable.

All field and laboratory testing should be completed in accordance with relevant Malaysian Standards or standards published by internationally recognised organisations with comprehensive backgrounds in dam engineering (e.g. USBR, USACE). Nuclear density meters and other field testing equipment utilised during construction should be calibrated at frequencies recommended by manufacturers to ensure they provide reliable results.

6.8.4 Critical Areas and Construction Signoffs

All critical areas in meeting the design intent and dam safety should be identified before construction and highlighted in the Quality Plan as hold points for inspection and signoff by the Contractor and Designer including the followings:

- Foundation preparation including such items as shaping, strength, surface texture, foundation defects and dewatering.
- Preparation of pre-work such as formwork, reinforcing steel, embedded items and cleaning for concrete pours.
- Quality and consistency of key materials such as concrete, earthfill, filter or drainage materials.
- Bedding, jointing, backfilling and protection of any penetrations through embankment dams.
- Installation, protection and reading of any instrumentation for the monitoring of dam performance.
- Installation of embedded items for equipment critical to dam safety, the fabrication/procurement and installation of gates and valves that is critical to dam safety,
- Installation of stressed anchors, installation and testing of gate or valve control and backup systems that is critical to dam safety.

6.9 CONSTRUCTION RECORDS

Accurate and comprehensive construction records should be established to provide a background for future dam safety evaluations, and the design and construction of any necessary rehabilitation works. The safekeeping of records is of vital importance and the following construction records should be stored in an appropriate records system and backed up at a different location.

6.9.1 Investigation Records

Records of all investigation activities completed during construction including drill hole logs, trial pits, trench logs, shaft logs, construction adits, investigation photographs, field and laboratory test results and investigation reports.

6.9.2 Foundation Records

All excavations form part of the permanent works and all foundation areas for Significant and higher hazard rating dams, and where the geology is complex, should be logged, photographed, mapped and interpreted in a foundation report. The excavated foundation profile should also be recorded.

6.9.3 Day-to-day Construction Records

The construction records of the day-to-day activities should be kept including correspondence, progress reports, minutes of meetings, design changes, site instructions, grouting records, activity reports, test results and the like.

6.9.4 Quality Control Records

All visual inspection and testing records (e.g. inspection check sheets, field and laboratory test results, test reports, quality control reports).

6.9.5 Monitoring Records

Any monitoring records gathered during construction which could have a present or future impact on dam performance and dam safety (e.g. rainfall, river flows, seepage flows, construction pore pressures, settlements, concrete temperatures).

6.9.6 Construction Photographs

A systematic record of construction activities, suitably annotated with dates, locations and descriptions. Particular attention should be given to foundation conditions and treatments, material preparation and placement, filter and drainage systems, construction and contraction joints, and embedded items associated with facilities that are essential for dam safety (e.g. gate guides, gate supports).

6.9.7 As-Built Drawings

As-built drawings should be prepared to provide a clear depiction of what was actually constructed. The preparation of as-built drawings requires the recording of as-built data as construction proceeds.

For all dams a construction report should be completed following the completion of construction. The construction report for an uncomplicated Low hazard rating dam will normally be brief in comparison to those completed for Significant or higher hazard rating dams. All construction reports should provide an accurate summary of the construction process with a focus on:

- Construction methods and equipment.
- Any observed differences between assumed and actual site conditions.
- Any necessary changes during construction to address actual site conditions.
- Any problems that arose and how they were dealt with during construction.

- As-built records.
- A summary of all field and laboratory test results.
- A selection of supporting photographs.

Copies of all key construction records, drawings and documentation should be provided to the Dam Owner at the end of the project.

6.10 INSURANCE DURING CONSTRUCTION

There is a wide range of insurance policies that can be adopted for the management of risks during dam construction. Most construction projects include Contractor’s all risks polices, which protect the insured against accidental loss or damage to the works that results from construction activities, and civil liability policies which protect the insured against liabilities to third parties that may result from construction accidents. Other insurances can include Contractor’s plant and machinery policies, which protect the insured against damage to plant and machinery items utilised during construction, and all risks erection policies which protect the insured against losses arising from the erection, installation, testing and commissioning of machinery and plant.

The Dam Owners and Contractors should discuss their specific project insurance requirements with appropriate insurance agencies. Many construction risks can be minimised through active on-site management which should not be discounted in preference to a comprehensive insurance policy. Examples include:

- The identification and treatment of unsuitable foundation conditions.
- The management of flood events during construction.
- The identification and resolution of potential dam safety deficiencies during construction.

6.11 COMMISSIONING

6.11.1 Dam Safety Risks

Initial impoundment or commissioning provides the first test of the design and construction of a dam. Many historical dam failures initiated by internal erosion or piping have occurred on first filling or in the first five years of operation. It is important that commissioning procedures are appropriate to the dam and enable the Designer, and later the Dam Owner, to regularly monitor its performance during and following reservoir filling. It is also important that Designer is involved throughout the commissioning process to ensure that the performance of the dam and its appurtenant structures are consistent with the design philosophy and intent.

6.11.2 Personnel – Roles and Responsibilities

Personnel involved in the commissioning process and their usual roles and responsibilities are summarised as per **Table 6.1**.

Table 6.1: Roles and Responsibilities of Personnel in Commissioning Process

Personnel	Roles and Responsibilities
Dam Owner	Authorise the Designer to act if dam safety is in question during commissioning
Designer	Manage the process and initiate any necessary actions to preserve dam safety
Contractor	Implements commissioning under instructions and must be equipped and prepared to act readily in the event of unsatisfactory performance of the dam during commissioning
Technical Specialists	Provide specialist inputs as required in support of the Designer
Reviewers	Provide support to the Dam Owner
Regulators or the delegated independent consultant	Ensure by conditions included in authority approval, that the dam is commissioned in accordance with appropriate commissioning procedures
Dam Operator	Participate in commissioning to learn about the dam and its safe and effective operation during the commissioning process

The personnel and numbers involved in the commissioning of a dam should include the Dam Owner or Supervising Engineer, Designer, Contractor, Dam Operator, and technical specialists for monitoring the performance of the dam and gate/valve operation. The Designer should determine the necessary scope of the commissioning team.

6.11.3 Planning for Commissioning

The recommended procedures and practices for the formal commissioning of dams are provided below to enable the monitoring of dam performance during initial impoundment.

6.11.3.1 Commissioning Procedures

The Designer should prepare appropriate procedures for the commissioning of any dam. The procedures should reflect the hazard rating of the dam, its complexity, and any conditions included in consent documents that relate to commissioning. Recommended minimum commissioning procedures for Low, Significant, High and Very High hazard rating dams are listed in **Table 6.2**.

Table 6.2: Recommended Minimum Commissioning Procedures for Dams

Hazard Rating of Dam	Minimum Commissioning Procedures for Dams
Low	The Designer's provision of a list of items to be inspected or monitored during and following commissioning should be sufficient. The commissioning should be attended by the Dam Owner, Contractor and Designer. The Designer should complete a letter report on the results of the commissioning. Any unexpected results and necessary actions that were taken to address the unexpected results.
Significant	Outline responsibilities, pre-commissioning requirements, commissioning procedures and performance evaluation procedures. An EAP should be included. The commissioning should be attended by the Dam Owner (or the Dam Owner's Supervising Engineer), Contractor and Designer. The Designer should complete a brief report on the results of the commissioning. Summarises the commissioning process, highlights any unexpected results and comments on any necessary actions that were taken to address unexpected results.
High	The procedures should be comprehensive and reviewed by the Reviewer. An EAP should be included. The commissioning should be attended by the Dam Owner, Contractor and Designer. The Designer should complete a comprehensive commissioning report.
Very High	The procedures should be comprehensive and reviewed by the Reviewer. An EAP should be included. NADMA and dam regulatory body should be informed of the commencement of the dam impoundment. The commissioning should be attended by the Dam Owner (including key personnel responsible for emergency preparedness), Contractor and Designer. The Designer should complete a comprehensive commissioning report.

Commissioning should not proceed until all necessary planning has been completed, and procedures have been established and communicated to the personnel responsible for commissioning. The commissioning procedures should address the following:

- Definition of all parties involved and their responsibilities, the names of key personnel including backup personnel, and all personnel contact details.
- Physical works that must be completed before commissioning can commence.
- Rate of reservoir filling, reservoir level hold points and their duration, and criteria for the continuation of reservoir filling.
- A set of initial (baseline) measurements for all instrumentation and survey marks immediately prior to commissioning.
- Establishment of expected performance ranges for instrumentation by the Designer, to provide a guide for evaluating actual dam performance during and following commissioning.
- Commissioning procedure including, where appropriate:
  - Walkover inspections to check for any indications of unexpected behaviour.
  - Identification and measurement of seepage flows or changes in seepage behaviour.
  - Measurement of piezometric pressures and groundwater levels (at prescribed frequencies or reservoir elevations).
  - Measurement of settlements and deformations (at prescribed frequencies or reservoir elevations).
  - Measurement of concrete stresses and temperatures (at prescribed frequencies or reservoir elevations).
  - Testing of installed plant and equipment critical to dam safety (e.g. spillway gates).
  - Testing of spillway performance.
  - Inspections and/or monitoring of the dam and/or reservoir shoreline at specified hold points.
- The recording and communication of monitored data, interpreting the monitored data, and evaluating the performance of the dam against acceptable performance criteria.
- Actions to be taken in the event of a developing dam safety emergency.

Commissioning should not proceed until the Designer and the Dam Owner’s Supervising Engineer has carried out appropriate readiness checks and is satisfied that commissioning may proceed. Prerequisites for commencing reservoir filling should include:

- Completion of minimum works on the dam, structures and reservoir area.

- Installation and dry testing of equipment, controls, telemetry and alarms.
- Installation of all instrumentation and the establishment of monitoring systems, including the establishment of expected performance ranges for all installed instrumentation.
- Provision of on-site materials and equipment for possible emergency use (e.g. filter materials, rockfill stockpiles, excavators, bulldozers).
- Preparation of commissioning procedures, which include any necessary limitations on the rate of rise in the reservoir level, and communication of them to relevant commissioning personnel.
- Confirmation that all statutory requirements have been and will be met during commissioning.
- Completion of other activities not directly related to dam safety.

As part of a formal quality control system, detailed readiness checklists should be prepared and utilised for various components and activities. A typical content of a Commissioning Procedures Document for Significant or higher Hazard Rating Dam is listed below.

CHAPTER	DESCRIPTION
1.0	SCOPE
2.0	RESPONSIBILITIES
3.0	PRECOMMISSIONING REQUIREMENTS
4.0	CONSENT REQUIREMENTS
5.0	COMMISSIONING PROCEDURE - Commissioning Sequence - Gate Closure - Reservoir Filling - Observation and Monitoring Requirements - Gate Testing Requirements
6.0	PERFORMANCE & EVALUATION - Performance Criteria - Performance Evaluation and Reporting - Conceivable Problem Areas
7.0	EMERGENCY ACTION PLAN
8.0	COMMISSIONING RECORDS

9.0	REFERENCE DOCUMENTS APPENDICES A - Readiness Check Lists B - Observation Lists C - Acceptable Performance Criteria DRAWINGS Instrumentation Locations Reservoir Filling Curve Spillway & Low Level Outlet Rating Curves

6.12 MANAGEMENT OF COMMISSIONING

6.12.1 Control

Control starts with proper planning but must incorporate the ongoing evaluation of all data gathered and feedback to those implementing the commissioning. The control must provide for rapid and effective responses to situations which warrant or demand action to preserve dam safety. All parties concerned must be prepared to implement all actions necessary for dam safety.

It is vital that there are clear and workable arrangements for the rapid evaluation of data, decision making and the initiation of actions to preserve dam safety.

6.12.2 Typical Commissioning Issues

A number of issues can arise during the commissioning process which requires consideration by the Designer. They often include:

- A desire by the Dam Owner to commence operation as soon as possible particularly for commercial projects (e.g. hydroelectricity) where income streams will assist in the reduction of loans secured for financing the projects. Dam safety interests must be given priority over commercial interests, and commissioning should be completed at a pace that is judged appropriate by the Designer.
- Inspection and monitoring frequencies should be specified by the Designer in the commissioning procedures base on the characteristics of the dam, the parameter being monitored (e.g. seepage, piezometric pressure), and the stage of the commissioning process. Daily and even round-the-clock observations are usually

necessary above certain reservoir levels until a stable condition is reached. Once the dam is deemed operational and the Designer has confirmed that the dam is performing as expected, observation frequencies usually reduce to weekly or monthly.

- Where practical, commissioning should include the completion of spillway tests; however, in many cases, the performance of spillways cannot be tested until the occurrence of large flood events. In such cases appropriate commissioning procedures (e.g. inspections, monitoring of installed instrumentation) should be prepared for use during a future large flood event. The Designer should witness the performance of the spillway during the large flood event.
- Duration of commissioning should cover until the dam is performing in accordance with design expectations. Sometimes it will be necessary for the Designer to commission a dam before stable conditions are reached. For example, piezometric pressures and seepages in a zoned embankment dam often do not stabilise for many months or years following reservoir filling.

6.12.3 Confirmation of Satisfactory Performance and Handover

Handover marks the point where the Designer is satisfied with the performance of the dam and its associated hydraulic structures, and the Dam Owner is assigned full responsibility for operating the dam.

The Designer must, on the basis of the performance of the dam during commissioning, determine the handover point and any associated conditions, and convey them clearly to the Dam Owner.

The Dam Owner should be fully conversant with all operating, maintenance and surveillance requirements and the EAP. The operating personnel must be fully trained, are capable of operating and maintaining all facilities in accordance with the specified procedures, are capable of completing all routine surveillance and monitoring, and have a clear understanding of their roles and responsibilities in a dam safety emergency.

6.12.4 Commissioning Records

The commissioning process must be recorded in a commissioning report. This report provides an important permanent record of initial performance compared with design expectations, and any actions undertaken during commissioning to address unexpected performance. The report will constitute a benchmark for ongoing surveillance and safety evaluations, and may fill a vitally important role in any subsequent examination of a developing dam safety deficiency. Typical contents of a commissioning report prepared for a Significant or higher hazard rating dam are listed below:

CHAPTER	DESCRIPTION
1.0	INTRODUCTION
2.0	COMMISSIONING 2.1 Procedures 2.2 Timeline 2.3 Results and Consequent Actions - Introduction - Seepage Records - Piezometric Records - Deformation Records - Spillway Performance - Intakes and Controls 2.4 Conclusions and Recommendations TABLES Seepage Records Piezometric Records Deformation Records DRAWINGS APPENDICES

7 DAM AND RESERVOIR OPERATION AND MAINTENANCE

7.1 INTRODUCTION

Dam Owners are responsible for the safe O&M of their facilities. Proper operation and good maintenance is essential in ensuring the continued viability and safety of a dam and its appurtenant structures. Improper operation and poor maintenance will invariably result in abnormal deterioration, a reduced life expectancy or failure.

Dam designers must take into account in their design a large number of natural hazards and phenomena such as floods, earthquakes, landslides and the vagaries of foundations. Dam owners should operate and maintain the dam to standards established in the Designer Operating Criteria (DOC).

Documentation of procedures and practices is needed to ensure the safe operation of the dam under various conditions. The potential impacts of operations on the public, the environment, and other stakeholders should be documented.

Maintenance activities should be prioritized, carried out, and documented with due consideration of dam safety and the implications of failure.

7.2 PROCEDURES AND PROTOCOLS

Dam Owner should understand the parameters within which the reservoir is to be operated for normal, unusual and extreme loading and operating conditions.

The operation of a reservoir should not present undue risk to people and property, the environment upstream and downstream of the dam, and downstream dams on the river. Procedures for the operation of reservoirs in a cascade development should be developed considering the safety of the whole cascade system.

Dam Owners should ensure that their dam and reservoir operational plans and protocols are appropriate and provide sufficient margin to ensure the safety of the dam under all loading conditions and foreseeable operational scenarios. Sufficient freeboard should be available between the full supply level and the dam crest, neighbouring property and infrastructure, to prevent overtopping or flooding during unusual and extreme inflow scenarios. There may also be a need to limit the rate at which a reservoir level is lowered, via outflows, to ensure that the stability of the dam and reservoir shoreline is not adversely affected.

7.3 OPERATION AND MAINTENANCE IN RELATION TO DAM SAFETY MANAGEMENT

A dam safety management system for Significant and higher Hazard Rating dams should include the following O&M procedures:

- Reservoir operation procedures during normal, unusual (e.g. floods), extreme (e.g. earthquakes) and emergency conditions (i.e. conditions that could result in dam failure if appropriate actions are not initiated).
- Operating procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. reservoir level thresholds, gate/valve openings and discharge rates.)
- Maintenance procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. visual inspections, battery/fuel checks, changes in lubricating fluids, major overhauls).
- Testing procedures for gate and valve systems that fulfil dam and reservoir safety functions, including power supplies, operating systems, and control and protection systems, to ensure ongoing functionality and reliability.
- Civil works maintenance procedures (e.g. internal drainage system cleaning, instrument repair, vegetation and debris clearing, upstream erosion protection reinforcement).
- Any procedures for the monitoring of upstream reservoir slopes and downstream banks (e.g. the stability of upstream landslides during high reservoir levels or rapid reservoir drawdown, and the stability of downstream river banks during high discharges).

7.4 OPERATION AND MAINTENANCE MANUAL

An O&M Manual should be prepared to provide operators with the information they need for the safe operation of the dam. The format and content should be specific to the site. An outline of a typical Manual is provided in **Appendix D**.

Documentation for the Manual should be prepared during the construction phase and then updated at the time of major changes to the structures, equipment, or operating conditions.

An Operations and Maintenance Log should be provided (as part of the database / book) at all dams and entries should be periodically verified by the Dam Owner to ensure compliance with authorised procedures and instructions set out in the Manual.

Operations and Maintenance Manuals should be "controlled" documents and Dam Owners should ensure that all relevant personnel have copies which are current and that no unauthorised (uncontrolled) copies are used in the operations of the dam. Records should be kept at designated location and status of each "controlled" copy of the Manual. Manuals should be reviewed (and, if necessary, updated) at 5 yearly intervals or when circumstances change.

7.5 OPERATOR EXPERIENCE AND TRAINING

Operating personnel should be competent, qualified and trained to fulfil the requirements of the dam and reservoir O&M procedures and should be able to:

- understand threats to the safe performance of the dam;
- recognise indicators for the development of its potential failure modes;
- understand the risk related to inappropriate operation or accidental mis-operation;
- understand the consequences of dam failure (including unintentional flow releases);
- know how to initiate appropriate response actions;
- decide when to seek specialist technical advice.

The level of experience, qualifications and training of the operating personnel should be adequate to match the complexity of the dam and appurtenant structures. The nature of the dam's potential failure modes should be clearly understood by the operating personnel. The training process and operator competence certification should be documented in the Dam Owner's quality assurance records.

7.6 REVIEW AND TEST

The Dam Owner, with support from appropriate technical and operations and maintenance personnel, should periodically review and test the dam's O&M procedures and protocols, particularly those where dam and reservoir safety is dependent on the correct operation of gates and valves.

7.7 DAM AND RESERVOIR OPERATION

7.7.1 Operating Criteria and Constraints

The operations should take into account the complexity of the site, consequences of mis-operation, availability of staff to respond to changing conditions, the type and size of flow control equipment, and site-specific considerations.

Operators require criteria that define operating limits and extensive reliable data to ensure safe operations within those limits. The purpose of defining operating constraints is to ensure the operation of the dam does not violate any design assumptions that could affect the safety of the dam.

Constraints on dam operations intended to maintain the integrity of the structures should be defined during dam design and reviewed periodically. The operating procedures should take into account the constraints which include the following:

- Maximum safe discharge rates for all flow control equipment.
- Highest safe reservoir level beyond which dam components or reservoir rim may start overtopping and become unstable or cause flow control equipment to be inoperable.
- Reservoir levels at which overflow discharge structures, fuse gates, or fuse plugs are intended to operate, expected outflows, and post-activation follow-up requirements.
- Physical restrictions on operations that may impact dam or reservoir rim stability; this should include precautions to be taken during drawdown events, first filling of the reservoir, or refilling of a reservoir after a period of low water level.
- Legal constraints on discharge rates and downstream water level.

7.7.2 Data Requirements

Dam operators require systems and data to support their operating decisions. The following data should be prepared during the development of documentation:

- Headwater and tailwater elevations, needed for making operating decisions in a timely manner.
- Ways to gauge flow volumes through generating units or flow control equipment operation; including rating curves showing the relationship between discharge and reservoir water level
- Weather data and access to watershed flow data (river gauges, rain gauges, flood warning systems, etc.) to allow reservoir inflow forecasting.
- Information on uncontrolled upstream inflows or flow data and travel times between dams on interconnected watercourses.
- Highest reservoir level that the dam system is expected to be able to withstand without failure; this elevation may be above maximum operating or regulatory levels but can be critical for emergency operations.

- Statistics for normal values of inflows, such as plots of minimum, maximum, and average inflows versus time, throughout a typical year, so that operators will know if inflows are within normal statistical ranges.
- Expected inflow design flood (IDF) inflow values and the reservoir elevation during the IDF event.

7.7.3 Operating Procedures

Operating procedures should be defined for all expected conditions for normal, unusual or flood, and emergency conditions.

- *Normal conditions* — expected throughout much of the life of the facility and may be defined as routine conditions.
- *Unusual conditions* — deviations from routine, including changes in operations required because of flow control equipment failure, debris blockages, seismic events, or large floods.
- *Emergency conditions* — events that might lead to dam failure if action is not taken and could include extreme floods, seismic events, failure of a dam component, or equipment failure.

Operators should realize that even normal flood conditions could lead to emergency conditions if poorly managed. Procedures should be specific enough to define what actions are to be taken, by whom, and when.

Operating procedures should also include the requirement to document operating conditions and activities, such as reservoir water levels, inflows, discharge flows, equipment operations, unusual events, alarms and resulting actions, public activity, or any other incidents that were related to operations or could have affected operations. An operations log or record of actions should be maintained so that a periodic check of compliance with procedures and operating constraints can be made to help define potential omissions, procedural improvements, training requirements, or other overall operating enhancements.

7.7.3.1 Normal Conditions

Normal operating procedures should be well defined and documented and should include safeguards and redundancies where necessary. Normal operating procedures should be a comprehensive set of documents outlining the following:

- Operating duties and authorities of staff involved in reservoir operations.

- Procedures for flow control equipment operations outlining local flow control equipment operation versus remote or automatic operation, the use of alarms, staged gate opening or notifications or warnings for downstream stakeholders, remote cameras, and any other physical or procedural safeguards.
- Identification of areas impacted by operations, including downstream communities, other Dam Owners, and industries, as well as any sensitive downstream areas that may be flooded for spillway discharge less than full capacity.
- Staffing requirements and time required to complete system operations.
- Communication protocols with other stakeholders.
- Procedures to ensure that enough gates are operational during flood.
- Procedures for debris handling; this might include boom installation and routine debris removal.

7.7.3.2 Unusual Conditions

Flood operating rules should be predefined and specific enough that operating staff can follow them without seeking approval. This guidance is critical to ensure required operations are properly executed even if communications are lost under flood conditions.

Dam operators need to be aware of situations where operations could go from normal to unusual or emergency conditions. Procedures should include internal notifications, interim contingency plans for alternate discharge or reservoir manipulation, dispatch of maintenance staff, and criteria for return to service. In general, contingency plans should be in place for deviations from normal operating conditions, such as the following:

- Shutdown of flow control equipment for maintenance or other planned activity.
- Flow control equipment inoperability due to power loss, failure to operate (opening or closing), unplanned event, or blockage due to debris.
- Failure of an upstream dam or other water-retaining structure.
- Rapid drawdown events that could threaten dam or reservoir rim stability.
- Development of sinkholes, slumping, or sudden increase in seepage or turbid flow through embankment dam structures.
- Loss of control system, water level gauging, or control of flow control equipment.
- Inability of staff to access site for normal operations or during flood conditions.

Early identification and mitigative actions are critical to prevent unusual conditions from becoming emergency conditions. Where possible, systems should be in place to identify and warn operators (through alarm systems) of the development of unusual conditions. This will then allow operators to take action to mitigate unusual conditions or to decide if the situation warrants implementation of the emergency plan.

7.7.3.3 Emergency Conditions

Emergency operation procedures would typically be defined in the emergency plan. There may, however, be mitigative measures that operations staff can implement to avoid emergency situations. These mitigative measures may be outlined within either the O&M Manual or the emergency plan and might include the following:

- Seismic events that damage dam structures and require reservoir drawdown to prevent failure and (or) carry out emergency repairs
- Reservoir inflows that exceed those defined as inflow design flood values.
- Loss of flow control equipment during flood events due to debris, power failure, or loss of control system and rising reservoir levels projected to exceed maximum safe reservoir levels.

It may be useful to include a table or description of scenarios that identify events that could lead to activation of the emergency plan. The authority of operating staff to initiate emergency procedures, along with possible triggers, should be defined.

7.7.4 Flow Control

Information related to flow control system operations should be identified and documented. This may include manufacturer's information, design reports, and other relevant information. Procedures and supporting documentation should be in place for water level gauge installation, calibration, maintenance, and repair.

Supervisory control and data acquisition (SCADA), or other control systems are important operational tools. Procedures should be in place to ensure these systems are adequately designed, sufficiently robust, and periodically checked to provide remote dam operators with suitable and timely data for dam operation. Where practical, alarms should be in place to warn operators of situations that could lead to problems.

In addition, some critical dam surveillance instrumentation may be linked into the control system to provide real-time indication of potential dam safety issues.

All emergency systems should be identified and documented. This could include dam-breach early warning systems, emergency power supplies, and other related equipment and systems. These systems should be included within the maintenance and surveillance program to ensure they are functional when needed. Staff should be familiar with these systems for response in emergency situations.

7.7.5 Reservoir Operation Records

Records and data associated with a reservoir's operation should be recorded and stored securely in a way that allows their review during routine dam safety monitoring, and annual and comprehensive dam safety reviews. These include rainfall, reservoir inflows, reservoir lake levels, reservoir outflows, and all operations (including inspections, maintenance and testing) of gates and valves.

Incidents such as unusual loading conditions, operations, and occurrences, together with any evaluations and lessons learned, should also be recorded.

7.8 DAM AND RESERVOIR MAINTENANCE

There is a range of regular maintenance activities that contribute to the ongoing safety of dams and their reservoirs. Such activities will also maintain, or enhance the value or life of the asset and may minimise more extensive maintenance requirements and associated costs, or prevent the need for costly repairs or remedial works that could otherwise arise.

The following are common examples of maintenance activities, many of which will be required in some form for any dam. However, each dam and its setting is unique and will therefore have its own set of maintenance requirements. In recognition of this, maintenance requirements should be determined in consultation with appropriate Technical Advisers.

7.8.1 Maintenance Programs

Maintenance of equipment and systems is important to ensure operational availability, safe operations, and integrity of the dam. Mechanical and electrical systems related to flow control equipment are critical as failure due to lack of maintenance can be sudden and dramatic. Civil structures may develop more maintenance issues as they age. The maintenance needs of dams may vary throughout different stages in their life cycle.

Maintenance programs should identify the components of the dam requiring maintenance, define the schedule of those activities, and track which systems were maintained, what type of maintenance was performed, when it was done, and by whom. This type of information is valuable for identifying chronic problematic equipment issues or components of the system that might require replacement to ensure reliability.

Most maintenance can be scheduled or defined on the basis of time (weekly, monthly, etc.), usage (number of cycles, hours of operation, etc.), or observed condition from periodic visual inspection (excessive wear, corrosion, etc.). Routine maintenance may range from a simple change of lubricating fluids to a complete overhaul with replacement of major parts.

Dam Owners need to be prepared for emergency maintenance. This might include having critical spare parts, tools, equipment, and trained, competent staff ready in the event of an emergency.

7.8.1.1 Reservoir Shoreline and Erosion

The reservoir shoreline can be susceptible to the effects of a dam's operation and the following maintenance activities, where necessary, should be completed:

- Repair rip-rap damage or surface erosion on the dam face.
- Repair excessive beaching or erosion of the reservoir shoreline.
- Maintain any facilities provided for the management of shoreline stability.

7.8.1.2 Appurtenant Structures and Debris Management

Spillway and intake facilities that fulfil dam safety functions should remain unobstructed to provide their full flow capacity on demand. In addition, appurtenant structures such as spillways, conduits and open channels (canals, flumes) may require periodic maintenance to ensure they remain capable of safely discharging their design flows.

The following maintenance activities, where necessary, should be completed:

- Repair damage such as scour, erosion, cracking or waterstop failure in spillway chutes, stilling basins and outlet conduits.
- Maintain the functionality of drainage channels below spillways and of venting/air supply features included in discharge facilities to prevent cavitation.
- Maintain booms to prevent debris entry to spillway outlets and water intake facilities.
- Remove dead or unstable timber from the reservoir shoreline and the dam face.
- Manage and/or remove aquatic weed growth in the reservoir.
- Clean screens on intakes and outlet facilities.

7.8.1.3 Drainage Systems

Dams, their abutments, appurtenant structures and reservoir landslides (where they exist) often rely on effective drainage of surface and sub-surface water for their ongoing stability and safe performance. Usually, effective drainage will also improve the ability to effectively monitor dam performance indicators such as seepage, leakage and uplift.

To maintain the effectiveness of surface and sub-surface drainage systems the following maintenance activities, where necessary, should be completed:

- Maintain adequate surface drainage at dams, abutments and reservoir landslides, such that they are not unnecessarily saturated or eroded, and effective inspection and measurement of seepage/ leakage is possible.
- Maintain adequate sub-surface (internal) drainage systems at dams, foundations, abutments, reservoir landslides (where they exist) and structures such as spillway chutes, stilling basins and retaining walls to relieve piezometric pressures and/or foundation uplift, and allow effective inspection and measurement of uplift and seepage conditions.
- Periodically drain dam and abutment seepage areas and dam toes inundated by tailwater levels, where possible, to allow effective visual inspection and monitoring of seepage flows.

Dam and foundation internal drainage systems should be monitored for condition and performance with respect to their design assumptions and cleaned, if necessary and appropriate, to maintain their effectiveness. When choosing and implementing cleaning methods, extreme care should be taken to ensure the dam and foundation are not pressurised or eroded by the cleaning operation, and the drains are not damaged. Monitoring and recording of uplift pressures and drainage flows should be completed prior to and following cleaning (after conditions have stabilised) to verify the effect of the drain cleaning and the sensitivity of the drains to plugging, and to allow an appropriate drain cleaning frequency to be established.

7.8.1.4 Vegetation Control

Vegetation on and adjacent to a dam and its abutments should be kept to a minimum and, in particular, trees and large vegetation should not be allowed to establish on the dam or in the vicinity of its abutments and toe. Grass cover on embankment dams should be kept short.

The objectives of vegetation control are to:

- Prevent root penetration, which could affect the safety of a dam.
- Allow unimpeded observation of dam performance indicators such as seepage, leakage, slumps, instability and deterioration of materials.

Where vegetation has been allowed to establish on dam or abutment faces, the removal of the vegetation should be planned and executed with inputs from a Technical Adviser.

Dam and abutment slopes should also be kept clear of animal burrows, and activities that can result in rutting/ tracking on dam faces (e.g. grazing and vehicle activities) should be minimised. Where it does occur, rutting and tracking should be repaired.

Maintenance activities will be somewhat dependent on the dam type and its characteristics, and the actual loading and operating conditions. Any damage should be photographed and recorded. The following maintenance activities, where necessary, should be completed:

- Maintain and repair surface and joint sealing systems (including waterstops).
- Repair cracks and defects.
- Maintain or restore freeboard provisions.
- Repair wave-induced surface erosion.
- Repair concrete damage, and reinforcement or steelwork corrosion.
- Repair seepage-induced erosion and/or slumping.

7.8.2 Concrete Dams and Appurtenant Structures

Maintenance needs for concrete dams, concrete-faced dams, and appurtenant structures should be identified including the following:

- Regular cleaning of foundation and internal drainage systems
- Maintenance of surface and joint sealing systems
- Sealing of cracks

Some concrete materials are subject to alkali aggregate reaction (AAR), which causes expansion of concrete, pattern cracking, and ultimately loss of structural integrity. AAR can affect operations by causing closure of sluiceway openings, leading to binding and inoperability of logs or gates. AAR can also cause deck beams or slabs to shear at bearing points, and loss of strength can lead to load de-rating of sluiceway structures, causing the inability to move lifting equipment to pull logs. In some cases, special maintenance procedures may be needed to mitigate the effects of AAR.

Sluiceway guides need periodic maintenance, since deteriorated guides or roller paths for gated sluiceways could lead to binding of gates. Deterioration of gains in stoplog sluiceways can lead to logs jamming or turning over so they cannot be removed.

7.8.3 Embankment Dam and Appurtenant Structures

The maintenance required for embankment dams and appurtenant structures should be identified. Maintenance might include items such as the following tasks:

- Removing and mowing vegetation; establishing desirable vegetation cover
- Controlling burrowing animals
- Replacing deteriorated riprap
- Restoring settled crest and freeboard
- Repairing seepage-induced slumping
- Cleaning the drainage system
- Controlling surface erosion

7.8.4 Spillway Structures, Approach and Outlet Channel

Some types of spillway structures and approach channels may require periodic maintenance to ensure their operability or integrity to safely discharge required flow. Maintenance requirements for these structures should be identified and may include the following:

- Clearing of debris; removal of vegetation from spillway approach and outlet channels and from the reservoir (where it may migrate and block discharge).
- Repair of cavitation damage or eroded aprons or unlined spillway channels after spill events
- Routine cleaning of debris from energy dissipaters, from joint repairs in concrete linings, and under drainage systems.
- Removal of vegetation and repair of fuse plug initiation channels to ensure they will trigger as planned and not trigger prematurely.

7.8.5 Penstocks, Tunnels, and Pressure Conduits

Well-designed penstocks, tunnels, and pressure conduits typically provide many years of service if appropriate inspection and maintenance programs are followed. Tunnels, pressure conduits, and penstocks may fail to perform as a result of a design deficiency, operator error, poor maintenance, unusual loading, and ageing. Consequences of failure of a tunnel, penstock, or pressure conduit through an embankment dam can be severe, including uncontrolled release of reservoir, dam breach, loss of life, environmental damage, structural damage, and loss of generation.

Effective maintenance includes the following tasks:

- Applying suitable internal or external coatings to extend the life span of existing pipelines or penstocks.
- Repairing concrete tunnels and conduit linings or removing rock falls in unlined tunnels.

7.8.6 Gate and Valve Systems

Gates and/or valves that fulfil dam and reservoir safety functions should be considered as an integrated system that includes their lifting/operating systems, associated power supplies, and control, protection and communication systems. Some Dam Owners designate these as ‘dam safety critical systems’ which contribute to the following safety functions:

- Safe retention of the reservoir under all loading conditions.
- Safe control of reservoir inflows and outflows (e.g. normal operation or flood discharges).
- Reservoir drawdown in response to a dam safety incident or emergency.

An uncontrolled release of the reservoir is an event during which there is no control over the quantity of the stored contents released or the rate of discharge from the reservoir. Examples of conditions at appurtenant structures that could result in an uncontrolled release of the reservoir include:

- Inappropriate operation or failure of gates and valves that fulfil a dam or reservoir safety function.
- Overtopping and subsequent erosion downstream of an appurtenant structure or erosion of a dam or abutment adjacent to an appurtenant structure.
- Internal erosion in the foundation beneath an appurtenant structure, or in a dam or abutment adjacent to an appurtenant structure.
- Instability of an appurtenant structure.

7.8.6.1 Inspection, Maintenance and Testing of Gates and Valves

Regular inspection, maintenance and testing should be conducted for the gate and valve system to ensure they are in good working order and capable of performing normal and emergency operation under all conditions. Performance monitoring of gates and valves is dominated more by direct inspection and testing.

Gate and valve equipment and components can fail instantaneously. Failure Modes and Effects Analysis (FMEA) is an example of a process available to understand the reliability and robustness of gate and valve systems. Robustness with respect to power sources, control methods, access, communication and mechanical equipment is typically provided by removing 'single points of failure' providing backup sources or methods, and maintaining a ready supply of critical spare parts (e.g. hydraulic pump, electric motor, winch brake).

Regular inspection, maintenance and testing also ensure that operational personnel are familiar with the equipment and its performance, particularly if the equipment is infrequently used or has been recently modified.

Inspection, maintenance and testing activities for gates and valves typically include but are not limited to:

- Lubricating moving parts and keeping oil levels topped up.
- Ensuring suitable fuel is available.
- Controlling or repairing corrosion.
- Operation of equipment that is infrequently used (e.g. standby generators).
- Ensuring batteries are charged.
- Repairing and replacing worn or damaged equipment.
- Condition monitoring (e.g. oil condition, motor currents, hydraulic pressures and visual inspections).
- Testing of control, protection and communication systems.
- Functional testing under a range of load conditions and all available control methods and power sources.

Inspection, maintenance and testing requirements for gates and valves that fulfil dam or reservoir safety function should ensure very high levels of operational reliability under all foreseeable conditions. Appropriately skilled and experienced mechanical and electrical Technical Advisers should be consulted in developing gate and valve inspection, maintenance and testing plans, and in undertaking performance reviews and assessments.

7.8.6.2 Functional Testing of Gates and Valves

Programmes and plans for the testing of gates and valves should include functional testing to confirm that the system (including backup power supplies and controls) fulfils its dam or reservoir safety function reliably. Gates and valves that are rarely used (not used in normal operations) should be specifically tested at appropriate frequencies that reflect the importance of their operational function and the consequences of their non-operation.

Functional testing of gates and valves should include opening (e.g. spillway gates) or closing (e.g. penstock intake or canal inlet gates) using both normal and backup power supplies and all possible control modes (automatic, remote and local). For electric motor driven winch gear, mechanical screw drives and electric motor driven hydraulic systems, motor currents should be recorded. For all hydraulic systems (including diesel-hydraulic backup systems) hydraulic pressures should be recorded. Motor currents and hydraulic pressures are valuable condition monitoring parameters, and should also be compared against settings of motor overload relays and pressure relief valves respectively. The settings of pressure relief valves should also be confirmed.

Economic, environmental and public safety considerations can affect the practicability of tests that result in large flows. In such cases Dam Owners may choose to develop alternative test procedures that meet appropriate objectives and may include:

- Performing the tests during scheduled spills or normal operations.
- Performing ‘balanced’ (no flow) tests in air or water with bulkheads in place. Gate/valve and bulkhead arrangements will vary and the limitations of such alternative testing need to be understood.
- Performing ‘unbalanced’ tests in water with upstream bulkheads in place (limited flow only). Again, gate/ valve and bulkhead arrangements will vary, and the limitations of such alternative testing need to be understood.

The extent and frequency of the testing procedures should reflect:

- The gate and valve system performance requirements.
- The equipment available to perform the dam or reservoir safety function (e.g. numbers of gates, type of lifting equipment, backup power supplies and alternative means of operation).
- The age and condition of the equipment.

Testing programmes and plans should be developed by the Dam Owner in consultation with appropriate Technical Advisers and/or Technical Specialists (e.g. Gates Specialists, Mechanical Engineers, Electrical Engineers, Controls Engineers and Communications Engineers).

FMECA and reliability assessments can allow gate and valve system testing to be targeted at vulnerabilities.

As a general guide, **Table 7.1** provides suggested testing frequencies for gate and valve systems installed in High and Medium Hazard Rating dams and appurtenant structures.

Table 7.1: Suggested Gate and Valve Testing Frequencies for Significant or higher Hazard Rating Dams

Gate/Valve Dam or Reservoir Safety Function	Backup Power Source Test	Unbalanced Head (Flow) Test	Balanced Head (No Flow) Test
Passage of Floods (refer Note 1)	Monthly. Minimum opening (refer Note 2). Initiated by backup power source (i.e. battery and motor startup checks).	Annual. 15% opening, or, one full rotation of moving parts (refer Note 3). Initiated by normal and backup power supplies and all control modes.	5-yearly. Full range. Initiated by normal and backup power supplies and all control modes.
Reservoir Dewatering (refer Notes 1 and 4)	Six-monthly. Minimum opening (refer Notes 2 and 5). Initiated by backup power source (i.e. battery and motor startup checks).	5-yearly. 15% opening, or, one full rotation of moving parts (refer Notes 3 and 5). Initiated by normal and backup power supplies and all control modes.	10-yearly. Full range (refer Note 5). Initiated by normal and backup power supplies and all control modes.
Machine or Water Supply Intake (refer Note 6)	Not applicable	5-yearly. Full-flow trip testing.	Not applicable

Note 1: The risk of the gate or valve not returning to its pre-test position should be evaluated before the test.

Note 2: The minimum opening to lift the gate or valve open and demonstrate operation of the backup power source.

Note 3: For large spillway gates or dewatering outlets this may result in very large discharges, in which case an appropriate alternative may be determined in consultation with a Technical Adviser or Technical Specialist.

Note 4: Where the equipment is designed for reservoir dewatering or the Dam Owner intends to use it for reservoir dewatering.

Note 5: Where the likelihood of a damaging earthquake that could require reservoir dewatering is significant (e.g. dams with low seismic robustness in a moderate to high seismicity region, and with high consequences of failure), consider the necessity of a higher testing frequency in consultation with an appropriate Technical Adviser or Technical Specialist, taking into consideration the performance requirements of the gate/valve and the consequences if the gate/valve fails to operate.

Note 6: Where intakes have automatic 'trip' closing, trip circuit testing (without gate closure) at a minimum annual frequency should be considered.

7.8.7 Infrastructure and Services on Dams

Necessary maintenance of infrastructure, including site access, may include the following:

- Grading and replenishment of granular surface roads
- Removal of debris on access road
- Maintenance of bridge structure and deck
- Cleaning of access road culverts and ditches and removal of log dams
- Maintenance of signage to ensure emergency responders can locate remote sites
- Clearing of roadside or access path vegetation

Maintenance requirements for public safety measures include issues such as the following:

- Regular inspections to ensure integrity of all system components (signs, fences, etc.)
- Protocol for timing of replacement of missing and (or) damaged components, depending on criticality of the item and redundancy
- Installation and removal of any seasonal structures, such as booms or buoys

Dam Owners must ensure that they are informed and consulted about installation, O&M activities for the infrastructure and services owned by third parties and that the safety of the dam and appurtenant structures is not compromised by the presence or maintenance of these items.

8 SURVEILLANCE AND SAFETY REVIEW

8.1 INTRODUCTION

Dam incidents and failures have been attributed to root causes such as undetected progressive unsafe trends, instantaneous loading acted on dam, deleterious material behaviour or inherent deficiencies from construction processes. This is inevitable, for instance, the ageing trends of the dam cause deterioration of structural integrity over time and nature forces such as earthquake or PMF cause immediate extreme loading on dam. Lessons learnt and knowledge gained from past dam failures have contributed to forming prudent and systematic procedures to identify such potential events and carry out necessary dam safety actions during the operation stage of dam.

Dam Owners should make sufficient arrangement to ensure that the surveillance and safety review program is adequately carried out and updated their dam hazard rating accordingly. This is the intent of this section, which will define the practices to ensure dam failures could be prevented or their harmful effects mitigated by carrying out proper surveillance and safety review.

8.2 SURVEILLANCE

8.2.1 General

There are similarities of antecedent tendency that cause deficiencies and subsequent development of incidents and failures. Dam surveillance programme aims to detect such tendencies timely to enable dam safety actions to be taken, thus preventing oversight. Surveillance should start, preferably, during construction stage of the dam. This ensures that background information that reflects the behaviour of dam is fully recorded, including any anticipation of problems or issues that may lead to deficiencies. This valuable record during construction till initial filling of dam is vital information to be passing on to the dam owner and operator.

Unless it is a low hazard dam where not appropriate, surveillance program deemed should be in place for all dams.

Dam engineers, in conjunction with the Regulatory Bodies, should be consulted to analyse the present data and conditions of the dam and its appurtenant structures so that an appropriate surveillance program could be established.

Modern technology has been continuing to enhance traditional monitoring methods. It provides the opportunity to acquire data and analyse dam performance information in real time or historically through electronic data logging. Technology should only supplements, and does not replace, site surveillance. The value of applying state-of-the-art technology should be considered when establishing or reviewing Surveillance Program. Frequent comparison of electronic data and manual readings should be carried out to cross check data quality, where applicable.

At a minimum, surveillance program should include:

- Inspections
- Performance Monitoring
- Ensure availability of dam records relating to performance of dam (e.g. investigation, design and construction reports)
- Verification and assessment on recorded data and other information
- Proper recording and reporting of surveillance
- Independent review of the surveillance program

8.2.2 Inspection

The primary aspect of a dam surveillance programme is the sufficient frequency of inspection for detecting deficiencies in conditions and symptoms of deterioration of dam. Dam safety inspections should be carried out to determine and update the status of the dam and its appurtenant structures in terms of its structural integrity and safe operation.

Generally, there are four different levels of inspection required. Each recommended for different purposes as tabulated in **Table 8.1**.

Routine Visual Inspections usually comprise daily to weekly visual observations of the dam by the operator. Comprehensive Inspections should be undertaken in conjunction with Dam Safety Inspection (section **8.5**), and with Dam Safety Reviews (section **8.7**), if necessary. Intermediate Dam Safety inspections are carried out between Comprehensive Dam Safety Inspections. They are less detailed and concentrate on recording any activities, changes to programs, and evaluations of surveillance data since the last inspection.

Some details of inspection procedures and practices are provided in **Appendix E**.

Inspections and technical assessment should be carried out by qualified and experienced personnel (e.g. dam engineer and relevant specialists), specially trained and capable to identify deficiencies in dams. Dam Owners should ensure that adequate training and education are provided to all operational personnel and they are aware of the consequences of failure of the dam and of the deficiencies that have been found in similar dams.

Table 8.1: Surveillance Inspections

Type of Surveillance Inspection	Personnel	Purpose
Comprehensive Dam Safety Inspection or Formal Safety Inspection	Dam Engineers and Relevant Specialists	The identification of deficiencies by a thorough in situ inspection; by evaluating surveillance data (e.g. adequacy of recorded dam instrumentation data, hydrological data) ; and by applying current criteria and prevailing knowledge. Equipment should be test operated to identify deficiencies. For a Safety Review consider: - Draining of outlet works for internal inspection. - Underwater inspection of submerged structures.
Intermediate Dam Safety Inspection or Periodic Safety Inspection	Dam Engineers	The identification of deficiencies by visual evaluation of the dam and review of recent surveillance data, with recommendations for remedial actions. Equipments are inspected and, preferably, tested.
Routine Visual	Operation Personnel	The visual observation, identification and reporting of deficiencies of the dam with duty of care by dam operating personnel.
Unusual/ Special/ Emergency	Dam Engineers and Relevant Specialists	A special hazard assessment of a particular dam event (e.g. emergency drawdown, extreme floods, post earthquakes, prolonged drought) to determine the need for preventive or remedial actions.

8.2.2.1 Frequency of Surveillance Inspection

The frequency of surveillance inspections should be set in accordance to the dam hazard rating commensurate to the consequences of dam failure, the type and size of the dam and the value of the dam to the owner and the community. For surveillance, the recommended frequency of inspections is as shown in

Table 8.2. More frequent inspection may be necessary where a dam is known to have some deterioration or anomalies. On the other hand, less frequent routine visual inspections may be appropriate for particular types of dams, such as flood detention basins that are normally empty. However, this would be balanced by the need to inspect these basins after/during each significant storm events.

Table 8.2: Frequency of Surveillance Inspection

Dam Hazard Rating	Type of Surveillance Inspection			
	Comprehensive Dam Safety Inspection (Formal Safety Inspection)	**Intermediate Dam Safety Inspection (Periodic Safety Inspection)**	**Routine Visual**	**Unusual/ Special/ Emergency**
Very High	On first filling then every 5-yearly	Annual	Daily[1]	Whenever necessary and when event occurs
High	On first filling then every 5-yearly	Annual	Daily to[1] Tri-Weekly	Whenever necessary and when event occurs
Significant	On first filling then every 7-yearly	Annual to 2-yearly	Twice Weekly to Weekly[1]	Whenever necessary and when event occurs
Low		On first filling then every 5-yearly	Monthly	Whenever necessary and when event occurs

Note 1: Dam Owners may carry out a review to determine if a reduced or increased frequency of inspection is satisfactory. The review should be undertake by a dam engineer and includes legal requirements, dam hazard rating and consequences, type and size of dam, dam failure modes and performance monitoring arrangements.

8.2.2.2 Methodology of Surveillance Inspections

Methodical inspections should be established to include all status of dam safety aspects are correctly recorded and appraised. Field inspection checklists should be prepared specifically to the design or safety assessment procedures. This includes:

- Observation of a dam safety features and the potential deficiencies related with them.
- Desktop study on previous inspection reports should be done before surveillance inspection.

Appendix E provides further detail on matters in surveillance inspection program. Some key references for dam safety inspections could also be referred to ICOLD (1987), New Zealand Society on Large Dams (NZSOLD) (2015), ANCOLD (2003), CDA (2013), FEMA (2004), FEMA (1987) and TADS (1990).

8.2.2.3 Inspection Reports

Ongoing records of the condition and any observable trends of the dam and its appurtenances provide the basis for recommended dam safety action to the Dam Owner. Inspection reports should be fully documented by the inspecting personnel and signed off, as appropriate, and kept securely and should be readily available for review as required.

Routine inspection should be reported on dam-specific report forms that cover the relevant details of the dam (see **Appendix E**).

The executive summary of each intermediate and comprehensive dam safety inspection report should identify items requiring urgent attention, along with recommended remedial actions needed to bring back the appropriate dam safety levels. These factual reports must be prepared by the inspecting personnel and will contain subjective interpretations of visual observations.

All reports should be prepared using a similar dam-specific format and structure. Reference on report preparation could be made to the example in the training module “Documenting and Reporting Findings from a Dam Safety Inspection” (TADS, 1990).

8.2.3 Monitoring

Monitoring is a means of determining performance trends and detecting any deficiencies. This process consists of the data acquisition, recording, analysis and presentation from instrumentation devices installed at dams. The monitoring requirements and the relevant installed instrumentation in the dam should be identified by the dam designer and subsequently by dam engineer undertaking the dam safety review.

The dam engineer shall conduct the surveillance program to ensure that the maintenance and appropriate modification of the monitoring system is carried out adequately. The Dam Owner is responsible for resourcing and funding the activities (see **Appendix E**).

Monitoring items include, but not limited to:

- Reservoir levels, which provide a record of the loadings on the dam.
- Seepage (e.g. measurement at any point on the dam, abutments, or reservoir rim or even well downstream of the dam) is one good indicator of a dam’s performance.
- Rainfall (i.e. at dam and in catchment), which may relate to the amount of seepage.
- Pore-water pressures and water table levels, which may be related to above mentioned reservoir level, seepage and rainfall.

- Surface and internal displacements.
- Stresses, which may be measured in embankments or structural concrete.
- Seismic events, which may be measured on a local or regional basis by Dam Owners who choose to instrument their dams for seismic response. Interpretation and maintenance of this monitoring is best conducted by a seismologist.

8.2.3.1 Frequency of Observation

The monitoring frequency should be determined by taking into account the risk assessment, dam hazard rating and the value of the dam to the Dam Owner and the community. The higher the hazard and risk, the more frequent the monitoring.

In the construction and initial filling stages, closer monitoring with prudent supervision and analyses should be carried out compared to the operational phase to provide early detection of any adverse developing conditions as the dam experiences its first loadings. In addition, during prolonged drawdowns and subsequent refilling, close monitoring should be undertaken to find out any deleterious effects of drying out of dam embankments, cores, foundations and abutments.

After special events, such as large floods, rapid drawdowns and earthquakes, close monitoring should be undertaken. If any adverse trend develops or worsen, more detailed monitoring should be undertaken.

As an initial guide, the frequency of observations should be determined by the dam designer (preferably in conjunction with the dam engineer responsible for dam surveillance). However, the dam engineer responsible for surveillance should regularly review the monitoring program in conjunction with the comprehensive dam safety inspections.

The frequencies shown in **Table 8.3** are a guide for dams that are “in operation” and have no known deficiencies.

Table 8.3: Guide for “in Operation” Dam Monitoring Frequencies

Monitoring	**Dam Hazard Rating**			
	Low	**Significant**	**High**	**Very High**
	Monthly	Twice Weekly to Weekly (TC)[2]	Twice Weekly to Weekly (TR)[2]	Daily to Twice Weekly (TR)[2]
Reservoir Level	Monthly	Twice Weekly to Weekly (TC)[2]	Twice Weekly to Weekly (TR)[2]	Daily to Twice Weekly (TR)[2]
Seepage	Monthly	Twice Weekly to Weekly (TC)[2]	Twice Weekly to Weekly (TR)[2]	Daily to Twice Weekly (TR)[2]

Chemical analysis of seepage		Whenever required	Whenever required	Whenever required
Pore pressure	Consider	3-Monthly to 6-Monthly	Monthly to 6-Monthly	Monthly to 3-Monthly
Surface movement, Control Datum (e.g. geodetic pillar)		10-Yearly	5-Yearly to 10-Yearly	3-Yearly to 5-Yearly
Surface Movement Marker	Consider	Consider	2-Yearly	Yearly
Internal movement/ stresses		Consider	2-Yearly	Yearly
Seismologic			Consider (TR)[2]	Consider (TR)[2]
Post-tensioning		10-Yearly	5-Yearly to 10-Yearly	5-Yearly

Note[1]: These frequencies may need to be varied according to the conditions at and the type and size of dam, and applies to instrumentation already installed at the dam.

Note[2]: The frequencies quoted assume manual reading of the instrumentation. Where automated readings are available more frequent reading would be appropriate

Note[3]: Preferably all cables, but at least a significant representative sample, to be monitored.

(TR – telemetry recommended) (TC – telemetry to be considered)

8.2.3.2 Principles of Monitoring

A number of principles are provided in **Appendix E**. Detailed guidelines on monitoring could also be referred to various references such as (ICOLD, 1987), (NZSOLD, 2015), (ANCOLD, 2003), (CDA, 2013) and (FEMA, 2004).

8.3 DAM RECORDS

Dam Record includes the documentation of investigation, design, construction, commissioning, operation, maintenance, surveillance, safety review, remedial action, rehabilitation, as well as all monitoring measurements.

Some information will never be changed and is suitable for reduction and permanent storage electronically with backups. Sufficient information should be kept handy in a database in easily accessible form to meet any situations which could arise, say, during emergency.

Some data that change with time are derived from dam safety surveillance, monitoring, operations and maintenance activities. Such data should be accumulated in the comprehensive dam safety inspection and dam safety review reports.

8.4 SURVEILLANCE ASSESSMENT

Assessment in this context means the on-going evaluation of the dam safety based on data obtained from inspections and monitoring, in terms of its condition and operation.

Assessment is a regular important step where decisions affecting the safety and operation of the dam are made. Many dam deficiencies could be detected by visual inspections. There are cases where instrumentation has not detected problems that are known to exist. There are also situations where an instrument may purport to indicate an anomaly but no visual distress can be seen. Cross reference and evaluation should therefore be assigned to dam engineers qualified to make recommendations based on their expertise and interpretations.

Dam surveillance should be made by a dam engineer who is familiar with the detailed history of the dam including criteria and limitations used in design and sound knowledge of performance of the dam up to the present. Further details about surveillance are provided in **Appendix E**.

8.5 COMPREHENSIVE DAM SAFETY INSPECTION REPORTS

The Comprehensive Dam Safety Inspection Report is an in-depth review of the performance of a dam with a view to stating whether or not the dam is considered to be safe. They should be prepared at regular intervals (at least five yearly) for all significant or higher Hazard Rating dams with the Hazard Rating reviewed every five years for other dams. The report should summarise and extend previous reports to provide a clear picture of long-term trends. The reports should be prepared by experienced dam engineers, preferably who are or, if not, have at least consulted in detail with, those who are, familiar with the dam in term of its components and history.

The amount of detail in a Comprehensive Dam Safety Inspection Report will depend on the consequences of failure of the dam. Generally the higher the Dam Hazard Rating, the more detailed the report should be. The following issues should be addressed in the report:

- Physical details of the dam
- A review of the Dam Hazard Rating
- Observations during the inspection
- What has occurred since the previous inspection (e.g. incidents, actions arising from recommendations made previously and other actions)
- Comment on operations and maintenance

  - Comment on EAP of Dam Owner integrated with disaster management plan of NADMA (Section **10**)
  - A review of performance as indicated by operational and surveillance data since the previous inspection
- An evaluation and interpretation of the structural performance of the asset
- The need for further action (safety review (Section **8.7**), dam rehabilitation (Section **9**) or specialist studies)
- A review of monitored data and other information. (What are the issues being addressed? Is the approach effective? Does the surveillance program need to be altered?)
- Flood handling capability of dam and appurtenant structures
- A statement about the assessed safety of the asset against current standards
- A statement on the adequacy of the dam safety programme

(Note: Intermediate Dam Safety Inspections also cover the items marked “o” but to a lesser depth of evaluation, mainly concentrating on events and surveillance data since the last Inspection)

A Summary should be included to provide detailed statement of the report findings and recommendations.

8.6 INDEPENDENT AUDIT

The purpose of an independent audit is to assess the on-going appropriateness of the dam monitoring and inspection programs and its adequacy of surveillance evaluation and reporting. It should:

- determine the extent to which the current dam safety procedures and practices meet the Dam Owner's obligations and/or specified requirements;
- provide the Dam Owner with independent assurance that appropriate resources are committed to the program and that sound technical practices are in place.

The audit should be undertaken by a dam engineer who is independent of the on-going surveillance program. The Dam Owner should obtain an independent audit of the dam’s surveillance program at regular intervals (e.g. 10-yearly).

8.7 SAFETY REVIEW

8.7.1 Introduction

Safety Review is a comprehensive evaluation and procedures for assessing the dam safety as an entirety, which comprises a detailed study of dam engineering with specialist supports, where relevant, such as civil engineering, structural engineering, hydraulic and hydrology, geotechnical engineering, engineering geology, mechanical and electrical engineering, seismology, design aspects and assessment of the records and reports from investigation, design, construction, commissioning, operation, maintenance and surveillance activities.

A Safety Review should assess the integrity of a dam against known failure modes and mechanisms for the various types of dams based on current acceptable safety criteria (e.g. engineering standards, dam safety guidelines) or risk management criteria, which may defer from original construction time of the dam.

Safety Review Report is produced to document the Safety Review and to recommend remedial or maintenance work. Dam Owners may use risk assessment techniques with Safety Reviews to determine the urgency and extent of works and to prioritise remedial works of their dams.

8.7.2 When to Undertake a Safety Review

The requirements for undertaking a safety review are considered due to:

- recognized significant deficiency or weakness during the surveillance program or by other means
- identified unusual results or extreme events such as flooding, earthquake or landslide that have adverse impact on dams or harmful consequences
- the age of the dam
- a change in accepted standards of safety, hazard rating, changes in arrangements at the dam or technology
- undertaken as part of continuous improvement of a risk assessment process
- Dam Owner, regulatory body or legal requirements
- if not undertaken for the reasons stated above, an appropriate periodic schedule at 7 to 20 years intervals (depending on risk level, dam hazard rating and technology changes) should be carried out for all dams (refer **Table 8.4** below).

Table 8.4: Frequency of Scheduled Safety Review

Dam Hazard Rating	Scheduled Dam Safety Review
Very High	5 – 7 yearly
High	7 – 10 yearly
Significant	10 – 15 yearly
Low	15 – 20 yearly

8.7.3 Personnel Capabilities

The personnel who undertake Safety Review should be qualified and experienced dam engineer. Where necessary, the review is supported by other specialists deemed necessary to complete the entire review. It also depends on the dam type and level of the inherent risk.

8.7.4 Safety Review Procedures

Generally, there are two types of dam safety review, namely:

- Dam Safety Review
- Special Dam Safety Review

In absence of the dam safety review requirement as stated in **8.7.2**, a periodic schedule of dam safety review should be carried out to ensure safety in its entirety, as part of the dam safety management program. The extent of the dam safety review should commensurate to its Dam Hazard Rating.

A special dam safety review is carried out when deemed required; following an unusual event, observation and emergency, or when a potential or confirmed dam safety deficiency has been identified.

8.7.4.1 Dam Safety Review Procedures

The exact procedures for every dam should be drawn upon site-specific and special nature of the dam itself, rather than from general prescribed procedures. More often than not, specific advice should be obtained from relevant expertise as mentioned in section **8.7.3**.

The recommended dam safety review procedures include:

- Adequacy and review of all available relevant information including databases, design reports, construction reports and surveillance records. These include design limitation and performances, and indication of deficiencies and adverse trends from the abovementioned.

- Review of known and potential hazards and dam safety threats.
- Review of the Dam Hazard Rating.
- Review of the outputs from the FMEA, the identified potential failure modes and their key performance indicators. Also, consider review of the appropriateness of the design loads and conditions such as the need to revise flood estimates, seismic loadings, update current material properties.
- Detailed on-site inspection of the dam and appurtenant structures; including changes that were made and the reasons for such changes and its design revisions. For construction stage, review any potential for the development of unsafe conditions (e.g. unexpected foundation conditions, presence of seepage, large grout takes, indications of distress or movements, poor construction methods leading to latent unsafe conditions, inadequate materials testing and control, lack of survey control during construction or repair which may have resulted in zones being misaligned or being of inadequate thickness, erosion, mechanical and electrical equipment malfunction, ageing of the dam).
- Site inspection and witnessing of testing of gates and valves that fulfil dam and reservoir safety functions (including their operating equipment, power supplies and control, protection and telecommunication systems). Testing may not be necessary if the Dam Owner has completed and documented recent tests that adequately satisfy the test requirements (both hydraulically and structurally; however, the operation and performance records for the tests should be reviewed in depth.
- Assessment of the adequacy of the dam and its appurtenant structures, including all gate and valve systems that fulfil dam and reservoir safety functions, to safely perform to current intended criteria for all loading conditions. The reviewers are unlikely to reanalyse the dam but may identify that there is a need for further analysis, design or assessment of an element of the facility and identify this as a dam safety issue.
- Adequacy and review of the dam safety management system compatible with current state-of-the-art design method and approach, and operating, surveillance, maintenance and testing procedures and records, including clarifying matters of detail with operations, dam safety and surveillance staff.
- Review on previously identified dam safety issues and either the adequacy of their resolution, or whether there are impediments that prevent their resolution.
- Review of the organisation of operational resources and infrastructure.

- Review of emergency preparedness including procedures, training, exercises, facilities and equipment.

8.7.4.2 Special Dam Safety Review Procedures

Following an unusual event, observation or emergency, or when a potential or confirmed dam safety deficiency has been identified, a special dam safety review procedures should be implemented. These may include:

- Adverse surveillance observations or instrument readings.
- Large rainfalls or floods.
- Strong winds.
- Earthquakes.
- Landslides into reservoir.
- Man-made damage.

The scope of works of a special dam safety review would be specific to the nature of the dam conditions and any identified potential or confirmed dam safety deficiency:

- A review of records and reports from investigation, design, construction and surveillance.
- Site inspections and investigations (e.g. exploratory geotechnical or geophysical investigation by excavation, drilling, density testing, or shear wave testing).
- Natural hazard assessments (e.g. flood, seismic, geologic, reservoir landslides).
- Stability and performance assessments (e.g. structural, flood passage, rock mechanics, erosion, scour).
- Failure Modes and Effects Analysis (FMEA).
- Dam-break modelling and consequence assessment.
- The identification of preliminary remedial actions or mitigating measures (structural or non-structural).

8.7.5 Safety Review Report

Up to date dam records such as relevant chronological investigation, design, construction, commissioning, O&M, rehabilitation, monitoring and inspection data should be initially acquired. The performance and safety of the dam is then assessed with:

- designer’s criteria
- current relevant standards

- present guidelines
- appropriate prediction or assessment of the theoretical performance of the dam
- updating of risk assessment studies, as necessary.

Attention should be given to view the dam in its entirety when assessing dam safety. The results of various features being monitored can have little significance when considered alone, but when viewed in conjunction with other monitored results or observations, can have broader significance.

Further investigation may be required prior to concluding a satisfactory dam safety review. The investigation may include:

- where insufficient plans or obsolete data exist, the dam may have to be surveyed and new plans drawn
- sampling and testing of materials in the dam and its foundations in conjunction to the required geotechnical drilling and mapping
- calculation of new design flood
- revision of seismic loadings

Special attention should be given to changes in land use that may have occurred since construction of the dam. This includes such activities as mining, urbanisation or clearing of the catchment area. Attention should also be given to changes in developments downstream of the dam which may be affected by, or influence unusual releases from the dam.

The Safety Review for older dams may need to be more extensive because of probably lack of data, change in design criteria (e.g. uplift under a concrete dam, additional flood or earthquake data) and deteriorating conditions due to ageing, inadequate maintenance or for other reasons, such as sedimentation.

Comments should be made regarding the frequency of inspections, surveillance program, and operation and maintenance procedures. Conclusions should also be drawn, where relevant, regarding the adequacy of the main features of the dam (i.e. foundations, main wall, spillway, outlet works, associated equipment and monitoring system). Such comments and conclusions should take into account of modern developments in hydrology, hydraulics, geotechnical engineering, engineering geology, structural analysis and design criteria relating to dams.

The outlines of Dam Safety Review should report, including:

- A summarised statement on the dam safety indicating whether the dam is in an appropriate safe level and satisfactory condition.
- Findings on remedial or emergency action should be carried out and when to rectify any deficiencies in the dam.
- Cost estimation of recommended remedial actions.

Supplements, detailing all related reference materials, photographs, drawings, data plots, inspection reports, test results and any other information relevant to the dam safety.

For a specific special dam safety review, it should include:

- any dam safety issues investigated and/or identified in the review, including potential or confirmed dam safety deficiencies
- possible interim risk reduction measures and long-term risk reduction options, and comments on timeframe for their implementation
- the categorisation of identified dam safety issues into physical infrastructure issues, potential or confirmed dam safety deficiencies, and non-conformances
- comment on previously identified dam safety issues and either the adequacy of their resolution, or whether there are impediments that prevent their resolution.

9 DAM REHABILITATION

9.1 INTRODUCTION

Dam upgrading is usually required due to changes that impact on dam safety such as upstream catchment changes, reservoir changes, legislative changes, downstream changes, technological advances and standards of practice that subsequently affect the dam hazard rating.

Dam upgrading involving raising an existing dam for increasing the storage capacity of the reservoir is not for purpose of upgrading the dam safety standard. The dam raising works should be carried out similar to a new dam development from the investigation, design, construction and commissioning.

Dam rehabilitation is required when a dam no longer meets an appropriate level of safety. The remedial action evaluation process should select a timely, yet cost effective rehabilitation action, which could include interim or long-term remedial works, maintenance, changes to operating procedures, or decommissioning.

The legal and authorities requirement for upgrading and rehabilitation should be complied. The requirement for EIA shall be referred to respective guidelines of the relevant authorities. For dam upgrading and rehabilitation that result in enlarging the inundated area, the additional reservoir area may be used as a guide for complying the EIA requirements (e.g. 200 hectares or more for water supply, flood mitigation and irrigation dams, 400 hectares or more for hydroelectric power dams).

The dam rehabilitation projects, particularly significant projects, usually require processes similar to those for new dams. Dam safety considerations must be addressed during rehabilitation work, especially those involving flood passage that need to be managed throughout the rehabilitation work. The urgency of a rehabilitation work should reflect the nature of the identified deficiency and the level of the risk it presents (e.g. for a Significant hazard rating dam, an inability to safely pass a 1 in 100 AEP flood event should be urgently addressed but an inability to withstand the effects of a 1 in 2,500 AEP earthquake event could be addressed over a longer period).

9.2 DAM DEFICIENCIES

Dam rehabilitation is measures to be taken after comprehensive evaluation of the existence of a non conformance dam safety issue. These issues are usually detected during surveillance programs, evaluations of monitoring, or safety reviews. Causes of deficiencies could be due to:

- Inappropriate design or construction
- Changes to safety criteria (e.g. design, regulation)
- Changes to Dam Hazard Rating
- Ageing deterioration or damage of materials
- Operation and maintenance related problems
- Inadequate surveillance procedures
- Damages from natural incidents (e.g. flood, earthquakes)
- Man-made damages (e.g. vandalism, sabotage, terrorism)
- Interpretation of updated knowledge and data (e.g. analytical techniques, material properties)

Deficiencies vary in uncertainties and severity on dam records to imminent potential of dam failures. The type of rehabilitation required, and its urgency, is determined by the characteristic of the deficiency, the related risks to the dam and its Dams Hazard Rating.

9.3 ASSESSMENT PROCESS

Timely investigation and information obtained for relevant analysis to the particular deficiency may involve geotechnical investigations, site monitoring and records review. The consequences of a declining situation and its likelihood should be considered. On the other hand, there may be chances where in fact outcomes with no deficiency or no further investigations are required after the assessment.

In critical cases where the risks are high, or where high hazard situations are associated with considerable uncertainty, EAP should be executed and interim risk reduction measures expedited (e.g. lower the reservoir storage).

In normal cases a safety assessment should be carried out to determine an appropriate solution based on the severity of the deficiency and whether only maintenance is required. Some degree of judgement is required. Uncertainties are investigated while interim remedial measures could be arranged at the time when this assessment is carried out. Any analyses on the possible deficiencies should be reported directly to Dam Owners. Risk reduction options may also be included into the report.

In response to a dam deficiency, the remedial actions to be considered are made on:

- Solutions based on technically sound engineering principles.
- Decision analysis techniques to be used in studying dam deficiency issues to benchmark the quality, consistency and justification of solutions or remedial actions.

The techniques used involved both quantitative and qualitative methods to give a systematic ways to make dam safety decisions.

The deficiency review process is outlined below:

- Appraisal of Likelihood of Dam Failure

Dam safety deficiencies are indications or conditions which show potential dam failure scenarios could be developing. The review should made comparative scenarios with case histories and acceptance criteria. Some critical risk for most scenarios is initiated by typical contributing factor (refer **Table 9.1**).

Table 9.1: General Causes of Dam Problems

Typical Dam Failure Scenarios	Contributing Factors
Surpassing Spillway Capacity lead to Overtopping	Inadequate capacity for Peak Flood, Spillway Blockage.
Dam Stability	Material Yield, High Internal Pressures.
Erosion and Piping	Filter Consistency, Material Properties.
Deformation	Earthquake, Material Changes.
Containment Loss (for hazardous materials)	Inflow Volume, Operation.
Hydromechanical Plant and Equipment	Uncontrolled Release of Reservoir Content

- Damage Level and Dam Hazard Rating Assessment

Justifying remedial actions require examining the consequences due to a dam failure. If it has not previously been undertaken, the review should include a hazard assessment to demonstrate whether dam failure substantially increases the loss of life and damage to property, and the environment, beyond that caused by the failure-initiating event (i.e. flooding or earthquake) if failure did not occur.

- Risk Assessment

The review may include a risk evaluation to compare the estimated risks with tolerable risk criteria - see the **Appendix B** Assessment, Consequences and Dam Hazard Rating, in determining whether the existing risks are tolerable.

While the risk to life should be the predominant consideration, the risk assessment should include other aspects of quantitative risk assessment (e.g. an Economic Risk Assessment) based on:

- Costs of remedial action solutions;
- Costs associated with property damage averted;
- Determination of various social or environmental losses; and
- Costs associated with installing permanent or temporary community support services.

This is accomplished using reasonable estimates of loading frequencies, failure response probabilities and damage values. Dam Owners should also consider other relevant matters such as the As Low As Reasonably Practicable (ALARP) principle, regulatory requirements and business interests in their assessment.

- Report

A summary of the deficiency review should be documented in a report to the Dam Owner. The report should include the following:

- Indicate the dam deficiencies causing the problems and their severity against acceptable criteria (risk or standards based);
- Clearly demonstrate whether there is an unacceptable likelihood that the dam would fail under potential loading conditions;
- Recommend remedial actions. These should primarily be to reduce the risk to life from a dam failure to tolerable levels; or otherwise demonstrate, on the basis of an economic risk assessment that the economic benefits exceed the cost of the remedial works;
- Indicate the degree of urgency or; priority for remedial action. For dam portfolios, or dams with multiple identified deficiencies, those posing the greatest public hazard together with those having the highest risk of failure, or greatest deviation from acceptable risk criteria, are usually given priority for further study or remedial action.

9.4 DAM REHABILITATION STUDY

a. Remedial Action Study

A Remedial Action Study may be required to develop alternative risk reduction options for a dam deficiency (structural, non-structural or combinations of both). These options may also include traditional standards based engineering options. It is also required to evaluate the effectiveness (i.e. level of risk reduction) and costs of these alternatives and to present information on them to the Dam Owner in a manner such that a preferred option may be identified and implemented.

The study should be undertaken by a dam engineer, and other appropriate specialists, with all available information reviewed. Where information deficiencies are determined, action should be taken at an early stage to obtain the additional information required.

b. Interim and Long Term Measures

Both interim and long-term remedial measures should be postulated and examined. Interim measures can be modified as the understanding of the deficiency and its implications becomes clearer. Staged and prioritised implementation of remedial measures may be necessary for practical reasons.

The alternatives should be compared primarily on the basis of reduction in risk to life, followed by other damage costs and risk costs. All impacts should be identified and described including those, which are difficult to give a monetary value to (i.e. social, environmental, legal). Costs should also include future expenditure to make the measures effective. Indirect costs may also be involved.

An optimum remedial option should be recommended and suitable detailed investigations should have been undertaken to determine that the solution proposed is practical and will not create other problems. It may not necessarily be the least cost solution.

Any report on proposed remedial action should demonstrate that the proposed action is aimed at reducing risks to the Public, from dam failure, to tolerable level. Ideally, it should also demonstrate that any proposed risk reduction action is cost effective and consistent with technical, environmental and publicly accepted standards.

9.5 EXECUTING RISK REDUCTION OPTIONS

9.5.1 Short-Term Remedial Actions

Short-term remedial actions are those required when a deficiency has been observed at a dam, to provide an initial control of the risk or consequence of a dam failure. These actions include but are not limited to implementation of:

- EAP, and its associated Disaster Management Plan, which could involve evacuation of population at risk in the event of a dam crisis.
- Alert systems based on detection of dam failure or conditions which could result in a dam failure.
- Adaptation of the relevant dam operations including controlled release of the storage to drawdown reservoir levels.
- Increased monitoring and surveillance.

Short-term remedial actions are carried out as temporary measures prior to the implementation of the absolute long-term solution to the unsafe conditions. In various cases, after some careful monitoring of the situation, the short-term remedial action may be then continued as the long-term solution, or attach along to it, when the conditions deemed to be under control.

9.5.2 Long-Term Remedial Works

Long-term remedial works are mainly works required at a dam that reduce the risk of a dam failure to an acceptable level for sustaining the dam. This may includes in dam raising or overall augmentation of the dam to increase storage or any other grounds.

Dam remedial works vary considerably and the list is extensive. Dam engineer should assess and decide on appropriate remedial works required to bring up the level of safety of the dam to the intended level.

9.6 TYPICAL REHABILITATION WORKS

Typical conditions that necessitate rehabilitation works on concrete dams include ageing of the foundation and the dam body, the adoption of different design criteria arising from a change in the hazard rating, a higher understanding and requirements of flood and earthquake hazards, and damage incurred during extreme flood or earthquake events.

Some common remedial works that are usually considered are:

- Upstream river regulation to reduce or control inflow.
- Grouting or slurry trenches to reduce seepage under a dam.
- Raising a dam to increase flood handling capacity.
- Augmentation of a spillway or spillways to increase its flood discharge.
- Improving operating controls and procedures.
- Strengthening a dam (e.g. buttressing) to improve stability during extreme floods or earthquakes and to bring it up to currently recognised standards.
- Retrofitting of properly designed drainage / filter protection systems to reduce uplift, control leakage, or control piping.
- Stressing, anchoring, internal grouting or surface treatment of concrete dams to improve stability or arrest deterioration.

9.6.1 Concrete Dams

Some common conditions and rehabilitation measures for concrete dams are as per **Table 9.2** below.

Table 9.2: Some Examples of Typical Conditions and Rehabilitation Measures for Concrete Dams

Conditions	Rehabilitation Measures
• A loss of foundation strength or stability • Foundation erosion • Degradation of grout curtains • Degradation of drainage facilities • Degradation of concrete • Cracking of concrete • Degradation of dam faces • Deterioration of structural joints • Loss of post-tensioned force in cable anchors • Insufficient flood passage capacity • Inadequate structural stability under normal, flood or earthquake load conditions	• Increasing the vertical force by enlarging the profile of the dam, adding ballast, or installing post-tensioned cable anchors. • Increasing the resisting horizontal force by the construction of a downstream buttress. • Draining the dam and its foundation to reduce uplift. • Grouting or the construction of shear keys to provide additional friction along sliding surfaces. • Installing an upstream waterproof membrane to reduce dam leakage. • Installing an upstream staunching blanket to reduce foundation seepage. • Installing a crest wall and/or raising the spillway chute walls and/or providing additional spill measures to increase flood capacity. • Toe protection works to prevent erosion of the foundation.

9.6.2 Embankment Dams

Some common conditions and rehabilitation measures for embankment dams are as per **Table 9.3** below.

Table 9.3: Some Examples of Typical Conditions and Rehabilitation Measures for Embankment Dams

Conditions	Rehabilitation Measures
• Observation of material transport through the dam, along conduits, or through the foundation related to backward erosion piping or seepage erosion. • The presence of preferential seepage path due to backward erosion piping or seepage erosion along conduits or foundation, or due to development over time in the dam or through infilled joints in the foundation. • Observation of slumps, depressions or deformation of the dam or the abutments. • Identification of potentially liquefiable materials in the dam or its foundation. • Usage of dispersive clays. • Hydraulic fractures in low stress area (e.g. through core trenches and adjacent to conduits). • Internal instability of non well-graded embankment materials (e.g. gap graded). • Identification of a low permeability core (or similar element) not constructed high enough to assure dam safety during normal or flood operating conditions. • The lack of filter and drainage protection for the impervious earth core, where a filter is necessary for the prevention of internal erosion or piping and drainage protection of seepage control. • An improved understanding of material performance under normal, flood or earthquake loading conditions (e.g. erodibility, permeability, liquefaction). • Insufficient flood passage capacity. • Inadequate structural stability under normal, flood or earthquake load conditions.	• The placement of toe buttresses and/or the provision of additional drainage facilities to reduce piezometric pressures in the downstream shoulder. • The installation of filter and drainage zones to provide protection against internal erosion and piping. • Increasing the freeboard to safely accommodate an extreme flood event by raising the dam crest, by constructing a concrete wave wall along the dam crest, and/or by increasing the existing spillway capacity.

9.6.2.1 Erosion

Erosion involving embankment dams includes:

- Internal erosion and piping in the embankment, its abutment or its foundation due to insufficient protection, inadequate material compatibility and seepage control
- External erosion resulting from wave action on the upstream face or overtopping of the embankment

External erosion could be identified through visual inspection and repaired within the appropriate time frame prior to becoming a dam safety deficiency.

On the contrary, internal erosion may not be observed easily over a long time, and may become a significant dam safety deficiency. It may pose unacceptable risk upon detection that could occur within embankment or in foundation.

9.6.2.2 Deformation

Deformation that can severely threaten dam safety includes:

- differential settlements that cause development of hydraulic fracturing, cracking, low confinement pressures at interfaces between embankment dams and hydraulic structures and/ or coupled with subsequent increased seepage and internal erosion
- loss of shear resistance in the embankment or foundation materials due to saturation, creep, or liquefaction resulting in slope instability or excessive crest settlement that could lead to overtopping failure
- slope instability due to inadequate shear strengths
- liquefaction of the embankment or its foundation during large earthquake

Other deformations that results from embankment consolidation and foundation settlement during construction, or fluctuating reservoir levels usually allowed for in design of the freeboard and may be less significant to dam safety.

9.6.3 Appurtenant Structures

Some common conditions and rehabilitation measures for appurtenant structures are as per **Table 9.4** below.

Table 9.4: Some Examples of Typical Conditions and Rehabilitation Measures for Appurtenances

Conditions	Rehabilitation Measures
• Wear and tear of appurtenances (e.g. spillway, outlet facilities such as gates, valves, other mechanical and electrical equipment). • Requirement for additional capacity (e.g. spillway capacity, generation capacity). • Addition or omission of dam function (s). • Degradation of appurtenances (e.g. cavitation or abrasion damages on spillway surfaces, low level outlet facilities and scour valves). • Degradation of concrete. • Cracking of concrete. • Scouring of immediate downstream of discharge facilities. • Deterioration of structural joints. • Ageing or shorter lifespan of component of appurtenances (e.g. due replacement, deterioration conditions due to corrosion, erosion, excessive vibration and poor maintenance). • Outdated or unsupported softwares, communication system and control system.	• Increase spillway capacity. • Construct auxiliary or emergency spillway. • Reduction in normal operating level of the reservoir. • Increase freeboard or flood storage capacity by raising the dam and spillway. • Increase spillway chute's wall height. • Repair of damaged energy dissipating structures. • Installing a crest wall and/or raising the spillway chute walls and/or providing additional spill measures to increase flood capacity. • Upgrading of downstream discharge capacity to reflect the characteristic of spillway and its upgraded operational requirements, particularly for large catchment dams. • Timely rehabilitation of low level outlet facilities.

10 EMERGENCY ACTION PLAN

10.1 INTRODUCTION

The good practices used for design, construction, commissioning, operation, maintenance and surveillance of dams will reduce the risk of dam failures. Nevertheless, extreme or unusual circumstances could occur and result in dam failure or hazardous discharges from reservoir. Therefore, it is prudent for Dam Owners to identify conditions which could lead to these EAPs to be implemented.

10.2 EMERGENCY ACTION PLAN

EAP should be in place for all dams where there is potential for loss of life in the event of dam failure. An EAP is an official plan that:

- Identifies emergency conditions that could jeopardize the structural integrity of the dam which require immediate action.
- Provide actions the Dam Owner will take to alleviate the emergency condition at the dam.
- Recommend measures in response to, and mitigate, these emergency conditions at the dam which should be followed by the Dam Owner and operation staff.
- Provides timely alert to appropriate emergency management agencies for their implementation of protection measures for downstream populations, property and environment.
- Provide list of actions to the Dam Owner and operating personnel for the coordination and the responsibilities of all those involved in managing an incident or emergency.

The plan should list actions that the Dam Owner and operating staff should take if an incident or emergency develops. While effectiveness of the EAP could be enhanced by a uniform format that ensures all critical aspects of emergency planning are covered, each plan must be tailored to site-specific conditions and to the requirements of the Dam Owner. Careful research and co-ordinated planning with all involved parties will lay the foundation for a responsible and thorough EAP.

The process of developing an EAP generally involves some or all of the following actions:

- Determine and identify those conditions that could forewarn of an emergency and specify the actions to be taken, and by whom.

- Consequences and hazard rating assessment of a dam can assist in preparing an EAP.
- Identify all jurisdictions, agencies, and individuals who could be involved in the EAP. Co-ordinate the development of the EAP with these parties.
- Identify primary and back-up communication systems, both internal (between persons at the dam) and external (between dam personnel and external entities).
- Identify all necessary dam safety resources, tools, equipment, and keys, and where they can be located, if required in an emergency.
- List and prioritise all persons and entities involved in the notification process, and draft a Notification Flowchart.
- Develop a draft of the EAP.
- Hold meetings with all parties (including emergency management agencies) included in the notification list for review and comment on the draft EAP.
- Make any revisions, obtain the necessary plan approval, and disseminate the EAP to those who have responsibilities under the plan.
- Drill and revise the EAP at regular intervals (see section **10.5.2** and **10.5.3**).

10.3 ROLES AND RESPONSIBILITIES

The responsibility of the dam safety lies with the Dam Owner. The Dam Owner should:

- Develop and maintain a dam safety emergency plan for all dams where there is the potential for loss of life in the event of dam failure.
- Determine the area, height, rate and timing of potential inundation from relevant dam break floods downstream of the dam.
- Establish and resource an alert and communication system for the timely notification, to operating personnel and emergency authorities, of impending/ actual emergencies.
- Provide relevant State, or local, emergency management agencies with details of dam safety emergency response actions (e.g. water releases) and their downstream effects.
- Liaise regularly with emergency agencies to coordinate and maintain appropriate emergency planning arrangements.
- Ensure personnel with responsibilities under the plan have access to controlled copies of the plan.
- Regularly update and periodically test the plan (see section **10.5.2** and **10.5.3**).

State emergency management authorities should have separate guidelines for the preparation of Disaster Management Plans.

10.4 PREPARATION OF EMERGENCY ACTION PLAN

As per recommended practices, the content of an EAP should at least incorporate the sections as described below:

- Introduction
- Roles and Responsibilities
- Emergency Identification, Evaluation and Classification
- Notification
- Attendance and Communication Procedures
- Inundation Maps
- Preventive Actions
- Appendices

a. Introduction

The introductory section of an EAP should include a title page, a statement of purpose and notification flowchart. The document cover identifies it as an Emergency Action Plan and specifies the dam and emergency situation(s) for which it was developed.

The EAP should begins with a Notification Flowchart clearly summarising for the emergency situations considered, who is responsible for notification, which is to be notified, timing for notification, and the prioritised order of notification. The flowchart should include individual names and position titles, office and home telephone numbers, and alternative contacts and means of communication (e.g. satellite phone or radio call numbers). Additional copies of the flowchart should be readily available to each individual having responsibilities under the plan, and should be posted on prominent locations at the dam site and local emergency operations centre.

b. Roles and Responsibilities

This section should specify the person(s) or organisation(s) responsible for the surveillance, maintenance and operation of the dam and the persons and/or agencies responsible for implementing various phases of the EAP. It is recommended that this section should also contain a short summary information section to assist implementation by disaster management agencies.

c. Emergency Identification, Evaluation and Classification

This section should include procedures for the timely and reliable identification, evaluation and classification of existing or potential emergency conditions.

Since an EAP has little value unless it can be implemented in a timely manner, surveillance at the dam should ensure that sufficient time will be available for notifying responsible officials and warning the public. At unattended or remote controlled dams, special consideration should be given to surveillance procedures or the need for automatic warning devices.

Once an emergency situation has been identified and evaluated, it should be classified as to its urgency so that the appropriate action can be taken.

d. Notification

The notification portion of the EAP should contain a listing of all persons to be notified in the event that an emergency situation develops. For each type of emergency situation, the EAP should clearly indicate who is to make a call, when it is to be made, to whom it is to be made, and in what priority.

The number of persons to be notified by each responsible individual should be kept to a minimum and use of news media should be pre-planned to the greatest possible extent. At a minimum, it is recommended that the designated entity should contact as per below accordingly.

Dam Owner will contact:

- Engineer/ management staff/ public affairs officer
- Local disaster management agencies
- Dam safety program officer
- Other regulatory authorities
- Upstream and downstream Dam Owner

Towards the end of the emergency, the Dam Owner, being the entity that activates the EAP, is responsible for determining when the dam safety situation has stabilised. The Dam Owner should, in consultation with engineers and dam safety experts, inform the termination of dam safety emergency at the dam to the local disaster management agency.

e. Attendance and Communication Procedures

The EAP should detail any instrumentation for monitoring the behaviour of a dam and explain how warning systems would be implemented. Access to information provided by instruments should be instantaneous to facilitate immediate action by operators. It is recommended that a qualified/experienced observer be at the dam when flood conditions, or signs of serious structural distress, have been identified.

The detailing of access in the EAP should focus on primary and secondary routes and means for reaching the site under various conditions (e.g. helicopter, foot, or boat). It should also detail the expected flood arrival time.

The detailing of communication of necessary information to relevant parties should focus on primary and secondary means under various conditions. The availability and use of alternative communications systems should be detailed.

f. Inundation Maps

Whenever communities or significant numbers of dwellings are located in the flood plain downstream of a dam, inundation maps should be prepared to define the extent of flooding and assist emergency authorities in their planning functions downstream of the dam. These maps should show an outline of the area inundated by the dam failure flood(s) in enough detail to identify dwellings and other significant features (e.g. roads, bridges) that are likely to be directly affected. They should also give an indication of flood wave travel times, depths and velocities.

g. Preventive Actions

This section should detail preventive actions taken both prior to and following the development of emergency situations to prepare for any emergency. It should detail provisions for surveillance and detection of an emergency situation and should clearly indicate what can be implemented in a timely manner. An important factor in the effectiveness of the EAP is the prompt detection and evaluation of information obtained from instrumentation and/or physical inspection and surveillance procedures.

The time factor from the onset of an emergency to awareness of imminent damage and its effect on the workability of the EAP should be detailed. Timely implementation of the EAP is a crucial element in its effectiveness and appropriate effective warning systems are imperative for emergency authorities to minimise loss of life and property damage.

The following factors should be outlined in this section of the EAP:

- Surveillance, Monitoring and Warning Systems;
- Adverse Time Response and Flood Arrival Time
- Alternative Source of Power and Communication;
- Emergency Supplies and Resources;
- Co-ordinating Information (e.g. weather forecasts, stream flow); and
- Actions to prevent or mitigate dam failure (e.g. lower the reservoir or limit inflows and outflows).

h. Appendices

Following the main body of the plan there should be an appendix section that contains basic information about the dam, data used in the development of the EAP and instructions for the maintenance of the plan. Specific topics, which should be covered in the **Appendix F** include the following:

- Dam Location and Description
- Inundation Maps Background Information (e.g. 1% AEP Flood, Dam Crest Flood, dam break floods)
- Recording of Emergency Situations
- EAP Training and Review

Guidelines and training literature for the preparation of EAP‘s are contained in FEMA (1987) and TADS (1990).

10.5 EMERGENCY ACTION PLAN ASSESSEMENT AND MAINTENANCE

10.5.1 General

Upon completion of a first draft of the EAP, it should be reviewed to evaluate its workability and comprehensiveness, and to make sure that nothing has been overlooked. It should then be signed off by all involved agencies and controlled copies distributed.

Even after the EAP has been developed, approved and distributed, further exercise, update and revision of the plan should be carried out to ensure effectiveness and as part of the continuous improvement of the plan. Without periodic maintenance and consultation with emergency authorities, the EAP will become outdated, lose its effectiveness, and no longer be workable. If the plan is not tested, those involved in its implementation may become unfamiliar with their roles.

If the plan is not updated, the information contained in it may be rendered outdated and useless.

10.5.2 Exercise the Plan

It is essential that an EAP be tested periodically by conducting a drill simulating emergency conditions. Testing is necessary to train participants, as well as to identify weaknesses in this plan. For High and Very High Hazard Rating dams (and dams with recognised deficiencies), an annual in-house review is recommended for dam owner personnel and, at least once every five years, a drill (e.g. field or desktop) should be conducted that is co-ordinated with all State and local counter disaster officials having downstream planning responsibilities in association with the EAP.

Lesser testing frequencies could be implemented for lower Hazard Rating dams, depending on the risks involved, but a drill at least every ten years is recommended.

For a Dam Owner with a number of dams, particularly dams that are grouped in one area or are of one particular type, the requirement to exercise the EAP of every dam at the frequency suggested above may be difficult. For such Dam Owners it may be possible to trial the EAP of one dam that is typical of the group of dams, with its operations staff, and use the opportunity to train the other operations staff in the area as well.

Immediately following a test or actual emergency, an evaluation should be conducted with all involved parties. The evaluation should discuss and evaluate the events prior to, during, and following the test or actual emergency, actions taken by each participant, the time required to become aware of an emergency and implement the EAP, deficiencies in the plan, and what improvements would be practicable for future emergencies. After the evaluation has been completed, the plan should be revised, if necessary, and the revisions disseminated to all involved parties.

Some typical exercises of the EAP include:

- Seminar/ Dialogue – a discussion carried out to orientate participants to new or revised plans, policies or procedures (e.g. Seminar on Evacuation Procedures). The presenters/ participants should include NADMA and other relevant authorities with a role in EAP.

- Workshop – a discussion to build specific plan or policy (e.g. Training and Exercise Plan Workshop for developing or revising the frequency of training and exercise for a specific dam).

- Tabletop Exercise – a simulated set up scenarios to assess plans, policies and procedures by a group of key personnel.

- Competition – a simulated operation involving some teams in a competitive environment using rules, data and procedures created to represent an actual or assumed real life scenario.

- Drill – An exercise that is coordinated, supervised used to test a single operation or function within a single entity, such as testing sirens and alert systems, calling suppliers or contractors, checking available facilities or material and testing call on those listed on the Notification Flowchart.

- Functional Exercise – An exercise that tests and/ or validates the coordination, direction, and control between various inter-agency coordination centres (e.g. emergency operation centres and agencies' offices). Functional exercise does not involve any "on ground" activities for participants in response of a simulated incident in real time.

- Full-Scale Exercise – A full-scale exercise involved all entities named in EAP. The participants involved would carried out "on ground" activities in response to a simulated event in real time, such as activation of the emergency operation centre and role-playing to simulate an actual dam failure.

Recommended frequency of exercises is tabulated as per **Table 10.1** below. Dam Owner should determine actual frequencies appropriate to their dam, with consultation of the disaster management agencies.

Table 10.1: Recommended Frequency of EAP Exercise

Type of Exercise	Frequency
Seminar/ Dialogue	Annually
Workshop and Competition	After Dam Safety Review or during revision of EAP
Drill	Annually
Tabletop Exercise	Every 4 years before functional exercise
Functional Exercise	5-yearly

Full-Scale Exercise	To be considered when there is a need. It should be carried out at least after a functional exercise. Whenever possible, the emergency management resources should be shared among the participants.

10.5.3 Update of the EAP

For updates of the EAP, it is recommended that:

- emergency contact numbers in all EAPs should be updated at least annually.
- regular testing and periodic review of the overall plan should be conducted to assess its workability and efficiency (i.e., timeliness).
- plan for the improvement of weakened areas; this includes aspects such as a periodic review of the downstream area to identify changes or new developments that might affect the priority of notification and evacuation and the information shown on inundation maps.
- the updated (revised) version (or simply the affected pages) should be distributed to all involved parties; for High and Very High Hazard Rating dams, it is recommended that the entire EAP be reprinted and distributed to all parties at least every five years and ten yearly for other dams.

11 CHANGES AND DECOMMISSIONING

11.1 INTRODUCTION

This section provides guidelines for public safety surrounding dams, lifetime changes, sedimentation management, change of dam use, decommissioning of dams and issues associated with life cycle management.

Dams usually last several generations. It is almost unlikely that the environment, its use and societal priorities will remain unchanged over the life of a dam. Different operational requirements, technology advances and changes in performance expectations may necessitate the modifications or upgrade works to a dam and its appurtenant structures.

Many aspects of life cycle management need interaction with the public and interested parties. Changes in management of dam safety, modified operating procedures and potential decommissioning projects will involve the consideration risks and the stakeholders will be interested to know the manner in which risks are considered and the ensuing decision.

Dam Owners should be aware that there are many changes that can occur over a dam’s lifespan that may require dam safety management, the issues that may arise and the processes involve in resolving them.

The management of public safety surrounding dams including:

- Lifetime changes that may necessitate dam safety management.
- The 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.

In addition, if the costs of rehabilitation works are high or if a dam reaches the end of its economic life, Dam Owners and Regulators will need to consider whether the dam should be decommissioned and removed, or modified for an alternative use or mode of operation.

11.2 PUBLIC SAFETY SURROUNDING DAMS

The existence of a water body attracts the public. In addition, the demand for public access is increasing over time as is the range and nature of water-based recreational activities.

Public safety hazards that are typically encountered at, and in the vicinity of, a dam and reservoir include:

- Hazards associated with reservoir operation – changing water levels, submerged intakes, submerged structures which may be located just beneath the reservoir surface, and floating debris.
- Hazards associated with discharges from spillway and sluice facilities, or climbing on or traversing these facilities – physical drops, high water velocities and turbulence, unsecured deck gratings over sluice gate openings, and automatic or remote operation of spillway and sluice facilities.
- Hazards associated with approaching the spillway or intake facilities from the reservoir.
- Hazards associated with intake and conveyance facilities – physical drops, high water velocities, steep and slippery canal side slopes, and high undercurrents associated with inlets to conduits, tunnels, drop inlet structures and inverted siphons.
- Hazards associated with other discharge sources including power stations and surge relief facilities, sudden increases in flow, high water velocities, turbulence and vortices, and slippery shoreline surfaces at low tailwater levels.

The protection of the public and operating personnel from hazards associated with the presence of a dam, is an important component of dam safety management. Some controls considered necessary for the mitigation of public safety hazards may place constraints on dam operation which, in turn, may influence dam safety. For example, a constraint on the rate of spillway gate opening to reduce the risk to downstream river users could reduce the Dam Owner’s ability to safely manage a large flood event.

Dam Owners are obligated under the prevailing laws and legislations to ensure that dam workplaces are safe for operational employees and persons who enter the site.

The following subsections outline a recommended approach for the management of public safety at dams. The approach includes:

- Identifying and assessing potential hazards.
- Controlling the hazards by changing operational procedures, installing physical controls, or installing warning signs and devices.
- Managing the hazards through a documented public safety plan, inspection and maintenance activities, and continual review and improvement processes.

The material in MyDAMS reflects recommended practices included in the Canadian Dam Association publication “Dam Safety Guidelines” (2007) and their associated “Guidelines for Public Safety around Dams” (2011). Further references should be made to the above guidelines published by CDA.

11.3 LIFETIME CHANGES

There are many changes that can occur over a dam’s lifespan that may influence dam safety management. These may include changes and modifications initiated by the Dam Owner, and external influences to which the Dam Owner has no control over but needs to be aware of.

Some potential lifetime changes that may influence dam safety management are:

- Upstream catchment changes – land use changes upstream can result in changes in flood risk, sediment and debris inflows and changes in water quality. All these can influence the ability of the dam to meet safety requirements. Additional dams built upstream may also represent a change in risk for the existing dam.
- Reservoir changes – sedimentation, land use changes along reservoir boundaries, recreation accommodation, and the potential instability of reservoir slopes due to erosion or drawdown operations all require dam safety management
- Dam use and operation changes overtime in response to changes in use or demand. This could mean an existing use is discontinued and replaced by a new function. Progressive deterioration – despite regular prescribed maintenance, some dam components will deteriorate. This will lead to the need for periodic replacement, upgrades or rehabilitation to maintain an acceptable level of dam safety.
- Sudden deterioration – this may occur following a major event, during which the dam performed as intended but not without incurring damage that required repair (e.g. spillway channel or stilling basin erosion) or operational modifications to maintain an acceptable level of dam safety. In an extreme case decommissioning may be necessary.
- Legislative changes – these may result in changes to acceptable dam safety thresholds. As legislation can be considered to represent the expectations of society, these changes reflect the evolving acceptance of risks by communities.
- Health and safety considerations – dam safety management typically incorporates a range of physical measurements to verify performance. Where measurements rely on personnel accessing structures, future health and safety requirements may limit

access and necessitate the introduction of alternative measurements or systems to verify dam performance.

- Downstream changes – the population and/or value of the environment and infrastructure, located within the potential dam-break flood inundation area, will almost certainly change with time. While this is likely to be a progressive evolution it will probably manifest itself in a series of step changes in dam safety requirements appropriate to the Hazard Rating of the dam.
- Technological advances and standards of practice – technological improvements and an improved understanding of dam performance may result in a corresponding shift in dam safety requirements.
- Public safety considerations – dam operation during normal, unusual and extreme loading conditions can result in risks to public safety. Future changes in the level of risk considered to be acceptable by the public could necessitate operational changes that have a consequential effect on dam safety.

11.4 RESERVOIR SEDIMENTATION MANAGEMENT

Sediment accumulation in reservoirs can also have dam safety implications which include the potential for:

- Overloading of concrete dams, due to the increased loading from saturated silt adjacent to the upstream face of the dam.
- Blocking of spillway or sluice gates.
- Abrasion damage in appurtenant structures.
- Depletion of live storage volumes and the consequential reduction in flood attenuation by reservoirs.
- Increased flood levels towards the upstream ends of reservoirs.

The impact of reservoir sedimentation on the safety of dam should be assessed during the life of a dam to ensure that the effects of sediment accumulation remain within the design assumptions. Such assessments should be incorporated within dam safety management systems but, where there is the potential for significant effects on dam safety, Dam Owners should consider the development of a separate sediment management plan.

Typically, where required for dam safety, sediment management plans should include:

- Monitoring requirements to establish the characteristics of sediment accumulation in the reservoir (e.g. locations, deposition rates).

- Regular assessments of the potential effects of sediment accumulation on dam safety.
- Mitigation measures to ensure sediment accumulation does not adversely affect dam safety.
- Appropriate timelines for obtaining any necessary variations to operational consents and implementing the mitigation measures.

ICOLD Bulletin 115 provides guidelines and a number of case studies for sediment management.

11.5 CHANGES IN DAM FUNCTION

A change in use is where the function of a dam is different from its original function. For example, a dam constructed primarily for hydropower generation or primarily for water supply could, if it was no longer required for its original function, be modified for use as a recreational asset. Such a change in use would likely result in a change in reservoir operation.

Many dams offer a level of flood control, and infrastructure and communities may have developed downstream of a dam partially in response to the level of flood protection provided by the dam. In such a case, maintaining and changing the use of the dam would be unlikely to change the level of flood protection provided by the dam. The alternative of decommissioning and removing the dam could result in an inadequate level of flood protection for the infrastructure and communities downstream of the dam.

The specific requirements relating to change of use for dams, any demolition activities or modifications to an existing dam necessary for a change in use would require an authority approval.

A change in use may also necessitate the identification of an alternative Dam Owner with an interest in maintaining the dam for the alternative use. In assessing whether a change in use is a viable option, Dam Owners will need to consider:

- Who will be legally liable for the ongoing safety of the dam.
- Future ownership options.
- Whether an alternative Dam Owner can be identified with an interest in maintaining the dam for an alternative use.
- Who will be responsible for the ongoing surveillance, O&M of the dam.

From a dam safety perspective, it is important that any change in use incorporates an appropriate dam safety management system.

11.6 DAM DECOMMISSIONING, DISCONTINUED, ABANDONMENT AND SITE REHABILITATION

11.6.1 Decommissioning

A dam is decommissioned when:

- it is taken out of service
- actions are taken to the extent that only an appropriate negligible residual hazard is permanently or temporarily remains
- a detailed examination of the site conditions and downstream situation should be performed to ensure appropriate decommissioning works. These include any of the following:
    - Diversion of inflow away from the dam's storage or pass the dam
    - Lowering of the spillway crest or removal of the spillway control gates or structures
    - Permanent enlargement or opening of the outlet works
    - Effective removal of all or part of the dam inlet and outlet
    - Removal or confinement of impounded detrimental material
    - Treatment of stored liquid or sediments prior to release in a safe condition

Decommissioning may require of environmental impact assessment and dealing with uncovered issues (e.g. acidic earth, control of erosion and sedimentation). Under urgent situation, decommissioning may have to be carried out with reduced consideration of possible environmental impacts.

11.6.2 Discontinued

A dam may be considered discontinued when:

- there is no usage for it or its stored contents
- it is not practical to remove the dam

But it is still:

- impounds water or other contents at normal or flood periods
- poses a downstream hazard

- must be maintained in a safe condition at all times

Dam Owner is still responsible to continue normal dam safety management practices at the dam. This option provides possible restoration of the dam, whenever Dam Owner requires.

11.6.3 Abandonment

Abandonment of dam should be considered when:

- Adequate dam structures has been removed or altered, hence making it unable to impound a storage, in present or future, and constitutes no risk to the public and environment
- It does not require any continual dam safety actions such as operation, maintenance and surveillance

A complete removal and the reinstatement of the site is the ideal option but this may not be practical for all but the small dam structures. The safe extent of any structural or hydraulic modification required at a dam for abandonment should be determined by a qualified and experienced dam engineer.

11.6.4 Site Rehabilitation

Dam and storage areas generally required to be rehabilitated for decommissioning of dams and its reservoirs. Dam Owner is responsible to ensure that the stored solids or liquids for discharge to the environment in present and future are legal and acceptable. In a nutshell, effective rehabilitation should ensure that no structures, landforms, or contaminated materials, should be left on site or result in discharges to the environments, causes:

- Danger to life, property or the environment.
- Instability, with respect to erosion or dimensional features.
- Damaging surface runoff, seepages, or groundwater.

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APPENDICES

APPENDIX A: LEGAL REQUIREMENT

A.1 OVERVIEW OF STATE LEGISLATION

A.1.1 Peninsular Malaysia

The legislative scenario within States in Peninsular Malaysia is highly complex and fluid with continuous changes occurring in the field of management of water resources. The Waters Act 1920 was the original legislation in place in most states in Peninsular Malaysia. Selangor pioneered the implementation of an integrated water resources management model by enacting the LUAS Enactment in 1990. Malacca established a regulatory framework for its rivers and coast in 2005 followed by Kedah in 2007. Over the last few years several states have amended and taken measures to implement the Waters Act 1920 (such as Pahang, Johor, Negeri Sembilan and Perak). The Waters Act does establish the right to control and licence any disruption or diversion of any water from rivers. LUAS has proclaimed safety and buffer zones and taken steps to control activities on the reservoirs of dams. Selangor has continued to pioneer action into integrated management of its water resources. It is however apparent that each State has adopted its own approach to the management of water resources. In relation to dam safety, states have adopted various measures to manage safety of dams in accordance with their capacity. BaKaJ – Badan Kawal Selia Air Johor exerts control over certain aspects of dams by using relevant provisions under the National Land Code and the State Waters Enactment. In the States of Johor, Pahang and Terengganu, buildings within dam sites (other than the dam itself) must comply with the requirements of the Street, Drainage and Building Act by local authorities. All states impose the requirements of spatial planning under the Town and Country Planning Act when new dams are built. Dam Owners would also have to comply with various provisions related to the National Land Code and Local Government Act (as almost all parts of the Peninsular are under the jurisdiction of a local authority). Increasingly it is also likely that all States will adopt laws related to the management of water resources. However no State has actually issued licenses to dam operators stipulating conditions in such licenses. No State has made specific rules or adopted any guidelines for the safety of dams. Dam Owners should keep abreast of the continuing development of laws at the State level. A listing of State Legislation relevant to Dam Owners is enclosed as **Annex A1**.

A.1.2 Sabah

Sabah has enacted its own legislation (independent of federal legislation) especially on matters of forestry, natural resources, water, electricity, town and country planning and environment. With the exception of the Sabah Water Resources Enactment (SWRE) and the Environment Protection Enactment, none of the other laws in Sabah refer to dams. The SWRE does contain provisions to regulate matters related to actual construction, maintenance and operation of dams in a safe manner. All water activities shall be authorised by a licence in accordance with the provisions of this Enactment. Applications shall be made for the Director's approval. The Director shall take into consideration the State, regional and local significance of water resources as well as the interest to the public authority. Licences granted may be imposed with conditions as well as altered, suspended or cancelled. However Sabah has not taken any steps to formulate rules, guidelines or standards pertaining to dams. The Environment Protection Enactment in Sabah mentions dam from the perspective of protecting the environment as a whole. Prior to the construction of any dam, the dam owner will have to comply with the requirements of the Environment Protection Enactment. The Owner will have to carry out an EIA in accordance with the provisions of the latter Enactment and obtain approval for various measures to mitigate any adverse environmental impacts. The Enactment applies to the construction of dams, artificial lakes or reservoirs with a surface area of 50 hectares or more for impounding of water. The Town and Country Planning Ordinance applies throughout Sabah. However the local authority for the area is deemed to be the Planning Authority. Dam owners should identify the local authority, if any, which has jurisdiction for the area where the dam is sited. The Ordinance requires the local authority to regulate and plan any development, earthworks or buildings within their area of jurisdiction. The definition of "buildings" may include dams in Sabah. No development is allowed except in accordance with the district or local plan and subject to development permission granted by the Local Authority. All the above mentioned legislation provide for various penalties, stop work orders, compounding of offences, fines and jail terms upon conviction. There is specific legislation which enables the state to regulate dams in Sabah but it appears that no rules, standards or guidelines have been implemented to date. A List of the relevant laws in Sabah is contained in **Annex A2**.

A.1.3 Sarawak

Sarawak has enacted its own legislation (independent of federal legislation) especially on matters of forestry, natural resources, water, electricity and environment. Sarawak has 3 major laws which regulate water resources in general and dams in particular. They are the Natural Resources and Environment Ordinance, Water Ordinance and the Electricity Ordinance. These laws vest the State with sufficient powers to govern and regulate dams related to electrical power and water supply. Prior to the construction of any dam, the dam owner will have to comply with the requirements of the Natural Resources and Environment

Ordinance. The Owner will have to carry out an EIA in accordance with the provisions of the latter Ordinance and obtain approval for various measures to mitigate any adverse environmental impacts. The Ordinance applies to the construction of dams, artificial lakes or reservoirs with a surface area of 50 hectares or more for impounding of water. The building of any dam on rivers is also regulated by the Water Ordinance. Sarawak has proposed the building of several large dams with the purpose of generating hydro electric power. Currently it has used the provisions in the Electricity Ordinance (licensing to generate power) to control safety aspects of hydro power dams through the imposition of appropriate conditions in the License. It appears that similar controls have not been imposed on other dams such as those pertaining to flood mitigation and water supply. Sarawak Hidro Sdn. Bhd and Sarawak Energy Berhad have adopted their own Guidelines for the safety of the dams. To date Sarawak has not adopted any Standards or Guidelines to be imposed on dam owners/operators. The Buildings Ordinance 1994 applies in all local authority areas in Sarawak. Dam owners should identify the local authority, if any, which has jurisdiction for the area where the dam is sited. The Ordinance requires the dam owners to obtain the approval of the local authority prior to undertaking any development, earthworks or buildings within their area of jurisdiction. The definition of "buildings" may include dams in Sarawak. No development is also allowed except in accordance with development permission granted by the local authority (in consultation with the planning authority). All the above mentioned legislation provide for various penalties, stop work orders, compounding of offences, fines and jail terms upon conviction. Compared to most States in Peninsular Malaysia, Sarawak appears to be in a better legislative position with regards to the imposition of regulatory controls over the safety of dams. However they have not adopted detailed rules, Guidelines or standards to be imposed on dams. The adoption of the Guidelines as part of a national approach to safety and security of dams will benefit all states. A list of all relevant laws related to dams in Sarawak is enclosed as **Annex A3**.

A.2 SUMMARY OF KEY FEDERAL LEGISLATION APPLICABLE TO DAMS

Presently there is no dedicated Federal law which specifically addresses the safety of dams. Only 7 Federal laws make reference to dams but these laws are not targeted at dam safety. The Street Drainage and Building Act requires dam owners to comply with its provisions in relation to the construction, operation and maintenance of buildings. The Environmental Quality Act refers to construction of dams and reservoirs with regard to fulfilling the EIA requirements. The Electricity Supply Act relates to licensing for the generation of electricity. The Fisheries Act imposes controls on construction of dams for the purposes of protecting sources of fish. The FMA and OSHA have provisions safeguarding the safety of workers at dam sites. The National Parks Act provides controls over the construction of dams subject to provisions to protect flora and fauna. The Water Services Industry Act stipulates controls pertaining to development of dams and reservoirs in relation to water supply. The CIDB Act defines construction industry to include construction works of dams and reservoirs. The Protected Areas and Protected Places Act enables the declaration of dam sites as “protected places” for purposes of security. The List of Federal legislation which has some relevance to dams is enclosed as **Annex A4**. These are some of the primary legislation that Dam Owners need to comply with. None of them however deal with safety of the dam structure itself.

ANNEX A1: LISTING OF STATE LAWS IN PENINSULAR MALAYSIA

JOHOR

1. Water Supply Enactment (No. 119)
2. Water Supply Rules 1986

KEDAH

1. Kedah Waters Management Board Enactment, 2007
2. Muda Agricultural Development Authority Act, 1972
3. Water Supply Enactment (1990)

KELANTAN

1. Water Supply Enactment 1995

MELAKA

1. Malacca River And Coastal Development Corporation Enactment 2005
2. Melaka Water Resources Enactment 2014

NEGERI SEMBILAN

1. Water Act 1920 (Revised - 2007) (Act 418);

PAHANG

1. Pahang Water Resources Enactment 2007

PERAK

1. Perak Water Act 1920
2. Perak Water Board Enactment 1988

PERLIS

1. Water Supply Enactment

PULAU PINANG

1. Water Supply Enactment 2004
2. Water Supply (Catchment Area) Order 2004

PUTRAJAYA

1. Control of Activities on the Lake (Putrajaya) By Laws 2004

SELANGOR

1. Selangor Waters Management Authority Enactment 1999

ANNEX A2: LIST OF STATE LAWS – SABAH

1. Environment Protection Enactment 2002
2. Forest Enactment 1968
3. Land Ordinance
4. Parks Enactment 1984
5. Town and Country Planning Ordinance
6. Water Resources Enactment 2003

ANNEX A3: LIST OF STATE LAWS – SARAWAK

1. Buildings Ordinance, 1994
2. Electricity Ordinance, 2007
3. Forests Ordinance, 2015
4. National Parks and Nature Reserves Ordinance, 1998
5. Natural Resources and Environment Ordinance, 1993
6. Sarawak Electricity Supply Corporation (Successor Company) Ordinance 2004
7. Sarawak Land Code 1958
8. Sarawak Rivers Ordinance, 1993
9. Water Ordinance, 1994

ANNEX A4: LIST OF FEDERAL LAWS

1. Construction Industry Development Board Act 1994
2. Environmental Quality Act 1974
3. Electricity Supply Act 1990
4. Factories and Machinery Act 1967
5. Fisheries Act 1985

6. National Land Code 1965*
7. National Parks Act 1980
8. Occupational Safety and Health Act 1994
9. Protected Areas and Protected Places Act 1959
10. Street, Drainage and Building Act 1974*
11. Suruhanjaya Perkhidmatan Air Negara Act 2006
12. Town And Country Planning Act, 1976*
13. Waters Act 1920*
14. Water Services Industry Act 2006

* Legislation which are adopted and implemented by State Government.

APPENDIX B: ASSESSMENT, CONSEQUENCES AND DAM HAZARD RATING

B.1 INTRODUCTION

This Appendix sets forth an assessment, consequences and hazard rating system for dams. The intent is to provide straightforward definitions that can be applied uniformly by all federal and state dam safety agencies and can be readily understood by the public.

B.2 DAM SAFETY ANALYSIS AND ASSESSMENT

B.2.1 Hazards

B.2.1.1External Hazards

External hazards are beyond the control of the dam owner, and originate outside the boundary of the dam and reservoir system. External hazards include the following conditions:

- Meteorological events — These include floods, intense rain events (causing local erosion, landslides, etc.), temperature extremes, lightning strikes and wind storms.
- Seismic events — These may be natural or caused by economic activity such as mining or even reservoir-induced seismicity.
- Reservoir environment, including all reservoir rim features such as upstream dams, slopes around the reservoir, etc., that pose a threat - The reservoir environment also includes any deleterious substances, or burrowing or other animals that can affect the physical performance of the dam.
- Human sabotages and vandalism

B.2.1.2Internal Hazards

Internal hazards are errors and omissions in the design, operation and maintenance of the dam and water conveyance structures, including the following hazards:

- Inadequate consideration (i.e. in the design, operation and maintenance) of the performance of the reservoir rim and upstream dams
- Inadequate consideration of the impacts of seepage on downstream habitats

- Construction errors or design compromises to accommodate natural or imposed deviations from the design assumptions
- Errors where maintenance requirements are not fully defined at the design stage
- Errors and omissions in development and maintenance of operating rules or means of verifying adequate operation (e.g. water level recorders) and closure conditions

Internal hazards can be further subdivided into the following sources:

- **Water (or tailings) barrier —** This includes all elements retaining or interfacing with the body of water (or tailings), including the main dam, any concrete spillway structure with water/tailings retaining function, saddle dams, etc. Spillway gates that function as water retaining subsystems form part of the water barrier.
- **Hydraulic structures —** This includes all water conveyance structures required to direct water around or through the dam in a controlled way. Typically, spillway structure, low level outlet structure, and power water passages (canals and penstocks, etc.)
- **Mechanical and electrical sub-systems —** This includes all mechanical and electrical equipment and machinery required to control the reservoir level. This will encompass all mechanical and electrical subsystems and controls at the dam site and, in the case of remotely controlled dams, the remote control centre. The definition of the system boundary will include the boundary around the control systems.
- **Infrastructure and plans**

  The infrastructure includes all instruments and their physical supports, as well as access roads, audits, portals, etc., required for siting and reading the instruments required to verify the performance adequacy of the dam. The plans describe all of the non-physical dam safety activities necessary to support dam safety including the engineering design of all operating orders, maintenance strategies and plans, surveillance procedures, and the emergency plans, all of which form part of the engineering design. Plans also include forecasts such as inflow forecasting. Any failure of the infrastructure or a plan may impact on the dam safety.

B.2.2 Failure Modes

A 'failure mode' describes how element or component failures must occur to cause loss of the system function. At a general level, there are three dam failure modes: dam overtopping, dam collapse, and contaminated seepage. At a lower level, failure effects become failure modes at the next higher level in the system. The system should be broken down into sub-systems to a level where there is a thorough understanding of the failure modes of the elementary sub-systems.

- The overtopping failure mode is a situation where inadequate freeboard leads to the flow of water over the crest of the dam in a manner not intended or provided for in the design, construction, maintenance and operation of the dam.
- The collapse failure mode pertains to inadequate internal resistance to the hydraulic and other forces applied to the dam, foundations and abutments, even though the hydraulic operation is in accordance with the design intent.
- The contaminated seepage failure mode exists, primarily in mine tailings dams, which exclude the downstream regulatory limits as a result of dam or impoundment seepage.

B.3 RISK ASSESSMENT

B.3.1 Introduction

The ultimate goal of dam safety management is to ensure that all dams present an acceptable level of risk to the population. However, since this ultimate goal is not always achievable, the alternative goal may be to reduce the risk to a tolerable level, provided that it passes the test of reasonable practicability. By definition, *risk* incorporates both the consequences of an adverse event and the probability of such an event occurring.

This part of B.3 of the Appendix is meant to outline an emerging alternative of framework that allows dam safety decisions to be made on the basis of probabilistic risk criteria. It provides background for dam safety decision-making in terms of uncertainty, outlines practices that may be used to understand and evaluate the consequences that could potentially result from failure of a dam, and explores the concepts behind risk-based approaches.

MyDAMS, currently used the most widely applied approach to dam safety decision-making which has been essentially based on deterministic principles, rules and requirements that have been defined with the aim of ensuring a relatively high but unspecified level of safety. The rules and requirements are adjusted to provide proportionately higher safety levels when hazards or consequences are greater. The process of selecting and assigning specific values to safety requirements has relied on "engineering judgement", which does not explicitly and transparently take societal preferences into account.

There are many uncertainties (both in terms of occurrence and magnitude) related to internal and external dam safety hazards. A considerable level of conservatism is built into the deterministic framework to provide assurance that safety margins are adequate.

An alternative approach, risk assessment, is emerging as a method to improve the way dam safety decisions are made, particularly as those decisions become more complex and as society demands increased transparency and accountability (ICOLD 2005). Determination of failure probability is a complex task that is not readily accomplished with the current state of knowledge. The use of quantified risk methodologies is preferable for appropriate situations where the scientific techniques are available.

B.3.2 Equity and Efficiency

How safe is safe enough? Do applications using concepts of Probable Maximum Flood or Maximum Credible Earthquake as performance goals for high consequence dams provide sufficient level of safety? If so, is this level of safety appropriate or is it unjustifiably and unnecessarily high in some cases?

No human activity is completely free from risk of causing adverse effects, and measures reducing these risks beyond a certain threshold may be not practically achievable. While all stakeholders who could be adversely affected by a dam failure have rights to safety, there is a need to maintain a balance between the conflicting social objectives.

Dam safety framework should ensure that no individuals or communities should be unduly affected in the interest of the broader societal interests. On the other hand, society does not have infinite resources to spend on managing risks and often the resource spent inefficiently in one area is the same resource which is missing in another area where investment could be more beneficial.

Effective application of the balanced equity-efficiency approach requires acknowledgment that both economic efficiency and social equity are legitimate goals that society wants to pursue.

B.3.3 Individual and Societal Risk

The decision-making processes on dam safety matters affect the society. There is an increasing need to establish criteria on which the decisions can be made and justified. One effective way to address individual and societal concerns about the hazards posed by dams is by characterization in terms of risk and derivation of tolerability criteria.

'Individual risk' relates to concerns of how individuals see the risk from a particular hazard affecting them and their property. It is usually defined as the risk to a hypothetical member of the public living in the zone that can be affected in the event that a hazard occurs. The criteria for individual risk depend on such factors as: whether or not the exposure is voluntary, whether the individual derives benefit from accepting the risk, whether the individual has some control over the risk, and whether the risk engenders particular dread.

'Societal risk' is much more elusive than individual risk, for definition and estimation. In general, societal risk refers to hazards that, if realized, could impact society and thus cause socio-political response. Some see societal risk as simply a relationship between the frequency of a particular hazard and number of casualties if the hazard is realized. Societal risks in hazardous industries are discussed in one of the most exhaustive report by Ball and Floyd, 1998. In applications dealing with hazards from engineered installations where the predominant issue is life safety, societal risk is characterized by graphs showing frequency of events that could cause multiple fatalities.

B.3.4 Tolerability of Risk

Dam regulators in various countries and industries have spent considerable effort in determining the tolerability of risk to individuals and society (Ale 2005, HSE 2001, NSW Dam Safety Committee 2006, Rimington 2003). The approach in determining the tolerability of risk is fundamentally a matter of political choices, preferences and policies. Risk and uncertainty, are essential factors that have to be considered in the dam safety decision-making process. They should be explicitly included and expressed. When accepted, the concept provides guidance on how to establish criteria for separation of acceptable, tolerable and unacceptable risks. To the extent that data and technology are available, the criteria can be subsequently used to support transparent and informed decision-making processes that are logical and consistent.

The general idea of levels of risk that may be acceptable to the public, dam owners and regulators has always been present in dam safety considerations. More recently efforts have been made to define the criteria that separate different categories of risk. The following risk categories are recognized (HSE 2001, Rimington et al. 2003):

- **Broadly acceptable risk –** An annual risk of casualty that is lower than 10^{-6} from any particular source is generally taken as a negligible level of risk.
- **Unacceptable risk –** An annual risk of casualty to members of the public from a hazardous facility in excess of 10^{-4} has been explicitly deemed to be intolerable under normal circumstances. This does not preclude individuals from regular participation in sporting or recreational activities involving much higher levels of risk, often in the range of 10^{-3} to 10^{-2}.
- **Tolerable risk** – An annual risk of casualty (fatality) between the values of 10^{-6} and 10^{-4}, provided the risk is as low as reasonably practicable at the time.

More detailed discussion of how tolerability criteria have developed in the past in different countries and in different hazardous industries can be found in Hartford *et al.* (2004).

B.3.4.1Tolerable Individual Risk

Many countries in the world maintain databases on causes of death to their citizens. The data can be analysed and compiled in the form of a statement of what a particular community seems to have historically accepted as a reasonable risk (that is, what the society is willing to live with). For example, in Australia (Planning NSW, 2002), criteria have been outlined for assessment of acceptability of risks associated with potentially hazardous developments. Criteria for individual fatality risks for new installations range from 0.5×10^{-6} for hospitals, schools, childcare facilities and old age housing, to 0.5×10^{-4} for workers at industrial facilities. The criterion for persons occupying residential premises is 10^{-6} per annum.

B.3.4.2Tolerable Societal Risk

Societal risk criteria with respect to life safety are most commonly expressed as either single or multiple anchor points (with fatalities and frequencies as coordinates) or as lines on an FN diagram. These graphs illustrate the risk where there is a potential for multiple fatalities, by relating a cumulative plot of frequencies or probabilities (F) and the consequences (number of casualties, N) on a log/log plot. Very frequently the FN lines are defined by a single anchor point and the slope of the line. Most of the known FN criteria are drawn with slopes of between -1 and 2 on log/log diagrams. Slope -1 is commonly regarded as 'risk neutral' and slope -2 as 'risk averse' to multiple fatalities or large scale accidents. It appears that, at least in some jurisdictions, the societal aversion to risk increases with the magnitude and severity of losses. For instance, the Netherlands which uses slope -2 is an example of a society with progressively increased aversion to societal risk (Ball and Floyd 1998). On the other hand, Hong Kong which uses slope -1 is risk-aversion neutral (Hong Kong 2003).

B.3.4.3 ALARP Principle

An action reducing risk is clearly necessary if the risk is unacceptable. A less firm but unequivocal statement can be made about broadly tolerable risk. The Health and Safety Executive in the United Kingdom (HSE 2001) understands tolerable risk as *"a risk within a range that society can live with so as to secure certain net benefits. It is a range of risk that we do not regard as negligible or as something we may ignore, but rather as something* we *need to keep under review and reduce it still further if and as we can."* Further refinement of this statement is known as the *ALARP* principle. According to this principle, risk should be *As Low As Reasonably Practicable.* This requirement originates from the duty to reduce risks to life to the point where further risk reduction is impracticable or requires action that is grossly disproportionate in time, trouble and effort to the reduction of risk achieved.

B.3.5 Probabilistic Risk Assessment

In dam engineering applications, risk is expressed as the product of the probability and the adverse consequences of an event. It represents the probabilistic expectation (expected value) of the consequences.

Quantitative estimates of the risk (probabilities and consequences of possible adverse events) can be used as indicators of safety levels achieved and may be compared with specific safety goals also expressed in probabilistic terms. A probabilistic safety goal is usually expressed in terms of the annual probability of an adverse event and the associated consequences. A flood characterized by a peak daily inflow with a certain return period (frequency of occurrence, or probability of exceedance) is an example. Such defined safety goals can be subsequently used as a design or operational objective and interpreted as a desirable target for establishing reliable performance of safety. The selection of safety goals should be established within the context of societal and individual tolerance/acceptance of risk.

The safety management framework should make transparent all factors considered in decision-making on risks and thus help reassure the public and stakeholders that risks to people, property and environment are properly addressed. At the same time, the framework should ensure that the dam owners, in responding to economic pressures, will not be imposing intolerable risks. The framework should address all ethical, social and economic considerations of how to achieve the necessary trade-offs between benefits to society and adequate protection to individuals.

As illustrated on **Figure B.1**, the maximum level of societal risk for life safety should be less than 10^{-3} /year for loss of one life that was not explicitly foreseen and identified in advance of the failure; a higher risk is considered "unacceptable". The high societal aversion to catastrophic casualties should be reflected in setting the maximum performance goal in cases where more than 100 lives would be jeopardized. The risks should be made as low as reasonably practicable (ALARP) until they fall within a "broadly acceptable" region, which is set 100 times lower.

The maximum level of individual risk should be less than 10^{-4}/year. This is considered in terms of the 'maximally exposed individual' that is permanently resident downstream of the dam. Typically, the maximally exposed individual is exposed to the hazard significantly more than 50 % of the time.

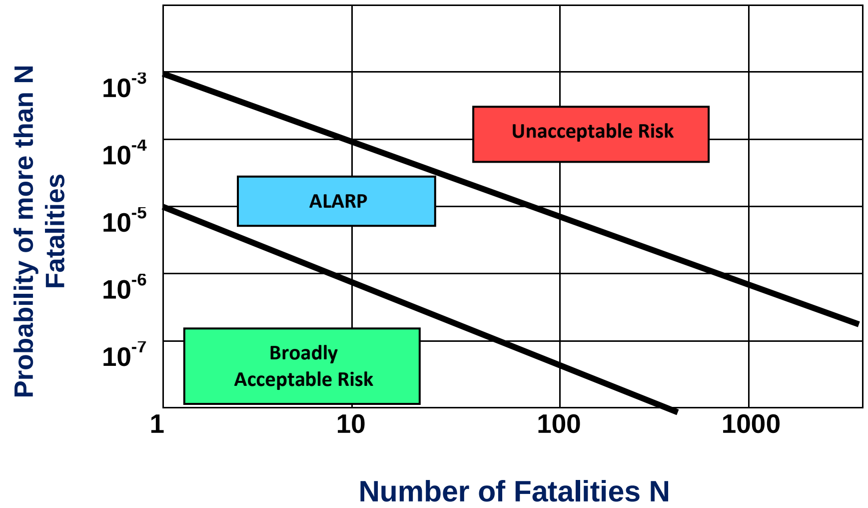

Figure B.1: Example of Societal Risk Criteria for Dam Safety in Canada

In order to calculate the risk to the individual, probabilistic methods must be available to quantify each factor in the following equation to calculate the Probability of Loss of Life (Pux.) for the maximally exposed individual.

$P_{LOL} = P_{Event} \times P_{Failure/Event} \times P_{Fatality/Failure}$

Where

P_{LOL} = Unconditional probability of fatality for maximally exposed individual from a hazardous event

P_{Event} = Unconditional probability that a hazardous event will occur of specified type and magnitude range

$P_{Failure/Event}$ = Conditional probability that the dam will actually fail, given the event

$P_{Fatality/Failure}$ = Conditional probability of loss of life, given dam failure

The risks calculated by the above formula need to be aggregated over all dam failure initiating events in order to obtain the total risk to the individual.

The conditional probabilities $P_{Failure/Event}$ that dams will fail, given an event, vary widely depending on the failure modes and the nature of the loadings. The actual value for a particular dam and event is often difficult to determine precisely. Hence, in some cases where no additional information is available, valid dam safety decisions can often be made on basis or relatively simple analyses by making the very conservative assumptions that $P_{Failure/Event}$ = 1 and $P_{Fatality/Failure}$ = 2. For example, these conservative and necessary assumptions are applicable to flood events resulting in major overtopping of unprotected earth embankments.

Risk-based analytical methods to support sound decisions and set performance goals with *appropriate* conservatism are discussed in ICOLD (2005).

B.4 DAM BREACH AND CONSEQUENCE ASSESSMENTS

Consequences of dam failure may include loss of life, injury, and general disruption of the lives of the population in the inundated area.

The analyses leading to consequence assessment and classification of the dam typically include the following steps: characterization of hypothetical dam breach, flood wave routing, inundation mapping, and evaluation of the impacts. A wide range of methods may be applied in each of these steps depending on the extent of information needed. The level of effort and resulting level of accuracy should be commensurate with the importance of the resulting dam safety decisions.

B.4.1 Dam Break Analysis

The dam break analysis involves determining the ultimate discharge from a hypothetical breach of the dam. The outcome of the dam break analysis is a flood peak or flood wave immediately downstream from the dam. This analysis to determine the discharge hydrograph requires evaluation of initial conditions and the breach geometry and timing.

B.4.1.1Initial Conditions

Initial conditions define the hydrologic state of the study area at the start of the breach including the reservoir levels and downstream flow conditions coincident with the flood scenario. In general, the following two hydrologic conditions may be evaluated:

- "Sunny-day" failures - These are sudden dam failures that result during normal operations and may be caused by an earthquake, mis-operation of the dam, or other event.
- "Flood-induced" failures - These are failures of the dam occurring coincident with a flood of magnitude greater than the dam can safely pass.

Reservoir levels and downstream tributary flow conditions in the assessment should be those most probable to occur coincident with the breach event. For example, the analysis of sunny-day failures coincident with maximum normal reservoir levels and combined with mean annual flow conditions in the downstream channels is reasonable. For flood-induced failures, reservoir levels used to estimate breach discharge should be appropriate for the failure mode threshold. Sensitivity analyses should be carried out to identify more critical situations for specific cases.

B.4.1.2Breach Location and Parameters

The magnitude of the peak discharge depends on the breach location within the dam structure, as well as breach parameters. These are determined through consideration of likely initiating events and failure modes. The number and level of detail of the events and modes considered will depend on the level of detail and resulting accuracy required in the consequence assessment. In general, for earthfill dams, both overtopping and internal erosion or piping failure are included. The main dam and saddle dams should be considered individually.

Breach parameters include shape, width, depth, and rate of breach formation. In general, breach parameters governing the ultimate size of the breach are critical for dams retaining large reservoirs and having populations at risk far downstream. The assumed rate of breach formation is of greater importance when considering small reservoirs (where the drawdown rate may be very rapid) and populations close to the dam.

The approach to estimating breach shape and timing varies depending on the type of dam.

- Concrete-gravity dams tend to have partial breach, as one or more monolith sections formed during dam construction are forced apart.

- Embankment dams in general do not tend to have complete or sudden failure. Once a breach is initiated, the discharging water will erode a portion of the dam until the reservoir is depleted or the breach further resists erosion.

Estimation of embankment dam breach parameters is one of the most uncertain yet most important components of consequence analysis and emergency preparedness planning. Breach parameters for earthfill dams therefore may require geotechnical engineering evaluation. The potential for foundation erosion to bedrock should be considered. It is recommended that sensitivity studies be conducted to determine the effects of different breach sizes and rates of failure on the resulting flood inundation. Reference information concerning dam break analysis could be referred to Chapter 2 of FERC (1993).

B.4.1.3Discharge Hydrograph

The discharge hydrograph provides the rate at which volume is released from the breached dam. While some preliminary assessments will only require estimation of peak breach outflow, most dam breach analyses require development of an outflow hydrograph, which describes the flow as it changes with time as the breach forms and reservoir drains.

Methods for developing a discharge hydrograph include the following:

- Simple triangular approximations
- Mathematical relations such as modified weir equations or energy equations
- Unsteady computer hydrodynamic flow modelling

General considerations in developing the discharge hydrograph should include the following:

- Effects of dynamic reservoir routing (size and shape of reservoir, and impacts on discharge)
- Potential tailwater influence
- Selection of a time step appropriate to the breach formation time

B.4.2 Flood Wave Routing

The flood wave routing component of the study is conducted to transfer the dam breach wave from the dam to a location downstream where the effects would be negligible. If other dams or water retaining structures are located downstream, the study must consider whether or not the flood wave would also cause downstream structures to breach. The consequence assessment for the upstream dams must include damages caused by downstream failures.

The simplest and most conservative procedures may be applied as a first approximation, and more detailed analyses conducted if necessary. For applications where the population at risk is far downstream from the dam, the methods and assumptions used for flood routing can be of critical importance. Flood wave routing methods range from simple translation of peak flow to application of hydrodynamic models. The analysis method selected should be commensurate with the required level of accuracy and the complexity of the downstream channel and infrastructure. In most dam breach situations, the flow being analyzed is several orders of magnitude greater than any recorded natural flood event. Due to the spatial variability of the flood plain and limited data available on its physical characteristics, the modeller must rely on experience and sound judgement in selecting channel and valley hydraulic characteristics. It is therefore important to carry out sensitivity analyses to get a better perspective on the potential variations of travel time and maximum stage that could occur as a result of the uncertainty in the hydraulic routing parameters selected.

Site visits in all cases help to assess the pertinence and accuracy of base mapping for the hydraulic assessments as well as consequence estimation.

B.4.3 Inundation Mapping

For assessment of inundation consequences, maps are required for delineating the area flooded in the event of dam breath. For emergency planning or risk management decision-making, the maps also should show representation of flood peak arrival time, depth of flow, in some cases velocity of flow, and significant emergency infrastructure such as roads and hospitals.

Inundation maps should be developed for "sunny-day" and "flood-induced" failure scenarios, as well as any combination of failure modes (or large outflows due from the dam) that may be considered useful for emergency planning.

The required resolution and accuracy of the inundation maps is commensurate with the sensitivity of the resulting consequence classification or emergency planning decisions. For most applications publicly available topographic mapping will suffice. However it must be kept in mind that inappropriate mapping may result in significant errors in estimates of flooded areas.

B.5 CONSEQUENCES OF DAM FAILURES

B.5.1 Loss of Life

The consequences of dam failure should be evaluated in terms of life safety. The PAR in the inundated area provides an indication of the number of people exposed to the hazard. It accounts for demographic and land-use factors for the inundated area. Some classifications rely on estimates of PAR, defined as the number of people who would be exposed to floodwaters and would experience consequences that could range from inconvenience and economic losses to loss of life.

Consistent estimates of expected loss of life are very difficult to develop. Some approaches to life safety quantification propose the population at risk' in the inundated area as a more easily verifiable indicator of people exposed to the hazard. However, this approach accounts only for demographic and land-use factors of the inundated area and disregards dynamic (hydraulic) characteristics of the dam failure event.

The potential for loss of life depends on many highly uncertain and variable factors, such as depth of flow, velocity, time of day, advance warning, topography, distance from the dam, transportation routes, historical patterns of human activity, and mobility of the population.

No simple, reliable, or universally applicable methodology is available. Different methods can produce very different estimates of loss of life. Estimates should take into consideration specific scenarios that account for a wide range of parameters. The assumptions, reasoning, and calculations should be clearly documented.

B.5.2 Economic Losses

Economic and social losses include damage to third-party property, facilities, other utilities, and infrastructure. Traditionally the damage to the dam owner's property is excluded from consideration as it seems appropriate to leave to the owner's decision how to deal with those losses. However, in many cases the owner's losses have significant impacts on society. Where appropriate, costs or values are assigned to social and cultural impacts, and included as economic consequences. Although exact determination of direct and indirect loss may be a very complex and difficult task, the monetary value can be established at least in principle.

B.5.3 Environmental Losses

To some extent, environmental losses can be assigned a monetary value, but they should be evaluated separately. There may be cases, for example, where a dam retains a large reservoir and there is no permanent PAR, but the environmental consequences could be very serious. The significance of environmental losses should be assessed in terms of whether restoration of the environment is feasible and how long it would take.

The losses should be evaluated in terms of both magnitude and duration of impact. In assessing the lasting impact, short- medium- and long-term consequences should be evaluated. With regard to the magnitude of impact, the loss or significance of deterioration, importance and criticality of impacted habitat, and the feasibility and practicality of restoration or compensation should all be taken into account. Since the nature of environmental losses is usually multi-faceted, it is impractical or impossible to arrive at a single numerical value characterizing the extent of the damage. For these reasons, a qualitative assessment may be more appropriate.

B.5.4 Cultural Losses

Social impacts such as damage to irreplaceable historic and cultural features, which cannot be evaluated in economic terms, should be considered on a site-specific basis. Separate assessments should be made of potential damages to sites of cultural and historic value, and the feasibility and practicality of restoration or compensation considered.

B.5.5 Cascade Projects

In the case of cascade projects, the safety of a particular dam is affected by any dams located upstream, so dam safety must be analyzed globally. The evaluation of failure consequences of a dam in a cascade must include the failure consequences of dams located downstream if such failure would be caused by the dam under study and if that failure would not otherwise have occurred in the scenario under study. The consequences also include the cost of rebuilding the downstream failed dams and the loss of production at those dams.

For dams in a cascade, the Inflow Design Flood (IDF) for a particular dam may be lower than the IDF of an upstream dam. In this case, if a flood with a frequency between the two IDFs occurs, flood releases at the upstream dam may cause the failure of the downstream dam. When the inflow flood exceeds the capacity of the flood control structures at the upstream dam, the failure consequences of the downstream dam are the responsibility of the downstream dam owner if the downstream dam is built later or same time as the upstream dam.

B.5.6 Incremental and Total Consequences

MyDAMS is based on the traditional assumption that due diligence and the standard of care expected of a dam owner relate to the potential damage above and beyond that caused by a natural event when the dam does not fail. The incremental consequences of failure are defined as the total damage from an event with dam failure minus the damage that would have resulted from the same event had the dam not failed.

Comparison of different scenarios sometimes demonstrates that there is a point when increasing the IDF level ceases to provide significant added safety. It may be acceptable practice, then, to base the IDF on the incremental consequences of dam failure. On the other hand, when a natural flood is routed safely through or over a dam, gradual inundation may leave time for people to move to higher ground. This should be taken into account when incremental consequences are being assessed.

For failure due to causes other than flood (sunny day failure), the incremental consequences may be the same as the total consequences. For example, if the dam failed after an earthquake, the incremental consequences (which are equal to total consequences) could be high. In this case, the dam should be designed to resist the earthquake loadings, but it would not be required to resist a flood with a similar return frequency. For this reason the consequences of a dam failure should be analyzed for a random (i.e. sunny day) failure as well as for a flood scenario in order to define design requirements for each. A dam could have low consequences from a flood failure even though there would be high consequences under a sunny day failure; in this case the consequences of flood failure would be used to establish the appropriate design flood. The higher of the two consequence scenarios will generally dictate the overall level of care in management oversight, inspection, maintenance and safety assessment.

B.6 CLASSIFICATION OF HAZARD RATING

Hazard Rating based on consequences or risk of dam failure are often used to provide guidance on the standard of care expected of dam owners and designers. **Table B.1** presents a classification that can be used for management, prioritization, and decision-making. Four classification ratings are adopted as follows: **LOW**, **SIGNIFICANT**, **HIGH** and **VERY HIGH**, listed in order of increasing adverse incremental consequences. The classification levels build on each other, i.e., the higher order classification levels add to the list of consequences for the lower classification levels, as noted in the table on the following page.

In some cases, an assessment of the PAR alone provides enough information to classify the dam and determine required safety levels and procedures. Once it is determined that there is any permanent PAR, refinement of the classification should be based on potential loss of life, in order to appropriately distinguish between dam where the risk is much higher than others. Some other classifications do this implicitly by considering population density, nature of human activity, characteristics of the affected area, and extent of damaged infrastructure, as well as the simple numerical count of PAR.

In Malaysia, there are great differences in topography and type of development. On flat terrain, a dam failure could inundate a huge area and large PAR, but the inundation would be shallow and slow-moving, so potential loss of life would be minimal. However, in steep mountainous terrain, more lives could be lost even though the PAR is much less. These factors must be considered when the dam owner and regulator assign consequence classes to dams where there is a permanent population in the downstream inundation zone.

Design criteria will become more conservative as the potential for PAR that results the loss of life and/or property damage increases. However, postulating every conceivable circumstance that might remotely place a person in the inundation zone whenever a failure may occur should not be the basis for determining the conservatism in dam design criteria.

The computation of probable loss of human life shall be estimated based on dam specific attributes. This dam hazard rating system does not contemplate the improbable loss of life of the occasional recreational user of the river and downstream lands, passer-by, or non-overnight outdoor user of downstream lands. It should be understood that in any classification system, not all possibilities can be defined. High usage areas of any type should be considered appropriately. Judgment and common sense must ultimately be a part of any decision on rating. Further, emergency procedures should not be a substitute for appropriate design, construction, and maintenance of dam structures.

Expected loss of life is not easily estimated because human activities are dynamic and there are many complex variables involved. To estimate potential loss of life, either detailed or complex modelling must be carried out or major assumptions made, such as reservoir elevation, seasonal recreation use and time of day. The upper limit estimate of loss of life would be the PAR but through consideration of specific scenarios, the analyst may be able to refine the estimate. The assumptions, reasoning and calculations should be clearly documented. If the hazard rating is based on incremental loss of life in a natural flood, flood and evacuation scenarios should be studied to ensure that the rating is appropriate.

Environmental, cultural and third-party economic losses should be estimated separately and taken into account in assigning the classification to a dam. The class should be determined by the highest potential consequences, whether life safety, environmental, cultural or economic. For purposes of general management oversight as well as inspection, maintenance and surveillance programs, a single classification for the dam system should be based on the failure scenario which would results in the worst consequences: either sunny day failure or flood failure. However, for determining design criteria for specific components at a site, the consequences of failure of the components may be considered separately. In other words, performance criteria should be based on the consequences of failure of the particular structure.

B.6.1 Low Dam Hazard Rating

Dams classified as low dam hazard rating are those where failure or mis-operation results in:

- no PAR
- minimal short term losses and no long term losses of environmental and cultural value.
- low economics losses and area contained limited infrastructure or services.
- Losses are principally limited to the Dam Owner's property.

B.6.2 Significant Dam Hazard Rating

Dams classified as significant dam hazard rating are those dams where failure or mis-operation results in:

- 1 to 10 PAR with disruption of lifeline facilities. Probable loss of human life will be computed based on the risk assessment's coefficient.
- No significant losses or marginal deterioration of important flora and fauna habitat. Restoration is in kind highly possible.
- Significant economic losses involving recreational facilities, infrequently used workplaces and transportation routes.
- Significant hazard rating dams are often located in predominantly rural or agricultural areas but could be located in areas with population and significant infrastructure.

B.6.3 High Dam Hazard Rating

Dams classified as High dam hazard rating are those dams where failure or mis-operation results in:

- 11 to 100 PAR with disruption of lifeline facilities. Probable loss of human life will be computed based on the risk assessment's coefficient.
- Significant loss or deterioration of critical flora and fauna habitat. Restoration is in kind possible but impractical.
- High economic losses affecting infrastructure, public transportation and commercial facilities
- Dams classified as high dam hazard rating are those where failure or mis-operation will probably cause loss of human life.

B.6.4 Very High Dam Hazard Rating

Dams classified as High dam hazard rating are those dams where failure or mis-operation results in:

- More than 100 PAR with disruption of lifeline facilities. Probable loss of human life will be computed based on the risk assessment's coefficient.
- Major loss or deterioration of critical flora and fauna habitat. Restoration is in kind impossible.
- Very high economic losses affecting important infrastructure or services (e.g. hospital, highway, industrial area, storage facilities for dangerous substances)
- Dams classified as very high dam hazard rating are those where failure or mis-operation will most likely cause loss of human life.

Table B.1: Dam Hazard Rating

Dam Hazard Rating	PAR[1,2]	Environmental and cultural values[2]	Infrastructure and economics[2]
Low	0	Minimal short-term loss; No long-term loss	Low economic losses; Area contains limited infrastructure or services
Significant	1 – 10	No significant loss or Marginal deterioration of important flora and fauna habitat Restoration is in kind highly possible	Significant economic losses involving recreational facilities, infrequently used workplaces and transportation routes
High	11 – 100	Significant loss or deterioration of critical flora and fauna habitat Restoration is in kind possible but impractical	High economic losses affecting infrastructure, public transportation and commercial facilities

Very high	> 100	Major loss or deterioration of critical flora and fauna habitat Restoration is in kind impossible	Very high economic losses affecting important infrastructure or services (e.g., hospital, highway, industrial area, storage facilities for dangerous substances)
Note 1: Definitions for Population at Risk (PAR): The number of people who would be directly exposed to inundation greater than 0.5m in depth within the dam break affected zone if they took no action to evacuate. **Note 2:** Inference for PAR, environment and cultural values, and infrastructure and economic losses: Losses or damages stated above are incremental, which dam failure might inflict on, are over and above any losses which might have occurred for the same natural event or conditions, had the dam not failed.			

B.7 ISSUES TO CONSIDER IN DAM HAZARD RATING

a. Rating of All Probable Failure and Mis-Operation Scenarios

The dam hazard rating assigned to a dam is based on consideration of the effects of a failure or mis-operation during both normal and flood flow conditions. The classification assigned should be based on the worst-case probable scenario of failure or mis-operation of the dam, *i.e.*, the assigned rating should be based on failure consequences that will result in the assignment of the highest hazard rating of all probable failure and mis-operation scenarios. Each element of a project must be evaluated to determine the proper hazard rating for the project. However, there is only one hazard rating assigned to the entire project. Individual elements are not assigned separate classifications.

The probable scenarios considered should be reasonable, justifiable, and consistent. For example, assuming reasonable breach parameters and a failure during normal operating conditions (“sunny day” failure) may result in the released water being confined to the river channel and no PAR, indicating a low hazard rating. However, if the dam were assumed to fail in a similar manner during a flood condition, and the result would be 1 to 10 PAR (excluding the occasional passer-by or recreationist) but significant economic losses on infrequently used workplace, a significant hazard rating would be appropriate. Once a project is placed in the high hazard rating, additional probable failure or mis-operation scenarios need only be considered if there is a need to determine if they would likely induce higher adverse incremental impacts.

b. Usage of Hazard Rating

In the process of establishing the dam hazard rating, various existing classification systems and the history of their development were reviewed. Most of the existing systems generally evolved from the FEMA 333, Federal Guidelines for Dam Safety – Hazard Potential Classification System for Dams. Although the original classification system was intended for limited use, *i.e.*, primarily to prioritize inspection programs, but over the years, the dam hazard rating or its equivalents had been evolving internationally into multiple systems with various nomenclatures and specific design criteria.

c. Significant of PAR Factor

Dam Hazard Rating categories would consider increasing levels of loss. However, a more than 100 PAR would designate a Very High Dam Hazard Rating regardless of the magnitude of other losses. If no PAR is probable as the result of dam failure or mis-operation, the dam would be classified as Low Dam Hazard Rating.

d. Failure and Mis-operation of a Dam Project

The terms failure and mis-operation of a project are used to define the causes of the hazard to upstream and downstream interests. Failure of a dam is meant to include any cause that breaches the structure to release the stored water contents. Mis-operation is meant to include any cause related to accidental or deliberate unscheduled release of the stored contents, such as a gate being opened more than planned but which does not result in full release of the reservoir contents.

e. Periodic Updating of Hazard Rating

It is the intent that each dam would be periodically re-evaluated and reclassified as appropriate. The frequency of review should be each time the project is scheduled for inspection, or at least once each 5 years. This allows for periodic changes in the assigned hazard rating category based on changed reservoir or downstream development.

f. Dam Hazard Rating Does not Reflect on Current Safety of a Dam

The term "Potential" were omitted in each classification system name but was explained in the general notes of the dam hazard rating. This term helps the public understand the significant difference between hazards that "may" become real and any current actual safety concerns for the dam.

g. Adoption of a Single Dam Hazard Rating System throughout the Nation

The Hazard Rating system should be a universal system for all regulatory agencies. The classification system category names should be adopted for consistency in the dam safety community and to properly educate the public on the need to properly maintain this component of the Nation's infrastructure.

It is considered that:

1. This Hazard Rating System for Dams provides a clear, simple, concise, and adaptable system to classify the hazard rating for dams.

2. The dam hazard rating does not reflect in any way on the current safety, structural integrity, or flood routing capability of the project water retaining structures.

3. The Dam Hazard Rating System should be adopted for all dams in Malaysia. This is necessary to eliminate confusion in the dam safety community and to educate the public on the importance of dam safety.

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ANNEX B1: LIST OF EXISTING DAM HAZARD CLASSIFICATION SYSTEM FOR FURTHER REFERENCE

1. DID Manual Vol. 9 “Dam Safety, Inspections and Monitoring – Hazard Classification
2. FEMA 333, Federal Guidelines for Dam Safety – Hazard Potential Classification System for Dams
3. Canadian Dam Association, Dam Safety Guidelines 2007 (2013 Edition) – Dam Classification
4. ANCOLD, Guidelines on Dam Safety Management 2003 – Dam Hazard Categories
5. NZSOLD, Dam Safety Guidelines: Module 2 – Consequence Assessment & Dam Potential Impact Classification

APPENDIX C: INVESTIGATION, DESIGN AND ANALYSIS

C.1 INTRODUCTION

This Appendix provides guidelines for investigation and design of new dams, analysis of existing dams, design of rehabilitation works and upgrading works for existing dams as follows:

- Common dam types and related design issues
- Assessment of risks and hazards and safety criteria for flood, earthquake and other hazards
- Investigation works that should be addressed during initial stages of design
- Criteria for design and evaluation of dams and safety issues that impact the design process
- Instrumentation systems for monitoring of dam performance

The objectives of this appendix are to provide guidance for Dam Owners, Designers and Contractors responsible for the investigation, design, performance monitoring, evaluation and rehabilitation and upgrading of dams. Specific investigation, design and analysis methods are not addressed. Designer should refer to internationally accepted design guidelines including reference documents provided in Reference of this document.

C.2 DESIGN CONSIDERATIONS

The Designer's objective is to ensure that the design reflects the characteristics of the site and the loading conditions applicable to the site. The Designer must demonstrate that the design has considered all hazards at a level appropriate to the hazard rating and the dam can meet durability requirements and the intended service life for the dam.

The Designer is required to assess all risks and demonstrate how the design will reduce risks to as low as reasonably practicable i.e. to the point that risk reduction is impractical or its cost is grossly disproportionate to the improvement gained.

The capacity of the structure or system to withstand changing conditions caused by sudden shocks, gradual stresses and cumulative change to reduce the risk of dam failure from unexpected and unpredictable events and occurrences should be considered. Robust design, resilient features and a whole-of-life safety management are critical to dam safety assurance. Access and facilities for future replacement of elements with shorter design live should be provided.

In cases which the dam forms a component of a larger system such as hydropower, water supply or irrigation the design needs to consider the performance requirements for the dam in the overall system.

C.2.1 Consequences of Failure, Dam Hazard Rating and Design Loads

In Malaysia the dam hazard rating is used to classify dams into four broad hazard categories based on consequence assessment. Many countries use this approach to determine the level of design and apply higher design safety factors for dams with higher hazard rating.

Design loading conditions for various dam types are presented and discussed in various USACE and USBR engineering manuals. It is commonly accepted internationally that it is not necessary to consider two extreme loading conditions to occur at the same time. However, the dam must not fail due to the effects of a second hazard of lesser loading. For example, a dam damaged by a major earthquake may experience an aftershock or flood before repairs can be completed but without failure.

Separate hazard rating can be applied to a dam, subsidiary dam and appurtenant structure if the consequences of their failure are different. A gate and/ or valve system that fulfils a dam safety function, is not assigned a hazard rating; however the design solution must ensure that the dam must not fail due to a functional failure of the gate and/or valve system.

C.2.2 Potential Failure Modes

A potential failure mode is a mechanism or set of circumstances that could result in the uncontrolled release of reservoir content. Mitigation to prevent or reduce the likelihood of a potential dam failure mode is a cornerstone of effective dam design.

Identified potential failure modes provide valuable information about a dam which should be shared across design, surveillance and monitoring, safety review and rehabilitation activities.

Identifying, describing and evaluating potential site-specific dam failure modes are important steps in evaluating the safety of a dam.

C.3 HAZARDS, THREATS AND PERFORMANCE CRITERIA

C.3.1 Introduction

There are a number of natural hazards primarily floods and earthquakes that can affect the safety of a dam during the construction and operation. There are a number of reservoir related hazards such as landslides, reservoir induced seismicity, high winds and waves, and seiches developed by fault movement or landslides into the reservoir that can affect dam safety. In Malaysia, so far volcanic hazards are not considered.

There are a number of threats relating to human activities that can affect the safety of a dam (e.g. human errors, oversights, inadequate supervision) which can usually be controlled by the Dam Owner while others (e.g. security breaches and vandalism) cannot be controlled but can be addressed by the Dam Owner.

Dam Owners and Designers have an obligation to identify and assess all natural hazards and threats relating to a proposed dam project and using design criteria appropriate to the hazard rating of the dam.

In some countries, risk assessment is used in establishing appropriate design criteria for hazard management (refer ICOLD Bulletin 130). However MyDAMS provides design criteria which are closely aligned to recommended criteria in ICOLD Bulletins.

C.3.2 Flood Hazards

C.3.2.1Permanent Works

The dam hazard rating and the incremental consequences of a dam failure (i.e. the consequences over and above the pre-breach condition) are the main determinants in selecting the IDF.

ICOLD Bulletin 82 includes a discussion on the selection of the IDF and lists IDFs adopted by a number of countries for particular dam classifications. FERC (1993) states that “the PMF should be adopted as the IDF in those situations where consequences attributable to dam failure for flood conditions less than the PMF are unacceptable. The determination of unacceptability is clearly necessary when the area affected is evaluated and indicates there is a potential for loss of human life and extensive property damage”. Based on the above information, recommended minimum IDFs for Low, Significant, High and Very High hazard rating dams are listed in **Table C.1**.

Table C.1: Recommended Minimum Inflow Design Floods

Dam Hazard Rating	PAR	AEP of IDF
Low	0 to 10	1 in 100 to 1 in 1,000
Significant	1 to 10	1 in 1,000 to 1 in 10,000
High	11 to 100	1 in 10,000
Very High	> 100	PMF

It is recognised that the estimation of extreme flood events in excess of the 1 in 100 AEP event can be difficult. Flood frequency analysis for gauged catchments (in which a standard probabilistic distribution is fitted to a long term series of annual flood maxima), and application of a regional flood frequency method for ungauged catchments using flood estimates scaled from other similar gauged catchments are accepted flood estimation approaches for larger catchments (>10km^2) in Malaysia. The reliability of extrapolated flood estimates based on a limited length of gauged flow record should be checked and reviewed by the Designer.

IDFs should always be estimated by hydrologists with experience in Malaysia hydrological conditions using established hydrological methodologies for Malaysia conditions. Understanding the effects of climate trends on Malaysia floods is still in its infancy and, given the uncertainties associated with the estimation of IDFs, MyDAMS does not recommend inclusion of the effects of climate change in the derivation of designed spillway floods.

Where the reservoir is large, the hydrograph for the IDF should be determined to allow flood routing and the calculation of the peak lake level and outflow from the reservoir. A complex routing model involving more than one reservoir should be peer reviewed by a suitably experienced hydrologist.

The effects of possible future land use changes on flood magnitudes should be assessed. For example, deforestation and subdivision development in upstream catchments are likely to result in increased runoff and larger flood events..

C.3.2.2Temporary Works

Information on diversion flood frequencies adopted by various countries for the construction of embankment and concrete dams is included in ICOLD Bulletin 108, and a discussion on the selection of an appropriate flood for the sizing of diversion works during construction is included in ICOLD Bulletin 144. There is no universally accepted method for selecting an appropriate flood for the sizing of diversion works during construction and the choice is generally based on the dam site, the dam type, the construction cost and the consequences if the diversion capacity is exceeded.

The performance criteria for diversion works during the construction of a dam, or the completion of upgrading or rehabilitation works, should be as follows:

- For new dams the risk (likelihood x consequence) of loss of life during construction, as far as practicable, should be no greater than that over the life of the dam.
- For existing dams the consequences of dam failure should not be increased during the completion of any upgrading or rehabilitation works.
- The design of any temporary works should include consideration of the hazard rating for any necessary cofferdams, and the design criteria for the cofferdams should be consistent with their dam hazard rating as recommended in section **C.5.3** of this appendix.

If the diversion design relies partly on upstream storage to attenuate the peak flow, the total volume of the selected diversion flood should be estimated and the diversion design should include consideration of the possibility of the available storage volume being exceeded.

The following subsections provide comment on the diversion works for concrete, embankment and concrete face rockfill dams.

a. Concrete Dams

For concrete dams, overtopping during construction would most likely lead to flooding of the work area and possibly some erosion of the dam toe. Provided the risk of toe erosion was not excessive, the main risks would be injuries or loss of life for construction personnel and damage to equipment. Because of the “block type” construction used for concrete dams, the level of potential damage and adverse effects can be managed and kept quite low. With an understanding of warning times and appropriate evacuation procedures the risks to personnel can be mitigated; however, damage to construction plant and the works and the tolerance for these costs are largely subject to the Dam Owner’s risk tolerance and/or an insurance matter.

If personnel and dam safety risks are adequately managed, a return period of 20 years may be appropriate for the sizing of the diversion works.

b. Embankment Dams

Embankment dams are highly unlikely to withstand sustained overtopping; hence the sizing of the diversion works is critical to dam safety during construction. Sizing of the diversion works should consider the likelihood of overtopping of the partially completed structure, the consequences of dam failure at various stages of construction, and the risks to the construction works, the construction programme and construction personnel. Diversion and spill facilities should not concentrate discharge flows onto the dam body.

The diversion works is critical before the dam construction reach the invert levels of the permanent flood discharge facilities. In some cases, temporary spillway facilities may be required to reduce the risk to an acceptable level. An appropriate flood warning and evacuation procedures should be implemented to reduce the risk to public safety during construction. Emergency action planning is addressed in **Appendix F**.

The Dam Owner and Designer should give consideration to the following guidelines for diversion capacity:

Incremental Consequences of Dam Failure During Construction of Embankment Dam	Capacity of Diversion Works
PAR 0 to 10	50 Years ARI
PAR 11 to 100	100 Years ARI
PAR > 100	250 Years ARI

c. Concrete Face Rockfill Dams (CFRD)

CFRDs, with well compacted free draining rockfill shoulders, usually have a greater resistance to overtopping than most embankment dams.

The guidelines included above for embankment dams are also applicable to CFRDs. However, added protection to the downstream face of a CFRD can reduce the likelihood of an overtopping failure (refer ICOLD Bulletin 141 (2010). If it can be demonstrated that proposed protection works on the downstream face will prevent dam failure, then it may be appropriate to include limited overtopping of the dam during the passage of the selected diversion flood event.

C.3.3 Seismic Hazards

Seismic hazards include ground motions, fault displacements, liquefaction, landslides, seiches and tsunamis. Clearly tsunamis will not affect dams remote from coastal settings; however, seiches generated by strong ground motions and/or fault displacements beneath reservoirs can affect dam safety.

The following subsections outline recommended practices for the selection of appropriate seismic hazard parameters for dams. Ground motions, fault displacements and liquefaction are addressed. Landslides and seiches associated with seismic activity are addressed in section **C.3.5.**

C.3.3.1Terminology

A number of terms are commonly used in the assessment of seismic hazards and the definition of seismic performance criteria. They include the Maximum Credible Earthquake (MCE), the Operating Basis Earthquake (OBE), and the Safety Evaluation Earthquake (SEE).

Definitions for each of the terms are included in the Glossary at the end of this appendix. For simplicity MyDAMS uses the MCE, SEE and OBE which are defined as follows:

- **MCE** – The maximum earthquake on a seismic source that is capable of inducing the largest seismic demand on a dam.
- **SEE** – The earthquake that would result in the most severe ground motion which a dam structure must be able to endure without uncontrolled release of the reservoir.
- **OBE** – The earthquake for which a dam, appurtenant structure and gate/valve system that fulfils a dam safety function is designed to remain operational, with any damage being minor and readily repairable following the event.

C.3.3.2Seismic Performance Criteria

Common practice for the seismic design and analysis of dams is to consider two levels of earthquake – the SEE and the OBE.

- The performance requirement for the SEE is that there is no uncontrolled release of the impounded contents when the dam is subjected to the seismic load imposed by the SEE. Damage to the structure may have occurred.

- The performance requirement for the OBE is that the dam and appurtenant structures remain functional and that the resulting damage is minor and easily repairable.

C.3.3.3Ground Motions

Ground shaking affects all structures, including gates and valves, above and below ground. Ground shaking at elevated structures on dams and features such as steep abutments can be amplified from the ground shaking that occurs at the valley floor.

Measures of ground shaking include peak ground motion (i.e. peak ground acceleration, velocity or displacement), response spectra or time-histories.

Acceleration is the more commonly used parameter for ground motions in dam design, with typically less use of velocity and displacement parameters.

a. Annual Exceedance Probabilities and Design Ground Motions

The OBE has traditionally represented ground motions that have an AEP of about 1 in 150. Some Dam owners may wish to adopt a higher standard for the OBE (e.g. an AEP of 1 in 500) to reflect the value of the asset or its importance for providing a service. Dam Owners should refer to other regulated requirements for essential infrastructure.

ICOLD Bulletin 148 provides recommended SEE ground motion parameters for the design and analysis of dams. Both sources consider the potential hazard rating of the dam as a basis for setting recommended levels for the design earthquake. MyDAMS provides AEP ground motions at the mean value, developed from both references and are as follows:

- **All hazard rating dams –** the SEE ground motion parameters may be developed by either a deterministic or a probabilistic approach. The probabilistic approach is favoured by many seismic hazard experts because it provides a uniform basis for evaluating the hazard and more consistent results. The deterministic approach can sometimes result in overly conservative design ground motions for dams located near low activity Quaternary faults and unconservative design ground motions near young (Holocene) high activity faults. The Designer should take this into account when assessing seismic hazard.

- **Low hazard rating dams –** the SEE ground motion parameters should be estimated at the 50th percentile level for the MCE if developed by a deterministic approach, and if developed by a probabilistic approach then at least a 1 in 500 AEP ground motion but need not exceed the 1 in 1,000 AEP ground motion.

- **Significant hazard rating dams –** the SEE ground motion parameters should be estimated at the 50th to the 84th percentile level for the MCE if developed by a deterministic approach, and need not exceed the 1 in 2,500 AEP ground motion developed by a probabilistic approach. If the deterministic approach is used the Designer needs to consider the PAR, Potential Loss of Life and consequences of failure in determining the appropriate percentile deterministic estimates of ground motion.

- **High and Very High hazard rating dams –** the SEE ground motion parameters should be estimated at the 84th percentile level for the MCE if developed by a deterministic approach, and need not exceed the mean 1 in 10,000 AEP ground motion developed by a probabilistic approach.

b. Methods for Estimating Ground Motion Parameters

ICOLD Bulletin 148 also provides guidelines for the selection of parameters to be used in the seismic design, analysis and safety evaluation of new or existing dams and their appurtenant structures. Recommended methods for estimating the SEE and OBE for Low, Significant, High and Very High hazard rating dams are as follows:

- **Low hazard rating dams** – unless the consequences of dam failure dominate decision making, simplified seismic design will normally be sufficient. Site-specific probabilistic seismic hazard studies will not generally be warranted. Deterministic estimates of seismic hazard associated with the MCE will require examination of published geological maps and fault databases to identify active faults and use of appropriate ground motion prediction models.

- **Significant hazard rating dams –** for most Significant hazard rating dams published data can generally be used to obtain probabilistic estimates of seismic hazard for design and analysis.

Deterministic estimates of seismic hazard associated with the MCE will require examination of published geological maps and fault databases to identify active faults. If embankment fill materials or foundations could soften when subjected to strong earthquake ground motions (e.g. cyclic softening or potentially liquefiable soils), or there are weak foundations, the recommended approach detailed below for High hazard rating dams should be employed. Where complex analysis is being used to determine the seismic performance of a dam, the selection of acceleration time history records will require the completion of site-specific seismic hazard assessments as described below for a High hazard rating dam.

- **High and Very High hazard rating dams** – A site-specific seismic hazard assessment should be completed by an experience seismologist using both deterministic and probabilistic analyses. The design ground motions for the SEE and OBE should be selected based on the results of the analyses, and should include response spectra and possibly acceleration time histories, depending on the analysis method. Uncertainties and site amplification effects should be addressed. Epistemic uncertainties associated with earthquake sources and ground motion prediction equations should be considered. Recommendations for the selection and scaling of acceleration time histories are included in Canadian Dam Association Technical Bulletin: Seismic Hazard Considerations for Dam Safety (2007). The selection and scaling of time history records suitable for the site and the structure being analysed requires an experienced specialist.

c. Seismic Analysis Methodologies

In addition to the dam hazard rating, the type of dam and its potential modes of failure, the proposed seismic analysis methodology can affect the selection of appropriate ground motion parameters.

Peak ground motion parameters and response spectra will be sufficient if simplified evaluation procedures are adopted. Dynamic finite element response analyses may be performed using either response spectra or acceleration time histories where linear elastic behaviour is expected. Where nonlinear behaviour is expected time histories will be required. Both horizontal and vertical components of ground motion need to be considered for concrete dams and for embankment dams with very steep slopes. Vertical accelerations can be equal to or greater than horizontal accelerations when close to the earthquake source, so specialist advice is recommended in determining these parameters. Damping rates for concrete dams are usually in the range of 3% to 10% but for embankment dams are usually in the range of 5% to 20%.

ICOLD Bulletin 148 provides more detail on issues that should be considered in the selection of seismic parameters for the analysis and design of embankment and concrete dams. Time history records can be either actual earthquakes at another location in a similar tectonic setting (subsequently scaled to the site peak or more commonly spectral accelerations) or generated synthetically using specialist software. The source earthquakes should be of similar magnitude and distance from the source to represent the energy anticipated for the SEE. There are many methods for scaling time histories and for matching the design spectrum. Advice from a Technical Specialist is recommended.

d. Aftershock Considerations

SEE shaking may lead to cracking, increased seepage and reduced strength. For high value assets and for all high and very high hazard rating dams, the site-specific seismic hazard assessment should include the estimation of aftershock parameters. The information will enable the determination of dam stability following an aftershock. Following a major earthquake a number of aftershocks should be anticipated. For the purposes of dam safety assessments at least one aftershock of one magnitude less than the MCE should be anticipated within one day of the SEE. Further aftershocks may be expected in the following days, weeks and months following the SEE. The characteristics of the aftershock earthquake sequence depend on the site specific MCE fault characteristic.

Repeated aftershocks can result in cumulative damage and reductions in dam stability. The Dam Owner and Designer should consider how the safety of the dam will be managed in the period through the aftershocks until repairs can be completed.

C.3.3.4Fault Displacements

There is no universally accepted definition of an active fault. In Malaysia, an active fault is a fault, reasonably identified and located, known to have produced historical earthquakes with epicentre nearby or showing evidence of movements one or more times in Holocene Epoch (i.e. in the last 10,000 years). Displacements associated with an active fault located beneath a dam can result in damage to the dam and the development of potential seepage pathways. Fault displacement in the reservoir can result in the loss of freeboard and the generation of seiches. Fault geometry or orientation and sense of movement may also result in general landform deformation.

Active faults that can result in displacement beneath a dam can include primary active faults and secondary active faults. Primary active faults are faults that have seismogenic potential (i.e. they are sources of earthquakes). Secondary active faults are faults that move in sympathy or as a consequence of movement on a nearby primary active fault. Movements will be much less than on a primary active fault, but the displacement can still be sufficient to require consideration in the design of a dam.

For engineering design purposes it is generally not considered necessary to design for fault displacement where the annual probability of fault displacement is below a certain threshold. For dam design it is recommended that the threshold for design be based primarily on the dam hazard rating.

a. Annual Exceedance Probabilities

The recommended performance criteria are summarised below:

- **Low hazard rating dams –**Fault displacements associated with the MCE should be based on median (50th percentile) deterministic estimates, but the displacements need not exceed the value associated with a 1 in 2,500 AEP event determined from a probabilistic fault displacement hazard analysis. Active faults with recurrence intervals up to 5,000 years should be considered.

- **Significant hazard rating dams –** Fault displacements associated with the MCE should be between the 50th and 84th percentile deterministic estimates, but the displacements need not exceed the value associated with a 1 in 2,500 AEP event determined from a probabilistic fault displacement hazard analysis.

If the deterministic approach is used the Designer needs to consider the PAR, Potential Loss of Life and consequences of failure in determining the appropriate percentile deterministic estimate of fault displacement and the fault recurrence interval threshold level. For dams of the significant rating 50^{th} percentile to 84^{th} percentile estimates associated with active faults with recurrence intervals up to 10,000 years should be considered.

- **High to Very High hazard rating dams –** Fault displacements associated with the MCE should be based on 84th percentile estimates, but the displacements need not exceed the value associated with a 1 in 10,000 AEP event determined from a probabilistic fault displacement hazard analysis. Active faults should be considered.

For low and most significant hazard rating dams it is not normally necessary to consider undertaking a probabilistic fault displacement hazard analysis and, for design purposes, the deterministic estimates associated with the MCE can be adopted. Foundation fault displacement need not be considered for the OBE.

b. Design Considerations

Preferably, dams should not be located across or immediately adjacent to an active primary fault, but sometimes geological setting faults can be very difficult to avoid. In cases where the dam is near to an active fault, design features that maximise resilience should be provided to adequately withstand the extent of anticipated fault movement, allowing for uncertainties in the fault displacement history.

If there is evidence that an active fault is located beneath a dam, the dam should be capable of safely accommodating the potential fault displacement without excessive reservoir leakage. For embankment dams Mejia (2013) states that recent practice has been to provide filter zones with thicknesses of at least twice the expected filter shear offsets corresponding to the design fault displacements. It is recommended that a similar factor be applied to estimates of fault displacement for the design of other critical elements of a dam.

Estimates of active primary fault displacement and secondary fault displacements should be based on site-specific studies undertaken by professionals with appropriate skills.

C.3.3.5Liquefaction and Lateral Spreading

Loose saturated sands, silty sands and gravelly sands in a dam foundation, or inadequately compacted sands and silts in an embankment dam, are susceptible to liquefaction. Liquefaction of a deposit could result in sufficient loss of shear strength to initiate a dam failure. Loss of strength under earthquake loads can also occur for more cohesive soils (e.g. silty clays and clayey sands) and these types of materials should also be evaluated.

Where such deposits are present in a dam foundation, or are proposed to be utilised for dam construction, their susceptibility to liquefaction should be assessed.

Fell et al (2014) includes a simplified method for assessing the liquefaction resistance of soil deposits. There are many other publications in the literature that provide guidance on determining the potential for and consequences of liquefaction (e.g. Idriss and Boulanger, 2008 and 2014).

Where liquefaction is possible, post-earthquake stability analyses should be completed, using liquefied or residual strengths of the liquefied materials, to review the stability of the dam following the earthquake.

The factor of safety, using residual strengths of the liquefied materials, should be greater than or equal to 1.2 (lower factors of safety may be acceptable depending on the confidence in the accuracy of the residual strength), or the displacements predicted using advanced numerical effective stress methods should be acceptably small. To guard against liquefaction or strength loss during or following earthquake shaking, it is good practice to:

- Either remove all loose foundation materials from the foundation and replace them with highly compacted materials, or densify the loose materials.
- Thoroughly compact all zones of embankment dams.
- Avoid using fill materials which tend to build significant pore pressures during strong shaking.

C.3.4 Volcanic Hazards

Volcanic activity is not considered for dam safety management in Malaysia. There are dormant volcanoes and volcanic rocks exist in some parts of Malaysia. Investigation program, design and analysis of these volcanic materials or grounds should be carried out in accordance to the Designer's recommendation and assessment.

C.3.5 Reservoir Hazards

For significant hazard rating dams and all higher hazard rating dams, consideration should be given to the effects of landslides, reservoir induced seismicity, high winds and waves, and seiches generated by strong ground motions and/or fault displacement.

C.3.5.1Landslides

The potential risk of the following should be considered:

- any part of the reservoir perimeter (e.g. a narrow ridge) which may be more likely to fail than the closure dam.
- any potential for landslide generated waves to affect communities adjacent to the reservoir.
- any existing landslides may reactivate or new landslides may develop under any of the possible reservoir conditions, to the extent that the dam could be overtopped
- reservoir operation could result in toe erosion adjacent to dormant or potential landslide areas.
- any of the reservoir surrounds in the proximity of the spillway and/or low level outlet facilities may fail and block the facilities or impair their functions.

- any risk of sediment or debris from affecting the performance of spillway and/or low level outlet facilities.
- any potential landslide areas are not adversely affected by reservoir drawdown.

ICOLD Bulletin 124 provides guidelines for the investigation and management of reservoir landslides, comments on possible risk mitigation measures, and discusses requirements and methods for the ongoing monitoring of reservoir landslide performance.

C.3.5.2Reservoir Triggered Seismicity

Reservoir Triggered Seismicity (RTS) is an increase in seismic activity following the formation of a reservoir. RTS is relatively uncommon but can occur (e.g. Benmore dam in New Zealand, 1965, and Oroville dam in California, 1975). Where it has occurred, the earthquake ground motions have been typically less than the SEE for the dam.

ICOLD Bulletin 137 notes that dams and appurtenant structures that have been correctly designed for seismic loads are protected against RTS; however, existing structures and facilities in the vicinity of a proposed reservoir could be susceptible to RTS as the resulting seismic loads could be larger than those assumed in their design.

C.3.5.3Wind and Waves

The effects of wind setup of the reservoir, adjacent to the upstream face of a dam, and wave run-up on the upstream face of a dam should be considered in setting the freeboard requirements for a dam. Wind speed, wind direction and fetch length are the predominant factors in establishing wind setup. Wave height, wave length and the physical characteristics (slope, roughness) of the upstream slope of the dam are the predominant factors in establishing wave run-up.

This Appendix have adopted the recommended freeboard provision included in Fell et al (2014) which is that the adopted freeboard should be the largest of the following three freeboard requirements:

- At maximum normal reservoir elevation the freeboard should be the wind set up and wave run up for the highest 10% of waves caused by a sustained wind speed, which is dependent on the fetch, with an AEP of greater than 1 in 100.
- At maximum reservoir elevation during the passage of the IDF the freeboard should be the greater of (a) 0.9m or (b) the sum of the wind set up and wave run up for the

highest 10% of waves caused by a sustained wind speed, which is dependent on the fetch, with an AEP of 1 in 10.

- At intermediate flood elevations the freeboard should be determined so that it has a remote probability of being exceeded by any combination of wind generated waves, wind set up and reservoir surface occurring simultaneously.

Methods for the determination of wave setup and wave runup are included in Fell et al (2014).

C.3.5.4Reservoir Seiches

Reservoir seiches, generated by strong ground motions and/or fault displacement, have the potential to overtop dams and affect dam safety. Embankment dams have a limited ability to withstand overtopping and large reservoir seiches could result in sufficient overtopping to initiate a dam failure.

Significant reservoir seiches can occur if the natural frequency of the reservoir is at or close to resonance with the dominant frequency of the earthquake waves affecting the site. Where a Significant or higher hazard rating dam is located close to an active fault, the potential for seiche waves to overtop the dam crest and initiate a dam failure should be assessed.

Where an active fault crosses the floor of a reservoir for a Significant or higher hazard rating dam the potential for reservoir seiches to initiate a dam failure should be assessed.

C.3.6 Threats and Other Hazards

Threats associated with errors/omissions in design, construction defects, inappropriate operation and the lack of maintenance can be minimised by identifying the threats, adopting appropriate quality assurance systems during design and construction, and preparing and implementing proper procedures for operation, maintenance and testing of the facilities.

Security measures should be provided to prevent vandalism including installation of barrier fences and security cameras, the enclosure of control systems critical to dam safety in secure buildings, the use of authorised access cards, and the installation of intruder alarm systems.

Dams and their associated facilities should incorporate appropriate systems to protect people from hazards associated with their operation. Typical areas that warrant attention include:

- Reservoir areas immediately upstream of intake facilities (e.g. powerhouse, spillway and penstock intake structures).
- Gate and stoplog shafts.
- Gate or valve operation areas.
- Spillway channels and discharge areas.
- Steep and slippery canal side slopes.

Proper protection can only be provided by identifying potential hazards, evaluating the risks, mitigating or controlling hazards through the installation of appropriate protection systems (e.g. warning signs, lake booms, fences, handrails, sirens), and ensuring that the operating personnel are aware of the hazards and their responsibilities for the proper management of the hazards.

C.4 INVESTIGATIONS AND DATA ASSEMBLY

C.4.1 Investigations and Data Assembly

All investigations and data assembly for the design must be to a level which is appropriate to the complexity of the dam site, the contemplated dam design or rehabilitation works, and the commercial value of the dam. Areas requiring investigation or measurement include topography, flood hydrology, regional and site-specific geology, seismic hazards (ground motions and fault displacement), foundation characteristics and construction materials.

C.4.2 Planning and Managing an Investigation Programme

Most investigation programmes are completed in a series of separate stages with the following objectives:

- A pre-feasibility investigation – to identify possible dam sites and dam types, or possible options for upgrading or rehabilitation of the dam, and obtain sufficient information for the planning of a feasibility investigation.
- A feasibility investigation – to identify a preferred dam site and dam type, or a preferred option for upgrading or rehabilitation of the dam, confirm the technical feasibility of the preferred solution, and estimate the cost of project development.
- A design investigation – to address any outstanding issues rose in the feasibility investigation, and any additional questions that are raised during the detailed design and construction of the dam or upgrading or rehabilitation works.

Many historical dam failures can be attributed to a lack of understanding of how the dam site would react to the construction of the dam and the formation of the reservoir. It is important that investigation programmes are carefully resourced, planned and managed to address all unknowns that could affect dam safety.

An appropriate process for the completion of an investigation programme is outlined in **Figure C.1**. It includes:

- Definition of the investigation objectives. Clearly, the objectives will vary depending on the anticipated dam type, or the proposed upgrading or rehabilitation, and the investigation stage.
- Collection and assessment of existing information and the identification of information gaps.
- Regional studies are often necessary to identify features within close proximity of the site that could affect the feasibility of its development (e.g. major fault systems and landslides), and site-specific studies are necessary to characterise the foundation and identify potential sources of construction materials.
- Implementing the investigation programme, reviewing the results as they become available and, if necessary, initiating additional investigation work. Investigation activities are often necessary during construction and, in some cases, following commissioning.

It is most important to document all investigation results, interpretations and conclusions during all stages of an investigation programme.

Drilling in an existing embankment dam should only be carried out using dry drilling techniques, avoid the use of water and high pressure air. Foundation drilling beneath an operational dam should include protection systems to avoid hole blowout due to high pressure zone in the foundation.

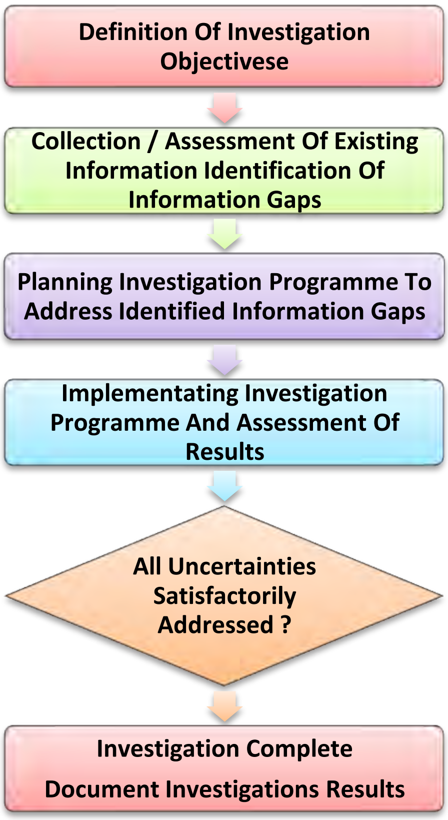

Figure C.1: Progressive Investigation Programme

C.4.3 Topography

Topographical maps for the investigation and design of any dam usually include:

- Regional maps at a 1:50,000 scale and with a 20m contour interval, which are available and published by Director of National Mapping.
- Site-specific maps to suit the site conditions which are typically at scales between 1:2,000 and 1:500 and with 2m to 1m contour intervals. Site-specific topographical mapping should be produced during the initial stages of an investigation programme using ground survey, photogrammetry, or remote sensing technology (e.g. LiDAR). The accuracy of photogrammetry and remote sensing techniques can be affected by vegetation coverage and, in some instances, manual ground surveys will be necessary to give the required resolution.

All site-specific mapping should be completed in relation to a regional coordinate system and datum, and all features recorded during an investigation (e.g. geological features, drillholes) should be located and levelled to the same coordinate system and datum.

C.4.4 Geology and Foundations

Regional and site-specific geological studies should be completed for all dams taking into account the complexity of the site, composition of foundation, the type of dam and its dam hazard ratings.

Information on the stratigraphy and the extent to which the materials are weathered or erodible, the strength and stiffness of the materials, the permeability of the materials and whether they incorporate potential leakage paths, and the joints and whether they are oriented in a manner that could contribute to foundation instability is important.

General consideration for investigation requirements are listed below, but not limited to:

- Site investigation activities such as examination of published geological maps, canvassing of local knowledge, inspection of the dam site and reservoir area for signs of surface instability, faults, dormant, ancient or potential landslides (particularly if they form the abutments) and other adverse geological features.
- Remote sensing imagery interpretation and an appraisal of the regional geology.
- Engineering geological mapping and interpretation of geological structures and defects in the dam and appurtenant structures area.
- Geological and foundation investigation programmes should be sufficient to permit rational design of the dam.
- Testing of the foundation materials to determine their characteristics and the extent of any necessary foundation excavation.
- Sufficient test pits and drillholes, with in- situ permeability testing, to characterise the foundation.
- Additional in-situ and laboratory testing (e.g. shear strength, consolidation) to determine the characteristics of the foundation materials, as appropriate to the site conditions.

In all cases, if the recommended minimum requirements identify any potential difficulties with the site (e.g. existing signs of slope instability, adversely orientated joints, weak or karstic foundation materials extending beyond the depths of the completed field work, the presence of volcanic ash or potentially liquefiable materials), additional investigation work should be completed. For High and Very High hazard rating dams, a more comprehensive investigation and focussed on key issues identified by technical specialists should be conducted which may include the following:

- Excavation and logging of shafts and drives.
- Drilling and monitoring of groundwater observation wells.
- Downhole geophysical electronic logging and core orientation.
- Geophysical and borehole logging of the subsurface foundation materials.
- Large scale in-situ tests (e.g. plate bearing tests, shear tests)
- Advanced material investigation (e.g. trial grouting, reactivity of concrete aggregates, slake durability tests)
- Reservoir slope stability investigations (e.g. drilling, groundwater observation, deformation surveys).

C.4.5 Construction Materials

The identification and investigation of potential construction material sources is a key component of any investigation programme for a dam project. Haul distances between the borrow areas and dam site, the characteristics of the available materials (e.g. material quality, variability in the borrow area), can affect the dam type and the cost of a dam project.

The Designer should be looking for materials that:

- Have sufficient strength when placed in the dam.
- Do not deteriorate during placement, unless this is a desired characteristic that can be achieved with an appropriate level of quality assurance.
- Do not have high rates of weathering where weathering could compromise their design performance or function.
- Do not have expansive properties (e.g. alkali-silica reactive properties in concrete aggregates).
- Do not have dispersive characteristics unsuitable for the cores of embankment dams.
- Have fines contents appropriate for their purpose (e.g. low permeability core, filter function, drainage function).
- Have good plasticity for use in the cores of embankment dams. Low plasticity materials can be used in dam cores but materials with good plasticity should be used if they are available.
- Lack plasticity and cannot hold an open crack for use as filter and drainage materials.
- Are not gap-graded and not prone to segregation.

A pre-feasibility investigation should include the completion of sufficient geological mapping to identify potential borrow material sources and enable the scoping of a later feasibility investigation. In comparison, a feasibility investigation for any dam project should include sufficient work to:

- Identify preferred borrow areas.
- Prove that sufficient volumes of the material are available from the preferred borrow areas.
- Establish that the preferred materials are suitable for their intended design use.
- Ascertain what likely processing requirements and construction methods will be necessary during the construction of the dam or rehabilitation project.
- Select the appropriate dam type(s), or rehabilitation works, with respect to the foundation and available construction materials.
- Provide assurance that the materials will meet the design specification.

To satisfactorily address the above questions, a feasibility investigation normally includes:

- An exploration programme (test pits, shafts and/ or boreholes) to log the available borrow materials, recover samples for laboratory testing, and enable the estimation of borrow area volumes.
- A laboratory testing programme to establish the characteristics of the materials and the suitability of the materials for their intended use. Laboratory testing requirements will vary according to the dam type and borrow material, but would typically include:
    - Gradation, water content, Atterberg limit, compaction, permeability and strength tests for fine grained embankment materials. Dispersion tests may also be necessary in some instances.
    - Gradation, permeability, soundness and durability tests for transition, filter and drainage materials.
    - Gradation tests for rip-rap and rockfill materials.
    - Gradation, specific gravity and absorption, abrasion, soundness, durability and alkali-aggregate tests for fine and coarse concrete aggregates.
    - Petrographic analysis to assess the suitability of rip-rap, rockfill, transition, filter and drainage materials, and concrete aggregates.

- Construction trials to demonstrate the applicability of materials or construction methods, for example:
  - Concrete mix design.
  - Embankment trials to determine appropriate fill placement, conditioning and compaction methods, to determine the properties of the placed fill, and to confirm quality control methods.
  - Grout mix design tests and trial grouting.

An assessment of the investigation results to confirm the suitability of the materials for dam construction, establish likely processing requirements, and estimate the costs of embankment or concrete placement.

C.5 DESIGN CONSIDERATIONS

C.5.1 Introduction

Performance criteria to demonstrate that required levels of dam safety are met can be determined through a standards-based approach or a risk-based approach.

An outline of the two approaches is as follows:

C.5.1.1Standard-based Approach

Established design practice is based on the standards-based approach. It utilises design criteria largely based on deterministic concepts of reliability and uses numerical measures of performance such as safety factors. The actual probability of failure cannot be explicitly evaluated using a deterministic approach. The risks are managed implicitly through the adoption of a dam hazard rating, the selection of an appropriate IDF and SEE for the dam hazard rating, and the application of appropriate factors of safety or performance parameters (e.g. deformation) during the design process.

It is common practice to select an IDF and SEE with lower annual exceedance probabilities for higher hazard rating dams to reduce the levels of risk where the consequences of failure are high.

The standards-based approach does not directly account for uncertainties in loads and the ability of a dam to resist the loads. It acknowledges uncertainties through the use of factors of safety and the completion of parametric sensitivity studies. This approach has been very successful, is widely accepted by the dam engineering profession, and has been generally adopted in MyDAMS for the setting of dam design criteria and the evaluation of dam performance.

C.5.1.2Risk-based Approach

In a risk-based approach estimates of risk (probabilities and consequences of possible adverse events) can be used as indicators of dam safety levels achieved and may be compared with specific dam safety goals also expressed in probabilistic terms. Risk assessment can be a complex process, the risk-based approach can enhance the understanding of potential failure modes and adverse consequences, highlight the greatest contributors to risk, and provide insights into possible means for reducing risk and adding resilience.

A risk-based approach may be appropriate in some instances to validate the design and provide an enhanced understanding of residual risks where appropriate data is available. In addition, the adoption of a risk-based approach may be appropriate in some instances to achieve specific risk reductions or compare the relative merits of alternative design solutions for rehabilitation projects.

C.5.1.3Design Considerations

Much of dam design relates to achieving appropriate physical arrangements for the various components and careful detailing to account for the resulting hydraulic and seepage forces. Such details are included in recognised texts, technical papers and ICOLD bulletins and are beyond the scope of MyDAMS. However, all designs should give due attention to a number of important dam safety considerations including the following:

- Wherever it is practical and cost is reasonable secondary lines of defence should be incorporated within design arrangements.
- Possible changes in material characteristics or the inadequate performance of critical design elements within the expected life of the dam (e.g. physical degradation of materials, drain blockages).
- Shapes and dimensions to avoid excessive stresses and provide structural resilience to unexpected events.
- Ready access for future maintenance or repair.
- Health and safety during construction and operation.

C.5.2 Design Methods

C.5.2.1Analysis Techniques

A detailed discussion on design methods is beyond the scope of MyDAMS and Designers are referred to ICOLD bulletins and other references listed in References.

The selection of the appropriate analysis method to adopt for the design of a dam, the analysis of an existing dam, or the rehabilitation of an existing dam should take into consideration the dam type and the dam hazard rating, and the ability of the analysis method to evaluate the safety of the dam against its potential failure modes. Rational design methods based on material properties and currently accepted factors of safety in the dam engineering profession should be adopted for all dams. Design methods should be comprehensive and reflect nationally and internationally accepted practice.

C.5.2.2Potential Failure Modes

The identification and assessment of potential failure modes for a dam (new or existing) can be achieved through the completion of a Failure Modes and Effects Analysis (FMEA). Using the findings and understandings developed from the completion of FMEAs, dam designs can then be refined to address the identified potential failure modes and minimise the potential for failure mode development through the addition of risk reduction resilience. The design phase can also utilise the potential failure modes to establish the surveillance and monitoring procedures for the dam.

Potential failure modes for a dam can often be difficult to identify and evaluate. Subtle geological features that can have an important influence on the safety of a dam can be difficult to identify (e.g. isolated lenses of openwork gravels beneath the core of a dam). However, historical dam failures (ICOLD 1974) and an analysis of historical embankment dam failures by internal erosion and piping (Fell et al 2014) do provide useful information.

FMEAs should be completed during the design of any new Significant or higher hazard rating dam and the design of any rehabilitation works for an existing Significant or higher hazard rating dam. Later comprehensive safety reviews (refer section **8** of Parent Document and **Appendix E**) for Significant or higher hazard rating dams should include a review of the FMEA report and incorporate any necessary recommendations to update the FMEA report to better reflect actual dam performance. Additional guidelines for the completion of FMEAs and their consideration during comprehensive safety reviews are provided in section **E.5** of **Appendix E** (Dam Surveillance).

C.5.3 Temporary Work

For a dam constructed under contract, the design of temporary works is usually the Contractor's responsibility. However, the Designer should have key decision making authority for the following temporary works:

- The diversion works during the construction of a new dam or the rehabilitation of an existing dam.
- Diversion arrangements during construction should be carefully considered in relation to the potential for floods to outflank the diversion facilities and the consequences that such an event could have on dam construction and people, property and the environment downstream of the dam.
- Any other temporary works which could affect the permanent works.

The Designer should specify the parameters for diversion during construction (i.e. diversion facilities, their capacity and their associated cofferdams). The Contractor should propose final diversion details for approval by the Designer, based on risk allocation set out in the contract documents. The design for any cofferdams should reflect their dam hazard rating.

Any temporary works which in any way affect the permanent works, as designed and specified, must be reviewed and approved by the Designer.

C.5.4 Foundations and Abutments

C.5.4.1Foundation Defects

Foundation defects can affect the integrity and stability of any dam type and untreated foundation defects have contributed to many dam failures around the world.

Clearly the foundation for any dam must fulfil the following five functions:

- provide stability and not degrade over time.
- provide sufficient stiffness to ensure deformations are within acceptable limits.
- control and limit seepage flows and uplift/ piezometric pressures beneath the dam.
- prevent the transportation of dam materials through the foundation.

Any concerns that arise in relation to the above functions should be addressed by appropriate foundation engineering.

Dam sites geological conditions can be complex and many defects may not become apparent until foundation excavation gets underway. The challenge is to keep the uncertainties within acceptable limits; however, there are some geological environments that require more care during investigation, design and construction. They include:

- Clean coarse sands, gravels and cobbles (open work deposits) which could provide a pathway for foundation piping or the piping of embankment materials into the foundation.
- Loose silt or sand deposits that are potentially liquefiable.
- Infilled joints that could be eroded out and provide the potential for high seepage flows or the piping of embankment materials.
- Interbedded soil deposits (fine against coarse) that could provide the potential for foundation piping.
- Weak strata, interbeds and seams with low strengths which could result in potential sliding failure surfaces within the foundation.
- Highly compressible and/or dispersive soils which could result in collapse and differential settlements, and cracking or foundation piping.
- Volcanic deposits whose engineering properties can vary enormously over short distances. Lava flows can be underlain by beds of breccia, scoria or sand with high permeability and low resistance to erosion. Sites where tuffs, lahar deposits and agglomerates are present often incorporate low density and low strength materials.
- Karst features (caves, sinkholes) which can result in high seepage losses and further sinkholes following impoundment by the washing out of infilling or overlying materials.
- Persistent sub-horizontal joint sets that control the shear strength at the dam/foundation interface or within the dam foundation.
- Faults and other major discontinuities which can incorporate low strength materials and, if unfavourably orientated, can affect dam stability.
- Active faults (primary and secondary) that can result in displacements beneath a dam and the initiation of internal erosion, increased uplift pressures and reductions in dam stability.
- Landslides or unstable rock abutments that may require substantial remedial works to protect the long-term integrity of the abutments.

C.5.4.2Foundation Treatments

Foundations for dams require treatment to satisfy the requirements of stability, deformation and water tightness. Generally the scope of any foundation treatment depends on the type of dam, the dam hazard rating, and the characteristics of the foundation materials. For a Significant or higher hazard rating concrete gravity dam on a rock foundation it will be necessary to remove all overlying materials to a suitable rock quality, treat particular rock defects, and it may be necessary to complete a programme of consolidation and curtain grouting.

ICOLD Bulletin 129 provides a detailed account of foundation treatment methods which are grouped into excavation and surface treatment, treatment by sealing measures, treatment by drainage measures, and treatment by strengthening measures. In addition, ICOLD Bulletin 88 provides a detailed account of the investigation, design and treatment of rock foundations.

Excavation and surface treatment involves the removal of all undesirable materials necessary to achieve a foundation that satisfies or can be treated to achieve the requirements of stability, deformation and water tightness. This necessitates the following for particular dam types:

a. Zoned embankment dam

The removal of all erodible, weak, unstable or liquefiable, compressible or loose materials, and the treatment of any rock defects to achieve a uniformly varying foundation and abutment profile, to enable a tight bond between the core material and its foundation, and to provide an adequate defence against the development of a preferential seepage erosion pathway capable of transporting embankment materials along the foundation and abutment contacts.

Foundation shaping is required to remove steps or prominent features that could result in areas of low stress and initiate settlement cracking in the core.

If it is uneconomic to remove liquefiable materials they must be stabilised by special ground improvement works. Impervious foundation materials beneath the dam's drainage features which would prevent proper functioning of the feature must be removed. If necessary, graded filters should be installed to prevent the erosion of shoulder materials into the foundation and foundation materials into the embankment.

b. Concrete face rockfill dam

Seepage paths beneath the plinths (upstream toe slabs) are short and hydraulic gradients are high so it is most important that excavation and surface treatments minimise the potential for erosion or piping in the foundation beneath the plinth. Excavation methods should be selected to minimise the potential for foundation damage and foundation clean up should be completed to a standard that ensures a well bonded contact between the concrete and foundation rock.

Apart from a short distance downstream of the plinth, where soil and soft weathered rock should be removed if filter and transition materials are installed between the face slab and downstream rockfill, the foundation beneath the downstream rockfill often only requires the removal of surface deposits to expose the points of hard in situ rock. If the foundations are weathered then the section downstream of the concrete plinth could be founded on material which is more prone to erosion and piping. In this case filters will need to be more extensive. Gravel deposits are often left in place as they frequently have a higher modulus of compressibility than well compacted rockfill.

c. Concrete gravity dam

Apart from low head structures which may be built on suitable overburden materials but require special treatments for the control of seepage flows, all concrete gravity dam foundations should be cleaned down to reasonably uniform surfaces of competent rock.

Foundation defects such as weathered zones, fault zones and weak seams should be excavated to appropriate depths and backfilled with concrete. In some cases, where prominent defect zones containing erodible material are present, it may be necessary to excavate upstream and downstream cut-off shafts and backfill them with concrete. In other cases, where the global stability of concrete monoliths is adversely affected by unfavourably orientated weak foundation seams (e.g. bedding surfaces, joints, fault and shear surfaces) that form blocks or wedges, it may be necessary to remove additional material or construct shear keys to achieve adequate margins of stability. Foundation treatment by drainage of discontinuities associated with foundation blocks and wedges is recognised as one of the most effective procedures available, as drainage can reduce or remove both hydraulic driving pressures and uplift pressures on resisting planes.

C.5.5 Embankment Dams

C.5.5.1Introduction

Embankment dams (refer **Figure C.2** to **Figure C**.4) which are the most common type of dam in Malaysia, principally because their construction involves the use of locally available natural materials requiring a minimum of processing. Homogenous dams could be adopted where cohesive soils are found abundant. Otherwise, zoned earthfill dam may be adopted with seepage barrier of commonly either central clay core or sloping core.

Embankment dams are grouped according to the types of material used in their construction. They commonly include:

- Homogeneous earthfill dams which are constructed from a single material except for a pervious zone which is placed beneath the downstream shoulder or at the downstream toe.
- Homogeneous earthfill dams which incorporate additional features such as:
  - an upstream geomembrane liner as an impermeable barrier, or
  - a concrete core wall as an impermeable barrier.
  - filter and drainage materials (such as a chimney drain linked to a pervious downstream blanket at the foundation contact) to maintain the downstream shoulder in a dry condition and to control and discharge seepage flows.
- Zoned earthfill dams which normally incorporate a low permeability core material, higher permeability shoulder materials, and filter and drainage materials for the control and discharge of seepage flows.
- Zoned earth and rockfill dams which normally incorporate a low permeability core material, rockfill shoulder materials, and filter and drainage materials for the control and discharge of seepage flows.
- CFRDs with an upstream concrete facing and a rockfill or gravel embankment.
- Rockfill dams with a central impervious core of earth, asphalt or concrete.

The following subsections discuss potential failure modes for embankment dams, loading conditions which must be taken into account during their design, evaluation and rehabilitation, and recommended performance criteria for embankment dams. A number of defensive design details that are important to dam safety are also discussed.

Figure C.2: Earthfill Dam – Mengkuang Dam (provided by Jabatan Bekalan Air, KeTTHA)

Figure C.3: CFRD – Bakun Dam (provided by Sarawak Hidro Sdn Bhd)

Figure C.4: Clay Core Rockfill Dam – Sungai Selangor Dam (provided by Syarikat Pengeluar Air Sungai Selangor, SPLASH)

C.5.5.2Potential Failure Modes

It is important that the identification of potential failure modes for a dam is based on site-specific conditions and the specific characteristics of the dam.

They are also a valuable tool for use during the design of new dams and the upgrading or rehabilitation of existing dams to ensure that potential dam vulnerabilities are addressed and risk reduction measures are incorporated as appropriate.

Embankment dams can be vulnerable to and should therefore be designed against:

- Deformation and consequent loss of freeboard and/ or increase in seepage.
- Internal deterioration through internal erosion and piping from one of the following processes:
    - Concentrated leak erosion – Occurs in soils which are capable of sustaining an open crack or gap, or in the interconnecting voids in a continuous permeable zone. Erosion occurs along the sides of the crack or gap, or in the voids, where the shear stress of the seepage flow exceeds the critical shear stress of the soil particles.
    - Backward erosion – The detachment of soil particles when seepage exits to a free unfiltered surface such as the ground surface downstream of a soil foundation, the downstream face of a homogeneous dam, or a coarse rockfill zone immediately downstream of a fine grained core material. Erosion starts at the exit point and a continuous passage is developed by backward erosion when the seepage gradient exceeds the 'flotation gradient' of the soil.
    - Suffusion – Selective erosion of finer particles from the matrix of coarser particles. A potentially suffused soil is a gap-graded soil which has a deficiency of medium sized particles to fill the voids between the coarser particles. This process can occur via seepage through the main body of a dam which is not protected by an adequate filter. Suffusion is also experienced at the toe of embankment dams where foundation seepage under artesian pressures emerges through the overburden.
    - Contact erosion – Selective erosion of fine particles along a contact surface between a fine soil and a coarse soil, caused by flow passing through the coarse soil (e.g. flow occurring along a contact surface between silt and gravel sized materials).

- In the backward erosion process, detached particles are carried away by the seepage flow and the process gradually works its way towards the upstream side of the embankment or its foundation until a continuous pipe is formed.

Flaws in an embankment dam that would be considered vulnerabilities in an FMEA include:

- Cracks caused by settlement or hydraulic fracture.
- Irregularities or steps in the abutment or foundation profile.
- Desiccation cracks near the crest – drying shrinkage
- Gaps or cracking adjacent to spillway walls or conduits.
- Poorly graded materials or segregation, giving rise to coarse zones susceptible to high seepage flows and the migration of fines.
- Poorly compacted layers which can give rise to interconnected voids or a gap wetting induced collapse.
- Poor compaction at interfaces between separate zones of a dam.
- The lack of sealing or inadequate protection of joints in the core/foundation or core/abutment contact areas.
- The lack of filters.
- Inadequate drainage provisions.
- Relic defects in soil foundations.
- In-filled defects in rock foundations.
- Dam or foundation soils susceptible to liquefaction.
- High foundation permeability that enable the development of artesian pressures and potential blowouts at the dam toe.

Potential cracks in an embankment dam that would be considered vulnerabilities are shown in **Figure C.5** and the influence of a number of factors on the likelihood of cracking occurring are listed in **Table C.2**. Transverse cracks are especially hazardous to water-retaining embankments because they present an open pathway across the embankment that can potentially quickly erode and downcut, leading to a breach. Fong and Bennett (1995) report transverse cracks are more prone to occur near the abutments of embankment dams. Swaisgood (1998) reports that they particularly tend to occur where abutments are steeply sloping and stiffer than the embankment. Transverse cracking in embankment dams is also possible where differential settlements occur across steps in foundations or rigid structures.

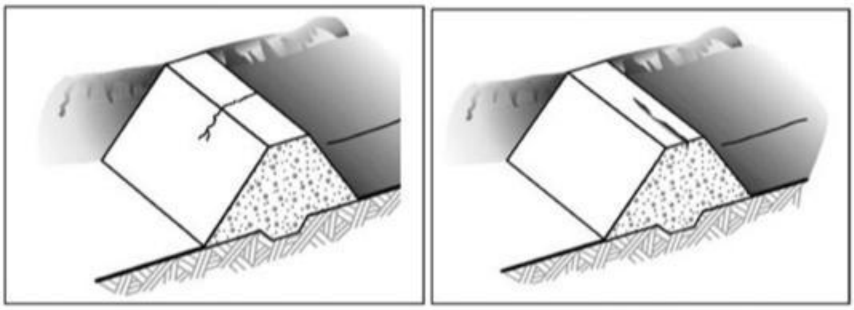

Figure C.5: Longitudinal and Transverse Cracking (from USFWS 2008).

Table C.2: Influence of Factors on the Likelihood of Cracking or Hydraulic Fracturing (from Foster and Fell, 2000).

Factor	Influence on Likelihood of Cracking or Hydraulic Fracturing		
	More Likely	**Neutral**	**Less Likely**
Overall abutment profile	Deep and narrow valley. Abrupt changes in abutment profile, continuous across core. Near vertical abutment slopes.	Reasonably uniform slopes and moderate steepness (e.g. 0.25H:1V to 0.5H:1V)	Uniform abutment profile, or large scale slope modification. Flat abutment slopes (>0.5H:1V)
Small scale irregularities in abutment profile	Steps, benches, depressions in rock foundation, particularly if continuous across width of core (e.g. haul road, grouting platform during construction, river channel).	Irregularities present, but not continuous across width of the core.	Careful slope modification or smooth profile.
Differential foundation settlement	Deep soil foundation adjacent to rock abutments. Variable depth of foundation soils. Variation in compressibility of foundation soils.	Soil foundation, gradual variation in depth.	Low compressible soil foundation. No soil in foundation.
Core characteristics	Narrow core, H/W>2, particularly core with vertical sides. Core material less stiff than shell material. Central core.	Average core width, 2<H/W<1 Core and shell materials equivalent stiffness.	Wide core, H/W<1 Core material stiffer than shell material. Upstream sloping core.
Closure section (during construction)	River diversion through closure section in dam, or new fill placed a long time after original construction.		No closure section (river diversion through outlet conduit or tunnel).

Cracking, creating an opening and/or loose materials and a resulting preferential seepage erosion pathway, can also occur at the interfaces between embankments and spillway walls, conduits and other rigid structures that are located adjacent to, beneath, or pass through embankment dams. Inappropriate details at embankment/structure interfaces, the lack of filter and drainage protection, and low stresses associated with arching of embankment fills across the tops of conduits, can initiate cracking and the erosion of embankment materials. Many embankment dam failures have been influenced by inappropriate design details, and inadequate filter and drainage protection adjacent to conduits.

As indicated previously, the identification of potential failure modes for a dam should be based on site-specific conditions and the specific characteristics of the dam. However, as an aid, the more common potential failure modes identified for embankment dams, which are related to the dam and its foundation, are outlined in **Table C.3**.

Table C.3: Potential Failure Modes for Embankment Dams

Potential Failure Mode	Common Causes
Overtopping	Insufficient freeboard to accommodate storms and flood events
Internal erosion of embankment materials	Presence of defect or crack, cohesionless core material or core material with a Plasticity Index less than 7, dispersive soils, lack of adequate filter protection
Suffusion of embankment materials	Cohesionless core material or core material with a Plasticity Index less than 7, gap graded embankment materials.
Internal erosion of embankment materials into foundation materials	Open joints at interfaces, lack of adequate filter protection, lack of or inappropriate foundation treatment.
Internal erosion of foundation materials	Foundation material has a Plasticity Index less than 7, dispersive foundation materials, lack of or inappropriate foundation treatment.
Instability of downstream shoulder	Weak foundation, weak shallow seam in foundation, poor conditioning and compaction, lack of effective drainage and saturation of downstream shoulder, insufficient shear strength, strong earthquake shaking.
Instability of upstream shoulder	Weak foundation, poor conditioning and compaction, rapid drawdown of reservoir, insufficient shear strength, strong earthquake shaking.
Loss of freeboard, overtopping and subsequent erosion	Insufficient freeboard to accommodate foundation and embankment settlement, settlement following seismic loading, liquefaction of embankment and/or foundation materials, seiches generated by earthquakes, uplift of the reservoir due to fault displacement, reservoir Landslides.
Erosion along embankment/structure interfaces	Inappropriate design details, lack of filter and drainage protection, poor compaction adjacent to structure.

C.5.5.3Loading Conditions

Loading conditions for the design, upgrading and rehabilitation of embankment dams could be referred to various ANCOLD guidelines, CDA (2007), and various USACE and USBR engineering manuals.

Loading conditions that should be considered in the design, upgrading or rehabilitation of an embankment dam are:

- Normal loading conditions.
- Unusual loading conditions.
- Extreme loading conditions.

Normal loading conditions are those which the dam is expected to continuously withstand during normal operation. Examples include steady state seepage and embankment stability with normal maximum reservoir elevation, and embankment stability with no reservoir for a flood detention dam.

Unusual loading conditions occur on an infrequent basis. Examples include the end of construction condition where high pore water pressures can exist in core and foundation materials, severe wave action, rapid drawdown of the reservoir, and the OBE. Minor damage, such as crest settlement and minor shallow or surface cracking, is acceptable; however, the dam should continue to behave in a satisfactory and safe manner.

Extreme loads are those associated with low probability events which, if they were to occur, would be considered severe tests of a dam’s performance and would require diligent visual inspection and observation, and a readiness to respond to a dam safety emergency. Examples include floods at or above the IDF, earthquakes at or near the SEE, and the post-SEE loading condition. Significant damage to the structure is possible and major repairs may be required; however, the damage must not result in an uncontrolled loss of the reservoir.

C.5.5.4Stability and Deformation Performance Criteria

Potential stability failures for embankment dams under different loading conditions should be assessed in terms of minimum factors of safety.

a. Static Assessment

For embankment dams, the dam, foundation and abutments must be stable during construction and under all operating conditions, including full or partial drawdown.

Recommended minimum factors of safety for limit equilibrium stability studies, for static loading conditions, are listed in **Table C.4**. The recommended factors of safety reflect those adopted by the Canadian Dam Association. In addition, for static loading conditions, they are similar to those adopted by the US Bureau of Reclamation and the US Corps of Engineers.

Table C.4: Recommended Minimum Factors of Safety for Slope Stability – Static Assessment

Loading Condition	Slope	Minimum Factor of Safety[1,2,3]
End of construction before reservoir filling	Upstream and downstream	1.3
Long-term (steady state seepage, normal reservoir level)	Downstream	1.5
Full or partial rapid drawdown	Upstream	1.2 to 1.3[3]

Notes:

1. The factor of safety is a representation of the factor required to reduce operational shear strength parameters, or increase the loading, in order to bring a potential sliding mass into a state of limit equilibrium, using generally accepted methods of analysis.
2. Higher factors of safety may be necessary if there are high levels of uncertainty in the inputs to the stability analysis.
3. Higher factors of safety may be required if drawdown occurs relatively frequently during normal operation.

The above factors of safety are appropriate for the design of new dams on high strength foundations with low permeability zones constructed of soil which is not strain weakening, using reasonable conservative shear strengths and pore pressures developed from extensive geotechnical investigations of borrow areas, laboratory testing and analysis of the results.

b. Seismic Assessment

A dam may be damaged during an earthquake but it must be able to safely contain the reservoir contents in its post-earthquake condition. Earthquake damage could include crest settlement and lateral spreading, longitudinal or transverse cracking, separation or cracking at the boundary of embankment and concrete structures, and/or slope movements on the upstream or downstream face of a dam. Crest settlement must not result in the reservoir overtopping the crest of the dam, and slope movements must not result in the loss of freeboard or the loss of support to the core or upstream water retaining membrane. Cracking or separation should be limited to the depth above the full supply level and, if not, immediate intervention is necessary to protect against a seepage erosion induced breach of the dam.

A wide variety of methods are available to evaluate the seismic stability of embankment dams which include pseudo-static methods, simplified methods of deformation analysis, and numerical modelling techniques.

The use of simplified stability analyses using a pseudo-static approach should only be used as a screening tool. Yield acceleration is the analytically calculated acceleration applied to a potential slide mass that indicates an instantaneous factor of safety against sliding of 1.0. If the peak acceleration for the SEE loading condition (taking into account structural amplification response) is greater than the calculated yield acceleration, the implication is that at each time during the earthquake when the yield acceleration is exceeded some displacement will occur. The Designer should then establish the extent of predicted cumulative displacement and determine whether the dam will continue to retain its contents in its damaged state.

Simplified methods exist for evaluating embankment seismic response and are appropriate for most applications. Linear and non-linear dynamic analysis methods are normally only utilised for High or Very High hazard rating dams where stability and deformation studies indicate marginal safety or material degradation, or where the dynamic response of the dam is not readily estimated. Recommended minimum requirements for seismic stability are listed in **Table C.5**. The recommended factors of safety for the pseudo-static and post-earthquake loading conditions reflect those adopted by the Canadian Dam Association (2007).

Table C.5: Recommended Minimum Requirements for Slope Stability – Seismic Assessment

Loading Condition	Slope	Minimum Factor of Safety or Acceptable Deformation
Extreme (applied as pseudo-static load)	Upstream and downstream	1.0
OBE (consider embankment response)	Upstream and downstream	Generally 1.0. Minor deformations are acceptable provided the dam remains functional and the resulting damage is easily repairable
SEE (consider embankment response)	Upstream and downstream	Deformations are acceptable provided they do not lead to an uncontrolled release of the impounded contents
Post-earthquake	Upstream and downstream	1.2 to 1.3

Empirical methods can be used to estimate earthquake induced embankment crest settlements. These are generally based on historical data and offer reasonably coarse estimates.

Embankments with short natural periods in the order of 0.1 second (e.g. low height and stiff cross sections), are likely to experience near resonant response and high spectral accelerations at the embankment crest.

Longitudinal cracking will likely occur along the crest and upper faces of the embankment. There is limited case history knowledge of transverse cracking on embankment dams, but the examples identified tend to occur at higher accelerations or are directly related to foundation shape discontinuities. Most documented cases of embankment dams subjected to earthquakes with a Moment Magnitude (Mw) >6.75 and a peak ground acceleration (PGA) >0.3g report transverse cracking in addition to longitudinal cracking.

Clearly the assessed damage (cracking and settlement) for the SEE should incorporate some margin to provide assurance that an uncontrolled release of the reservoir cannot be initiated. The Designer should consider the dam fundamental period in response to ground motions and case studies of dam performance. Some examples of useful methodologies that Designers can consider are outlined below. Fell et al (2014) describe a simplified methodology for estimating settlement and cracking in embankment dams subjected to seismic shaking. ICOLD Bulletin 141 also includes simplified methodologies for assessing likely deformations in rockfill embankments subjected to strong earthquake ground motions.

For detailed numerical analyses, the Designer should utilise the above simplified methodologies as validation checks.

C.5.5.5Design Details

In addition to meeting the above performance criteria, successful embankment dam design relies on the adoption of good defensive design details. These are addressed in a number of ICOLD bulletins and include:

- Providing ample freeboard and appropriate crest details.
- Using the best available materials in the more critical areas of the embankment.
- Providing well designed and constructed filter and transition zones to ensure compatibility between adjacent materials.
- Providing ample drainage zones for the interception and control of seepage flows.

- Providing good design details (e.g. flaring or widening the filter and transition zones) at all interfaces between the embankment and its foundation, and at all interfaces between the embankment and concrete structures (e.g. spillways and diversion culverts).
- Providing adequate protection against erosion by wave action and runoff.

a. Freeboard and Crest Details

ICOLD Bulletin 142 states that the most common cause of failure for any dam type is overtopping of an earthfill embankment and that overtopping should not be accepted as a design criterion for any embankment dam. While the bulletin provides detailed information on the safe passage of floods, it includes no recommendations for the determination of minimum freeboard allowances. MyDAMS has adopted the minimum freeboard provisions included in Fell et al (2014).

In addition to overtopping by wind generated waves, the freeboard provision should be sufficient to protect the dam against overtopping caused by abnormal events such as an earthquake (ground motions and / or fault displacement), a seiche and a landslide into the reservoir.

Crest details for an embankment dam should be designed to:

- Provide a suitable width for construction and, if appropriate, a suitable width for a permanent access road. Unless a permanent access road is needed, a crest width of 6m should be sufficient for most dams.
- During extreme flood conditions the reservoir level, excluding waves, should not exceed the top of the impervious core. In addition, any filter and transition materials should extend to the top of the core material.
- Contain the reservoir without inducing seepage erosion on the downstream face during extreme floods.

b. Embankment Materials

It is important to establish the characteristics of the naturally occurring materials and where they could be best utilised in the construction of the embankment.

The construction specification should include material grading envelopes, filter compatibility requirements, target moisture contents, compaction requirements, quality control tests and quality assurance requirements. Trial processing and embankment trials are recommended to establish final specification parameters. Strict adherence to the compaction specification is necessary to avoid the presence of crushed layers, that adversely affect permeability contrasts, and uncompacted layers that encourage embankment settlement and cracking. Cores susceptible to desiccation cracking should be protected from drying out during any construction shutdown and capped at their crests to minimise the potential for desiccation cracking during their operational lives.

c. Filter, Transition and Drainage Zones

Seepage through embankment dams must be managed to prevent erosion and degradation of dam components. Filters and drainage zones should be provided where the shoulder material is coarse in relation to the core, should be considered essential where the core incorporates dispersive soils, and should be provided around culverts, conduits and any penetrations through the dam. Filter, transition and drainage zones must be designed to ensure compatibility between adjacent materials, and provide sufficient drainage capacity to safely accommodate the anticipated seepage flows under all loading conditions, including the post-earthquake condition.

Filters can be divided into critical and non-critical filters. Critical filters are those that are critical to the control of internal erosion in a dam and, as such, they should be designed and constructed to meet stringent, no-erosion filter criteria. Non-critical filters are those that can be readily repaired if erosion occurs. ICOLD bulletin 164 includes a detailed account of internal erosion processes and provides guidelines for the assessment of the vulnerability of a dam to failure or damage by internal erosion. It also includes a discussion on design methods for critical filters. Khor et al (1989 and 1992) investigate ability of crushed rock filters to control internal erosion of dam core constructed of tropical residual soils.

The following general criteria apply to filters:

- The granular filter should be non-plastic and highly unlikely to hold an open crack.
- The filter should be designed to meet ‘no-erosion’ criteria.
- The filter should be sufficiently permeable for the seepage flow to pass through it without significant build up in pressure.
- Gap graded filters, and gradings prone to segregation or degradation, should be avoided.
- Filter and drainage zones must be sufficiently wide to adequately perform their filtering and drainage functions.

- Filter placement methods should minimize the potential for segregation and contamination.
- Filter compaction levels should be dense enough to be dilative but not so dense as to become brittle and crack prone.

d. Assessing Filters in Existing Dams

ICOLD Bulletin 164 provides guidelines for the engineering assessment of the vulnerability of an existing dam to internal erosion. The guidelines include the identification of potential internal erosion failure modes, screening of the potential failure modes according to particular dam, foundation and concrete structure characteristics, identification of those potential failure modes that are more likely to occur, and analysis of the more likely potential failure modes to determine whether internal erosion could initiate, continue and progress.

If the filter protection systems within an existing dam are insufficient to resist the more likely potential failure modes, it will be necessary to consider the need for remedial works to reduce the potential for failure to occur. A quantitative risk assessment of internal erosion is complex and should only be carried out by technical specialists experienced in the technique.

e. Protection around Conduits

A conduit or pipe through an embankment dam is a common location for the initiation of internal erosion, particularly for existing dams that do not include good filter protection. Inappropriate conduit details, the lack of filter and drainage protection, and low stresses associated with arching of embankment fills across the tops of conduits can initiate the erosion of embankment materials. Erosion can progress through the loss of material into the conduit, erosion along the outside of the conduit, and water losses from the conduit. Many embankment dams have failed through inappropriate conduit design, and inadequate filter and drainage protection adjacent to conduits. FEMA L-266 (2006) and Fell et al (2014) provide recommended practices. The completion of a risk assessment may assist in establishing whether a potential deficiency of an existing dam needs to be addressed.

f. Interfaces between Embankments and Concrete Structures or Abutments

Interfaces between embankment dams and concrete structures are potential sources of internal erosion. All concrete surfaces adjacent to embankment materials, particularly core materials, should be smooth and free of construction defects (e.g. horizontal offsets along construction joints), and should incorporate slopes no steeper than 1 (horizontal) in 8 (vertical) to encourage positive contact pressures along the interface.

Filter and drainage materials should always be provided for the control of seepage flows along such interfaces.

Many of the features outlined above for interfaces between embankment dams and concrete structures are also applicable to dam abutment contact surfaces.

g. Drainage Pipes

Drainage pipes should only be utilised in areas where they are readily accessible for maintenance or replacement (e.g. in toe drains).

The Designer should specify corrugated smooth wall pipe rated for the embankment loads with the perforation size based on the filter grading.

h. Toe Drainage Capacity

High drainage capacity at the downstream toe can be provided by a toe drain system or by a zone of materials with a suitable grading to withstand the predicted flow.

This might be achieved through coarse free draining fill at the dam toe or a partial height toe buttress (often referred to as a Swedish berm). Scandinavian researchers developed empirical methods for the design of drainage buttresses to prevent toe unravelling based on large scale tests. Nilsson and Bartsch (2007) provide an empirical relationship between the mean rock particle size (D50), the downstream slope of the rockfill and the unit discharge flow based on these test results.

i. Surface Erosion

The upstream slopes of embankment dams and their abutments require protection against erosion by wave action.

ICOLD Bulletin 91 provides a detailed discussion on loads that need to be considered and design criteria that should be adopted for the design of upstream slope protection systems including dumped rip-rap, hand placed rip-rap, soil cement facings, concrete paving and precast concrete blocks, bituminous concrete linings, gabions and reno-mattresses, steel and timber facings and RCC facings. The design methodologies included in ICOLD Bulletin 91 should be adopted for the design of upstream slope protection systems.

To ensure the protection of underlying materials rip-rap should be well graded and durable, and should extend a sufficient distance down slope to protect the underlying material from wave action at the minimum reservoir operation level. Downstream slopes should also be protected from erosion where they are constructed from materials other than rockfill.

C.5.6 Concrete Face Rockfill Dams (CFRD)

C.5.6.1 Introduction

CFRDs are a form of embankment dam that rely on the upstream concrete face slab for water retention. Asphaltic concrete has been used as a variant to conventional concrete in some dams in the world.

Typical CFRD design will have a concrete plinth, founded on competent rock at the upstream toe of the dam, to connect the face slab to the foundation. This is a critical element of the dam.

The following subsections discuss potential failure modes for CFRD dams, loading conditions which must be taken into account during their design, evaluation and rehabilitation, and recommended performance criteria for CFRD dams. A number of defensive design details that are important to dam safety are also discussed.

ICOLD Bulletin 141 and Fell et al (2014) provide detailed accounts of the design and construction features of CFRDs and their performance.

C.5.6.2 Potential Failure Modes

As stated previously, the identification of potential failure modes for a dam should be based on site-specific conditions and the specific characteristics of the dam.

However, as an aid, the more common potential failure modes for CFRD dams, which are related to the dam and its foundation, are outlined in **Table C.6**.

Table C.6: Potential Failure Modes for CFRDs

Potential Failure Mode	Common Causes
Overtopping	Insufficient freeboard to accommodate storms and flood events
Excessive leakage and unravelling of downstream shoulder	Settlement, defect or crack in facing slab or plinth, shoulder material not coarse enough to withstand leakage discharge

Internal erosion of embankment materials	Defect or crack in the facing slab, lack of adequate filter protection, high fines content in embankment fill
Internal erosion of foundation materials	Foundation material has a Plasticity Index less than 7, dispersive foundation materials, lack of or inappropriate foundation treatment, high gradient around plinth
Instability of downstream shoulder	Defect or crack in facing slab, weak shallow seam in foundation, lack of effective drainage and saturation of downstream shoulder, insufficient shear strength, strong earthquake shaking
Instability of upstream shoulder (sliding failure involving/ disrupting the face slab)	Rapid drawdown of reservoir, insufficient drainage, strong earthquake shaking
Loss of freeboard, overtopping and subsequent erosion	Insufficient freeboard to accommodate foundation and embankment settlement, settlement following seismic loading and/or foundation materials, seiches generated by earthquakes, uplift of the reservoir due to fault displacement, reservoir landslides
Loss of freeboard, overtopping and subsequent erosion	Insufficient freeboard to accommodate foundation and embankment settlement, settlement following seismic loading, liquefaction of embankment and/or foundation materials, seiches generated by earthquakes, uplift of the reservoir due to fault displacement, reservoir landslides

Fell et al (2014) outlines a framework for assessing potential failure modes for a CFRD. Rogers et al (2010) describes the failure of the Taum Sauk reservoir in the USA and the combination of factors leading to this failure. Pinto et al (1998) discusses incidents of cracked upstream face slabs due to high stresses attributed, in part, to the valley shape. Wieland (2009) provides descriptions of damage to CFRDs from earthquakes but notes that there are few observations of dam responses to strong earthquakes. A classic example of performance of Zipingpu Dam during strong earthquake was published by Prof. Xu Zeping (2008).

C.5.6.3Loading Conditions

The loading conditions that should be considered in the design or rehabilitation of a CFRD are as stated for an embankment dam in section **C.5.5.3**.

C.5.6.4Stability and Deformation Performance Criteria

The dam, foundation and abutments must be stable during construction and under all operating conditions, including full or partial drawdown. Recommended minimum factors of safety for limit equilibrium stability studies, for static and seismic loading conditions, are the same as for embankment dams and are listed in **Table C.4** and **Table C.5**. The comments and guidelines relating to embankment stability, deformation and post-earthquake performance in section **C.5.5.4** are also applicable to CFRDs.

Settlement may occur under static conditions or as a result of earthquake shaking. The potential for settlement should be assessed and consequent effects that should be addressed during the design include the loss of freeboard and the risk of overtopping and the extent of damage to the upstream face slab.

The performance of the upstream face slab is critical to dam performance as extensive cracking could result in sufficient leakage to threaten the stability of the dam. In addition, a stable well founded plinth and a stable supporting backfill are critical to the performance of the face slab. An inadequate transition between the concrete face slab and rockfill can restrict flow into the rockfill if cracking or joint opening occurs in the slab, and poorly graded materials with the potential for internal instability could result in increased leakage and unraveling or instability of the downstream shoulder. The design process should include an assessment of the potential settlement of the dam, and the potential cracking or joint opening in the concrete face slab, and sufficient seepage and stability analyses to demonstrate that the embankment has adequate reserves of stability.

C.5.6.5Design Details

In addition to meeting the above performance criteria, successful CFRD design relies on the adoption of good defensive design details.

a. Location and Orientation of the Dam

If the concrete plinth crosses or rests on any foundation features that could displace under reservoir loading or in an earthquake, the dam should be oriented to minimise the offset implications for the plinth. In the vicinity of such foundation features, specific details to reduce damage to the plinth should be assessed and filters with dimensions at least 1.5 times the expected offset should be placed behind the perimetric joint between the face slab and the plinth.

An upstream impermeable blanket, with appropriate filter layers, should also be considered to cover the plinth and perimetric joint in the location of the foundation feature.

b. Slab Thickness

The upstream face slab is a stiff element that relies on rockfill support, and any loss of support will result in slab cracking and leakage.

The slab thickness must be sufficient to accommodate robust joint details. Consideration should also be given to situations where the valley shape could introduce high compressive stresses in the face slab. Problems have occurred with high CFRDs in narrow canyons, where the dam height and crest length have had roughly equal dimensions.

The face slab will develop high in-plane stresses from the cross-valley component of earthquake ground motions, and the potential for shear failure and spalling needs to be addressed in the slab design.

c. Freeboard and Crest Details

The recommendations included in section **C.5.5.5** are also applicable for CFRDs.

Crest structures, including wave walls, require careful detailing to accommodate:

- The predicted settlement without compromising the watertightness of the joints.
- The different response characteristics, in comparison to those experienced by the main rockfill embankment, during strong earthquake shaking.

d. Material Zoning

Filters are required beneath the face slab and immediately downstream of the plinth to restrict flow into the rockfill, if cracking or joint openings occur in the face slab, and to limit deformation of the slab at the perimetric joint and restrict flow into the embankment or foundation if the perimetric joint opens.

The gradations of the embankment materials must be internally stable and the embankment zones should increase in coarseness towards the downstream face and toe. Where embankment materials break down under compaction and result in materials with high proportions of sand and silt, the resulting fill may not be free draining. In such cases filter and drainage layers must be provided beneath the face slab and along the foundation contact to ensure the controlled collection and drainage of leakage to the dam toe.

e. Compaction Standards

Earlier CFRDs were constructed of dumped rockfill. This is no longer recommended due to the effects of excessive settlement on the concrete face slab and other rigid structures.

The long-term settlements of well compacted rockfill can be expected to be in the range of 0.1 to 0.2% of the embankment height. Strong ground motions during earthquakes will produce greater settlements.

f. Facing Slab Joints

The spacing of vertical joints in the face slab should consider the predicted embankment settlement under all loading conditions. Generally, more joints and narrower slab widths are recommended to provide more articulation of the slab. Joints should also be located and detailed above features likely to initiate differential settlement (e.g. steps in the foundation).

Shear keys and durable water stops that can sustain some movement are recommended details at the perimetric joint and at all vertical joints. The joint dimensions need to account for the reversible nature of the embankment dam response to earthquake ground motions.

g. Foundation and Abutment Shaping

Prominent features (steps or irregularities) in the foundation or abutments should be removed to reduce the likelihood of differential settlement.

As stated earlier, narrow valleys can result in high compressive forces in the upstream face slab.

C.5.7 Concrete Gravity and Buttress Dams

C.5.7.1 Introduction

Concrete gravity dams and buttress dams are grouped according to the types of material used in their construction and how they achieve their strength and stability. They commonly include:

- Conventional concrete gravity dams (refer **Figure C.6**) which are constructed from conventional concrete and rely on the shearing resistance developed at their base, as a result of their weight (hence the name gravity) less uplift under the dam, and the integrity of the foundation to resist the imposed load from the reservoir. Guidelines for the design of concrete gravity dams are provided in FERC (1993) and USACE (1995).

Figure C.6: Concrete Gravity Dam – Klang Gates Dam (provided by Puncak Niaga (M) Sdn Bhd)

- RCC dams (refer **Figure C.7**) which are constructed from zero slump concrete using traditional earth placing methods and similarly rely on the shearing resistance developed at their base, as a result of their weight less uplift under the dam, and the integrity of the foundation to resist the imposed reservoir load. Hansen and Reinhardt (1991) provide an overview of design considerations for RCC dams.

Figure C.7: RCC Dam – Sultan Azlan Shah Dam (provided by Lembaga Air Perak)

- Concrete buttress dams (refer **Figure C.8**) which incorporate an upstream concrete face supported at intervals by a series of support buttresses. They rely on their weight, the structural strength of face and foundation slabs, and the integrity of the foundation to resist the imposed reservoir load. The shearing resistance to resist the reservoir load is developed primarily along the buttresses, as opposed to beneath the entire base for concrete gravity dams.

Figure C.8: Concrete Buttress Dam – Muda Dam (provided by Lembaga Kemajuan Pertanian Muda)

C.5.7.2Potential Failure Modes

The general comments on the identification and evaluation of potential failure modes included in section **C.5.5.2** for embankment dams are also relevant to concrete gravity and buttress dams.

Fell et al (2014) includes some statistics on dam failures which highlight that failure rates between 1900 and 1975 for concrete gravity and concrete buttress dams were 0.3% and 2.6% respectively of dams built. These figures can be compared with the failure rate quoted for embankment dams, over the same time period, which was 1.2% of dams built. The available information demonstrates that the safety of concrete buttress dams between 1900 and 1975 was significantly less favourable than the safety of all other dam types over the same time period. With respect to the relatively high failure rate of buttress dams, in comparison to that for concrete gravity dams, it is noted that concrete gravity dams are far more robust than the relatively thin slabs and narrow buttresses that support buttress dams.

It is also well recognized that most concrete gravity dam failures relate to foundation issues (Douglas, Spannagle and Fell 1998). Douglas, Spannagle and Fell reported that for 10 concrete gravity dam failures 6 were related to foundation issues, one was related to a structural issue, one was related to an appurtenance structure, and 2 were classified as unknown. Following the publication of their report the Camara Dam in Brazil, which was an RCC gravity dam, failed due to foundation problems. Thus, the available evidence shows that seven of eleven concrete gravity dam failures were foundation related.

Hansen and Nuss (2011) summarise the seismic performance of concrete gravity and buttress dams that have experienced earthquakes with peak ground accelerations greater than 0.3g. Observations from the research indicated that:

- Well-constructed RCC dams performed no differently in earthquakes to dams built of conventionally placed mass concrete.
- Seismic ground motions can be amplified significantly at the dam crest, with in excess of 2g being recorded at some dams. Damage to equipment and buildings from high accelerations at the dam crests was evident and highlighted the need for careful consideration of amplified ground motions during design.
- Rock slope failures from abutments and onto access roads caused significant damage and delayed access to some sites.
- Cracking in dams occurred at changes in geometry, highlighting the importance of avoiding the inclusion of such features wherever possible.
- Concrete buttress dams developed horizontal cracks at high elevations where there were significant changes in structure stiffness.
- Foundation fault displacement can result in severe damage if fault movement mitigation features have not been included in the design.

The more common potential failure modes for concrete gravity and buttress dams, which are related to the dam and its foundation, are outlined in **Table C.7**.

Table C.7: Failure Modes for Concrete Gravity and Buttress Dams

Potential Failure Mode	Common Causes
Sliding along concrete lift joints in the dam, or cracked surfaces in the dam	Poor lift joint bonding, high uplift pressures, insufficient shear strength
Structural failure	Deterioration in concrete quality, overstressing of buttresses during cross valley seismic loads

Sliding along the concrete/foundation interface, or planes of weakness in the dam foundation	High uplift pressures, insufficient shear strength, inappropriate foundation treatment
Piping of foundation materials	High gradients through foundation, lack of or inappropriate foundation treatment

C.5.7.3Loading Conditions

Loading conditions for the design and rehabilitation of concrete dams are presented and discussed in various ANCOLD guidelines, CDA (2007), and various USACE and USBR engineering manuals.

Loading conditions that should be considered in the design, evaluation or rehabilitation of concrete gravity and buttress dams, and the general performance criteria for concrete gravity and buttress dams for each loading condition, are similar to those outlined in section **C.5.5.3** for an embankment dam. Comments on each loading condition and examples of each loading condition for concrete gravity and buttress dams are provided below.

- During normal loading conditions the behaviour of the dam should remain in the linearly elastic range. In a rigid body analysis the normal loading condition should include the consideration of dead loads, hydrostatic loads (headwater and tailwater), loads imposed by silt deposition upstream of the dam and backfill materials adjacent to the dam, internal and external uplift pressures and temperature effects.
- During unusual loading conditions minor non-linear behaviour of the dam is acceptable; however, any necessary repairs should be minor. Any rigid body or cracked base analysis should include the consideration of all the loads outlined above for the normal loading condition in combination with the OBE, including hydrodynamic loads, and in combination with an appropriate reduction in the efficiency of underdrains (if present).

C.5.7.4Stability and Structural Performance Criteria

As for embankment dams, potential stability failures for concrete gravity and buttress dams under different loading conditions are usually assessed in terms of minimum factors of safety. The factors of safety generally relate to sliding stability and compressive stresses at the dam toe.

The primary performance indicator for concrete gravity and buttress dams is their stability against a sliding failure, either along the dam/foundation contact or along a plane of weakness in the dam or dam foundation. Recommended minimum sliding factors of safety (defined as the available shear strength divided by the net driving force) for limited equilibrium stability analysis of concrete gravity and buttress dams are provided in

Table C.8. The tabulated figures and accompanying notes generally reflect the material included in NZSOLD (2015) and are similar to those included in CDA (2007). NZSOLD (2015) should be referred to for additional information relating to failure surfaces, concrete strengths, dam/ foundation interface strengths, and dam foundation strengths. Note that the recommended factors of safety relate to sliding failures along the dam/foundation contact, along a plane of weakness in the dam, or along a joint set or other plane of weakness in the dam foundation.

Table C.8: Recommended Minimum Sliding Factors of Safety for Concrete Gravity and Buttress Dams

Loading Condition	Minimum Sliding Factor of Safety		
	Friction and Cohesion Present		Friction Only Present
	Not Well Defined[1,2,6]	Well Defined[1,2,6]	Well Defined[2,6,9]
Normal	3.0[4]	2.0[4]	1.5[3]
Unusual	2.0[4]	1.5[4]	1.3[3]
Extreme – Flood	1.5[4]	1.3[4]	1.1[3]
Extreme – Earthquake	Refer note 10		
Post-earthquake		1.2[11]	1.1

Notes:

1. Given the significant impact a very small amount of cohesion can have on shear resistance, the recommended minimum sliding factors of safety for friction and cohesion should be used with extreme caution.

For stability within the body of the dam and at the dam/foundation interface:

2. ‘Well defined’ means that a sufficient number of tests have been completed to define the strength parameters with reasonable certainty (i.e. the assumed strength parameters should be exceeded by 80% of the test results from a test regime involving an appropriate number of tests).

3. In some cases Ø for concrete could be significantly lower than 45° (e.g. cracked surfaces, open joints, lift joints incorporating a cement slurry bond layer). In such cases and in all cases where friction alone controls the stability of the dam, Ø should be determined from laboratory tests.
4. The minimum sliding factors for friction and cohesion assume that the sliding surface will pass through intact concrete or well-prepared construction joints.
5. In assessing the strength of the dam/foundation interface consideration needs to be given to the thoroughness of the foundation clean-up and whether the strengths of parts of the foundation below the interface may control the stability. For the 'well defined' case for existing dams, strength tests should be carried out on core samples taken from the interface zone (typically a few metres below the interface surface).

For stability within the foundation of the dam:

6. 'Well defined' means that there is good exposure of the foundation material at the dam site and that there is sufficient reliable data to establish the existence and persistence of foundation discontinuities (e.g. faults, joints, bedding plane shears) and define the foundation strength parameters with reasonable certainty (i.e. the assumed strength parameters should be exceeded by 80% of the test results from a test regime involving an appropriate number of tests).
7. Recommended shear strength parameters for foundation discontinuities, for incorporation in stability assessments, are listed in the following table:

Discontinuity	Typical Feature	Strength Parameters
Clean discontinuity (no previous displacement)	Clean joint Bedding plane	f($ø_b$, i) c'=0
Thick infilled discontinuity (no previous displacement)	Infilled joint Infilled bedding plane	f(ø) of infill material (note b) c'=0
Discontinuity with previous displacement	Shears Faults	f($ø_r$) of infilling and f(i) of wall rock c'= 0
Multiple discontinuity	Highly jointed rock mass	m_b, s, a, σ_c

Notes:

a) Strength parameters:

f function of

c' cohesion (at zero normal stress)

$ø_b$ basic friction angle (for wet surfaces)

$ø_r$ "effective" residual friction angle i average roughness angle

m_b, s, a Hoek-Brown Criterion (1995) parameters

σ_c uniaxial compressive strength of intact rock

b) Test to be carried out on remoulded samples; ø to be based on peak strength under drained conditions; c' to be neglected.

8. The minimum sliding factors assume the adoption of reasonably conservative strengths. For the friction only condition the adopted strength should be at or near the lower bound of good quality test data.

9. Where weak surfaces (e.g. bedding plane shears) are present in the foundation, the actual strength will usually be the frictional strength. In such situations the criteria should be met using the frictional strength.

For stability within the body of the dam, at the dam/foundation interface, and within the foundation:

10. The earthquake load case is used to determine the post-earthquake condition of the dam. In line with US recommendations (e.g. FERC, 2002) a minimum Factor of Safety is not given. If sliding assessments indicate displacement, then the Designer needs to consider the amount of displacement that has occurred along the surface analysed whether it is at the dam/foundation contact, in the dam or in the foundation.

11. For the post-earthquake load case the minimum sliding factor should not be less than 1.2 for the friction only 'well defined' case. If the sliding factor falls below 1.1 there is a high likelihood of failure given that the friction only strength condition has been reached. In such a case the dam should be remediated as a matter of urgency to meet the minimum sliding factor recommended for the 'normal' loading condition.

If a cracked base analysis indicates unacceptable results then the stability analysis can be completed assuming that the base cracks all the way through to determine if the dam is stable under the limit case of complete cracking.

Other performance indicators include the position of the resultant force, tensile stresses at the dam heel and compressive stresses at the dam toe. Recommended criteria for the position of the resultant force and maximum compressive stresses for rigid body analysis of concrete gravity and buttress dams are provided in **Table C.9** and **Table C.10.** The recommended criteria reflect those included in Canadian Dam Association (2007) and USACE (1995).

Table C.9: Recommended Position of the Force Resultant for Concrete Gravity and Buttress Dams

Loading Condition	Position of the Force Resultant
Normal	Preferably within the middle third of the base (i.e. 100% compression). For existing dams it may be acceptable to allow a small percentage of the base to be under zero compression if all other performance criteria are met (note 1).
Unusual	75% of the base should be in compression and all other performance criteria should be met.
Extreme	Within the base and all other performance criteria should be met.

Notes:

1. All possible failure modes should be addressed under a potential cracked base scenario wherever tensile stresses are present at the dam/foundation contact or along a plane of weakness in the dam foundation.
2. Rocking may occur under extreme earthquake loads and some permanent displacement could result. The Designer needs to determine whether this occurs and, if it does, demonstrate that the reservoir is not released and that post-earthquake stability is adequate.

Table C.10: Recommended Maximum Stresses for Concrete Gravity and Buttress Dams

Loading Condition	Normal Compressive Stress
Normal	$<0.3xf'_c$
Unusual	$<0.5xf'_c$
Extreme - Flood	$<0.5xf'_c$
Extreme – Earthquake	$<0.9xf'_c$
Post-earthquake	$<0.5xf'_c$

Notes:

1. In addition to the above, the maximum foundation bearing pressure should be less than the allowable bearing pressure, as determined by an appropriately qualified technical specialist, for normal and unusual loads, and less than 1.33 times the allowable bearing pressure for extreme loads.
2. Within the body of a dam, tensile stresses during normal loading conditions may be acceptable so long as the limits of 0.1xf'c and 0.05xf'c (where f'c is the compressive strength of concrete) within the concrete mass and at lift joints, respectively, are not exceeded and all other performance criteria are met. Tensile stresses during

earthquake loading conditions may be acceptable so long as they do not exceed 1.5 times the above limits and all other performance criteria are met.

3. In the absence of specific testing, tensile strengths at the dam/foundation interface, and along defects in the foundation, should be assumed to be zero.

As stated for embankment dams, higher sliding factors of safety and lower compressive stresses than those listed in the above tables may be necessary if there are high levels of uncertainty in the inputs to the rigid body analyses, particularly in the strength of foundation materials.

The results of non-linear analysis models should be validated against the results of alternative analyses, including those for pseudo-static and linear elastic analyses, and the sensitivity of the results to variations in the assumed model parameters should be assessed.

C.5.7.5Design Details

There are a number of design details for concrete gravity and buttress dams that can affect dam safety.

a. Dam Geometry

Concrete gravity dams are usually constructed in discrete dam blocks. While there may be construction expediencies that make this advantageous, the primary reason for discrete blocks is to provide contraction joints for thermal expansion and contraction during construction and long term operation. In conventional mass concrete gravity dams the transverse joints are constructed at formed faces; however, in RCC dams the joints are typically created as the RCC is placed. Experience gained from RCC dams constructed without transverse joints demonstrates that transverse cracking will occur, often induced at undesirable locations due to foundation or other irregularities. In uniform RCC dams, where there are no irregularities, transverse joints have been observed to form at about 15m intervals. When joint control is exercised, joints are typically constructed at 20m to 30m intervals; however, a thermal assessment of the structure should be completed to determine the ideal spacing.

Sliding stability requirements and the available shear strength at the foundation interface are likely to dominate the base dimensions. High tensile stress zones should be avoided wherever possible and, if they are unable to be avoided, the dam shape should be adjusted to reduce the tensile stresses as much as reasonably practicable. Cracks should be expected to propagate from high tensile stress zones and, as such, the following should be considered carefully during dam design:

- Geometrical modification of the heel of a dam to reduce tensile stresses, or the incorporation of higher strength concrete in the heel of a dam to increase the tensile capacity of the concrete. Higher strength conventional concrete may be appropriate in the heels of RCC dams to increase the tensile capacity of the concrete.
- The avoidance of prominent changes of slope and sharp discontinuities in the foundation profile to reduce the likelihood of high tensile stress zones.
- The avoidance of sharp changes in the upstream or downstream face geometry to reduce the likelihood of high tensile stress zones. High tensile stress zones often result from changing the face geometry to achieve a wider dam crest for a road across the top of a dam. Koyna Dam in India cracked at a change in slope on its downstream face during an M6.5 earthquake in 1967.
- The seismic design of concrete buttress dams. Changes in cross-sections within face slabs and floor slabs are particularly vulnerable to cracking if not detailed for high seismic loads, and slender monoliths have poor seismic resistance to cross valley seismic ground motions. Sefid Rud dam in Iran suffered cracking at the top of its buttress monoliths during an M7.3 earthquake in 1990.

b. Foundation Defects and Discontinuities

The identification and appropriate treatment of foundation defects is discussed in section **C.5.4** of this Appendix. In addition to the measures required for the control of seepage flows, the design challenges for concrete gravity and buttress dams include the identification of all defects and discontinuities that could affect dam stability, the determination of their shear strengths, and the design of any necessary strengthening works to ensure adequate reserves of stability. The assessment of the foundation is one of the most important aspects of the design and safety evaluation of concrete dams as most historical concrete dam failures have resulted from foundation weaknesses (e.g. Sheffield Dam and Morris Shepherd Dam in the USA).

The design of new dams, the safety evaluation of existing dams, and the design of rehabilitation works for existing dams should consider the sliding resistance along any identified joint or shear plane with an orientation that could influence the development of a sliding failure. The Designer should also consider the stability of any combinations of joint or shear planes that form unstable wedges of rock and could result in dam block displacements.

The determination of foundation shear strengths can be difficult and, while the adoption of conservative values from published information may be sufficient for Low hazard rating dams, foundation shear strengths for Significant and higher hazard rating dams should be based on the results of laboratory tests. Fell et al (2014) includes recommended practices for the assessment of shear strengths in clean discontinuities, infilled joints and seams showing evidence of previous displacement, thick infilled joints, seams or extremely weathered beds with no evidence of previous displacement, and jointed rock masses with no persistent discontinuities.

c. Shear Transfer

Shear keys are resilient features that can provide some load transfer between dam blocks.

For new designs the stability of straight gravity dam blocks, designed by 2-D analysis, should not be reliant on load transfer with their neighbouring dam blocks. However, for existing dams constructed with shear keys, it is appropriate to assess and consider the load transfer that can be accomplished during extreme seismic loads or high flood conditions. It is quite likely that load transfer between monoliths and/or the interlocking of monoliths upon initiation of any sliding movements have contributed to the good stability record of concrete gravity dams.

d. Upstream Face

The concrete specification for the upstream face of a concrete gravity or buttress dam should encourage long term durability, crack control and water tightness. Higher strength conventional concrete is commonly used in the upstream face of a mass concrete or buttress dam. For an RCC dam, conventional concrete or grout enriched RCC is often used at the upstream face.

The concrete specification at the upstream heel of a dam should reflect the size and extent of any tensile stresses that develop during unusual or extreme loading conditions. This is particularly important at sites that are located in areas of high seismic risk. For RCC dams located in areas of high seismic risk, conventional concrete should be used in the upstream heel rather than grout enriched RCC.

The durability of the upstream face also needs to be considered if the reservoir is highly acidic. The treatment of water flowing into the reservoir may be an option at a mine site. However, if such a system is unavailable, not applicable, or unreliable, the Designer must demonstrate that the structure meets durability criteria. Sulphate-resisting cements or upstream membranes may provide sufficient resistance. The design life of the solution and the practicality of repair or replacement during the life of the dam should be considered.

e. Drainage Facilities

Drainage facilities are frequently installed in concrete dams for the control of uplift pressures at the foundation contact, along a plane of weakness in the dam foundation, and along concrete lift joints. Guidelines for the estimation of uplift pressures are included in the literature (e.g. Canadian Dam Association (2007), Fell et al (2014)). Such guidelines are appropriate for the design of new dams; however, stability assessments for existing dams can be based on measured uplift pressures with appropriate allowances for seepage trends.

Points that should be considered during the design of a drainage system include:

- The location and depth of the foundation drains. Ideally they should be located in a gallery, drilled to intersect defects, and extend beneath any potential failure surface. They should also be oriented to intersect foundation defects, installed downstream of any grout curtain, and drilled following the completion of any foundation grouting.
- The spacing and diameter of the foundation drains. Drain spacing will be somewhat dependent on the foundation geology; however, for an efficient drainage system, the spacing should not exceed 3m. The diameter of the drains should be a minimum of 75mm to enable drain maintenance.
- The potential for erosion of foundation materials into the drillholes. If any drillhole intersects foundation materials considered likely to erode into the hole, then a suitable filter and screen standpipe should be installed. The filter should be removable for maintenance and replacement.
- The location, spacing and diameter of internal drains. Ideally they should be located close to the upstream face of the dam and drain into a drainage gallery.

Their spacing should be sufficient to ensure they don't encourage longitudinal cracking and their diameter should be at least 150 mm to minimise the potential for leakage to bypass the drains and to facilitate future cleaning.

- The watertightness of drainage galleries. Drainage galleries should preferably be located within the dam body and not in an area where high tensile stresses could result in the development of a crack between the upstream face and the gallery. Unless suitable mitigating measures can be reliably installed, the watertightness of a gallery located external from the dam body, at the heel of the dam, could be affected by dam block displacement.

- The reliability of any installed dewatering facilities necessary to pump water from drainage galleries to the tailwater. If the post-earthquake stability of the dam relies on the effective control of uplift pressures, any pump facilities and their associated pipelines should be designed to remain operational following the SEE.
- The future maintenance of the drainage system. Without ready access to the drainage system, for inspection and maintenance, its long-term effectiveness cannot be assured and uplift pressures should be assumed to vary linearly between full headwater pressure at the heel of the dam and full tailwater pressure at the toe of the dam.

f. Freeboard and Crest Details

Concrete gravity and buttress dams can usually accommodate some overtopping without serious damage and, as such, the freeboard provisions can be somewhat less than those detailed for embankment dams in section **C.5.5.5** of this Appendix. However, from a dam safety perspective it is important that sufficient freeboard is provided to ensure the safety of the dam, its abutments and appurtenant structures are not compromised during the IDF, and to enable the continued operation of appurtenant structures (e.g. spillways) during the IDF. In some cases, additional freeboard provisions may be required by the Dam Owner to meet asset management objectives.

The crest width for the non-overflow section of a concrete gravity or buttress dam is usually set by stability considerations and any access requirements for the maintenance and repair of appurtenant structures (e.g. spillway gates).

g. Horizontal Lift Joints

Concrete gravity dams and buttress monoliths are generally constructed in horizontal layers. RCC dams may also be constructed using sloping layers, but the resulting lift joints are essentially the same as horizontal lift joints. The bond at horizontal lift joints is critical to:

- Prevent the development of potential sliding failure modes in the dam body.
- To provide adequate tensile resistance between the concrete layers.
- To prevent the development of potential horizontal seepage paths that could result in high uplift pressures within the dam body.

Lift joint preparation is a key factor in achieving adequate bond between concrete layers. Lift joint surfaces should be clean and free of loose material and dirt. High pressure water cleaning to ensure the removal of concrete laitance and green cutting of previously placed layers can be used to provide better bond conditions. For RCC dams the Designer must specify the parameters for the following joint preparation options:

- Fresh RCC directly on a compacted RCC layer. Time limits and temperature parameters before initial set are required and, during this time window, a new layer may be placed over a compacted layer of RCC. After initial set, a cold joint develops which requires treatment with a mortar bedding layer. The time and temperature parameters should be developed and demonstrated during an RCC construction trial.
- Mortar bedding on a cold joint immediately before fresh RCC. The Designer may chose this procedure for all lift joints.

The bond at horizontal lift joints should be confirmed by obtaining cores from a trial RCC embankment and testing them in a laboratory. Bond quality checks, by obtaining cores and testing them in a laboratory, should also be part of the construction quality assurance process.

h. Construction, Contraction, Expansion and Isolation Joints

Joints are provided in concrete gravity and buttress dams to minimise cracking and the effects of cracking on relative movement. They include inclined or vertical construction joints for practical concrete construction, contraction joints to regulate the locations of cracks, expansion joints to accommodate volumetric changes in adjacent concrete blocks, and vertical isolation joints to enable movements at specific locations (e.g. directly above a fault in the dam foundation).

All joints require seals to limit joint leakage. The seals must be strong enough to withstand rough treatment during construction and the water pressure, flexible enough to accommodate relative movements between adjacent concrete sections, and durable enough to remain effective during the design life of the dam.

A wide range of sealing materials is available and a successful joint system is heavily reliant on the selection of the most appropriate seal and the design detail for the joint. ICOLD Bulletin 57 provides guidelines for the selection of the most appropriate material and its installation in vertical and horizontal joints.

i. High Velocity Flow

Surfaces exposed to high velocity flows require considerable attention to detail by the Designer and strong quality assurance requirements during construction. Hydraulic flow characteristics need to be carefully modelled and negative pressures should be avoided to reduce the risk of cavitation. High quality surface finishes are often required to avoid cavitation type erosion.

Conventional concrete should be the minimum specification for high velocity flow surfaces, including spillway surfaces on RCC dams.

A relatively small amount of bed load can be highly abrasive to concrete surfaces. Silica fume in the concrete mix provides a more durable surface and steel plates are sometimes installed around gates and abrupt transitions to minimise the potential for erosion.

While numerical hydraulic modelling can be used, the limitations of these techniques must be understood. Physical models may be necessary to ensure hydraulically efficient spillway geometry; however, they should only be undertaken by experienced modellers.

j. Concrete Mix Design

Concrete mix design requires care to ensure the concrete is a reliable construction material and that it delivers the specified strength and durability objectives. In many cases on-site concrete manufacture will be required. The batching plant for conventional concrete and any plant for the manufacture of RCC must be appropriate for the mix designed and have a production rate that exceeds the maximum required delivery rate at critical times in the construction programme. The Designer should record the results of concrete mix trials, to demonstrate the suitability of the selected mixes, and should receive concrete plant acceptance testing quality control records as evidence that the concrete mixes meet the design requirements.

The control of temperature rise is important in mass concrete and RCC construction. The Designer must specify the mix design, acceptable cement properties, acceptable pozzolanic materials (non-cementitious materials that can replace cement but achieve the specified strength and durability requirements) and acceptable temperature parameters. Methods for determining mass concrete mix proportions are provided in American Concrete Institute (ACI) (1989) report 211.1 and methods for determining RCC mix proportions are provided in ACI (1988) report 207.5R.

Many concrete gravity dams, including RCC dams, often require cooling and insulating systems for the management of thermal effects during construction. ANCOLD (2013) and ICOLD Bulletins 107, 126 and 136 include guidelines for assessing the need for temperature control, and outline alternative construction practices for the prevention of uncontrolled cracking.

Consideration should be given to the following during the design and production of concrete mixes for concrete gravity and buttress dams:

- The need for low heat cements.
- The need for low alkali cements to reduce the risk of alkali silica reactions.
- Sulphate resisting cements if there is a risk of exposure to highly acidic water.
- The benefits of pozzolan replacements (Class F (low lime) fly ash is preferred).
- The necessity for silica fume or other additives to meet durability requirements (e.g. for high velocity water surfaces).
- Maximum placing temperatures.
- Minimum placing temperatures.
- Target slumps.
- Quality control test target ranges and acceptance levels.

Production quality control tests should include:

- Consistency tests such as slump tests for mass concrete and Vebe test times for RCC.
- Compressive strength cylinders.
- Tensile tests of cores through lift joints.

C.5.8 Appurtenant Structures

C.5.8.1Introduction

Appurtenant structures are those structures at the dam site, other than the dam itself, that are designed and are required for the safe containment and control of the reservoir under all loading conditions.

Typical appurtenant structures include spillways, penstock intake structures, water intake structures, canal inlet structures, and low level outlet structures. Pipelines and penstocks downstream of intake structures should also be considered appurtenant structures if there is no gate or valve designed to isolate them from the reservoir contents. Appurtenant structures often incorporate mechanical and electrical equipment (e.g. gates, valves, gate and valve operating equipment, standby generators) for the controlled discharge or release of the reservoir contents.

C.5.8.2Potential Failure Modes

The general comments on the identification and evaluation of potential failure modes included in section **C.5.5.2** for embankment dams are also relevant to appurtenant structures.

Inadequate design and/or inappropriate operation of appurtenant structures can significantly affect the safety of a dam, particularly an embankment dam. In addition, many appurtenant structures are located in prominent positions on dams or abutments and are therefore vulnerable to large ground motions during earthquakes. Various reviews of earthquake related damage to dams (Fell et al (2014) and Hansen and Nuss (2011)) note earthquake damage to elevated equipment for the operation of appurtenant structures.

The more common potential failure modes for dams, which are related to the design and operation of appurtenant structures, are outlined in **Table C.11**.

Table C.11: Potential Failure Modes related to Appurtenant Structures

Potential Failure Mode	Common Causes
Overtopping	Insufficient spillway capacity, inappropriate operation of spillway facilities, inability to operate spillway facilities (spillway blockage, gate jamming through pier deformation, equipment malfunction, control systems failure, power supply failure, lack of access for manual operation, no operator for manual operation).
Erosion	Cavitation damage, erosion by abrasion or uplift of stilling basin leads to loss of spillway chute followed by backward erosion to reservoir.
Erosion of embankment materials	Inadequate detailing of embankment/structure interfaces (e.g. spillway, intake and conduit interfaces), inadequate filter protection systems adjacent to appurtenant structures, rupture of pipeline through embankment.
Structural gate failure	Overstressing of gate arms, gate bearing seizure.

C.5.8.3Loading Conditions

Loads and loading conditions that should be considered in the design or rehabilitation of an appurtenant structure are similar to those outlined in section **0** for a concrete dam.

It is also frequently necessary to analyse the performance of the structure, or a component of the structure, under various gate/valve and hydraulic operating conditions. Examples for each loading condition include the following:

- Normal loading conditions – All gates/valves open, all gates/valves closed, adjacent gates/valves open and closed. These operating conditions are common in canal inlet, penstock intake and spillway gate structures, and bottom outlet gate/valve structures.

- Unusual loading conditions – All maintenance bulkheads in place, adjacent maintenance bulkheads in place and not in place, and normal gate/valve configurations with the OBE. These operating conditions occur in canal inlet, penstock intake and spillway gate structures, and bottom outlet gate/ valve structures. An additional operating condition is the dewatering of stilling basins for inspection or the completion of remedial works.

- Extreme loading conditions – All gates/valves open during the IDF, adjacent gates/valves open and closed during the IDF, and normal gate/valve configurations with the SEE. These operating conditions occur in spillway, canal inlet and penstock intake structures, and bottom outlet gate/valve structures. Other operating conditions relevant to spillways and their stilling basins include discharges during the IDF and rapid reductions in discharge following the IDF.

Design loads for an appurtenant structure relate to the function it performs, the asset it protects and the potential consequences if the structure fails. If a gate is required to operate post-SEE, then the gate, its operating equipment and the structure supporting the gate must be designed for the same level of ground shaking as the dam it is protecting allowing for ground motion amplification effects. If the appurtenant structure is a structure required to contain the reservoir (examples a penstock or a surge chamber) then the design loads should reflect the consequences of its failure.

C.5.8.4Stability and Structural Performance Criteria

Performance criteria for appurtenant structures are similar to those outlined in section

C.5.7.4 for concrete dams and the recommendations relating to sliding factors of safety, the position of the force resultant, and normal compressive stresses are applicable.

Appurtenant structures should have adequate reserves of weight to ensure flotation does not occur during all loading conditions. Factors of safety recommended in USACE (2005) are 1.3 for normal loading conditions, 1.2 for unusual loading conditions and 1.1 for extreme loading conditions.

Appurtenant structures and installed mechanical equipment that fulfils a dam safety function should be operational after the SEE. Accordingly, they should be designed to accommodate the amplified loads relevant to their locations during the SEE for the dam.

Structural elements that support gates and valves for safe operation of the reservoir must be designed to ensure the equipment is able to perform its function post-SEE.

C.5.8.5Gates and Valves that Fulfil Dam Safety Functions

Gate and/ or valve systems that fulfil dam safety functions often include:

- Spillway gates for the retention of the reservoir during normal loading conditions and during and following extreme loading conditions, the controlled release of flood flows during flood events, and the controlled release of dewatering flows in a potential dam safety emergency.
- Spillway gate types include crest mounted radial gates, orifice radial gates, vertical lift wheel gates, flap gates and rubber dams. **Table C.12** has been developed from Chander Sehgal (2000) which outlines selection criteria for spillway gates and their operating equipment. Examples of spillway gate types are shown in
- **Figure C.**9 to **Figure C.11**.

Table C.12: Design Requirements and Suitability of Spillway Gate Types

Design Requirement	Radial Gate (Crest Mounted)	Radial Gate (Orifice)	Vertical Lift Wheel Gate	Flap Gate	Rubber Dam
Flood control	Yes	Yes	Yes	Yes	Yes
Storage above spillway crest	Yes, gate height limited by height of piers	Yes, gate height not critical to storage	Yes, gate height limited by height of piers	Yes, gate height limited to 3 to 4m by high lifting loads	Yes, height limited to 3 to 4m by strength of material

Passage of debris	No, except when gate fully open	No	No, except when gate fully open	Yes	Yes
Sediment sluicing	Yes, but ineffective for high crest heights	Yes	Yes, but not preferred as wheels can be jammed by sediment	No, except when gate fully open	No, except when gate fully open

- Low level sluice gates (orifice radial gates or vertical wheel gates) or valves for the retention of the reservoir during normal loading conditions and during and following extreme loading conditions, and the controlled release of dewatering flows in a potential dam safety emergency. Low level sluice gates can also be used for the sluicing of accumulated sediment and the controlled release of flood flows during flood events.
- Penstock intake gates (usually vertical wheel gates) and water intake valves for the isolation of ruptured downstream penstocks and pipelines that could affect dam safety.
- Dewatering pumps and discharge facilities for the control of uplift pressures during normal loading conditions, and during and following extreme loading conditions.
- Power supplies, gate lifting and valve operating equipment, and protection, control and communication systems and the ancillary (backup) features for operation of the above facilities.

Figure C.9: Crest Mounted Radial Gates – Bakun Dam (provided by Sarawak Hidro Sdn. Bhd.)

Figure C.10: Vertical Lift Wheel Gate at Klang Gates Dam (provided by Lembaga Urus Air Selangor)

Figure C.11: Pneumatically Actuated Gates (Obermeyer Spillway) at Babagon Dam provided by Jabatan Air Sabah)

In addition to normal, unusual and extreme loading conditions, all designs should include the consideration of other loading conditions including equipment malfunction (e.g. hoist rope failure, seized trunnion or roller bearing, jammed gate), gate over-pour, floating debris and sunken log effects, and flow induced vibrations. ICOLD Bulletin 102 includes a detailed discussion on flow induced vibrations and guidelines to limit flow induced vibrations.

All gates should be designed and detailed to limit deformations. Excessive gate deformation during extreme loading conditions could result in gate jamming and severe loss of sealing. In low level gates excessive leakage could limit access for unjamming operations.

All gate designs should incorporate material durability in the critical components (e.g. bearings, bushes, pins, etc.) and the avoidance of corrosion opportunities overall.

All structural arrangements should facilitate ready access for the operation, inspection, maintenance, repair or replacement of gates, valves and their components. Safe access under emergency conditions and during exceptional circumstances (e.g. storm, failure of electricity supply, severe winter conditions, etc.) should be provided.

Upstream facilities (e.g. bulkheads, guard valves) and downstream isolation facilities should be provided to allow the inspection, maintenance and repair of all gates and valves that fulfill dam safety functions. Bulkheads should not be assumed capable of closure against flow unless specifically designed for such an operational scenario.

The design should include the completion of a study to assess the potential for failure of gates, valves and their operating and/or control systems, including multiple failures, and the likely effects of such failures during extreme loading conditions. For example, gate unavailability during an extreme flood event could initiate an overtopping failure of an embankment dam or sufficient toe erosion to initiate a sliding failure of a concrete dam.

Appropriate back-up systems should be included to ensure reliable operation during all loading conditions. Back-up systems could include gate and equipment redundancy (e.g. multiplicity of gates, power supplies, electric motors, pumps, hydraulic pumps with petrol/diesel motor drives), local and remote control, and automatic triggering of safety devices.

All gates and valves that fulfil dam safety functions and can only be electrically operated should be connected to at least two independent sources of power supply.

Adequate lighting should be provided for safe access and operation of the facilities at night.

All control systems and associated equipment (e.g. control cabinets, cabling, batteries) should, where feasible, be located where the rupture of water-carrying conduits cannot threaten their integrity. If this is not feasible, appropriate protection systems should be provided to ensure the operation of the equipment is not adversely affected (i.e. provide fail-safe operation). Any facilities housing control systems and associated equipment must not collapse and prevent equipment operation post-earthquake.

All associated power supply cables, hydraulic piping, and control and communication cables should be designed and detailed in a manner which ensures their availability following an extreme event (e.g. adequately supported to withstand the SEE, looped connections across vertical contraction joints which may move during a large earthquake). Primary and backup power supply cables to gate hoist motors should be routed along separate paths.

All gates and valves should be designed and detailed in a manner that enables easy inspection, maintenance, testing and repair, and replacement when they are no longer capable of reliably fulfilling their design functions.

C.5.8.6Design Details

There are a number of design details for appurtenant structures that can affect dam safety and warrant careful consideration during their detailed design. Design details associated with conduits, ungated and orifice spillways, and low level outlet facilities are discussed in a number of ICOLD bulletins and are outlined below.

a. Conduits

- Where conduits are installed through or beneath dams they should be designed for non-pressurised flow conditions. They should also incorporate upstream bulkhead facilities, to isolate the conduit from the upstream reservoir, and be of a sufficient size to enable inspection and the completion of any necessary repairs.
- Where pressurised conduits are installed through or beneath embankment dams, preferably only for Low hazard rating dams less than 10m in height, they should incorporate suitable facilities for the detection and monitoring of any conduit leakage, and an upstream valve to enable maintenance or replacement of the outlet control valve. They should also be designed to withstand the internal pressures associated with rapid closure of the outlet control valve and be pressure tested to 150% of the maximum operating pressure prior to backfilling.
- Where pressurised conduits are installed through concrete dams they should be steel lined and incorporate an upstream bulkhead facility to isolate the conduit from the upstream reservoir. The steel lining should be designed to withstand the maximum negative and positive internal pressures associated with rapid start up and closure of the downstream control facility (i.e. valve or turbine).

b. Ogee Crest Spillways and Morning Glory Spillways

Examples of ogee crest spillways and morning glory spillways are shown in **Figure C.12** and **Figure C.14**

Figure C.12: Ogee Crest Spillway – Kelau Dam (provided by JPS Malaysia)

Figure C.13: Labyrinth Spillway – Putrajaya Dam (provided by Perbadanan Putrajaya)

Figure C.14: Morning Glory Spillway – Sungai Langat Dam (provided by Pengurusan Air Selangor Sdn Bhd)

- Where local conditions can affect the reliability of gate operation, consideration should be given to the adoption of an ungated spillway. Local conditions that can affect the reliability of gate operation include a remote site, difficult site access, a lack of skills for gate O&M, debris accumulation, reservoir slope instability and short peaking times for flood events. If an ungated spillway has piers and a bridge, these must be positioned to provide sufficient flow passage and minimize the risk of debris accumulation.

- Wherever it is practicable an auxiliary spillway and discharge channel are recommended to be sited clear of an embankment dam to give extra protection for extreme events and/or failure of the main spillway to take all of its design flow. Where an auxiliary spillway is provided the design discharge for the primary spillway is usually less than the IDF. However, both facilities, in combination, must be capable of safely discharging the IDF.

- Auxiliary spillways with fusing mechanisms to initiate discharge require special care in their design. The consequences of fuse elements breaching and their effects on the downstream area need to be evaluated. Fusing mechanisms must be reliable and vehicles should not be allowed to travel across fuse plug embankments. An example of an auxiliary spillway with a fusing mechanism is shown in **Figure C.15**.

Figure C.15: Auxiliary Spillway – Timah Tasoh Dam (provided by JPS Malaysia)

- Auxiliary spillways and discharge channels should be located and/or protected to minimise the potential for erosion to threaten the safety of a dam, to result in excessively high downstream discharges, and to result in excessive downstream environmental damage.

- For all spillways the likelihood and consequences of spillway blockage should be carefully evaluated. This is particularly important for orifice spillways with small inlet structures (e.g. tunnel spillways, morning glory spillways) and service spillways for flood detention dams. Usually, where there is a likelihood of spillway blockage, the only option is to provide an auxiliary spillway and discharge channel. An example of a morning glory spillway is shown in **Figure C.14**.

- Where flow conditions in approach channels are unsymmetrical or energy dissipation facilities incorporate flip buckets discharging into scour holes, hydraulic modelling should be completed to confirm design assumptions and finalise design details (e.g. head/discharge characteristics, chute wall heights, energy dissipation details, flow conditions downstream of energy dissipation facilities). In some cases computational hydraulic modelling will be sufficient (e.g. head/ discharge characteristics, chute wall heights); however, physical hydraulic modelling will be necessary for the detailed design of spillways with unsymmetrical inflow conditions, unconventional energy dissipation facilities and flip bucket shapes, and the determination of stable scour hole dimensions.

- Bridges located above spillway gate structures should be suitably restrained to ensure they are operational following the SEE and to ensure they do not impede gate operation following the SEE. Spillway bridge performance is especially important if spillway operating equipment required for post-SEE operation is fixed to the bridge. In addition, any gantry cranes located close to spillway gate structures should be tied down to prevent overturning during the SEE.

- Dividing walls and piers in spillway gate structures should be designed for the cross-valley component of the SEE earthquake loading. Small deformations of piers can exceed spillway gate side tolerances and result in gate jamming. An example of a gate structure with piers is shown in **Figure C.9**.

- Ideally, any necessary changes in the directions of spillway chutes should be included where subcritical flow conditions occur. If changes in alignment are necessary where supercritical flow conditions occur, they should be large radius bends and should be designed to ensure the resulting shockwaves are contained within the chute.

- Particular attention should be given to the adverse effects of high velocity flow, turbulence and abrasion. High velocity flow and turbulence effects include cavitation, the initiation of high uplift pressures beneath slabs, and slab vibration. Abrasion effects, which are normally limited to low level orifice spillways, can result in sufficient concrete loss to necessitate the completion of concrete repairs. ICOLD Bulletins 58 and 81 provide guidelines for the effective control of cavitation damage, and the design of chutes/tunnels and energy dissipation facilities.

- Spillway outlet tunnels beneath or adjacent to dams should be designed for non-pressurised flow conditions.

- It is important to consider the effects of high spillway discharges on the safety of a dam. Where spillways are expected to discharge high flows over long periods of time, severe damage can occur and affect the safety of a dam.

- Care is required in the design of spillway features to ensure spillway discharges are not adversely affected by physical impediments (e.g. the bottoms of gates in their fully open positions, stoplog storage facilities, bridges, rails, walkways) and high tailwater conditions.

- Tailwater conditions, which affect the design and performance of energy dissipation facilities, need careful evaluation taking into account the potential for long-term changes that could result from modified downstream river conditions.

c. Low Level Outlet Structures

- For Significant and higher hazard rating dams, the necessity for a low level outlet facility that enables the reservoir to be lowered in a potential dam safety emergency should be considered, particularly where embankment dams are located in the vicinity of active faults. Other facilities (e.g. deep spillway gates, penstock intake structures and water supply outlets) to provide sufficient dewatering in a potential dam safety emergency should be considered. The risk posed by the remaining pool after reservoir lowering (i.e. the likelihood and consequences of a dam failure following the reservoir lowering) needs to be understood.

- The design of a low level outlet facility should be such that it does not compromise the safety of a dam and, as such, the recommendations outlined above for conduits and orifice spillways are also applicable to low level outlet structures.

- Low level outlet facilities often incorporate intake/ outlet towers which can be free-standing on an enlarged base or foundation mat, partially embedded within embankment dams or structurally tied to the upstream faces of concrete gravity dams. Examples include the shafts of morning glory spillways and water intake towers.
- The failure of an intake/outlet tower, during or following an earthquake, could result in the uncontrolled release of a reservoir and, as such. All intake/outlet towers should be designed to accommodate SEE loadings. ICOLD Bulletin 123 provides guidelines for the seismic analysis and design of intake/outlet towers. The partial embedment of intake/outlet towers in embankment dams is not recommended because of the increased risk of dam failure if slope displacements of the dam were to occur during an earthquake.

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APPENDIX D: OPERATION AND MAINTENANCE MANUAL

D.1 INTRODUCTION

The efficient and effective management of a dam is enhanced by the provision of an O&M Manual.

The O&M Manual should include a brief summary of key project information, such as the purpose and history of the project development, the ownership, any significant site modifications, and the consequences of dam failure. The components of the dam system should be defined and documented to the extent that it would enable staff to understand their characteristics and interactions.

Infrastructure associated with the dam should be adequately documented. This would include an inventory of communications contacts and systems (land line, cellular, satellite, radio, etc.); road, rail, or other access routes; and both primary and secondary access routes, to ensure accessibility in an emergency. Legal agreements on ownership and usage by others should be identified.

Public safety systems and maintenance requirements should be documented, including procedures for installation and removal, if required, as well as the timing.

Security requirements and practices (including those for physical site, equipment, and cyber security) should be documented, but it may be advisable to keep the documentation confidential.

D.1.1 O&M in Relation To Dam Safety Management

A dam safety management system for High and Medium Hazard Rating dams should include the following O&M procedures:

- Reservoir operation procedures during normal, unusual (e.g. floods), extreme (e.g. earthquakes) and emergency conditions (i.e. conditions that could result in dam failure if appropriate actions are not initiated).
- Operating procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. reservoir level thresholds, gate/valve openings and discharge rates.)
- Maintenance procedures for gate and valve systems that fulfil dam and reservoir safety functions (e.g. visual inspections, battery/fuel checks, changes in lubricating fluids, major overhauls).

- Testing procedures for gate and valve systems that fulfil dam and reservoir safety functions, including power supplies, operating systems, and control and protection systems, to ensure ongoing functionality and reliability.
- Civil works maintenance procedures (e.g. internal drainage system cleaning, instrument repair, vegetation and debris clearing, upstream erosion protection reinforcement).
- Any procedures for the monitoring of upstream reservoir slopes and downstream banks (e.g. the stability of upstream landslides during high reservoir levels or rapid reservoir drawdown, and the stability of downstream river banks during high discharges).

D.2 SUGGESTED CONTENTS

Information and instructions in an O&M Manual should follow a reasonably standardised format. The following major section headings are suggested as a basic Manual outline for the majority of dams and should be varied according to the specific features of the dam:

- Preliminary Pages
- Dam Safety Emergency Plan and Communications Directory (referenced for extreme and high Hazard Category dams).
- Chapter 1 - General Information and Project Information
- Chapter 2 - Structural O&M Procedures
- Chapter 3 - Reservoir and Spillway Operations (normal and extreme conditions)
- Chapter 4- Inspection ,Maintenance and Testing of Gates and Valves System
- Chapter 5 - Dam and Reservoir Safety
- Chapter 6 - Responsibility, Accountability and Reporting
- Appendices

Preliminary pages should include the cover sheet, title page, table of contents, revision sheet, as well as any necessary certification and/or verification required by the Dam Owner. It is also desirable to include an aerial photograph of the dam and reservoir in these pages.

Details on the Dam Safety Emergency Plan, and associated Communications Directory, are covered elsewhere in MyDAMS (see section **8**). For extreme and high Hazard Category dams, these can be lengthy documents, which are usually prepared separately and referenced in the O&M Manual.

The first chapter, "General Information" should contain detailed information and instructions concerning the administration of the dam and reservoir as well as information on the Manual.

The second chapter, "Operations and Maintenance Procedures" should contain the detailed information and instructions necessary for the O&M of the dam, its appurtenant structures and equipment.

The third chapter, "Reservoir and Spillway Operations" should contain the detailed information and instructions necessary on all aspects of reservoir operations. It should also include a Storage Management Plan detailing water quality and environmental management issues/practices. This is particularly important when there are public use management issues around the storage.

Details on the fourth and sixth chapters are covered elsewhere in MyDAMS.

Appendices should contain all necessary drawings, maps, photographs, charts, lists of supporting and reference material.

D.3 EDITORIAL SUGGESTIONS

Manuals should give detailed understandable instructions able to be followed by a responsible person knowledgeable in dam and reservoir operations but not necessarily familiar with the particular dam in question. The use of drawings, marked photographs, colour coding and numbering valves, switches, concrete blocks, drains, etc., physically and in the manual are recommended to supplement step-by-step operation or maintenance instructions. These aids simplify instructions considerably and reduce the chance of error in their use.

The following editorial comments are suggested to improve the readability of the manual and to assist in the preparation and revision of the manual:

- Start each chapter on a new page (to facilitate revision) and use coloured card dividers between chapters.
- Each chapter should stand alone without reference to other chapters.
- Page numbering should be in the form 1-1, 2-1, etc., for the different chapters to allow for future revision without affecting overall page numbering.
- Use lists rather than narration to outline instructions and information whenever possible.

- Include drawings, sketches, graphs, manufacturer's instructions, photographs, references, etc., in Appendix or text.
- Avoid vague words (i.e. periodically).
- Bind manual in loose-leaf folder for ease of revision, additions and updating.
- Give each manual an identification number and keep a record of the location and status of each copy.

D.4 GENERAL INFORMATION

D.4.1 Purpose, Location and Description

The purpose of the dam, its reservoir and appurtenant structures should be clearly indicated in this part of the Manual. A brief history of the dam from inception to the Present time, indicating significant dates and events, should be included. Where appropriate, other significant data, landmarks or unique features and pertinent information on the darn and dam site should also be detailed including comments on identified problems from design, construction and subsequent behaviour.

The river or watercourse on which the dam is situated and location of the dam relative to readily identifiable points such as towns or cities is required in the manual.

Information should also be given on the access routes to the damsite including condition and alternatives. Where applicable, airports, either commercial or private, railway stations and seaport should also be identified. The most expeditious route should be indicated. The availability of special equipment for accessing the dam (helicopter, four wheel drive vehicles, should be noted.

Suitable location and/or topographic maps, kept up-to-date, should be included. These maps should be clear and precise.

A detailed description of the dam and its appurtenant structures should be included.

D.4.2 Administration, Operations and Responsibilities

All areas of responsibility in the administration, operations and maintenance of the dam, damsite and reservoir should be clearly indicated in the Manual. Some of the responsibilities that should be identified are as follows:

- Ownership;
- Administration;

- Operations of equipment at the dam;
- Reservoir inflow and flood forecasting;
- Authorising spillway flood releases;
- Authorising water supply and irrigation releases;
- Recording reservoir data;
- Routine inspection;
- Maintenance;
- Modifications (i.e. dam and equipment); and
- Dam safety and surveillance.

Administrative and operational relationships between the various operating and end user organisations should be detailed. Formal agreements as well as more informal arrangements should be referenced.

Agreements with other agencies or organisations, which have an essentially indirect interest in the dam or its operations and maintenance should be detailed. These agencies or organisations could have an interest in the following:

- Land management;
- Civil defence, counter disaster or emergency service activities;
- Environmental protection;
- Fish and/or wildlife;
- Forests;
- Geological surveys;
- National parks;
- Outdoor recreation;
- Soil conservation;
- Dam safety;
- Water resources;
- Research studies.

Organisation arrangements in the form of flow charts would be useful.

The operating personnel responsibilities should be specifically identified in the Manual. This should include regularly scheduled duties which they are required to perform. A typical schedule for the duties is given in section **D.7**.

D.4.3 Data Reporting and Operations Log

Brief instructions and standardised forms for the collection and reporting of all types of dam and reservoir data should be included. Lengthy or more detailed instructions, if required, disposition of the data reports.

For example, routine data may be required at a dam on the following:

- Reservoir inflow;
- Spillway outflow;
- River releases;
- Irrigation, water supply and hydropower draw off;
- Weather;
- Surveillance and monitoring; and
- Water quality.

Each dam should have an Operations Log whether or not it has full or part time attendants or is normally unattended. This log should be maintained by operations personnel preferably in a bound book and should contain a chronological record of all important events at the dam for future reference. This log could be helpful in providing clues to the cause of equipment failure and the development of unusual conditions.

Records in the log would vary according to the type and needs of the individual dam but typical entries could include details of the following:

- Attendance at dam;
- Normal or emergency operations of the outlet works or spillway gates;
- Start-up and stopping of mechanical equipment;
- Tests on standby equipment;
- Tests and exercising of outlet and other valves, gates, penstocks or stoplogs;
- Tests and exercising of spillway gates and associated controls;
- Minor and major maintenance activities including both scheduled and emergency;
- Reservoir and dam inspections;
- Unusual conditions or occurrences, including acts of vandalism;
- Emergency attendance at the dam;
- Reservoir water surface elevation;
- Changes to normal operating procedures;
- Communications network checks;

- Safety and special instructions;
- Names and addresses of official visitors (e.g. staff carrying out comprehensive inspection); and
- Other relevant items pertaining to the O&M of the dam in both normal and emergency situations.

D.4.4 Public Safety and Health

Instructions for public and personnel safety and protection at the dam or on the reservoir should be included in the Manual. Instructions required by the relevant legislations in which the dam is located should be included. Unsafe conditions and hazardous areas should be listed. The type and location of warning signs and other safety features or equipment should be noted.

Areas of the dam and reservoir restricted to the public should be detailed. Purpose of restriction should be explained.

Restricted areas which are potentially hazardous could include the following:

- Confined spaces, especially those with no ventilation;
- Spillway approach areas, chutes and stilling basins;
- Control buildings and valve areas;
- Intake or outlet channels adjacent to hydraulic structures subject to surging or rapid changes in water level during releases;
- Active landslide areas.

Suitable warning and restriction signs should be positioned at appropriate places around the dam and referenced in this Manual.

Reference should be made to the Communications Directory for local law enforcement, medical and fire services.

D.4.5 Attendance, Communication and Warning Systems

The individual or operating unit responsible for and extent of attendance at the dam should be noted in the Manual. Attendance could be either:

i. full-time (working hours)
ii. part-time (specific period) or
iii. unattended or remote operated

If unattended the frequency of inspection and other details relating to the operation of gates and valves and collection of data should be noted.

The means of communicating with the dam both in normal and emergency situations should be identified. All available communication means including phones, facsimile, relevant car-phones, radio and relevant pager links whether to public or private facilities or individuals should be noted. If no facilities are available at the dam the location and owner of the nearest phone or radio should be noted.

It is preferable that actual phone numbers and other communication numbers should be listed in the Communications Directory for the dam. However, a suitable reference to the Communications Directory should be included in this section of the Manual.

In addition to communication facilities a brief description of the emergency warning systems including alarms at the dam should be included. Reference should be made to the Dam Safety Emergency Plan.

D.4.6 Control of Operations and Maintenance Manuals

Distribution of Manuals should be determined on the basis of need for operations, maintenance, supervisory purposes and records only. To ensure that they are kept continuously revised a record should be kept of the distribution and location of all Manuals.

The person or organisation responsible for revising and recording the location and distribution of all Manuals should be clearly nominated. Formal procedures should be clearly established for revising the Manual with periodic reviews being conducted to ensure that the instructions are still relevant and/or are being observed by all personnel. All revisions or other changes to a manual should have approval of the responsible person or organisation.

In revising a Manual it is recommended that each revised sheet should clearly show the revision number and date. A summary listing of revised sheets should also be filed in the preliminary pages of the Manual to provide a convenient method of checking for current completeness.

D.4.7 Training

Suitable schedules, outlining frequency, subject matter and personnel involvement, should be established for routine training of operations, maintenance and other staff associated with the dam, reservoir and appurtenant structures. Standby or alternate staff should receive the same training. Training should encompass all activities relating to the O&M as well as safety precautions and procedures to be adopted in accident or emergency situations.

D.4.8 Supporting Documents and Reference Material

Supporting documents comprise the necessary instructions for all phases and levels of responsibility in the O&M of the dam and reservoir. All supporting documents that are part of the total instructions should be listed. The distribution of these documents and responsibility for preparing, updating and revising should also be listed.

These documents will vary according to the size, type and usage of the dam but may include the following:

- Designers operating criteria;
- Dam Safety Emergency Plan;
- Relevant state or federal government legislative acts;
- Flood forecasting and operating criteria;
- Basin or river operating plan;
- Power station operating instructions;
- Irrigation operating instructions;
- Water Supply Operating instructions
- Administrative procedures;
- Damsite security plan;
- Reservoir or river pollution contingency plans;
- Regional emergency handbook;
- Major maintenance procedures;
- Maintenance schedules;
- Manufacturer's instructions and drawings;
- Reservoir management plan (land, recreation, fish and wildlife);
- Regional communications directory for dams; and
- Instrumentation reports and/or results.

Reference material should consist of a listing of relevant manuals, contract documents, drawings, memorandums of understanding, reports and other reference books which contain information useful in the operating and maintenance of the dam. It is suggested that relevant Dam Safety Guidelines should be included in this listing.

D.5 OPERATIONS INSTRUCTIONS

The operating procedures should take into account the constraints which include the following:

- Maximum safe discharge rates for all flow control equipment
- Highest safe reservoir level beyond which dam components or reservoir rim may start overtopping and become unstable or cause flow control equipment to be inoperable
- Reservoir levels at which overflow discharge structures, fuse gates, or fuse plugs are intended to operate, expected outflows, and post-activation follow-up requirements
- Physical restrictions on operations that may impact dam or reservoir rim stability , precautions to be taken during drawdown events, first filling of the reservoir, or refilling of a reservoir after a period of low water level
- Legal constraints on discharge rates and downstream water level

D.5.1 Data, Information, Procedures and Protocols

Basic data required to accompany the instructions should include, but not be limited to, the following:

- Dam structure details including type, height and other dimensional data, location, year completed and hazard classification;
- Full Supply Level and Minimum Operating Level of the reservoir;
- Spillway type, capacity and associated details including spillway design flood;
- Outlet works type, capacity, reservoir draw-down rates and associated details; and
- Capacity and surface area curves.

Following the basic data, the detailed procedures and practices to be followed for particular situations should be detailed. Some of the situations that should be covered are as follows:

- Normal operation, including riparian release procedure;
- Flood emergency release procedure;
- Flood warning practices; and
- Limitations on reservoir draw-down rate to prevent dam reservoir slopes and embankment instability, downstream surges.

Each procedure or practice should provide complete, clear, step-by-step instructions for operating all necessary equipment associated with a dam including the outlet control valve and spillway gates. The frequency and nature (e.g. flow test, static test, dry test) of operational check testing of this equipment should be specified. Correct sequences should be emphasised and sketches, drawings and photographs to aid in identifying specific handles, buttons, levers, etc., should be included. Provision and usage of backup equipment should be outlined.

The correct method and sequence of opening and closing guard gates, gate usage during low and high flow, openings at which excessive vibrations are experienced, and operating problems peculiar to a specific gate should also be listed. For hydraulic and electric gates, a schematic diagram should be provided showing each component (including back-up equipment) and its place in the operating sequence.

Instructions should also be issued for the general operation of the reservoir, including monitoring and regulation of inflow and outflow. These might include maximum water levels to be allowed at different times of the year and maximum and/or minimum permissible carry over storage and outlet releases. Instructions should also describe operation of the outlet to limit or prevent excessive spillway flow, and the method for periodic drainage of the reservoir to permit inspection of normal submerged areas, e.g. outlet or foreshore slope.

Reservoir operating curves should be available for each normal mode of operation and for emergency conditions.

D.5.2 Gates and Valves System

All auxiliary power system, such as a petrol or diesel-operated generator or other appropriate energy source, is essential if the outlet and spillway gates and other dam facilities are electrically operated. This system should be clear of extreme flood levels and access and lighting for extreme events is essential.

All spillway and outlet gates should be tested on a regular schedule including alarms and indicators. The test should include use of both the primary and the auxiliary power systems.

D.5.3 Security and Public Safety

a. Site Security

Site security is a matter of concern at all major dams. This includes terrorism implications and preventing structural damage vandals and unauthorised operations of outlet or spillway gates. In most cases restricting public access is essential, and in some instances electronic security devices and/or watchmen should be considered.

b. Public Safety

Public safety is also of paramount importance at all dams and reservoirs. Specifically, public safety on the reservoir near the dam, in areas adjacent to the reservoir, and below the dam should be considered. Safety measures could include identification of high watermarks to indicate past or probable reservoir levels and stream flows, posting of safety instructions at highly visible and key locations, and providing audible safety warnings upstream of and below outlets as appropriate.

c. Communication

Communications should be maintained among affected government bodies and with the public to enhance the safety aspects of the operation of the dam. Communication alternatives include written communications, radio, telephone, television and newspapers.

D.6 MAINTENANCE INSTRUCTIONS

D.6.1 Maintenance Priorities

Maintenance is a task that should never be neglected. If it is, the consequences and costs could multiply. Maintenance could be prioritised as follows:

a. Corrective Maintenance, which may require immediate remedial action and even prior emergency action, such as evacuation, if warranted. These relate to the most critical of conditions at a dam, which call for immediate attention. These conditions may include, but are not limited to:

   - A dam being over-topped or about to be over-topped;
   - A dam about to be breached by erosion, slope failure or other circumstances;
   - A dam showing signs of piping and/or internal erosion;
   - A blocked or otherwise inoperable spillway at a dam; or
   - A dam showing signs of excessive seepage.

b. Preventive Maintenance - This can be further broken down into routine or condition-based maintenance:

   i. Condition-Based Maintenance - This may be relatively urgent. It should be scheduled bearing in mind the Dam Owner's resource constraints, the risks involved with not doing the maintenance and the owners priorities on the dam and within his darn portfolio. These may include, but are not limited to:

- Clearing undergrowth and trees from embankments, sealing any consequence piping / erosion areas, and establishing a good grass cover;
- Regrading and reseeding eroded areas and gullies;
- Repairing defective but still operational spillways, gates, valves and other appurtenant features;
- Repairing deteriorated concrete, metal or jointing compounds; and
- Maintenance and repair of cracks and joints in concrete structures.

ii. Routine Maintenance - Routine scheduled maintenance tasks at a dam could include:

- Mowing and general minor repairs;
- Maintenance of electrical and mechanical equipment and systems (e.g., servicing stand by generator, gantry crane, spillway gates);
- Operation of electrical and mechanical equipment and systems (e.g. exercising
  valves, exercising gates);
- Operation of scours and outlets to keep them clear of silt;
- Maintenance of monitoring equipment;
- Testing monitoring equipment and alarms;
- Testing security equipment;
- Testing communication equipment
- Inspections (discussed elsewhere in MyDAMS); and
- Monitoring upstream and downstream developments, which could have an impact on the dam or its hazard category.

D.6.2 Maintenance Checklists and Schedules

Specialists should prepare maintenance checklists and schedules indicating the maintenance procedures, frequencies and protective measures for each structure and for each piece of operating, communications, and power equipment, including monitoring systems. Special attention should be given to known problem areas.

Special instructions should be provided for checking operating facilities following floods, earthquakes, and other natural phenomena.

Maintenance procedures include preventative measures such as painting and lubrication as well as repairs to keep equipment in intended operating condition, and minor structural repairs such as maintaining drainage systems and correcting minor deterioration of concrete and embankment surfaces. The design staff should be advised of any significant maintenance work.

Maintenance of retarding basins is essential to ensure their ongoing performance. Outlets should be maintained clear and tree growth in overflow sections removed to maximise performance during floods. Grass cover should be maintained to prevent scour and erosion during flood events.

A list of tasks included in the maintenance instructions may comprise but is not restricted to the following:

- removing brush and trees;
- removing debris, including silt upstream of outlets;
- regrading the crest and/or access roads;
- removing harmful fauna;
- operating and lubricating gates;
- adding rip-rap when needed;
- sealing joints in concrete facings;
- clearing seepage measuring weirs, surface drainage channels and pits;
- maintaining monitoring points;
- maintaining security of operating equipment;
- repairing damaged or deteriorating concrete;
- cleaning uplift pressure and other drains;
- maintaining all associated electrical and mechanical equipment;
- reporting any abnormalities observed during the course of maintenance (e.g. higher than normal seepage or new seepage locations);
- removing floating debris from the reservoir;
- maintaining spillway protection floating booms;
- painting of metal and timber surfaces;
- maintaining road bridge bearings and expansion joints across spillways;
- maintenance of coating and protection from impact for steel conduits outlet works;
- maintaining outlet works tunnels;
- maintaining valves; and
- maintaining safety signs and barriers.

D.7 SAMPLE DUTY SCHEDULE FOR OPERATING PERSONNEL

The following checklist should be used as a guide in preparing a duty schedule for operating personnel. The frequencies of these duties should be varied according to circumstances (e.g. the condition of the equipment). All activities, or lack of activities with reasons, should be recorded in the dam logbook.

(1) DAILY

- Visual inspection of dam
    - Crest of dam
    - Upstream and downstream faces
    - Visible portions of foundation and abutment contacts
    - Galleries
- Record water and flow rates
    - surface elevation
    - reservoir inflow and spillway discharges
    - releases
    - seepage

- Complete logbook which should include the above information

(2) MONTHLY

Check condition of:

i. Dam and Reservoir:

- Spillway stilling basin
- Outlet works stilling basin
- Critical landslide areas
- Reservoir area
- Drainage systems, toe drains
- Measuring devices and alarm levels
- Fauna problems
- Security and safety devices
- Communication devices
- Vegetation growth (there may be too much or too little)

ii. Electrical System

- Standby generator
  - Run for minimum of 1 hour
  - Keep battery charged
  - Check fuel supply
- Replace light globes

(3) THREE MONTHLY

i. Outlet Works

- Operating instructions - up to date and legible
- Check gate air vents on downstream face
- Clean gate control switchboxes
- Check security and safety devices
- Read weather gauges and record data
- Make required changes in gates and valves
- Check log or safety boom
- Check spillway outflow channel for debris
- Check instrumentation schedule
- Record pertinent information in Operating Log
- Check seepage weir condition
- Grease hydraulic gate hanger
- Check
  - Signs that warn public of hazards
  - Trashrack of intake structure
  - Outlet works stilling basin
  - Valve house

ii. Spillway

- Check for debris in inlet channels
- Check operation of gates
- Check fence condition and caution signs
- Check and clear bridge drains
- Clean inside of motor control cabinet

(4) SIX MONTHLY

i. Outlet Works

- Check hydraulic oil lines
- Check oil reservoir level in hydraulic system
- Lubricate gate rollers
- Check rubber seals and seal clamp bar
- Check hoist cables – lubricate

ii. Electrical System and Equipment

- Change oil in standby generator
- Check exposed electrical wiring
  - Outlet works, valve house
  - Spillway bridge
  - Gate hoists

(5) ANNUALLY

i. Outlet Works

- Paint
  - Metalwork
  - Colour-coded valves
  - Woodwork and trim
- Exercise gates and valves

ii. Spillway

- Exercise equipment

(6) FIVE YEARLY

Examine intake structure, trash racks and stilling basin, which normally are underwater; less frequent if experience indicates. This should coincide with the Comprehensive Inspection and may need to be done by divers.

i. Dam and Reservoir

- Review the O&M Procedures.

ii. Mechanical

- Check and re-paint metal work on gates, bridges, pipes, fences, etc.
- Check hoists cables – lubricate
- Check mechanical hoist bearings and flexible coupling bearings
- Check gear cases
    - Hoist gear case, replace grease
    - Spur gear units and gear motors

iii. Electrical

- Check electrical conduits, pull-boxes and switches
- Outlet works valve house
- Gate hoists
- Spillway
- Galleries

iv. Outlet

- Check condition of interior and exterior of outlet conduit.

D.8 REVIEW AND TEST

The Dam Owner, with support from appropriate technical and operations and maintenance personnel, should periodically review and test the dam's O&M procedures and protocols, particularly those where dam and reservoir safety is dependent on the correct operation of gates and valves.

APPENDIX E: DAM SURVEILLANCE

E.1 INTRODUCTION

For the safe operation of dams and reservoirs, dam surveillance procedures should be in place as the Dam Owner's “first line of defence”. There are similarities of antecedent tendency that cause deficiencies and subsequent development of incidents and failures. A robust surveillance provides the aims to detect such tendencies timely to enable dam safety actions to be taken, thus preventing oversight.

There are various levels of inspections to be executed appropriately:

- Regular inspection is carried out during daily operating conditions.
- Comprehensive inspection is carried out for a period following, unusual or extreme loading conditions (e.g. floods and earthquakes), or when a potential dam safety deficiency exists.
- Emergency inspection is necessary when there is imminent dam safety deficiency developing to a threat.

E.2 DAM SAFETY INSPECTIONS

E.2.1 Personal Safety

For safety reasons it is advisable to have two or more personnel on each inspection, particularly for dam safety activities in isolated areas.

E.2.2 Equipment

The following items are often useful:

- checklist, field book and pencils;
- recording device;
- cameras (still and video);
- hand held levels;
- probe;
- safety gear; (e.g. waders, harnesses, hard hats, safety boots, breathing apparatus, gas detector and anything else to comply with safety regulations);
- tape measures;
- torch (”mine safe " for unventilated conduits, tunnels or adits);
- shovel;

- geologist's hammer;
- binoculars;
- first aid kit;
- stakes and flagging tape;
- crack gauge; and
- lock-off labels.

E.2.3 Recording Inspection Observations

Check and record status of all items on a checklist. Provide accurate location of -questionable areas and take photographs. Note extent of such areas (i.e. length, volume, width and depth or height). Give a brief description of any anomalous condition, such as:

- Quantity/quality of drain outflows, seepage and its source(s);
- Location, type and extent of deteriorated concrete;
- Location, length, displacement and depth of cracks;
- Extent of moist, wet or saturated areas; or
- Changes in conditions from previous inspection(s).

E.2.4 Records

A signed dated report should be completed for each inspection, and filed with any photographs taken (These must be dated and labelled). Related monitoring readings and weather conditions (especially air temperature and recent rain) should also be included in the inspection report along with the dam's water level.

Observations should be promptly compared with previous records to look for unexpected differences.

E.2.5 Routine Inspections

As noted in section **8.2.2**, the most important activity in a dam surveillance program is the frequent and regular inspection of the dam for abnormalities in conditions and for deterioration. The earliest detection of obvious problems will come from the daily to weekly visual observations by the dam operator. However, the dams engineer (surveillance) or the Dam Owner may require a more thorough and wide-ranging observation of the dam and its surrounds by a trained inspector other than the daily operator, specifically for dam safety purposes, and considered recommendations for corrective action. These latter reports would form the basic "formal" records of the dam's condition for archiving and future surveillance reference.

E.2.5.1 Routine Visual Inspection and Surveillance

Routine visual inspections are carried out generally by the dam operator and a brief written report is made. A typical Routine Visual Inspection report form is included below and should be adapted to suit the particular dam with reference to the checklist given in **E.2.13**. The report should be used to record new developments and changes to existing developments, as well as to record action items.

The reports are to be reviewed by the dam engineer, responsible for surveillance, action Items noted and the report filed for future reference. If appropriate the reports are referred to the Dam Owner for noting any actions required.

The Routine Visual Inspection report form must include clear instructions for the inspector on immediate actions, and who to contact, in an emergency situation.

Figure E.1: Typical Routine Visual Inspection Report

Water Surface Level (e.g. FSL) Overflowing	.... m Yes ☐ No ☐
Dam Crest: Any depressions/cracks/changes? Any deformation of crest, etc.	Yes ☐ No ☐ Yes ☐ No ☐ Details:... ....
Upstream Face of Wall: Any deformation/slumps/changes?	Yes ☐ No ☐ Details:... ....
Downstream Face of Wall: Any unusual or changed features — evidence of movement, slumping, subsidence or new seepage	Yes ☐ No ☐ Details:... ....
Spillways: Any obstructions or damage?	Yes ☐ No ☐ Details:...

	....
Seepage: Any obstructions or damage to seepage weirs Readings:	Yes ☐ No ☐ Depth of flow Flow Turbid Detail V1.................mm ....l/sec yes/no V1.................mm ....l/sec yes/no
Read Rain Gauge	....................mm
Visit entered in Site Log book	Yes ☐ No ☐
Is it necessary for Manager, Asset Management to note any incidents?	Yes ☐ No ☐
Inspected by:	Signed:............................ Date:....................
Checked by Dams Engineer (Surveillance):	Signed:............................ Date:....................
Data entered in Dam Log book:	Signed:............................ Date:....................
Sent to Records:	Signed:............................ Date:....................

E.2.6 Crucial Inspection Times

Inspection is recommended, regardless of the regular schedule, in the following cases:

- During and immediately after the first reservoir filling of a new dam or after augmentation;
- During and after a significant rapid drawdown;
- Before a predicted major rainfall or filling;
- During (if possible) and after heavy flooding; and
- Immediately following an earthquake, sabotage or overtopping, and then regularly for several months to detect any delayed effects.

E.2.7 Embankment Dams

The following items should be noted, and inspecting staff should be trained to appreciate the implications of their occurrence.

E.2.7.1 Upstream Slope

Cracks, slides, cave-ins or sink holes, erosion and deterioration of rip-rap. When a reservoir is emptied, the exposed area should be thoroughly inspected and photographed to record its condition.

E.2.7.2 Downstream Slope

Cracks, slides, sink holes, excessive erosion, inappropriate vegetation, or turbid, excessive or new seepage should be noted. Slope failures require immediate evaluation. Early warning signs include a bulge near the toe of an embankment or vertical displacement in the upper portion of an embankment.

If any of the above conditions are seen or suspected, they should be recorded and the opinion of an experienced dam engineer should be obtained.

E.2.7.3 Top of Dam (or Crest)

Questionable conditions on the crest should not be disturbed or obscured before the opinion of an experienced dam engineer has been sought.

Some potentially threatening conditions are longitudinal cracking, transverse cracking, misalignment and excessive settlement.

E.2.7.4 Seepage Areas

No dam is completely leak proof. However, changes in the nature of the seepage, (e.g. flow or turbidity) should be observed as an indicator of potential problems occurring inside the dam or foundations. An inspection for seepage should be made when a reservoir is full and the seepage can be expected to be at its maximum.

E.2.8 Concrete Dams

Concrete dams may fail due to the development of structural cracking, foundation and abutment weakness or severe concrete deterioration. In addition, concrete dams can react particularly to seasonal effects with temperature induced movements and cracks opening more in wet season than in dry season. These effects can be greater than hydrostatic load induced movements and should be considered when setting surveillance requirements and reviewing surveillance data.

Access to the downstream face, toe area, and abutments of concrete dams may be difficult and require special safety equipment and procedures. However, regular inspection with powerful binoculars initially can identify areas where change is occurring.

Monitoring helps detect structural problems in the dam, abutments, or foundation. Cracks may develop slowly at first. If a suspected structural crack is discovered, the opinion of an experienced dam engineer should be sought. The installation of monitoring instruments, such as crack pins, may be required to be read on a regular basis.

E.2.9 Spillways

A spillway should provide a safe exit for excess water from a reservoir. A conscientious annual maintenance program should be pursued and inspections should note whether this is in effect.

Water must be conveyed safely from the reservoir to a point downstream of the dam without endangering the spillway or the embankment. A range of spillway flows should be observed to confirm that the design is adequate.

Spillway inspection should also look for obstructions, cavitation erosion, deterioration of floor and walls, deterioration of joint sealants, misalignment at joints, or cracking.

Walls of spillways usually have weep (or drain) holes and occasionally spillway floor slabs also have these. When it is safe to enter the spillway, plugged weep holes should be probed and where necessary cleaned out (to restore drainage). Care should be taken not to damage or remove any drainage filter material placed behind the wall or below the spillway floor.

Misalignment of spillway walls or floor slabs should be noted and compared with that of previous inspections, to check for progressive or unexpected deformation.

E.2.10 Outlets

An outlet should always be operable. Before a valve or gate is operated, it should be inspected and all appropriate parts lubricated and repaired if necessary. It is also prudent to advise downstream residents of unscheduled large or prolonged discharges. Such discharges should be increased gradually, so as to minimise the risk of damage downstream.

All aspects of the outlet should be checked for deterioration (e.g. rusting, dissimilar metal corrosion, protection systems, weld cracks, etc.).

For routine testing of a valve or gate for operability, appropriate operating procedures for isolating the valve or gate from the reservoir pressure should be applied.

For testing valves or gates under normal operation conditions, or simulated emergency conditions, appropriate fail-safe test procedures should be applied.

Outlet pipes, 750 mm or greater in diameter, can be inspected internally, provided the system can be emptied and entry made safe. Tapping the conduit interior with a hammer can help locate voids outside the pipe, and between the lining and the pipe. Smaller diameter pipes can be inspected by remote TV camera.

Great care should be taken to observe appropriate procedures when refilling the outlet pipes so as to safely discharge all air trapped during refilling.

Appurtenances underwater should be inspected whenever the reservoir is drawn down or at least at five-year intervals. If a significant problem is suspected, or the reservoir remains full over extended periods, divers should be used for an underwater inspection.

The full range of valve or gate settings should be checked. The operation of all mechanical and electrical systems, backup electric motors, power generators, and power and lighting wiring associated with the outlet should also be checked.

E.2.11 Operational Preparedness Checks

All mechanical equipment should have operating instructions and prescribed O&M plans. Equipment, including spillway gates, sluice gates, valves, stoplogs, pumps, flash-boards, relief wells, emergency power sources, siphons, and electrical equipment should be operated as prescribed in the operations plan. Testing, as appropriate, should cover the full operating range under actual operating conditions. Each operating device should be permanently marked for easy identification, and all operating equipment should be kept accessible. All controls should be checked for proper security to prevent vandalism. All operating instructions should be checked for clarity and maintained in a secure, but readily accessible location.

E.2.12 Other Areas for Inspection

The foundations, abutments, and reservoir rim should all be inspected regularly (e.g. weekly to monthly).

Inspections should be made far enough downstream to ensure that there are no problems developing that could affect the safety of the dam, such as excessive foundation seepage, valley slope failure or blockage downstream of the spillway.

The reservoir surface and shoreline should also be inspected regularly (e.g. weekly to monthly) to identify possible problems for the dam's safety. Whirlpools indicate that water is escaping rapidly. If this is not attributable to the outlet system, a very dangerous situation exists. A build up of rafts of weed, timber and debris can be blown along the reservoir mid cause blockage at outlets and spillways. Wave and rainfall erosion of exposed banks can cause continuing turbidity problems. In steep country, large landslides coming into the reservoir could cause waves that will overtop the dam or could cause water quality problems; and suspect areas should be appropriately monitored.

Development upstream, and other catchment characteristics that might influence the quantity or quality of reservoir water or silt inflows, should be noted in major inspection reports to anticipate possible problems or the need for modifications to the dam.

Development downstream in flood plains should also be regularly assessed, as the extent of development and the PAR downstream dictate the level of inspection, monitoring and surveillance required at the dam and the extent of flood preparedness planning, which relate directly to the damages and legal liability should the dam fail.

E.2.13 Inspection Checklist Sample (Select appropriate items for particular dam inspection)

a. General

Record:

- Names and roles of persons making the inspection
- Date of inspection
- Weather conditions (cloud cover, rain, wind, temperature) on day of inspection
- Dates and amount of most recent rainfalls
- Storage level
- Date and magnitude of most recent flood (earthquake)

b. Earth/Rockfill Embankment Inspection

Check for:

- Bulges, displacements, depressions (particularly in crest)
- Alignment
- Crest condition
- Cracks-longitudinal / transverse (give width and location)
- Seepages, damp spots
- Sinkholes
- Gullying
- Tree or shrub growth / Condition of grass cover
- Burrows
- Rip-rap condition
- Wave beaching
- Debris accumulations
- Evidence of soil dispersivity
- Operator or public safety issues
- Other anomalous conditions

c. Concrete Dams

Check for:

- Offsets at joints
- Cracking (describe type, width, location and orientation)
- Spalling
- Matrix condition
- Lift joint condition (efflorescence, seeps)
- Leakages
- Erosion
- Joint filler condition
- Metalwork condition
- Pressure relief drains, holes (note flows, blockages, etc.)
- Condition of any lighting, ventilation provisions
- Operator or public safety issues
- Other anomalous conditions

d. Instrumentation

Check:

- Seepage weir flow depths
- Clarity of seepage
- Fines accumulation?
- Iron precipitates
- Drowning of weirs?
- Condition of weirs including obstruction and sedimentation
- Condition of piezometers / groundwater holes /monitoring enclosures, etc.
- Piezometer readings
- Surface settlement points condition
- Relief well flows / pressures
- Condition of tiltmeters, pendulums
- Condition of any other instrumentation
- Operator or public safety issues

e. Spillways

e.1. Approach Channel

Check:

- Alignment
- Depth
- Obstructions (trees, flood debris, rockslides, etc.)
- Log boom

e.2. Control Structure

Check:

- Condition of mechanical / electrical equipment (e.g. gates)
- Offsets at joints
- Cracking (describe type, width, location and orientation)
- Spalling
- Matrix condition
- Lift joint condition (efflorescence, seeps)

- Leakages
- Erosion
- Joint filler condition
- Pressure relief drains, holes (note flows, blockages, etc.)

e.3. Chute

Check:

- As for control structure where concrete
- Erosion (note present extent and say whether stable or progressive)
- Instability due to erosive undercutting?
- Tree growth and its effect on spillway operation
- Debris

e.4. Dissipator and Stilling Basin

Check:

- As for control structure where concrete
- Evidence of gravel abrasion of concrete
- Sediment accumulations
- Erosion (record present extent and say whether stable or progressive)
- Debris
- Instability due to erosive undercutting?
- Tree growth and its effect on spillway operation

f. Abutments / Immediately Downstream / Reservoir Rim

Check for:

- Stability (e.g. slips, slumps, movements)
- Seepages
- Sinkholes
- Erosion
- Evidence of artesian pressures
- Vegetative cover

g. Outlet Works

Check:

- Condition of concrete
- Condition of metalwork
- Condition of valves
- Condition of mechanical / electrical equipment
- Condition of protection systems
- Maintenance requirements

E.3 SPECIAL INSPECTION / REVIEW AREAS (TO BE CONSIDERED BY DAM ENGINEERS DURING COMPREHENSIVE INSPECTIONS / SAFETY REVIEWS, ETC.)

Check:

- Access conditions (normal, flood, post earthquake, changes)
- Communications (normal, flood, post earthquake, changes)
- Documentation (drawings, reports, O&M manual, DSEP, log books)
- Key dimensions against documentation
- Procedures adequacy (normal, emergency)
- Operator knowledge, experience, training
- Inspection/ monitoring frequency and adequacy
- Site security (access, manning, alarms, locks)
- Hazard Rating update (changes to affected population, infrastructure, environment)
- Incidents, concerns
- Site geology
- Design adequacy (flood, seismic, operations)

E.4 MONITORING

E.4.1 Installation of Measurement Devices

Devices must be robust enough for long-term use and simple enough for operations personnel to make observations and their installation should be controlled by specialists. Check readings should be taken before, during and after installation, so that, where possible, replacements can be made for damaged items, or adjustments can be made.

Similarly, independent check readings and calibration checks should be made at regular intervals throughout the life of the instrument.

E.4.2 "Up-Front" Review of Data

Data should be under continual scrutiny from the earliest possible time to ensure that the processed results make sense. This is particularly important for instrumentation linked to alarm telemetry. The following points generally apply:

- Raw data should be simple and unambiguous;
- Since data forms the basis of any mathematical model used for judgment on safety,' at least two mutually corroborative sources should, where possible, be used in such a model (e.g., surface movement targets and internal movement devices); and
- Each data reading system should have facilities to detect the occurrence of "obviously different" data, which can be caused by either:
    - Transcription errors;
    - Instrumentation malfunction; or
    - Abnormal behaviour of the dam.

Such situations should be investigated immediately. If it is found that change is attributable to abnormal behaviour, the Dam Owner should initiate further investigations to explain the abnormality and ensure that it is not indicative of a worsening situation with respect to darn safety. Given that time may be a critical factor in responding appropriately, the Dam Owner should preferably consult an experienced dam engineer, familiar with the dam, to fast-track any response.

E.4.3 Long Term Storage of Data

Data "screened" of obvious errors and thus available for the evaluation of dam safety should be stored in perpetuity as hard copy or on computer. The data provides a record of the behaviour of the dam from its inception and will be invaluable as a past record. If the computer is to be the sole means of storage, then backup files, on separate systems, are absolutely essential.

Stored information should be secured within the framework of a data file system, with appropriate back-ups. Dam Owners should note that where the format of data storage becomes outdated, it will need to be carefully transferred to updated systems to ensure future users have ready access to the data. Where ownership of a dam changes, the new Dam Owner should ensure that stored data is transferred from the previous Dam Owner.

E.4.4 Data Presentation

Instrumentation readings and inspection reports can result in a rapidly expanding mass of data which should be reduced to a form suitable for clear presentation. Once the data are presented, graphically or numerically, the interpretation and evaluation phase can follow.

E.4.5 Personnel

Since monitoring can be expected to extend over the life of a dam (100 years or more) new or “change-over" staff require adequate documentation of, and training in, dam instrumentation. It is essential to have, and keep, as-constructed records of the instrumentation.

Ideally there should always be at least two members of the "extended" surveillance staff capable of maintaining and repairing any of the instrumentation. Education and training of staff involved in instrumentation must be on-going.

E.4.6 Automation

Special points to note are:

- Any telemetry system should be regularly tested and maintained, be compatible with its instrumentation, and transmit data to a continuously manned or alarmed station at the dam or elsewhere;
- The danger that automation may interrupt the vital direct link between primary event and human judgment should be avoided;
- Since a well designed and maintained dam is generally more reliable than any single alarm device, the facility to quickly corroborate alarm information should be available and used; and
- Periodical testing and, verification of equipment/alarms is essential.

Further details are provided in ICOLD Bulletin 41 (1982) and the upcoming Bulleting 158 (still a preprint at the time of preparing MyDAMS). The following **Figure E.2** extracted from ICOLD Bulletin 118 explains the extent of definition of the concept of surveillance to be used in this **Appendix E**.

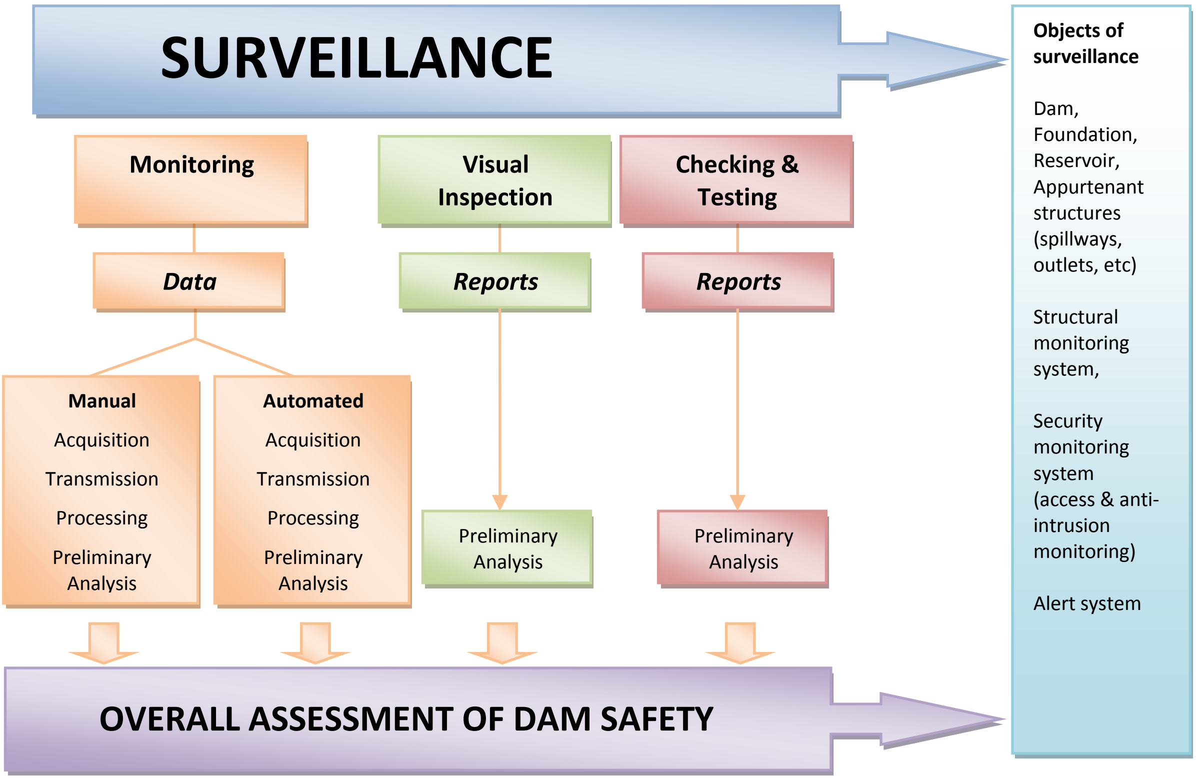

Figure E.2: Concept of Surveillance

E.4.7 Computerised System

A computerised system of receiving and reviewing numerical data and some related text is generally as outlined in **Figure E.3**. However, the following points should be considered (Stirling and Benwell, 1989):

- The database selected should be of the relational type or, possibly, the object oriented type appropriate to the database being managed;
- The system should have a good user interface which makes entry to and extraction from the database relatively simple;
- The database package chosen should have a good query language, so that the interrogation of the database is relatively simple;
- Ideally the system should include automatic reading and recording of dam instrumentation (i.e. data logging);
- The system should enable correlation of seepage, storage level and rainfall;
- Data entry routines should have some form of error checking (data validation);
- The results from surface movement surveys should be incorporated into, and analysed in, the same database as embedded dam instrumentation data. Instruments

used for surface movement surveys should, where possible, be capable of automatically recording observations;

- Ideally, the data stored in the database should include raw instrument readings as well as corrected or calibrated data; and

The sophistication of the database should be tailored to the amount of data received from a dam. Many dams would not need a computer database. However, all dams require some form of systematic and readily retrievable "data file" to store relevant reports and historical information; and this should be preserved for the life of the dam.

To preserve such records in perpetuity is not often an easy task and could involve lodging records in a relevant public or commercial archive.

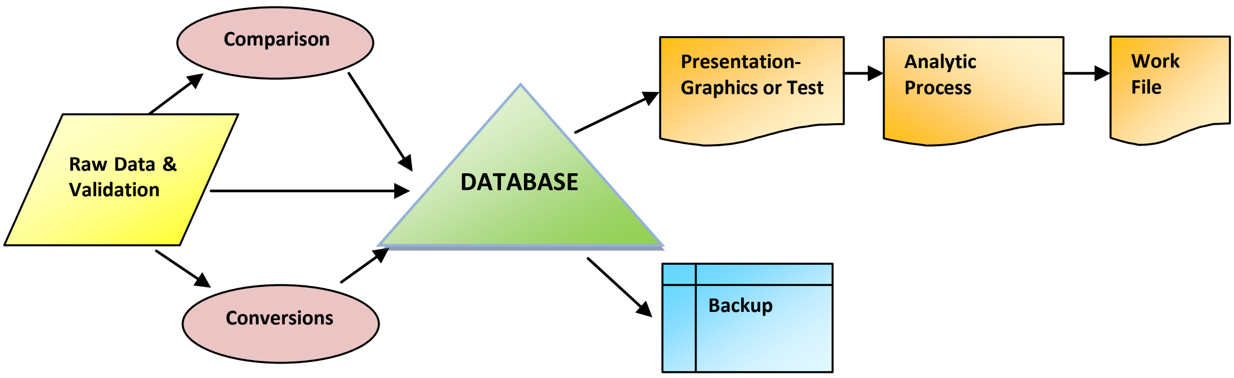

Figure E.3: Data Systems

E.5 SURVEILLANCE EVALUATIONS

E.5.1 General Interpretation

All new data should be thoroughly examined in context with existing data.

The sophistication of the evaluations should be tailored to the amount and variety of data received from the dam, which should in turn relate to the importance of the dam. It is recommended that for evaluations for all dams of significant or higher Hazard Rating the Dam Owner should consult an experienced dam engineer.

a. Situation "Normal"

Normally the latest set of observations can be quickly scanned as numbers in a table or points on a plot and be seen to be as expected. In simple cases such as settlement or horizontal deflection of fill or gravity dams the reading should be within a millimetre or two of expectation, for a well planned observation schedule.

For high thin-arch dams, reservoir water level and seasonal temperature variations can justify statistical regression checks, and here again the observation should be within a few millimetres of a well organised prediction from regression.

Leakage and piezometric data, when notionally cleared of local runoff effects, should generally follow any significant reservoir head changes. Seasonal opening and closing of joints or cracks in concrete dams can be reflected in gallery or toe drain flows, but after allowing for such influences, there should be negligible long term change.

b. Anomalies – Real or Not?

It sometimes happens that an isolated instrument reading, or a survey observation, will indicate some severe distress or a strain, deformation or pore pressure, which, if valid, would represent a real threat to the dam.

Every effort should be made to urgently assess such a situation, with repeat readings, repair of blown fuses, or possibly even extra instruments, targets or reference pillar checks.

If, on inspection, the dam is not in distress, and the adjacent parts are not indicated as behaving abnormally, that instrument reading or survey observation must be taken as anomalous, however carefully it purports to have been checked as “correct".

c. Typical Assessment (of "Overall Picture")

In foundations with piezometers in-line upstream and downstream of grout and drainage curtains, and flow measurement of drains or drainage adits, it is possible to develop a good picture of the water table.

Ideally the piezometers will continue to indicate a roughly linear head drop along the seepage path. Rises and falls can be expected to follow reservoir level changes.

If tightening of foundation joints by creep causes a slow reduction in the long term mean leakage flow, the head pattern described above should still apply.

If pressures build up downstream of the drainage curtain that cannot be attributed to seasonal influences, consideration of some extra drainage drilling is indicated.

d. Emergency Action "Triggering"

The dam engineer (surveillance) should be familiar with the designs, recent performance and possible failure mechanisms of all dams for which he has surveillance responsibility.

If the perceived need arises, and there is a recommendation for emergency action, immediate personal access should be available to the Dam Owner's personnel to put the action into effect. Senior management persons must not usurp the authority of the appointed dam engineer unless they are appropriately qualified and experienced and ready to accept possible criminal charges related to the consequences of dam failure.

Staff at the dam should be sufficiently trained to recognise an emergency and have the authority to trigger emergency action in the event of a disruption in communication. Close, regular liaison with those responsible for emergency services should be maintained by owners of very high, high and significant Hazard Rating dams, particularly with regard to inaugurating, testing or upgrading EAPs.

E.5.2 Factors for Consideration

The evaluation of a dam's performance usually requires a close inspection of the dam and its appurtenances, examination of water pressures and seepage records and the various measured movements relative to the abutments or of differential movement within the dam. These data are then compared with design assumptions, predictions and historical behaviour patterns to fully evaluate the existing situation.

E.5.2.1 Seepage

Seepage through, around or under a dam is expected. The quantity and nature of seepage, the seepage paths, and the velocity of the seepage waters are of concern in analysing the dam's structural behaviour.

The quantity and nature of seepage is important for several reasons:

(a) Leaching – Seepage may dissolve or leach some of the chemical constituents of the concrete, rock or soil. Leaching may provide an enlarged seepage path resulting in progressively increasing seepage. Dams founded on limestone are subject to this problem. Evaluation of the composition of the seepage water (e.g. turbidity, dissolved salt content, etc.) can give a further insight into dam behaviour.

(b) **Weakening –** Seepage water may completely saturate soils and rock, and cause excessive uplift (pore pressures) as well as softening and weakening of soil and rock.

(c) **Loss of Storage –** Excessive leakage may, in extreme cases, compromise the storage capability of the reservoir.

(d) **Indication of Behaviour –** Increases in seepage quantity with time may indicate the onset of internal erosion, and decreases may indicate infilling of seepage paths, with possible build up of internal pressures in dams and their foundations.

The location of a seepage path is of concern because:

(a) **Piping –** If seepage is confined to a few discrete paths and the velocity becomes sufficiently high to move soil particles, progressive erosion may occur resulting in a "piping" failure.

(b) **Leaching –** Seepage waters may result in concentrated dissolution.

(c) **Drainage –** If discrete seepage paths are present and are not intercepted by drains, then drains should be installed.

Seepage (or pore) pressures within a dam and its foundations, if exceed design values, may compromise the stability of a dam.

E.5.2.2 Movements

Some movement of all or part of a dam can be expected (e.g., seasonal movements due to temperature change or rainfall absorption, or changes in water level). Movements may be in the vertical plane, the axial plane (along the dam's axis), the upstream-downstream plane, or rotational. It is common for more than one direction and mode of movement to be present in a dam.

Vertical movements occur as a result of consolidation of the foundations or the material in the embankment. Such settlement is typically greater along the crest of the dam than along the heel or toe and is also usually greater near the centre of the dam than near the abutments.

Such settlement can result in cracking. Minor upward vertical movement (heave) can also occur at the toe of an embankment dam due to fill creep or excess uplift pressures.

Vertical movement of the centre of a fill dam with respect to the abutments is generally associated with horizontal movement toward the centre of the dam. This axial movement results in tension, which can involve cracking of the core or face membrane.

Upstream-downstream movements are usually in the downstream direction and are typically due to hydrostatic forces acting on the upstream face of the dam. These movements can be horizontal or rotational. Upstream movements in a concrete dam are usually associated with “bowing” of the dam due to expansion and are usually temperature driven. Upstream movements of an embankment dam are usually of a rotational-type and may occur during "rapid drawdown". These rotational movements may be a deep-seated or a relatively shallow configuration in the upstream face and indicate formation of a slope failure. The slides may extend into the foundation, intersect at the dam's heel or toe, or may be entirely contained within the dam. The general cause of such movements is deficient shearing resistance along the often saturated failure surface associated with high uplift pressures and reduced effective stresses.

E.5.3 Crucial Times for Evaluation

During the life time of a dam, from initial planning, through construction, reservoir filling, and operation, an evaluation may be necessary as follows:

E.5.3.1 Pre-construction

Evaluation of pre-construction conditions using various instruments can be valuable. During the initial planning and design stages several important considerations affecting dam safety should be investigated. They include:

(a) **Normal groundwater levels –** The existing ground-water level in the abutments, dam area, reservoir rim, and downstream of the dam and its seasonal variation should be determined.

(b) **Quality of the groundwater –** Groundwater mineral composition can be compared with later seepage water mineral composition and the reservoir water to aid in determining if dissolution is occurring.

(c) **Seepage at abutments –** Seepage due to natural groundwater at abutments prior to construction will affect the design of the dam and later evaluation of the dam's performance.

(d) **Landslide scars/faults –** Old landslide scars and faults in the vicinity of the dam indicate the potential for additional sliding during reservoir construction and operation.

(e) **Permeability of existing materials –** For the foundation, abutments, and reservoir floor, treatments such as grouting cut-off walls and upstream blankets may be required to reduce the effect of excessively permeable materials.

(f) **Foundation settlement –** Knowing the characteristics of foundation materials allows anticipated settlement of the dam to be estimated.

(g) **Fill and foundation shear strength –** The shear strengths of the relevant materials are needed to determine the stability of the dam.

(h) **Seismic –** The seismic risk at the dam site is used to design the dam to resist loading up to the SEE. Preparations should also be made to assess the potential for reservoir induced seismicity.

(i) **Hydrologic –** Catchment conditions, flood potential and the likelihood of changing conditions affecting future flood magnitude are important in determining spillway capacity.

E.5.3.2 During Construction

Installation and observation of instrumentation begins during construction to provide essential background data for the behaviour of a dam and to ensure that the dam is performing in accordance with the designer’s intent. Visual observation is also vital during this period. Important considerations affecting dam safety during the construction phase of a dam include:

(a) **Instrument Installation –** Many types of instrument may be installed during dam construction. These include piezometers, pressure cells, strain gauges, settlement and movement measuring devices and thermometers. It is absolutely essential that proper care be taken during their installation, and to protect them from construction operations, otherwise no information of value will be obtained from them. Incorrect installation techniques produce information detrimental to interpretation. Instruments must be tested as they are installed. Continuous supervision by specialists with authority to require repair or replacement is vital in the rough construction environment.

(b) **Settlement –** Consolidation of foundation and embankment materials result in settlement of the surface of the dam as it is constructed. Settlement measuring instrumentation (such as hydrostatic manometers and cross arms), installed during construction, record such settlement.

(c) **Observation of Excavations –** During construction, excavations for foundation and core trenches should remove undesirable materials. Visual observations by experienced personnel during this phase are extremely valuable and should be carefully recorded. Based on these observations, there may be need for instruments to be relocated, or added, or for design changes. This information can be important in diagnosing subsequent anomalous behaviour.

(d) **Increasing Pore Pressures –** Rapid construction of embankments, at high moisture contents, may cause excessive pore pressures, which would result in instability if not allowed to dissipate. Records of such construction pore pressures can be of long-term significance.

(e) **Slide Movements –** Slide movements due to high pore pressure building up during construction may be noted either visually or by instrumentation.

(f) **Temperature –** Excessive temperatures, built up from cement hydration in concrete dams, may cause subsequent thermal cracking if not controlled.

(g) **Permeability –** Filter permeability should be checked as placement can compact a filter more than specified.

E.5.3.3 During First Reservoir Filling

The first filling of a reservoir is normally the critical condition for dams. At that time, the first true analysis of the behaviour of a dam with reservoir loading can be made. Instrumentation readings and visual observations should be conducted very frequently during this period with particular attention paid to the following matters:

(a) **Seepage –** As the water level in the reservoir rises, it is especially important to watch both the dam and abutments for increases in seepage quantities, changes in seepage clarity, new seepage locations and the functioning of drains.

(b) **Pore Pressure –** At this time frequent reading should be taken to monitor pore pressure changes and patterns.

(c) **Dam Movements –** The increasing load from the reservoir water will cause movements of the dam, particularly in the downstream direction. These require close monitoring, ideally including correlation with movement controlling factors.

E.5.3.4 During Normal Operation

The normal trouble free operation of a dam over many years is the goal for which the dam was built. The water level in many reservoirs fluctuates each year resulting in seepage quantity and pore pressure fluctuations on a regular, somewhat predictable basis. It is therefore important to establish a regular instrumentation monitoring schedule and a regular visual inspection of the facility and to summarise the findings in regular surveillance reports on the dam. Any significant unusual changes noted should be an immediate cause for further investigation.

E.5.3.5 During Record Reservoir Fillings or Following Earthquake

Record fillings of reservoirs and earthquakes can subject a dam to loading conditions that it has never been subjected to before. These can be critical. Instrumentation readings and visual observations should be conducted very frequently during and following these times with particular attention paid to the first filling matters (section **E.4.3.3**).

E.5.3.6 During Rapid or Prolonged Drawdown

Occasionally, the reservoir level is lowered rather quickly for some reason. The term “rapid” depends on the type of material in the dam and abutments. In some relatively permeable materials, "rapid" may mean hours or days, while in low permeability materials, a "rapid drawdown" might cover a period of weeks, months or longer. During drawdown the external reservoir water pressure is removed but the internal pore pressures in the dam and abutments remain, to dissipate much more slowly in impermeable materials. This creates a condition wherein slides and movements may occur in the upstream face or core of an embankment, the abutments, or anywhere along the reservoir rim. In addition, collapse compression has been experienced in upstream “dirty” rock fill shells after drawdown leading to stressing of the adjacent core. Surface movements and pore pressures in the upstream shoulders and core of embankment dams require special monitoring at this time and subsequent refilling.

E.5.4 Data Interpretation

E.5.4.1 Data Presentation

The use of graphical presentation of instrumentation data is normally considered necessary for the evaluation of dams. Graphical presentation by computers is simple and rapid and reduces the chance of plotting errors and enables ancillary computations and data variation checks to be performed.

Data presentation, when properly done, is of very significant value, but incorrect data plotting may cause errors in interpretation. The characteristics of incorrect plotting include:

(a) **Improper Scale –** Proper and consistent scales must be used. Movements should not normally be shown larger than full-scale (1:1).

(b) **Excessive data –** In general, each plot should contain only two variables; (e. g. water level and time.) There may, however, be a large amount of data points on a single instrument or even a number of instruments. The number of instruments shown on a single sheet of plotting is a matter of common sense. Plot lines should not repeatedly cross each other and distinctly different line symbols should be used for each plot.

(c) **Coloured Lines –** Distinguishing plots solely by colour should be avoided due to the use of black and white photocopying (e.g. when "quoting" plots in subsequent communications).

E.5.4.2 Detection of Errors

Data errors can usually be detected either in the field at the time of reading or in the office during processing or reviewing. Often, it has been found that if the instrument reader knows what the previous reading on an instrument was, he can re-check the current reading if it differs significantly. In addition, the risk that the reader will report a reading close to the previous one without actually making an observation, or even where a different reading is actually obtained, has to be considered.

E.5.4.3 Normal and Abnormal Conditions

Application of the terms "normal" and "abnormal" depends on the particular characteristics of a dam in question. The behaviour of pressures, strains, movements, and seepage, should be compared to the behaviour anticipated during the design of the dam and any pre-construction data gathered from the dam site. It is important for dam designers to state acceptable “ranges” in design reports and operating instructions. For dams with limited design data, historical behaviour patterns should be developed.

E.5.4.4 Correlation of Inspection/Monitoring Data

The recommendation for major remedial works on a dam should not depend on uncorroborated evidence. Ideally any visible anomaly should be confirmed by anomalies recorded on associated instruments.

It is important to compare measured aspects of a dam's behaviour over identical date ranges. Since observations cannot always be made concurrently, response factors, such as regression coefficients, should be used to determine the most probable values on the chosen comparison date, for observations that could not be made on the date. Reservoir water level, ambient temperature, and age since construction should be included among the controlling variables in these studies. In comparing the dam designer's predictions and the prototype's performance, regression can be an important tool in separating the effects of temperature, water load and creep, so that each may be compared in turn.

In general, those responsible for interpreting monitoring results should endeavour to make all possible logical linkages throughout the range of dam data obtained from observations and inspections and be vigilant in the detection of errors and false alarms. Familiarity with the reliability of installations and observers is a great advantage in making a judgment as to whether an "alarm" is false or real as a result of a genuine excessive change in the value of the entity being monitored. In this regard, close liaison between dam operators and surveillance personnel is critical.

REFERENCES

ICOLD Bulletin 41 (1982). Automated Observations for the Safety Control of Dams

ICOLD Bulletin 118 (2000). Automated Dam Monitoring Systems

ICOLD Bulletin 158. Dam Surveillance Guidelines, Preprint

Stirling, D.M. and Benwell, G.L. (1989). Surveillance Data Management – Review of Practice in Australia. ANCOLD Bulletin No. 84

APPENDIX F: EMERGENCY PREPAREDNESS

F.1 INTRODUCTION

This Appendix provides a framework for the development of EAPs to reduce the potential for dam failure through pre-planned interference actions should a dam safety emergency event arise and, in the event that a dam failure cannot be prevented, to limit the effects of a dam failure on people, property and the environment. The Appendix includes:

- An outline of emergency preparedness planning and processes.
- Recommended procedures for the development of EAPs.

The objective in preparing the Appendix is that it is consistent with NADMA for the crisis management of emergencies.

F.1.1 Principles and Objectives

All dams should have emergency response procedures in place if emergency procedures could reduce the potential for dam failure, if there is population at risk, or if implementation of emergency procedures could reduce the potential consequences of failure. Emergency action procedures are included in documents with a variety of names such as an Emergency Preparedness Plan (EPP), an Emergency Response Plan (ERP), a Dam Safety Emergency Plan (DSEP), or an Emergency and Disaster Management Plan (EDMP). In MyDAMS, emergency response procedures are included in an EAP.

The level of detail in the procedures should be adequate to ensure all necessary information and directions are conveyed, but not so wordy as to inhibit the reader from gaining a clear and definitive understanding of the actions to be taken. Principle 11 in the Parent Document states that:

Effective emergency preparedness and action plan should be in place for dams.

The objectives of this appendix are to provide guidance for the development of dam specific EAPs, and outline appropriate testing and training programmes to confirm the ongoing effectiveness of dam specific EAPs.

Planning for a dam safety emergency is a necessary risk management task, especially for Dam Owners where there is a potential for loss of life or heavy environmental damage and costly restoration in the event of dam failure. An EAP, that describes the actions to be taken by a Dam Owner or Operator during a dam safety emergency, should be prepared for all

Significant or higher Hazard Rating dams. Guidance on the classification of dams by hazard potential rating is provided in **Appendix B**. Notwithstanding this, Dam Owners may choose to prepare EAPs for dams that present a lesser hazard for their own organisational risk management goals and objectives.

Effective emergency management relies on the establishment of a clear emergency response plan and strategy that is understood by all involved in the dam safety emergency and is supported by the following:

- An EAP that details the actions the Dam Owner or Operator will take in response to a dam safety emergency.
- A maintenance, testing and training programme to improve and confirm the ongoing effectiveness of the EAP.
- A local emergency plan developed by NADMA, prepared in coordination with and using inputs from the Dam Owner, for their own purposes to warn and evacuate residents in the flood plain should this be necessary.

F.1.2 Scope of Appendix

This appendix provides guidance in emergency action planning for dams. It is specific to dam safety emergencies that have the potential to endanger the integrity of the dam, damage downstream property and result in loss of life. It is not relevant to other emergencies (e.g. a personal accident or an oil spill) or dam safety incidents, such as large flood events or observed departures from expected dam performance, which do not endanger the integrity of the dam, damage downstream property or result in loss of life. The appendix addresses:

- Potential dam safety threats and dam safety emergencies.
- Procedures for the development of EAPs.
- What should be included in EAPs.
- Sample EAP format.
- Responsibilities for maintaining and updating EAPs.

A list of reference documents is included at the end of this appendix to assist Dam Owners in the development of EAPs.

F.2 EMERGENCY PREPAREDNESS PLANNING

Emergency preparedness planning is planning that allows all involved with the dam and the potential consequences of dam failure, including the Police and NADMA, to be prepared for the management of a dam safety emergency. It is an important component of a dam safety management system and includes the preparation and maintenance of an EAP, and regular training exercises to ensure that emergency management personnel are familiar with the EAP and their responsibilities and that they are able to fulfil their duties during a dam safety emergency.

F.2.1 EAP Documentation

Where appropriate, there should be an EAP for each phase of a dam's life cycle – during construction, first filling and normal operations, rehabilitation and decommissioning. EAPs should be controlled documents covered by appropriate procedures for distribution and the management of changes.

The EAP should be referenced in O&M procedures so that there is a seamless transition in the management between normal operating conditions to emergency conditions. This is particularly important with respect to Operations and Maintenance procedures for plant and equipment that fulfil dam safety functions.

F.2.2 Potential Dam Safety Threats and Dam Safety Emergencies

Potential dam safety threats can be initiated by a range of conditions that include:

- A flood.
- An earthquake.
- A landslide into the reservoir from the reservoir slopes, or from the abutments.
- The identification of abnormal behaviour (e.g. evidence of significant seepage, piping, spillway blockage, inoperable gates, etc.).
- Incorrect operation.
- Accidental damage.
- Sabotage.

Potential dam safety threats will vary depending on the hazards and risks, and the characteristics of the dam and its reservoir, and the EAP should reflect the particular site-specific hazards and risks, and the characteristics of the dam.

Once a dam safety emergency has been declared, it is important that it is classified using pre-defined criteria to trigger the appropriate emergency response. Typically, three levels of emergency response are defined, with increasing levels of urgency:

- **Internal event** – Only impacts on the Dam Owner and the response can be managed internally.

- **Potential emergency** – Has the potential to affect external parties and the Police, NADMA, emergency services, and local and regional authorities should be notified of the situation.

- **Imminent failure** – An event that will affect external parties is underway. A dam failure has either occurred, is occurring or is obviously about to occur. The Police, NADMA, emergency services, and local and regional authorities should be immediately notified of the situation.

Note that Dam Owners cannot declare disaster emergencies; they can only be declared by people with specifically designated roles in accordance with the National Security Council Act 2016.

A simple flow chart showing a typical process for the management of a potential dam safety threat, or a dam safety emergency, is shown in **Figure F.1**.

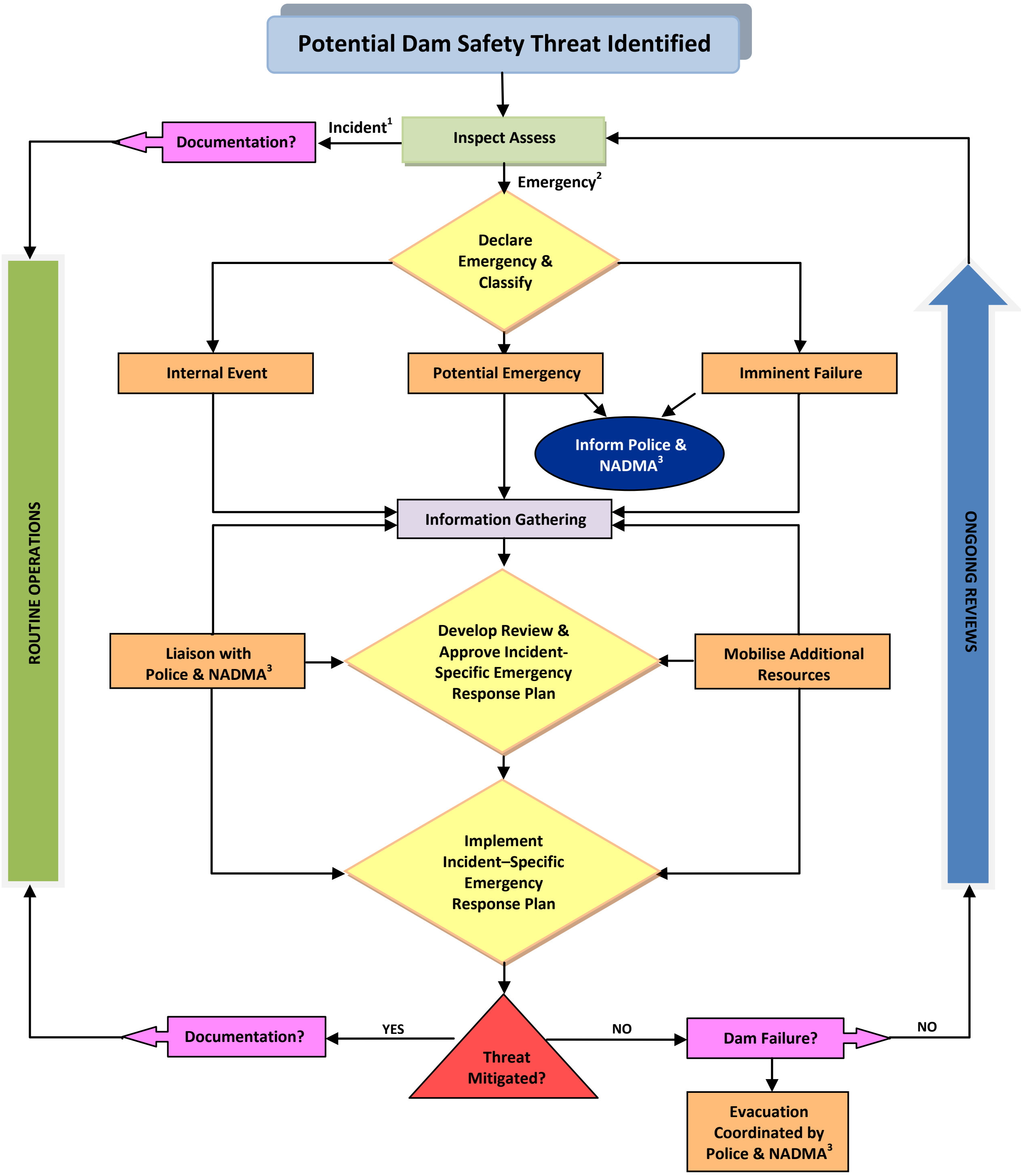

Figure F.1: Typical Process for the Management of a Potential Dam Safety Threat or a Dam Safety Emergency

Note 1: An incident is defined as an occurrence that requires a response from one or more agencies, but is not an emergency.

Note 2: An emergency is defined as a situation that poses an immediate risk to life, health, property, or the environment and requires a coordinated response.

Note 3: National Disaster Management Agency.

F.3 EMERGENCY ACTION PLAN

F.3.1 Development of an Emergency Action Plan

An EAP should detail the actions that the Dam Owner and operating personnel should take in a dam safety emergency. The EAP should be specific to the dam and should include emergency procedures for each of the identified credible potential failure modes for the dam.

Where a chain of dams is located on a river system, coordination is necessary to ensure that emergency actions taken at one dam do not jeopardize the safety of a downstream dam.

Where a single Dam Owner has a portfolio of dams, it may be appropriate to develop a generic EAP that details common company procedures and includes, within separate appendices or reference documents, site-specific information and procedures relating to each dam and its credible potential failure modes.

The development of an EAP requires coordinated planning with all involved parties. In this regard an EAP has two components:

- The internal procedures that the Dam Owner or Operator carry out in the event of an emergency at the dam (who does what when).
- The information needed by external agencies so they can develop their own emergency plans (e.g. inundation maps, notification procedures).

The steps in developing an EAP are generally as follows:

- Identify those situations or events that may require the initiation of an emergency action. Reference should be made to potential failure modes for the dam (refer Parent Document and **Appendix C**) and the likely consequences of a dam failure (refer **Appendix C**).
- Identify performance or surveillance indicators which may indicate that an emergency is developing.
- Identify key sources, agencies, and individuals who are able to supply information for input into the EAP.
- Identify all jurisdictions, agencies, and individuals who will be involved in implementing the EAP.
- Identify primary and auxiliary communication systems, both internal (between owner/operator personnel) and external (between owner/operator personnel and external agencies).

- Identify all persons and agencies involved in the notification process (by liaison with the local NADMA Group), and draft a notification procedure. Include who should be notified, in what order, and what other actions are expected of downstream agencies.
- Liaise with relevant Local and State Government agencies to ensure the EAP will have a good fit with wider community emergency plans.
- Develop a draft EAP.
- Discuss the draft EAP fully with all parties included on the notification list, seeking review and comment.
- Make any revisions, obtain any necessary approvals, and circulate controlled copies of the completed EAP to those who have responsibilities under the plan.

F.3.2 Contents of an Emergency Action Plan

An EAP should include, or include references to, the following information and procedures:

- The purpose of the EAP.
- EAP responsibilities.
- Emergency contact lists.
- Identification, assessment and classification procedures.
- Notification procedures.
- Preventive and emergency actions.
- Emergency termination actions.
- Access to site, including site location maps and main and alternative access routes.
- Response procedures for any situation where access to the dam may be impaired (e.g. during periods of darkness, adverse weather, transport disruptions, road closures).
- Communication systems.
- Emergency power supplies.
- Sources of emergency materials, supplies and equipment.
- Technical and operational support resources.
- Warning systems (if used).
- EAP maintenance and training.
- Dam break inundation maps and tables.
- Any additional information required to ensure an appropriate response to a potential or imminent dam safety emergency.

F.3.2.1 Purpose of an EAP

The purpose of an EAP is to provide a pre-determined plan of actions that a Dam Owner is able to implement if a dam safety emergency develops.

As such, an EAP should be designed to:

- Minimise the potential for dam failure should a potential dam safety emergency arise.
- Limit the effects of a dam failure on people, property and the environment In the event that a dam failure cannot be prevented.

An EAP should take into account the credible potential failure modes applicable to the dam and the potential downstream consequences of the breach discharges associated with those potential failure modes. It should define and prioritise the implementation of those actions that realistically may be achieved to minimise the potential for loss of life and damage to property and the environment.

F.3.2.2 EAP Responsibilities

This section should specify the person(s) or organisation(s) responsible for the surveillance, maintenance and operation of the dam and the person(s) and or agencies responsible for implementing various stages of the EAP. Delegated authorities for key personnel should be specified.

The availability of emergency personnel to fulfil their responsibilities during a dam safety emergency can be affected by large natural events such as floods and earthquakes. For example, nominated emergency personnel may be directly affected by a large earthquake and unavailable to assist in the management of a dam safety emergency that arises following the earthquake. It is therefore important that EAPs incorporate a level of resilience to ensure appropriate personnel are available to assist in the management of a dam safety emergency.

F.3.2.3 Emergency Contact Lists

The EAP should include an easy to find list that provides key emergency contact details.

The details should include names, roles, addresses and contact details (landline and mobile telephones numbers), and the details should be updated on a regular basis to ensure they remain current.

F.3.2.4 Identification, Assessment and Classification Procedures

Potential threats which could endanger the safety of the dam and could require immediate action should be included in the EAP.

If detected early enough, potential dam safety threats can be assessed and preventive or remedial actions can be taken prior to the declaration of a dam safety emergency to avoid a dam breach or mitigate the size and extent of a dam breach. The EAP should contain clear procedures for taking action when a potential dam safety threat is identified.

A special dam safety inspection should be carried out as quickly as possible following the identification of a potential dam safety threat. Appropriate monitoring should take place during the assessment of the potential dam safety threat and continue until the threat has been resolved. A list of qualified dam inspectors and technical specialists, keyed to the type of dam safety threat, should be included in the key emergency contacts list included in the EAP.

The declaration of a dam safety emergency requires that a responsible person decides if and when an emergency should be declared and the EAP implemented.

Any hesitancy in declaring a dam safety emergency could affect the effectiveness of any emergency actions. Clear guidance should therefore be provided in the EAP on the conditions which require a dam safety emergency to be declared, who is able to declare a dam safety emergency, how the emergency declaration should be recorded, and what guidelines should be followed in classifying the emergency (internal event, potential emergency or imminent failure).

F.3.2.5 Notification Procedures

The first step with regard to notification is the ‘decision to notify’. This decision is particularly important for the evacuation of any PAR and the notification procedures should detail who has the authority to make the decision to notify and how the decision should be made according to the timing of the event (day, night, weekend). Any hesitancy in making the decision to notify could affect the effectiveness of the evacuation of any PAR.

The Police, NADMA, and local and state authorities should be notified of any potential emergency and immediately notified of any imminent failure.

Notification procedures must be clear and easy to follow. The EAP should include a list of all persons to be notified in the event that a dam safety emergency is declared, and clearly indicate who is to make the calls and in what priority. The number of persons to be notified by each responsible individual should be kept to a minimum. The procedure, which is often best presented in a notification flow chart, should include notification to the Police, NADMA, Dam Owner, Technical Advisers, Contractors, Local Authorities and State Authorities as appropriate. The procedure should also include individual names and position titles, office and home telephone numbers, and alternative contacts and means of communication. Copies of the notification procedure, or flow chart if prepared, should be available for all individuals having responsibilities under the EAP, and should be prominently posted at the dam and the Dam Owner's emergency operations centre.

Early notification to the Police will allow them to determine if they have sufficient resources to respond, or if they will need to call in NADMA. The local NADMA may or may not decide to declare a disaster emergency.

The EAP does not necessarily need to include details of briefings for the news-media but procedures for these should be pre-planned. Consideration should be given to the use of a dedicated person, skilled in media briefings, to prepare statements and provide regular updates to the news-media.

F.3.2.6 Preventive and Emergency Actions

This section should detail preventive actions that can be taken both prior to and following the declaration of a dam safety emergency to remedy or mitigate the potential effects of a dam failure. In broad terms, such actions are likely to fall into one of the following categories; intervention to prevent dam failure, reducing the level of the hazard (lowering the reservoir level), slowing the rate of deterioration, or reducing the consequences of the failure. Depending on the dam safety emergency, there are likely to be potential actions available in more than one of these broad categories.

Actions taken prior to the identification of a potential dam safety deficiency, that can assist in the mitigation of a dam failure or minimise the downstream effects of a dam failure, include:

- Agreements with supporting third parties to respond at short notice with equipment, materials or expertise.
- The stockpiling of materials.
- The installation of warning systems to alert the PAR.
- Establishing coordinated plans and procedures with District Office and NADMA.

Preventive or remedial actions taken prior to the declaration of a dam safety emergency may include reservoir drawdown (refer Section **4**), limiting inflows and outflows, placing material to curb potential seepage erosion or piping discharges, placing material or sand bags at low spots on a dam crest, or controlled breaching.

Preventive actions taken following the declaration of a dam safety emergency may include initiating physical works to reduce the likelihood of dam failure, reservoir drawdown, or evacuating people from the likely inundation area.

The EAP should include events or indicators that would initiate implementation of the EAP. These may be based on the design criteria adopted for the dam, the historical performance of the dam, or the results of a completed

Failure Modes and Effects Analysis (FMEA). The following factors and emergency response actions should be outlined in the EAP:

- Events and indicators that would initiate the EAP.
- The nature of the discharge (size, contents) that may potentially be released in a failure.
- Estimated times to respond to an adverse event (e.g. estimated time before failure, time for earthmoving equipment to reach site, available warning time for downstream population).
- Information from third parties (e.g. weather forecasts, river flows) that can assist in the timing of preventive actions.
- Details of any warning systems.
- Actions that can be taken to lower the reservoir, or limit reservoir inflows and outflows.
- Actions that can be taken to remedy or alleviate the dam safety emergency.
- Actions to mitigate the potential effects of a dam failure.

F.3.2.7 Emergency Termination Actions

The EAP should include procedures for terminating a dam safety emergency and notifying the emergency authorities that the dam safety emergency has been resolved. The emergency authorities are responsible for declaring an end to any public emergency response process.

Following the termination of a dam safety emergency, as determined by the Dam Owner and/or his/her Technical Adviser, the Dam Owner or Technical Adviser should fully document the emergency response in a report. The report should include discussion on:

- The event or condition that initiated the emergency.
- The response actions taken by the Dam Owner and all emergency service agencies.
- The extent of any damage to the dam.
- The extent and effect of any downstream inundation.
- The justification for terminating the dam safety emergency.
- The strengths and weaknesses of the existing EAP including the emergency management procedures, equipment, resources and leadership.
- Corrective actions to address any identified weaknesses in the EAP.

F.3.2.8 Access to Site

The description of access should focus on primary and secondary routes, the means for reaching the site under various conditions (e.g. road, foot, boat, helicopter, bulldozer), and the expected travel times.

Earthquakes and heavy rainstorms can result in landslides, tree falls and bridge washouts that prevent road access for days or weeks. Poor weather can also prevent helicopter access. It is therefore important that the accessibility of the site following a large natural event, and the effects of possible access constraints on the availability of equipment needed to manage a dam safety emergency, are given early consideration and that EAPs incorporate a level of resilience to minimise the adverse effects of access constraints. If access constraints are likely following a large natural event, it may be appropriate to store essential equipment at the site.

F.3.2.9 Response Procedures where Access to the Dam may be Impaired

The EAP should include response procedures for any situation where access to the dam may be impaired. Access could be impaired during:

- Periods of darkness, including those caused by power failures. Appropriate responses may include establishing emergency power and lighting, limiting areas of access or inspection, or waiting until daylight.
- Adverse weather, including extremes of temperature, or storms. Appropriate responses may include temporary shelters, appropriate clothing and equipment, or unmanned surveillance.

- Transport disruptions.
- Road closures.

F.3.2.10 Communication Systems

Full details should be included of the internal and external communication systems as they apply to the EAP. Commonly used communication systems (cell phone, land line telephone and email) are vulnerable to failure or overload in the adverse conditions that may lead to a dam safety emergency (e.g. earthquake, storm, heavy rainfall, etc.). As such, the robustness of the available communication systems should be assessed and, where appropriate, enhanced by additional communication systems.

Examples of additional communication systems are trunk radios, satellite phones and internet messaging.

F.3.2.11 Emergency Power Supplies

Details on the location and operation of emergency power supplies (e.g. portable generators, fuel) should be included.

F.3.2.12 Sources of Emergency Materials, Supplies and Equipment

The location and availability of emergency supplies (e.g. food for response teams) and materials (e.g. rip rap, filter and drainage materials) for emergency use should be addressed.

The location and availability of equipment (e.g. torches, cameras, emergency lighting, earthmoving plant) and local contractors that could be mobilised in a dam safety emergency should be included.

F.3.2.13 Sources of Technical and Operational Support Resources

In a dam safety emergency it may become necessary to obtain specialist technical support to consider dam performance trends and identify the need for any preventive actions or temporary support works. It may also become necessary to obtain additional resources for operation of the facilities (e.g. during a basin wide emergency that affects the operation of a number of dams).

Managing a dam safety emergency is demanding on staff and additional resources may be required if the emergency is likely to extend beyond 10 hours. In addition, resources from outside the affected area may be appropriate in some circumstances (e.g. following a large local earthquake on-site resources may be affected by family or other concerns).

The EAP should include a listing of technical and operational support personnel, together with their contact details.

F.3.2.14 Alert Systems

Alert systems are sometimes installed to provide warnings to residents, camp grounds, and parks that are close to a dam. Where they are installed, full details of the warning systems and their activation, including who is responsible for any decision to activate the warning systems, should be included in the EAP.

F.3.2.15 EAP Maintenance and Training

The Dam Owner is responsible for issuing, maintaining and updating all registered copies of the EAP. It should be a controlled document.

The EAP should include provisions for appropriate review of the document, its procedures and communications systems for currency, relevance and operability. The review should be completed on a regular basis, at least annually, and include updating, as necessary, the names and contact details for all personnel with emergency management responsibilities. The EAP should also be reviewed during the Dam Safety Reviews to verify that it is current and that the information, guidance and direction are consistent with the dam's condition and performance.

Provisions should also be included for the training of personnel involved in the activation and implementation of the EAP. This is to ensure all personnel nominated in the EAP are familiar with the elements of the plan and their responsibilities, and are able to fulfil their duties during a dam safety emergency. Training exercises can range from a limited table top exercise for a specific dam safety emergency to a full scale simulation of a dam safety emergency which includes multiple failures (domino effects). Some details of the exercise could be referred to Appendix H of FEMA, 2013.

The frequency and type of training exercises should reflect the consequences of failure and should be sufficient to maintain the Dam Owner's readiness for a dam safety emergency. It should also reflect the level of turnover in personnel having emergency preparedness responsibilities. A frequency of two to three years would be appropriate in most instances. From time to time, Police and NADMA officers should participate in the training to maintain their readiness for a dam safety emergency and maintain coordination across all affected parties.

F.3.2.16 Dam Break Inundation Maps and Tables

Dam break inundation maps (refer **Appendix B**) assist Police, NADMA, and Local and State Authorities in the development of management and evacuation plans. However, inundation maps are usually based on worst case dam failure scenarios and understanding the actual condition of the dam, and the most realistic dam breach scenarios, are important for communication of the risk to the downstream population.

Dam break inundation maps should be included or referred to in all EAPs prepared for Significant or higher hazard rating dams. They should show inundation areas at scales sufficient for the identification of areas at risk and should include inundation tables which show at key locations:

- The arrival time of the first flood waters.
- The arrival time of the peak flood level.
- The peak flood elevation above mean sea level.

It may also be useful to express flood levels as relative depths at key locations (e.g. bridges) and the time at which key structures may become unusable. State Authorities have a responsibility for state scale natural hazard information, including flood hazard maps. Where the estimated discharge that would result from a dam failure is similar to the flood size already mapped, the existing inundation information held by the State Authority may suffice.

F.3.2.17 Additional Information

Additional items frequently incorporated as appendices in an EAP include:

- General site plans, drawings and photographs.
- Details and operating instructions for gates and valves that fulfil dam safety functions.
- Information for assessing reservoir dewatering options.
- Procedures for the recording of emergency situations (e.g. flood inspection check lists, post-earthquake check lists, emergency action log, and emergency termination log). A sample of incident status summary is provided at Annex F.

F.3.3 EAP Format

The effectiveness of an EAP can be enhanced by the adoption of a uniform format that ensures all information and procedures are included and easily understood.

While an EAP should be formatted in a way that is most useful to and consistent with the organisation involved in its implementation, the sample format outlined in **Figure F.2** for a Significant or higher hazard rating dam should result in a user-friendly document that facilitates a timely response to a potential or actual dam safety emergency.

An EAP for a Low hazard rating dam need not be as detailed as that for a Significant or higher hazard rating dam, but should be sufficiently detailed to meet the Dam Owner's risk management goals and objectives.

EMERGENCY ACTION PLAN

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UP-FRONT MATERIAL

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EAP Signature and Approvals

EAP INFORMATION

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    - 4.4 Termination and Documentations
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APPENDICES

1 Drawings

2 Inundation Maps and Tables

3 Checklist and Forms

4 Reservoir Drawdown Plans

Figure F.2: Sample format for an EAP (Significant or higher Hazard Rating Dam)

F.4 RESERVOIR DRAWDOWN PLANS

For many dams, a primary response to a dam safety emergency may be to reduce the hazard by drawing down the reservoir. Depending on the characteristics of the dam safety emergency and the available drawdown facilities (e.g. spillways, low level sluices), the achievable drawdown may be limited to the normal operational range of the reservoir or it may be possible to drawdown the reservoir to the invert levels of the discharge facilities.

Reservoir drawdown plans should be developed for all Significant or higher hazard rating dams that incorporate drawdown facilities, and the plans should either be referenced or incorporated within the EAPs. Because drawdown requirements in a dam safety emergency are often difficult to establish, drawdown plans should include sufficient flexibility to respond to changing conditions and contain sufficient information to assist decision makers in determining appropriate courses of action.

A reservoir drawdown plan might contain:

- Dam safety conditions that could necessitate reservoir draw down.
- An outline of reservoir inflows and whether or not they can be controlled.
- An outline of the available drawdown facilities, their discharge capacities and their drawdown limitations.
- Limitations on the rate of drawdown to prevent serious damage to the dam, (e.g. a rapid drawdown failure of the upstream slope of an earth dam), and prevent instability in the abutments or the reservoir slopes including any dormant or suspected landslides.
- Limitations on the rate of discharge or discharge rates to reduce downstream impacts.
- Alternative drawdown scenarios and drawdown procedures.

- Plots of reservoir level versus time, for the alternative drawdown scenarios and procedures, which reflect drawdown and discharge limitations and clearly show drawdown progress.
- Links to the EAP and emergency notification lists.

REFERENCES

ANCOLD (2003). Guidelines on Dam Safety Management

CDA Dam Safety Guidelines 2007 (Edition 2013)

Fell et al. (2014). Geotechnical Engineering of Embankment Dams, 2nd Edition, published by CRC Press 2014, ISBN: 978-1-138-00008-7 and ISBN 10: 1-1380-0008-6

FEMA 93 (2004). Federal Guidelines for Dam Safety

FEMA P-64 (2013). Federal Guidelines for Dam Safety: Emergency Action Planning for Dams

New Zealand Dam Safety Guidelines – 2015

Annex F1: Incident status summary

Incident:

Incident Name:			
Incident Number:			
Report Version: ☐ Initial ☐ Update ☐ Final	Incident Commander(s) & Agency or Organisation:	Incident Management Organisation:	Incident Start Date/Time:
Current Incident Size or Area Involved:			
Percent (%) Contained or Completed:		Total Percentage (%) of Perimeter that will be Contained or Completed:	

Incident Type:		Incident Complexity Level: ☐ Single ☐ Complex	Report Time/Period: from Date/Time: To Date/Time:
Incident Description:			
Cause:			
Fire Suppression Strategy:			
Strategy	(%)		
Monitor			
Confine			
Point Zone Protection			
Full Suppression			

Prepared by: Printed Name: Date/Time Prepared:	Approved by: Printed Name: Signature:

City:	District:	State:
Unit:	Incident Jurisdiction:	Incident Location Ownership

Coordinates:
Longitude: UTM
Longitude: Zone: Easting: Northing:

Short Location or Area Description (list all affected areas or a reference point):

Note any geospatial data available (indicate data format, content, and collection time information & labels):

Observed Fire Behaviour or Significant Events for the Time Period Reported (describe fire behaviour using accepted terminology. For non-fire incidents, describe significant events related to the materials or other causal agents):

Primary Fuel Model, Materials, or Hazards Involved (hazardous chemicals, fuel types, infectious agents, radiation, etc):

Damage Assessment Information (summarize damage and/or restriction of use or availability to residential or commercial property, natural resources, critical infrastructure and key resources, etc):			
Structural Summary	# Threatened (up to 72hrs)	# Damaged	# Destroyed
Single Residences			
Multiple Residences			
Mixed Commercial / Residential			
Non-residential Commercial Property			
Other Minor Structures			

Public Status Summary: Indicate the Number of Civilians (Public) Below:				Responder Status Summary: Indicate the Number of Responders Below:			
	Previous Report Total	# this Reporting Period	Total # to date		Previous Report Total	# this Reporting Period	Total # to date
Fatalities				Fatalities			
With Injuries/Illness				With Injuries/Illness			
Trapped/In Need of Rescue				Trapped/In Need of Rescue			
Missing				Missing			
Evacuated				Evacuated			
Sheltering in Place				Sheltering in Place			
In Temporary Shelters				In Temporary Shelters			
Have Received Mass Immunisations				Have Received Mass Immunisations			
Require Immunisations				Require Immunisations			
In Quarantine				In Quarantine			
Total # Civilians (Public) Affected:				**Total # Responders Affected:**			

Life, Safety, and Health Status/Threat Remarks:

32. Weather Concerns (synopsis of current and predicted weather; discuss related factors that may cause concern):

Life, Safety, and Health Threat Management:	Active?
No Likely Threat	☐
Potential Future Threat	☐
Mass Notifications in Progress	☐
Mass Notifications Completed	☐
No Evacuation(s) Imminent	☐
Planning for Evacuation	☐
Planning for Shelter-in-Place	☐
Evacuation(s) in Progress	☐
Shelter-in-Place in Progress	☐
Repopulation in Progress	☐
Mass Immunisation in Progress	☐
Mass Immunisation Complete	☐
Quarantine in Progress	☐
Area Restriction in Effect	☐
Road Closure	☐
Trail Closure	☐
Area Closure	☐

Projected Incident Activity, Potential, Movement, Escalation, or Spread and influencing factors during the next operational period and in:
12 hours:
24 hours:
48 hours:
72 hours:
Anticipated after hours:
Strategic Objectives (define planned end-state for incident):
Current Incident Threat Summary and Risk Information in 12-, 24-, 48-, and 72-hour timeframes and beyond. Summarise primary incident threats to life, property, communities and community stability, residences, health care facilities, other critical infrastructure and key resources, commercial facilities, natural and environmental resources, cultural resources, and continuity of operations and/or business. Identify corresponding incident-related potential economic or cascading impacts:
12 hours:
24 hours:
48 hours:
72 hours:
Anticipated after hours:
Critical Resource Needs in 12-, 24-, 48-, and 72-hour timeframes and beyond to meet critical incident objectives. List resource category, kind, and/or type, and amount needed, in priority order:
12 hours:
24 hours:
48 hours:
72 hours:
Anticipated after hours:
Strategic Discussion: Explain the relation of overall strategy, constraints, and current available information to: 1) critical resource needs identified above, 2) the Incident Action Plan and management objectives and targets, 3) anticipated results. Explain major problems and concerns such as operational challenges, incident management problems, and social, political, economic, or environmental concerns or impacts.
Planned Actions for Next Operational Period:
Projected Final Incident Size/Are:
Anticipated Incident Containment or Completion Date:

Projected Significant Resource Demobilisation Start Date:		
Estimated Incident Costs to Date:		
Projected Final Incident Cost Estimate:		
Remarks (or continuation of any blocks above – list block number in notation):		
Resources (summarise resources by category, kind, and/or type):		
Agency or Organisation	Resource	Total Personnel