

4 Investigation, Design and Construction

4.1 Introduction

Dams engineering is not an exact science as it frequently involves uncertainties beyond prevailing knowledge. It relies heavily on mathematical principles, physical laws, experienced judgement and known safe practices.

Dam safety management requires that critical uncertainties are recognised, investigated and resolved to acceptable risk levels. Consequently, the investigation, design and construction phase of dams engineering plays an important role in dam safety.

At time of writing philosophies of risk assessment and management were starting to influence the design, management and operation of water dams throughout Australia. This guideline embraces those philosophies as far as they have been incorporated in published ANCOLD Guidelines. Dam owners are encouraged to utilise those philosophies to develop management and operation programs. However, this guideline will await broader dam community assessment of the methodologies before incorporating risk management as a recommended approach to management.

4.2 Issues concerning the dam owner

No two dams are the same. There are many issues including safety issues, which a dam owner should consider when developing a dam. Issues that are specific to dam safety include:

- the failure impact rating of the dam (that is whether the dam will have a Category 1 or Category 2 failure impact rating)
- the resources required to adequately address the technical issues associated with the investigation, design and construction of a dam
- the resources required to adequately manage the dam in a safe manner
- dam safety statutory requirements
- the consequences of potential dam failure.

Other issues, while possibly having dam safety implications, are primarily asset ownership issues. These include:

- environmental or downstream impacts which need to be considered
- the economic viability of the dam
- long-term maintenance management implications of dam ownership.

4.3 Consequence assessment

The regulation of referable dams under the *Water Act 2000* is based solely on the population at risk in the event of a dam failure. However, dam designers, on behalf of dam owners, may also wish to consider other potential consequences to determine design standards for a dam. These other consequences may include:

- economic loss of the asset
- commercial losses and social impacts
- impacts due to loss of water supply
- damage to property and infrastructure
- environmental damage.

If the owner wishes to take these factors into account he or she could undertake an assessment of the consequences of dam failure. A methodology for undertaking a consequence assessment can be found in the Australian National Committee on Large Dams (ANCOLD) Guidelines on the Assessment of the Consequences of Dam Failure.

The effort and resources a dam owner should put into a dam safety management program and the scope of the program is related to the consequences of the failure of a dam on life and property, as well as the complexity and novelty of the dam.

Some of the more common scenarios to be considered in consequence assessments include:

- dam break - the uncontrolled release of pondage for 'sunny day' conditions and a range of flood events
- remote floods - flood surges well downstream of dam which can coincide with storage release
- upstream floods - backwater effects of the dam during floods
- water supply loss - failure of pumps, outlet facilities, reservoir pollution etc
- operational problems - accidental opening of flood gates, equipment malfunction etc.

A consequence assessment should provide a profile of the potential damage of dam failure. In cases where failure does not impact on population and is of economic consequence only to the owner, a case may exist for a minimal dam safety management program. In contrast, where the potential for substantial damage costs exist and significant impact on others is likely, dam safety management should be more rigorous.

Dam owners should periodically review the consequence assessment to monitor any change in circumstances such as development downstream. Such developments can make non-referrable dams 'referable' and can cause changes to the required design standards.

4.4 Investigation

Many investigations are undertaken when developing a dam. Most focus on comparing alternate sites and determining the viability of a particular site, rather than focussing on dam safety issues. Examples of these investigations include:

- economic assessment of a dam, including water pricing studies
- land use studies
- impact assessment studies, including social, cultural heritage, and environmental studies.

Two areas of investigation predominantly relate to dam safety issues. These are:

4.4.1 Geological and geotechnical investigations

These include geological and geotechnical assessments of the site and materials. They are generally carried out in stages ranging from broad scoping levels to more detailed investigations depending on the findings of each stage. Each stage should be thoroughly planned to ensure that all matters, which may affect dam safety, are identified, investigated and appropriately resolved by the designer.

Investigations should not be limited to the dam site alone. The geology, topography and the depth of water held in the storage area should be considered. This ensures that major leakages, slope instabilities and significant reservoir-induced seismic activities, which may jeopardise the safety of the dam, are considered in the design.

All work undertaken in the geological and geotechnical investigation stage should be properly recorded and presented in a comprehensive report. This will enable the designer to define the extent of any further work required prior to finalising the design. Investigations are generally on going through the construction period as the foundations become fully exposed or the extent of any foundation work, such as grouting, is recognised. Consequently, investigative reports need to be updated and amended as construction proceeds. When construction is complete, a full and comprehensive report should be available as a reference for on-going surveillance of the dam and subsequent safety reviews.

4.4.2 Hydrological investigations

A suite of hydrological investigations should be undertaken to develop dam safety data for the proposed dam. These hydrological investigations, which are independent of yield hydrology⁴, involve:

- developing an appropriate run-off model for the catchment
- calibrating this run-off model with historical flood data where possible
- assessing any operating limitations and criteria, which are to apply to spillway discharges
- assessing the consequences of potential failure of the dam:
 - particularly the population at risk - see NR&M Guidelines for Failure Impact Assessment of Water Dams
 - for best practice purposes to determine other consequences of failure (eg economic and environmental costs) using the ANCOLD Guidelines on Assessment of the Consequences of a Dam Failure (May 2000) if appropriate
 - determining the spillway design standard, spillway design flood and, if the spillway is a gated structure, determining any operating rules which are to be applied.

All work (including documentation of mathematical models) undertaken in hydrological investigations should be properly documented and presented in a comprehensive report. This will enable the designer to finalise the design and will assist subsequent reviews of this aspect of the design.

⁴ Yield hydrology is a major issue for the dam owner but has minor significance to dam safety.

4.5 Design

4.5.1 General

Factors which should be considered during the design of a dam, include:

1. Physical characteristics

- dam type
- location and alignment
- size and shape
- appurtenant works.

2. Geotechnical information

- material properties and availability
- foundation properties and treatment
- geological characteristics
- seismic loadings.

3. Hydraulic aspects

- type of spillway, means of flow control and energy dissipation
- hydrological characteristics
- hydraulic design and water loadings
- stream diversion requirements
- flood mitigation capacity.

4. Stability

- structural capacity of principle elements

5. Construction methods and sequencing

- including watercourse diversion requirements during construction

6. Operational aspects

- operational complexity and reliability
- requirements for ongoing monitoring
- technical capability and availability of operations personnel.

7. Environmental aspects

- environmental impacts including the effects of storage and barriers
- effect on upstream and downstream areas
- magnitude of downstream releases.

4.5.2 Specific Design Requirements

While the way in which these aspects are applied to a particular dam depends on its dam failure impact rating, size, importance, complexity and consequences of a dam failure, the key principles are:

- all dams structures should be designed to suit the loads to be applied to them in accordance with:
 - ANCOLD guidelines
 - relevant Australian Standards
 - notices (compliance and information) issued from time to time by the chief executive
 - generally accepted engineering practices

- in particular, dams must be able to withstand seismic loadings, flood loadings, normal operating loadings, construction loadings, post construction loadings.
- the regional and site geology must be understood and engineering geology models developed to form the basis for design
- the foundations must be capable of supporting the dam structure and controlling seepage
- the reservoir basin and rim must be sufficiently impermeable to prevent excessive losses of water (Any seepage must be controlled and instability must not occur at any stage of reservoir operation.)
- construction materials must be identified to meet site and design requirements
- the spillway size must be established on the basis of accepted engineering standards—ANCOLD Guidelines on Selection of Acceptable Flood Capacity for Dams, 2000 (Hydrological and meteorological information used in the design must be appropriate for the dam locality and dam use)
- the cut-off design must be established on the basis of the loadings, strength of the available materials and the need to control the seepage (For embankment dams, the designer must incorporate adequate lines of defence including properly designed drains and properly designed filters to ensure the long-term integrity of the seepage control system)
- the outlet works must meet the requirements for the reservoir operation and must have provisions for safe operation and maintenance
- provision must be made for the long-term monitoring of the structural performance of the dam and its components
- an appropriate dam safety management program must be developed and adhered to through the investigation, design and construction processes to ensure all matters are properly attended to and adequately recorded.

Some of these factors may have a direct impact on dam safety, while others may have an indirect impact. The dam designer should be a registered professional engineer, highly experienced and with a good knowledge and understanding of dams. In some cases, dam owners may want to establish a review board of experts to provide guidance on the design of the dam. For large projects, dam owners may wish to engage a project design engineer who is assigned technical coordination responsibility for the dam during its design and construction.

These factors influence the construction cost of a dam. The designer should develop a design, which meets accepted safety standards and the needs of the owner (including budget). The designer should be aware of new technology and methods being adopted elsewhere, which may provide cost savings. Such savings should be critically evaluated in terms of possible long-term costs, which may occur should safety and operational problems be experienced with the dam. The more that is known about the site conditions and foundation materials the less conservative the design has to be, resulting in lower construction costs.

The designer should establish specific onsite construction and operational inspection programs for review by appropriate design personnel and technical specialists. These programs should include frequent inspections during construction to confirm that site conditions conform to those assumed for design or to determine if design changes may be required to suit the actual conditions. A major requirement is inspection and approval by the dam designer of the dam foundation and foundation treatment before the placing of dam materials. The final design inspection of the construction should include a complete review of the surveillance undertaken and testing of any operating equipment.

The designer should determine surveillance requirements for the dam including:

- inspections - operational design inspections should continue throughout the life of the project, in accordance with a formal inspection program covering all project features. The inspection program should meet the regulatory requirements specified in the dam safety conditions in the development permit

- instrumentation - as part of the surveillance requirements, there may be a need for instrumentation (eg settlement and foundation pressure). The designer should identify the need for, and position of instrumentation and include a schedule for timely reading, collecting, reducing, and interpreting the data. The design should include an advance determination of critical instrument observations or rates of data change and a plan of action if observations indicate a critical condition may occur. These critical instrumentation figures should be based on the design assumptions.

4.6 Construction

The supervising constructing engineer(s) should be experienced in dams engineering and be able to detect when variations to specified procedures are necessary, or when special attention is required in relation to:

- foundation treatment
- material selection and placement
- material manufacture (eg filters)
- material testing
- stream diversion
- concrete manufacture
- construction equipment selection
- other issues which can affect the safety of the dam.

The constructing engineer should have:

- a comprehensive understanding of the design
- responsibility for technical coordination between design and construction engineers
- responsibility for managing the construction staff to assure compliance with specifications.

One of the most important aspects of dam construction is the foundation inspection. It is seldom possible to fully identify all the characteristics of the foundations of a dam during the investigation stage. Once the foundations have been fully exposed and prepared, there may be a need to amend the design requirements. Inspections by the designer are necessary to confirm any amendments. If unanticipated conditions such as geological features are encountered, the designer must be involved in determining appropriate design changes.

Regular site visits and inspections by the designer and review engineers (where appropriate) are recommended.

4.7 Design and construction documentation

4.7.1 Data Book

Dam owners should compile and maintain a Data Book. A Data Book is a convenient source of information summarising all pertinent records and history. It should encompass the documentation of investigation, design, construction, operation, maintenance, surveillance, remedial action as well as monitoring measurements. A Data Book may be large and consist of several documents eg drawings, electronic data files and printed reports or smaller depending on the type and complexity of the dam.

4.7.1.1 Data Book Checklist

Data Books should include the following information:

General

Table of Contents

Background Information

- Statistical Summary of the main features of the dam
- Aerial Photograph of the Dam (if available)
- Historical Events (prior to construction, during construction and subsequent operation)
- Record of incidents at the dam
- Relevant Correspondence

Geological Information

- Regional Information
- Site Information
- Seismicity
- Relevant Correspondence

Hydrologic Information

- Design Floods
- Current Inflow Design Flood
- Relevant Correspondence
- Failure Impact Assessment
- Consequence Assessment

Foundation Information

- Description
- Design and Analysis
- Treatments
- Construction Records, Changes, and Modifications
- Instrumentation
- Known deficiencies (eg seepage, etc)
- Relevant Correspondence

Dam Structure

- Description
- Design and Analysis
- Treatments
- Construction Materials
- Construction records, changes, and modifications
- Instrumentation
- Deficiencies (eg cracking, etc)
- Relevant Correspondence
- as constructed drawings

Other Features -Spillway, Outlet Works, Mechanical Systems

- Description
- Design and Analysis
- Details of relevant control systems and operating principles
- as constructed drawings

4.7.2 Design Report

On most projects, a Design Report should be compiled once the design and construction stages are completed. However, on major projects, this may have to be staged. The designer should document the design and construction of the dam including:

- Designer's Operating Criteria (DOC), eg gate operating rules and cone valve operation protocols
- design parameters adopted and assumptions made (and their bases)
- methods of analyses
- results of analyses and investigations (numerical and physical)
- hydraulic model testing of final spillway arrangements
- complete set of drawings and specifications
- summary of As-Constructed documentation and other construction information (see 4.7.3).

The Design Report must contain sufficient information so that in the event of any safety problems relating to the dam, information can be quickly and easily obtained to resolve the problem.

When preparing a design report, the designer should consult the checklist of dam technology issues included as Appendix 3 - Checklist of Dam Technology Issues.

4.7.3 As-Constructed documentation

The constructing engineer should provide a complete record of the construction to assist in determining solutions to any safety problem, which may arise during the life of the dam. As a minimum, this record should include:

- decisions to adapt the design to actual field conditions
- as-constructed drawings indicating the actual lines, levels and dimensions to which the structure is built
- construction processes
- systematically compiled and comprehensive photographs and, where appropriate, videos of the construction, with particular coverage of significant events which include:
 - foundation treatment
 - material preparation and placement
 - filters, cut-offs
 - core materials
 - joint preparation
- foundation surface mapping of rock defects
- material test results and comparison with assumed design parameters
- instrumentation data including precise instrument locations and initial instrument readings
- construction inspection reports.

The As-Constructed documentation should be summarised and either incorporated into the Design Report or produced as a separate Construction Report.