Dam Safety Management of Council Dams in New South Wales, Australia, including two Case Studies

Management der Talsperrensicherheit von "Council Dams" in New South Wales, Australien und zwei Fallbeispiele

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Abstract

The Department of Water & Energy (DWE) dam safety program ensures NSW councils properly manage their 180 dams. The dam's "hazard" category governs spillway capacity and surveillance. The regulator, bases its standards on the ANCOLD Guidelines.

Spring Creek dam, is an earth dam with a concrete core wall and no filter. In 1966, a slide occurred. Piezometers revealed pore pressures downstream rose immediately with storage. The spillway was inadequate. Upgrading began in 2005.

Malpas dam is a zoned earth and rock dam with no filters and inadequate spillway. A risk assessment determined low failure probabilities. The regulator thus required no upgrading.

Zusammenfassung

Das Programm für Talsperrensicherheit des „Department of Water & Energy (DWE)" stellt sicher, dass die sog. Councils im australischen Bundesstaat New South Wales ihre 180 Talsperren ordnungsgemäß betreiben. Die Gefahren-Klasse regelt die Kapazität der Hochwasserentlastung und die Überwachung auf der Basis von ANCOLD-Vorschriften.

Der Spring Creek Damm ist ein Erddamm mit einer innenliegenden Dichtwand aus Beton ohne Filterschichten. Im Jahre 1966 ereignete sich eine Rutschung. Piezometer-Messungen zeigten, dass die Porenwasserdrücke auf der Luftseite mit dem Aufstau unmittelbar anstiegen. Die Hochwasserentlastung war unzureichend. Die Sanierung begann 2005.

Der Malpas Damm ist ein zonierter Erd- und Steinschüttdamm ohne Filter mit einer unzureichenden Hochwasserentlastung. Bei einem Risk Assessment wurden niedrige Versagenswahrscheinlichkeiten festgestellt. Die Aufsichtsbehörde forderte daher keine Anpassungsmaßnahmen.

1 Introduction

In Australia, local government councils operate under state government statute, and are responsible for their dam's safety under the Local Government Act and the Dam Safety Act.

The 1974 amendment to the Local Government Act enabled the NSW state government to provide the necessary dam safety expertise and assistance to councils, now through the Department of Water & Energy (DWE), to ensure that the councils manage and operate their dams in a safe manner.

Over 180 council dams fall under the DWE dam safety program. The Government provides some financial assistance to councils towards the cost of remedial works for deficient dams.

2 NSW Councils Dam Safety Program

75 council dams are prescribed in the Dams Safety Act 1978, under which the Dams Safety Committee (DSC) was formed, as the regulator of dams in NSW. This Act gave the DSC power to obtain and examine information and to maintain surveillance of dams, and to require dams be made safe

The DSC thus requires owners to submit dam surveillance reports every 5 years. Depending on the content of the reports, safety reviews and remedial action may be required.

As a result of these requirements, DWE set up, in partnership with councils, a dam safety program covering:

- Routine dam inspections by councils
- Annual (for high, and every 2 and 3 years for significant and low hazard dams respectively) dam inspections and instrumentation data review by DWE
- Five-yearly dam surveillance reports
- Hazard rating assessments
- Dam safety emergency plans
- Dam safety training courses by DWE

These are carried out on dams of all types with heights and storages ranging from 2 to 90m and 2 to 180,000ML. Of the council owned dams, 48 are HIGH hazard.

2.1 Hazard Rating

Hazard rating is based on the consequences of a dam failure. Loss of life basically defines a high hazard. Risk of failure is not considered. This rating governs the standards for a dam. **Table 1** details the ANCOLD hazard categories.

2.2 Safety Standards

These are based on the ANCOLD Guidelines for Selection of Acceptable Flood Capacity [1], Dam Safety Management [2] and, Risk Assessment [3].

Until 2000, all High hazard dams in New South Wales had to be capable of passing the Probable Maximum Flood (PMF) with a probability of about 1 in 1,000, 000.

The 2000 Flood guidelines have a fallback standard for Flood Capacity wherein extreme hazard requires PMF, High A PMP Design flood, High B 10^{-4} to 10^{-6} , High C 10^{-4} to 10^{-5} Significant 10^{-3} to 10^{-4} ,and Low/Very Low 10^{-2} to 10^{-3}: as well as an alternate acceptable risk based approach, see **Figure 1**. In 2006 the NSW Government endorsed the use of the risk based approach.

2.3 Portfolio Risk Assessment

As a result of the DWE dam safety program, 21 of the 180 council dams were identified as deficient and needing remedial works. The estimated cost was $85 million. Portfolio Risk Assessment was used for developing a program based on risk of failure, consequences of failure and cost of upgrading. The outputs obtained included, failure risk for each dam, failure modes for each dam, population at risk and economic damage, and remedial options.

Table 1: ANCOLD Hazard Categories

<table>
<tr><th rowspan="2">Population at Risk</th><th colspan="4">Severity of Damage and Loss</th></tr>
<tr><th>Negligible</th><th>Minor</th><th>Medium</th><th>Major</th></tr>
<tr><td>0</td><td>Very Low</td><td>Very Low</td><td>Low</td><td>Significant</td></tr>
<tr><td>1 to 10</td><td>Low</td><td>Low</td><td>Significant
Change to High C for one life lost</td><td>High C</td></tr>
<tr><td>11 to 100</td><td rowspan="3">Unlikely</td><td>Significant</td><td>High C</td><td>High B</td></tr>
<tr><td>101 to 1000</td><td rowspan="2">Unlikely</td><td>High A</td><td>High A</td></tr>
<tr><td>>1000</td><td>Unlikely</td><td>Extreme</td></tr>
</table>

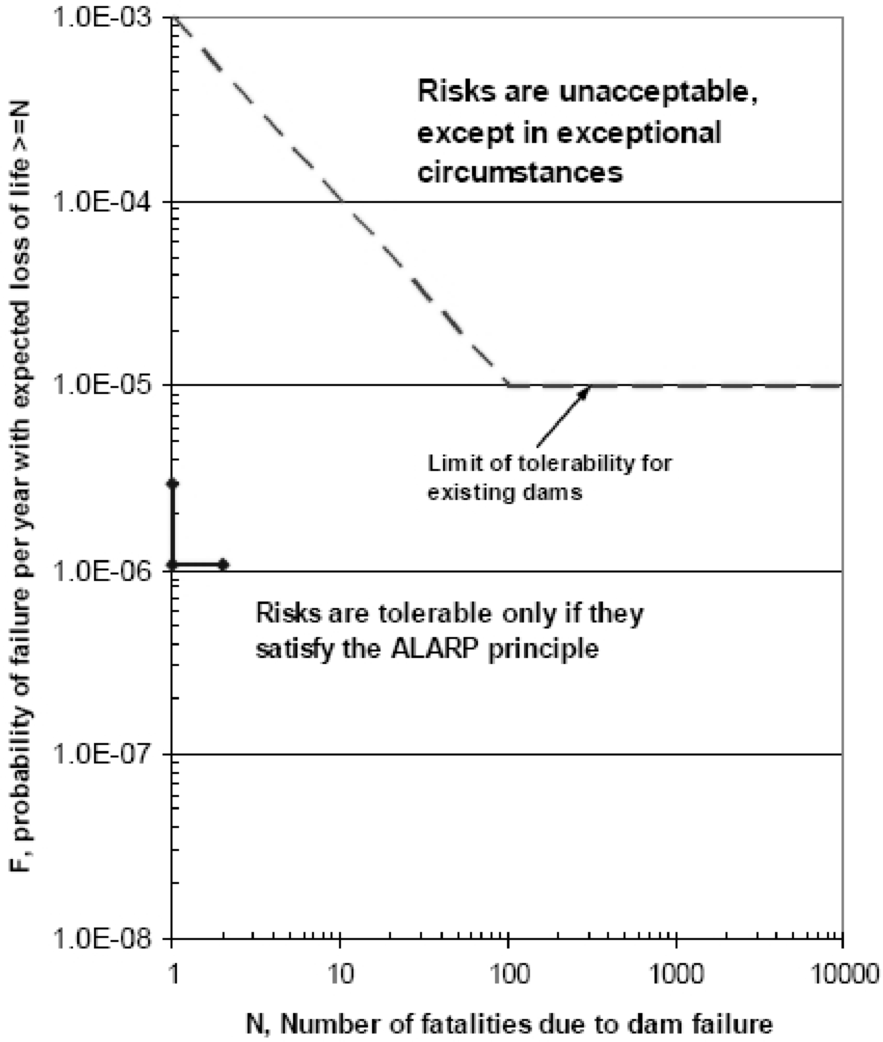

Figure 1: ANCOLD Societal Risk Guideline: Existing dams

3 Spring Creek Dam

Spring Creek Dam (built 1931) is a zoned earth fill embankment, with a central concrete core wall. The original dam was 14.5m high and the crest was raised by 1m and the storage was increased by 2m to 4700ML in 1947. In 1969, after a downstream slope failure, the embankment was rebuilt to a height of 16m [4].

The embankment consisted of outer random earth fill shoulders supporting an inner zone of selected earth fill. There was no internal filter.

3.1 Embankment Failure 1966

In 1966, after heavy rain following a long dry spell, a slope failure occurred, see **Figure 2**, The dam was not overtopped but 80m of the downstream slope slumped, burying the scour outlet.

Figure 2: Spring Creek Dam, 1966 Downstream Slope Failure

The concrete wall was probably cracked with a plane of weakness between the old and new fill. The long dry period before the failure dried out the outer zone of the embankment, permitting shrinkage cracks to develop. The rapid rise in storage and heavy rain allowed water to penetrate these cracks on the upstream side and hence through the cracked core wall, while rainfall also penetrated the downstream cracks, saturating the new fill and reducing its strength to a point where shear failure resulted.

Excavation of the slipped material revealed several pockets of loose saturated material in the 1931 section. After reconstruction, the factor of safety was greater than 1.5.

The 1994 Surveillance Report recommended, that Council install piezometers in the downstream shoulder to ensure no adverse pore pressures were developing which could lead to another failure.

3.2 Hazard Rating

A dam break study showed 5 houses would be flooded so the dam is a HIGH hazard.

3.3 Spillway Capacity

The catchment area is 63km$^{2.}$ and the spillway capacity is 310 cumecs.

The 1992 estimate of the PMF, 3800 cumecs, resulting from the 2 hour PMP (400mm), gave a peak outflow of 2960 cumecs. The Annual Exceedance Probability (AEP) of the failure flood lay between 1 in 100 and 1 in 3000. The dam's spillway was deficient.

3.4 Monitoring

In 1998, the new piezometers indicated high downstream pore pressures [4] directly related to and responding very rapidly to change in storage level. This confirmed the core wall was compromised.

3.5 Material Investigations

Standard Penetration Tests (SPT) indicated CI soils of low plasticity. A soft, saturated sandy layer was found at 9m where the test equipment fell under its own weight.

Further investigations confirmed the presence of pockets of saturated fill of very low strength just downstream of the core wall in the original dam. Where samples were recovered, moisture contents up to 27% over the liquid limit were found.

As the stability of the dam was questionable it needed to be strengthened.

3.6 Remedial Works

These involved installing a filter on the downstream slope with a foundation blanket filter to control seepage and piping. The embankment was raised by 4m from downstream. A 3 metre wide berm was on the downstream slope for stability. An embankment saddle dam was built on the right of the spillway. The existing spillway was widened and new abutment walls were constructed to retain the adjoining dam embankments to provide the freeboard to pass the 1:100,000 AEP flood. The total capital cost was approximately $6.5 million.

4 Malpas Dam

Malpas Dam is a 30m high zoned, earth and rockfill dam built in 1968. It has a catchment of 195km^2 and a storage capacity of 13, 000 ML.

The Portfolio Risk Assessment (PRA) concluded there is justification for upgrade works due to deficiencies in the flood capacity, and the lack of a modern filter.

4.1 Piping Assessment

A piping risk assessment was performed [5] using the event tree framework of Foster & Fell [6] This considered each stage of piping, i.e. initiation, continuation, progression, detection /intervention and breach.

4.1.1 Crack

The likelihood of a crack developing through the core was considered to be **very low** due to good compaction of the core, uniform abutment profile, and good core performance indicated by the piezometers.

4.1.2 Erosion Initiates

If a crack exists, would erosion of its walls occur? The maximum flow gradient across the core is 0.15, so the shear stress applied by leakage through a thin crack (i.e. 1 – 5 mm wide) is low, (<5 Pa) less than the estimated critical shear stress of the core (>40 Pa) soil with an I_{HET}>4, as found in the hole erosion tests. Erosion is thus unlikely to begin.

4.1.3 Continuing Erosion

A downstream filter or transition zone will prevent continuing erosion if piping initiated in the core. Zone 3 was designed as a transition zone between zones 1 and 2, and the outer rockfill zones.

Its materials are relatively broadly graded so an assessment for suffusion was carried out. (soils with internally unstable gradation lose their finer particles by seepage) the results showed there is a low probability for the Zone 3 materials to suffuse.

If piping were to initiate in the core the Zone 3 transition would permit some erosion of the core before the transition sealed the leak. So, continuing erosion is very unlikely.

4.1.4 Progression

This considers whether the pipe will remain open, and, whether the pipe will enlarge.

The assessment indicated that the pipe is likely to remain open but with some self-limiting by erosion of materials from the upstream transition zones into the pipe, thus helping to seal the downstream transition material and restricting flow.

4.1.5 Breach

For Malpas Dam, breach formation would be by unraveling of the downstream rockfill leading to large scale instability, or gross enlargement of the pipe.

For piping with “some erosion”, flows up to 100 L/sec based on case histories are expected. Such flows would not cause unraveling of the downstream rockfill zone.

4.2 Overall Assessment

Each of the stages of piping has a low likelihood. So, the overall likelihood of piping is very low. The above assessment was used for estimating the conditional probabilities for the event tree, see Figure 5,. The probability of a concentrated leak developing was 1×10^{-3}, and for erosion initiating 1×10^{-2}. This was 100 times less than the historical probabilities of piping initiation derived from the statistics of dam incidents. Malpas Dam was significantly better than the “average dam” in the statistics due to the good compaction of the core, and low erodibility of the core, and low potential for differential settlement cracking. After applying the judgmentally based probabilities to the other phases of piping, the total probability of piping per annum was 4×10^{-8}.

4.3 Spillway Assessment

The spillway hydrology assessment was a standard procedure using flood routing and flood frequency analysis and will not be discussed. The dam crest flood has an AEP of 1 in 250,000, which translates through the event tree into an annual probability of failure due to overtopping of 2×10^{-6}.

4.4 Loss of Life

This was assessed using Graham’s Method, and the results of a dambreak study which found that 7 dwellings would be effected, with the first dwelling over 6 hours flow time downstream.

Loss of life was estimated as one for piping, and two for overtopping. When the risk cases were plotted on the ANCOLD Societal Risk Criteria **Figure [1]**, it was found that the risks were tolerable, and no upgrading was needed.

4.5 Outcome

Without a risk assessment, Malpas Dam would have required the installation of downstream filters to satisfy modern criteria, and would have required a PMF capacity spillway. It was estimated that over $6 million was saved by the use of risk assessment.

Acknowledgement

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Literature

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[6] Foster, M; Fell, R; Davidson, R; Wan C: Estimation of the Probability of Failure of Embankment Dams by Internal Erosion and Piping Using Event Tree Methods. ANCOLD Bulletin No 121, August 2002.

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