Marlette Lake Dam Resilient Infrastructure Project

BCA 3 – Project Useful Life Justification

The life-span of dams vary based on a variety of criteria as is described in the attached article. A typical life-span for a well maintained dam could exceed 100 years. In a Dam Safety Fact Sheet prepared by the US Army Corps of Engineers, a statement is made that "52 percent (of the dams managed by the USACE) have reached or exceeded the 50-year service lives for which they were designed." While the Marlette dam has been in service for over 145 years, for purposes of the BCA, a project useful life of 50 years has been selected to be conservative.

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Life-span of storage dams

Dam engineers and dam owners may not always have a clear idea about the life-span of their projects. Here, Martin Wieland discusses the many factors which could impact on the useful life of a dam

Above left: Figure 1 – Leaching traces at downstream face of Garichte gravity dam completed in 1931 in Switzerland due to high water-cement ratio and high permeability of mass concrete; Above right: Figure 2 – Enguri arch dam in Georgia: 272 m high dam with peripheral joint (top); leakage of bottom outlets (bottom)

SIMILAR to other major infrastructure projects, the design life-span of the dam body is given as a time-span varying between the concession period and typically 100 years. However, the life-span of hydromechanical steel structures, electromechanical equipment and control units is shorter than that of the main civil/structural components and are specified by the suppliers, who also provide instruction manuals describing operation and maintenance. For the civil parts of a water storage facility, however, there are often no manuals on maintenance, although there may be guidelines on regular visual inspections and dam monitoring.

It has to be recognized that there is a direct relationship between dam safety and its life-span, i.e. if the dam is unsafe its life-span has expired.

Safety criteria for assessment of the life-span of dams

The life-span of any dam is as long as it is technically safe and operable! In view of the high damage potential of large storage dams, the safety has to be assessed based on an integral safety concept, which includes the following elements (Wieland and Mueller, 2009):

- 1. Structural safety (main elements: geologic, hydraulic and seismic design criteria; design criteria and methods of analysis may have to be updated when new data are available or new recommendations, guidelines, regulations or codes are introduced).
- 2. Safety monitoring (main elements: dam instrumentation, periodic safety assessments by dam experts, etc.).
- 3. Operational safety (main elements: reliable rule curves for reservoir operation under normal and extraordinary (hydrological) conditions, training of personnel, dam maintenance, sediment flushing, engineering back-up etc.).
- 4. Emergency planning (main elements: emergency action plans, water alarm systems, evacuation plans, engineering back-up etc.).

Therefore, as long as the proper handling of these safety issues can be guaranteed according to this integral safety concept, a dam can be considered as safe.

With the number of people living in the downstream area of a dam and the economic development the risk pattern may change with time, calling for higher safety standards to be applied to the project.

Factors affecting life-span of dams

The main factors, which have an impact on the service life and which may call for upgrading of a dam are the following:

- (i) Changes in the design criteria (hydrology and seismic hazard) based on new information obtained since the initial design of the dam.
- (ii) Changes in methods of analysis and new safety concepts (for example, n-1 rule for flood discharge facilities of embankment dams).
- (iii) Results of risk assessments (new risks and change in risk acceptance criteria).
- (iv) Ageing of construction and foundation materials and components.

As any changes in the above items are reviewed periodically (e.g. during detailed five-year-inspections of large dams), effects such as climatic change on floods etc. can be taken care of. As a matter of fact, this has been done and is being done for other hazards, such as earthquake action, which has not been considered at all in the design of older dams. To adapt an old dam to new seismic design and flood safety criteria is often more drastic than the rather long-term changes in the floods.

Ageing and its impact on the life-span of concrete dams

One of the important safety concerns is ageing of the concrete and of the foundation rock, i.e.

- (i) Chemical processes (swelling due to alkali aggregate reactivity (AAR), sulphate attack, leaching (Figure 1), etc).
- (ii) Physical and mechanical processes (thawing-freezing and drying-wetting cycles, cracking due to seismic actions or non-uniform foundation movements etc).
- (iii) Biological processes (growth of plants in cracks, mussels etc).
- (iii) Seepage in the foundation and the dam body (dissolution of material, weakening of conglomerate, change in uplift of the dam and the foundation resulting in changes in the stability of the dam and abutment).

The ageing processes have to be followed by periodic visual inspections, tests and by monitoring of the dam, but not everything is visible or measurable.

Dense frost-resistant concrete should have a very long service life. Concrete dams, which do not have any steel reinforcement, have a much longer service life than reinforced concrete structures exposed to weather. The oldest concrete dams are about 120 years old. Masonry dams can be much older and still be in service. However, these are usually low structures used in irrigation projects or for water supply.

An extrapolation of concrete performance to 150 or 200 years is rather difficult as no reference projects exist. However, engineers have studied concrete mixes which would guarantee a very long life.

A service life of up to 1000 years would be possible for concrete structures made of special (low-heat) cements and stable aggregates and without steel reinforcement. It is obvious that under ideal environmental conditions (temperature, humidity etc.) the life-span of a concrete dam can be very long. But at the same time, it can also be very short if some of the safety-relevant elements are no longer functioning properly.

An example for uncontrolled safety decrease is the 272m high Enguri arch dam (the world's highest arch dam) in Georgia, which was completed in 1984. Due to civil war in the 1990s, dam safety monitoring (cables and equipment were removed), dam maintenance and emergency plans no longer worked and within a few years it was not clear if the dam was still safe or not (Figure 2). Gates of bottom outlets were leaking, and due to a deficient grout curtain and the failure of pumps used for removing the drainage water, uplift pressure increased. Since then the safety of the dam has been re-established and a new dam monitoring system has been installed.

Due to the many factors affecting the operational condition and environment of a dam, it is not possible to give a number for the remaining service life of existing dams. This has to be assessed periodically on a case-by-case study. Quite a few concrete dams may, however, require major rehabilitation, especially those showing signs of abnormal behaviour or AAR. Also, uncontrolled sedimentation may shorten the use of the reservoir and may block intakes but does not have a serious effect on the safety of the dam structure or its life-span as long as bottom outlets and spillway gates can still be operated properly. But sediment flushing can cause serious erosion in bottom outlets and sediment flushing tunnels, and sediments can damage turbines within a short period of time.

Below: Figure 3 – Deficiencies in hydromechanical equipment: Leakage of spillway gates (left) and corrosion of penstocks (right)

Above, top: Figure 4 – Damaged concrete slab of concrete face rockfill dam detected after the first filling of the reservoir; Figure 5 – Erosion damage at dam toe (left) and concrete protection in plunge pool after operation of the tunnel spillways (right)

Life-span of dams and components

The service life of a well-designed, well-constructed and well-maintained and monitored embankment and concrete dams can easily reach 100 years. Hydromechanical elements such as gates and their motors have to be replaced after 30 to 50 years. The life-span of penstocks is 40 to 60 years (Figure 3).

The service life of electro-mechanical equipment varies from 20 to 60 years (Table 1) and electronic control units and software may have to be exchanged as frequently as office computers as they may become technologically outdated and maintenance may no longer be available.

A summary of service lives of structural elements and components of different hydro power plants are given by Giesecke and Mosonyi (2005).

Ageing and its impact on the life-span of embankment dams

Embankment dams are engineered structures using mostly natural materials, part of which may be processed (e.g. filters). In dams with upstream impervious facings, concrete or asphaltic concrete is used. In concrete face rockfill dams (CFRDs) cracking of the face slab is a problem as this leads to undesired seepage losses and accelerated corrosion of the steel reinforcement (Figure 4).

The life-span of a reinforced concrete face slab element is definitely shorter than that of a riprap of reasonably strong rockfill.

Table 1:
Life-span of new electro-mechanical equipment in years: Values for estimated life-span are based on regular maintenance, availability of spare parts, and qualified personnel

Equipment	Typical life-span of new components
Shut down vlave	60 years
Turbine stationnary parts	50
Turbine Governor	30
Generator	40
Exciter machine	40
MV switchgear	35
LV switchgear	35
Auxiliary transformer	40
Battery systems	20
Battery chargers	25
Cables	50
Generator protection	20
Voltage regulator	20
Synchronisation	20
Unit control system	20
Plant control system	20
Emergency diesel	50
Step up transformer	50
HV switchyard	45

Therefore CFRDs may need more maintenance than a conventional rockfill dam with impervious core.

Asphaltic concrete and geotextiles are sensitive to ultraviolet rays which cause brittleness of the material leading to cracks and finally to its ultimate disintegration.

Ageing also affects the foundation of a dam. With embankment dams these ageing processes can be more critical than with concrete dams because they are often founded on alluvial deposits or residual soils. Water flow through the foundation can result in strength changes over time. Particularly sensitive are clayey materials, but also rocks may reduce their strength. Water flow through the foundation can affect foundation permeability, dissolution of soluble rock, and leaching of grout curtains. Finally, seepage may wash out infilled joints or cause erosion in the soils of the foundation (especially with dispersive soils) leading to the formation of 'pipes'. All these processes are usually very slow and only develop over a time span of many years.

The foundation is as essential for the life-span of the dam structure as the structure itself. Maintenance of a foundation is by providing it with supplementary treatment, for example by reinforcing or extending the grout curtain or by replacing it with a positive or semi-positive cutoff, by installing relief wells or any other means of drainage depending on the actual situation and its requirements.

Properly designed and constructed embankment dams can remain structurally stable and safe for centuries as long as they are not subjected to erosion processes. There are also a few landslide dams, which have blocked valleys for many years and remained stable, such as the 650m high Usoy dam in Tajikistan, which was formed by a massive landslide triggered by a magnitude 7.3 earthquake in 1911

Embankment dams are most vulnerable to floods (Figure 5), internal erosion and seismic loading. However, a well-designed and maintained embankment dam is a very resilient structure and can also sustain extreme loading conditions. However, periodic safety assessments are indispensable as they will show what measures have to be taken to maintain or even extend the life-span. Deficiencies observed after commissioning must be rectified as early as possible.

Conclusions

The life-span of a dam is as long as proper maintenance can be guaranteed. This statement does not capture all aspects of safety, but it clearly indicates that a dam, which is safe at the time of completion, does not automatically remain safe. Unfortunately, quite a few dam owners still believe that a dam, which was safe at the time of its completion, will always remain safe. Some of them even abandon monitoring of the dam structure if instrumental data have remained the same for several years. Neglecting civil maintenance will unequivocally lead to a shortened life-span, which signifies an economic loss, and in a loss of confidence in the safety of dams by the affected people. Maintenance of the electromechanical and hydromechanical components is more common than civil maintenance as component failure and corrosion are more common phenomena, which have direct consequences, e.g. on the operation of the power plant. In the large dam structures internal deterioration and deficiencies are often not as readily visible as in the usually accessible hydromechanical and electromechanical components.

In some cases the economical life of a storage project may be governed by other factures such as siltation of the reservoir, etc. IWP&DC

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Wieland, M., Mueller, R., 2009. Dam safety, emergency action plans, and water alarm systems, Int. Journal Water Power and Dam Construction, January 2009

Archive search

To read further articles on the subject of storage dams, or for papers by the author, Martin Wieland, why not try a keyword search in our online archive at www.waterpowermagazine.com., where you'll find all articles published in the magazine since January 1998.

For example, a search on the phrase 'storage dams' wil bring up 21 articles. The term 'refurbishment' will locate over 200 papers.

A search for Martin Wieland will bring 17 papers, including recent articles on the features of the Wenchuan earthquake and its impacts on dams in the area, together with a paper on dam safety, emergency action plans and water alarm systems.

Dam Safety Facts and Figures

USACE dams contributed to $485 billion in damages prevented from 2004 to 2013, with $13.4 billion in damages prevented in 2013. USACE flood damage reduction projects avoid $8.00 of damages for each $1.00 invested.

Approximately 95 percent of the dams managed by USACE are more than 30 years old, and 52 percent have reached or exceeded the 50-year service lives for which they were designed.

- **Funding for Dam Safety Projects:** dam safety projects executed by USACE are cost shared with a local sponsor and vary based on original authorization. The construction is fully funded by the U.S. Government up front and billed back to the cost shared sponsor over a set time period of years following construction completion.
- Dams with highest life safety risk receive 100% of what can be efficiently expended in the program year, taking into account both budgeted funds and carryover balances. This includes dams that are currently under study (haven't reached final budget requirement decision) but have fully-funded interim risk reduction measures in place during the ongoing budgetary process.
- In fiscal 2016, the construction budget for ten of these dams is $258 million. In addition, $52 million is budgeted in fiscal 2016 for construction on one dam with very high economic risk. Extremely high risk dams are funded to capability at $234 million in fiscal 2016; very high risk dams are budgeted to $76 million.
- Dam Safety portfolio averages 56 years old.
- To fix all dams that need repairs would take $24 billion, 50 years with the current funding stream.

USACE owns and operates:

- six of the 10 largest U.S. reservoirs
- six of the 10 largest U.S. embankment dams
- 50% of all federally-owned dams

EXAMPLE: Wolf Creek Dam (Kentucky) impounds the second largest reservoir east of the Mississippi River, 12th largest in U.S., was among our highest risk dams and was in an active state of failure. A barrier wall in the foundation was completed at a cost of approximately $600 million and included enough concrete to fill 89 Olympic-size swimming pools. (290,000 cubic yards). This dam has returned to full service.

EXAMPLE: Pine Creek Dam (Oklahoma) has seepage along conduit and leakage through conduit joints; the problem is Worsening – increased seepage during May 2009 record pool, reclassified from very high risk to extremely high risk. Construction has started on a new outlet structure and cutoff wall.

dam safety