The Lessons Learned and Construction Challenges for the Leslie Harrison Dam Upgrade

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Leslie Harrison Dam is located on Tingalpa Creek in the Redlands region, approximately 18 km southeast of Brisbane. It is classified as an extreme hazard category dam with a large population at risk only a short distance downstream.

The dam comprises a 25 m high zoned earthfill embankment, with a dry well concrete intake tower and an outlet conduit located at the base of the dam near the old river channel. The spillway has a 43 m wide concrete gravity ogee crest, with a concrete lined chute terminating in an energy dissipator structure.

Seqwater is undertaking a staged upgrade of Leslie Harrison Dam to address deficiencies identified during the Portfolio Risk Assessment (URS 2013) and Geotechnical Investigations (GHD 2016).

While the dam has met the water supply needs of the community for the past 50 years, the upgrade ensures local residents will be well served into the future. Additionally, the structure will meet the most up to date requirements of dam safety management and national industry standards.

Construction of the Stage 1 upgrade commenced in June 2018 and involved the removal and replacement of liquefiable material in the foundation, modernisation and extension of the outlet works, addition of a new downstream filter buttress to the embankment, and lastly, the installation of both active and passive anchors within the spillway ogee and lower chute floor.

As with any major project, the works involved a number of challenges that had to be addressed. This paper provides an insight into the key challenges encountered and how these were overcome by the design and construction teams using practical engineered solutions. The intent is to provide the reader with an account of the "lessons learned" during the construction phase, along with recommendations for future dam upgrades.

Keywords: Upgrade, construction, Leslie Harrison Dam

Introduction

Leslie Harrison Dam is situated within a highly populated region of Southeast Queensland, and is owned and operated by Seqwater. The community relies on the embankment dam's 13,000 ML storage capacity for drinking water, which it has supplied since construction was completed in 1968, along with a subsequent raise of Full Supply Level in 1984.

More recently, an upgrade of the dam was initiated to ensure both its longevity and compliance with modern standards. The upgrade philosophy for Leslie Harrison Dam was a risk-based approach. Initially, all potential failure modes were investigated and quantified, and an assessment of these failure modes confirmed the following key risk contributors:

- Liquefaction of the foundation alluvium under the dam during an earthquake;
- Piping through the embankment at various locations across the dam;
- Failure of the concrete spillway ogee crest due to the weak seams in the foundation.

Based on these findings, a suite of works was designed for construction via a two stage upgrade process as follows.

Stage 1

- Installation of anchors (both post-tensioned and passive) and pressure relief drains within the spillway;
- Construction of a downstream shear key, via the replacement of liquefiable material in the foundation;
- Construction of a downstream filter layer (to dam crest level) and downstream weighting berm. By necessity, this also included outlet works modifications to accommodate the increase in width of the dam cross section.

Stage 2

- Raising the embankment section and spillway entrance walls above probable maximum flood (PMF) level;
- Raising the spillway bridge deck and spillway gate raising gear to enable the gates to be lifted above PMF flood level;
- Spillway chute floor strengthening works.

The following paper presents a discussion of lessons learned from the perspectives of the designer and asset owner on the construction team that managed the works during the Stage 1 upgrade (Figure 1).

Figure 1 - Plan extent of works

Installation of anchors and drains within the spillway

The design solution involved retrofitting 17.5 m long post tensioned anchors and associated pressure relief drains at the spillway crest to improve stability, as well as 12 m long galvanised dowels in the spillway chute (upstream of the dissipater basin) to improve stability and resist pressure transients. Works within the spillway were challenging for a number of reasons:

- Presence of weak foundation materials (including coal layers);
- Limited original construction records;
- Variability of existing concrete;
- Practicalities associated with construction on steep grades.

The lessons learned in addressing these challenges are outlined in the following sections.

Drilling method

Considerable time and effort was spent by the construction team assessing the drilling method for the anchors and drains in the spillway. While there was a good understanding of the geology beneath the spillway, which indicated variability in localised outcrops of weaker materials (i.e. coal seams), there was limited information from the original construction records regarding the methods that were used to treat them at the time. The key concern identified was damage to the spillway foundation from uncontrolled pressures during drilling for installation of anchors and drains (i.e. hydro fracture).

After careful consideration and robust discussions with the Contractor, the construction team assessed the proposed drilling methods, against the design requirements and potential for damage. The lesson learned was to work with the Contractor to consider different drilling techniques that satisfy the design requirements and allow for efficient installation. For Leslie Harrison Dam, rotary wash boring methods were successfully used to drill the anchor and drain holes in the spillway, via the following controls:

- Advancing a casing head ahead of the wash bore drill head (Figure 2);
- Keeping feed water pressures as low as possible during drilling;
- Monitoring any pressure changes in feed water during drilling;
- Monitoring existing spillway drains for any changes in flow during drilling;
- Downhole camera inspections following drilling.

Figure 2 - Drill head showing casing (circled) and wash bore bit

Anchor installation

Installation involved waterproofing the drill holes, insertion of the anchors, grouting and stressing. Furthermore, the anchors (and drains) were installed on steep grades on the ogee crest. This introduced a number of practical challenges for the Contractor in terms of safe installation methods and for Seqwater in terms of long-term inspection and monitoring.

Prior to installation, the construction team spent significant time reviewing the proposed anchor details and installation methodology against the design requirements. This was because the specialist subcontractor preferred to use proprietary products and installation methods. The construction team was subsequently on site during the installation to monitor drilling, water tests, fabrication, installation, grouting and stressing.

Lessons learned from the experience at Leslie Harrison Dam were as follows:

- Installation of anchors is an activity that requires a high level of supervision at each stage to ensure compliance with the design requirements;
- Installers prefer to use proprietary products and methods to suit their anchor system;
- Waterproofing of anchor holes is variable depending on the foundation geology and nature of ground conditions at that location;
- Cycling of anchor loads is important to achieve minimal test load losses during monitoring;
- Retrofit design must adequately consider practical installation and ongoing inspection and maintenance requirements.

Existing concrete

Concrete technology has advanced considerably since the late 1960's when the dam was constructed. The current strength of existing concrete can be well beyond that specified in the original design. This was most evident when existing concrete was demolished for installation of the anchors. Existing concrete specified as 25 MPa was behaving well in excess of this strength. This raised concerns over damage to surrounding concrete (i.e. micro-cracking) during demolition. Lessons learned were as follows:

- Suitable methods for demolition of existing concrete need to be developed to limit the potential for damage to surrounding concrete;
- Hydro demolition of old concrete can take a considerable amount of time and is an inherently hazardous activity near watercourses;
- The size and strength of aggregates found in old concrete can reduce the efficiency of cutting and drilling operations;
- Old concrete can vary in composition as well as strength. The existing drainage system under the spillway consisted of "low fines concrete" as per the original design. This material was essentially a free draining cemented gravel, which the wash boring head could not easily penetrate, or maintain drilling pressure;
- In light of the above, taking test cylinders of existing concrete at the design stage is recommended, to inform construction specifications and allow for assessment of suitable demolition methods.

Existing dowels and reinforcement

As part of the spillway works, an investigation was performed to establish the condition of the existing dowels and reinforcement in the spillway chute, to confirm design assumptions and to determine the extent of future upgrade works. This was to ensure that existing dowels and reinforcement had not corroded to a point where there was no longer sufficient structural strength in the spillway chute slabs to resist uplift during flood events.

By exposing the existing reinforcement at several locations (Figure 3), the following was established:

- Reinforcement within the existing concrete was in good condition with minimal signs of corrosion. This included reinforcement in areas that have been inundated by tidal flows for the past 50 years;
- Reinforcement at the interface of concrete and underlying foundation showed some evidence of corrosion. The maximum loss of section was measured at 20%, which agreed with design assumptions. Again, this included reinforcement in areas that have been inundated by tidal flows for the past 50 years.

Figure 3 - Condition of existing reinforcement

The results of the investigation showed that existing reinforcement in half century old dams should not automatically be considered suspect or beyond its design life without first completing investigations. This information will be of relevance to future dam upgrades in Southeast Queensland (although the importance of investigations on a case-by-case basis is acknowledged with respect to making dam safety decisions).

Construction of downstream shear key

The design solution for the downstream shear key works involved the 5-10 m deep excavation of all existing liquefiable alluvial material down to a rock foundation. This was followed by replacement with zoned sand, gravel and rockfill quarry run materials.

As the dam is used for water supply purposes, the Full Supply Level (FSL) was maintained throughout the project, and construction of the downstream shear key therefore presented one of the highest risk activities for the project (Figure 4).

Figure 4 - Excavation at toe (looking upstream)

Risk mitigation during construction was achieved via the following control measures:

- Developing a good understanding of ground conditions and material behaviour;
- Practical design based on a range of reservoir levels, groundwater levels and safe excavation slopes;
- Trials of a groundwater dewatering system to control levels during construction;
- Preparedness and planning prior to excavation;
- Access to real time data on ground conditions;
- Efficient excavation and backfill.

The lessons learned in applying this risk mitigation are described with reference to the following practicalities.

Geological model

The benefits of having a comprehensive geological model cannot be over emphasised. Considerable resources were allocated to formulating a geological model during the design phase to develop a good understanding of ground conditions and materials present (Figure 5). The challenge during construction was to identify the boundary between residual materials and rock foundation (which could remain) and liquefiable alluvial materials (which had to be removed). The definition of this boundary was crucial in allowing the design requirements to be satisfied.

During the initial stages of the construction phase, test pitting and dynamic cone penetrometer (DCP) testing were used to:

- Cross-check the geological model;
- Provide the construction team with an understanding of the target material locations and depths (i.e. what the materials looked like, and how they physically behaved once excavated).

Without a detailed geological model for reference, it would have been difficult, if not impossible, to identify the material boundaries correctly on site. Incorrect identification of material boundaries had the potential to result in poor design outcomes along with unfavourable cost and schedule implications for the project.

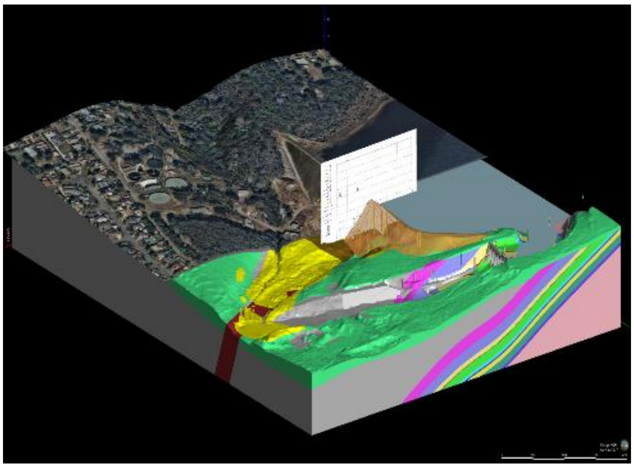

Figure 5 - Geological model

Dewatering

Groundwater dewatering is a standard component associated with excavation works. Implementing the most efficient method(s) of groundwater dewatering for a particular site can be a challenge due to the variability of the materials and permeability within the excavation footprint. The construction team observed that the theoretical design is sometimes best supplemented by "trial and error" on site.

Initially, a single line of wellpoints were designed and installed to remove groundwater from the excavation area around the perimeter. Although the wellpoints were functioning, groundwater levels were not able to be lowered below safe excavation levels. The decision was made by the Contractor to install a second line of wellpoints at a lower elevation to supplement the first installation (Figure 6). This proved successful and excavation was able to proceed safely without any incidents throughout construction works while the dam was maintained at FSL.

Live instrumentation

Acceptable excavation and groundwater levels were specified according to slope stability analyses performed by the design team. The installation of telemetered piezometers and tilt meters allowed the construction team to monitor groundwater levels and movement in real time via a web-based portal (Figure 7). The advantages of installing telemetered piezometers and monitoring included:

- Dam safety was monitored and maintained at all stages of excavation. This was particularly relevant overnight when there was no visual monitoring on site;
- It allowed early warning for slope stability issues and time to rectify any concerns identified;
- The efficiency of the dewatering system could be readily observed. This facilitated a robust discussion on the installation of a second line of wellpoints.

Material selection

Given the depth and extent of excavation required, backfill needed to be as fast and efficient as possible (Figure 8). Instead of specifying earthfill, the design team incorporated the placement of gravel and rockfill material. The lessons learned here were that placement of gravel and rockfill material had the following benefits when compared to earthfill material:

- Efficiency of materials management (i.e. moisture condition and mixing were not required);
- Time savings in terms of placement, compaction and testing requirements;

- Free draining nature of gravel and rockfill materials allows for construction during periods of wet weather;
- Flexibility of plant movements.

The obvious trade-off for the above benefits is the increase in cost of gravel and rockfill material over earthfill material. This trade-off was assessed during design by evaluating the reduced risk exposure and time efficiency, and it became readily apparent during construction that the correct decision was made.

Figure 6 - Double row of dewatering wellpoints (indicated as shown)

Figure 7 - Web based portal for piezometer data

Figure 8 - Simultaneous excavation and backfill

Site access

On any construction project, plant and heavy vehicle access is a critical factor in productivity. Due to the dam's location within a suburban area (the nearest houses downstream are only 300 m from the dam), access routes were investigated thoroughly by giving due consideration to the associated benefits and drawbacks of each potential route. The preferred option involved crossing Tingalpa Creek downstream of the spillway chute and a concept design was prepared for a dumped rock/earthfill causeway. The Contractor proposed an alternative design, which made use of a temporary bridge directly over the spillway dissipater (Figure 9). This was subsequently accepted by Seqwater and proved to be a critical link in the success of the project. The lessons learned from this experience are as follows:

- Temporary, steel truss bridges are a feasible alternative to dumped rock/earthfill causeways for access over spillway chutes;
- Single spans of 50-60 m are achievable for heavy vehicle (T44 loading) movements;
- Piled abutments constructed within close proximity to spillway walls (< 10 m) are possible;
- Keeping heavy vehicles off suburban streets is a significant risk reduction and community benefit for large construction projects.

Figure 9 - Temporary access bridge over spillway

Construction of downstream filter buttress and weighting berm

The design solution here involved the addition of a downstream filter buttress to improve protection against piping and seepage, and a downstream weighting berm to improve stability during flood and earthquake events. As a result of the downstream weighting berm, the existing outlet conduit and pipework needed to be extended downstream to match the new embankment footprint.

The construction of filter buttresses and weighting berms on existing earthfill dams is not a new concept. However, in the authors' experience, there are always efficiencies to be gained and lessons to be learned from each project, which are unique to a particular site. The following provides an overview of the experience at Leslie Harrison Dam.

Existing embankment materials

It should not be assumed that embankment materials will be entirely consistent, or that design phase investigations will be representative of the entire site. The use of natural materials to build an earthfill dam ipso facto guarantees its variability. Furthermore, it should not be assumed that constructed works comply with the specifications provided at the time.

Given the above, construction specifications should include clauses that cover the following potential scenarios:

- Tree roots in foundations and/or embankments;
- Oversize material (e.g. boulders) in foundations and/or existing embankments;
- Foreign matter (e.g. asbestos, waste, quarry remnants) in foundations and/or embankments;
- Loose and/or saturated materials in existing embankments;
- Granular materials in existing embankments (Figure 10);
- Low plasticity clay in the dam core.

In view of this variability, dam owners should recognise that a high level of supervision is required during construction to account for changes to the design that may result. Furthermore, the adequate documentation of any issues is vital for future reference (e.g. dam safety reviews, future upgrades, etc.).

Figure 10 - Granular materials uncovered at crest

Practical design

Dam construction is a specialist skill set within the civil construction industry. Given the limited number of dam upgrade projects compared to general civil works projects, there is a limit of specialist expertise available. To address this issue, a practical design will simplify construction works and provide a better chance of meeting design requirements and long-term performance of the dam asset. The following items provide guidance at the design stage so that construction proceeds smoothly:

- Zone widths should be specified horizontally, not perpendicular to the batter. It is simple to measure and construct a horizontal width and the dimension is guaranteed, even if the batter slope changes;
- Specify common dimensions and zones where possible. Try and avoid changes in widths or materials up and down the batter as this will likely lead to confusion during construction works;
- Avoid using the terminology “thick” or “thickness” on drawings, as this can be open to misinterpretation;
- Specify realistic parameters and/or acceptance criteria for construction materials, accounting for limitations and variability of local sources;
- Consider conventional construction methods that can easily be applied to achieve the design requirements;
- Specify realistic tolerances, taking into account the physical nature of the material being placed. For example, nominating a tolerance of +/- 200 mm for a Zone 2A sand filter is reasonable. However, nominating the same tolerance for riprap with a D50 of 300 mm is not practical.

Placement efficiency

While construction methodology is best informed by the expertise of the Contractor, an understanding of plant operations for filter placement efficiency is still very useful for any engineer on site, as filter placement will affect long-term performance of the dam. Examples from this particular upgrade include:

- Getting a shared understanding on acceptable filter placement quality between the construction team and Contractor at the outset is paramount for an efficient operation. This shared understanding must also make its way to site supervisors and plant operators;
- Minimising handling, transport and placement operations for filter materials limits the potential for breakdown during construction works;
- Side tipper trucks are beneficial in carting and placing quarry run materials to an embankment in a single operation. This increases placement efficiency and also reduces the size of site stockpiles (which in turn frees up space on small/tight sites);
- Work faces that have a boundary between a “clean side” for placement and a “dirty side” for excavation can eliminate rework due to contamination of newly placed filters.

Work front extent

For dam safety during construction, downstream earthworks operations are often limited to a specified panel width (Figure 11). However, what is technically possible, what the Contractor deems necessary and what the dam owner is comfortable with, may not be congruent. There is a balance that needs to be achieved between opening up a work front that is acceptable in terms of dam safety, what gives the Contractor sufficient flexibility and what is palatable for the dam owner. This should be considered at the design stage for a range of conditions, and incorporated into construction specifications. Specifically:

- Stability assessments to inform the maximum size of work fronts;
- Specifications to include a hold point that relates to acceptance (by the dam owner) of the work front (proposed by the Contractor) prior to excavation starting;

- Specifications to nominate the ownership of risk and consequences of non-conformance, should the work front widths be exceeded by the Contractor.

Figure 11 - Work front panel width

Waterstop selection

By extending the existing outlet conduit and pipework under the new weighting berm, a new waterstop had to be installed at the junction of the old and new sections of circular concrete. The design drawings identified a Greenstreak waterstop, which is a PVC product, however the radius of the conduit was found to be too tight for the PVC material to be installed. Instead, a more flexible EPDM rubber waterstop was installed which provided a better performance outcome. The lessons learned here were as follows:

- PVC waterstops cannot be fitted to a radius of < 5 m, unless they have been specifically manufactured to do so. The inherent stiffness of PVC means that it is difficult to install on a curved surface generally;
- EPDM rubber waterstops provide more flexibility when fitting to a radius of < 5 m. Note that the shape of the cross section of the waterstop will also impact upon its flexibility;
- Consider specifying custom made waterstops to suit a given radius, as straight sections of waterstops are extremely difficult to install on curved surfaces (even though it can be done, albeit after considerable time and effort);
- Pre-order waterstops well ahead of the installation schedule to minimise any delays to the project.

Quality control

The material zones used at Leslie Harrison Dam included the following:

- Zone 2A (a quarry run river sand);
- Zone 2B (a quarry run gravel);
- Zone 3 (earthfill won from site and also imported from other earthworks projects);
- Bedding gravel (a quarry run gravel);
- Rockfill and Riprap (a quarry run graded rock).

In controlling the quality of these materials, the following practical steps were taken to ensure compliance with the specifications at all times:

- Testing was performed at the quarry prior to the transportation of materials to site. This was supplemented by quarry inspections by the construction team;
- Ongoing material tests at the quarry were performed to ensure continued consistency of materials and their quality;
- Ongoing material tests were performed for placed material on site as per traditional earthworks lot systems.

The above steps allowed a clear expectation of the required material quality to be established at the start of the project. This was reinforced by checking and cross-checking of test results by the Contractor, asset owner and designer collaboratively throughout the duration of the project. The outcome was that issues were identified early; in most cases even before non-compliant materials were brought to site. This had obvious time and cost savings for both the Contractor and Seqwater, and was a definite win for the project.

Conclusions

With any dam upgrade, there are always efficiencies to be gained and lessons to be learned for each individual project. From the Leslie Harrison Dam upgrade, there were a number of key learnings that were made along the way and which will be directly applicable to dam upgrades in Southeast Queensland in the near future. Some of these have been outlined in this paper. The authors hope the reader has gained some appreciation of the issues that can arise, and the corresponding solutions that can be implemented. The intent was to capture and disseminate this information so that we can continue to improve within the dam engineering profession.

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