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"Seeking Relief" Rising Pore Pressures in Earth Dams – A Case Study

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ABSTRACT

Patea Dam is owned by Trustpower Ltd. (Trustpower) and is a zoned earth dam. On commissioning, lake pressures were observed to be transferring into the underlying geology. This created an increased artesian pressure within the footprint of the structure, reducing the dam's Factor of Safety (FoS) below what would be expected of a high Potential Impact Classification (PIC) dam. Remedial measures were investigated to correct long-term pressure trends at Patea Dam and ensure the long-term safety of the dam for its owner; the residents below the dam; and the recreational users of Lake Rotorangi. The approach of drilling relief wells into the underlying foundation is a method that had been historically used at Patea Dam, resulting in successful alleviation of excess artesian pressures. In April of 2015 a further two wells were commissioned to reduce the ongoing build-up of pore pressure. Numerous obstacles were overcome during the installation process, including challenging access and dangerous weather conditions to reach a satisfactory outcome for all parties involved. Initial results saw an approximate drop of 2m in the artesian pressures below the toe of the dam increasing the dams FoS and reducing artesian pressures to below identified alarm levels. This case study shows how relief wells can be successfully installed, even with numerous challenges, to safe-guard an important piece of New Zealand's infrastructure for the future.

1 INTRODUCTION AND PROJECT BACKGROUND

The Patea Hydro Electric Scheme owned by Trustpower and commissioned in 1984 consists of a zoned earth dam located 35km upstream from Patea Township in South Taranaki. The dam location was chosen due to a favourable diversion arrangement, simple geology, and the local availability of material suitable for dam construction. The dam has an overall crest length of 195m, with a maximum height of 78m and the upstream and downstream slopes of 1 in 2.5 and 1 in 2 respectively. Essentially the dam was constructed using the siltstone and sandstone material found in close proximity to the site. The dam was commissioned in 1984.

A series of monitoring piezometers were installed to monitor possible increases in artesian pressures within the toe of the dam. During the first month of filling it became apparent that lake pressures were being transmitted relatively rapidly into the sandstone layer below a limestone unit, creating artesian conditions that could lead to instability of the dam toe slope. As a remedial action, a series of 15 relief wells were installed in early 1984 to mitigate the rising artesian pressures. A second set of relief wells were installed in 1996 due to piezometric levels exceeding warning levels once again.

Following the 1996 relief well installation, a general rising trend in piezometric levels was observed with readings exceeding warning levels once more. As part of the 2010 Comprehensive Safety Review it was recommended that consideration be given to installing additional remedial measures (relief wells) to improve overall dam stability ensuring the future integrity of the dam.

2 REGIONAL GEOLOGY

The Institute of Geological Nuclear Sciences Ltd. (GNS) 1:250,000 geological map of the Taranaki area (GNS geological 2008 map 7) indicates the site is underlain by Matemateaonga Formation with Tangahoa Formation found above. The dam structure is founded within the Matemateaonga Formation. Matemateaonga Formation is predominately muddy sandstone with repeated shellbed limestone, siltstone, sandstone and minor conglomerate layers. These rocks are layered and dip gently towards the southwest at between 4° and 6° downstream.

2.1 Dam Site Geology

The geology encountered on-site during construction is shown schematically in Figure 1. The geological units were primary alternating limestone and sandstone/siltstone layers. The upper layer consisted of superficial protective tailrace backfill/riprap comprising large, irregular boulders from ground level to between 4m and 7m depth. A 1m thick, extremely strong limestone layer (Limestone 2) underlies the riprap layer. The base depth of Limestone 2 is deeper nearer to the powerhouse than by the right abutment. The boundary between the Limestone 2 and the underlying BS2 siltstone/ sandstone was observed as a sharp contact. BS2 siltstone/sandstone material comprised minor marine fossils found in the form of shell fragments. Another sharp contact was observed into an additional strong limestone layer (Limestone 1) with large shells, whole and fragmented. The final underlying layer is blue grey massive sandstone similar to BS2. An aquifer has been identified within this lower sandstone layer (BS2) and is capped in place by the Limestone 2 unit above.

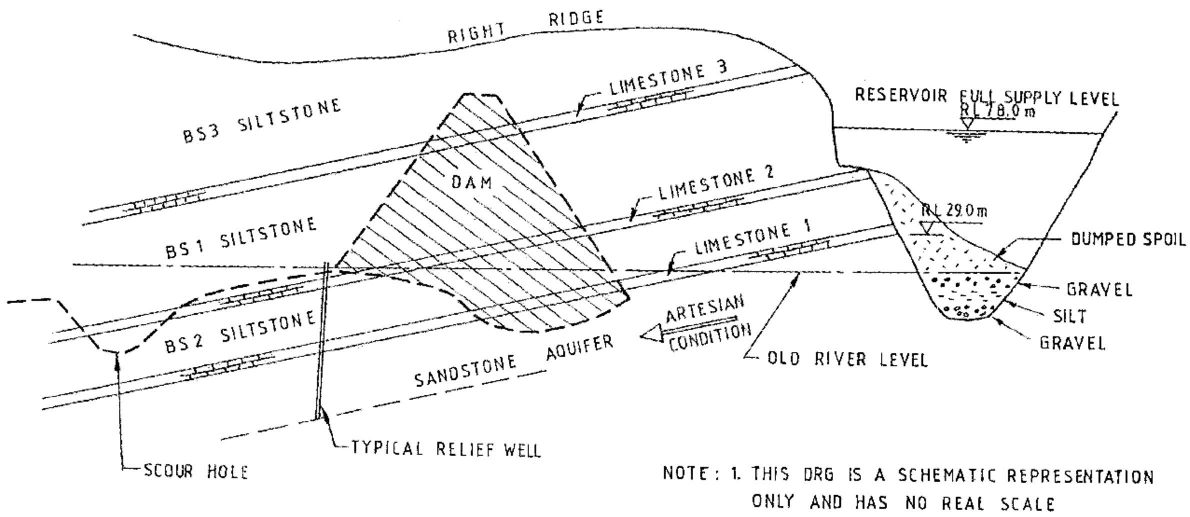

Figure 1. Schematic geological and artesian profile at Patea Dam

3 DAM STABILITY AND REMEDIAL MEASURES

The Patea Dam is considered a high Potential Impact Classification (PIC) dam which is a rating that represents the consequence of a dam failure. According to the guidelines (NZSOLD, 2015), high PIC dams are required to undergo a high level Comprehensive Safety Review (CSR) every five years. CSRs review the civil, geotechnical, mechanical and electrical safety aspects of a dam. The Commissioning Addendum report identified foundation piezometric levels, equating to a FoS against buoyant uplift of 1.5, for the purpose of determining appropriate alarm levels. These alarm levels were determined via stability analysis – for example a warning level of RL 26m was deduced. The 2010 CSR commented that W02 piezometric levels were close to the RL 26m and noted there would be a FoS reduction during a large seismic event (Grilli, 2010). The CSR reviewer recommended installing additional relief wells to reduce the increasing artesian pressures, or to place free draining rock-fill toe support. Trustpower indicated a preference for relief well installation.

4 RELIEF WELL DESIGN AND INSTALLATION

Two pressure relief wells (PR1 and PR2) were drilled to a depth of 38.5m and 40m respectively below the dam toe ground surface. Two open standpipe piezometers (PP1 and PP2) were drilled to a depth of 19m (1m into the aquifer) to replace existing damaged standpipe piezometers. The new pressure relief wells and piezometers were drilled at the dam toe marginally upslope of the original monitoring points. This allowed for monitoring of groundwater flows, groundwater depths, and to provide a safety buffer between the site crew and the variable tailwater levels for relief well installation. The locations of the above remedial measures are shown in Figure 2.

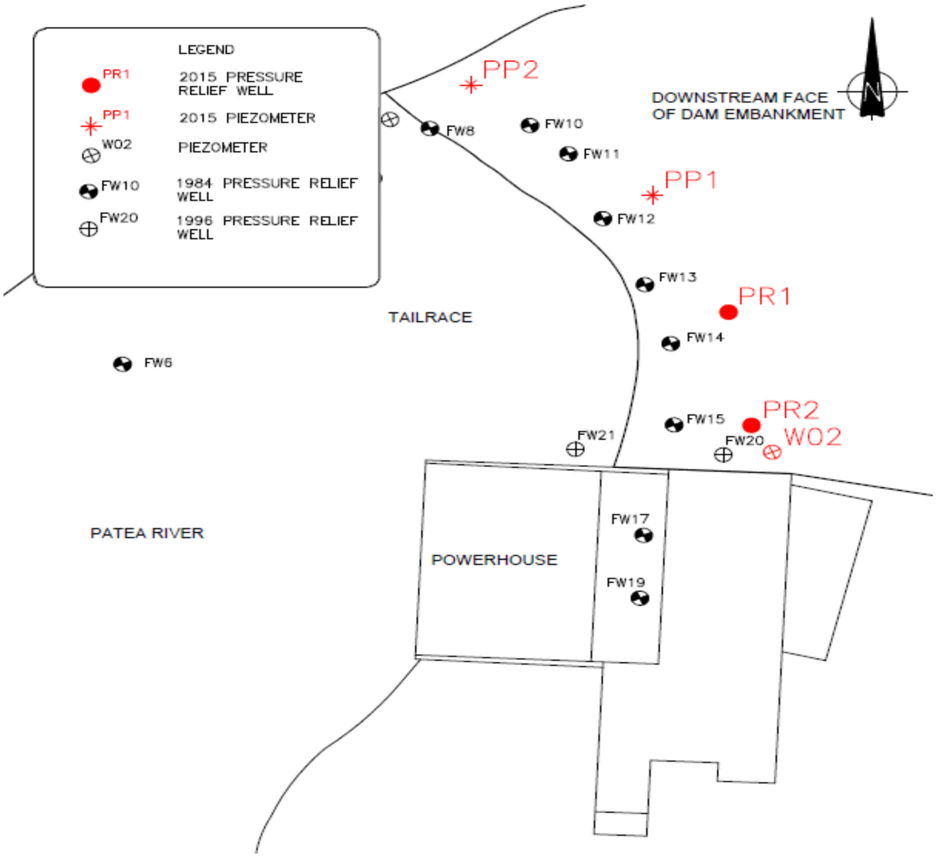

Figure 2. Patea dam remedial measures site plan

4.1 Relief Well Design

The 2015 relief well and piezometer configurations were retained from the original as-built design, with some exceptions. The elements retained from the original design included the casing material, grout backfill detail, non-return valves (to prevent high tailwater levels pressurising the foundation), and casing diameters. Target depths of 20m below the limestone were also retained in the final detail of the relief wells.

Some design modifications were required from the original relief well design to increase their longevity and usefulness. These are discussed below.

4.2 Design Modifications

4.2.1 Upstand Improvements

The original relief well design included cut gas slots around the full circumference of the well casing. This design was not conducive to flow monitoring, whereas the new relief well upstands have aligned spouts, which are more suitable for flow monitoring.

4.2.2 Relief Well and Piezometer Slotted Screen and Backfill Detail

Current practice for pressure relief well screens is for screen openings to be no greater than the D_{50} effective diameter of the backfill filter material, for example, gravelly sand (Fell 2014). D values are typically ascertained from particle size distribution curves. For uniformly graded filter material (as used in the 2015 installation) screen openings were no larger than the D_{15} value. This minimises excessive filter in-wash through slot openings and allows groundwater inflow. The 2015 relief well screen openings were 0.5mm, consistent with the original design.

A comparison of the 2015 relief well backfill with the equivalent used during construction/ commissioning was completed. The Commissioning Report (Beca, 1985) notes the backfill comprised filter sand and specifies the piezometer filter material as that used in Zone 4 of the embankment dam.

Zone 4 grading values, indicated a D_{15} value of 0.22mm. This value is noticeably lower than the 0.5mm slot openings and is low when compared with Fell's criterion for screens and filter material. Hence, it is suggested in-wash of fine filter material may have migrated into the older relief wells with time, reducing their effectiveness.

The backfill is also required to be sufficiently fine to act as a filter to the bedrock as seepage flows into the well. The D_{15} of 0.7mm meets the no erosion criteria for the siltstone/sandstone. It is noted that this is slightly coarser than the Zone 4 grading used in the 1984 and 1996 relief well installations.

4.3 Relief Well Drilling and Installation

Due to the remote nature of the site and difficult access (there is no road access to the dam toe), specialist equipment was required. This equipment comprised of the HPP150 (designed, built and customised by Webster Drilling Limited), heli-portable drill rig, steel drum mixers, tools and accessories.

Borehole pressure relief well 2 (PR2) was predominantly cored, with samples retrieved and classified according to the New Zealand Geomechanics Society (NZGS) Guidelines (NZGS, 2005). The remaining boreholes were classified from observations of drill rig vibrations, monitoring drilling water loss/gain, drill bit progression, observations of drill cuttings and return fluid.

The purpose of coring PR2 was to prove the underlying geological units. Remaining boreholes were drilled via augering and mud rotary drilling with direct circulation, whereby core sample was not retrieved. This method was used to speed up drilling times and to reduce the overall budget costs.

As expected, drilling progress through tailrace backfill (often comprising riprap boulder material) and limestone strata was slow and associated with moderate to heavy drill rig vibrations. Drilling in sandstone/siltstone was steady, with light drill rig vibrations.

An auger was used to drill through the tailrace/riprap layer, and the 200mm casing was inserted to varying depths. The casing was grouted in place and left overnight to set. Aside from PR2, drilling difficulties were encountered for all boreholes in the initial tailrace/riprap layer which meant the 200mm casing could not be inserted to 5m preferred depth. The site team reported that loose material, possibly due to elevated tailwater levels, collapsed back into the borehole, preventing full insertion of the 200mm casing.

Following installation of the 200mm casing, the team commenced a 100mm diameter drillhole through the grout backfill and into the limestone and BS2 layers. The 100mm diameter steel casing was then installed, with the base founded in Limestone 1, grouted and left overnight to set. The final stage of drilling was to reach target depths below Limestone 1. The 2015 drilling indicated that the geology was consistent with what we expected described in sections 2 and 2.1.

5 MONITORING RESPONSE AND OBSERVATIONS

Following the installation of the 2015 relief wells, foundation piezometer W02 responded with a noticeable decrease in piezometeric levels. Figure 3 highlights the W02 pressure trends and when relief wells were installed. Current W02 piezometric levels are the lowest since mid-2005 and are approximately 2m lower than the monitoring system warning level of RL 26m. This suggests an increased FoS above 1.5. Foundation piezometer W02 is a key piezometer as it has historically exhibited good response to relief well installations.

It was also noted that a gradual 1.2m decrease of piezometric levels occurred during drilling of PR1 to the newly installed Piezometer 1 (PP1), and Piezometer 2 (PP2) from 15 to 22 April 2015. Monitoring over this time also showed a piezometric level increase of 0.5m on 6 April 2015 followed by a 1m step decrease on 7 April 2015. It is unclear what caused W02 to increase and decrease from 6 to 7 April 2015, particularly as no drilling occurred during this period. Prior to Easter, PR2 drilling had only progressed into the (upper) Limestone 2 layer. One possibility may be a foundation response following a period of heavy rain and increased reservoir level. It is consider the W02 pressure decrease from 15 to 22 April 2015 was caused by the drilling and installation of PP1, PP2, PR1, and

PR2. The artesian pressure responses described during the duration of the 2015 relief well programme is shown in Figure 4.

Another observation noted from the completed relief wells was a sulphur-like smell of the discharged water. This was particularly noticeable following completion of PR2 and, to a lesser degree, PR1. It is assumed the groundwater odour may be due to water contact with limestone formations and/or organic content. This is not considered a dam safety issue.

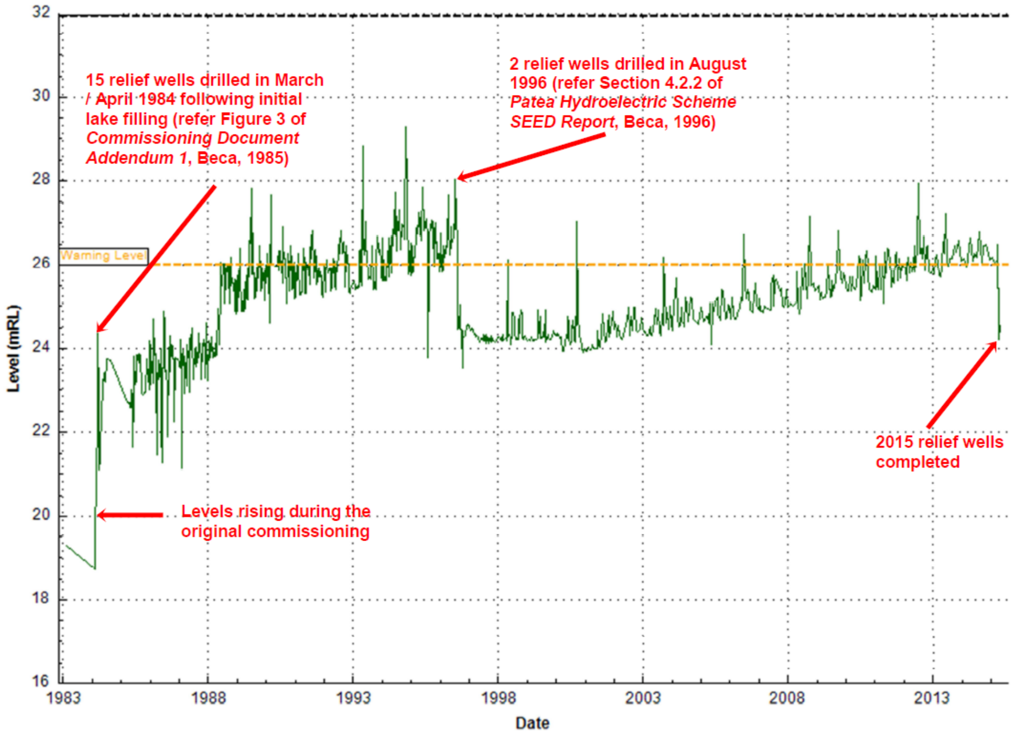

Figure 3. Annotated time series plot for foundation piezometer W02 (entire instrument history)

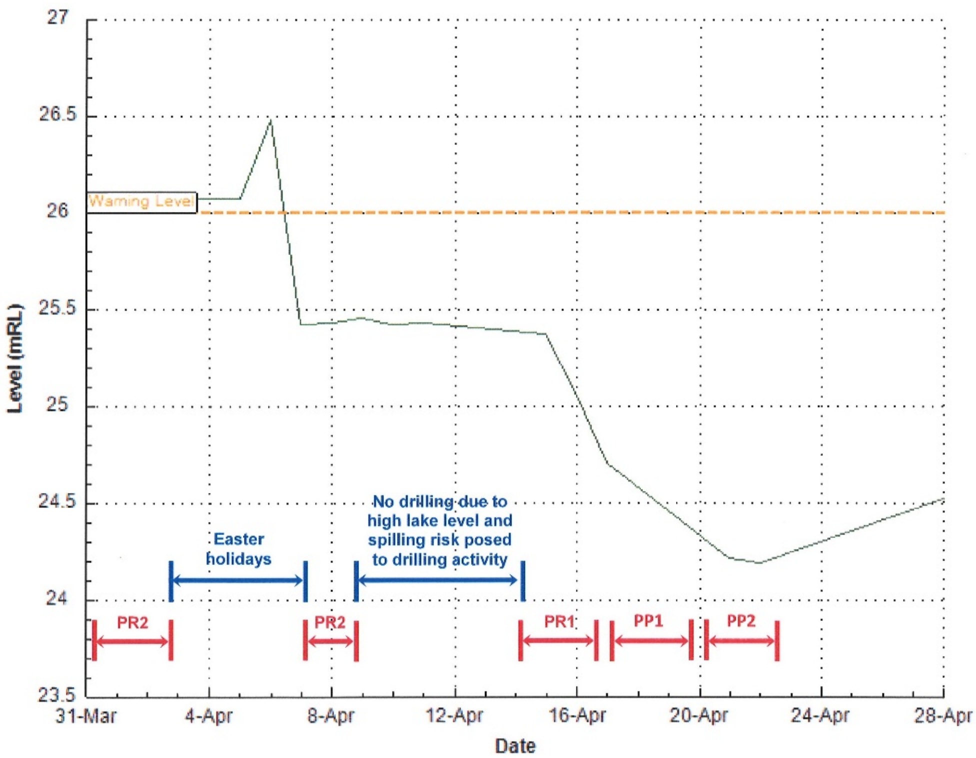

Figure 4. Annotated time series plot for foundation piezometer W02 during installation (four week period)

6 CONCLUSION

The purpose of the relief wells is to reduce gradually increasing artesian pressures that have developed under the dam since commissioning. Due to the high PIC rating of Patea Dam, implications of dam instability (potential or confirmed) should be investigated and remediated. The installation of relief wells into the aquifer below Limestone 1 was historically successful and was the preferred remediation to reduce artesian pressures in 2015. Installation of the 2015 wells was difficult due to access issues and geology that were successfully overcome. Relief wells installed had an immediate effect on artesian pressures below the dam with levels dropping during drilling. Currently piezometric levels are below warning levels indicating the relief wells installed in 2015 are performing satisfactorily.

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