Shake, rattle and grind: characterisation of the Rowallan Dam foundations using sonic drilling

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ABSTRACT

Rowallan Dam is located in the headwaters of the Mersey River in northern Tasmania. It consists of two earth and rockfill embankments up to 43m high, separated by a ridge of Precambrian quartzite on which the spillway structure is located. The left embankment is located over an ancient river channel that has been buried by up to 44m of glacial till. Investigations were conducted on the dam in 2010 to characterise the embankment and foundation conditions for a detailed quantitative dam risk assessment. Drilling in glacial tills can be a difficult exercise due to the highly variable nature of the deposits which can vary from very hard boulders to soft silts and sands. Sonic drilling is a technique that has been around for some time, however, its introduction into Australia and its use in the Australian dam projects is relatively new. The technique relies on resonant vibration of the drill string to progress the drill head forward rather than rotation of a diamond cutting head or auger teeth. Sonic drilling was conducted on the left embankment foundation as it appeared to offer the best solution to these difficult drilling conditions. This paper discusses the overall program of investigations at Rowallan Dam with specific emphasis on the use of sonic drilling in the left embankment foundation. It concludes that sonic drilling was the most appropriate technique in this application with close to 100% core recovery in the very difficult conditions but it does have its limitations.

Keywords: glacial till, dam foundations, sonic drilling, core recovery

1 INTRODUCTION

Rowallan Dam is located in the upper reaches of the Mersey River and is the main storage of Hydro Tasmania's hydroelectricity development on the Mersey-Forth system. The embankment and appurtenant works were constructed in the 1960s forming a 134,000ML storage. There are two central core earth and rockfill embankments separated by the central spillway founded on a ridge of rock at relatively shallow depth. The right embankment is 43 m high and is founded on a hard quartzite rock foundation, and the left embankment is 28 m high and is founded partly on rock and partly on glacial deposits.

A dam safety risk assessment of Rowallan Dam was undertaken in 2000 and was reviewed in 2009 following a detailed review of the available information from design, construction and post construction. Several key knowledge gaps were identified that potentially had a significant effect on the outcomes of the risk assessment.

One key knowledge gap was associated with the properties of the glacial foundations below the left embankment. This had implications for dam safety including the risk of: piping through the foundation, and, embankment instability associated with liquefaction of the foundation under earthquake loading. The key unknown with the foundation was the type(s) of glacial deposits present (eg. basal till, ablation till or fluvio-glacial deposits) and their properties (i.e. classification, gradation, layering).

A program of investigations was undertaken for the entire dam and foundations. On the left abutment foundation these investigations included seismic refraction survey, sonic drilling and test pitting followed by a suite of laboratory testing. This paper focuses on the sonic drilling component of the foundation investigations as this technique is relatively new to Australia and the benefits that this brought to the project.

2 GEOLOGY

The dam site is situated at the downstream end of a (now flooded) glacial drift plain that is 10 km long and up to 500 m wide. At the dam site the foundation rock comprises Precambrian Howell Group quartzite and schist overlain by Pleistocene age glacial deposits.

The upper Mersey Valley was glaciated on three occasions during the Pleistocene. The youngest, Rowallan Glaciation, probably commenced after 28,000 years BP, that the maximum ice limit was attained before 13,500 years BP, and retreat occurred before 10,000 years BP (Hannan & Colhoun 1987). Mitchell & Paterson (1970) indicate that the dam site is within the “terminal zone” of the Rowallan Glacial Advance but Pollington et al (1993) show the terminus at Parangana dam, some 7 km down valley from Rowallan Dam.

Figure 1 shows a section across the valley of the left embankment. The spillway (on the right of the section) is located on a ridge of quartzite and schist (refer Plate 1) that separates the left and right embankments. The ridge is separated from the western wall of the valley (forming the left abutment of the left embankment) by a 150 m wide, buried channel of the Mersey River that is inferred to be fault controlled. The buried channel is infilled with glacial material (Paterson 1962) that has been variously described as till and as fluvioglacial material in different reports. It has a maximum depth of approximately 40 m which is 27 m below the bed of the Mersey River which is itself beneath the right embankment. The left embankment was constructed across this channel infill.

The material in the buried channel is described by Paterson (1962) and Mitchell & Paterson (1970) as a compacted, impermeable, unstratified heterogeneous mixture of boulders, cobbles, pebbles, sand silt and rock-flour. The coarse fragments are sub-rounded to sub-angular ranging up to 2 m in diameter and are mostly derived from dolerite. The matrix consists of sand to clay-sized rock fragments and minerals (no clay minerals were found in the deposit). The material is fresh within several metres of the surface.

Immediately downstream from the dam site the nature of the glacial drift deposit is reported to change, and fluvioglacial sand and gravel channels are dominant in the surface layer. Mitchell & Paterson (1970) state that none of the channels pass into the buried channel against the left abutment, but this had not been clearly demonstrated and remained a key geological issue to be resolved during the project.

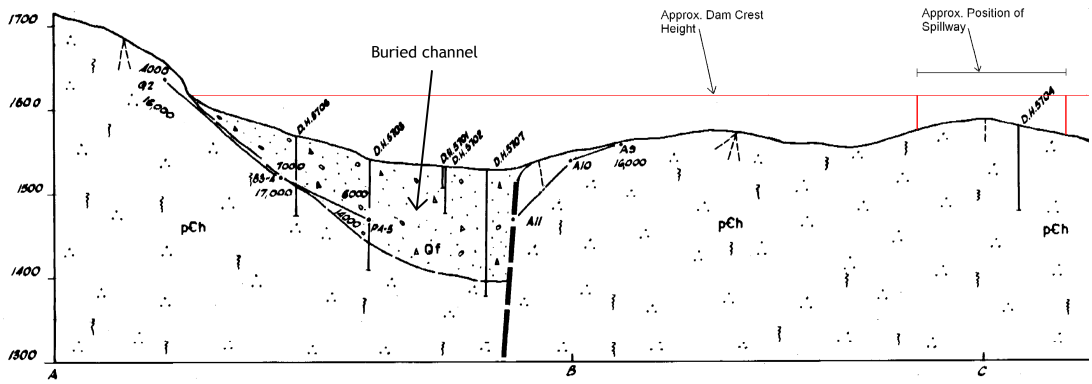

Figure 1: Geological profile beneath left embankment looking downstream showing buried glacial sediment channel and inferred fault (Paterson, 1962).

The following is a summary of the main material types at and close to the dam site.

2.1 Bedrock

Bedrock observed in the dam area consists of Precambrian quartzite and schist as described by Paterson (1962) and others. The quartzite is massive to weakly foliated, extremely high strength, and fresh. The schist is interlayered with the quartzite and is characteristically foliated, slightly weathered to fresh and of high to very high strength. The quartzite and schist bedrock of the abutments and the central ridge have been glaciated and all weathering products have been removed such that fresh, sound hard rock crops out at the surface (glacial striations and grooves are preserved).

Plate 1: Unweathered foliated quartzite exposed in the spillway. Note the gravelly brown (basal till) remnants on the rock in the foreground.

Plate 2: Ablation till exposed in a forestry road cut above the right abutment of the dam

2.2 Till

Till is material deposited directly by (or from) glacier ice. Many types of deposits formed in glacial environments are labelled as “till”. The following terminology was adopted for the Rowallan dam site.

2.2.1 Basal Till

A layer of very compact, dense bouldery material in a silty fines matrix. Basal Till is widespread in the Rowallan area. It is seen ‘plastered’ onto rock in the spillway (Plate 1) and was also observed in roadcuts along forest tracks. This material is interpreted to represent till that was over-ridden and compacted (heavily overconsolidated) by the force of the ice load. The till can appear stratified as a result of the over-riding by the ice. The remnants exposed in the spillway show that it is very erosion resistant, and also that the material can be quite variable in grading over short distances.

2.2.2 Ablation Till

Till deposited as ablation moraine; i.e., as material that was carried on or within the ice and deposited as the ice melted. It is characteristically very bouldery material dominated by rounded dolerite boulders (Plate 2) but with occasional very large angular or subangular blocks of dolerite, basalt, quartzite/schist or Permian sedimentary rock. This material is less dense than the basal till and shows an upper (brown) weathered zone. It may vary over short distances but is typically non-bedded, lacking persistent lenses or layers.

2.3 Fluvioglacial Material

Fluvioglacial landforms result from erosion and deposition by glacial melt-water. The only true fluvioglacial landforms observed in the site area are outwash terrace remnants downstream from the dam. The fluvioglacial materials exposed in the spillway channel include coarse sandy gravels, interbeds of sand and gravelly sand and lenses that appear to represent old channel features.

3 PURPOSE OF FOUNDATION INVESTIGATIONS BELOW LEFT EMBANKMENT

One of the key geological data gaps from the literature review was the nature of the glacial deposits below the left embankment. Fluvio-glacial deposits, if present below the left embankment, have the potential to contain gravelly outwash deposits and seepage pathways along which piping could initiate. Also, liquefaction under earthquake loading could be an issue for fluvio-glacial deposits and/or ablation till.

Foundation investigations were proposed to address this data gap as input to the risk assessment of the existing embankment as well as targeted at providing information for design of risk reduction upgrade works. The purpose of the investigations on the left embankment downstream toe was to:

- Assess the geological history for the deep glacial trough below the left embankment and the steep contact with the Permian bedrock;

- Assess the properties and structure of the glacial deposits including particle size, density, layering, presence of open voided zones, seepage for assessment of piping and stability related failure modes;
- Investigate the toe detail below the left embankment where founded on glacial deposits. This included confirmation and sampling of the filter blanket and assessment of the upper portion of the foundation (material properties and assessment of influence of compaction on the density and strength).

4 SONIC DRILLING

4.1 Sonic Drilling Background

The concept of sonic drilling has been attributed to a Romanian George Constantenesco around 1910 (Dickey, 2011), with development of the technology starting in the 1930s by Ion Basgan and progressed in the US by Albert Bodine in the 1940s and 1950s, principally as a pile driving technology. The technology was sold to the Hawker Siddeley office in Canada which worked on the technology for drilling purposes until the 1980s when it ceased development work (Anon, 2002). However, a mechanical engineer, Ray Roussy, saw potential in the technology and continued to work on it privately, eventually forming the Sonic Drilling Company Ltd (Dickey, 2011). The drilling methodology is (Boart Longyear, 2010):

- The oscillations are produced at the drill head by counter rotating masses that transmit longitudinal vibrations to the cutting face through the drill string at 100-150Hz.
- The vibrations are combined with rotation at the cutting face to advance the core barrel by tuning the drill string to its resonant frequency.
- A casing sleeve is advanced over the core barrel.
- The core barrel is retrieved. The core is extracted from the barrel with gentle vibration for logging and sampling as required and the process repeated to the required depth.

A literature search on sonic drilling produced hundreds of articles on the technology, however, the majority of these are articles in trade magazines promoting the latest model or the technology, but little in the way of independent evaluation of the technology. Richterich et al (1994) did undertake an evaluation of sonic drilling in comparison to cable tool technology for geo-environmental investigations. The key conclusions of the report were:

- The sonic drill was capable of penetrating the test site's variable deposits of sandy gravels with cobbles and boulders and silty sands with close to 100% core recovery;
- The drilling speeds were significantly higher than a comparable cable tool rig;
- There was heating of the core recovered, although this could be mitigated and this may be an important consideration depending on the application (eg. if trying to sample volatile organics);
- There was some disturbance to the outer edges of the core, but the centre was largely intact;
- There were failures of the drill pipe where it screwed together through fatigue;
- No generation of wastes other than the core recovered (a significant advantage in a contaminated site)

4.2 Sonic Drilling at Rowallan Dam

In planning the investigations for the foundations of the left embankment, careful consideration of possible geological conditions that would potentially be encountered was made. Earlier drilling at the site prior to the construction was located upstream of the current alignment of the dam and indicated that the glacial deposits were till with numerous cobbles and boulders. Downstream of the dam, outcrops of fluvio-glacial deposits had been found. Any technique applied would need to be able to clearly distinguish between the two as presence of dense till would rule out piping and liquefaction as credible dam failure modes. Table 1 summarises the capability of the differing techniques for the hypothesised conditions. Percussion was clearly not suitable due to lack of core recovery. Auger was unsuitable due to likely presence of cobbles and boulders which would prevent penetration. Cable tool was discounted due to its very slow rate of penetration in mixed deposits and previous experience of the authors that core stones can be driven through the matrix, giving misleading results. Coring would no doubt be able to penetrate the deposits, however, there was high likelihood of the loss of the matrix material into the drilling fluids, particularly if sandy or silty. The best option appeared to be sonic although expensive.

Table 1: Relative merits of drilling techniques

Technique Characteristic	Percussion (using casing advancing)	Hollow Flight Auger	Diamond Coring	Cable Tool	Sonic
Ability to recover silts, sands and gravels	Poor	Y	Poor	Y	Y
Ablility to penetrate mixed hard and soft deposits	Y	N	Y	Y	Y
Rate of penetration	Fast	Moderate in soft, Nil in hard	Moderate	Slow	Fast
Core recovery in mixed hard and soft	Poor quality	N/A	Variable	Variable	Near Complete
Core disturbance of recovered material	High	High	Low	Moderate	Some?
Waste generation	Low	Low	High	Low	Low
Noise generation	High	Moderate	Moderate	Low	High

5 FINDINGS OF THE GEOTECHNICAL INVESTIGATIONS

5.1 Investigations

Test pitting in the crest of the dam and at the downstream toe of the dam successfully obtained samples of the core, filters and rockfill to allow a detailed assessment of the piping risks through the embankment. Seismic traverses downstream of the left embankment was not particularly useful in determining the depth to bedrock as the results were difficult to interpret and did not clearly identify the trough feature. Test pitting and the sonic drilling were however able to demonstrate clearly that the foundations of the dam consisted of a relatively thin layer of approximately 1m of ablation till overlying a very dense and stiff basal till over the Permian bedrock. An updated model of dam foundations can be seen in Figure 2.

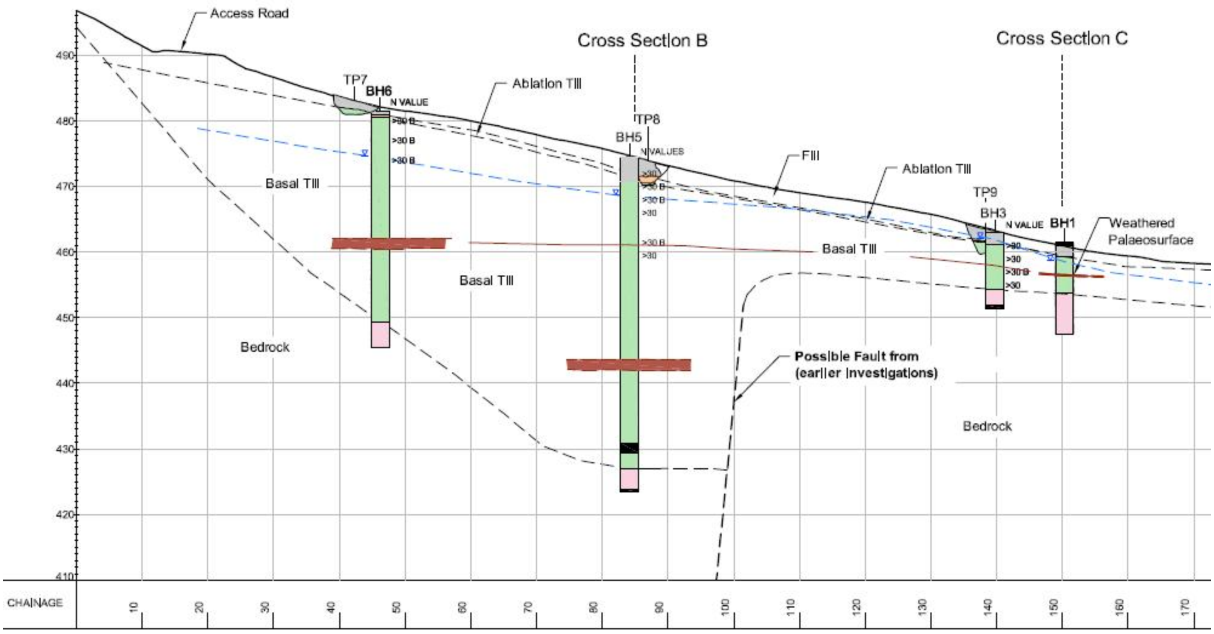

Figure 2. Updated Geotechincal Model of left embankment foundation

6 DISCUSSION

Sonic drilling for the Rowallan Dam project proved to be the best technology for the investigation of the left embankment foundations, due to its ability to recover close to 100 per cent of the core in the glacial till. Due to the high recovery, there was confidence that there were not any permeable zones within the foundation of significance, and, silt or sand layers that might be susceptible to backward erosion piping or liquefaction. The recovery was able to detect a number of paleosurfaces in the basal till confirming the geological history of a number of advances and retreats of the glacier in the valley. The technology is able to undertake standard down hole testing such as SPTs (these were successfully undertaken at Rowallan) and taking thin walled tube samples (not successful at Rowallan due to the very dense condition of the basal till. Advantages of the technology from this investigation are:

- high core recovery in difficult drilling conditions;
- rapid advancement of the drilling, reducing site supervision costs;
- low waste generation which is an advantage in environmentally sensitive areas.

Nonetheless, there are some downsides to the sonic drill technology:

- dependant on the control of the rig, the hard rock on site was broken into a series platey sections along the foliations or reduced to rock flour in weathered rock if maximising the rate of penetration. If intact samples of the rock mass are required, core drilling will produce a better result as advised by the drillers prior to the engagement.
- The core is not undisturbed even in the soil zones. If undisturbed samples are required, thin walled tubes should be taken in advance of the coring although due to the density of the foundation at Rowallan this was not possible.
- The vibrations have the effect of heating the samples. This was particularly apparent in the rock which was generally too hot to handle when removed from the core barrel. Where temperature may affect testing, for example, moisture content, care will be required to ensure representative samples are obtained.
- The rig is quite noisy and this may be an issue in urban environments or sensitive ecological environments. The investigations at Rowallan Dam had to be delayed due to the presence of an active Wedge Tail Eagle nest in close proximity to the site.

7 CONCLUSION

The Rowallan Dam left embankment foundation presented a challenging geological environment with its deep glacial deposits. A number of technologies were considered to undertake these investigations and sonic drilling was selected, although the authors had not previously had personal experience of this technology as it is a relatively recently introduced tool to Australia. The high core recovery achieved by the sonic drill rig in the mixed hard and soft deposit was critical to the success of the investigations. Sonic drilling offers an excellent tool to investigate soft, or mixed hard and soft deposits quickly where a high core recovery is required. Nonetheless, it is not the most suitable tool for hard rock conditions where the structural properties of the rock are required or when disturbance of the core by vibration and heating may affect the results of the investigations, although these can be mitigated with careful planning.

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