Assessment of the Gordon Power Station Long-Term Cavern Stability

D. Sainsbury
Geotechnica, Victoria, Australia

P. Hills
Pitt and Sherry, Tasmania, Australia

K. Stacey, S. Hughes
HydroTasmania, Tasmania, Australia

B. Sainsbury
Deakin University, Victoria, Australia

ABSTRACT: The Gordon Underground Power Station in Tasmania was completed in 1978. Regular inspections of the original ground support elements installed have documented deterioration in their visual characteristics over time. To assess the current and required Design Life stability a detailed three-dimensional discrete element model (3DEC) has been developed. The model includes the consideration of the Cavern, Surge Chamber and Drainage Gallery including sections of the Access Tunnel. The model response has been verified through construction records and geotechnical instrumentation that was installed. It provides a basis to consider the effects of potential long-term ground support degradation on the Cavern stability.

1 INTRODUCTION

The 432MW Gordon Underground Power Station, is the largest power station in Tasmania and forms part of Hydro Tasmania's Gordon-Pedder Hydro-Electric Scheme. Excavation of the Machine Hall Cavern at a depth of 183m was completed between 1972 and 1974, and the Power Station was commissioned in 1978. In addition to the Power Station, the hydro power scheme involved construction of four dams to form two supply reservoirs from Lake Gordon and Lake Pedder. During construction of the cavern, detailed geological mapping and deformation monitoring was conducted. A significant wedge bounded by two faults and an Amphibolite Dyke with an estimated mass of 400T was identified in the crown of the Cavern. The wedge was heavily supported at the time and re-supported in 2019. Since commissioning there has been no further instability identified in the Cavern complex. However, as the Power Station is critical to the future supply of renewable energy to the east coast of Australia, a three-dimensional discontinuum model has been developed to accurately simulate the observed and monitored ground conditions during construction and reliably assess the geotechnical risks associated with the current and future ground support capacity. The numerical simulation has been conducted in the distinct element code 3DEC (Itasca Consulting Group, 2016). 3DEC has been specifically developed to analyze the performance of excavations in jointed rock masses, together with the interaction of support elements.

2 GEOTECHNICAL AND MODELLING PARAMETERS

The Gordon Cavern is situated within a complex sequence of Precambrian metamorphic rocks that include Quartzite, Schist and Amphibolite Dykes. A description of the engineering design, rock mechanics studies and observations during excavation of the Machine Hall was documented by Lack, Bowling, and Knoop (1975) and Roberts and Andric (1975). These studies have formed the basis for the current model validation. Detailed studies were also conducted during construction to estimate the intact rock strength, *in situ* stress regime and *in situ* deformation modulus.

These values were used as the basis for the model parameters and are presented in Table 1 and Table 2.

Table 1. Rock mass parameters

	UCS (MPa)	GSI	*mi*	Deformation Modulus (GPa)
Quartz	84	60	20	20
Schist	67	50	10	7
Amphibolite	39	50	10	10

The current cavern configuration and exposed Quartzite and Schist is presented in Figure 1.

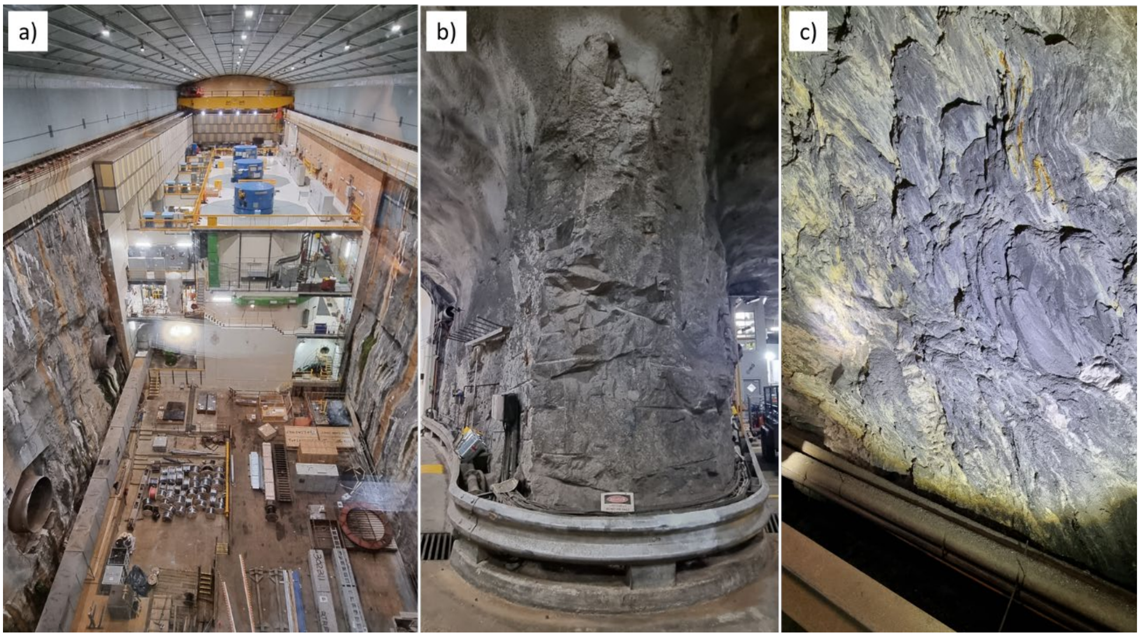

Figure 1. a) Current surface conditions within the Cavern; b) Exposed Quartzite; c) Exposed Schist in the access drive

Detailed investigations of the *in situ* stress regime were conducted during detailed design and construction of the cavern (Lack, Bowling and Knoop, 1975). Based upon more recent knowledge and understanding of the regional *in situ* stress regime throughout southwest Tasmania, a site-specific stress regime at the cavern location was derived for the numerical simulation as presented in Table 2.

Table 2. Stress Regime

	Magnitude (MPa)	Dip (°)	Dip Direction (°)
σ_1	10.3	23	261
σ_2	7.2	15	164
σ_3	4.7	62	043

A detailed structural model of the major faults identified during excavation of the Cavern was developed. The structural model was used to specify explicit structures within the numerical model that can slip and separate. Their properties are provided in Table 3 and distribution presented in Figure 2c.

Table 3. Explicit structure properties

Kn (Pa/m)	Ks (Pa/m)	Cohesion (kPa)	Cohesion (kPa)	Friction (°)	Tension (kPa)	Dilation (°)
$1e^{10}$	$1e^{9}$	10	0 (residual)	24	0	0

2.1 *Ground support*

The primary support of the Cavern consists of 4.9m and 3.6m grouted slot and wedge rock bolts. The bolts are mechanically end-anchored bolts with copper tubes attached for grouting of the drill hole annulus (Pender, Hosking and Mattner, 1963). The bolts were intended to have full grout encapsulation to provide corrosion protection, however, inspection and testing of the bolts has found that although an attempt was made to do so, many of the bolts remain ungrouted, and that, 50 years or more after installation, many are suffering from corrosion.

The bolts have been simulated with the in-built hybrid bolt structural element logic within 3DEC. However, there is significant uncertainty regarding their *in-situ* capacity. At the nearby Poatina Cavern that was commissioned in 1964, failure loads between 17T and 21T were reported (Colebatch, Endersbee and Paxton, 1963). Recent pull-testing of bolts at Poatina returned pull out failures at 18T. In lieu of a detailed understanding of the *in-situ* anchor capacity and grout properties, conservative mechanical properties were adopted for the analyses and are presented in Table 4. Further discussion on the simulation of grouted slot and wedge bolts with the hybrid bolt logic at the Poatina Power Station Cavern and numerical pull-test simulation is provided in Sainsbury et al., (2022).

Table 4. Slot and wedge rock bolt properties

	Modulus (GPa)	Yield Strength (kN)	Yield Strain	Grout Strength (kN/m)	Grout Stiffness (kN/m/m)	Shear Strength (kN/m)	Shear Stiffness (kN/m/m)	Shear Strain
Bolt	182	150	0.03	100	500	120	1000	0.01
Anchor	182	150	-	400	1000	-	-	-

Simulated pull tests were conducted on the modelled rock bolts. When full grout encapsulation was simulated, the bolts reached the full capacity of the steel rod. Without encapsulation the bolts slipped at the simulated anchor capacity of 4T.

3 DEVELOPMENT OF NUMERICAL MODEL

3.1 *Model Geometry*

The Power Station complex simulated in 3DEC is presented in Figure 2a. The explicit fault structures simulated and distribution of the Quartzite, Schist and Amphibolite rock masses are presented in Figure 2b and Figure 2c respectively.

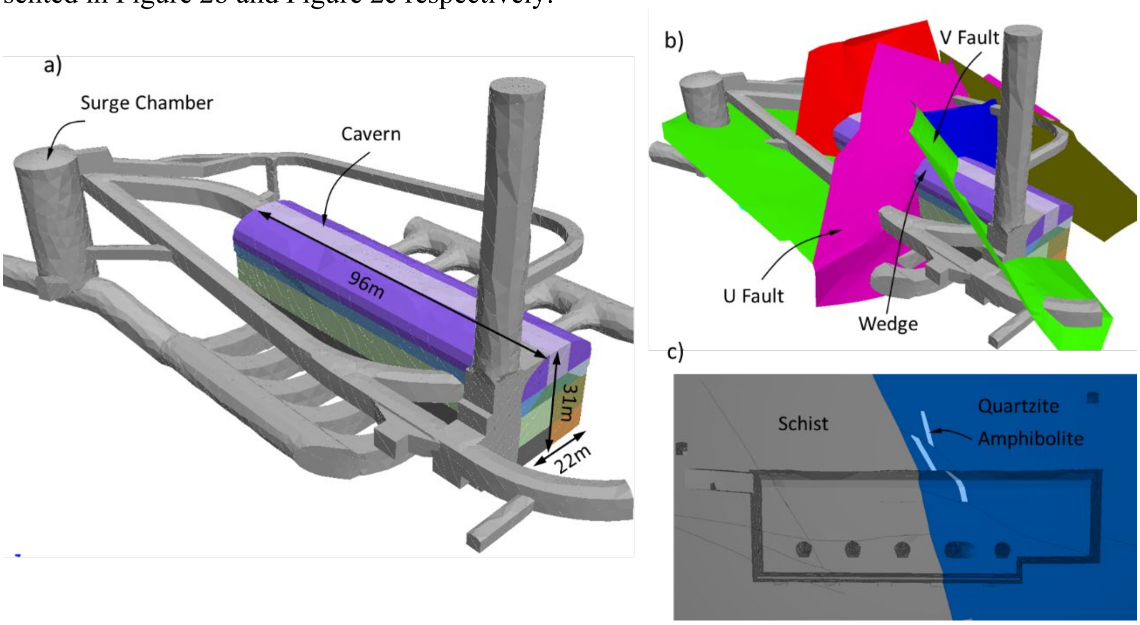

Figure 2. a) Power station complex simulated in 3DEC; b) explicit structures; c) geotechnical domains

3.2 *Cavern response after excavation*

Excavation of the Gordon Cavern was simulated with a 6 m advance followed by placement of rock bolts at the completion of each excavation stage. The placement of bolts was simulated in-cycle to ensure an accurate load-path is followed during sequential excavation. Excavation was simulated with ten stages that are consistent with those documented by Lack, Bowling, and Knoop (1975) and Roberts and Andric (1975). Figure 3 presents the response of the model after completion of the Cavern excavation.

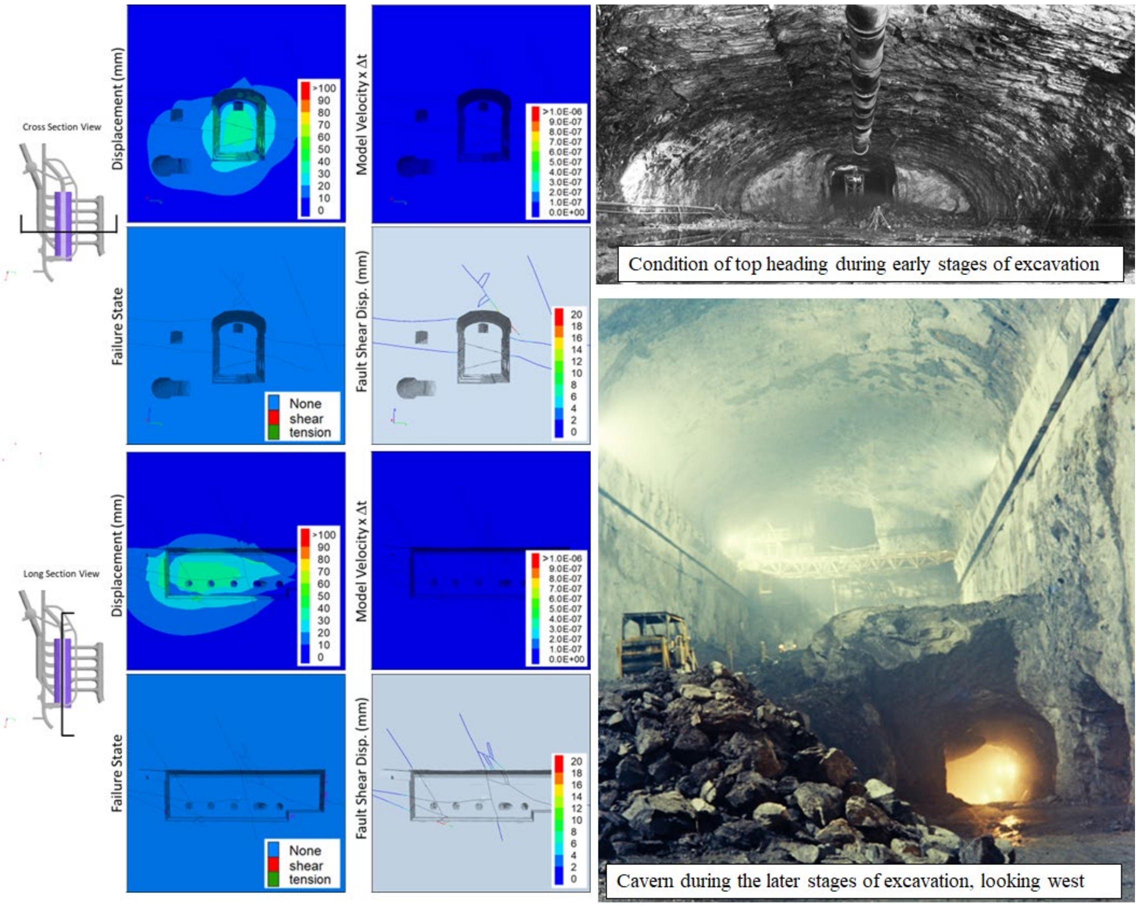

Figure 3. Model response after excavation and support of the Cavern compared to *in situ* observations.

The criteria used to present the rock mass response includes total displacement, rock mass failure state, shear displacement of the explicit bedding planes and model velocity. The model is stable with no indication of rock mass failure or instability. Increased deformation within the Schist rock mass is predicted in the model, which is consistent with the observed rock mass response during excavation.

3.3 *Back-Analysis of Monitoring Instrumentation*

During construction of the Cavern, 21 rock dilation meters that consist of a steel rod anchored at the far end of a drill hole were installed. Since installation, all serviceable dilation meters have consistently recorded relatively stable measurements. Figure 4 illustrates the location of a select number of dilation meters that have been used to verify the response of the model.

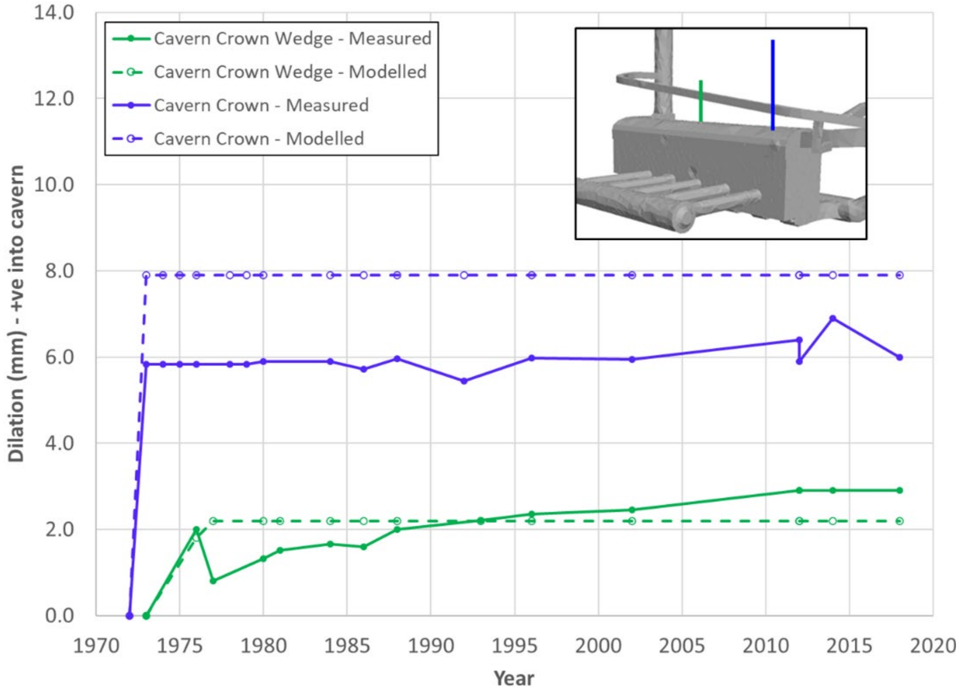

Figure 4. Location and response of dilation meters in Cavern compared with simulated responses.

3.4 *Assessment of long-term ground support degradation*

To assess the impact of potential long-term ground support degradation on the overall Cavern stability, a series of models were analyzed that simulated a progressive reduction in ground support capacity and shear strength of the large-scale faults. Figure 5 illustrates a comparison of rock mass displacement and shear displacement with the removal of the rock bolts and reduced fault shear strength to cohesion= 0 and friction angle=15°.

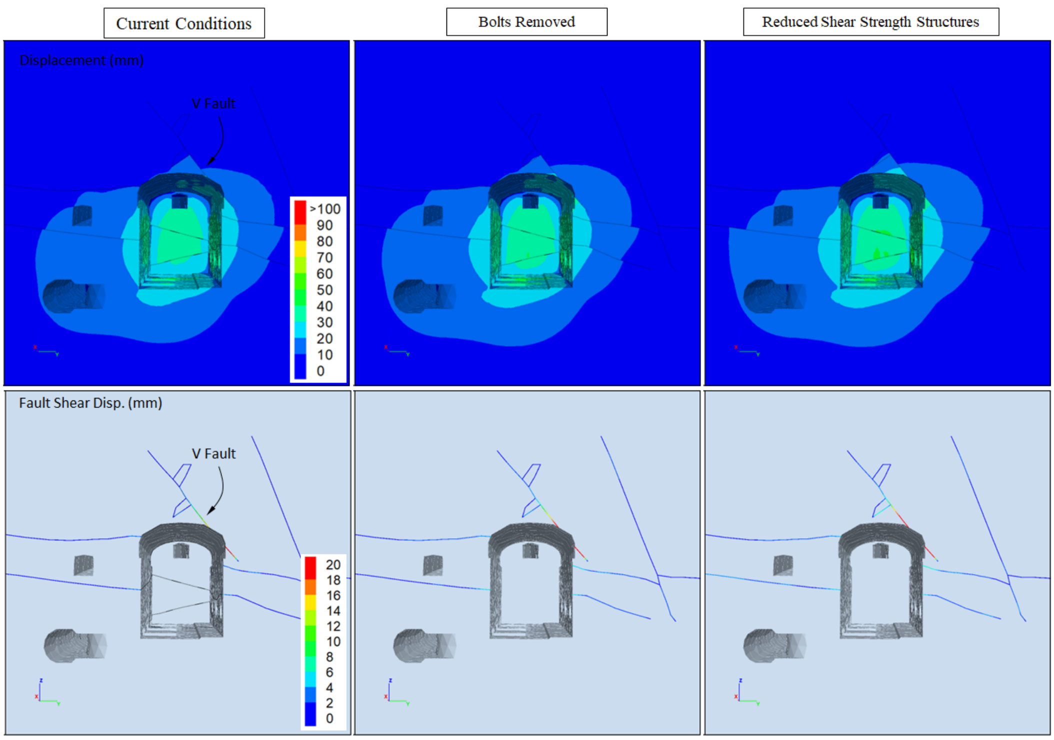

Figure 5. Model response of Cavern over remaining Design Life through removal of bolts and decrease in fault structure properties.

Even with the ground support removed and extremely low fault properties simulated, the Cavern is predicted to remain stable. A minor increase in rock mass deformation is predicted with the removal of rock bolts. A minor increase again is predicted with the reduction of shear strength of each major structure. The stability of the Cavern reflects the original design philosophy of the Hydro Electric Commision of Tasmania, that was to "*make the rock support itself in a safe manner*" (Endersbee and Hofto, 1963). This self-supporting response was a response of careful site selection that included "*the roof would be in generally sound rock*" and the lower levels of the Cavern, although situated in Schist "*the foliation surfaces dipped in the most favourable direction, eastwards and at right angles to the long axis of the Station*" (Roberts and Andric, 1975).

4 CONCLUSION

Detailed, three-dimensional discontinuum numerical modelling has been conducted to assess the long-term stability of the Gordon Power Station Cavern. Back-analysis of the as-built excavation sequence within the model provides a close match between available monitoring data and the response of the model. To assess the impact of potential long-term ground support degradation on the overall Cavern stability, a series of models have been analyzed with progressive reduction in ground support capacity and shear strength of the large-scale faults. With all cases analyzed, the Cavern is predicted to remain stable. A minor increase in rock mass deformation is predicted with the removal of rock bolts from the model, with an additional minor increase predicted with the reduction of shear strength of each major structure.

The long-term cavern stability is a testament to the considered geomechanical investigation and design philosophy which included excavation of pilot tunnels, in situ monitoring excavations, innovative stress measurement and analysis.

REFERENCES

Colebatch, G., Endersbee, L. and Paxton, H. 1963. 'Discussion - Grouted Rock Bolts', Proceedings of the Institution of Civil Engineers: Geotechnical Engineering, July-Augus, pp. 145–150.

Endersbee, L. and Hofto, E. 1963. 'Civil Engineering Design and Studies in Rock Mechanics for Poatina Underground Power Station, Tasmania', The Journal of the Insitution, 35, pp. 129–208.

Itasca Consulting Group 2016 '3DEC Version 5.2'. Minneapolis: Itasca Consulting Group.

Lack, L., Bowling, A. and Knoop, B. 1975. 'Rock mechanics Studies and Instrumentation for the Gordon Underground Power Station, South-West Tasmania', in Proc. Second Aust-NZ Conference on Geomechanics. Bris.

Pender, E., Hosking, A. and Mattner, R. 1963. 'Grouted Rock Bolts for permanent support of major underground works', Journal of the Institution of Engineers Australia, 35, pp. 145–150.

Roberts, G. and Andric, M. 1975. 'Geological Factors in the Location of the Power Station and Associated Works, Gordon River Power Development Stage One, South-West Tasmania', in Proc. Second Aust-NZ Conference on Geomechanics. Brisbane, Australia.

Sainsbury, D., Stacey, K. Sainabusry, B. and Hills, P. 2022. 'Geotechnical Considerations Associated with the Poatina Power Station Cavern', Australian Geomechanics Journal, 57(4), pp. 133–152. Available at: https://doi.org/https://doi.org/10.56295/AGJ5745.