

Innovations in strand anchor design as part of the support system for a deep underground cavern

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ABSTRACT: Australia is undertaking several nation-building renewable projects involving pumped hydro with large underground caverns which will house power stations providing large-scale storage and on demand energy. During construction the caverns require a temporary crane to be constructed to manoeuvre and position key components of the turbine machinery within the cavern. The large cranes transfer considerable loads, so it is critical that the crane rails are supported within the cavern walls by corbels using multistrand anchors. DYWIDAG has developed an innovative multistrand anchoring system for large capacity loads which overcomes the issues of grouting and stressing in an inclined hole. This system ensures the corbels are supported and connected to the rock while the challenges of the inclined angle during installation are addressed correctly. DYWIDAG's Smart Anchor monitoring system provides 24/7 remote monitoring of the forces in the anchors to ensure they are within the predicted ranges.

1 INTRODUCTION

Australia is undertaking its largest transition in history in the energy sector, shifting to renewable energy. A key part of this transition is a national shift to pumped hydro for the nation's main source of energy. These pumped hydro projects involve linking large reservoirs with long inclined tunnels to large caverns which will form some of the largest and deepest caverns in the world. Given the sheer size of these caverns, the construction sequence and methodology is monitored closely. During the construction phase, a temporary crane is constructed to manoeuvre and position key components of the turbine machinery in the correct locations within the cavern. Due to the considerable loads to be transferred by the large cranes it is critical that the crane rails are supported within the cavern walls by corbels which are installed as the primary support.

DYWIDAG, global systems supplier of ground support for geotechnics and tunnelling has developed, supplied and supervised the installation of an innovative bar and multistrand anchor system for large capacity loads to support corbels in the transformer hall and machine hall caverns. The innovation overcomes the issues of grouting and stressing in an inclined hole ensuring the corbels are supported and connected to the rock while the challenges of the inclined angle during installation are addressed correctly.

1.1 Challenges

There are several issues to be considered in the design and installation of the corbels in caverns for pumped hydro:

- High permanent loads in a rock mass with variable quality
- Deep underground anchoring with limited installation space
- Anchor installation in inclination
- Complex grouting requirements

- Design life of a fully permanent system

2 INNOVATION

The key innovations were developed due to the importance of adapting the DYWIDAG multistrand anchor system to the requirements of deep underground caverns in pumped hydro. These caverns require a permanent post tensioning anchor solution for high permanent loads in a rock mass with variable quality. Deep underground anchoring is required in a limited space with complex grouting under an inclined angle. DYWIDAG worked with their partner Anchor Packers Australia, to develop an anchor packer design which assists in overcoming the challenges associated with grouting in challenging geological conditions.

2.1 *Corbel Design*

The corbels supporting the crane are anchored to the rock mass by prestressed multistrand anchors. Due to the high permanent loads in a rock mass with variable quality each corbel was designed with two multistrand anchors installed at inclined angles (13 degrees and 18 degrees) in lengths up to 23m. Extra GEWI® 63.5mm rock bolts were installed for additional support. Working loads were up to 1161kN which indicated it was not possible to achieve these loads with single bar anchors and multistrand anchors were used to anchor deep into the rock mass.

2.2 *Multistrand Anchors*

Most pumped hydro projects require a permanent multistrand solution with 100-year design life. The design life of a fully permanent strand anchor system is not achievable with a DCP strand anchor design while grouting under an inclined angle. Two anchors would be required with a larger bore hole and higher associated costs. DYWIDAG worked collaboratively with the client and partner Anchor Packers Australia (subcontracted by DYWIDAG), to develop an anchor design to accommodate the specific design life requirement of 5 years. The bonded length of the anchor would be protected by a HDPE corrugated sheathing and the grouting procedure would grout both an inner and an outer annulus in one pass.

2.3 *Angled bearing plate*

DYWIDAG worked with the project and design team to refine the multistrand anchor design and develop angle compensating bearing plates tailored for each of the inclined angles to suit the anchors. As a leading global supplier, DYWIDAG leverages extensive technical experience to support clients in adapting multistrand anchor system designs to site requirements. The plates were welded to the corbel to ensure the correct inclination was achieved and to avoid any displacement during the tensioning of the anchor. The bearing plates perform to the specification provided the drillers and welders complete their work as per the QA/QC requirements.

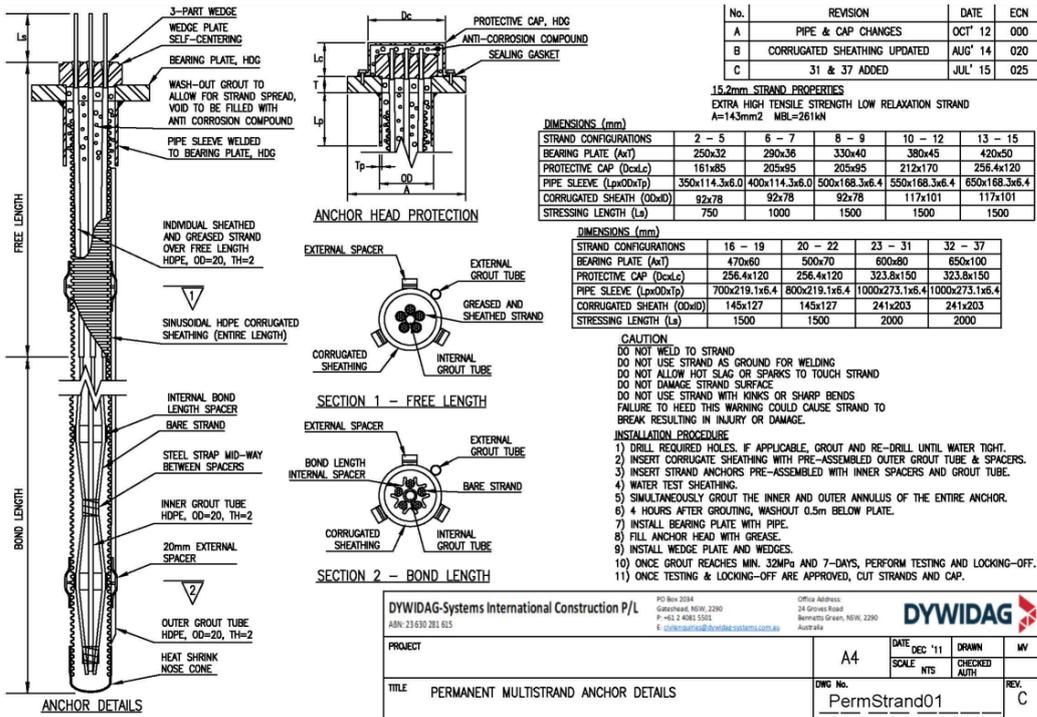


Figure 1. Multistrand anchor detail.



Figure 2. Corbel with bar anchors and angled bearing plate for strands.

2.4 Anchor installation

The installation of the post-tensioned anchors was challenging as it requires making an anchor packer that was robust enough to allow the anchor to be pushed into the borehole and withstand potential abrasion and damage from the borehole wall during installation. The packer was installed deep into the hole to separate the bond and free length during grouting procedures.



Figure 3. Anchor Installation.

2.5 Grouting under an inclined angle

To overcome the challenges of grouting upwards with two multistrand anchors installed at inclined angles (13 degrees and 18 degrees) DYWIDAG worked with Anchor Packers Australia to develop an innovative packer system designed to ensure that the bond length of the strand anchors could be grouted at the inclined angle. Failure to follow the correct grouting process may result in anchor failure either during testing or at any point during their service life.

In geological formations that are not waterproof, conventional grouting of the bond length may lead to serious issues including grout egress and water ingress. These risks are amplified when aquifers or open fractures within the rock allow:

- Grout to leak out, reducing the integrity of the bond
- Water to enter, decreasing the strength of the grout with the bond length and increasing the corrosion risks

Grouting with the theoretical volume of grout under atmospheric pressure conditions is only acceptable in holes that are proven to be watertight. In any other situation the integrity of the bond length cannot be assured.

2.5.1 Consequences of compromised grouting

If the bond length grout is compromised bare strand may become exposed to groundwater leading to:

- Corrosion, especially if the water is acidic or oxygenated
- Decreased bond strength as water weakens the cured grout
- Decreased bond length

Ultimately this may lead to anchor failure in both the short and long term.

The cost of anchor failure may significantly impact a project due to:

- Increased installation costs due to re-drilling and re-grouting
- Project delays
- OH&S issues
- Decreased client confidence
- Placing a critical piece of the pumped hydro equipment out of service for a prolonged period.

Due to its criticality, the anchor packer design required significant attention with a highly collaborative effort between DYWIDAG and the client. The original packer design included a rubber membrane with an air inflatable packer which is inflated with air to ensure pressure is maintained while grouting and curing is taking place.

While the trials conducted of this system were successful, there was an element of risk identified with the packer design not sufficient to withstand the unexpected water pressures within the cavern. The packer design was modified to a grout inflatable packer which allowed the pressure grouting of anchors to be inflated to a much higher pressure, up to 16 bar (1600kPa). This change ensured the bond length was uncompromised from water ingress during the grout curing time. The anchors grout within the bond length could effectively be guaranteed to be free from defect when grouted as per the specification. This reduced the risks of grout leakage and increased the practicality of the installation in line with available resources onsite at the crew's disposal. The refined packer design included a geo textile bladder which would be inflated with grout and a special sealing arrangement at both ends to hold the grout inside at high pressure. Each anchor would be grouted in two passes. The first pass involving grouted inflation of the packer to form a grout "plug", and the second completes grouting of the bond length after sufficient curing time of the grout packer.

The main challenge with strand anchors being used in this application is that each individual strand which makes up the multistrand anchor requires sealing to maintain sufficient pressure within the packer inflation zone so that it completely blocks the borehole allowing for stage 2 grouting.

Drawing on experience in cable stayed bridges, DYWIDAG developed a sealing system similar to that which is used in cable stayed bridges, comprising compressed rings and at either end of the packer. This refined anchor packer resulted in all anchors being successfully grouted to the required test loads.

3 END TO END QUALITY

DYWIDAG was contracted to supply the complete package of manufacturing the ground anchors, the underground installation supervision, stressing equipment and the digital SMART anchor force monitoring. As well as the innovative strand anchor grout packer which had very specific requirements for this application.

3.1 *Procurement*

The project's highly detailed construction sequence required DYWIDAG's logistics chain to support the project with Just In Time manufacturing and delivery to site of all components. DYWIDAG's bar and multistrand anchor systems hold local and global approvals with full mill certifications provided on all products.

3.2 *Product Quality*

The multistrand system was manufactured under stringent factory conditions in the Australian factory, with the various number of strands required for the project coiled and delivered to site. DYWIDAG's GEWI bar system 12–75mm bar is manufactured in Germany from steel billets produced from scrap metal from the car manufacturing industry using mainly green energy and has ACRS approval against AS4671 and AS4672.

High quality and consistency of product was able to be achieved by producing the anchors in DYWIDAG's factory rather than on site in challenging and uncontrolled conditions with limited space. The factory production of the anchors allowed for:

- Standard and consistent work procedures
- Quality factory manufacturing
- High level safety standards
- Consistent and controlled work environment
- Bespoke equipment
- Experienced production team
- End to end quality registration

3.3 Stressing Equipment

The jack is placed on the corbel providing a limitation of diameter of 440mm with the final prestressing being carried out from a working platform under the corbel. The working platform proved limitations on the dimensions of the jack and loads on the platform. DYWIDAG was contracted to provide calibrated and maintained stressing equipment for the duration of the stressing works which included 150 tonne and 300 tonne multistrand jacks, pumps and gauges.



Figure 4. Stressing in progress of bar and strand anchors



Figure 5. Stresing in progress of bar and strand anchors.

3.4 *Site supervision driving quality*

Due to the criticality of the inclined angle of the anchors, the client required full site supervision to ensure the correct installation of the corbels. DYWIDAG holding TfNSW site supervision approval for the installation of strand and bar anchors, provided around the clock supervision personnel for the entire scope of the installation. This ensured consistency and accuracy of product installation and testing for this highly critical scope of works to ensure consistent quality and fill any knowledge gaps of the main contractor's site crew.

3.5 *Load acceptance and testing*

Each anchor had an acceptance test performed on it to verify it was installed and grouted correctly and was holding the load as per the design requirements.

3.6 Monitoring challenges and requirements

Given the challenging and highly loaded anchors and the pivotal role of these anchors in the construction program the decision was made to monitor anchor loads using DYWIDAG Smart Anchors. This state-of-the-art technology is an automated solution that continuously monitors loads in real time to a digital platform with alerts sent to key stakeholders when thresholds are triggered. This eliminated the need for continuous expensive on-site test and provides designers and asset owners with assurance regarding anchor loads. A solution that was previously unavailable.

DYWIDAG's Smart anchor technology is installed on strand anchors at the Te Ara o Te Ata (Mt Messenger Bypass project) and received a merit award at the Ground Engineering Awards in the UK 2024. This advanced monitoring system allows for live data to be observed remotely.

Infrastructure Intelligence features:

- Real time data feed and presentation
- Adjustable trend charts and tabular data
- Alarm management and status reporting
- Data downloads
- Central data/document archive
- 3rd party data feeds
- Tailored display



Figure 6. Smart anchor installed on a strand anchor

4 CONCLUSION

DYWIDAG has been working collaboratively with clients and our partners to provide innovations to the DYWIDAG strand anchor design as part of a support system for deep underground caverns. The innovations address the current site challenges for anchoring with high permanent loads in a rock mass with variable quality, deep underground anchoring with limited installation space, anchor installation in inclination, complex grouting requirements and the design life of a fully permanent system.