Geotechnical and structural monitoring system deployment for the spillway of a dam at Padcal mine in the Philippines

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The Padcal Mine in the Philippines has been in service for over 50 years. To complete the most recent life-extension projects of the mine, the owner has been upgrading the most recently built tailing dam. It is a concrete gravity dam, the largest of its kind in a tailings facility in the world. To ensure long term reliability of the dam, a major instrumentation system has been installed to provide real-time structural data. Instruments include in-place inclinometers, joint meters across concrete blocks, piezometers within the dam and extensometers. In-place inclinometers were installed in the already-built concrete structure between the spillway and a gallery. Multipoint extensometers were installed through the existing structure into the soil underneath the dam. This being an already-existing dam under expansion, retrofitting the existing structure with new instruments was met significant hurdles. In this case study, we present the methods developed to tackle these challenges.

1 INTRODUCTION

The Padcal mine, a gold and copper mine located in the Benguet province in the Philippines, has been in service for decades. It has proven reserves of 216 million lbs of copper and 627 000 oz of gold. It employs 2000 people locally and has been at the centre of the economic development of the region. Though there are still significant reserves and more exploration to be done, the mountainous landscape and heavy rainfalls of the region limit the mine operator's flexibility with regard to tailings storage. It appears that this will be the main factor limiting the lifespan of this mine.

The challenges of maintaining a large tailings system of this type in this landscape was abruptly brought to public attention in 2012. The mine was faced with significant challenges when an acid waste drainage tunnel under penstock 3 ruptured (Catholic Bishops Conference of the Philippines 2012). The mine operator claims that this was a "force majeure" event caused by heavier than usual rainfalls (Caluza 2013). An estimated 20 million metric ton of tailings escaped through punctured roof of the tunnel (Dinglasaz 2013). The leak led to a significant increase in heavy metals levels downstream and ecological damage to the creek (Dinglasaz 2013). It also damaged one of the offset dikes of the tailings, lowering its capacity for future operations. The leak was plugged with a large concrete boulder that gave sufficient time for the team to backfill the tunnel. Because this section of the tailings was compromised, there was an increased risk of further failures due to damage to the existing dams. To limit the risks that future heavy rainfalls could pose, a new concrete gravity dam with three 12-meter spillways was designed and built (Dinglasaz 2013). As of 2014, the first sections of the dams and a first spillway was put in service, designed to accommodate up to 1500 mm of rain. A satellite image of the dam in 2014 before the opening of the first spillways is shown in Figure 1 (a). Over the following years, two more spillways were built and the top of the dam was raised, as shown in Figure 1 (b).

This ambitious project requires a significant amount of instrumentation for close monitoring during construction, operation and for future maintenance. Several types of instruments were selected and installed: piezometers, temperature probes, in-place inclinometers (IPI), strain gages, multi-point borehole extensometers (MPBX), 3D jointmeters and weir monitors. Our involvement in the project came in after construction had begun and existing structures had to be retrofitted to accommodate a complex instrumentation plan. A brief overview of all instruments will be given. More attention will be devoted to inclinometer casing, IPIs, MPBX and jointmeters. The unique situations encountered in this project will be discussed, as well as the novel approaches deployed to tackle them. Adding embedded instrumentation to an existing structure poses difficulties that are otherwise uncommon, such as drilling through galleries. However, the fact that the dam was still under expansion allowed for creative and novel instrumentation installations.

In this project, we provided the instruments themselves, installation services and training. Installation of the instruments took place over several missions in from 2016 to 2018. Many instruments, such as piezometers and thermistor strings, were installed by the local staff after training, while more complex instruments such as MPBX were installed during one of these missions. All instruments except manual inclinometer surveys were intended to be read by data loggers provided and installed during the final mission.

2 INSTALLATION

2.1 *Context*

A satellite image of the dam (google) from 2018 is shown in Figure 1 (b). It can be seen that, as of 2018, the three spillways are built, and that water is flowing in spillway 3.

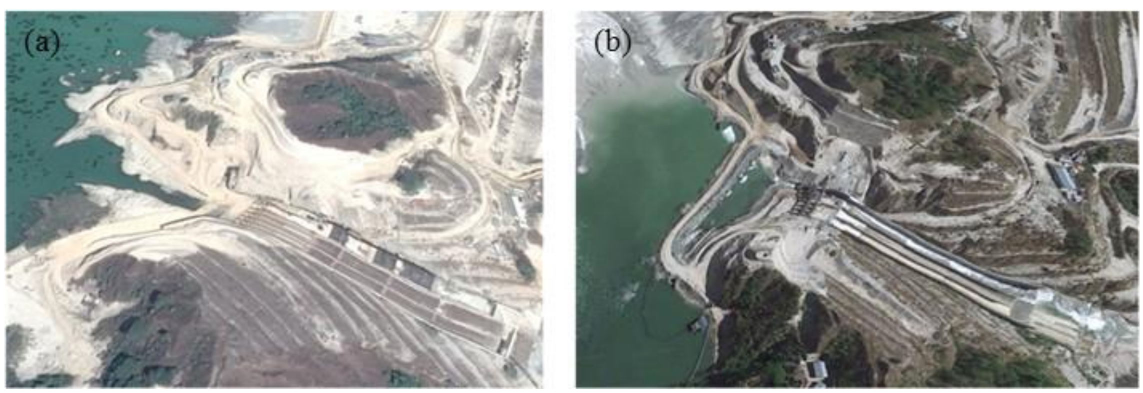


Figure 1 Padcal mine concrete dam. (a) The dam in early 2014. Two of the three spillways were completed. (b) The dam in 2018. The three spillways are seen, with water overflow going down spillway 3.

2.2 *Inclinometer casing*

Inclinometer probes are a frequently used instrument in structures such as dam to follow long term deformation of the structure (Dunnicliff 1993). Six inclinometer casing boreholes were drilled in the structure, from which manual readings are taken using a Geokon GK-604D probe. Manual inclinometer probes allow for low-cost, long-term monitoring, but are slow and do not provide real-time information on the structure.

The boreholes were drilled from the top of the structure down into the gallery, and then down again through the floor of the gallery. In theory, these boreholes should have been drilled before the gallery roof was built, but delays in the work schedule and availability of instrumentation specialists delayed this installation.

In this project, the casing had to be inserted from the top of the dam, down into the gallery, where another worker would align the casing inside the borehole for final installation. This was the only way to accommodate the 3m casing length. This operation is illustrated in Figure 2.

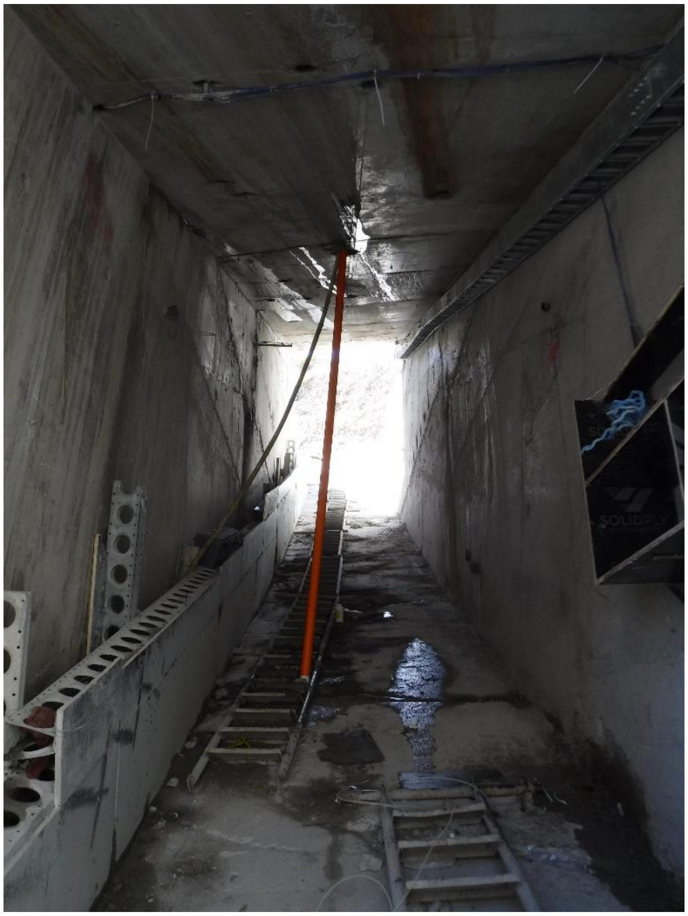


Figure 2 View from inside the gallery where inclinometer casing is being installed. The casing is slid through the roof of the gallery after which a worker will go and insert in the borehole in the floor of the gallery.

2.3 *IPI*

Tiltmeters are often used in large structures such as dams to follow long term health. Due to their rigidity, some failure modes will register a tilt of the structure (FERC 2018) (Dunnicliff 1993). This tilt can be measured with tiltmeters installed on the surface after construction but we took advantage of the fact the structure was being extended to embed single-point in-place inclinometers in the structure. The selected IPI (Geokon 6300, vibrating wire) is commonly used in inclinometer boreholes as a permanently installed chain of sensors (Dunnicliff 1993).

Installation was conducted after the first layer of blocks above the gallery had been poured but before the top of the dam was erected. The IPI casing was installed and held in-place with the IPI inside until the new concrete form was poured. After the installation, the tubing was protruding approximately 3 m above the current level of concrete as shown in Figure 3 (a). It was securely attached until the new form was poured because impacts or stormy weather could have bent or broken the casing and the instrument inside.

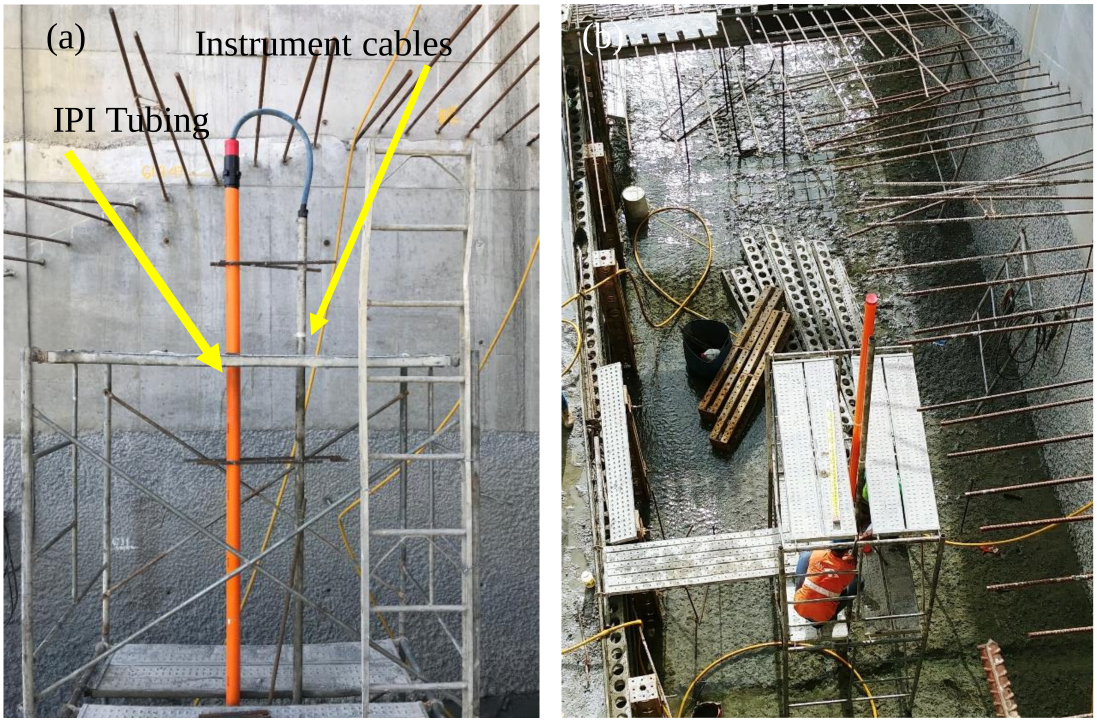


Figure 3 (a) IPI casing sticking out after instrument installation. (b) IPI casing sticking in the in-use spillway

It was originally planned that the inclinometer casing would be installed from the roof of the gallery and installed pushing up. However, the low availability of hardware such as metal plates and anchors to hold the tubing in place forced a different installation. Tubing was installed in a shallow borehole from the top of the block with its bottom resting on the bottom of the borehole without having broken through inside the gallery, preventing insertion of the instrument from the inside of the gallery. Additionally, it was discovered on-site that the IPI's themselves was too long to be manipulated and inserted from the bottom up and would have had to be inserted from the top in any case. Temporary scaffolding was built to access the top of the casings to insert the IPI's inside the casing. This can be seen in Figure 3 (b) where the casing is sticking outside the water in the spillway.

The three permanently embedded IPIs allow for real-time monitoring of the angle of top of the dam, as opposed to the manual readings which have a long turnaround and no real-time capabilities.

2.4 *MPBX*

MPBX are commonly used to follow either settlement or uplift in structures such as dams (Dunnicliff 2013). Just like for inclinometer casing, most boreholes had to be drilled from the top of the structure, into a gallery and then down to the bottom of the dam at more than 45 m from the top of the dam. The MPBX head was intended to be installed recessed in the floor of the gallery. A few others were installed through the dam sidestepping the gallery and with the head located at the top of the structure.

Borehole drilling for MPBX was very similar to drilling for inclinometer casing installation but the silty soil at the foundation of the dam would close up quickly after drilling, giving a window shorter than an hour for the insertion of the lowest MPBX anchor. In normal conditions, drilling casing is available and inserted to keep the borehole intact until instruments are installed but it was unavailable in the region. Despite this difficulty, the bottom anchors of all MPBX but one were installed at the intended depth. For this single MPBX, the head stuck out above the floor of the gallery, and a concrete form was poured to protect and solidly anchor the head to the structure within the gallery.

A typical installation of these instruments, as described in the manufacturer's manual, requires that there be a larger recess bored at the top of the borehole to easily connect the anchor rods to the head and remove the suspenders. The larger drilling bit was not available on site, but it was possible to make the best of this unique situation. The MPBX heads were left sticking out of the boreholes, held in place with its bladder anchor, knowing that they would be fully encased in a new concrete block. This unique opportunity helps reduce costs and installation time with respect to the standard installation of MPBX.

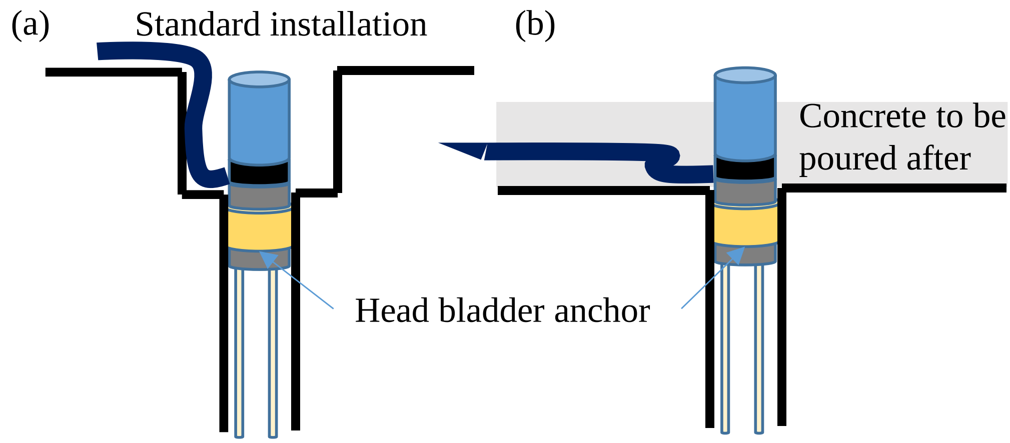
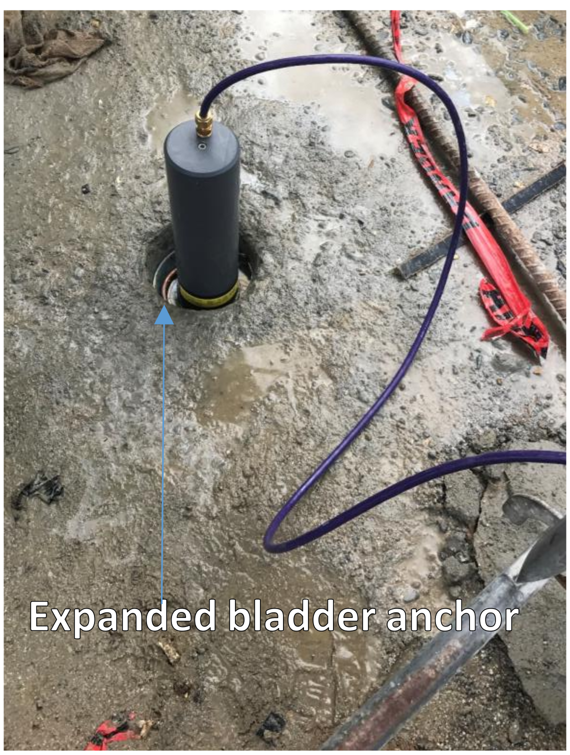


Figure 4 (a) Standard MPBX head installation. (b) Modified MPBX head installation

Figure 5 shows the final installation of an MPBX head before it is encased fully in concrete. Because the MPBX was to be installed directly in the boreholes without casing, bladder type anchors for the rods were used. These anchors provide direct contact with soil and/or rock and preclude the need for grouting. The system is designed in such a way that each anchor can be inflated sequentially to anchor locally each rod. In addition using bladder anchors, the MPBX were grouted in place to limit water circulation along the inside of the boreholes. The bladder anchors were inflated only after the grout had set. This double approach ensures the most reliable



long term measurements with anchors stronger than simple groutable anchors and the benefits of a watertight grout-filled borehole.

Figure 5 (a) MPBX head sticking out from the floor of the gallery (b) MPBX head after being encased in concrete

Another minor hurdle that was that there were no clear indications of where rebar were in the concrete blocks. No ground penetrating radar or other methods were available on-site. Whenever a rebar was hit during the drilling of a borehole, the drilling rig had to be moved to start a new borehole.

2.5 *3D jointmeters*

The 3D jointmeters are attached directly to the structure. They are potentiometers sensors that allow for direct measurement of the position of each sensor. The Pico-tec jointmeters used in this project are faster and easier to install than traditional jointmeters as there is only a rod and a single 3D reading point rather than three instruments installed perpendicular to each other in a standard 3D assembly as compared in Figure 6. A typical assembly (b) requires installation and commissioning of three different instruments in various configurations and the installation of supports and right-angle metal plates. This is time-consuming and measurement points are a bit spaced out. As shown in (a), this novel jointmeter has a single rod that is read by an internal 3D assembly of potentiometer sensors. This simple design allows for more compact and more localized installations.

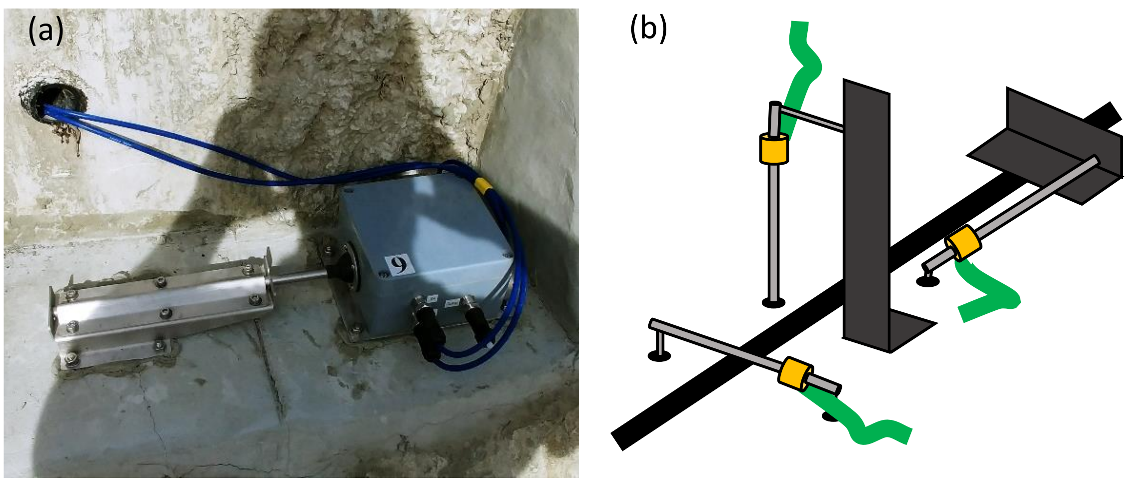


Figure 6 (a) Pico-tec jointmeter (b) traditional 3D jointmeter

Because the entire structure is accessible during construction, installation of these instruments on nearly all blocks was greatly facilitated when compared to other dam monitoring projects, where we are required to go in and install instruments on an already-built dam. This complete coverage of the structures gives a complete image of the mechanical of the dam for the consulting firm to follow short and long-term behavior of the dam.

2.6 *Other instruments*

Geokon vibrating wire piezometers were installed in the core and under the dam, with cables running out to the side of the dam. Thermistor strings were installed at selected levels to follow concrete curing. They are also used to detect changes in temperatures that could indicate water ingress. Vibrating wire stain gages (Geokon 4200) were embedded in the concrete blocks.

2.7 *Data logging*

The instruments discussed in this project are vibrating wire-based instruments with the exception of thermistor strings and 3D jointmeters. All were directly integrated in Campbell Scientific-based data loggers. All instruments were installed with sufficient lead cable that the cables could be routed to a data logger. Though splicing cables is always possible, it adds a weak point that is not compatible with the long term requirements of dam monitoring.

As is often the case in remote projects, hardware that is taken for granted in other parts of the world can be hard to come by. A large number of the instrument cables were intended to run through the main gallery and held and protected by cable trays or clamps. However, this type of hardware was not readily available so bits of rebar were fixed in drilled holes in the concrete and the cables attached to the rebar with tape or cable ties.

The data logging system was fully centralized as shown in Figure 7. All multiplexers and data loggers are located in a single room. This approach increases the manpower requirements for and cost of cabling itself, but it’s a troubleshooting is greatly simplified when working from a single location.

Figure 7 Data logging system where all instruments are connected

3 CONCLUSIONS

The instrumentation program designed for the extension of the Padcal mine’s concrete gravity dam was met with unique challenges. Installing and commissioning instrumentation in a regular dam poses difficulties not found in other projects, but adding instruments to a dam currently under expansion provided new opportunities for creative solutions. It was possible to take advantage of the future concrete pours to install embedded tiltmeters rather than to install them only at the top of the structure. It was also possible to install MPBX in a more time-efficient manner by not recessing the MPBX head in the borehole and protecting it until the concrete forms were poured. It was also an opportunity to install a novel type of 3D jointmeters that are much easier and simpler to install than traditional 3D jointmeters. This monitoring system will help the mine operator take full advantage of the new structure and will contribute to its maintenance and operations for decades to come.

REFERENCES

Catholic Bishops Conference of the Philippines – National Secretariat for Social Action. 2012. The Philex Mine Tailings Spills of 2012: An Independent Fact-Finding Mission Report. September

Caluza, D. 2013. Pangilinan: Philex not required to clean up San Roque dam. *INQUIRERER.NET*. June 29 2013.

Dinglasan, R. R. No stranger to mine spills, Philex still wants rehab of aging tailings pond. *GMA New*, February 11 2013

Dunnicliff. 1993. Geotechnical instrumentation for monitoring field performance. *John Wiley and Sons*. New York City.

FERC. Engineering Guidelines for the Evaluation of Hydropower Projects. *Federal Energy Regulatory Commission*, Chapter 3.

FERC. Engineering Guidelines for the Evaluation of Hydropower Projects. *Federal Energy Regulatory Commission*, Chapter 9.