2019 Canadian Consulting Engineering Awards

Technical Category C: Water Resources

Phu Kham Copper-Gold Operation

Stage 2 Emergency Spillway Development

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Knight Piésold CONSULTING

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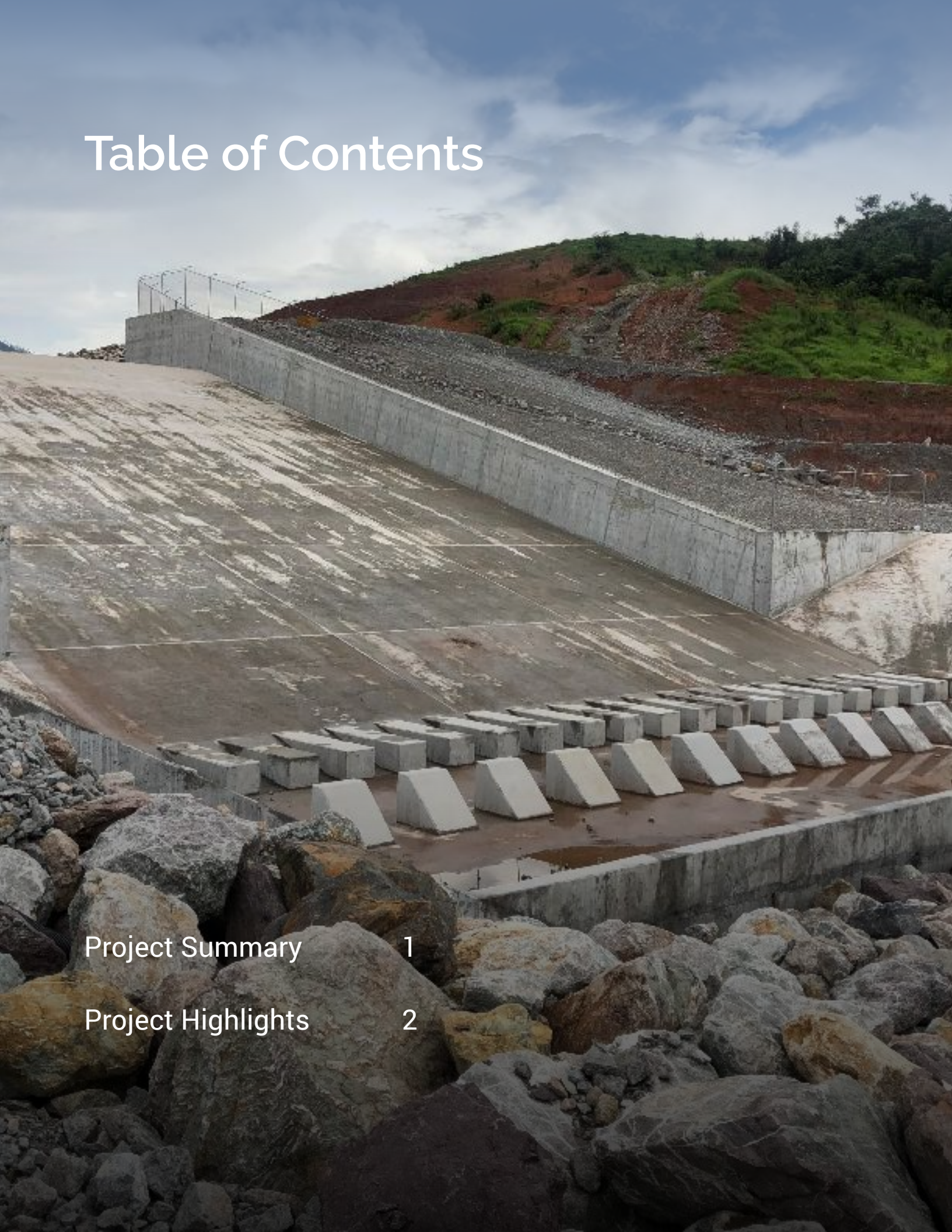


PROJECT SUMMARY

A relocated emergency spillway is being developed by PanAust Limited at their Phu Kham Copper-Gold Operation (Phu Kham Operation) located in mountainous jungle terrain in northern Lao People's Democratic Republic. Knight Piésold designed the emergency spillway to ensure safe operation of the tailings storage facility (TSF) during extreme flood events.

The spillway, being developed in five construction stages, was designed to accommodate ongoing raises of the TSF over the remaining life of the mine. Stage 1 construction required a 30-m-deep excavation through a ridgeline to establish the spillway invert. Stages 2 through 4 require the construction of a zoned earthfill embankment to support a reinforced concrete chute spillway with an energy dissipation structure. At Stage 5, the spillway will be converted into a closure saddle dam.

Knight Piésold employed an innovative approach to accommodate future raises of the TSF, designing the final arrangement first to ensure a saddle dam could be easily executed, with the understanding that staging proposed at the initial design stage would undoubtedly be modified with the changing requirements for tailings and water storage. A modular reinforced concrete chute spillway was chosen as the preferred spillway alternative to allow for modifications to the chute during the raises.

Stage 2 of the spillway construction was completed in June 2018. Salient details of the Stage 2 spillway are as follows:

Design rainfall event	72-hour probable maximum precipitation = 1,500 mm
Chute spillway	
Chute slope	30%
Chute elevation drop	15 m
Stilling basin	USBR Type III
Inlet and outlet channels	Riprap lined

Stage 2 completed spillway chute, looking upstream

PROJECT HIGHLIGHTS

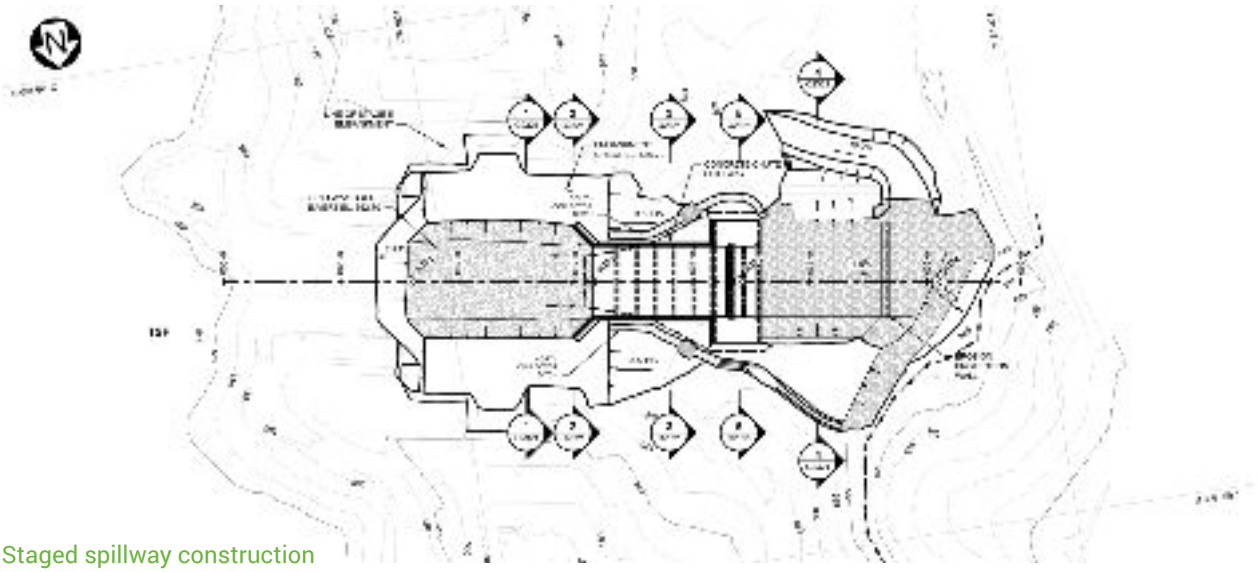
Q.1 Innovation

The Phu Kham Copper-Gold Operation (Phu Kham Operation) is located in Lao People's Democratic Republic in mountainous jungle terrain and is exposed to a four-month annual monsoon season. The tailings storage facility (TSF) at the Phu Kham Operation was initially designed as a non-release facility and operated for full containment of the design flood. An emergency spillway, which was later found more economical, was initially developed at the eastern abutment of the main TSF embankment dam.

The TSF, over the life of the Phu Kham Operation, is being raised periodically to accommodate additional tailings and water storage. The emergency spillway is raised along with the dam raises. Raising the spillway is not a trivial exercise and requires careful consideration of changing tailings and water storage conditions, as well as the changing spillway surroundings and associated risks. As the TSF embankment was raised, the dam footprint extended over the eastern abutment and the spillway became integrated into the dam wall.

Increased risks due to the potential for spillway flows to impact embankment dam integrity resulted in the project owner, PanAust Limited (PanAust), requiring the relocation of the spillway to reduce risks to the TSF. Knight Piésold designed a spillway exceeding current design standards, while providing PanAust with a cost-effective risk and water management strategy. The spillway—designed to safely divert the probable maximum flood (PMF) away from the TSF—ensures safe TSF operation during extreme flood events.

Knight Piésold proposed the relocated spillway to be developed in five stages throughout the remaining life of mine to allow for the spillway invert to be raised annually as the tailings dam is raised. Stage 1 construction required a 30-m-deep excavation through the western ridgeline of the TSF to achieve the spillway invert. Stages 2



Staged spillway construction

PROJECT HIGHLIGHTS

through 4 require the construction of a zoned earthfill embankment to support a reinforced concrete chute spillway with an energy dissipation structure. Stage 5 requires the embankment and spillway complex to be converted to a saddle dam at mine closure.

Executing a design such as this required an innovative approach where the final arrangement (Stage 5) needed to be designed first to ensure a saddle dam could be feasibly executed. This design also required that all intermediate stages of spillway development could be feasibly executed with the understanding that the staging proposed at this initial design stage would undoubtedly be modified with the changing requirement for tailings and water storage.

Knight Piésold delivered all aspects of project preliminary studies, engineering design, and construction supervision. Key design criteria of the emergency spillway include:

Dam failure consequence classification	High B (ANCOLD 2012)
Design flood annual exceedence probability (AEP)	72-hour PMF of 203 m^3/s
Minimum wet season storage allowance	1:250-year AEP
Width of spillway	30 m
Freeboard	1 m

Stage 1 emergency spillway channel excavation

Stage 1 riprap lined emergency spillway channel completion

PROJECT HIGHLIGHTS

Q.2 Complexity

Spillways, under most circumstances, are required for safe TSF operation, helping to control the release of excess water within the impoundment to a location downstream. It is essential for spillways to operate throughout their design life and within prescribed regulatory requirements. At the Phu Kham Operation, this condition became more challenging because the emergency spillway needed to be incorporated into the design of the TSF.

TSFs are typically designed for the final arrangement anticipated at mine closure. In order to reduce mine operating capital costs, TSFs are often constructed in staged lifts as dictated by tailings production estimates. Consideration for the spillway is required with each lift. At the Phu Kham Operation, multiple factors that influenced dam and spillway geometry were considered, including supernatant pond volumes, climatic conditions, tailings production rates, volumetrics of the impoundment, spillway location, geotechnical considerations, and mine closure criteria.

It is common to develop temporary spillways for TSFs using riprap lining, which is much more cost-effective than reinforced concrete. In the case of the Phu Kham Operation's spillway, steep terrain surrounding the TSF limited the use of riprap lining. A modular chute spillway was proposed during the initial design of the Phu Kham Operation's spillway. The chute was designed following standard design practices to meet the current state-of-the-art spillway design. Specific elements of the chute structure were designed such that they could be easily removed or modified during future spillway raises. This aspect resulted in minimizing the cost of future construction and rework of structural components.

Concrete placement at the Stage 2 chute spillway

Stage 2 energy dissipator construction in progress

PROJECT HIGHLIGHTS

Staged Spillway Construction

A staged spillway construction concept was developed to target the required spillway crest elevation for each TSF dam raise during mine operation. Stage 1 construction included the excavation of a 30-m-deep cut to create a riprap lined free overflow open channel spillway. Stages 2 to 4 included the construction of an engineered zoned earthfill spillway embankment and a reinforced concrete spillway on top of the embankment. The energy dissipation structure and chute structure of each construction stage are kept in place and new control structures and additional chute sections are added as required as per the TSF operation requirements. Concrete contraction joints and PVC waterstop allow adjacent concrete placements of future stages.

Hydrotechnical and Hydraulic Studies

Hydrotechnical studies were initially completed to estimate the probable maximum precipitation (PMP). Flood routing software was then utilized to apply the PMP across the contributing catchment areas including the TSF in order to determine the PMF flow. Flood routing was completed for the emergency spillway at each stage of the TSF operation phase development. Hydraulic calculations and computer fluid dynamic model studies were completed to assess the hydraulic performance and discharge of the free overflow crest controlled spillway, formation and length of the hydraulic jump created by the energy dissipation structure, and outlet flow velocities at the end of the structure. Hydraulic calculations were also completed at the confluence of the emergency spillway outlet channel and the natural drainage channel into which the spillway flows.

Reinforced Concrete Chute and Energy Dissipator Structure

The spillway dimensions were fixed after a review of the preliminary hydraulic studies based on the TSF maximum water surface elevations, PMF routing, and a preliminary economic comparison of alternatives. The reinforced concrete control section is provided to minimize turbulence during discharge and provide a stable crest control sill. The reinforced concrete chute is designed with a slope of 3.5H : 1V. The chute terminates with a hydraulic-jump stilling basin, similar in geometry to a USBR Type III stilling basin. The emergency spillway is designed for uplift pressures, drainage of foundations to limit adverse hydraulic effects, and cavitation impacts at areas of high-velocity flow.

Construction of the Stage 2 downstream erosion key

PROJECT HIGHLIGHTS

Outlet Channel

Discharge velocities need to be low to limit scouring at the toe of the embankment and unstable natural terrain. Bedrock or non-erodible foundation conditions are not present near the site; therefore, all outlet flow velocities were reduced to allow for riprap channel protection to be utilized. The outlet channel is designed as a trapezoidal riprap lined channel. The confluence with the natural drainage channel is located approximately 70 m downstream from the toe of the spillway embankment and includes an erosion protection key to limit possible back scour.

Steel Testing and Concrete Trial Program

Stage 2 construction was completed in June 2018. A robust quality control and quality assurance program was in place throughout construction to ensure all work was completed in accordance with the design. Due to the remote location of the Phu Kham Operation, detailed planning before construction was required to ensure all materials were procured and approved. Several issues arose with respect to the quality of some local concrete construction materials such as cement and reinforcement steel. These issues were overcome during construction planning through a thorough review of all quality documentation provided by suppliers as well as a concrete trial program.

Reinforcement steel tests completed by the suppliers identified that material strengths vary widely. Knight Piésold, therefore, completed designs assuming steel strengths were lower than specified resulting in the use of larger reinforcement bars to accommodate the lower strength steel.

The concrete trial program was conducted to assess concrete strengths and workability of fresh concrete for placement on the chute spillway (30% slope). Various mix designs were proposed that took into account the available aggregate materials, supplied cement, water quality, and the use of admixtures to achieve a concrete design for this specific site and application.

Stage 2 control structure

Stage 2 chute and energy dissipator completion

PROJECT HIGHLIGHTS

Q.3 Social and/or Economic Benefits

Risk Analysis

A potential failure modes analysis of the preferred spillway alternative was performed following a quantitative failure mode and effects analysis by a multidisciplinary team composed of design engineers, the engineer of record, representatives of the owner, mine operation managers, and construction managers. The risk analysis framework was developed by PanAust and included the evaluation of health and safety, environmental, social, security, regulatory, production, and financial consequences. The outcome of the risk analysis helped identify the lowest consequence option and key design requirements to manage the risks of the preferred spillway alternative.

Relocation Analysis

Identifying an alternative location for the spillway involved finding areas where flood discharge would have limited impact on local stakeholders (farmers, agriculture), the surrounding environment (loss of tailings through resuspension during high spillway flows, natural erosion and sedimentation), the TSF structures, and other existing mine infrastructure. The spillway was relocated along the northern end of the western rim of the TSF, which was selected for having no impact to local communities or existing mine infrastructure.

Local Participation

Spillway construction started in 2016, with Stage 2 successfully completed in 2018. Most of the work required for each stage of construction was completed by local contractors, with the purchase of goods and services from local and national suppliers. This helped to promote local skills training and employment and to increase local community participation. At the peak of Stage 2 construction, over 95% of the 120 people working directly on the project were Lao nationals.

Knight Piésold engineer providing core logging training to contractor engineers

PROJECT HIGHLIGHTS

Q.4 Environmental Benefits

Despite limited regulatory guidance in Lao PDR, PanAust, in recognition of its corporate responsibilities and social license-to-mine, has adopted leading practice international standards in its mine closure plan. The TSF's design facilitates closure and post-closure strategies, and the post-closure target ensures that the closed facility does not require ongoing maintenance and the lands can be returned to the original land use.

The mine closure plan considers that all TSF installations including the spillway embankment will remain in place after closure. The closure concept for the relocated emergency spillway is that the spillway embankment will act as a saddle dam to retain tailings within the TSF post mine closure. The closure plan also considers the changes in site water management as the facility is decommissioned.

During construction of Stage 5, the crest of the spillway embankment will be raised to match the specified closure crest elevation of the TSF. The concrete emergency spillway and outlet works developed during Stages 1 to 4 will be decommissioned. Prior to the construction of Stage 5, a separate purpose-built closure spillway will be developed to the north of the emergency spillway to accommodate post mine closure flow conditions.

The emergency spillway is sized to pass the critical PMF without overtopping of the TSF, preventing risks for uncontrolled flows over the embankment and environmental damage in the downstream catchment.

TSF embankment crest upstream side looking west

Mine closure plan ensures the site returns to its original land use

PROJECT HIGHLIGHTS

Q.5 Meeting Client's Needs

Mine tailings and water storage requirements change frequently based on mining demands. Climatic predictions in remote or under-developed areas rely on limited or no data. Knight Piésold designed an emergency spillway according to operational, climactic, and geotechnical parameters for the safe operation of the Phu Kham Operation's TSF, while providing PanAust with a cost-effective risk and water management strategy.

The emergency spillway was developed following a detailed assessment of risks, costs, and benefits. Failure modes risk analysis allowed PanAust to make a risk-informed development decision, mitigate and manage risks, and minimize the consequences of emergency flood discharge while meeting the TSF's operational requirements.

A staged lift constructed surface emergency spillway built over an earthfill embankment with adequate overtopping protection was found to be economical and feasible through detailed engineering and good understanding of the operating stages of the mine. This also provided sufficient flexibility for changes in mine operational conditions.

The Stage 2 emergency spillway was completed ahead of schedule and under budget by approximately US$960,000.

Stage 2 emergency spillway completion

Owner

PANAUST

Client

PHU BIA MINING