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EXPLORING ATLANTIC CANADA

DRILLING TECHNOLOGY

PROJECT PROFILE | PROFIL DE PROJECT

KOMBAT MINE

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Par Alexandra Lopez-Pacheco

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Inspired by a photo he saw of a Japanese castle moat (similar to this one at Kumamoto Castle), Stefano Utili began researching slope design, leading to the creation of OptimalSlope.

Old pictures and new approaches

Ancient Japanese moats may lead to better open-pit mine designs

By Alexandra Lopez-Pacheco

The idea for OptimalSlope, a recently commercialized software solution that its inventor Stefano Utili believes could potentially revolutionize how open-pit slopes are designed, can be traced back to a puzzling vacation photograph he saw some 20 years ago when he was working on his PhD in Italy.

"My professor had just returned from a trip to Japan and had seen a Japanese castle built in the 1700s, with a very strangely shaped moat," said Utili, now a professor of geotechnical engineering at Newcastle University in the U.K. The moat's walls were not shaped in a straight diagonal line as is the norm. Instead, they were concave.

"I wonder why they did that," Utili's professor said to him. Neither of them could figure out the answer. But the puzzle stuck with Utili. Over the years, as he became a professor himself and researched ways to improve pit-wall designs and slope stability, he continued to wonder about the peculiar moat. When he finally decided to solve the puzzle, he realized he might very well have also solved a modern challenge that could help open-pit mines reduce their environmental footprints and increase their revenues.

A deepening problem

Over the last 100 years, open-pit mining companies have had to progressively dig deeper and deeper in order to access ore. "Today," said Utili, "the deepest open-pit mine in the world is more than 1,000 metres deep."

This has increased the risk of slope failure such as the one that occurred in the 2013 slide at the Bingham Canyon mine in Utah, reportedly the world's largest and deepest open-pit mine. Its pit at the time was close to 1,000 metres deep and 4,000 metres wide when, after slope monitoring identified movement and work was stopped, an estimated 52 million cubic metres of rock slid into the pit. To avoid such failures, slopes are designed by prioritizing stability and safety. The optimal slope is the steepest possible (to reduce the amount of rock waste) while still preserving the lowest factor of safety risk.

"We analyze many different potential failure models and the lowest factor of safety," said Scott Cylwik, geotechnical project manager at Call & Nicholas, a Tucson, Arizona-based international mining consulting firm whose specialties include geological and geotechnical engineering.

Modern modelling and analysis take into account complex data specific to each site, but they always look to select one optimal surface angle for the entire slope – its planar shape. As a rule of thumb, the deeper the mine, the less inclined the pit walls need to be in order to prevent slope failures, which means today's large open pit mines have also become wider and wider and have to haul more waste rock out of the way to reach the valuable ore.

Courtesy of Stefano Utili

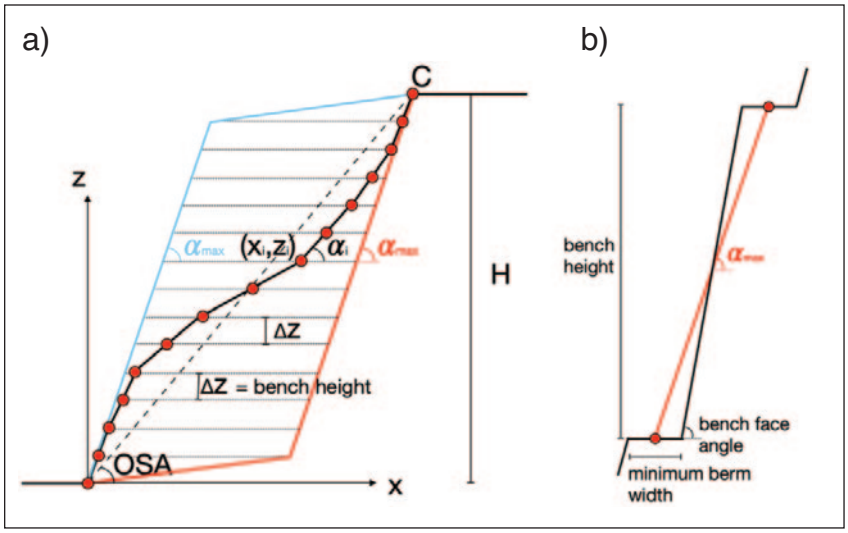

Figure A: A generic candidate slope profile. A uniform discretization along the z-direction is adopted. The red and blue lines enclose the region where the profiles are sought. In the context of open-pit mines, a good choice of Δz is to assume Δz equal to the bench height; figure B: Determination of αmax based on bench geometry (input to OptimalSlope).

"That means a bigger and bigger footprint for the operation," said Utili. "Mining is very energy intensive. We need to innovate to find ways to reduce the amount of waste rock."

Utili's research to solve the puzzle of the Japanese castle moat led him to develop an efficient analytical method based on the theory of limit analysis to calculate the stability of any slope shape. "Then I started to think 'what if actually there's a better shape than the planar one, and can I find this optimal shape for slope stability?'"

And what if, he thought, this shape not only offered more stability but also reduced the amount of waste rock? Instead of prescribing a linear surface shape to an open-pit mine slope as has been done for generations, Utili set out to identify the optimal shape of a slope based on the thickness of the rock layers present and their mechanical properties. This can be done for each sector of a mine, with the entire pit wall shape from crest to toe determined as a result of a mathematical optimization.

By 2021, his years of research had culminated in the development of the OptimalSlope software.

OptimalSlope

OptimalSlope uses geotechnical data typically present in the mine-block model for its analysis. It generates thousands of potential slope profiles to identify the optimal one with the highest stability number and overall steepest angle. But, as Utili set out to do, instead of following a one-size-fits all straight line with one single angle for the entire slope wall in a given lithological unit, OptimalSlope finds the specific shape that allows maximal overall steepness for each slope sector of the mine. This more precise shape makes for an overall increase of pit-wall steepness by an average of one to four degrees inclination for the same factor of safety as the conventional slope profile.

In 2021, Utili set out to demonstrate his new software through a case study using a Kinross Gold mine already in development. Because of a non-disclosure agreement, he cannot reveal the name and location of the mine, but Kinross provided the OptimalSlope team with the data and collaborated with the case study, the findings of which were subsequently published in the *CIM Journal*, Volume 12, 2021. The study conducted both a traditional slope design and an OptimalSlope one and then compared the two. The modelling for the Optimal-Slope design had 3.5 per cent less rock excavation than the conventional design and a net present value that was US$14 million higher as well as an estimated reduction of 61,300 tonnes of CO2 equivalent.

"To put the carbon-footprint reduction in context, taking the average carbon-footprint reduction calculated for the open-pit-mine case studies we have considered so far, imagine if every open-pit mine was to adopt OptimalSlope, this would lead to a global reduction of annual worldwide emissions by 0.1 per cent," said Utili. "That would be a significant reduction on a global scale."

Next steps

As a software solution, OptimalSlope can be upgraded to incorporate advancements in geotechnical knowledge as it becomes available. Late last year, Utili came across a published research paper by Cylwik on a new method of estimating anisotropic rock-mass strength. Utili reached out to Cylwik, hoping to incorporate this new method into OptimalSlope. That is now in the works.

Cylwik was impressed with OptimalSlope's novel approach. "The idea is a really good idea. We've never really tried that before. Intuitively, to me, the idea makes sense," he said. "And [Utili] has developed the software to do it."

The next step will need to be taken by mining companies and the geotechnical engineers they hire because they are the ones who identify the optimal slope angle for open-pit projects.

The prospect of a new advancement in slope optimization that reduces waste rock is an exciting one for Ernesto Vivas, principal mine plan advisor with digital global giant Hexagon. He too was impressed with OptimalSlope. "It's revolutionary," he said. "When I saw the approach, it really caught my attention and I saw its value right away. The consequences of OptimalSlope in the industry could be huge. Since the 1970s, when the industry started doing slope optimization, every now and then, there have been [breakthroughs] that have improved how we do it."

Those breakthroughs have taken slope optimization from the simple calculations of the 1970s to the more specialized and complex analyses of today. Its developers and supporters hope that OptimalSlope will be the breakthrough innovation that will take slope optimization to the next level, even if the approach may date (at least in part) to the 1700s.

"We don't know if the people who built the moat in Japan understood the mechanics behind it or if it was just intuition," said Utili. "Often, intuition is at play. There are no written records so we don't know. All I can say is, when I did the calculations for the material and dry-stacking technique they used, the resulting optimal shape was exactly the one they used." CIM

Further recommended reading

Stefano Utili's research paper was published in CIM Journal*, Vol. 12, No. 4. Visit cim.org.*