Geotechnical challenges of the biggest mining project in Argentina

RELLÁN, Gonzalo [a]; GARCÍA MENDIVE, Iñaki [a]; QUAGLIA, Gastón [a]; ABAD, Ariel [a]; FIGUEROA, Juan Natalio [a] and SFRISO, Alejo Oscar [a].
[a] *SRK Consulting, Buenos Aires, Argentina.*

Abstract. Pascua-Lama is the first bi-national mining project in the world, located between 3800 and 5200m.a.s.l. on the borderline between Chile and Argentina. Pascua lies on the Chilean side, in Huasco Province in the Atacama region, while Lama lies on the Argentinean side, in the Iglesia department in San Juan province. The project is developed by Barrick Gold and consists of the open-pit mine of one of the world's largest gold and silver deposits, with more than fifteen million ounces of proven and probable gold reserves and six hundred and seventy-five million ounces of silver contained within the gold reserves, as of December 31st 2013 and official reports. The project is still in the construction stage. Future production will include open-pit extraction from Chilean and Argentinean sides, primary crushing in Pascua, transportation of crushed ore to Lama through a 4.0km-long underground tunnel, stockpiling, processing and final disposal at the tailings dam in Lama. Site lithology can be characterized as superficial alluvial or colluvial soils generally followed by a competent cemented granular stratum named ferricrete which lies on top of a highly resistant igneous bedrock, mainly andesite, diorite and dacite. The paper describes the design and construction of some of the excavations, foundations, slopes, fills, retaining walls, MSE walls and CLSM fills, and the challenges imposed by high altitude, steep landscape, extremely cold winter temperatures and the complexity of the construction site.

Keywords. Excavations, Foundations, Granular fill, CLSM fill, Pascua Lama, Mining Project, Retaining Wall, MSE Wall.

1. Introduction

Pascua-Lama, the first binational mining project in the world, straddles the Argentine-Chilean borderline at between 3800 and 5200 m.a.s.l. Pascua is located on the Chilean side, in Huasco province, Atacama region, while Lama lies on the Argentine side, in Iglesia department, San Juan province. The project is being carried out by Barrick Gold and consists of the open pit exploitation of one of the largest gold and silver deposits worldwide, with more than fifteen million ounces of proven and probable gold reserves and six hundred seventy-five million ounces of silver contained within the gold reserves, as of December 31st 2013 according to available and officially reported data. Mine operation shall involve an open pit with a minimum mine life of 25 years, with most of the pit lying in Chile and the lesser part (roughly 25%) in Argentina [1].

Construction of the project is currently underway. The productive stage will involve extraction in Chile and Argentina, primary crushing in Pascua, conveying to Lama through a 4.0 km-long tunnel, stockpiling, final processing and disposal at the tailings dam in Lama.

Infrastructure necessary for processing, stockpiling and transport of ore comprises buildings exceeding 30m in height, foundations resisting vertical loads up to 9.7MN, circular tanks from 10m up to 54m in diameter having capacities in excess of 4500m³ and big buried pipelines and connecting facilities.

This work focuses on the geotechnical challenges faced during more than two years of construction of the process plant, and includes a description of the design and construction of compacted fills, foundations, buried pipelines, avalanche berms, concrete and MSE retaining walls and ground anchors, together with the challenges imposed by high altitude, sloping terrain, extreme winter temperatures and the complexities inherent to the plant site.

2. Challenges of the project

The site's mountainous terrain, weather conditions and seismic activity motivated the implementation of special constructive technologies, for example: i) Massive soil movements were executed under weather conditions that hindered compaction and moisture control, quality protocols included temperature control of soils and a strict monitoring on moisture content and lift thickness; ii) Extreme winter temperatures motivated the design of precast structures [2]. Nevertheless, in many cases the foundations had to be constructed on site under adverse climate conditions and with logistical restrictions that imposed the use of innovative constructive technologies; iii) Technical challenges addressed by a team of more than 5,000 people that worked in a high-mountain construction site, coordinating activities to accomplish a rigid and demanding schedule.

The following paragraphs show some examples of such demanding design and construction conditions, and the procedures followed to successfully assess them.

2.1. Leaching tanks

The leaching process required the construction of eighteen tanks with 18.0m diameter and 19.0m high on an artificially terraced fill 90m wide and 180m long. Due to the site's steep and uneven topography, the fill's maximum thickness was 14m.

The combination of a thick embankment and high tanks on a seismic area demanded detailed studies regarding the tanks' structural behavior for operational conditions and after seismic shaking. The fill's particular geometry, the spatial variability of the material properties and the complex design actions were addressed by a 3D static and dynamic finite element model (FEM) executed in Plaxis [3] and complemented with several 2D FEM models. The process of calibrating the material parameters of the HS-Small model available in Plaxis included triaxial testing of selected samples and back-analysis of the laboratory test results [4].

Figure 2-1 shows a settlement map at one of the particular construction stages of the model performed to analyze the construction methodology and decide the effect of the loading sequence on the settlements of the tanks.

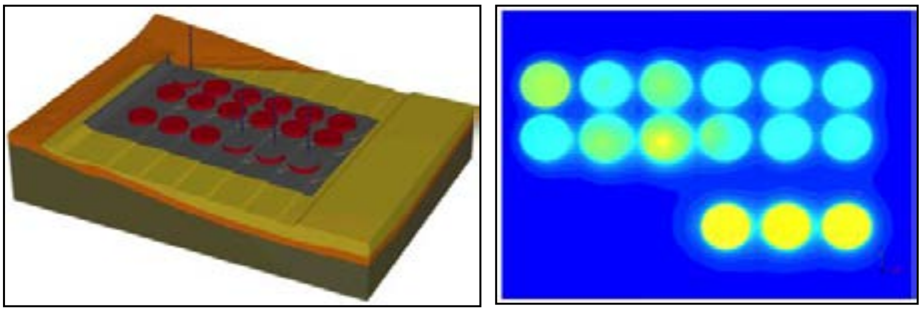

Figure 2-1. 3D view of the model (left) and settlement contour (qualitative, right).

2.2. Foundations of thickening tanks

The six thickeners consisted in tanks of 34m or 44m dia, built of in-situ welded steel sheets, braced metallic columns and precast foundations. Construction changes and slight modifications of the plant layout resulted in relocation of certain areas and –in some cases– new geotechnical foundation conditions.

The tanks were founded on compacted fill platforms instead of rock as originally assumed in the design. The difference in mechanical competence between the real ground and the ground assumed in the design required the implementation of ground improvement works. The tank's principal structure, the seal foundation level and the contact pressure were maintained since structural elements were already built and ready to install, including all the concrete precast foundations and superstructure. Differential settlements had to be kept to a minimum to avoid the risk of load concentration and buckling the welded connecting plates and elements.

The problem was solved by using a plain concrete slab-on-grade with variable thickness. The slab redistributed loads in the terrain, reduced contact pressures to allowable values and minimized differential settlements to required levels [5].

A concrete circular plate of 35.0m dia, 0.5m thick and having a with a central drop panel 1.20m thick was employed. The works were completed without impacting the scheduled construction program for the area. Figure 2-2 shows a sketch of the solution designed and a picture of the concrete plate.

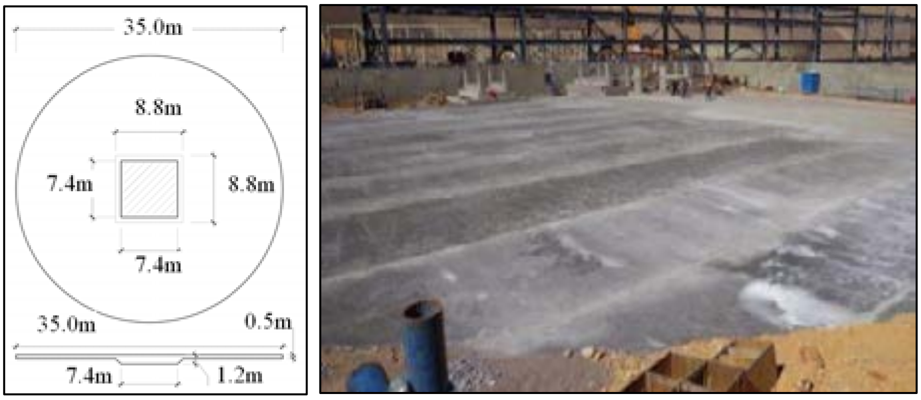

Figure 2-2. Circular stall sketch with central reinforcement (left) and casted on-site stall (right).

2.3. Buried pipelines

The construction of the processing plant involved the excavation of numerous trenches to install buried pipelines and connecting facilities for the fluid transportation system.

One of the pipelines consisted on a fiber glass reinforced polyethylene pipe 20mm thick, having a nominal diameter 2.0m and a length over 150m and a maximum soil cover of 9.0m. During the construction of each section, lateral granular fills were compacted to ensure that the ground stiffness required by the pipe-soil interaction model was achieved. This aspect of buried pipe design is important to allow the pipe to support surface loads with acceptable deflections [6].

The dimensions of the pipe and the construction complexity due to the adverse climate demanded an as-built verification to for QA/QC approval of the construction. The construction process of design sections was simulated with a FEM model that included the stresses and strains associated to the compaction process. A back-analysis was performed to calibrate the stiffness parameters of the lateral fills and reproduce the deformations recorded for each of the soil covers analyzed. The study was completed with the simulation of the complete constructive procedure for each section with the corresponding calibrated stiffness parameters were employed to calculate the final expected deformations in service conditions [3] [4].

The principal advantage of the implemented study consisted in the optimization of the service deformations without intervening the analyzed sections and delaying the pipes and fills construction. Figure 2-3 shows the recording of internal deformations and the settlement map of one of the FEM models.

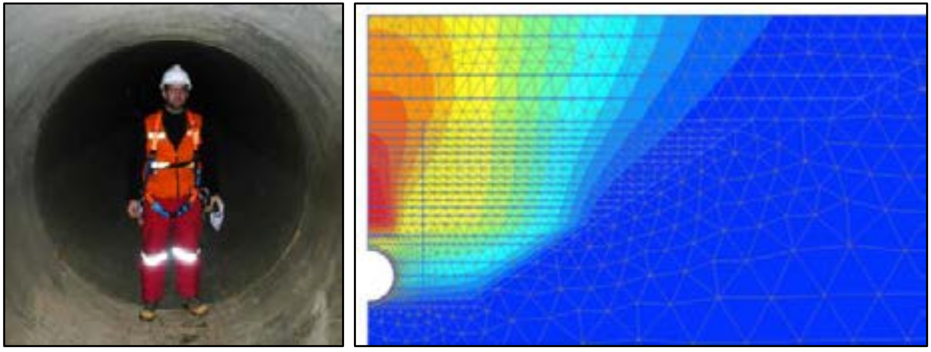

Figure 2-3. In-situ recording of deflections during backfilling (left) and settlement map of the FEM model employed for the back-analysis (right).

2.4. Avalanches control system

The processing plant is located in a valley, surrounded by mountainsides with mean slopes 30º to 37° that receive annual snow precipitations up to 800cm thick.

Containment berms were designed to protect the installed facilities against potential snow avalanches. Dr. Dave Mc. Clung, an international expert from UBC, visited the side and provided expert advice on assessing the avalanche risk and dynamic action against containment berms [7]. The designed sections were 8.0m and 6.5m high, with a crown width of 8.0m and 4.5m and 80° inclined front faces.

Structures' stability had to be guaranteed even for extreme conditions such as an earthquake and the earthquake-triggered avalanches. It was decided to design the containment berms using geosynthetic-reinforced MSE walls [8].

The designed structure is made of 0.30m thick compacted soil layers reinforced with 4-8m long geotextiles. A top protective layer of controlled density cemented fill was specified to resist to extreme climate and UV rays. The geotextile utilized was the non-woven GSE-NW8 widely available in the construction site. The designed structures were analyzed to resist design avalanches with a 1% exceedance probability. FEM models were employed to compute the factors of safety and associated risk of failure of the containment berms [3] [4]. The obtained safety factors varied from 1.13 to 1.18, acceptable values for extreme loads acting on highly resilient earth structures. Figure 2-4 presents a sketch of the design and an output of the FEM numerical model showing the potential failure surface.

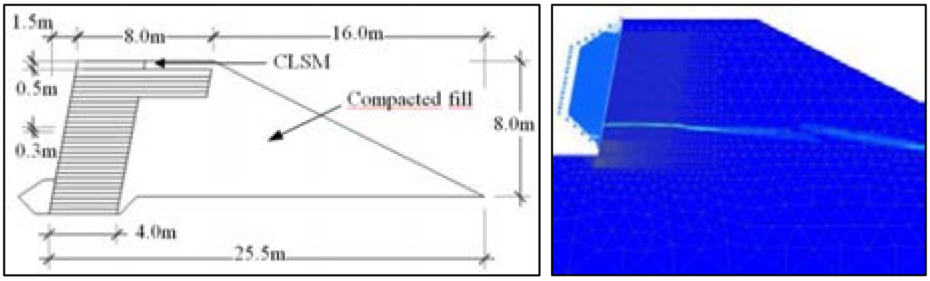

Figure 2-4. Designed sketch (left) and potential failure surface for the avalanche containment berms (right).

2.5. Retaining structures

The construction of numerous platforms in spatially limited extensions required the use of retaining walls in various parts of the project. One of the sites was the Merrill Crowe CCD area, where five tanks, 52m dia and a CCD clarifier, 56m dia, are located in a terraced platform following natural terrain's inclination and allowing for the transportation of processing fluids by gravity. This layout required the design and construction of retaining structures supporting vertical cuts 5.50m high between terraces.

Precast elements were employed and transported from San Juan city, located at more than 300km from the construction site through a mountainous road. Logistical transport and handling challenges imposed severe limitations to the weight and dimensions of the precast elements, so that the required wall sizes could not be built in one segment. Furthermore, in-situ casting of structural concrete was not an option due to the winter time when these works had to be executed: casting concrete in cold weather and under extreme strong winds would have required the deployment of tents and concrete heaters, delaying the construction schedule.

Two solutions were specified to provide on-site structural flexibility to changes in working space availability: i) Vertical walls made by three precast segments founded on a continuous footing and supported by concrete vertical ribs were connected to deadmen by steel anchors; ii) Precast cantilever panels 4.7m high and 3.2m wide, founded on a plain concrete bulk foundation 1.6m high and 5.6m wide. The structures were designed and analyzed using 2D FEM models in Plaxis [3] [4]. Figure 2-5 shows a sketch of the cantilever wall and an output of the numerical model implemented to analyze the segmental wall's potential failure surface and factor of safety.

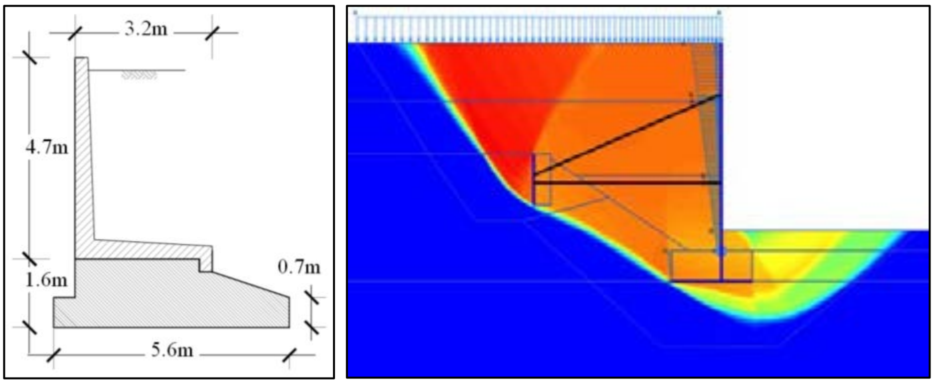

Figure 2-5. Pre-cast cantilever wall on plain concrete (left) and model for segmental tied-back walls (right).

2.6. Mechanically stabilized earth walls

The need to host ten thousand people in comfortable facilities operating under extreme weather conditions resulted in the construction of medium density hotel infrastructure. The prefabricated units were located in terraces that accompanied natural terrain topography. To materialize such terraces, several high slopes–up to 13m– and steep inclinations had to be designed and executed.

The embankments, slopes and face protections were designed to address extreme site conditions including frost, seismic activity and strong snow precipitations. A mechanically stabilized earth (MSE) slope was designed using available geosynthetics [8]. The selected alternative has the following advantages: i) The design could be executed with elements, equipments and materials available on site; no delays to schedule were expected; ii) Construction could be efficiently controlled by the site QA/QC department.

Geosynthetics required UV-ray protection –UV is very strong in the site– but it was impossible to cover the surfaces with natural vegetation since it is nonexistent at the construction site altitude.

The 11.5m high slope in the transition between Platforms 1 and 2 was constructed with the non-woven GSE-NW8 geotextile widely available at the project. The MSE slope was designed to have 0.45m-0.50m thick layers reinforced with geotextiles approximately 7.0m long. Figure 2-6 shows a sketch of the MSE wall and a picture of the face as-built; the hotel modules can be seen on the fills crest.

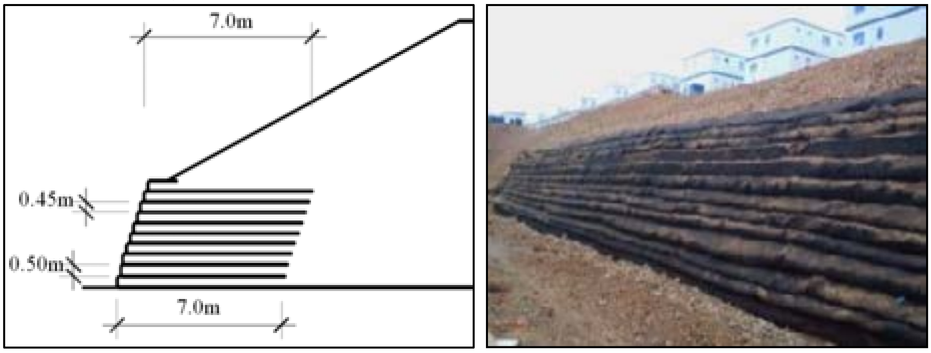

Figure 2-6. Sketch of the MSE wall (left) and the as-built face showing hotel modules on top (right).

2.7. Rock restitution using concrete

In many parts of the project, poor rocks or loose fill materials were found at the foundation level. In many cases, over-excavation of poor material and substitution with concrete was the simplest way to achieve design foundation conditions. This simple construction technique posed some challenges due to the very tight construction schedule, incompatible with the production, casting and curing of large volumes of concrete in cold and windy weather.

The electrical power plant of the processing plant was one of such places. In one of the racks, the rock surface had a steep slope and was deeper than expected, requiring the design of an anchored restitution concrete fill forming a buttress 18m high that restored the foundation level of the rack to design requirements.

The rock mass was relatively homogeneous and quite competent, allowing for the design of passive grouted anchors that secured the concrete buttress against the rock outcrop. The design working load of the anchors was determined after consideration of several failure mechanisms, for all construction and service conditions including seismic loading and potential water pressures [9]. Due to limitations in available equipment, short anchors, 0.80m long, were employed for this project. Figure 2-7 shows the completed restitution.

Figure 2-7. Concrete buttress for foundation restitution at the main power plant.

3. Conclusions

Pascua-Lama, the first binational mining project in the world, straddles the Argentine-Chilean borderline at between 3800 and 5200 m.a.s.l. This work outlines some of the geotechnical challenges faced during more than two years of construction of the process plant, and includes a brief description of the design and construction of compacted fills, foundations, buried pipelines, avalanche berms, concrete and MSE retaining walls and ground anchors, together with the challenges imposed by high altitude, sloping terrain, extreme winter temperatures and the complexities inherent to the plant site. The examples shown are:

i) The performance of 14m-thick compacted fills supporting eighteen leaching tanks 19m in height and 18m in diameter subjected to the site design earthquakes was evaluated by means of a 3D finite element model.

ii) In situ testing and FEM models were employed for the as-built assessment of serviceability of a 150m-long fiberglass reinforced polyethylene pipeline buried under a 9m thick backfill, without delaying the backfill works.

iii) Geosynthetic-reinforced MSE walls were employed to materialize avalanche berms up to 8m high, a design which is both resilient to extreme actions and could be executed with available materials and equipment.

iv) A similar design of a MSE wall was also used in Los Amarillos camp to generate terraced levels for installing prefabricated housing units.

v) Terraced platforms of the main process area were materialized by means of retaining concrete structures. Precast modular elements were transported 300km by truck through a mountain road. In order to provide for construction flexibility, two retaining typologies were designed: a modular anchored wall on a strip footing, and a precast cantilever wall on a plain concrete base.

vi) Six thickeners 34m to 44m dia were placed on compacted fills instead of rock without changing any structural element, by employing a plain concrete slab 35m dia which guaranteed negligible differential settlements while complying with the construction schedule.

vii) Foundation of a terraced concrete block to support an electricity distribution rack involved the execution of anchors to the underlying rock, which were optimized to comply with the equipment available on site, therefore reducing costs and accelerating construction time.

These few examples show the opportunity for excellence in geotechnical engineering and the advancement of local expertise that a world-class project like the Pascua-Lama project offers to developing countries like Argentina and Chile.

4. Acknowledgements

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