Independent Advisory Panel to IDB Invest
IAP Report N°5, March 2021
Ituango Hydropower Project
Colombia

Federico Ciampitti
Hydraulic, Mechanical & Electric Equipment

Via L Tolstoi 72, 20146 Milan Italy
Tel. +39 335 1007517
Federico.ciampitti@gamail.com

Pavlos Marinos
Engineering Geology and Geotechnical

23A, Penetoliou str. 11741, Athens, Greece
Tel. +30 694 4301993
marinos@central.ntua.gr

Alessandro Palmieri
Dam Engineering and Safety (Chair)

Via Massimi 25, 00136 Rome, Italy
Tel. + 39 063 5400737
Arp.palmieri@gmail.com

Contents

ANNEX A: LIST OF DOCUMENTS MADE AVAILABLE TO THE IAP

ANNEX B: "PRESUPUESTOS" OF THE YEARS 2021, 2020, and 2019

Acronyms used

ADT	Auxiliary Diversion Tunnel (GAD or SAD in Spanish)
BID	Banco Interamericano de Desarrollo
CAP	Capital Investment
CFD	Computational Fluid Dynamics
C&I	Control and Instrumentation (cables)
COD	Commencement of Operation Date (turbine units)
DRM	Disturbed Rock Mass
EPM	Empresas Públicas de Medellín
EPP	Emergency Preparedness Plan
FEM	Finite Element Analysis
GIS	Gas Insulated Switchgear
HPP	Hydro Power Plant
HV	High Voltage
IAP	Independent Advisory Panel to IDB Invest
IDG	Intermediate Discharge Gallery (DI in Spanish)
IDB	Interamerican Development Bank (BID)
IEC	International Electrotechnical Commission
LV	Low Voltage
MAF	Mean annual flow
MAS	Mean annual sediment yield
MLO	Middle Level Outlet
MOL	Minimum Operating Level
ANLA	National Authority of Environmental Licenses (ANLA in Spanish)
PH	Powerhouse
PF	Probability of Failure
PFMA	Potential Failure Mode Analysis
RLM	Response Level Matrix
TD2	Diversion Tunnel 2 (right)
EBIA	EPMs Board of Independent Advisors
m. asl	Meters above sea level

EXECUTIVE SUMMARY AND RECOMMENDATIONS

Instrumentation and monitoring continue to show satisfactory behaviors of the dam, and of the spillway. Slope stabilization works are proceeding and monitoring shows suitable performance.

The extensive repair works implemented to date allow to express a positive evaluation on the safety of the underground works in North side of the Powerhouse complex (Units 1 to 4).

The assessment relative to the South part, Units 5 to 8, remains challenging due to the extensive and complex treatment works of the disturbed rock mass affecting the pressure shafts, and the extent of the waterways not yet inspected (pressure shafts, penstocks, south machine hall, lower part of south surge shaft, tailrace 4). The IAP agrees with the designed treatment works, which will require careful supervision.

Permanent sealing the TD2, and secondarily the GAD, has been accurately designed and is under implementation. The IAP agrees with the design and the sequence of the activities. The process will present a moderate risk until the works are completed. A dedicated monitoring system is in place to alert workers and downstream communities in case of emergency situations during the execution of the sealing works. The IAP recommended to integrate the monitoring system in a dedicated Emergency Preparedness Plan.

The Intermediate Discharge Gallery will be used as the downstream part of the waterway that will ensure ecological releases even in extraordinary conditions (turbine out of operation and reservoir below spillway level). The design of the waterways has been defined, and the necessary steel lining components are being procured.

Commencement of operation dates of Units 1 to 4, compared with the expectations of March 2020, are shown below.

Commencement of Operation dates (COD) - comparison			
	COD in March 2020 schedule	COD in December 2020 schedule	Accumulated delay (months)
Unit 1	December 2021	July 2022	7
Unit 2	April 2022	October 2022	6
Unit 3	July 2022	January 2023	6
Unit 4	October 2022	September 2023	11

Accumulated delays are significant and can be mainly attributed to the impact of Covid 19, and to unexpected additional excavations of damaged rock in the draft tubes area.

Unit 1's COD is currently scheduled in July 2022 i.e., about 18 months from now. The IAP considers such period realistic for executing first and second stage concrete, erection, commissioning and testing of Unit 1.

Other important works still lay ahead (e.g., underwater works at the intakes, treatment of the horizontal bends of tailraces 1 and 2) at the same time, availability of all the necessary equipment on site is a positive element for achieving CODs. A similar assessment can be made for COD's achievement of Unit 3 and, cautiously, of Unit 4.

Regarding the other four units, in the South part of the machine hall, the last program of works (December 30th, 2020) features the following CODs.

Unit	Commencement of Operation Date (COD)
5	August 2024
6	October 2024
7	December 2024
8	February 2025

Progress of works will have to be closely supervised to respect the schedule, because extensive and complex treatment works need to be done, and a significant part of the waterways has not yet been inspected.

The IAP estimates that, currently, a cumulative investment cost (*total inversion*)[1] of about 16,000 billion COP, represents a reasonable assessment for Project's completion. The estimate should be updated regularly, as works proceed, to make sure that adequate resources are available to meet the CODs. Current estimate of the additional costs ascribable to the consequences of the May 2018 event is about 3,900 billion COP.

The IAP believes that, given the current timeline to Project's completion, and the increasing importance of securing adequate resources to that end, a closer review of cost and schedule becomes necessary in the near future. That would likely require more frequent interaction with EPM cost controllers.

Last, but foremost, the IAP underlines a topic pertaining to the safe operation of the Project. It is of vital importance that turbines can be operated, for a limited time, to lower the reservoir level in emergency conditions e.g., following a strong earthquake. That would entail operating the units below the 390 MOL, and the Project's EPP should contemplate such emergency operation. Should the experts of the turbine supplier fail to advise on the expected consequences of operating the units outside the design boundaries, EPM should seek independent advice from specialised experts.

Using the turbines in emergency conditions could be forsaken if the addition of a middle level outlet will prove feasible, and realised, during the life of the Project.

[1] Investment costs represent about 80% of the total Project's costs. Remaining cost items include: *Gastos preoperativos, operacion y comercializacion. Gastos financieros, IVA, Activos indemnizados.*

1. CURRENT PROJECT SITUATION

1.1 General

The Ituango Hydroelectric Project is under construction at the northwest of Colombia since 2009. The Independent Advisory Panel (IAP) was formed in 2018 to advise IDB Invest on technical matters of primary relevance to safety and sustainability of the Project. The IAP visited Ituango three times, in August 2018, March 2019, and September 2019 and issued respective Reports.

Due to the concomitant C19 pandemic, the IAP's fourth (May 2020) and fifth (February 2021) missions had to be organised virtually. All three IAP members attended the February 2021 mission. Despites the difficulties, thanks to an excellent organisation by EPM, and facilitation by IDB Invest, the virtual mission allowed the IAP to appreciate the progress made and get an update on the main technical issues of the Project.

The mission consisted of three video conferences, on February 23rd, 24th, and 25th. The first two days were devoted to presentations and discussions. On the last day, the IAP delivered a brief of their preliminary observations, which are elaborated and presented in this report.

The IAP wishes to acknowledge the highly professional contribution of all stakeholders to the discussions and exchange of views on the complex technical subjects pertaining to Ituango HPP.

1.2 Comparison with May 2020

During its February 2021 virtual mission, the IAP has observed the following key aspects.

- Performance of the dam continues to be in line with design expectations and correspondence between predicted and as-measured performance is excellent.
- The spillway is operating full time, which is beyond the design assumptions, and will continue so until turbine operation will be established. Monitoring of the plunge pool slopes does not show any sign of unacceptable distress.
- Power-house cavern complex- North Zone: all the underground areas, which were affected by uncontrolled river throughflow, have been inspected and repair works are underway.
- Unexpected voids, encountered in the lowest part of the machine hall, required additional excavation and backfilling.
- Monitoring of the underground openings continues to indicate satisfactory performance.
- Concreting works and equipment installation of units 1 to 4 is progressing and commencement of operation of the first unit (unit 1) is planned in July 2022.
- The supply and delivery to site of electromechanical equipment for the installation and commissioning of Unit 1-4 is secured and their procurement is no longer an issue for the project.
- Power-house cavern complex- South Zone: the "disturbed rock mass" affecting pressure shafts 5, 6, 7 and 8 has been investigated and delineated; treatment measures are being defined.
- The GAD has been temporarily secured with the installation of gates that can withstand the full reservoir pressure. Activities are concentrated on the TD2 adopting a well-studied design.

Flow through TD2 is closely monitored during the sealing operations. The IAP recommended to integrate the monitoring system in a dedicated Emergency Preparedness Plan.

- The workshop for penstock assembling is completed, trial production is ongoing and having all steel plates already at site represents an important achievement.

1.3 Options for Project's Completion

The following table shows the progression of IAP's assessment of the "Options for Project Completion" which were put forward since the IAP's involvement in the Project.

Options	August 2018	March 2019	October 2019	May 2020	February 2021
Full Rehabilitation	Preferable option; final confirmation after assessment of damages in the powerhouse complex	Confirmed preferable option	Substantially confirmed	Confirmed	Confirmed
Revise Project's Outputs	Not envisaged at this stage	Power output unmodified. Schedule of second stage power supply (units 5-8) to be assessed.	Power output unmodified. Sequence for putting in operation the Unit shall be independent from the original two stages power supply.	Power output unmodified. Unit commissioning sequence: U1 (Dec20), U2 (Apr21). Other units still to be defined.	Unit commissioning sequence: U1 (Jul22), U2 (Oct22), Unit 3 (Jan23), Unit 4 (Sep23), Unit 5 (Aug24), Unit 6 (Oct24), Unit 7 (Dec 24), Unit 8 (Feb25)
Revise Project's Purposes	Not realistic				
Project re-engineering	Addition of Middle Level Outlet (MLO) essential		Future decision on the MLO to be supported by a Potential Failure Modes Analysis.	PFMA workshop carried out. To be further developed to achieve a risk-informed decision on the additional MLO.	Operating the turbines at elevations below 390 m. asl is essential for dam safety in emergency conditions. Due consideration should be given to adding a MLO during the life of the Project.
Partial/ total retirement	Very unlikely, unless cavern location must be abandoned for excessive damages.	Partial retirement can be excluded.	Partial retirement excluded.		
Long-term vision	Project will have to be decommissioned at the end of its useful life, when coarse sediment management, to sustain run-of-river operation, will no longer be economical.	Bathymetric surveys should be initiated to assess sedimentation trends.	Long-term reservoir management retains its importance.	IAP would like to review results of bathymetric surveys carried out to date.	

1.4 Project's Risk Register and Emergency Preparedness Plan

Figure 1 shows the general risk matrix of the Project as assessed in February 2021. The assessment aggregates all element of risk (cost, time, people, reputation, environment, social).

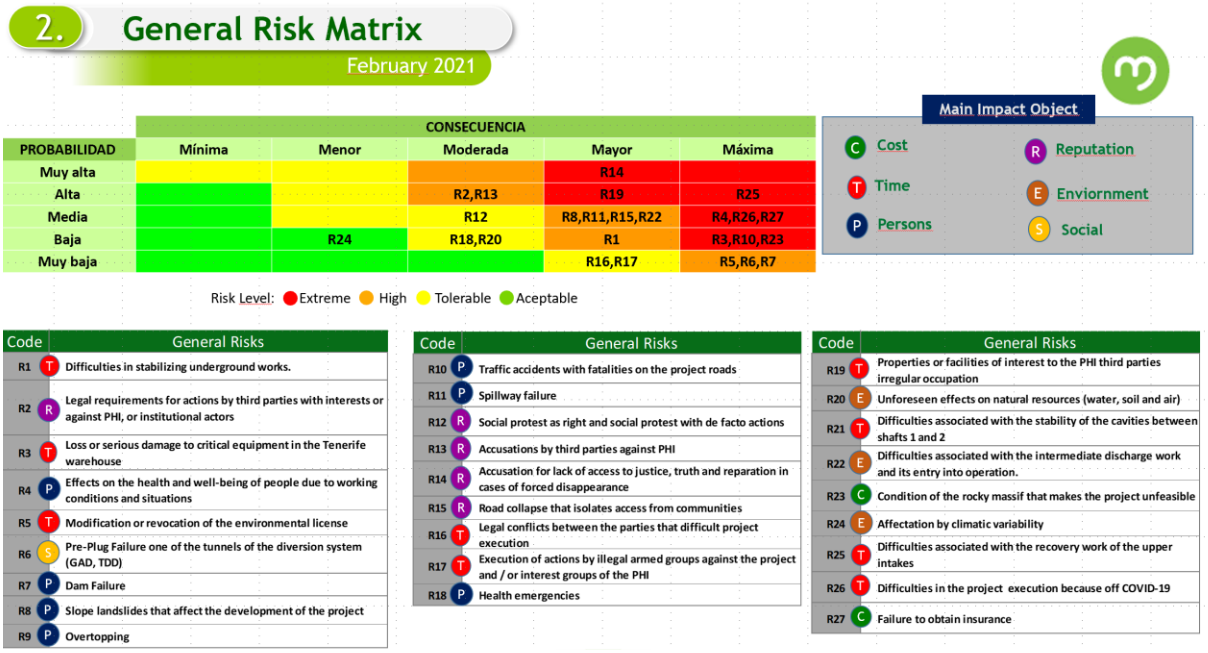


Figure 1: Project's General Risk Matrix in February 2021

While recognizing the importance of all element of risk, it is appropriate, for the IAP, to concentrate on those elements that are of a technical nature. They are compiled in the following table.

Disaggregation of Technical Risks		
R1: difficulties in stabilizing underground works	**R8**: Landslides that affect the development of the project	**R22**: Difficulties associated with the intermediate discharge work and its entry into operation
R6: Pre-plug failure in one of the tunnels of the diversion system (GAD, TD2)	**R11**: Spillway failure	**R23**: condition of the rock massif that makes the project unfeasible
R7: Dam failure	**R21**: Difficulties associated with the stability of the cavities between shafts 1 and 2	**R25**: difficulties associated with the recovery work of the upper intakes

The matrix pertaining to technical risks only is shown in figure 2.

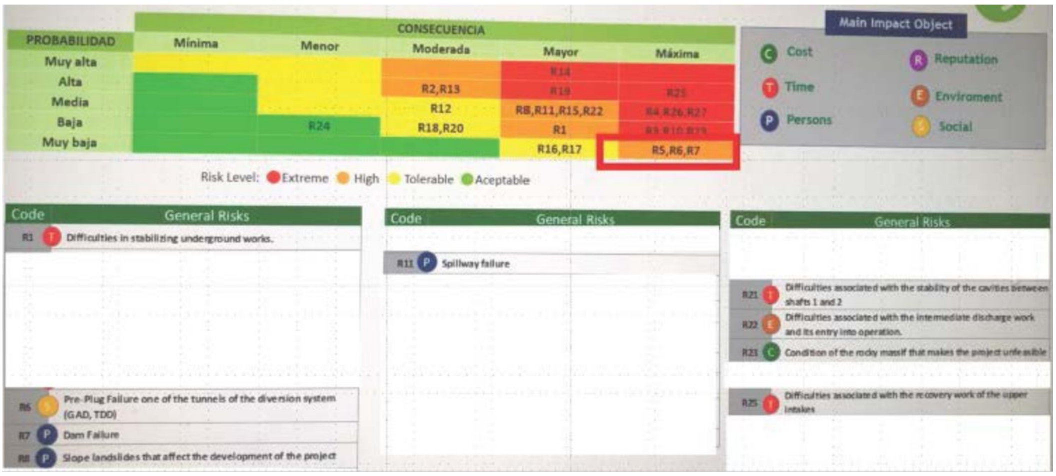


Figure 2: Matrix of Project's Technical Risks in February 2021

The IAP agrees, in principle, with the risk assessment of the different events, except in the case of R5 (GAD and TD2 sealing). Its probability of occurrence cannot be of the same level as that of “Dam Failure” (R7). Until successful sealing is achieved, the probability of occurrence of R5 should be moved up to «Baja».

Activities associated with R5 are discussed in the following paragraph.

1.5 Permanent Sealing of TD2 and GAD

GAD and TD2 have been affected by the April 2018 collapses that caused loss of control on reservoir levels. Currently, the GAD is under control, and works are ongoing to control the TD2. Providing permanent sealing to the Right Diversion Tunnel (TD2) and to the Additional Diversion Tunnel (GAD) is essential for bringing back downstream safety to pre-contingency time. Technical assessment follows.

GAD

Two wheeled sliding gates have been installed on the GAD as per original design; a concrete plug on the top of the gate structure has been placed to avoid any movement of the gates. With such installation the tunnel is technically plugged, and full hydraulic control has been re-established on the GAD. Two by-pass systems have been built, one around the gates, the other permits drainage towards the Intermediate Discharge Gallery (located above the GAD). Gate installation allowed the alert level to be reduced from red to orange, with significant relief for the population downstream.

The next step is to realise a “permanent” concrete plug, 22 m long, downstream of the gates, as foreseen in the original design; being the control of the GAD performed by the gates, the plug is not on the critical path and there are sound technical reasons not to rush to install the permanent plug. Both discharge and water pressures are continuously monitored along the GAD; results show stable values for both parameters.

TD2

The left tunnel (TD1), which runs parallel to TD2 had already been plugged before the collapse blocked the TD2 in 2018. The stability of the slope of the right valley side, that was associated with the year 2018 collapses, has been secured with remodelling of slopes and extensive reinforcement.

TD2’s discharge is constantly monitored and has stabilized at about 8 m3/s. That indicates that no leakage comes from the parallel TD1, which is at reservoir pressure upstream of the plug. That is a good indication of the quality of the rock mass separating the two tunnels.

Water pressures are also monitored in the TD2 and results show a clear declining trend, which can be attributed to a progressive sealing of the debris by turbidity carried with the river flows.

Therefore, while the TD2 cannot yet be considered “technically plugged”, all evidence permits to assign a low probability to the potential collapse of the natural obstruction.

Sealing of the TD2 must take place while water is flowing and therefore requires a complex and carefully planned procedure. Due to its unprecedented nature in hydropower projects, TD2 sealing has been thoroughly studied and a feasible solution is being implemented (Figure 3).

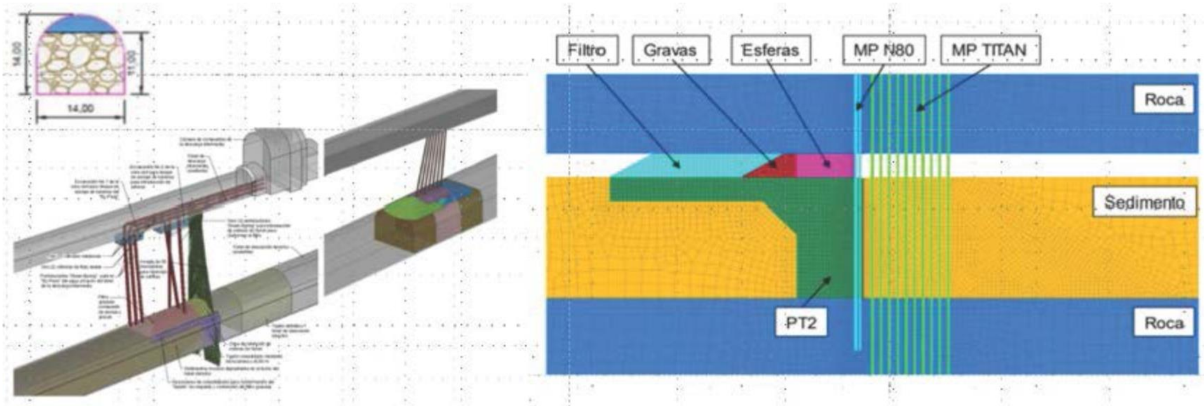


Figure 3: _Solution for sealing the TD2_

To date, 56 micro piles have been installed and 6 more are underway to close the gaps left by the executed grid, completion is expected in April 2021. After that, special plastic spheres (of different diameters) will be floated to be trapped by the piles grid. This is expected to force the residual flow through the by-pass system and facilitate progressive clogging of the waterway by means of gravel and sand first, and of special grouting after. At that point, grouting will be performed with special resin-based mixtures to totally seal the temporary barrier. That is expected to further reduce the flow to nominal values that will permit construction of the permanent plug under safe conditions.

The IAP considers the designed solution feasible and suggests considering the use of wet foams in the process. The flow through TD2 is closely monitored during the sealing operations, in terms of head and velocity, which inform three levels of alert to protect the downstream areas. The IAP understands that a dedicated emergency preparedness plan (EPP) is in place for the TD2 sealing. The EPP should include a Response Level Matrix (RLM), which is standard practice the manage dam safety. Fig. 4 shows a typical RLM for a dam.

NIVEL DE RESPUESTA	TIPO DE EVENTO					
	AVENIDA	SUELTAS DE EMERGENCIA	SISMO	FILTRACION / EROSIÓN INTERNA	LECTURA DE INSTRUMENTACIÓN ANORMAL /FALLO COMPUERTA	SABOTAJE / ACCIDENTE
ALERTA INTERNA (Situación manejada internamente)	El nivel del embalse crece hacia el nivel de avenida. Vertido se aproxima a la capacidad del cauce	Alerta de inminente vertido	Sismo menor que Design Basis Earthquake (DBE). T= 475 años	Filtraciones excesivas		Cualquier incidente de amenaza de ataque.
NIVEL I (Puede provocar una avenida aguas abajo. Notificar).	El nivel del embalse se aproxima al nivel de avenida, pero bajo el nivel de coronación.	El vertido excede de la capacidad del cauce.	Sismo mayor que Design Basis Earthquake (DBE). T= 475 años	Incremento excesivo de las filtraciones. Filtraciones con arrastres de finos.		Ataque que amenace la integridad de la presa o aliviadero.
NIVEL II (Prepararse para evacuar)	Las predicciones indican que el nivel superará la corona	Liberación controlada que puede inundar áreas habitadas	Inestabilidad de la presa consecuencia del sismo	Filtraciones ocasiona un flujo no controlado		Como anterior
NIVEL III (Evacuación)	Sobrevertido inminente	Como anterior	Integridad de la presa comprometida con el sismo	Formación de brecha en la presa		Como anterior

Figure 4: Sample Response Level Matrix for dams

The alert levels, associated with the monitoring system, should be consolidated in a dedicated RLM.

1.6 Safety Assessment

The last time the IAP had the possibility of visiting the Project, in presence, was September 2019. Like in May 2020, during the February 2021 Virtual Mission, Project staff provided a comprehensive description of the ongoing works. Availability of real-time video cameras, installed at key locations, significantly helped appraising the conditions of the works.

The main safety-related aspects of the Project can be summarised as follows.

- The level of instrumentation and monitoring of the Project is state of the art: all readings are automatic, centralised to control room, and remotely accessible.
- Performance of the dam is in line with design expectations and correspondence between predicted and as-measured performance is excellent.
- The activities related to the permanent sealing of TD2 and GAD are defined and their implementation is ongoing.
- A slope movement is in progress, in an area away from the works, and it does not represent a threat for the reservoir; the zone is monitored to define the needed interventions.
- The spillway is operating full time, which is beyond the design assumptions, and will continue so until turbine operation will be established. Monitoring of the plunge pool slopes does not show any sign of unacceptable distress.

- Most of the underground areas, which were affected by uncontrolled river throughflow, have been inspected and needed repairs defined. The large cavity between pressure shafts 1 and 2 has been successfully backfilled.
- The collapsed area between the PH cavern and north surge shaft is in advanced stage of rehabilitation.
- The South part of the Cavern and related waterways are affected by a large zone of disturbed rock mass, which has been investigated and delineated. Treatment measures are under definition.

Overall safety assessment:

- Despite the unprecedented events that impacted the Project, the undertaken works allow to express a satisfactory assessment on the safety of both surface and underground works.
- Sealing the TD2, and secondarily the GAD, presents a moderate risk until the works are completed. A dedicated monitoring system is in place to alert workers and downstream communities in case of emergency situations during the execution of the sealing works.

2. RESIDUAL RISK DURING OPERATION

2.1 Reservoir control during Project operation

In the current (March 2021) configuration of Ituango, incoming flows can only be discharged by the surface spillway, which implies maintaining the reservoir full all the time. Activating turbine operation will allow control of reservoir levels with remarkable reduction of the risk profile of the Project and it is therefore the current priority. The absence of a low-level outlet makes the turbines also the only means of controlling reservoir level during operation.

Adding an MLO to Ituango is not contemplated, as part of Project's completion, because the presence of the reservoir would make its construction remarkably challenging. Besides, given the instabilities that have affected the rock mass, it would be imprudent to undertake the operation before having appreciated, by long term monitoring, the overall stability of the rock mass environment. At the same time, the opportunity of adding a MLO should not be forsaken because it would remarkably increase Project' safety e.g., following a strong earthquake. In consideration of the difficulties involved, construction would have to be carefully planned and, if confirmed essential, built during the life of the Project.

2.2 Operating the units in emergency conditions

The operating head of Ituango reservoir, as defined in its design, is nominally limited to 30 m range: between 420 and 390 m. asl (fig 5).

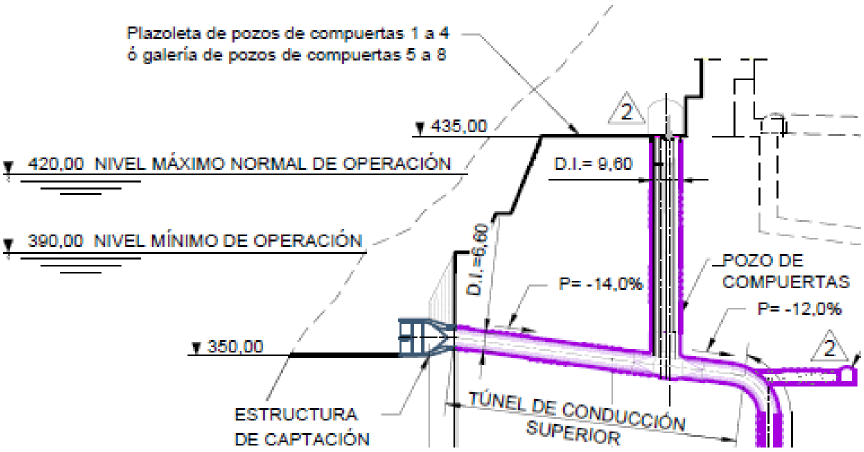


Figure 5: Maximum normal, and minimum operating levels

Regarding units' hydraulic head, it is important to record that the operating conditions of the units have been modified because of changes in the tailrace system and thalweg profiles.
The maximum design level in the surge shaft (almenara) to ensure the design net minimum head was 218.8 m. asl before the May 2018 event. The revised design levels, as recently communicated to GE by EPM, are appreciably higher as shown in fig. 6.

Caso de Operación	Niveles esperados en la almenara
Operando 4 Unidades	222,7
Operando 3 Unidades	222,39
Operando 2 Unidades	222,17
Operando 1 Unidad	222,04

Fig. 6: *Revised design levels in the surge shaft*

EPM informed that thalweg dredging, to reinstate the design levels, would not have a significant effect on initial generation with units 1 and 2, and therefore it is not planned before commissioning such units. That is because operating with reservoir level above the minimum head will ensure the respect of the minimum guaranteed head. The IAP would like to better understand whether the modified levels in the surge shaft, shown in fig. 6, are due to thalweg levels, or to some modifications to the geometry of the waterways downstream of the turbines associated with the rehabilitation works.

Operating the turbines below elevation 390 m a.s.l. can cause three types of impacts on the equipment:

- Formation of vortices above the intakes,
- Cavitation,
- Vibrations.

The different impacts are discussed in the following.

Vortex formation

If submergence is too low, intake works can be affected by vortices. Vortices entail several detriments in the hydraulic performance:

- Air entrainment, affecting hydraulic machinery, and causing pressure surges.
- Swirl entrainment, with increase of head losses.
- Enhancement of cavitation and vibration.
- Entrainment of floating material.

The minimum submergence can be estimated by empirical formulae and better defined on hydraulic models.
Application of available empirical formulae[2] has given the following results:

- It should be vortex-safe operating the turbines under minimum level of 373 m. asl.
- Vibrations should be monitored under 373 m. asl.
- Not recommended to go below 370, unless in extreme emergency conditions.

Cavitation and vibrations

Such phenomena can be triggered when the turbine operates outside the head and discharge (H-Q) values for which it has been designed. Fig. 7 shows the "hill chart" of Ituango's turbines along with guaranteed operating range and cavitation limits.

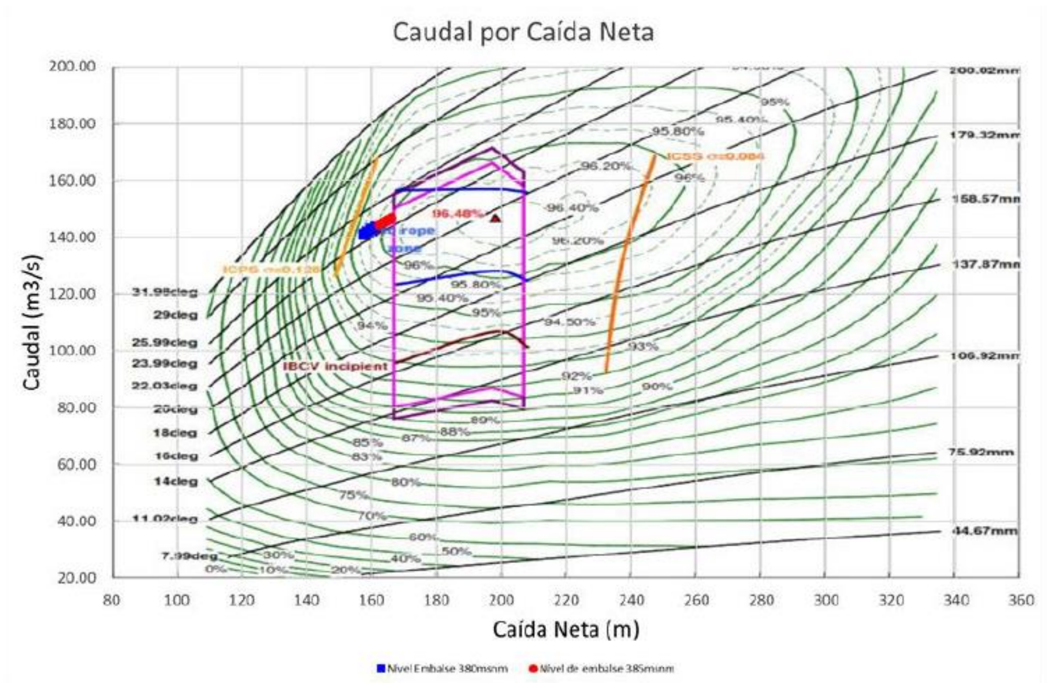


Figure 7: Turbines Hill Chart with guaranteed operating range and cavitation limits

[2] Domfeh, M.K., et al. (2020) "Free surface vortices at hydropower intakes: A state-of-the-art review" Scientific African, Volume 8, July 2020

Both cavitation and vibrations increase gradually and may reach damaging effects either if the unit is operated for a long period outside the design limits, or if operated in a H-Q area too far from the limits.

The extension of operating range for elevation at 385 and 380 are shown respectively in red and blue. The orange line on the left shows incipient cavitation limit for the pressurize upper part of the runner.

Should the units need to be operated outside the design limits, in emergency conditions, monitoring vibrations should be an obvious requirement to be specified in the Project's Emergency Preparedness Plan.

The contract obligation requested by EPM to GE did not include any operating range subject to limited number of operating hours per year (consequently the 50-hour limit as per IEC 60609 applies). However normal sector practice requires an additional area of operation for operation not exceeding 400 -1000 hours per year.

In its reply to the questions formulated by the IAP, GE reported that pulsation increase smoothly at the reduction of net head; expected vibrations should have been subject to a desk calculation by the manufacturer. Both values should be better checked at site on the prototype. There is enough evidence for requesting a better, non-contractually binding, expert opinion by GE experts in design and model testing.

<u>IAP recommendations</u>

The capability to lower the reservoir level below 390 m. asl may indeed become a critical measure to extent the reservoir management options, currently extremely limited, and consequently to increase Project' safety in operation.

In emergency conditions, the operator must make choices in line with the Emergency Preparedness Plan and, there should be no doubts on the trade-offs between causing temporary damage to the equipment, and failure of the dam.

The expected damages should be contemplated in the EPP. Preliminary responses by the equipment suppliers were unsatisfactory because such responses focused on the contractually guaranteed operation limits of the turbines. While that is legitimate position of the supplier, it fails to appreciate the spirit of the question, which pertains to emergency, not regular, operating conditions. Should the equipment supplier fail to assist, EPM should seek independent advice from a specialized consultant.

2.3 Reservoir Sedimentation

The IAP pointed out that, at an advanced stage of project's life, it could become valuable to flush sediments in the area of the intakes in order to prolong the life of the Project. To that effect, the option to open the IDG intake at el. 260 could be reconsidered, during the life of the Project. Planning should be based on bathymetric surveys. The IAP's request to review the bathymetric surveys carried out to date is hereby renewed, desirably during the next visit.

3. GEOTECHNICAL ASSESSMENT

3.1 Pressure Shafts 1 to 4 (North side)

No significant geotechnical aspect to report, except that civil works for the rehabilitation of shafts 1 and 2, which were affected by the large cavity, have been satisfactory completed. The focus is currently on assembling and installing the steel lining to the pressure shafts, starting with 1 and 2. Underwater works contract has been signed and activities are about to start in correspondence of the intakes, which will require the use of metallic bulkheads, the removal of debris in front of the intakes, and the repair/ replacement of the trash racks (see figure 8), the completion of the 20 m concrete lining to Intake 2 and the removal of concrete plug to intakes 3 and 4

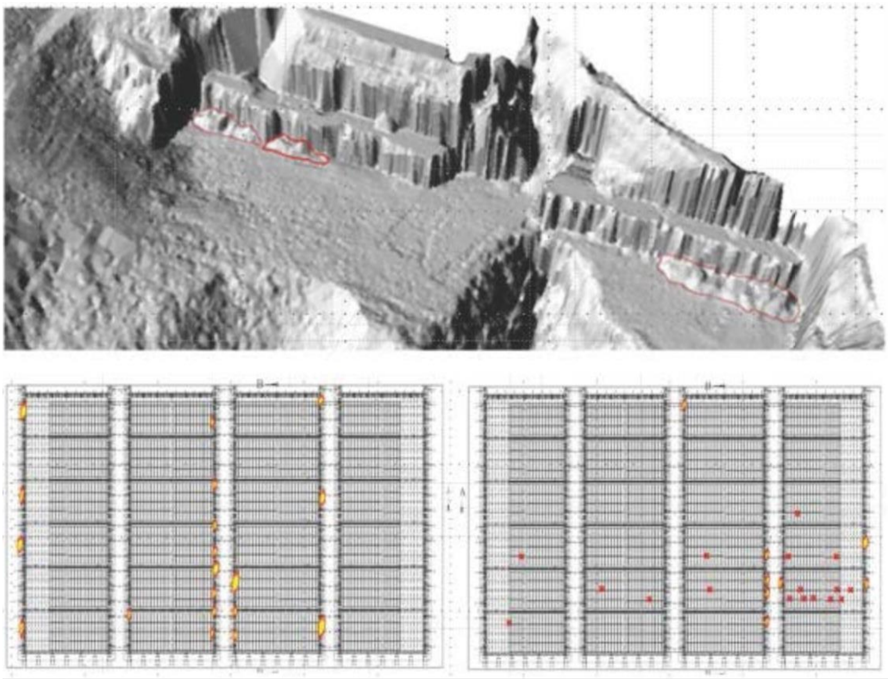


Figure 8: Repair works at Intakes 1 to 4

3.2 Pressure Shafts 5 to 8 (South side)

The area of the pressure shafts 5 to 8 has been affected by important movements that have interested a large portion of the rock mass. The volume of such "disturbed rock mass" (DRM) is currently estimated in the order of about 1 million m^3. Extensive drilling and grouting campaigns have outlined the shape of the DRM shown in fig. 9.

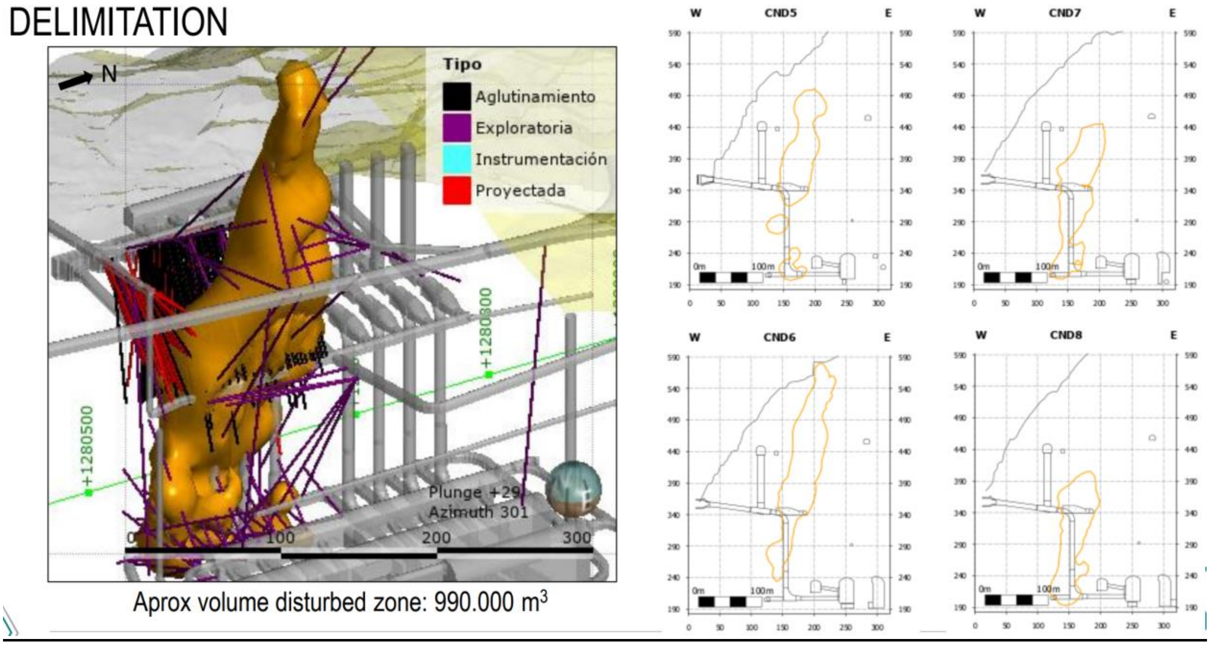


Fig. 9: *Delineation of the "disturbed rock mass"*

The key for assessing the treatment of the DRM requires understanding the status of the rock mass within the zone and that, in turn, necessitates appreciating what was the mechanism of failure.

The surface evidence of the large-scale movements is *El Romerito* landslide, which is in correspondence of the top protrusion of the DRM. Fig. 10 shows the landslide area and the progressive nature of the movements. The figure also shows the two major structural features in the area, the *Mellizo* and the *Tocayo* faults. Underground inspections have revealed movements of the order of a few centimetres associated with *Mellizo* fault.

Shafts 7 and 8 were used, for a period of 7 days (May 12th to 19th) at the beginning of the emergency discharge of May 2018. Those shafts had not been lined yet and, since the beginning of the discharge, intense noises were heard from the depth, clearly indicating that significant collapses were taking place along the waterways. On May 19th, the flow abruptly interrupted and, on May 26th, the gates of shafts 7 and 8 were closed.

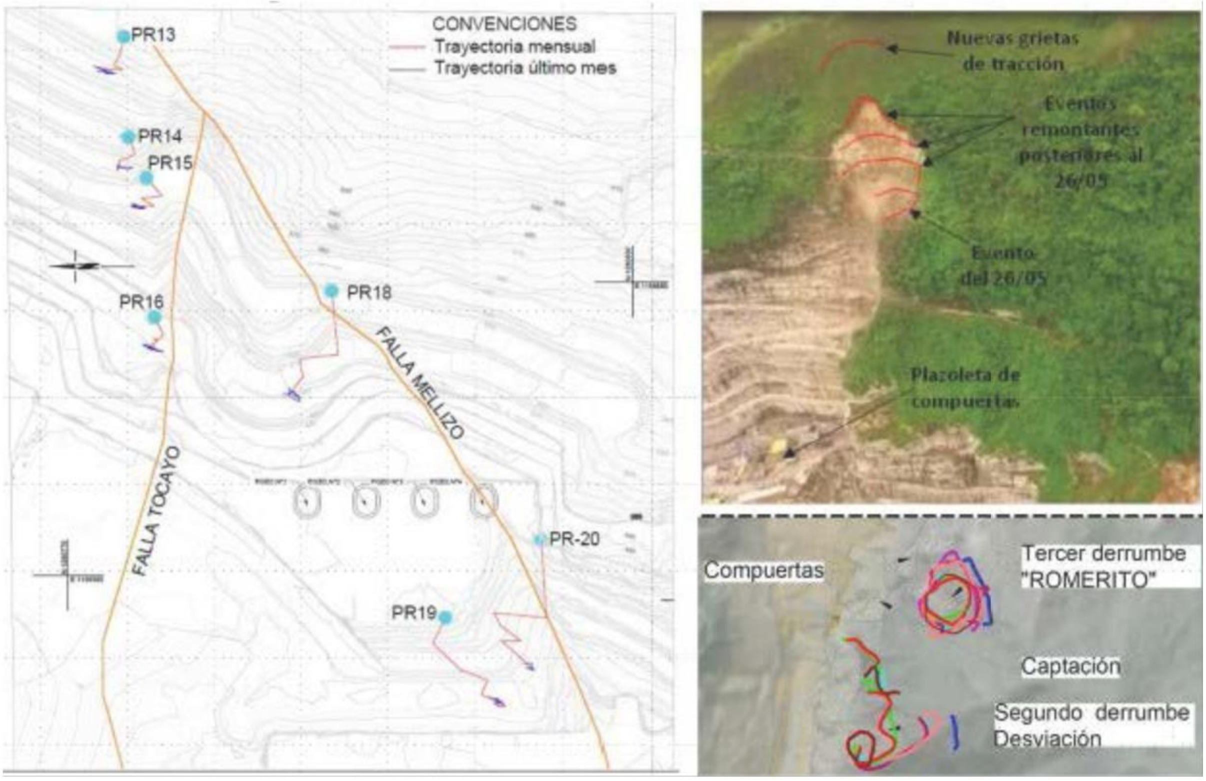


Fig. 10: *El Romerito landslide, located above the top protrusion of the DRM*

It is expected that the intense dynamic actions that occurred in that relatively short period stressed the rock mass and caused a progressive propagation of the disturbance towards the surface. That left behind voids in the lower part of the DRM and in its upper part near the *Romerito* landslide. The rest of the DRM is likely to have experienced dislocations of maximum extent along the Mellizo fault and of progressively reduced extent away from the top and lower portions.

Presence of voids has been evidenced by the extensive drilling and grouting program implemented in the DRM zone. Such voids are expected to be of a much smaller scale of those encountered in pressure shafts 1and 2. Figure 11 shows images of boreholes in which voids are clearly visible.

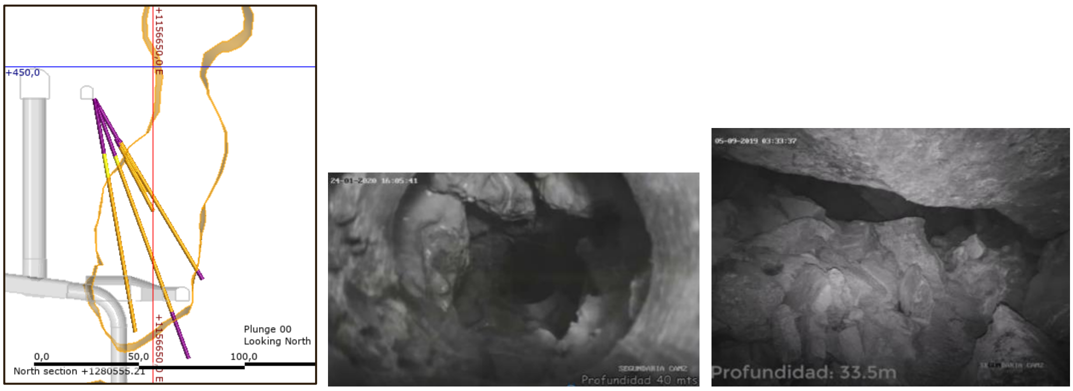


Figure 11: Voids inside boreholes in the area of the shaft 5

Grouting has identified zones of different grout consumption levels[3] (Figure 12). Absorptions above 5 m^3/m can only be associated with large voids, absorptions up to 0.5 m^3/m can be representative of jointed rock mass of negligible or minor disturbance.

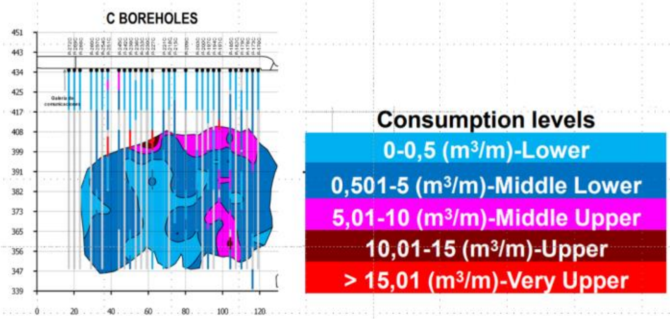


Fig. 12: Grout absorptions in the investigation boreholes

It seems plausible that the mechanism of failure, certainly associated with the dynamic forces during uncontrolled water discharge, can be described as a progressive movement of the rock mass disturbance upwards under the effect of gravity until the effects reached the *Romerito* area and produced the landslide.

The postulated failure mechanism has implications on the nature of the DRM. It is expected that large voids exist in the upper part and in the lower part of the DRM. Such voids are not expected to extend to the rest of the DRM, which should feature various degrees of disturbance, from disintegrated in the vicinity of the voids, to blocky and very blocky, with discontinuities of variable openings: more open in the vicinity of the borders, closer in the inner, vaster, part of the volume. Fig. 13 illustrated a conceptual model of the DRM based on the above considerations.

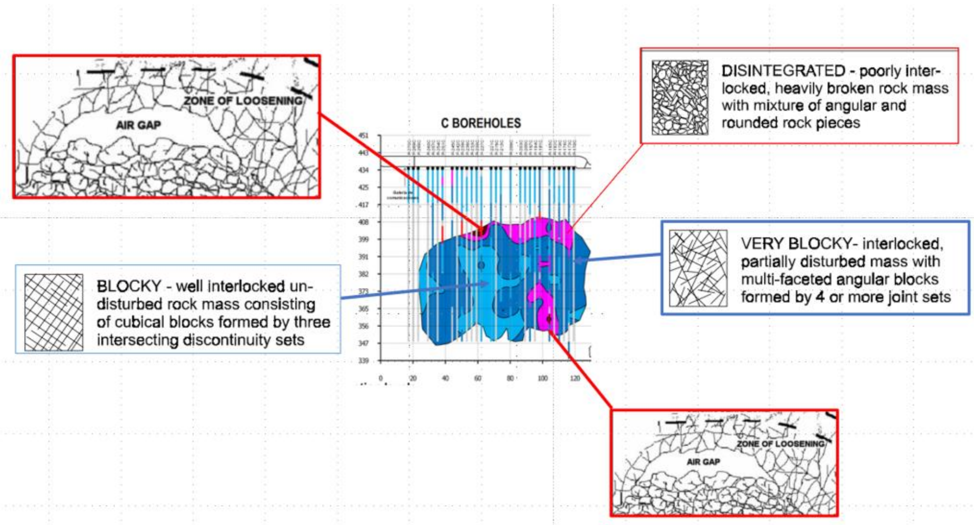


Figure 13: Conceptual model of the Disturbed Rock Mass

[3] When the grout absorptions are converted in cement takes, abnormally high figures are obtained. The IAP believes that the given figures in m^3/m should be revised. However, the given values are useful in relative terms for identifying zones where consolidation grouting measures should be concentrated.

The IAP agrees that grouting is the appropriate solution for treating the DRM, with different technologies:

a) Compaction grouting for large void filling.
b) Consolidation grouting for disintegrated to very blocky zones.
c) Permeation grouting for blocky to very blocky zones.

Techniques a) and b) should be appropriate for the «boundary disturbances» i.e., large voids and disintegrated rock. Technique c) should be appropriate for the DRM's core.

Permeation grouting should be carried out radially, from inside the shaft conduits while they are rehabilitated. Given the inevitable uncertainties associated with the volume of the DRM, the IAP recommends adopting systematic grouting patterns.

To check grouting's effectiveness, a series of geophysical investigations are planned (figure 15). IAP concurs noting that inclined boreholes will also be used. Drilling core will be collected, and water pressure tests performed.

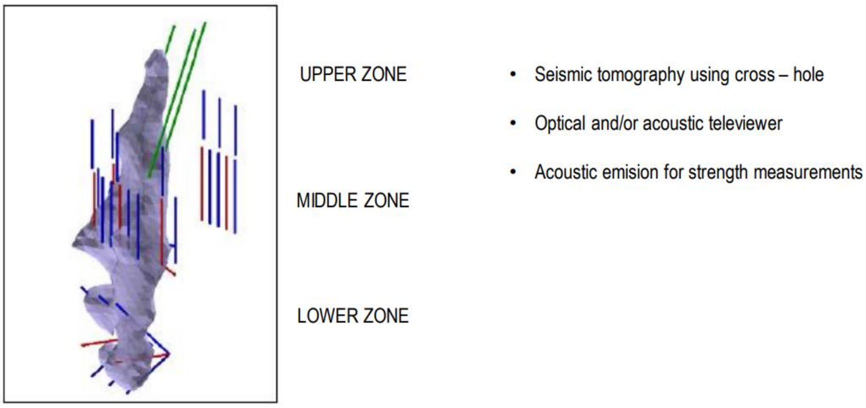


Fig 15: Geophysical investigations planned to assess quality of the grouting works

3.3 Powerhouse and Surge Shaft Caverns Complex

Figures 16 shows progress in the recovery and stabilization of the underground works, compared to the situation in April 2020.

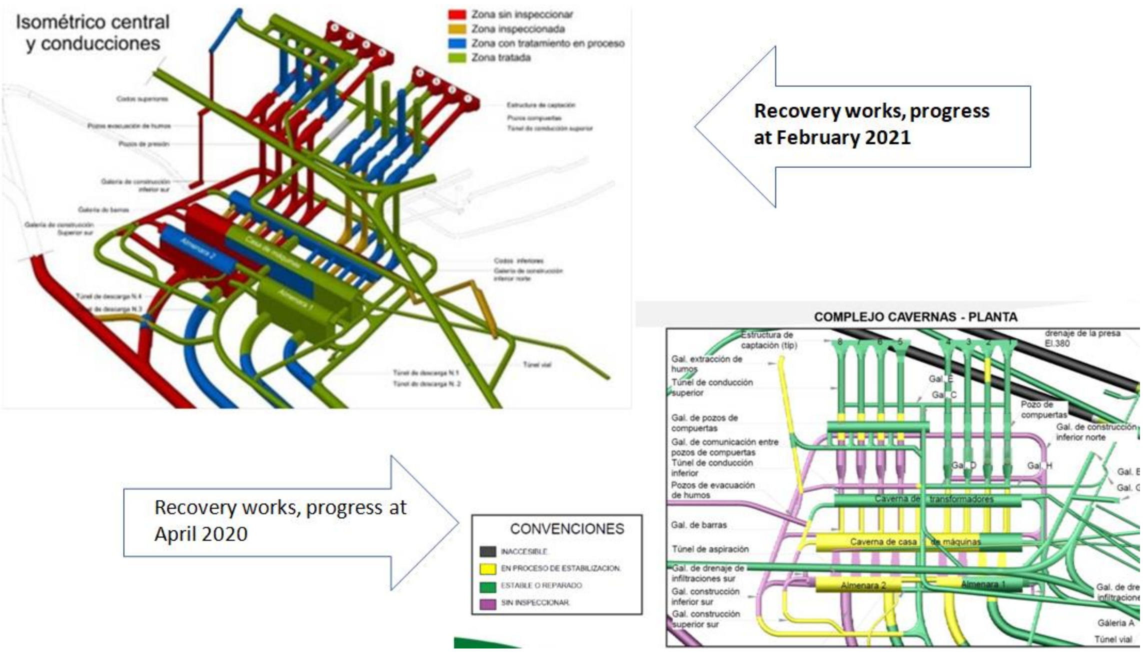


Figure 16: Recovery and stabilization of the work

Figure 17 shows two significative images of the ongoing activities.

Figure 17: Machine Hall, generator level (left) and backfilled North Surge Shaft (right)

The pillar between the surge tank 1 and the power cavern, where a big collapse occurred, has been re-constructed and final treatment works are in progress.

Monitoring is showing equilibrium results. Few localized movements were due to the temporary influence of rehabilitation works and equilibrium was soon regained. Some small deviations at a few instruments are kept under observation.

Water infiltrations continue to be remarkably low, despite the proximity of the reservoir, indicating a very tight rock mass away from the observed cavities. This is a reassuring fact for the long-term stability of the underground complex. The IAP reiterates its recommendation

of drilling pressure relief holes, at several locations around the permanent openings, to rapidly balance any water pressure increase during operation. Due to the tightness of the rock mass, only minor seepage flows are expected to achieve equilibrium.
Observations to date allow to confirm the no progressive failure due to stress re-distribution has occurred. Only several gravitational, structurally controlled failures, took place, few of them of big size. These local stabilities are being treated satisfactorily and voids are thoroughly backfilled with concrete. Mellizo and Tocayo, the two faults present in the caverns area, are not active and therefore they are not expected to affect the stability of the underground works after the implementation of the reinforcement measures.

A finite element analysis of the underground openings has recently been carried out, which provided satisfactory results under static conditions (fig. 18).

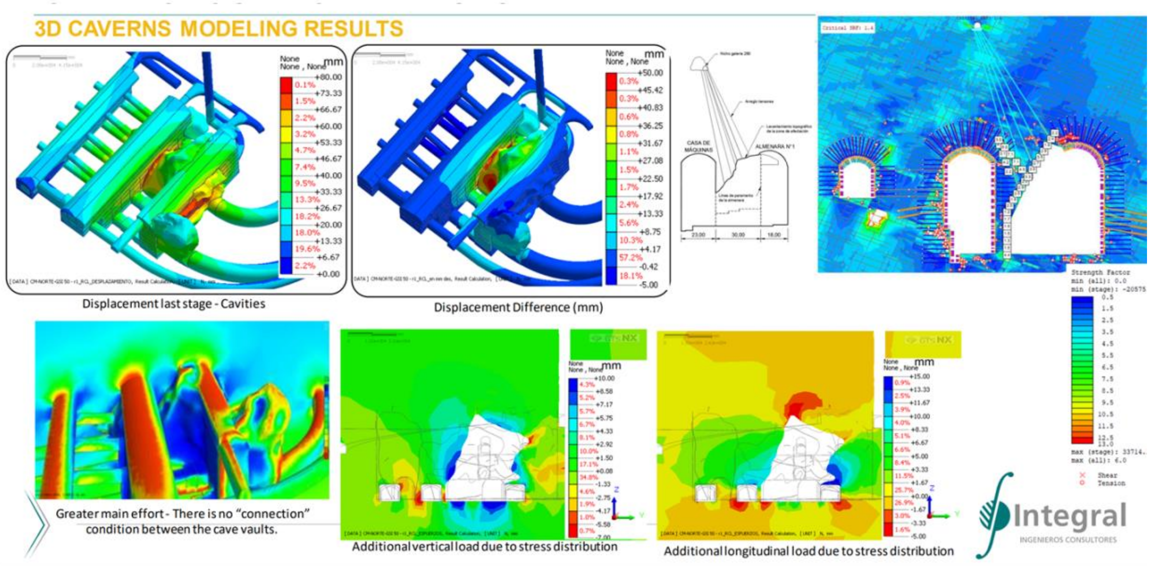


Figure 18: Underground works. Stability assessment

Seismic behavior was also investigated to study shear strains in the rock mass. According to the results shown in figure 19, shear strains increase in the DRM zone, but they do not extend along the surface slope, the faults, and the main underground excavations. This allows concluding that the underground complex is stable under seismic actions.

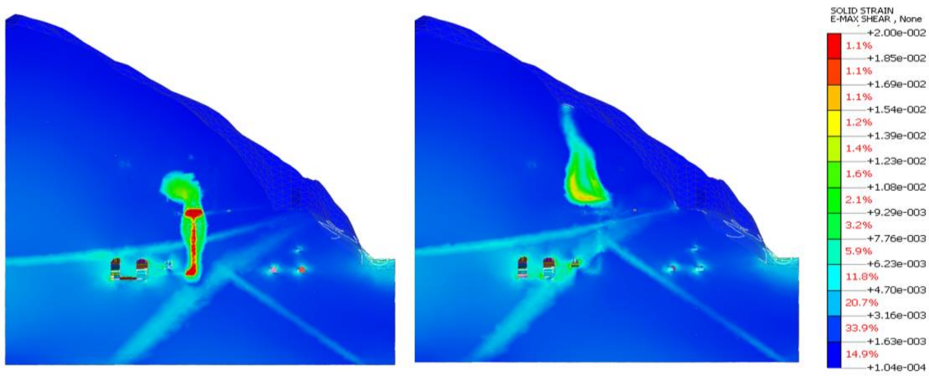


Figure 19: Shear strains in the rock mass under a seismic scenario

Upon completion of the reconstruction works, the underground spaces will be delimitated by sound rock and large-scale concrete backfills. The subject of differential dynamic response of such structures, under earthquake loading, was discussed during the meetings. The IAP observed that, usually, underground caverns do not present such problems because all elements tend to move together. Only isolated structures, such as columns, may be affected. Having said that, given the permanent nature and the size of the caverns, EPM may want to seek the advice of its Board of Advisers about the opportunity to carry out an analysis of induced deformations under seismic actions.

3.4 Intermediate Discharge Gallery (IDG)

No significant geotechnical aspects to report. The scope of the IDG is to guarantee in stream releases when:

- the reservoir is below the spillway level, AND
- generation goes out of operation.

Difficulties of opening the IDG intake, under 140+ m water pressure, have led to the decision to off-take water from higher elevations, along the power intake waterways.
Several alternatives were studied, from which the one that connects pressure shafts 3 and 4 with the IDG was selected (figure 20).

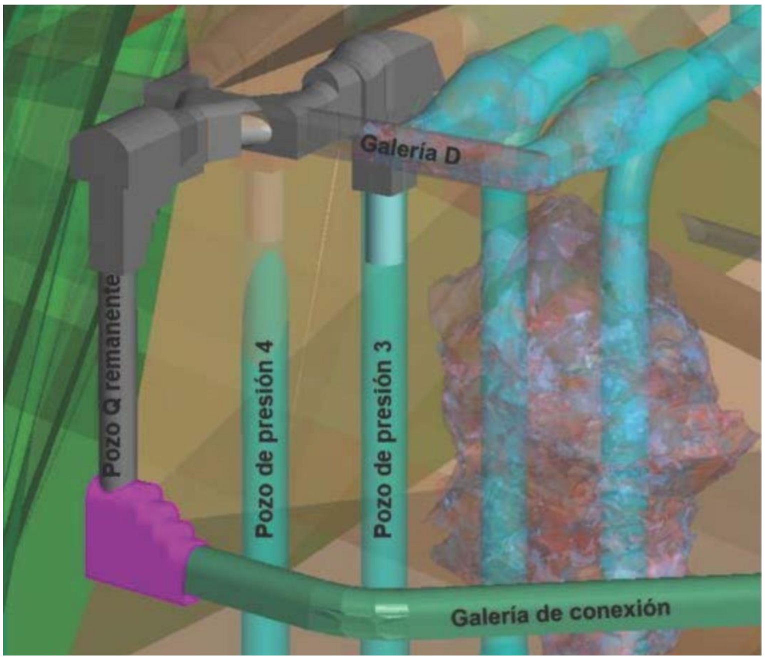


Figure 20: IDG solution adopted from shafts 3 and 4

The solution was studied with CFD (Computational Fluid Dynamic) software to examine the hydraulic behavior of the bifurcations and system junctions. After analysing several configurations, under different operating conditions, a bifurcation with a diameter of 5.4 m was selected. Operation manuals will be developed, and electronic (and/or mechanical) locks will be provided to prevent misoperation.

3.5 Dam

Recorded settlements continue to be very small, lower in comparison to other dams of this type and height. Displacements on the downstream side of the dam are monitored with Interferometric Radar SAR-X. After the end of dam construction, the rates of these displacements tend to decrease over time, and they were never high.

No recordable displacements from satellite monitoring in the July to December 2020 period. Magnetic extensometers show stable vertical settlements. These instruments showed variations below the accuracy range of the devices (2,5 to 10 mm) since the end of dam construction.
The settlement cells and the total pressure cells confirm the good performance of the dam. Calculated and measured deformations continue to exhibit good correspondence.

Foundation piezometers indicate a good performance of the grout curtain, with low elevations of the piezometric line. Variations in the readings of some piezometers at chainage 400 have been attributed to the grouting performed from gallery at el. 250 towards the deep curtain. In the section at ch. 330, two piezometers show levels that would imply a flow in the upstream direction (fig. 21). Since this cannot be real, a check should be done.

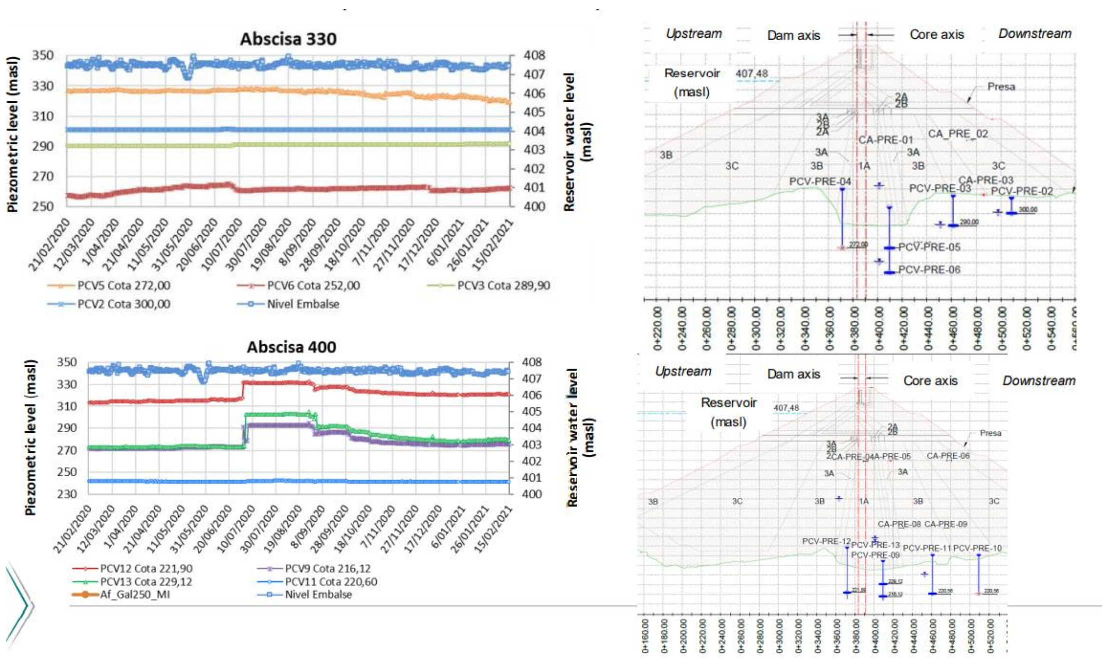


Figure 21: Foundation piezometers

The piezometers in the dam body show good behaviour in relation with the reservoir level (fig. 22). No abnormal changes were observed that could be associated with deficiencies of the transition zone next to the core, or the integrity of the core. An anomaly presented in the readings of one of the piezometers went back to normal (fig. 22). Piezometric readings also indicate good performance of the priority fill (fig. 23).

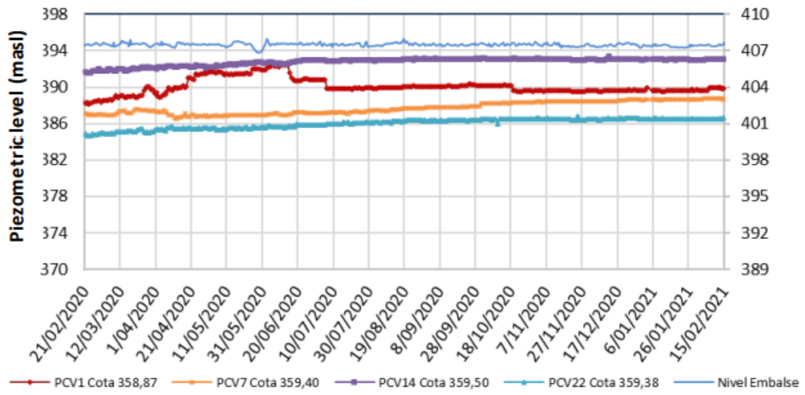


Figure 22: <u>Piezometers downstream of impervious core</u>

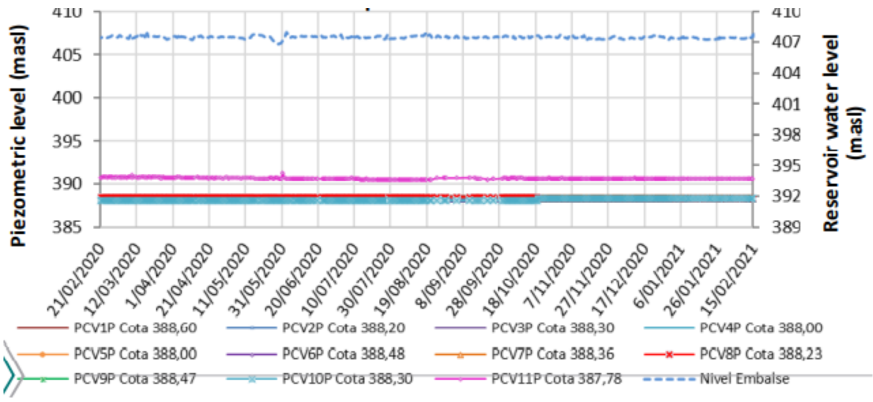


Figure 23: <u>Piezometric readings downstream the Priority Fill</u>

As shown in fig. 24, seepage rates through the dam body are very low. Seepage reduced from 40 to 2.9 l/s after the construction of the diaphragm wall. Another proof of the diaphragm's effectiveness. 2.9 l/sec is the rate recorded on February 23rd, with reservoir level at 407, 31 m. asl.

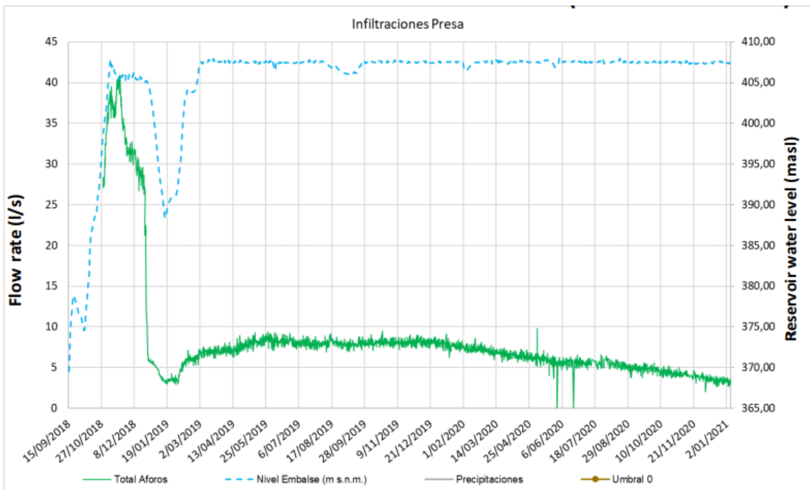


Fig. 24: <u>Seepage rates and reservoir levels</u>

In the left abutment, where additional grouting was undertaken, overall seepage is about 45 l/sec. In the absence of turbidity, the IAP considers the recorded flow acceptable.
In the right abutment, total seepage went gradually up to 100 l/s since October 2020, which is higher than previously reported (fig. 25). The Designer should assess the situation to determine whether additional grouting is required. The assessment should consider the spatial distribution of the seepage locations i.e., localized or distributed.

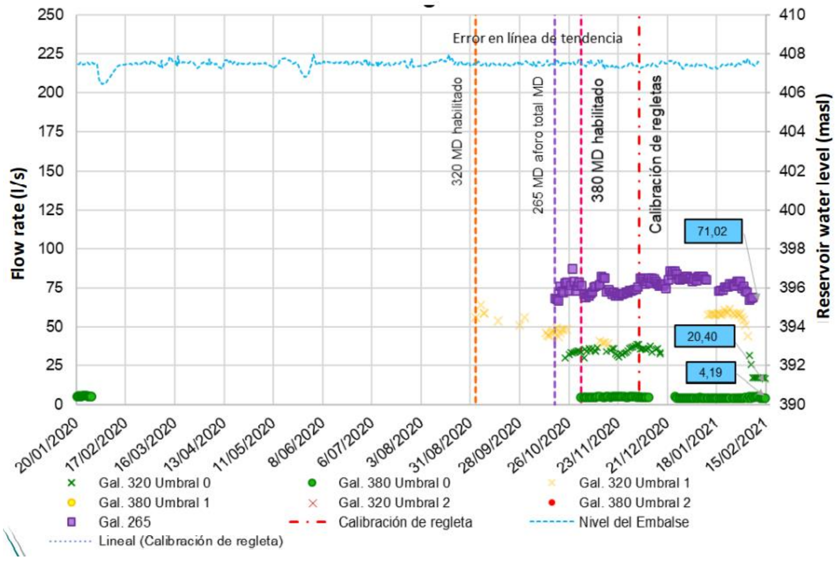
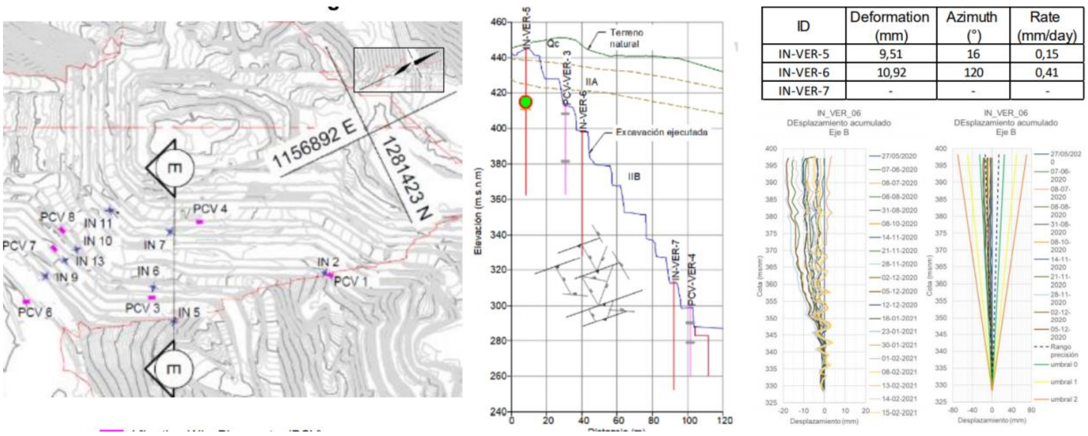


Figure 25: Seepage flows in the right abutment

3.6 Spillway Pool

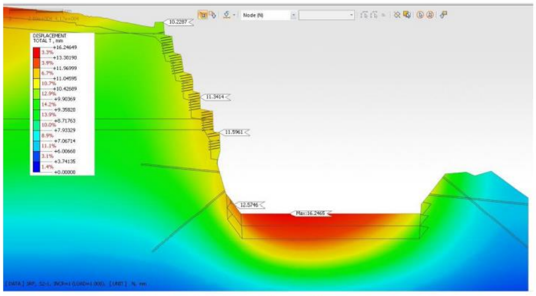
The monitoring system continues showing satisfactory slope performance. The plunge pool's geometry is designed to perform over the life of the project, and there is no evidence of abnormal conditions. From existing data, the rock mass at the pool is sound with few main discontinuities. The IAP concurs with the monitoring programme of the plunge pool's slopes and surroundings, which should be permanent. The displacements from the inclinometers are below those anticipated. The form of movements, shown in some of the inclinometer graphs, cannot be attributed to ground displacement because the movements should not start from the bottom of the inclinometer pipe. They are likely imputable to exogenous reasons (fig. 26).



ID	Deformation (mm)	Azimuth (°)	Rate (mm/day)
IN-VER-5	9,51	16	0,15
IN-VER-6	10,92	120	0,41
IN-VER-7	-	-	-

Figure 26: Plunge Pool inclinometers - Section E

Erodibility and stability analyses have been carried out to evaluate the effects that progressive pool scouring could have on the slopes (Fig. 27).



Desplacements. Scour level 190 MASL

Condition	Desplacement (mm)	Unitary Deformation (%)	Security Factor by SRF
Start operation of stilling (level 200MASL)	16	0,03	2,7
Scour level 190 MASL - Condition of desing	16	0,03	2,8

Resume desplacements, unitary deformation and SFR

Desplacements measure for inclinometers are less to calculated of model of slope stability showed above.

Figure 27: Slope stability- Section B-B

Boreholes drilled in the vicinity of the plunge pool's border do not indicate excessive scouring. Their cores show a good quality rock mass (fig. 28).

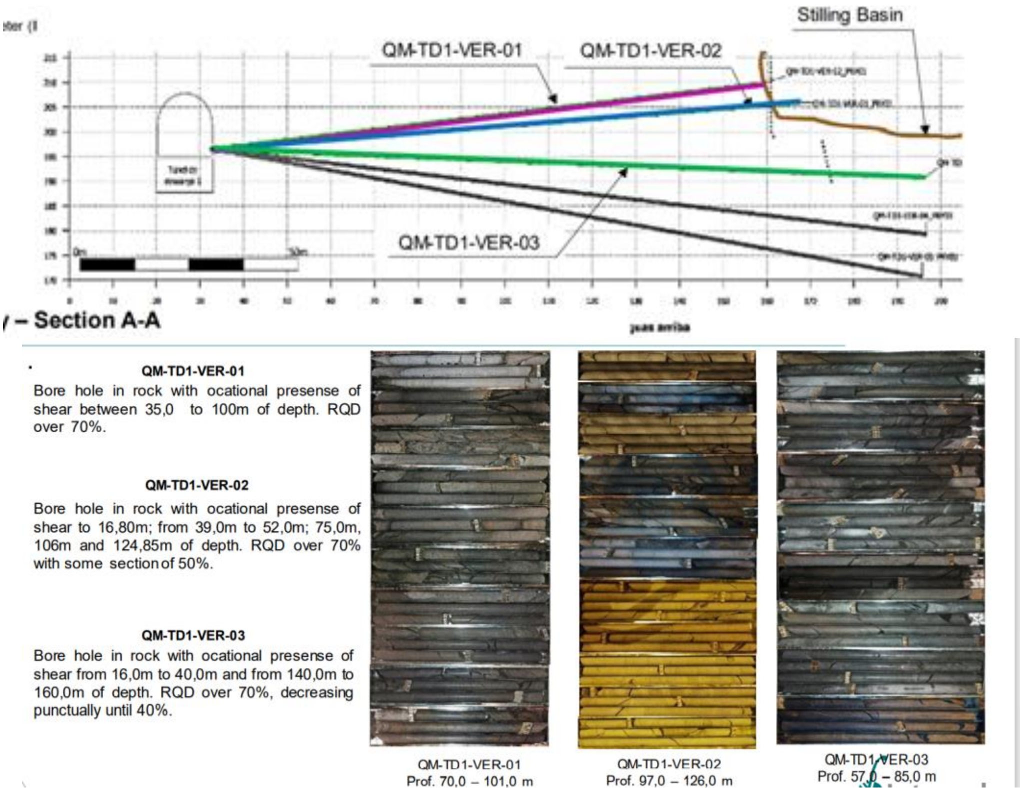


Figure 28: Rock mass quality in the plunge pool area

3.7 Slope stability of the right abutment

This is the slope over the platform of the intakes, including the *Romerito* collapse area. Excavation and stabilization work of the high part of the slope, down to elevation 570, is almost complete (fig. 29). Instrumentation continues to show an overall satisfactory performance of the slope (fig. 30).

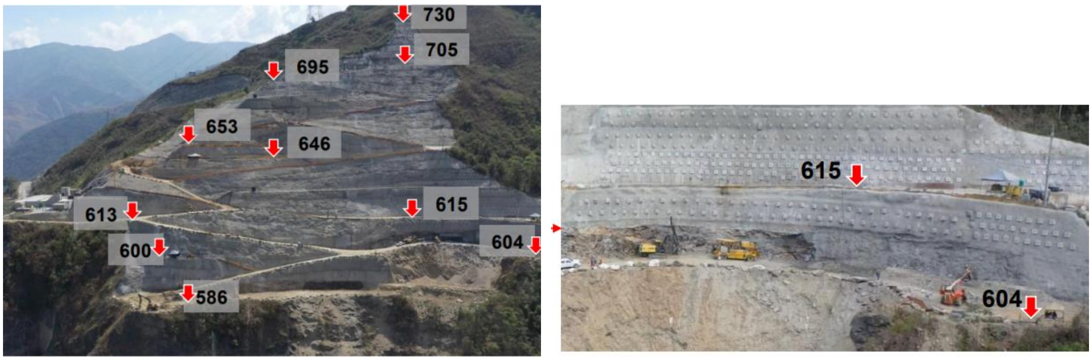


Figure 29: The high part of the slope over the intake's platform

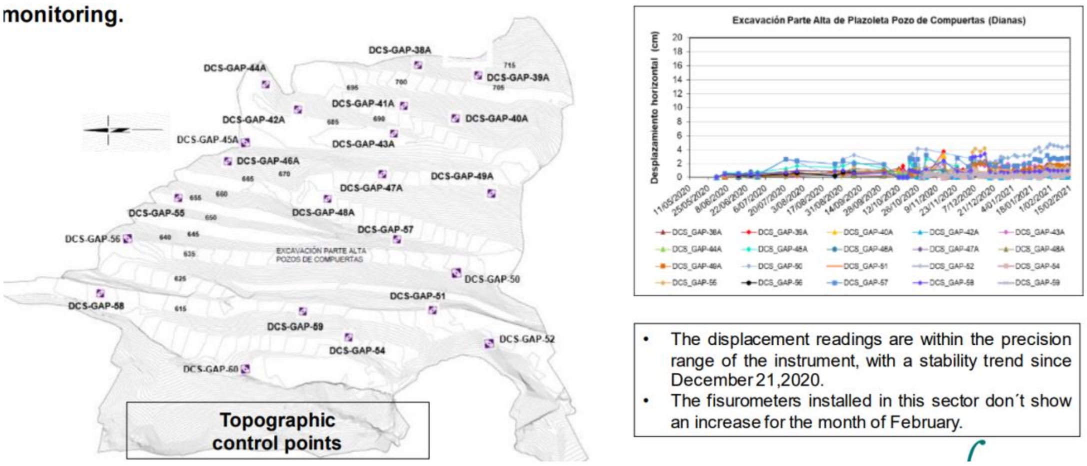


Figure 30: Slope above the intakes. Topographic monitoring

From the available information, the Romerito failure zone does not show any retrogressive evolution of the past events. In addition to anchors, consolidation grouting is contemplated for the reinforcement of the cavity's rim which is characterized by weak rock mass with shear zones (fig. 31). The IAP consider that anchoring can offer effective stabilizing forces, and grouting will provide additional safety. Drainage measures should be provided to limit the access of surface water, from the slopes above, into the cavity's rim.

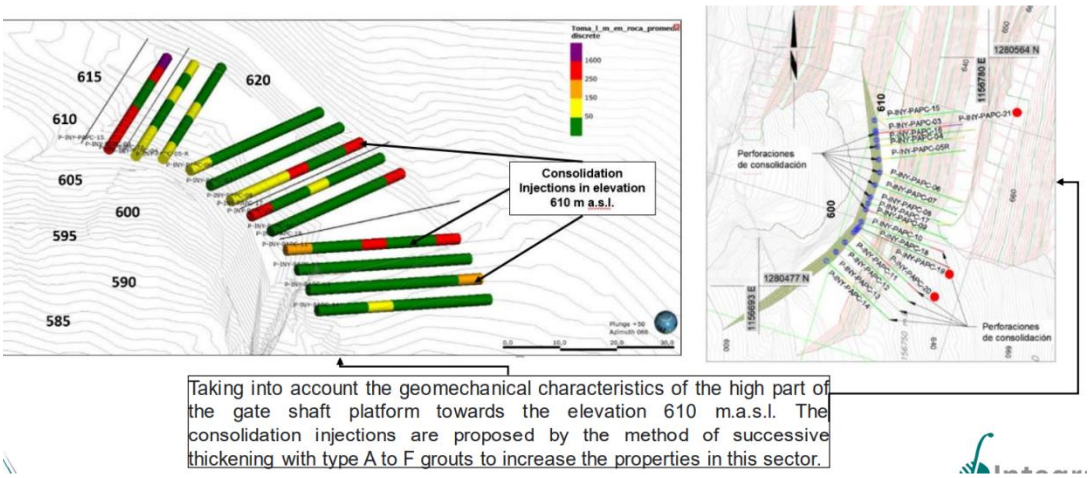


Figure 31: Consolidation grouting of the Romerito's rim

Satellite monitoring of the area showed some accumulated displacements in the lower, upstream part of the slopes (fig. 32). The morphology of this location is not in favor of displacement. Installation of surface monuments is recommended to follow the evolution of the movements.

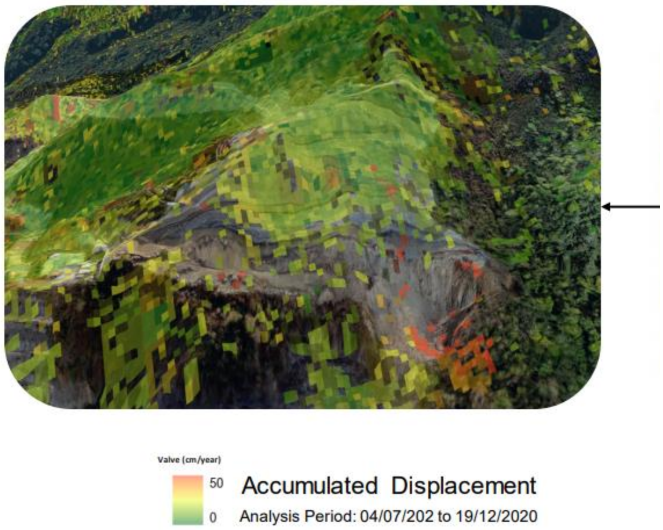


Figure 32: Satellite monitoring, July-December 2020.
Red points represent accumulated displacement up to 4 cm.

3.8 The slope further upstream to the south of *Romerito*

This slope is situated over the diversion works which was disturbed by the landslide in May 2018. The slope shows detachment of surface material from the upper part, left side as seen from the reservoir. These detachments, which correspond to a regression of the limits of the disturbed zone, have been detected by radar monitoring (fig. 33).

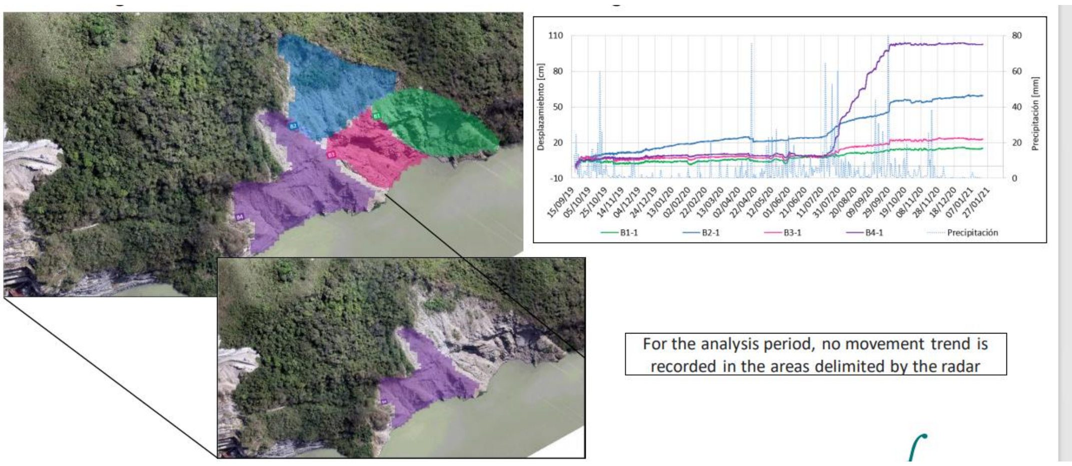


Figure 33: The upstream right-side slope. Radar monitoring.

To prevent progression of these detachments, a belt of anchored welded net and hydro seeding, is foreseen to protect the crown of the disturbed slope (fig. 34). The IAP finds the measures suitable, with the addition of a drainage ditch along the upper limit of the eroded slope.

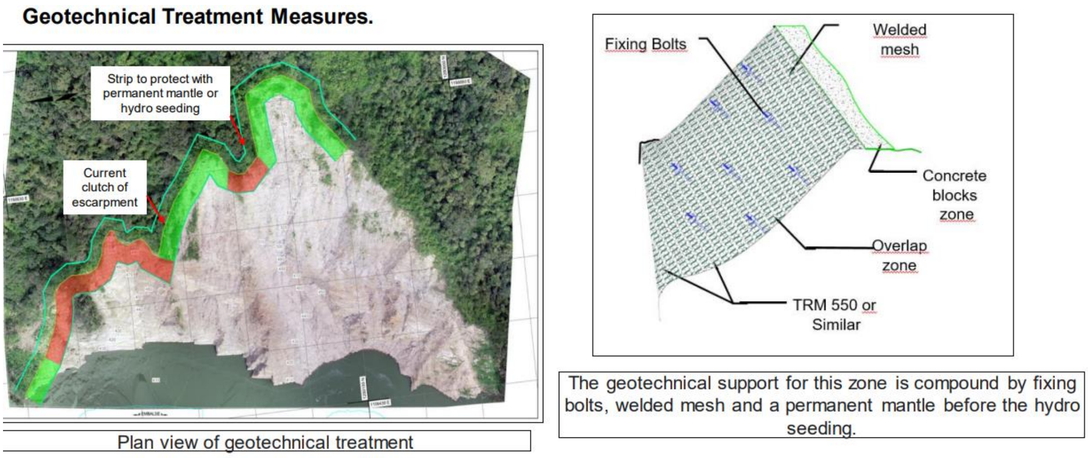


Figure 34: The upstream right-side slope. Treatment measures

Recent radar monitoring shows a stable condition for the whole disturbed mass. However, the presence of concave sections, and satellite monitoring indicating several "red dots", possibly associated with displacements (fig. 35), suggest that erosion could still progress inside the disturbed slope. That could be triggered by a storm and put at risk the entire slope by undercutting it. The IAP recommends that surface monitoring is undertaken with permanent interpretation of measurements.

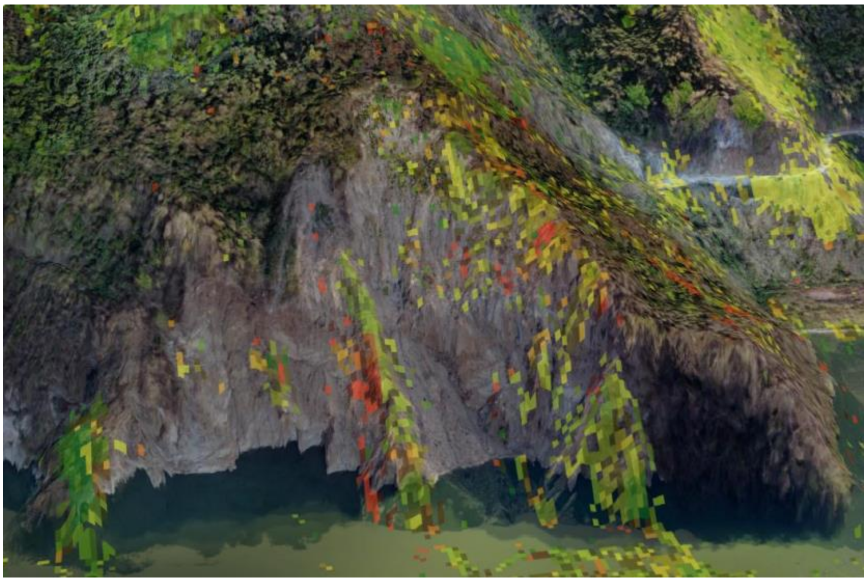


Figure 35: The upstream right-side slope. Satellite monitoring. Red points correspond to displacements.

3.9 Other slope stability features

Site investigation is ongoing between km. 900 and 1+300 of the diversion road on the left side of the reservoir. The beds of the gneissic schist dip into the slope in its high parts, which is a favorable element. At the same time, the morphology of the area indicates a potential for rotational slope failure. The three inclinometers, although relatively close to each other, show big differences of the sliding surface depth: 12 - 24.5 - 45.5m respectively. The few piezometers are reported not to have encountered ground water (fig. 36).

IAP believes that additional instrumentation should be installed, and a parametric stability analysis performed using reasonable soil properties. Surface signs of ruptures/ tension cracks should be mapped.

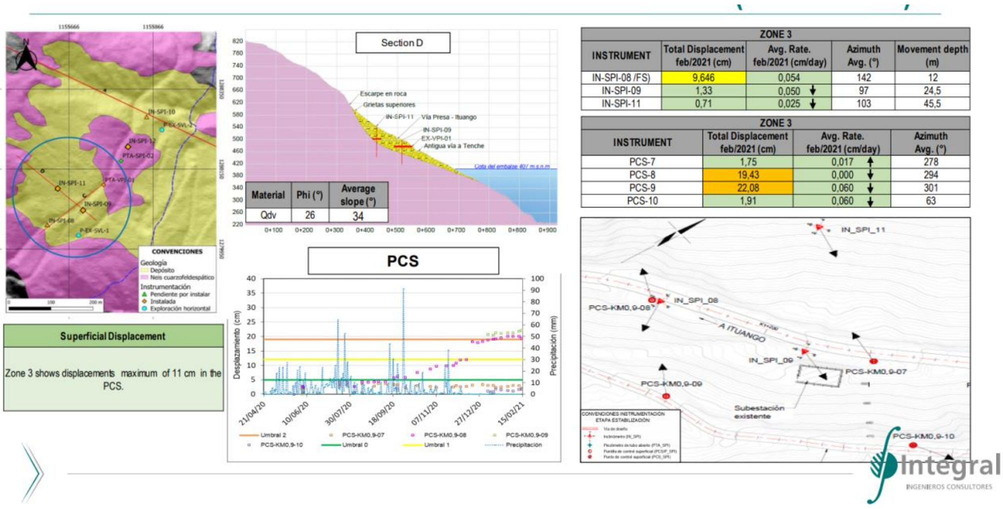


Figure 36: *Left side of the reservoir. Area of questionable stability, 0+900 – 1+300*

The IAP agrees with the ongoing reinforcement measures, that feature the anchoring of the slope over the lower road, which retains the upper one (fig. 37). A drainage ditch to intercept and drain the surface water away from the instable areas, should be foreseen.

Figure 37: Ongoing slope reinforcement works

4. ELECTRICAL AND MECHANICAL EQUIPMENT

4.1 Equipment installed in the cavern complex

During the February 2021 virtual mission, the IAP was enabled to observe, by remote cameras, the conditions of and the ongoing activities in the following areas:

- Transformer gallery (this and cable galleries were extensively visited in September 2019).

- North powerhouse cavern and the northeast part of the South cavern (the north part was physically inspected in September 2019 while the south part was at that time filled with debris).
- North surge shaft (the same north surge shaft and the south surge shaft were visited in September 2019).

A complete assessment of the damages to most of the electromechanical equipment was already available in September 2019 and it was confirmed during the May 2020 virtual mission. All the equipment already installed in the powerhouse's North area, including the mechanical parts embedded in concrete, were considered unsuitable for future operation. That assessment also applied to the step-up single-phase transformers and HV cables, the only components for which a possible recovery was not ruled out in principle. However, an EPM-Insurers joint survey decided for a complete replacement, mostly at Insurers cost. It must be added that the transformers' manufacturer (Siemens) would have not extended a guarantee for any equipment if not fully replaced.

Such decision paid off, because the "*Presupuestos*" for the years 2021 (annex B) show the significant amount received by Insurances (about 1,000 billion COP).

At the time of the May 2020 virtual visit, the transformers were still in place. Now all of them have been removed and the first 4 are already placed in their final positions.

Figure 38: two single-phase transformers 3 and 4

EPM is currently installing the 6 transformers, out of the of the original supply of 25 single phase transformers, which are sufficient for the first two units.

The other 19 are already procured, 7 of them are currently reported to be at the harbour in Colombia while 6 are expected in July 2021 and the remaining 6 in September 2021. Transformers' supply and installation are not on the critical path.

The damaged 11 HV single-phase cables are procured, 5 are already on site and the remaining will follow in the 2nd or 3rd quarter of 2021. Their delivery and installation are not on the critical path.

Figure 39: Ongoing civil works at the cable gallery before installation of cable trays and cables

Figure 40: Ongoing installation of overhead travelling cranes rails supports

The new 2 x 300 tons overhead cranes are already on site; installation of the rail supports is ongoing. The crane will be installed within the end of March 2021 mainly to respect commitment with the financers rather than because they are currently on the critical path. As a matter of facts, in the meantime, EPM is using mobile cranes and a temporary 25 t overhead.

At the end of 2019, the lowest parts of the units 1 to 4 and corresponding first and second phase concretes were finally assessed to be unsuitable for any remedial action. Rehabilitation of units 1 to 4 therefore started from first phase concrete.

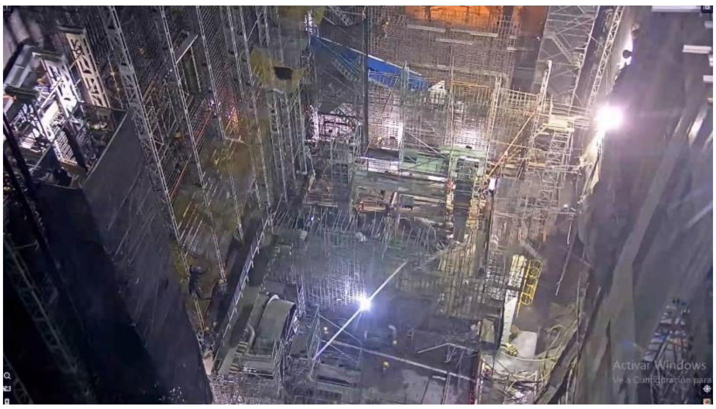


Figure 41: Unit 1 construction and installation activities

Construction and installation activities for Unit 1 are ongoing, though civil works concrete had to start approximately 20 m below the lowest part of draft tube for the cavity that was evidenced after removing the first phase concrete. As a result of the negative assessment of unit 3 and 4, EPM decided to go back to the original sequence for commercial operation, proceeding from 1 to 4. Unit 1 will be the first one to go in operation.

Construction and installation activities for Unit 2 are ongoing, in parallel to the ones of Unit 1, with some delay.

Figure 42: Unit 2 construction and installation activities

In parallel with construction and installation of Unit 1 and 2, EPM is proceeding with the demolition of first and second phase concrete of Unit 3 and 4.

Figure 43: Unit 3 and 4 demolition of concretes

Figure 44: Loading bay and access tunnel seen from South Powerhouse

To implement activities in parallel, EPM is using the bays of unit 5 and 6, temporarily backfilled, as additional loading bays.

Figure 45: Loading bay and unit 5 and 6 bays utilised as additional loading bays

EPM decided to replace the original reinforced concrete structure of the Control Room with a, faster to build, steel structure (fig. 46).


Figure 46: Civil works on the area of Control Room North

Fig. 47 summarizes the scope of supply of GE contract which has the objective of reintegrating the electromechanical equipment lost with the contingency.

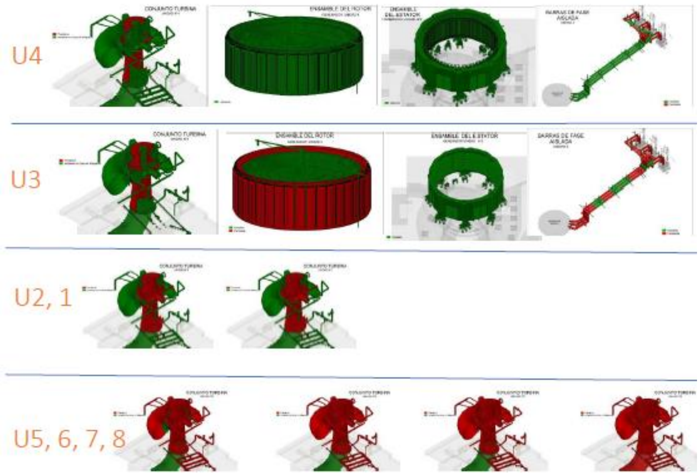


Figure 47: Scope of supply of GE contract

Most of the electromechanical equipment of units 5-8 are present in EPM's warehouse and delivery of the draft tubes is expected on time. It is therefore possible to affirm that, as of February 2021, the supply and delivery to site of electromechanical equipment for the installation and commissioning of Unit 1-4 is secured and that they no longer represent an issue for the project.

The following two pictures show progress in the draft tubes of Unit 1 and 2, which is the only ongoing electromechanical installation.

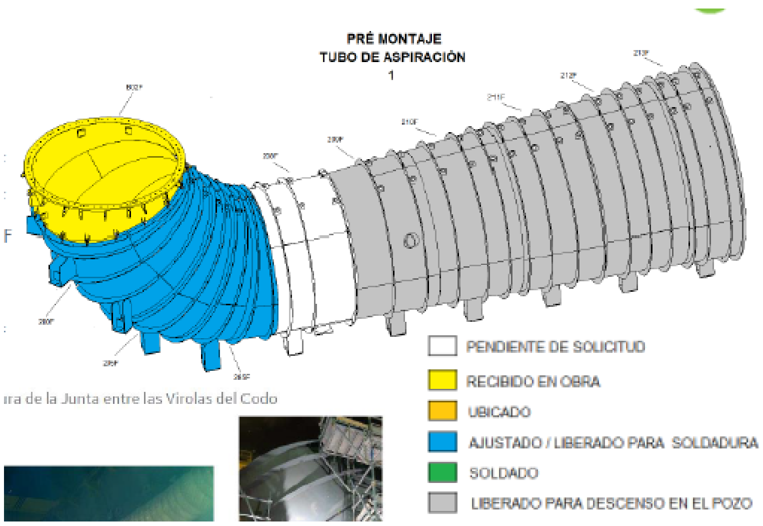


Figure 48: Unit 1 Draft tube (the grey portion is already in place)

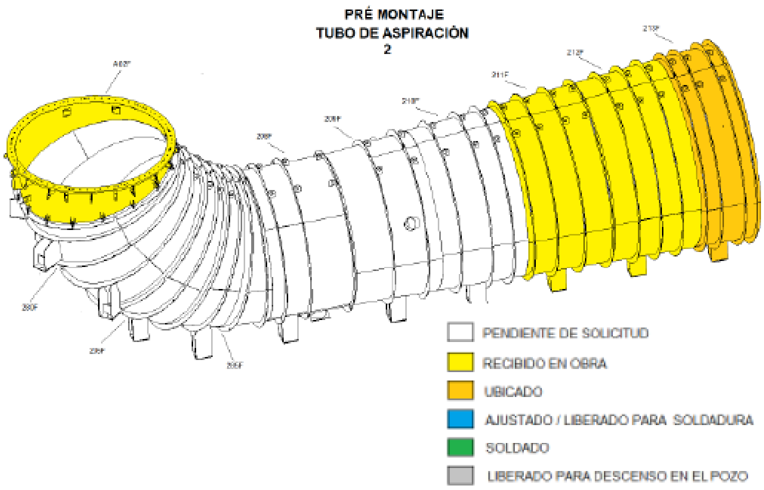


Figure 49: Unit 2 Draft tube

The installation of the guides of the draft tube gates is also in progress (fig. 50 and 51).

Figure 50: Ongoing installation of the guides of draft tube gates in the North Surge Shaft

Figure 51: Draft tube gates (archive, picture taken before May 2018)

4.2 Summary of the procurement progress

IAP report N. 4 detailed all the orders placed as of May 2020, for re-establishing the entire electromechanical supply of Ituango. In December 2020, several remaining contracts were signed, namely for the draft tube gates (with ATB), cooling and drainage systems, ventilation and air conditioning and firefighting system.

In the same month of December 2020, the additional packages were advertised, namely: LV and C&I cables, cable trays and conduits, powerhouse lift.

4.3 500 kV GIS switchyard

The 500 kV switchyard is completed. Several HV power cables and most of the power and control cables, coming from the power plant, will have to be reinstalled. The cable gallery and its connections with the 500 kV GIS switchyard are in good conditions. Stabilization works were carried out in the slope above the switchyard area (fig. 52).

Figure 52: The stabilization works [switchyard on the bottom left corner – archive]

4.4 Power Intakes Gates

Activities on the Intake gates and their operating systems are reported to be almost completed.

Fig. 53: Intake gates: Installation of final lighting in the external area

The following table summarizes the IAP's remarks on the Intake gates.

Hydro Mechanical Equipment	Progress of installation and testing	Remarks
Intake Gates Height Sliding Gates, 5.03 x 6.87 m, with stoplogs. Operation: oleo dynamic servomotors.	The area is now safely accessible, and an additional physical protection is installed above pit and control box of Unit 1 to 4. Installation almost completed.	Gates close under balanced pressure conditions and, in emergency, under the maximum hydraulic head and the rated flow of the Unit. However, it was demonstrated their capability to close under flow higher than the rated one.

4.5 Steel lining to vertical shafts and lower elbow

The original design foresaw steel lining only on in the horizontal section of the penstocks between the lower elbow and the spiral case of the units. The large cavity in the area of pressure shafts 1 and 2, forced to extend the steel lining to the entire shaft lengths. In the meantime, the steel lining of the lower elbow of unit 1 and 2 became accessible and repair started.

Figure 54: Lower elbow: steel lining repairing

Figure 55: Lower elbow: steel lining testing

Figure 56: Lower elbow: steel lining element manufacturing

The adoption of a self-standing, ductile, steel lining was recommended by the IAP. EPM acted rapidly, to avoid schedule delays in commissioning, and signed the corresponding contract in 2019.

Activities proceeded relatively smoothly, the workshop is already completed, trial production is ongoing and, notably, all steel plates for manufacturing the penstocks are already on site.

Figure 57: ATB workshop completed

Figure 58: One of the first steel lining section tested and ready to be installed

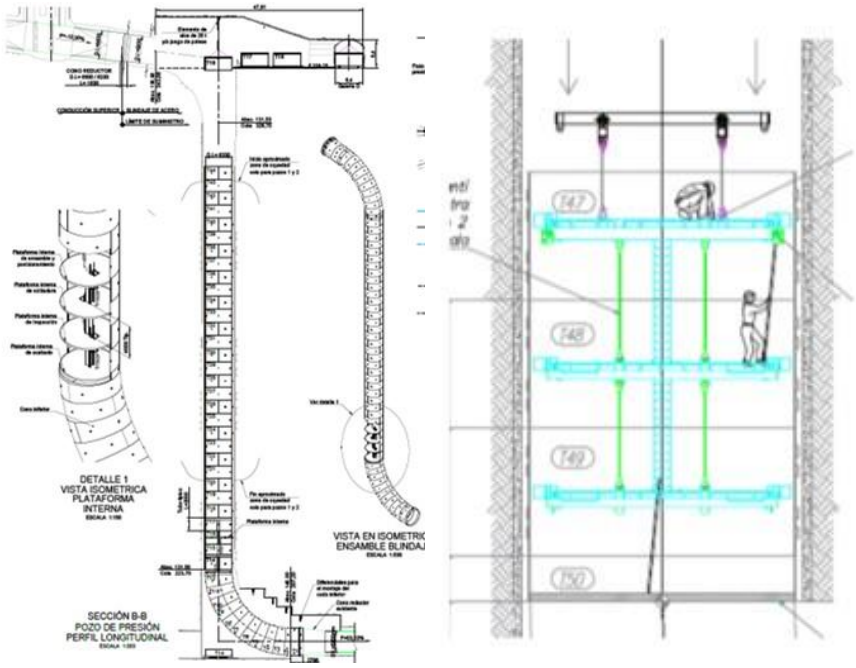


Figure 59: Penstocks installation method (Left) - Installation platform (Right)

4.6 Gates of the GAD

The two GAD vertical sliding gates were successfully lowered in February 2020. A concrete plug was placed on the top of the gates to block any movement (with such installation the tunnel is currently technically plugged) and the lifting systems and cranes were removed. Two temporary by-passes are installed to alleviate the reservoir pressure on the gates and to further increase safety when the permanent plugging of GAD will be built. One by-pass is direct (currently operated), the other is routed through the IDG (it will be operated at the time of plugging the GAD). After successful plugging of the GAD, the gate control chamber will be abandoned.

Figure 60: GAD gates in their final position with temporary direct by-pass system (left) and through the IDG (right)

4.7 Spillway and IDG Gates

The following table summarizes the IAP's brief remarks on the Spillway's and IDG's gates. EPM did not report any operation problems for the equipment already installed and operated.

Hydro Mechanical Equipment	Progress of installation and testing	Remarks
Spillway Gates Four Radial Gates (two with flap for debris) 15 m x 19,50 m Cumulated discharge capacity: 22.600 m^3/s (PMF) Operation: oleo dynamic servomotors, single control and oleo dynamic stations for each gate + common control	Already in operation, testing and common control completed. Diesel generator testing completed.	The position of the diesel generator building. In case of earthquake, rocks may fall from the slope and hit the building. Risk assessment is recommended. Statistics show that reliability of diesel generators in case of exceptional events is lower than expected.
Gates to intermediate Discharge Gallery Two Radial Gates + two Emergency Sliding Gates Size: 3 m x 3.90 m (Radial Gates) Setting capacity: 750 m^3/s with both gates in operation for all reservoir elevation higher than 350 m a.s.l. Operation: oleo dynamic servomotors, single control and oleo dynamic stations for each gate.	Already in operation conditions, testing and control completed. Steel lining installation duly completed.	The expected operating conditions i.e. 450 m^3/s may be reduced by the Environmental Authority.

5. PROJECT COMPLETION- SCHEDULE AND COST IMPLICATIONS

5.1 Progress of underground works' recovery

The scheme shown in fig. 61 provides a snapshot of the progress of the repair and recovery works in the powerhouse cavern complex. The following can be observed:

- Intakes 1 and 2 still require complex completion works (red).
- The rest of the waterways and underground structures associated with units 1 and 2 have been repaired/ recovered (green) or are in the process of being stabilized (blue); selected portions were re-evaluated for additional treatments.
- The transformer hall, reported as fully recovered a year ago, is undergoing additional treatments (blue).
- Recovery works pertaining to units 1 and 2, are behind schedule because voids were encountered in the draft tube area, that had to be excavated and backfilled.
- The waterways of units 5 to 8 have not yet been inspected and repairs are underway in the underground structure of the South part of the plant.
- Treatment of the pressure shafts to units 5 to 8 is ongoing and it is anticipated to be of significant extent.

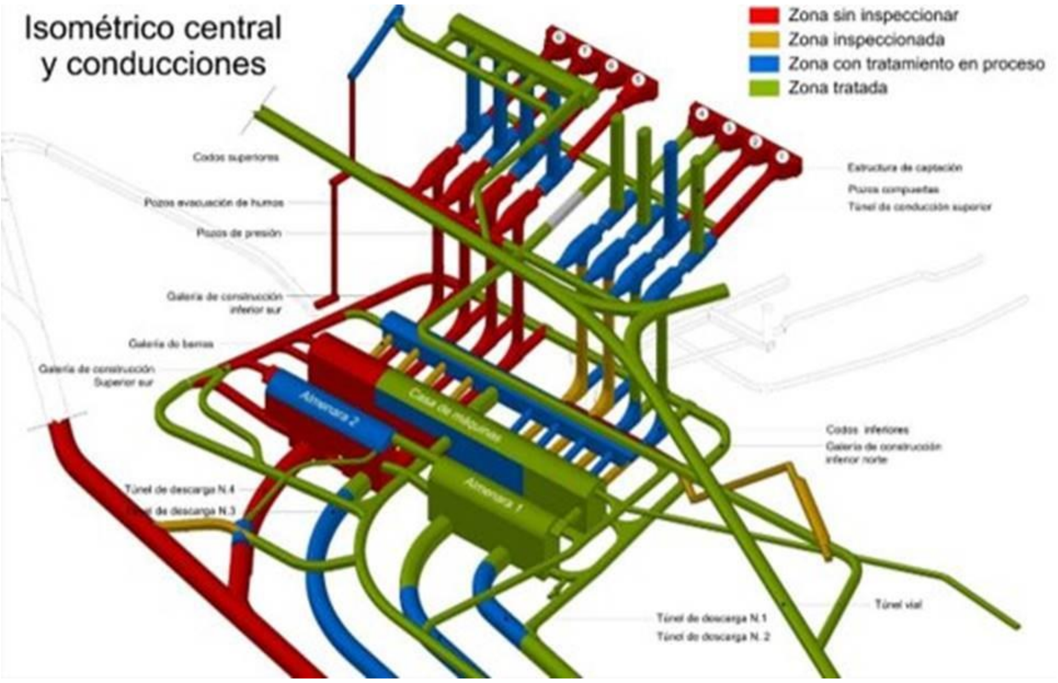


Fig. 61: <u>Recovery of underground works, progress overview as of February 2021</u>

5.2 Achieving Commercial Operation

The official schedule made available by EPM was transmitted to the IAP on March 30, 2020 and it was substantially a pre-COVID19 schedule for Colombia. A subsequent interim revision dated April 2020 was approved after the completion of IAP mission and subsequently transmitted to IAP. The current official schedule refers to December 2020. The following table compares the commercial operation dates (COD) contained in the schedules of March and December 2020, respectively.

Commencement of Operation dates (COD) - comparison			
	COD in March 2020 schedule	COD in December 2020 schedule	Accumulated delay (months)
Unit 1	December 2021	July 2022	7
Unit 2	April 2022	October 2022	6
Unit 3	July 2022	January 2023	6
Unit 4	October 2022	September 2023	11

The importance of the delay accumulated in the period among the last mission and the current one deserves comments.

COVID-19 had a negative impact on the project in two ways. It affected the activities on the critical path through suspension / reduction of the works. It also affected the maximum effort EPM was able to make on parallel fronts to introduce social distances to safeguard workers' health. That certainly reduced the logistic capacity of the project and production rates. The latter is, in IAP's opinion, the main reason for the disproportionate delay accumulated for the completion of Unit 3 and 4.

The effort to treat the voids discovered below the area of draft tube 1 and 2 directly affected the critical path for achieving Commercial Operation of Unit 1.

EPM's cautionary approach, constantly and comprehensively prioritizing safety and long-term sustainable operation of the project, contributed, though marginally, to the delays. Commencement of operation of Unit 1 is currently scheduled in July 2022, that means about 18 months from now. The IAP considers such period realistic for executing first and second stage concrete, erection, commissioning and testing of Unit 1.

The level of investigation and understanding of the damages and the remedial measures implemented in the section North of the project is currently so advanced that additional surprises are unlikely.

Current uncertainties on the dates for commercial operation of units 1 to 4 can be summarised as follows.

- The underwater activities to complete and rehabilitate the intakes, which are intrinsically complex.
- The horizontal bends of tailrace tunnels 1 and 2, where treatments are still in progress.
- The consequences of COVID-19's variants that could jeopardize the remarkable efforts and achievement of EPM in this domain.
- The EPM's decision to introduce "discontinuities" in the group of companies involved, currently and since the beginning, in the project, that normally does not pay off in similar circumstances.

At the same time, there are some items that have positive impacts on achieving the Commercial Operation of Unit 1-4.

- Equipment is present in the warehouses to guarantee the commercial operation of the first four unit (and the few remaining items will follow soon).
- Having GE Brazil directly involved in the erection of the first four units is a plus.
- Having ATB directly involved in the manufacturing at site and installation of the penstock is another plus.

5.3 Cost implications of the completion schedule

In the present report, the IAP decided to examine in some more detail, then done before, the subject of costs to completion because of the relevant information acquired to date.

We limited our analysis to the values of "*Inversiones*" (investment costs or capital investments- CAP), for the following reasons:

- CAP represents over 80% of the total project cost.
- Estimating the additional cost items (pre-operation, IVA, insurance payments) would require a deep insight on Project's accounting, which is beyond the IAP' scope.
- CAP estimates can be further refined, should that be necessary, using priced bill of quantities of the works.

It is important noting that, due to the fluctuations of the USD/ COP exchange rate, it is challenging to derive reliable figures in double currency. We have therefore made use of COP values only, without converting the figures into USD.

We used the following information:

- P2021: *Presupuesto* 2021, shared during the current mission.
- P2020: *Presupuesto* 2020
- P2019: *Presupuesto* 2019

Such information is shown in Annex B.

Fig. 62 shows the investment costs ("Total Inversion"), in the period 2016-2025, as contained in the three "*Presupuestos*".

	million COP		
Year	PR2019	PR2020	PR2021
2016	1,330,392		
2017	1,738,149		
2018	1,392,535	1,455,697	
2019	1,048,991	1,067,559	
2020	882,622	1,254,602	
2021	465,501	869,198	1,554,893
2022	278,995	350,383	768,898
2023	231,247	162,427	283,784
2024		70,593	88,262
2025			30,053

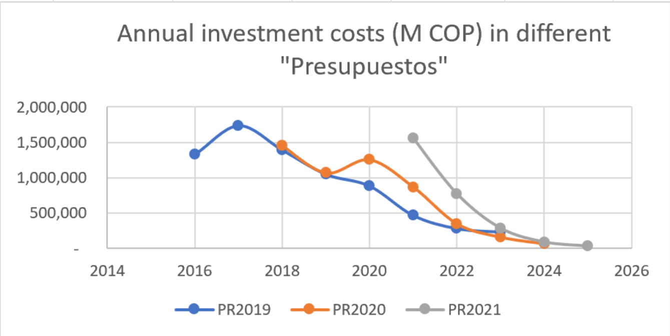


Figure 62: Annual investment costs

Plotted values show a progressive increase, after the year 2019, from P2019 to P2020 to P2021. That clearly reflects the impact of the May 2018 event and should be taken in consideration when deriving cumulative costs.

In May 2018, the Project was in a very advanced state and, had the event not occurred, completion costs would have been minor. It is therefore reasonable to use the costs of years 2019, 2020, and 2021 to estimate the impact of the May 2018 event on the Project's investment costs. The sum of those costs (P2021, annex B) gives 3,877,054 M COP[4], which is

[4] 1,067,559+ 1,254,602+ 1,554,893= 3,877,054 M COP

in excellent agreement with the "*Total Inversion Contingencia*" in fig. P2021 i.e., 3,873,202 M COP.

Cumulated costs are derived in fig. 63, using the most updated annual costs, among the three "*Presupuestos*", in each year. The pre-2016 costs (4,276,267 M COP) have been added in fig. 66. They have been calculated as the difference between the 2011-2020 investment costs in C2021 in annex B (10,668,956 M COP) and the sum of the 2016-2020 costs in the same C2021 (6,392,689 M COP).

Year	PR2019	PR2020	PR2021	Cumulative	Scaled up
pre 2016	4,276,267			4,276,267	4,276,267
2016	1,330,392			5,606,659	5,606,659
2017	1,738,149			7,344,808	7,344,808
2018	1,392,535	1,455,697		8,800,505	8,800,505
2019	1,048,991	1,067,559		9,868,064	9,868,064
2020	882,622	1,254,602		11,122,666	11,122,666
2021	465,501	869,198	1,554,893	12,677,559	12,677,559
2022	278,995	350,383	768,898	13,446,457	14,261,989
2023	231,247	162,427	283,784	13,730,241	15,649,660
2024		70,593	88,262	13,818,503	15,979,942
2025			30,053	13,848,556	16,014,696

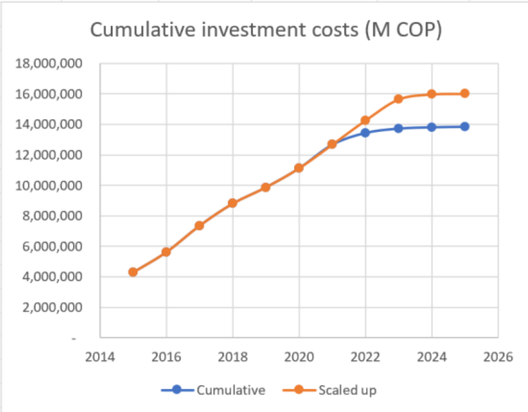


Figure 63: Annual and Cumulated Investment Costs

Observing the plot of the cumulative investment costs, one notes that the curve is practically flat after the year 2022 (blue line). The IAP disagree with that because:

- important civil works remain to be done which are characterized by appreciable uncertainties, and
- a flat curve is at odds with the differences in progressive cost estimates shown in fig. 62.

We believe that the orange curve ("scaled up"), with a cumulative investment cost of about 16,000 billion COP, represents a more realistic assessment of the investment costs to Project completion.

The results of the above analysis, and the inevitable uncertainties therein, make the IAP believe that, at this stage of the Project, a reflection on schedule and cost review is in order.

Since the beginning of its involvement, the primary objective of IAP's advice to IDB Invest has been on safety and sustainability of the Project. The subject of schedule and cost reviews has been included in IAP's reports because of its relevance to safety and sustainability of the Project.

The IAP believes that, given the current timeline to Project's completion, and the increasing importance of securing adequate resources to that end, a more detailed review of cost and schedule becomes necessary. That would likely require more frequent interaction with EPM's cost controllers.

ANNEX A: LIST OF DOCUMENTS MADE AVAILABLE TO THE IAP

01 - Ituango Informe ejecutivo mensual enero 2021 JV
1_220221_BID_TDD_GAD_DI
2_220221_BID_Ob_Sup SPILLWAY
3_220221_BID_Ob_Sup_Romerito_Des_0+900
4_220221_BID_CAVERNS
6_220221_BID_Dam
7_220221_BID_RFDS
24-02-21_BID_ Additional pics_Southern caverns
210227_BID_AfectacionSur
210227_BID_ZonaSur_CondicionPrevia_2004
BID RISK PRESENTATION 2021
Conductions Caverna Sur 2021-02-22
Cronograma Finalización Ituango 2021-02-18
Estado medida preventiva Feb2021
Hallazgos IAP misión 2021-02-25
Informe de seguimiento Obras BID- EPM JAT JIB
INFORME No. 26 - FINAL - 21 ENERO. 2021
ITUANGO - Costos Proyecto 2021
Ituango - Premisas cronograma versión 20201230 (A)
Ituango - Presentacion cronograma en barras 20201230 – BID
Ituango - Programa Base estabilización 20201230 (mpp)
Ituango Blindaje proceso logistica montaje_V1
ITUANGO-Costo ppto 2021 y comparación costo ppto 2020
ITUANGO-Evolución inversiones 2016 - 2021
Lechadas Consolidacion C.M - Almenaras-2
Mezclas concretos aglutinamiento
PRESENTACIÓN BID DE AMB4 GE_V1_FEB_24_DE 2021
Presentacion POYRY 20210224
Underground_Numerical_Model
UNDERTWATER WORKS PRESENTATION (BID)

Annex B: “Presupuestos” of the years 2021, 2020, and 2019

P2021

	CONCEPTO	TOTAL	2011-2020	2021	2022	2023	2024	2025
1	**Ingenieria y administración**	**2,170,718**	**1,626,003**	**334,131**	**108,512**	**44,055**	**34,412**	**23,605**
1.1	Estudios y diseños	53,963	53,963	0	0	0	0	
1.2	Interventoria	318,188	305,387	10,482	2,319	0	0	0
1.3	Interventoria-contingencia	283,473	151,283	87,475	44,715			
1.4	Asesoria	200,814	193,531	5,278	1,189	430	230	156
1.5	Asesoria-contingencia	251,552	162,212	84,341	1,659	1,655	1,684	0
1.6	Auditorías	6,787	4,050	1,095	1,095	547	0	0
1.7	Pólizas	132,900	117,041	6,051	5,999	3,617	192	0
1.8	Administración	920,813	637,427	138,880	50,946	37,806	32,305	23,449
1.9	Administración-contingencia	2,228	1,108	529	591	0	0	0
2	**Costos directos**	**11,129,434**	**8,953,246**	**1,217,958**	**659,014**	**239,569**	**53,549**	**6,097**
2.1	Infraestructura	1,902,506	1,836,299	41,082	19,430	2,764	2,931	0
2.2	Infraestructura-contingencia	30,937	19,688	11,250	0	0	0	0
2.3	Obras principales	3,472,240	3,319,581	24,727	44,758	76,897	6,277	0
2.4	Obras principales-contingencia	2,430,685	1,447,989	573,940	360,112	48,645	0	0
2.5	Equipos	1,319,739	1,204,250	17,599	27,851	48,990	21,048	0
2.6	Equipos-contingencia	755,315	172,444	407,374	139,271	35,587	639	0
2.7	Gestión ambiental y social	1,037,012	785,468	133,521	62,585	26,686	22,655	6,097
2.8	Gestión ambiental y social-contingencia	115,624	102,151	8,465	5,007	0	0	0
2.9	Conexión al STN	61,988	61,988	0	0	0	0	0
2.10	Conexión al STN-contingencia	3,388	3,388	0	0	0	0	0
3	**Tierras y servidumbres**	**94,783**	**89,707**	**2,804**	**1,371**	**250**	**300**	**350**
	TOTAL INVERSIÓN	**13,394,935**	**10,668,956**	**1,554,893**	**768,898**	**283,874**	**88,262**	**30,053**
	Gastos preoperativos, operación y comercialización	**802,078**	**640,388**	**144,028**	**17,662**	**0**	**0**	
	Gastos financieros (incluye diferencia en cambio)	**2,599,215**	**2,273,144**	**196,325**	**4,739**	**65,666**	**59,341**	
	TOTAL CON GASTOS PREOPERATIVOS Y FINANCIEROS	**16,796,228**	**13,582,488**	**1,895,246**	**791,299**	**349,540**	**147,603**	**30,053**
	IVA	**377,253**	**208,787**	**110,131**	**39,469**	**15,165**	**3,702**	**0**
	TOTAL CON IVA	**17,173,482**	**13,791,275**	**2,005,377**	**830,768**	**364,705**	**151,305**	**30,053**
	Baja de activos indemnizables	**-1,001,941**	**-1,001,941**					
	TOTAL CON BAJA DE ACTIVOS INDEMNIZABLES	**16,171,541**	**12,789,334**	**2,005,377**	**830,768**	**364,705**	**151,305**	**30,053**
	TOTAL INVERSIÓN CONTINGENCIA	**3,873,202**	**2,060,263**	**1,173,374**	**551,355**	**85,887**	**2,324**	**0**

P2020

PROYECTO ITUANGO
COSTO PPTO 2020
Millones COP Corrientes

	CONCEPTO	TOTAL	2011	2012	2013	2014	2015	2016	2017	2018	ESTIM. 2019	2020	2021	2022	2023	2024
1	**Ingenieria y administración**	**1.829.450**	**123.316**	**79.265**	**161.058**	**107.060**	**126.833**	**144.230**	**183.385**	**205.362**	**234.044**	**238.069**	**80.683**	**59.014**	**47.830**	**39.299**
1,1	Estudios y diseños	53.963	53.903	36	26	-2	0	0	0		0	0	0	0	0	0
1,2	Interventoria	487.397	12.251	19.690	29.481	30.936	38.721	53.751	69.412	71.746	65.728	45.715	16.381	12.571	12.719	8.296
1,3	Asesoria	334.954	13.891	12.442	18.271	32.820	31.391	27.564	31.106	36.296	66.277	57.988	3.150	2.517	879	363
1,4	Auditorias	4.307	120	247	251	217	328	425	427	0	651	547	547	547	0	0
1,5	Pólizas	112.893	19.402	18.666	4.542	7.262	7.616	10.250	11.524	14.016	10.751	3.992	4.544	328	0	0
1,6	Administración	835.936	23.748	28.185	108.488	35.828	48.778	52.240	70.916	83.304	90.637	129.827	56.062	43.050	34.233	30.640
2	**Costos directos**	**10.147.927**	**156.589**	**356.655**	**594.598**	**945.645**	**1.148.584**	**1.179.445**	**1.533.293**	**1.171.658**	**825.421**	**1.010.262**	**788.515**	**291.369**	**114.597**	**31.294**
2,1	Infraestructura	1.868.382	146.481	272.358	299.855	260.155	319.160	170.878	194.670	69.916	53.817	37.549	30.139	13.402	0	0
2,2	Obras principales	5.370.606	390	67.982	253.359	400.159	460.358	721.003	900.963	840.645	538.598	602.866	353.198	143.043	82.630	5.413
2,3	Equipos	1.780.283	0	0	0	183.520	193.177	207.606	290.442	133.156	117.919	237.265	311.570	92.747	7.991	4.891
2,4	Gestión ambiental y social	1.062.209	9.717	16.316	41.385	101.811	175.889	79.959	89.569	125.426	113.580	127.808	93.608	42.177	23.976	20.990
2,5	Conexión al STN	66.446	0	0	0	0	0	0	57.649	2.516	1.507	4.774	0	0	0	0
3	**Tierras y servidumbres**	**91.320**	**7.543**	**4.588**	**7.547**	**8.674**	**4.899**	**6.717**	**21.471**	**15.516**	**8.094**	**6.271**	**0**	**0**	**0**	**0**
	TOTAL INVERSIÓN	**12.068.696**	**287.448**	**440.509**	**763.203**	**1.061.379**	**1.280.317**	**1.330.392**	**1.738.149**	**1.392.535**	**1.067.559**	**1.254.602**	**869.198**	**350.383**	**162.427**	**70.593**
	Gastos preoperativos	**393.809**	**6.471**	**6.882**	**9.650**	**25.639**	**25.342**	**29.402**	**21.059**	**165.465**	**76.989**	**13.163**	**9.065**	**4.682**	**0**	**0**
	Gastos financieros	**2.479.576**	**0**	**0**	**40.366**	**64.033**	**139.280**	**233.368**	**285.302**	**335.465**	**397.635**	**388.602**	**376.437**	**112.692**	**73.540**	**32.857**
	TOTAL CON GASTOS PREOPERATIVOS Y FINANCIEROS	**14.942.082**	**293.919**	**447.391**	**813.220**	**1.151.051**	**1.444.939**	**1.593.163**	**2.044.510**	**1.893.465**	**1.542.184**	**1.656.367**	**1.254.700**	**467.757**	**235.967**	**103.450**
	IVA Descontable	**325.482**	**0**	**92**	**1**	**1.480**	**21.945**	**22.500**	**34.503**	**37.914**	**26.863**	**72.612**	**70.020**	**26.960**	**6.517**	**4.074**
	TOTAL CON IVA DESCONTABLE	**15.267.564**	**293.919**	**447.483**	**813.221**	**1.152.532**	**1.466.884**	**1.615.663**	**2.079.013**	**1.931.379**	**1.569.047**	**1.728.979**	**1.324.719**	**494.717**	**242.485**	**107.524**

P2019

PROYECTO ITUANGO
COSTO PRESUPUESTO 2019
Millones COPCorrientes

	CONCEPTO	TOTAL	2011	2012	2013	2014	2015	2016	2017	ESTIM 2018	2019	2020	2021	2022	2023
1	**Ingenieria y administración**	**1.917.040**	**123.316**	**79.265**	**161.058**	**107.060**	**126.833**	**144.230**	**183.385**	**205.319**	**184.263**	**169.739**	**162.396**	**142.349**	**127.825**
1,1	Estudios y diseños	53.963	53.903	36	26	-2	0	0	0		0	0	0	0	0
1,2	Interventoria	524.077	12.251	19.690	29.481	30.936	38.721	53.751	69.412	73.889	62.423	41.395	33.444	32.588	26.096
1,3	Asesoria	359.099	13.891	12.442	18.271	32.820	31.391	27.564	31.106	40.654	35.775	32.667	31.830	26.417	24.271
1,4	Auditorías	3.699	120	247	251	217	328	425	427	241	481	481	481	0	0
1,5	Pólizas	91.826	19.402	18.666	4.542	7.262	7.616	10.250	11.524	8.730	1.797	1.866	74	60	36
1,6	Administración	884.376	23.748	28.185	108.488	35.828	48.778	52.240	70.916	81.805	83.787	93.330	96.566	83.284	77.422
2	**Costos directos**	**9.252.651**	**156.589**	**356.655**	**594.598**	**945.645**	**1.148.584**	**1.179.445**	**1.533.293**	**1.229.575**	**852.209**	**712.884**	**303.105**	**136.646**	**103.421**
2,1	Infraestructura	1.851.025	146.481	272.358	299.855	260.155	319.160	170.878	194.670	86.974	65.131	27.996	4.702	2.482	182
2,2	Obras principales	4.542.189	390	67.982	253.359	400.159	460.358	721.003	900.963	758.011	504.392	372.629	102.944	0	0
2,3	Equipos	1.713.465	0	0	0	183.520	193.177	207.606	290.442	220.392	119.977	216.345	142.883	77.484	61.640
2,4	Gestión ambiental y social	1.084.989	9.717	16.316	41.385	101.811	175.889	79.959	89.569	162.205	161.369	95.914	52.576	56.681	41.599
2,5	Conexión al STN	60.982	0	0	0	0	0	0	57.649	1.993	1.340	0	0	0	0
3	**Tierras y servidumbres**	**94.760**	**7.543**	**4.588**	**7.547**	**8.674**	**4.899**	**6.717**	**21.471**	**20.803**	**12.519**	**0**	**0**	**0**	**0**
	TOTAL INVERSIÓN	**11.264.451**	**287.448**	**440.509**	**763.203**	**1.061.379**	**1.280.317**	**1.330.392**	**1.738.149**	**1.455.697**	**1.048.991**	**882.622**	**465.501**	**278.995**	**231.247**
	Gastos preoperativos	**246.726**	**5.279**	**6.894**	**7.230**	**24.377**	**25.863**	**31.717**	**21.310**	**80.157**	**16.989**	**13.163**	**9.065**	**4.682**	**0**
	Gastos financieros	**2.331.700**	**0**	**0**	**40.366**	**64.033**	**139.280**	**218.310**	**280.392**	**328.830**	**348.769**	**374.105**	**368.395**	**105.554**	**63.666**
	TOTAL CON GASTOS PREOPERATIVOS Y FINANCIEROS	**13.842.876**	**292.726**	**447.403**	**810.799**	**1.149.789**	**1.445.460**	**1.580.420**	**2.039.851**	**1.864.684**	**1.414.750**	**1.269.890**	**842.960**	**389.230**	**294.912**
	IVA equipos (Descontable)	**179.080**	**0**	**92**	**1**	**1.480**	**21.945**	**22.500**	**34.503**	**26.782**	**19.402**	**31.661**	**11.970**	**4.371**	**4.373**
	TOTAL CON IVA EQUIPOS	**14.021.956**	**292.726**	**447.495**	**810.801**	**1.151.270**	**1.467.406**	**1.602.919**	**2.074.354**	**1.891.466**	**1.434.151**	**1.301.551**	**854.931**	**393.601**	**299.285**