Tunnels: Blasting Optimization for advance 100%, with overbreak and underbreak lower than 5%

Work Cycle Quality, direct improvement of the efficiency and profitability of an underground work

Concessionary Chavimochic (CCH) Eng. Ernesto SALAS GARCIA
DNA-Blast Latinoamérica S.A.C. (DNA-Blast) M.Sc. Alan DÍAZ BUTRÓN

ABSTRACT: Is it possible to control blasting effects for the benefit of progress?, it's a constant question for all of who search optimal and precise results in tunneling. We're going to present case of CHAVIMOCHIC Project, in its third stage, executed by Concessionary, in cooperation with DNA-Blast. With sections of hydraulic tunnels between 25 m² and 41 m², the objectives were to obtain the best advance by blasting (≥ 95%) Minimizing damage in the excavations. In this context the use of advanced techniques, accurate and do not create risk in their daily use, become necessary. Magic does not exist, but technology does. Being in the vanguard of tools for simulations of blasting effects, Concessionary CHAVIMOCHIC applies in its project: DNA-Blast Technology with cutting edge equipment and vanguard techniques in seeking to achieve its objectives. Being in the vanguard of tools for simulations of blasting effects, Concessionary CHAVIMOCHIC applies in its project: DNA-Blast Technology with cutting edge equipment and vanguard techniques in seeking to achieve its objectives. From the design of blasting plan to "measure " based on an adequate distribution of explosive and initiation sequence, to more complex as the vibration control calculations to avoid any damage to the tunnel, combined with the contribution of geomechanical and geophysical parametres, allow to achieve our objectives with adequate fragmentation. No having more overbreak neither underbreak on the tunnel (≤ 5%), respecting rock mass clasification and drill depth. This paper shows continuous optimization process, desde el inicio de las excavaciones de túneles, from the begining on tunnels excavations, and also techniques applied to achieve required goals.

1. CONTEXT : CHAVIMOCHIC III STAGE PROJECT – TUNNELS EXCAVATIONS

It's located on the northwest of Peru, special Project CHAVIMOCHIC is between right bank of Santa river on the south, until Pampas of Urricape on the north. It's being developed in three stages, with the aim of ensuring irrigation water in Chao, Viru, Moche and Chicama valleys for a total of 144,385 hectares

Third stage is executed by CHAVIMOCHIC Concessionary (CCH), they are in charge of hidraulic structure construction, operate and maintain old and new works, also providing water supply project users, which also includes a first and second stage.

In this context, currently it is being developed with a final height of 95m the construction of the dam " Palo Redondo " (figure 1) for what excavations of tunnels are needed (hydraulic tunnels and one vial tunnel) with sections that vary from 25 m² to 41 m² and lengths from 350 m until 2600 m.

The tunnels excavation was planned with Drilling and Blasting method, under a geological reconnaissance control during the progress of tunnels that allows to 'guard' the planned project on the constructive process

To face these works, CHAVIMOCHIC Concessionary (CCH) could choose traditional or classic methods, or they could ask for consulting and apply non conventional methods based on mathematical and physical calculation interacting to each other, to optimize constructive process, essentially founded on greater efficiency or performance of each type of rock blasting by minimizing the damage in the final section and under safety standards that could ensure the success of the operation.

Specifically talking about what "surround" to blasting, it's evolved thank to improved technical process and development of environmental best practices, searching for interrelationship between geological data process and geophysical methods, allowing to control more parametres in excavation cycle, reflecting on the progress results, increasing production and improving global costs.

Figure 1: Dam Palo Redondo (May - 2016)

This searching led to Concessionary CHAVIMOCHIC to decide to apply and trust on DNA-BLAST Technology (Figure 2), the same technology that can be applied for design, simulation and optimization of blasting, thus implement exemplary extraction procedures from the technical, economic, social and environmental terms. Likewise, the internal development and use of software I- Blast, integrated within a protocol ad hoc measures and field engineering, help to improve acceptance, safety and productivity of existing techniques for blasting through the numerical simulation of blasting.

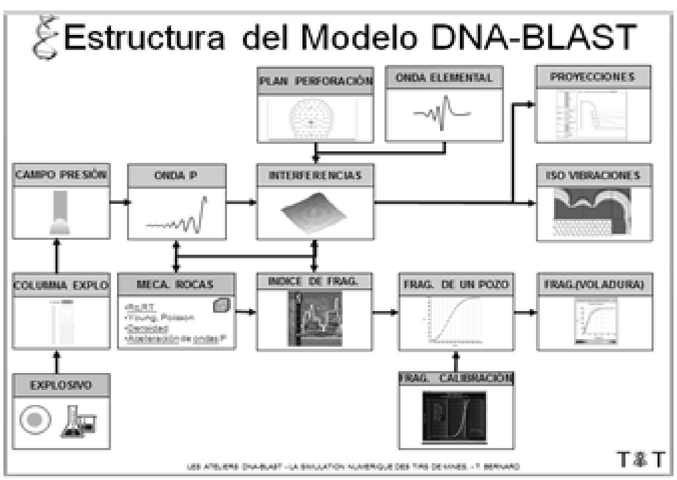

Figure 2: Structure of DNA-BLAST Model

2. OBJECTIVES: GOALS TO ACHIEVE

The main goal of DNA-BLAST engineering proposal is securing a mínimum efficiency of 95% in blasting a weighted way for all types of rocks and sections, for example: If we have a 30 m² section and drill with a rod of 13´, we must obtain 118.95 m³, having said that if we obtain 114 m³ after blasting, it will mean that blasting efficiency was 95,84%, which is greater than “required” mínimum efficiency.

Types of rocks are given by Bieniawski clasification (R.M.R.), *Z. T. Bieniawski (1979)*, drilling length permitted is related to self-reliance time once blasting is done in the tunnel, for structural studies already done.

The limits to advance by rock type, established by the geomechanics department, are:

Type II: 4.5 m
Type III: 4 m
Type IV: 2.5 m
Type V: 1.5 m

The equipment used is a Jumbo DT 820 from Sandvik with two boom semi-automatic (Figure 3), for sections from12 to 110 m².

Figure 3: Jumbo DT820 Drilling Control

Complexity on this project lies on obtaining an underbreak and an overbreak, non greater than 5%, that's why design and control of each blasting must be done with a high degree of accuracy, that allows achieve stated goals and especially to mantein the same standard throughout the excavation.

Additionally, not least, this service should be covered with the cost savings obtained by improving the efficiency of excavation for each blast, understanding that any technological improvement will be viable if it represents a decreasing on operative costs that can cover its own aplication and let a margin that sustains execution of these methods.

The greatest indicator of the effectiveness of the application of engineering methods, will be the reduction of operating costs, so it also included as a direct objective of this proposal.

3. ¿WHAT IS PROGRESS AND UNDERBREAK - OVERBREAK? MEASUREMENT METHOD

Progress, as was said on point 2, will be limited by maximum allowable length depending on rock type found blast to blast.

This length corresponds to 100 % permitted, the main requirement leads us to be able to maintain constant productivity, with designs performative meshes, allowing to protect the expected cost.

3.1. Progress – measurement method

Progress will be measured by rock type in each blast, by topography deparment, once material is evacuated, can measure the final result in the advancing front.

It is essential for stability, production cycle and direct cost, to control damage on section and get the smaller underbreak and overbreak as possible, because these will be considered as penalties to progress achieved.

By converting to linear meters, underbreak and overbreak subtracted directly the yield obtained. Monthly, as shown in Figure 4 , progress made by each blast will be assessed according to the type of rock, minus the advance measured quantity meters higher than 5% allowed for underbreak and overbreak, likewise respecting the expected costs.

TUNEL	
Longitud teórica (m)	198.40
Longitud Real (m)	204.28
Castigo (m)	4.35
Eficiencia de Servicio total	102.96%
Eficiencia de Servicio Efectiva	**100.77%**

Figure 4: Example of summary table of monthly progress

Example in figure 4 shows a typical monthly assessment, based on cumulated length by rock type of the period, real obtained length, penality due to underbreak and overbreak, real efficiency of the monthly progress and effective efficiency minus the "punishment" to real length. As we said previously, it also includes cost of designed meshes, which should not be more than estimated cost for the project, inicially considered with traditional excavation method by blasting.

3.2. Underbreak and Overbreak

We can define "overbreak" like unwanted excavation outside to specified theoretical profile, on the other hand, "underbreak" is the lack of excavation on the theoretical profile required.

Both results lead to increased costs as well, longer production cycle. Often, when there's overbreak, shotcrete is required to "fill" the affected area. In the opposite case, need for jackhammers or secondary blasting are essential to "break" the missing rock and reach the desired section.

In many cases overbreak can lead to inestability of rock mass risking construction of the tunnel.

Overbreak and underbreak are mainly a result of "damage" and geological structures themselves along the length of the excavation. Load factor and the sequence of blasting, play an important role too

The “damage” is measured in the section from the contour holes where the PPV (peak particle velocity) exceeds the critical PPV of in-situ rock.

Critical PPV is correlated to compressive strength and wave P velocity.

These effects can be reduced or eliminated by making a meticulous control of blasting parametres, such as:

- Drilling Control
- Diameter of holes
- Proper spacing
- Load distribution
- Output stream.

In figure 5, we can see graphically how underbreak and overbreak are shown from theoretical excavation line.

To delimitate these items, blast to blast, will allow to control required objectives, and make a continuous balance of the actual cost of construction of the tunnels against anticipated.

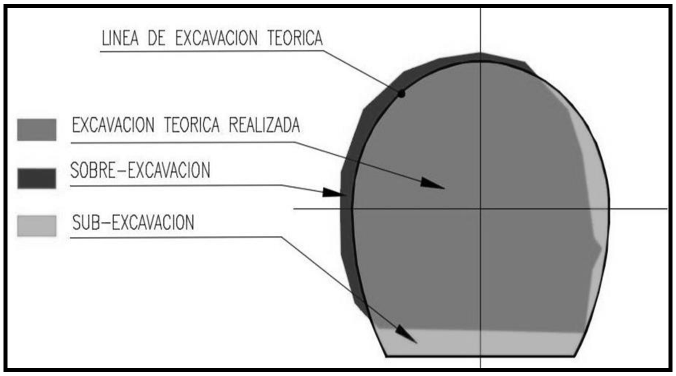

Figure 5: Overbreak and underbreak in section.

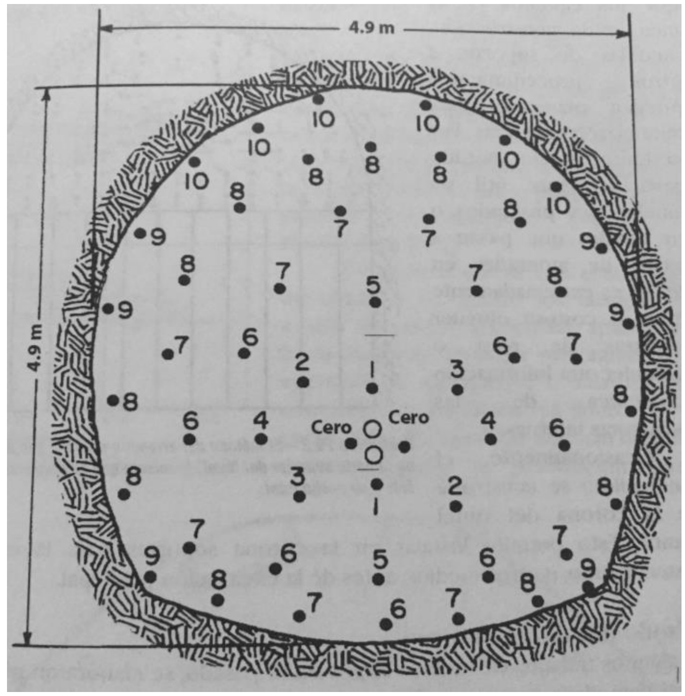

Figura 6: example of the full face method (Blasting Specialist Manual, 2008).

4. EXCAVATION METHOD BY BLASTING IN TUNNELS

Excavation of tunnels is a specialized field in construction industry, requires of trained professionals. Making a comparison with mining where main goal is recovering the mineral from a blasting, in tunnels excavation most of extracted rock generally will be intended to waste. In construction of tunnels, progress blast to blast, is a main concern, as long as efficiency and safety allow it.

For the construction of tunnels in project Chavimochic, "Full Face " method is used , this method as its name suggests is based on a mesh drilling to fly completely the tunnel section in a single shot or blasting as shown in figure 6.

Today, advances in equipment especially larger and more efficient jumbos, best drills and the use of better machines for cleaning material make this technique to be applied more frequently, being generally used in tunnels height of less than 9 m except the rock conditions lead us to make small blasting, in which case it would opt for the superior method starting with bank.

Blasting in tunnels is listed among the most complex, because it does not have a free face rather than the front, unlike superficial blasting, which can have two to three faces.

4.1. Voladura Tradicional en túneles

At present, in many tunneling projects, the issue of excavation by blasting is still based on "experience" of his collaborators but without any scientific basis.

What is experience?, experience (from latin *experiri*, "check") is defined for some as a form of knowledge or skill that comes from observation, participation and experience of a situation or event consistently. This term is closely related to the workplace and that is why many companies choose professionals who have more years of experience than young people who are iniciating their working life, of course, this type of selection is not based rather than time a person has been confronted with certain situations or specific work, but not everyone knows to capitalize on this experience and transform it into knowledge applicable.

So, experience is related to "know how to do something" and directly linked to the empirical.

Under this premise is that many tunnels are built today using the experience as a key point, without considering, for example the various geological throughout its excavation or even worse: to pretend from one tunnel to another there's no variation in design parameters blasting mesh rather than a change of section (more or less holes) , or in many cases only performing a mesh type for blasting by rock type.

There are different empirical formulas (figure 7) related to the design of blasting meshes, which will be adapted according to the experience.

$$N = 10\sqrt{A} + 10$$

N= número de taladros
A= Área de la sección

Figure 7: Empirical formula for calculating number of holes according to the section, used by Concessionaire Chavimochic in its initial forecast.

Thus the method of " trial and error" design used for drilling and blasting meshes (Figure 8) becomes an everyday alternative for many builders tunnels.

Still, this traditional approach has some advantages, such as:

- It allows to built its own experience.
- It doesn’t required technological tools.
- It’s easy to apply.
- It doesn’t have an initial cost.

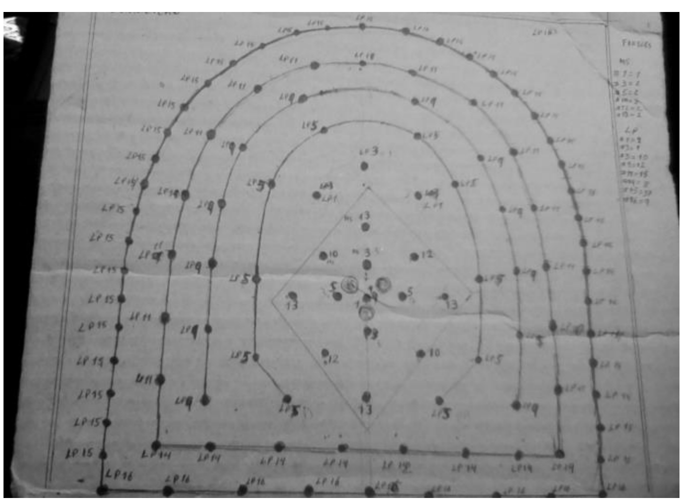

Figure 8: Design of a blasting mesh made empirically (trial / error method) .The same was done on a remaining explosive cardboard box.

But this “TRIAL and ERROR” method has some disadvantage too:

- No warranty of success, because there is no scientific support.
- It might last a long time, since it is adjusted according to experience during excavation (e.g. Putting one more or less hole to see the result)
- Need to start each new configuration, not taking into account the geological conditions can be very variable.
- It can not reach the expected results systematically.
- It can be risky, in safety issue to have no control of the effects of blasting.
- It's expensive, because it affects production cycle by not having controlled underbreak and overbreak, damaging self-sustainability of rock mass.

In conclusion this methodology that at the begining does not consider cost, more than the experience, can easily turn into a problem for the implementation and sustainability of any construction company.

4.2. Blasting based on scientific fundamentals for tunnels.

We can define science as an appropiate set of techniques and procedures used to generate knowledge for an specific topic.

Then, scientific method is directly related to a series of stages that we must follow to get a valid knowledg, using for this purpose, instruments or reliable means, avoiding subjectivity to solve or face a situation and going from cualitative to cuantitative through increasingly precise measurements.

Tunnel construction requires a detailed and extensive research before and during implementation. As for blasting, this will mean to anticipate and know more precisely geological variability throughout of excavation , through direct or indirect probes , allowing originating and to execute designs mesh to "measure" for blasting, adjusting parameters to the situation of rock mass to cross at that time.

To do a work based on science allow to reach required results and goals quickly and safely.

Although it can be seen as an "extra cost " in the construction process unlike traditional method, to have control of blasting effects eventually allow savings in time and tangible economic gains.

This is the reason why Concessionary Chavimochic (CCH), decided to use DNA-BLAST technology to be able to apply blasting engineering in excavation of tunnels, with support of the company that has the same name as the DNA -BLAST technology, betting on scientific innovation in the construction process of tunnels in Peru.

Briefly we can say that the DNA -BLAST model is based on physical and mathematical principles put into equations to represent the real world. This mimics the inner workings of blasting in order to reproduce its effects, it is certainly a real alternative compare to statistical models based on experimental laws only.

DNA -BLAST technology considered independently each of the elements (figure 9) which together constitute the result of blasting, performing a similarity, they would be like genes that make up the human body. Depending on how and to what extent these are combined, these so-called "genes blasting" and give different results for the same blasting, the same as we can seen in nature, every creature or species out of an original combination of different genes.

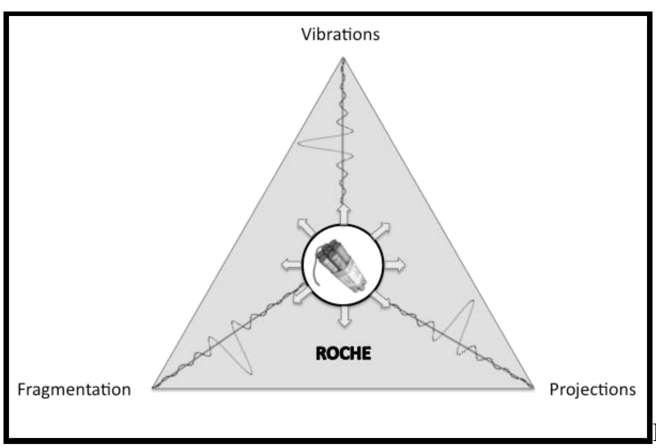

Figure 9: DNA -BLAST technology, global mechanism of detonation.

Identification of these genes and their potential interactions compression have enabled the creation of a measurement protocol and software to simulate and optimize all the parameters necessary to carry out a blast as expected.

Based on research for over 25 years of Phd. Thierry BERNARD (France 1965) and with a global expertise in explosives and blasting engineering, this technology allows the integration of all parameters that interrelate the phenomenon (geology, loading, geometry, sequence, etc ...) in order to process the interactions between these parameters, imitating for certain the natural phenomenon caused by blasting, allowing feed the physical equations that constitute the engine of this technology.

5. MEASURES, CONTROL AND ANALYSIS PROTOCOL FOR OPTIMIZATION OF BLASTING IN TUNNELS

The measures pre- and post-blast field, are necessary to make a control as an analysis of the results and thus necessary to optimize our design blasting to obtain the desired results.

These measures will also be complemented throughout the construction cycle by geophysical testing and direct drilling testing that will allow us to rebuild our geological model in- situ along the axis of the tunnel , also allowing feed our model with geomechanical parameters obtained in these tests.

This work is done by a group of engineers from the company DNA -BLAST who interact and collaborate in Chavimochic directly with production engineers and engineering and production department, in order to achieve the objectives and results require.

Significantly, the success of this protocol could not be accomplished without the real support of engineers and project team of Chavimochic, who participate and accompany all along process to apply.

5.1. Measures and controls in field

To be effective, optimization and continuous improvement can not rely only on a theoretical basis, but daily information collected during the work cycle.

Being one of the core activities within our process , an engineer will develop his activity purely in the field to feed our model, being part of the whole cycle corresponding to drilling and blasting.

He will oversee and participate in the following stages:

- He will give to responsable person in field in charge of the front, the document (Figure 10) that has the mesh to run detailed, as well as the digital file to enter into the jumbo for blasting in progress.
- To check proper drilling of planned mesh in the front of the tunnel (drilling time, number of holes, etc.) and retrieve the file generated by the Jumbo after drilling, verifying whether or not what was planned, had been respected.

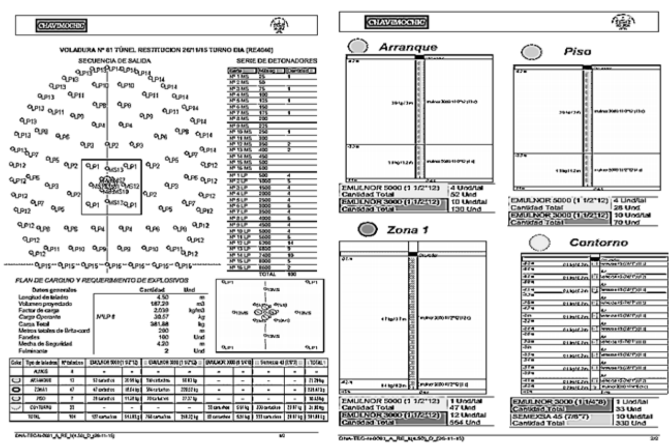

Figure 10: detailed field document indicating the amount and position holes, as well as the number and configuration of explosive charge by type of hole.

- To accompany the loading and sequencing of the mesh perforated verifying its proper implementation in field.
- To place and set seismographs for seismic recording (Figure 11).
- To take pictures of the front, before the blast.
- After running the blasting, he will take pictures for fragmentation analysis, projection of rock
- Once the front is cleaned, he will take pictures of the final result for analysis.

Figure 11: Instalation and check to an seismograph parameters before a blast.

- To control in the front, underbreak and overbreak. He will do a photographic record of number of *half barrels* (figure 12), from the contour as an indicator of respect and care for the final section

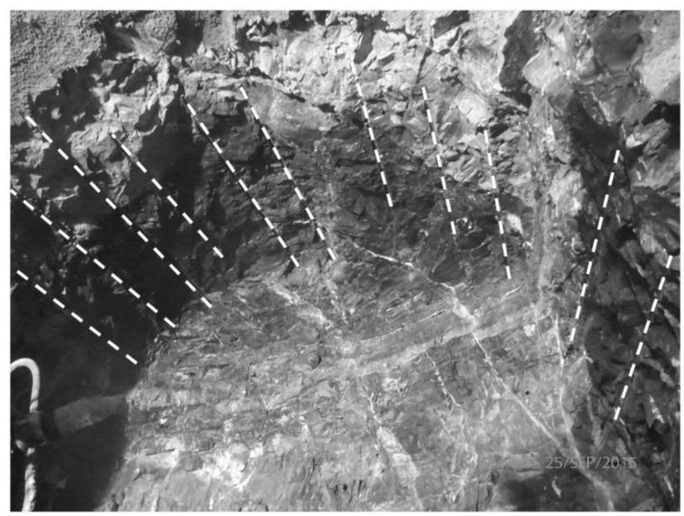

Figure 12: Photograph to control and analysis of *half barrel* related to underbreak and overbreak, as well as respecting to final section.

- To retrieve the seismic record for proper analysis.
- He will take notes of important data in field throughout drilling-blasting process, pointing any change or modification in-situ.
- To deliver all information obtained pre- and post-blast for their respective study and analysis.

In this stage, monitoring is essential to ensure optimal results, then this should be performed daily with the thoroughness and detail required.

5.2. Analysis of blasting result as an input for continous optimization.

Engineer in charge of analysis of post-blasting results, is a trained profesional to processing, analysis and interpretation of data coming from unitary operations of drilling and blasting process, to be able to interrelate them as esential part of the process for construction of tunnels in project Chavimochic. This data treatment represents, without a doubt, some sort of "bridge" between daily work in field and continous improvement for the next meshes design, considering as a goal to make them more efficient and profitable.

Analysis activities that are made:

- To analyze the actual record provided by Jumbo drilling equipment, verifying that the distribution, angle and length of the planned mesh (Figure 13) is respected .

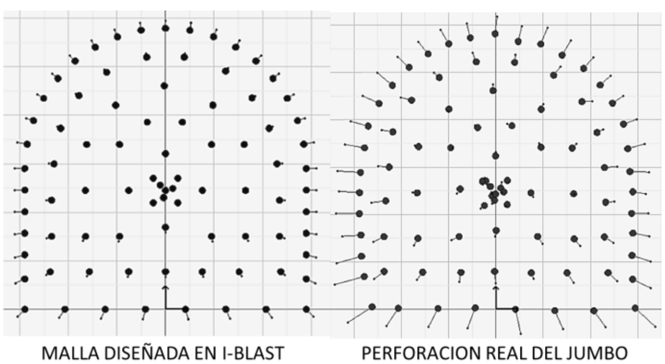

Figure 13: Analysis of planned mesh and real drilling done by Jumbo

- Analysis of the seismic level obtained, as control of the performance of blasting (more seismic level indicate less energy used in fragmentation).
- By analyzing the seismic signal (Figure 14) , we can verify proper output of all holes in the mesh and respect for the designed sequence can immediately pinpoint problems to be corrected in the next blasting.
- Calculating the actual damage around (Figure 15) section of the tunnel, using parameters such us:

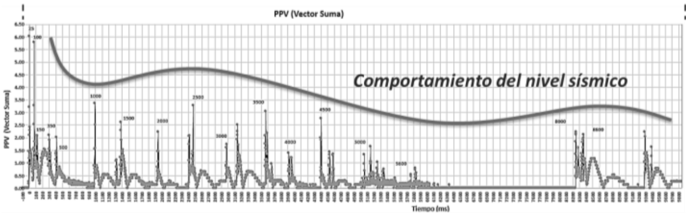

Figure 14: Analysis of seismic behavior of a blasting

  - seismic level obtained.
  - operating load used
  - P wave velocity, from geophysical seismic studies for tunnels, made in the same section where the blast took place, being able to analyze the displacement wave in the rock mass.
  - Young's modulus obtained by geophysical test for the section to be treated.
  - Rock density.
  - Compressive strength obtained from the drilling parameters from a destructive test mechanical probing in front of the tunnel made every 30m further using a camera that allows you to catalog the rock through accurately.

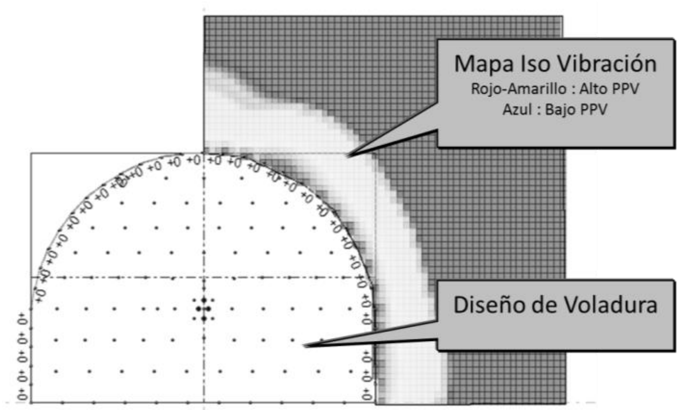

Figure 15: Damage Control, simulation carried out on I- Blast

- Control of progress achieved, also underbreak and overbreak by the information provided by topography, taken after cleaning the respective blasting.
- Fragmentation analysis through images using the I- Blast software (Figure 16), checking whether the planned goal failed or not (P80 ≤ 300 mm).
- Distance control projection of actual rock.
- Calculation of half barrels, this is a percentage value determined by the result of dividing quantity of half barrels by holes in the contour.

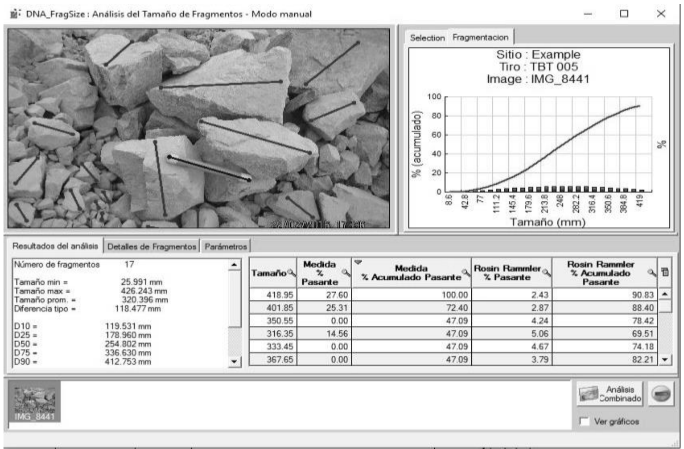

Figure 16: Fragmentation analysis by photos, software I-Blast

This value is an indicator of caring in section despite the destructive effect of detonation, and thus whether the section is being executed according to the design and the conditions of the construction process.

- Control of swelling factor using the amount of dump truck to evacuated, as data, comparing it with the excavated section further and to compensate for heterogeneity at the time of loading dump trucks (quick measurement), topographic measurements (volume) of rubbles are taken to verify this data. The swelling factor should be compared with fragmentation obtained as we mentioned, so that we can confirm the correct interpretation of both analyzes (when P80 is greater, then greater should be the swelling in a direct relationship). By improving swelling factor should lead us to be able to improve the cleaning time, as continuous improvement in productivity of the tunnel.

Analysis of each blast will finish in the drafting of a detailed report where the most outstanding values obtained will be appreciated, as well as observations and recommendations if necessary optimize the mesh for next blasting.

5.3. *Design and optimization of meshes blasting on a scientific basis.*

An explosion is a very fast phenomenon in the course of which appears in an extremely short time an important energy. This is the usual result of the expansion of a large volume of gas, often at high temperatures.

From the field data and analysis results based on calculations , an engineer can on this basis " fed " daily, design tailored meshes to the specific conditions in the field, obtaining a sustainable advance to throughout the excavation of a tunnel.

Unlike the traditional method, which makes changes at random and without any technical basis, to know and control a large number of parameters involved in the cycle of drilling and blasting, we can optimize continuously, identifying and adjusting the parameters necessary to achieve our goals.

The mesh design of a drilling and blasting plan is developed as follows:

- Once geological and geomechanical parameters are obtained in the field, we proceed to integrate them into our model in I- Blast software.
- Type, physico-chemical characteristics and the physical and mechanical properties of different explosives used in project will be entered into our model in I-Blast software.
- Thus, the models will be eventually adapted (geological, explosives) and updated on the exploitation or where there is need , allow us to save precious time between each blast , re-using the database own invariable elements of the project , allowing keep pace the rate of production of the tunnel excavation.
- For the mesh design for drilling, we must start from:
  - Holes position
  - Drilling direction
  - Depth of blasting
  - Number of holes
  - Type of holes (outburst, flat , horizontal and vertical production , contours, etc..) (figure 17).
- Unlike a superficial blasting, in this case we can only move the material toward the already excavated tunnel part. It is this situation that we must proceed "two times" for a tunnel blasting. So, on a part of the section we concentrate a certain amount of holes for excavating a first cavity in the target direction, which commonly: outburst. Once generated this cavity, the other holes "fly " the material on this central cavity continuing the output stream. Here's the importance of outburst in a blast of this type.

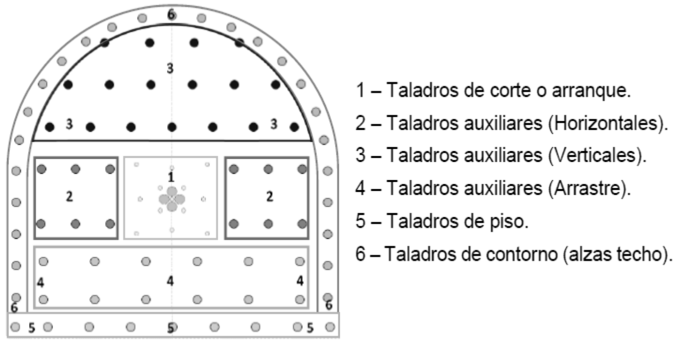

Figure 17: Types of holes in a classic tunnel section.

- As for the distribution and position of holes in the front of excavation, unlike the traditional method that tells us and a predetermined amount of holes, in our case we will find a final amount, starting from the first hole and adding holes geometrically (figure 18), taking into count volume of material to be moved and / or removed between the first and second hole, then adjust to the explosive charge needed. This principle is already integrated into the I- Blast software that allows us to design meshes in Chavimochic.

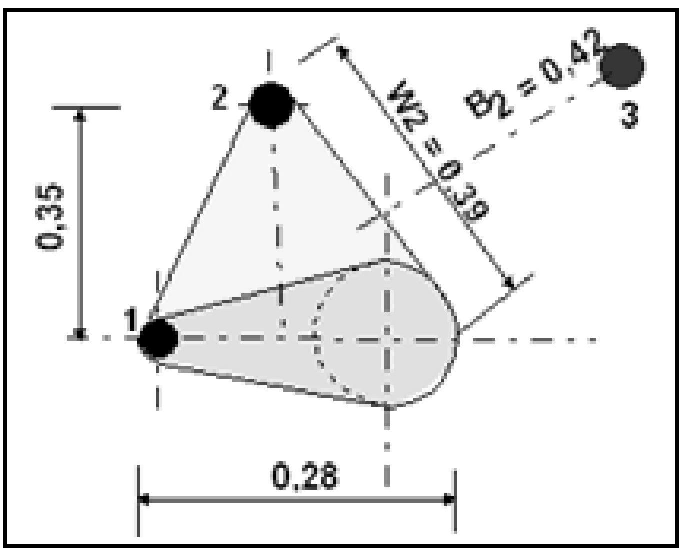

Figure 18: Example of calculating the position of the first 3 holes. (Thierry Bernard, 2003)

- Continuing the design, we must consider the following parameters, which will be also calculated by the I- Blast software using databases entered (e.g. Explosives Project) (Figure 19) , automatically:
    - The hole load (kg), varies the position of the mesh hole drilling. This generally decreases from the center outwards.

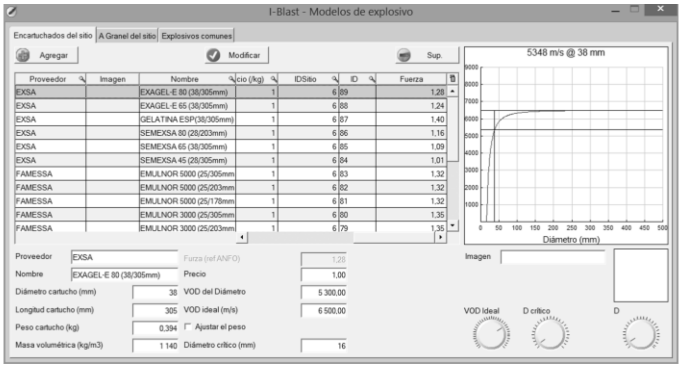

Figure 19: Example of integrated database explosives I- Blast software for designing meshes

- The linear load is the amount of explosive per meter of hole loaded (Kg/ml).
- The working load , being the amount of explosive that detonates at a time t (kg) , is an important parameter because it will determine the level of vibration emitted by the blast , which has a direct impact on the outcome of blasting plan and the production cycle of the tunnel.
- The total explosive charge used for blasting in progress. (Figure 20)
- The load factor, which is simply the amount of explosive expressed by volume of rock to blast (g/m³).

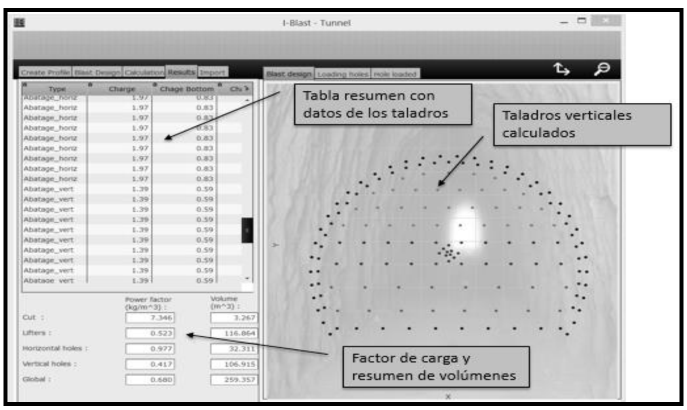

Figure 20: Design of blasting on I- Blast software, we can see: calculation of quantity and position holes, load summary by type of holes, summary table load factor and volume by type of hole and overall blasting.

- Energy distribution (Figure 21), just shows the energy used by volume of blasting (MJ/m³)

- To design the output sequence must take in count the objective of each type of hole, so we have:

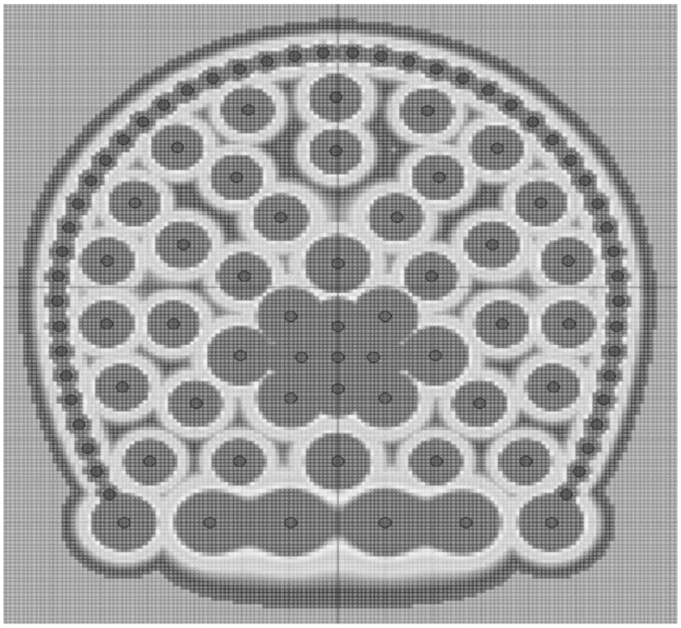

Figure 21: Energy Distribution in I- Blast software for rock blasting, type V, with Fc= 0.9 Kg/m³

- Outburst, will aim to create a central cavity (open face) of sufficient free section of any material, that's why the time emptying volume of material from the ejection speed (this speed is in a average of 40 to 60 m / s) are important and priority.
- The goal of the holes production, will make bigger this cavity until the next 'profile' of hole(s)
- Contour holes, aim to delimit the final section, taking as we make minimal damage to the rock mass. Normally they leave at the same time.

For the conception of the sequence (Figure 22), it is essential to create free faces as the blasting is developing, for this we select the best delay times avoiding as much as possible, have an overlap of time and holes together, that could increase our operating load and consequently generate a high level of vibration, this would be reflected directly in damage to the section, overbreak and underbreak.

We have mentioned the main stages of process design and optimization of meshes blasting and intervention I- Blast software as a tool for continuous improvement, allowing to save time in the development process.

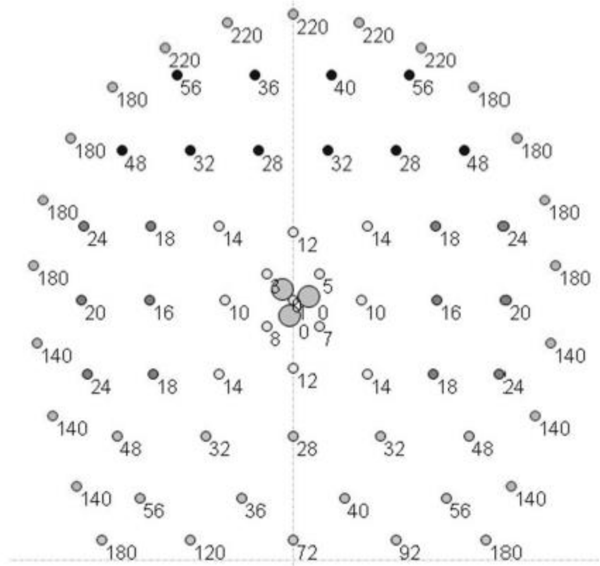

Figure 22: Design of blasting plan and sequence with I- Blast software

5.4. Importance of geophysics and mechanical probes as a source of geological and geomechanical information for the process of drilling and blasting

The method applied in Chavimochic is called "virtual witness - TSP ". It will allow us to feed in advance and continous way our database in order to design and optimize meshes drilling and plans blasting according to the geological conditions current structures, taking in count geomechanical and geological parameters, obtaining the same or higher advances to 95 % of the perforated length , and can maintain a degree of damage, overbreak and underbreak controlled and estimated maximum 5% of the excavated section. This method consists of two tests:

- A first mechanical probing of 30 m, which will provide geological, geomechanical information, essentially related to the compressive strength of the rock. This method consists of a horizontal drilling in the tunnel face where through a special sensor we record drilling parameters (Figure 23), in real time, including: the speed, torque, advance pressure, fluid injection pressure.

  The instantaneous advance rate (VIA), is the speed at which tool moves while drilling also call " drillability". Keep in mind that this " drillability " does not indicate the hardness of the geological formation, but compressive strength (index Somerton), showing a relationship with RMR (Rock Mass Rating)

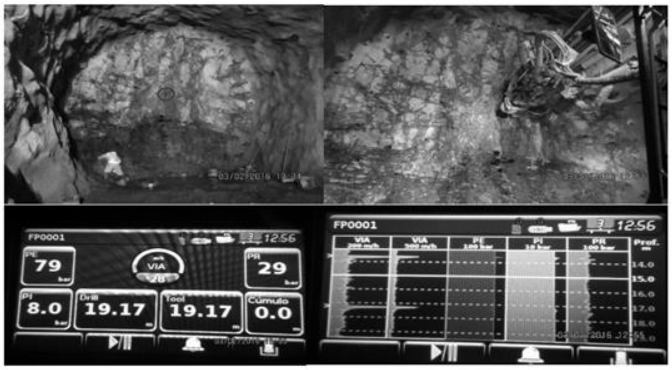

Figure 23 : Recording of drilling parameters using sensor in drilling equipment.

In the case of pressure fluid injection we indicate variations of plasticity of geological formations are drilled.

Rotation pressure expresses the effort required to rotate the bit in the hole and gives us the information if it is heterogeneous or not. This information is very important so that combined with the advance pressure and the instantaneous velocity provide us geological information by lithologic cuts and geomechanical rock from the analysis of compressive strength for location of faults and structures.

Using DNA-DRILL-LOG software (figure 24), we can,by combining these parameters and an adjustment index Somerton, obtain a curve equivalent to the compressive strength of the rock , which is located in relation to the progress of tunnel . Our design is based on the progress we want to get.

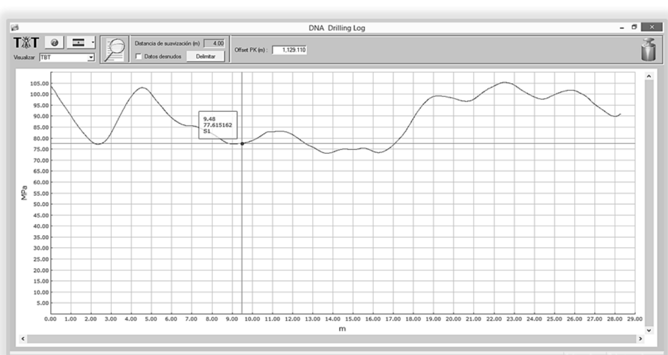

Figure 24: equivalent curve to the compressive strength of the rock after probing - Software DNA -DRILL -LOG

Once drilling is completed and data collected, we may obtain a hole image by introducing a camera to model our virtual mechanical indicator (Figure 25).

Figure 25: Camera for modeling virtually witness.

Once virtual witness is modelized, any geological event detected at the time of drilling is confirmed (Figure 26).

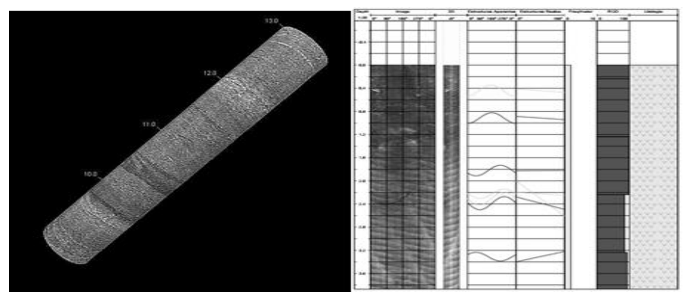

Figure 26: Virtual witness and its analysis.

This probe lets us know what kind of rock we can find before blasting, so we can anticipate and optimize our mesh , in order to obtain the desired progress and minimizing the risks of damage to the section.

- A second test: "tunnel seismic prediction - TSP " give us information about the geological structures. It's designed to locate and reveal changes in the rock mass and / or geological formations such as caves, faults, fractured zones, discontinuities in the advancing front.

  It is used predictively during tunneling using seismic reflection by detonating up to 24 small loads sequentially producing acoustic signals (seismic waves) which are received by triaxial sensors anchored to the rock in the side wall of the tunnel (figure 27).

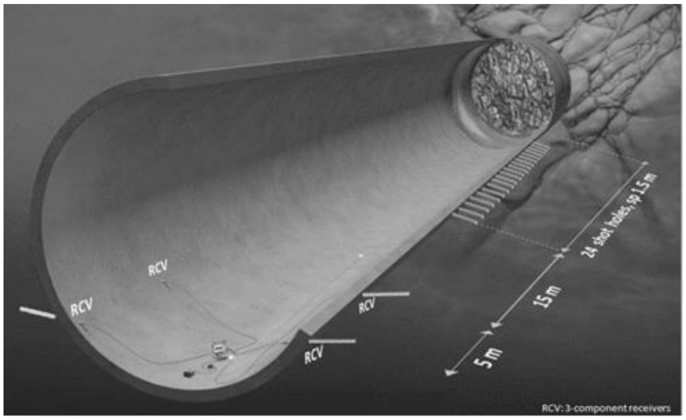

Figure 27: holes position and sensors for test TSP. (Imagen Amberg Technologies)

Seismic sensors capture the seismic signals produced by the shots and deflected by some sort of discontinuity of the rock mass, which will be recorded in a computer (Figure 28).

Amberg TSP PLUS Software process information received to determinated geomechanical characteristics of the rocks, such as Young's module, Poisson coeficient, P and S wave velocity. This will show in the model by reflectivity and values (figure 29).

This application has a range over 150 meters, however it is recommended to analyze every 100 meters. It is applicable in all types of rock with contrast in physical properties, except in soft soil where the method can not be applied.

Figure 28: DNA -BLAST engineer recording on the tunnel by TSP method.

For this analysis the acoustic impedance is used, it's the resistance that a system presents to waves propagate on it. The acoustic impedance is a function that varies with frequency.

The impedance at a given frequency indicates how much pressure is generated by the acoustic wave of that frequency. By acoustic impedance we can determine the reflection coefficient, then used it to detect discontinuities in the rock mass.

A contrast of acoustic impedance of at least 20 % is sufficient to detect geological discontinuities.

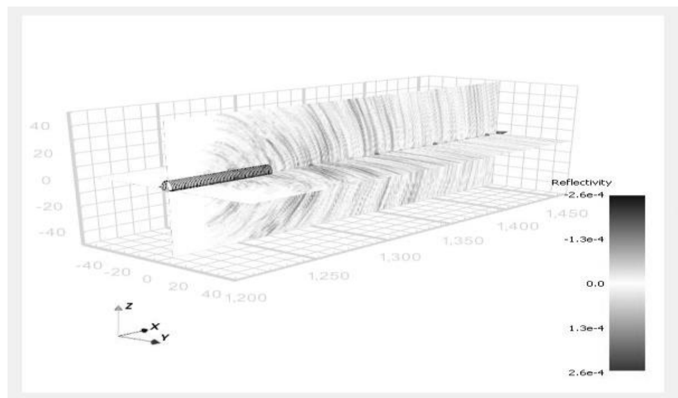

Figure 29: P-wave reflectivity as obtained from the model of TSP test.

The parameters obtained in the model (Figure 30) using this geophysical method help us to predict in advance the quality of the rock mass and get geomechanical parameters necessary for designing meshes and blasting plans.

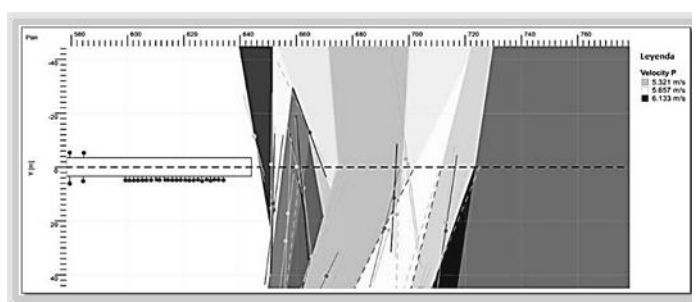

Figure 30: Geological model from TSP test

6. COSTS - SCIENTIFIC METHOD VALIDATION

To validate the performance of this method, a comparison between drilling meshes and blasting plans made in Chavimochic without the use of scientific parameters necessary to apply the technology of tunneling.

From this comparison the following analysis was obtained:

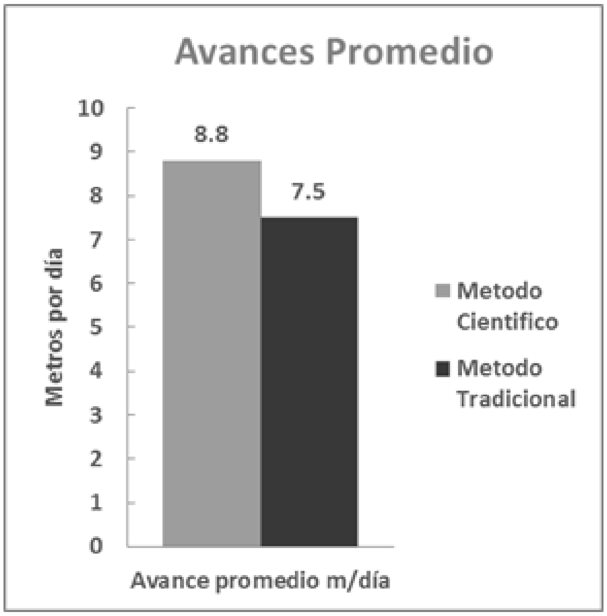

Figure 31 : Difference in average progress per day.

In Figure 31, we can note an increase in the average advance per day for a little over a meter, this means, that every 6 blasts made with the scientific method equivalent to 7 blasts made with the traditional method.

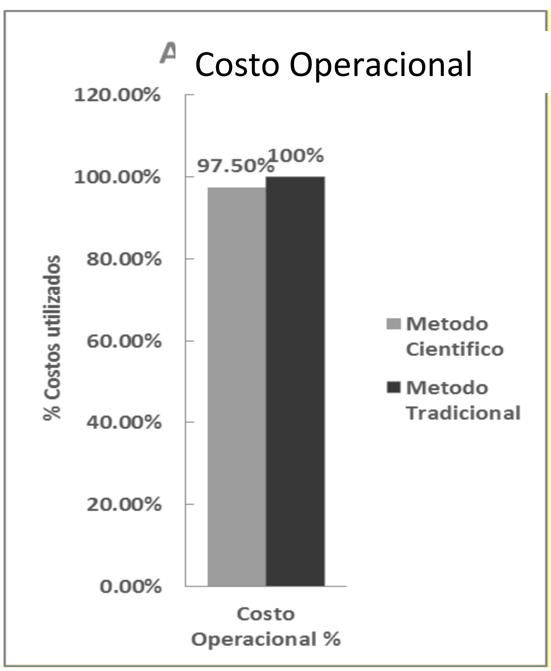

Figure 32: Comparison of Operating Costs

As part of the validation, a projection was made using the traditional method and the scientific method to the same length. Thus, after evaluating the operating cost for this length of tunnel, also including the same execution and service costs of the scientific method, we could achieve savings of 2.5 % compared to the traditional method (Figure 32).

As unmeasurable part of using the scientific method we can consider that control and reduction of damage factor to the rock mass, we build tunnels with greater stability, providing all involved every day in tunneling a working environment safe and increasing self-sustainability of the tunnel, in geomechanical terms, allowing further progress without the use of support.

7. *TECHNICAL BENEFITS AND PRODUCTION THANK TO IMPLEMENTATION OF BLASTING ENGINEERING*

The application of this engineering methodology as an essential part of the construction process of tunnels for Chavimochic, has several benefits as technical as productive, linked to a constant optimization and interaction with the client (Figure 33).

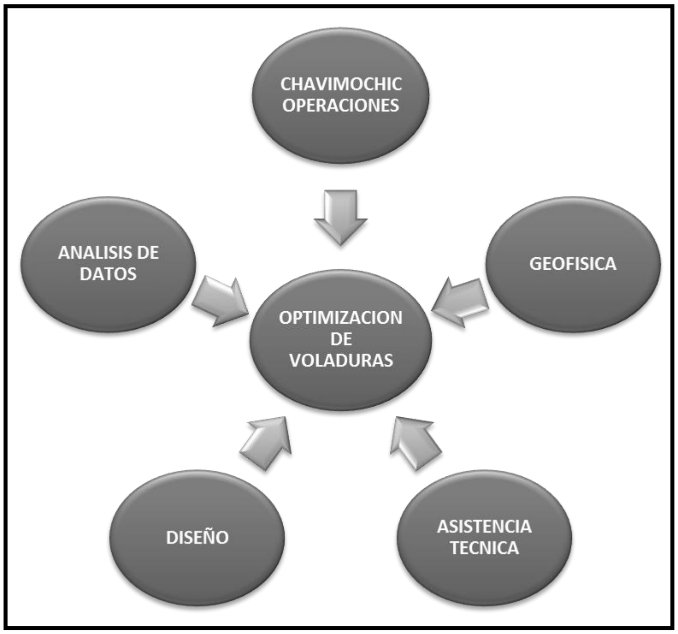

Figure 33: Interaction of the different stages for constant optimization.

Next, we will detail the main technical benefits:

- Geophysics, gives us the following technical benefits:
  - Estimation of geomechanical parameters
  - Identifying geological structures.
  - Identification of seismic zones (Vp) .
  - Knowledge of the behavior of the rock prior to excavation by blasting.
- The analysis of each blasting allows us:
  - Control of progress.
  - Control of the final section.
  - Blasting volumes.
  - Control of projection of the rock.
  - Adequate level of vibration.
  - Improve and control of fragmentation.
  - Damage control in the final section.
  - Minimize overbreak and underbreak.
- Proper design of blasting plans , produces:
  - Lower operating load.
  - Watch the contour of the section.
  - Control and improved fragmentation.
  - Swelling factor reduction.
  - Optimal initiation sequences.
- Control measures in field:
  - Monitoring the drilling process.
  - Control of the loading process.
  - Seismograph installation and registration of vibration.
  - Photos to control fragmentation.
  - Verification of the section and advance.

So we also find productive benefits, including:

- In Geophysics:
  - Efficient drilling meshes.
  - Blasting plans by each type of rock.
  - Sustaining of the scheduled tunnel.
  - Reduced risk of instability and delays.
  - Reduced the drilling tools.
  - Increased productivity.
  - Less downtime for research.
- The data analysis will have as benefits:
  - As for the progress, we will have better performance and bigger length of drilling.
  - Minor runtime tunnels.
  - A good fragmentation will give us greater efficiency in loading equipment and less time cleaning.
  - A controlled rock projection allow a faster cleaning of material and uniform displacement of the blasted material.
  - Minor damage to the section on safety, and damage level to control fragmentation.
  - As for the section, we have less overbreak and underbreak.
- Blast design , provides:
  - Reducing the operating load.
  - Lower level of vibration and damage.
  - Increased opening time in the tunnel.
  - optimal sequences in the field, ensuring good progress, fragmentation and projection control.
- Fieldwork conducted provides as follows:
  - Verification of blasting plans to avoid execution errors and delays.
  - Adequate contingency plans.
  - Measurements and records, allow us to save a lot of time, under thorough control results.

We must point that these technical and productive benefits, have to be reflected and "supported " by the planned cost of the project for tunneling.

8. ANALYSIS OF BLASTING RESULTS AS A SOURCE OF CONTINUOUS IMPROVEMENT

After initiating the phase of tunnel excavation in August 2015 to the third stage of Chavimochic, there have been a total of 730 blasting with a global advance of 2565 m.

We focus our results on the last 5 months, from January to May 2016. Conserving the initial intended target of obtaining an efficiency equal to or greater than 95 % by blasting with an overbreak and underbreak equal to or less than 5%. For blasting efficiency, we can indicate results above 100% was obtained, the "punishment" for the overbreak and underbreak less than 5% (Figure 34). Similarly, the estimated cost was covered, without incurring on any additional cost. Significantly, is performed, as we've already mentioned, between other control of blasting damage and vibration level in section and although in some cases, progress was over 100% by blasting, this does not affect the stability of rock mass, due to controls mentioned above.

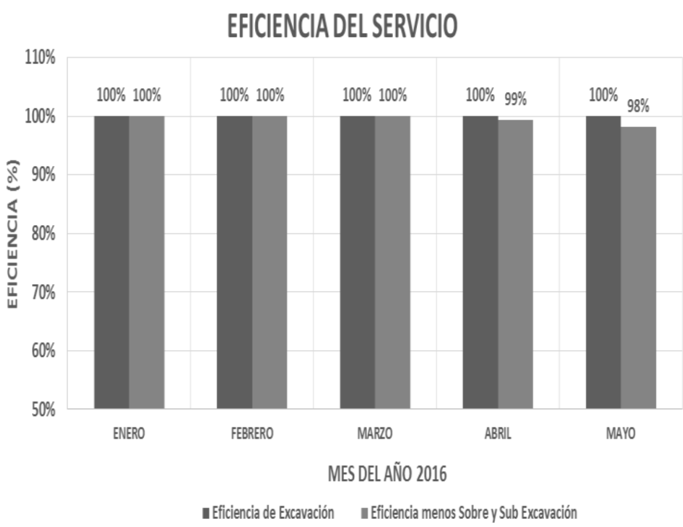

Figure 34: Result of blasting efficiency –Chavimochic Project from January to May 2016.

The goal of fragmentation: to be less than or equal to 300 mm, which is fulfilled according to the results obtained for each rock type between January and May 2016 an average result by rock type is presented (Figure 35).

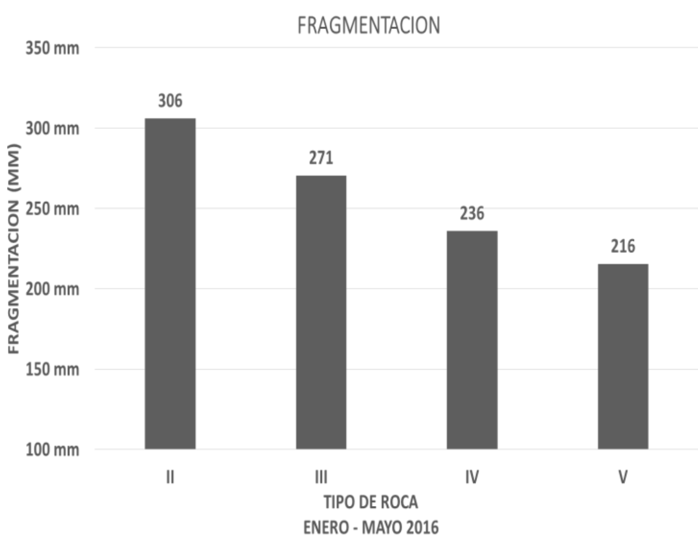

Figure 35: Result of Fragmentation –Chavimochic Project from January to May 2016.

An important part of the optimization process of blasting is undoubtedly saving time in the process of excavation, which is directly interlaced to effective blasting efficiency. So that could culminate to date (June 2016), with process of excavation of 2 tunnels, with lengths between 352 m and 590 m, obtaining a real time saver versus scheduled between 4% and 15 % (Figure 36).

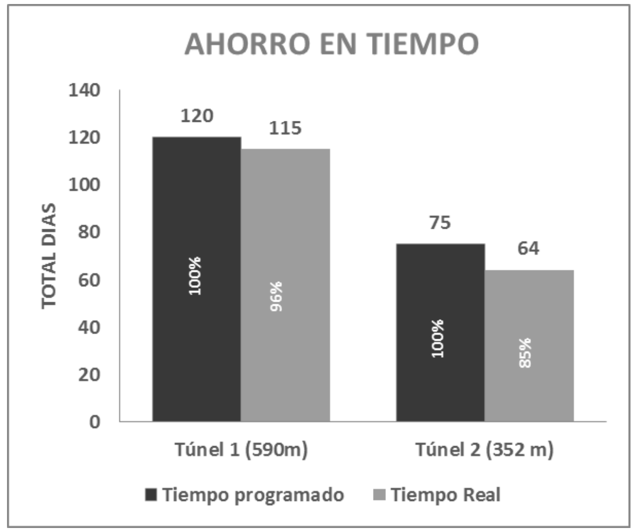

Figure 36 : Result of efficiency savings related to runtime.

CONCLUSION

The performance of the whole team CHAVIMOCHIC - DNA BLAST has allowed good results in productivity and progress in implementation of the tunnels, having from January to May 2016, 326 blasts and 1160.73m in tunnel excavation, and a total of 730 blasts and 2565.17m throughout the project.

It has been able to sustain performance indicators blasting, achieving an average of 100% in efficiency, minimizing damage to the section and controlling the overbreak and underbreak keeping them less than 5% expected.

Comparing cost of the traditional method with the application of the scientific method, operating costs were reduce at 2.50% during excavation of tunnels. This percentage already considered service costs and use of the scientific method, as well as non-quantifiable reductions including the issue of security by controlling structural damage rocky mass.

Geophysical tests and use of DNA Log software, allows to know the geological behavior of environment, to perform more efficient blasting plans.

The results of simulations carried out in the I- Blast software, used to design drilling meshes and blasting plans, are more precise and benefits related to optimization are even better when the model is powered with coherent and complete measures, made with the greatest rigor. With this purpose, DNA -BLAST team based on its technology and in coordination to Concessionary Chavimochic, has developed a protocol of performante and compatible measures with the production cycle for tunneling, this can be replicated for all material to be extracted in any location.

The contributed benefits to Chavimochic, both, the point of view of reducing damages as increased productivity, come from this unique combination of experience and technology forged over the last 25 years.

Our experience proves that these benefits are equally playable on any type of tunnel construction.

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