5. Shot hole development

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Blasting Technology with no sub-grade drilling for the conditions of Klokotniza quarry

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ABSTRACT: Klokotniza quarry, Haskovo, Bulgaria extracts marble dolomite. The blasting field is set up with boreholes of 11m depth, 110 mm diameter, sub-grade of 0.5 to 1 meters, and spacing of the plugs 3x3 meters.

Full-scale tests were performed on a new technology that aims to eliminate sub-grade drilling, improve fragmentation and reduce explosive mix consumption.

Results have shown well-formed bench levels under the borehole plugs, reduced explosive consumption by 15 to 17% and reduced cost of drilling of about 5%. Reductions were noted in the gas-dust emissions (15-20%) and the overall seismic effects (more then 15%) as a direct result of fewer explosive materials used in the blast. It is concluded that the new blasting technology to eliminate sub-grade drilling is feasible and effective for the conditions of the Klokotniza quarry.

1. INTRODUCTION

In recent years the extraction of inert materials in the republic of Bulgaria has seen substantial growth mostly credited to the modernization and expansion of the road infrastructure and related public works. In today's highly competitive environment, created by increased commerce within the EU and on the world market, continual innovation is crucial for the economy and the environment.

The main objective of the newly developed technologies in our industry should be to significantly reduce explosive consumption per meter of rocky mass, thus lowering the total cost of blasting operations and lessening the environmental impact of blasting.

Quarries are typically built 1000 – 3000 meters from settlements and this proximity requires special consideration in minimizing the adverse effects of blasting. Gas emissions from the blasting operations are typically in the range of 100-200l CO as large quantities of carbon dioxide and nitric oxides are also being released in the environment. Air quality and dust are also important concerns. Additionally, ground vibrations caused by the seismic effect of the blast should be brought to a level that causes minimal effect on residential and industrial buildings and equipment. Fly rock and shock wave of the blast should also be minimized (Kamburova 2007).

The adverse effects of blasting operations are to be controlled and brought in compliance with the standards developed by CEN per Directive

93/15/EEC of 5 April 1993 on the harmonization of the provisions relating to the placing on the market and supervision of explosives for civil use.

This paper reviews the results obtained from a full-scale testing at Klokotniza quarry of the technology developed by Frank Chiappetta that aims to eliminate sub-grade drilling, improve fragmentation and reduce explosive mix consumption.

2. CURRENT BOREHOLE TECHNOLOGY AT KLOKOTNIZA QUARRY

Klokotniza quarry is located in south-east Bulgaria near the settlement of Klokotniza. The rocks from which the valuable materials are extracted are marble limestone with strength of pressure of 8,000-10,000 kg/cm^2. This is a monolith no foliated metamorphic rock.

The current blasting scheme at the quarry utilizes boreholes laid out in a 3x3 meter pattern. The boreholes are drilled vertically with 105mm diameter, 10-11m depth, and are loaded with 8.65 kg roughly dispersed explosive.

Depicted in Figure 1 is a typical construction of the charge. The 10.65m borehole is loaded with continuous explosive column of 8.65m and 2m stemming and there is 0.5m sub-grade. The maximum quantity of explosive being blasted with a single delay charge is 500kg. The quarry utilizes diagonal scheme of blasting with non-electric technology and delayed interval between the charges of 25ms. Used is a combination of GDA-LM sensitised with TNT and GDA-BM sensitised with smokeless powder, as the average explosive consumption is 0.880 kg/m^3 (Kamburova, Lazarov 2003).

The conducted brief analysis of the currently used blasting parameters at Klokotniza quarry led us to the following conclusions:

- The relative large quantity of explosive used leads to larger quantity toxic gas and dust emissions, ineffective utilization of the energy of the blast and higher cost of blasting operations.
- The 3 x 3 meter scheme is too dense leading to excess of boreholes, materials and labour.
- The relatively small diameter of the boreholes of 105mm increases the cost of drilling.
- The 0.5m sub-drilling damages the top level of the next bench, leading to problems with initiating of the drilling and hinders the speed of drilling.

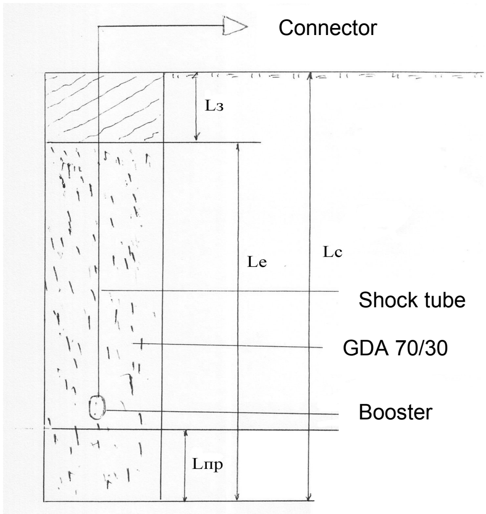

Figure 1: Typical charge construction at Klokotniza quarry. Lз Stemming-2 m; Lпр Sub-grade -0,5m; Lc Borehole-10,65m; Le Explosive-8,65m.

Reducing the relative expenditure of explosives and streamlining the blasting operations can substantially reduce these negative effects of the operations.

3. TESTING THE TECHNOLOGY WITH NO SUBDRILLING

The purpose of this research and industrial testing is to establish the overall effect of the technology with no sub-drilling and how it compares to the currently used technology at the quarry. More specifically, investigated were the fragmentation achieved with the two technologies, expenditure of explosive, level of the bottom bench, the emitted gas-dust emissions and the seismic effect of the blast.

The experimental blasting was conducted on a field with 85 boreholes mirroring the parameters of the currently used technology. The boreholes were with diameter of 105 mm, depth 10-11 m and layout of 3 by 3 m.

The blasting field was laid out with 5 rows and 17 boreholes on each row. The test field was divided into two sections – the first one had 8 boreholes per row, the second had 9 boreholes on each row. Both sections had a diagonal blasting scheme with 25ms delay between the charges and were blasted simultaneously with a zero delay connector and electric detonator of second class. Figure 2 illustrates the test field setup.

In the section of the field laid out with the currently used technology, the 40 boreholes had an average depth of 10.70m and 0.5m sub-grade. They were loaded with a standard full column of explosives as each borehole had 82kg explosive and 2m stemming at the top.

In the section of the field with no sub-grade, the 45 boreholes were loaded with a smaller column of explosives, a meter air deck by design of Power Deck TM at the bottom of the hole, and no sub-grade (Frank Chiappetta 2004). Over the plug the borehole was loaded with a non-cartridge explosive and 2m stemming. This construction reduced the column of explosives with 1.5m and led to 13kg savings per borehole. The overall reduction of expenditure of explosives in the tested section was 585kg (45x13kg) leading to 15-17% in cost savings. Furthermore, the average depth of the boreholes was 0,5 less the standard depth at the currently used technology which yielded reduction in cost of about 5%.

The results of the Normal and Power Deck TM blasting are as follows:

Good fragmentation was achieved in both section of the blasting field. (Figure 3.)

The floor of the next bench was well formed, and there were no significant differences between the two sections.

The experimental section with no sub-grade drilling produced very good results with savings of 15-17% on explosives and 5% on cost of drilling with good fragmentation and well formed bench level.

There was a substantial reduction of toxic gases emitted in the environment, clearly visible from the photos in the two sections of the tested field, the left side loaded with the current technology, the right side laid out with the new one (Figure 4.).

The conducted industrial testing established that the new technology with no sub-grade drilling is applicable for Klokotniza quarry and can be successfully implemented there. These results warrant a further study to identify the optimal parameters of the blasting scheme, depth, length and construction of the boreholes, and the used explosive.

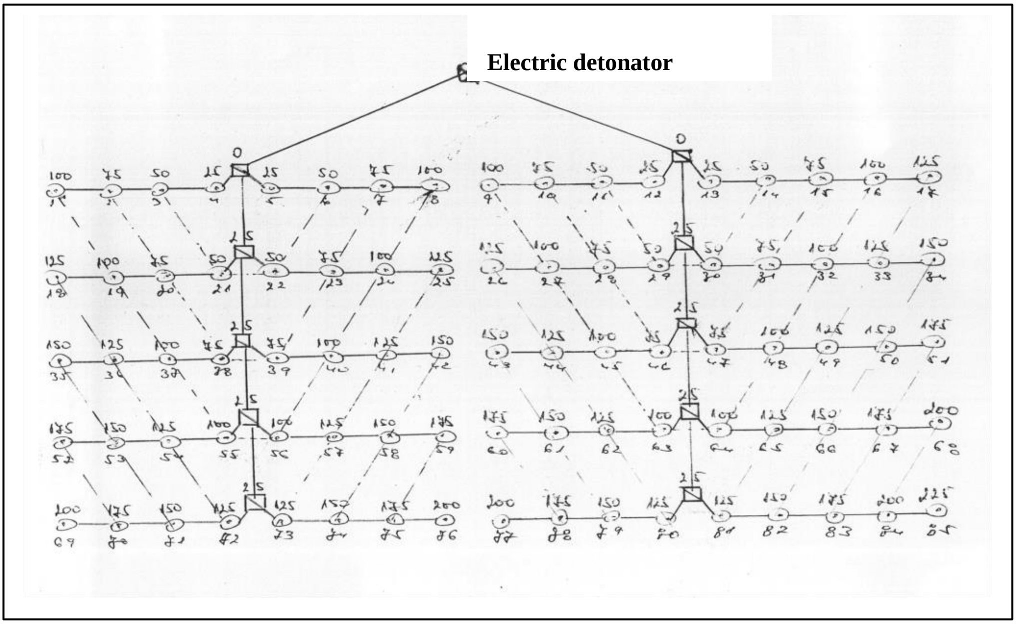

Figure 2. Layout of the blasting field. The section to the left is loaded with the currently used technology, the section to the right with the new no sub-grade technology.

Figure 3. Fragmentation of the material as a result of the blast. The section to the left is loaded with the currently used technology, the section to the right with the new no sub-grade technology.

Figure 4. Gas/dust emissions at the end of the blast. The section to the left is loaded with the currently used technology, the section to the right with the new no sub-grade technology.

The second industrial testing was conducted with a blasting scheme of 3,5 by 3,5m and average borehole length of 15m. The explosive used in this test was 10,7t of GDA-BM sensitized with smokeless powder. The blasting field was laid out in 5 rows with 20 boreholes on each row, divided in two equal sections with 50 boreholes each. The first section was constructed using the current technology with 0,5m sub-grade drilling.

The boreholes in the second section were constructed by the new technology with no sub-grade drilling and air deck of 1m. Similar to the first industrial testing, both sections had a diagonal blasting scheme with boreholes in diameter of 105mm and 25ms delay between the charges. The air deck in the borehole was created with the help of an elastic balloon, placed at 1m from the bottom using specifically designed flexible mechanism. The balloon was then inflated through it and once the required pressure was reached the content of the balloon was released automatically. The charge of explosive was placed above the balloon with the traditional set up. Both sides of the field were blasted simultaneously with a zero delay connector and electric detonator of second class.

Shown in Figure 5 are steps in preparing the air deck with the new elastic balloon technology.

The observed results from the conducted second industrial test are as follows:

– The explosive per borehole in the section with no sub-grade drilling was 17,3kg less than in the section with sub-grade. This resulted in overall savings of over 17% or 865kg explosive for the entire test.

– Very good fragmentation was achieved in the section with no sub-grade as the individual rocks were no larger than 60-65cm. The section of the blasting field with the traditional technology produced larger fragments as some of them reached 80-85cm.

– The new construction of the borehole and the flexible device for the elastic balloon are highly efficient and can be easily implemented in the quarry. They do not complicate operations and are relatively inexpensive (Figure 5).

The third industrial test used 10.3t explosive GDA-BM sensitized with smokeless powder. The entire field of 100 boreholes (5 rows with 20 boreholes on each) was set up with the new technology with no sub-grade drilling using the elastic balloon to create the air deck at the bottom of the hole. As the first two tests, used was a diagonal blasting scheme with boreholes in diameter of 105mm and 25ms delay.

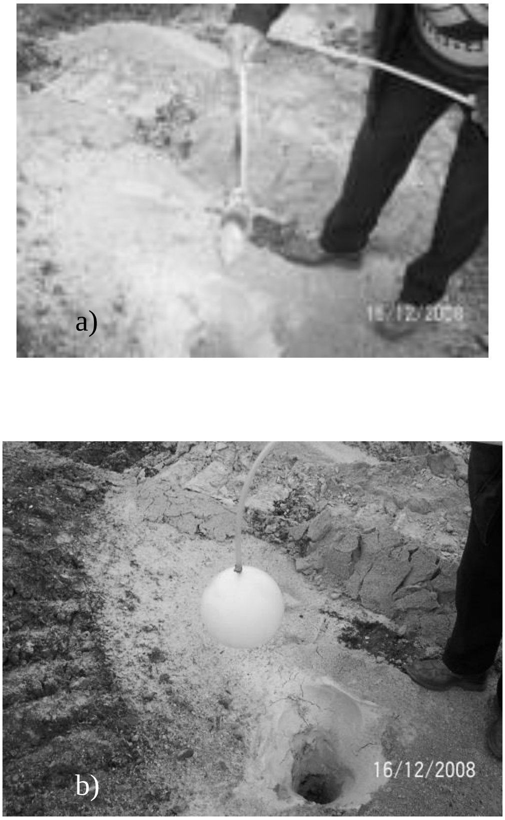

Figure 5. Preparing the air deck with the new technology of the flexible balloon.

The seismic effects of the test were absolutely acceptable as in 64m radius from the blasting field the vibrations reached a maximum of 17mm/s. Additionally, the lower bench was very well formed and its surface remained intact.

After the successful tests with no sub-grade drilling and air deck at the bottom of the borehole, conducted were industrial tests with different carrier of the physical blast at the bottom of the borehole.

To test the suitability of the new technology with no sub-grade drilling for sodden conditions, a plastic cartridge filled with water was lowered to the bottom of the borehole. The test field was laid out in 5 rows with 15 boreholes per row in a 3.5 by 3.5m scheme. The boreholes had depth of 15m, diameter of 105mm and in total 6,7t GDA-BM was used.

Figure 6 depicts the plastic water cartridge of 1m as the carrier of the physical explosion at the bottom of the borehole.

b)

Figure 6. Plastic water cartridge of 1m being lowered to the bottom of the borehole.

From the conducted industrial test utilizing the plastic cartridge filled with water for the carrier of the physical blast we can draw the following conclusions:

The blasting of the experimental field was successful and it covered 40m which is 10m less than the results achieved with the air deck.

The relative expenditure of explosive was reduced over 27% as the savings of explosive per borehole was 26kg.

Placing the water cartridge at the bottom of the borehole is practical and it doesn’t reduce the efficiency and productivity of preparing the field.

The fragmentation achieved was very good and the pieces were not larger then 40-50cm (Fig.7).

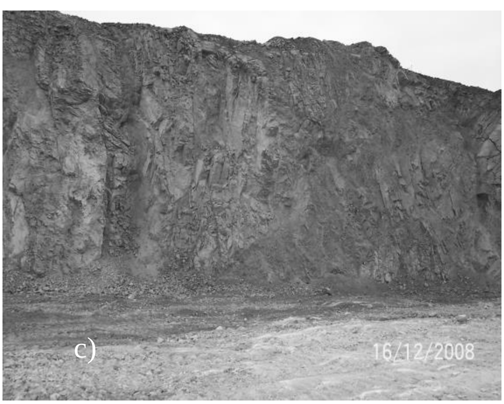

Figure 7. Fragmentation achieved with the water cartridge and floor of the second bench.

The test utilizing the water cartridge shows that the technology with no sub-grade drilling can be feasible and effective in sodden conditions.

4. CONCLUSIONS

Based on the conducted studies of the technology with no sub-grade drilling, we can conclude the following:

The current set up of the blasting field at Klokotniza quarry with boreholes with depth 11m, diameter of 110mm, and sub-grade of 0,5 leads to high average expense for explosives of 0,880 kg/m^3 rocky mass. The blasting scheme of 3 by 3m is labour intensive as there are too many boreholes being drilled. All this leads to greater pollution in the environment.

In recent years there have been numerous studies and experiments with the no sub-grade, air deck technology. The successful implementation of this technology leads to significant reduction of the harmful gas and dust emissions, the seismic shock and other negative effects of the blast.

In order to establish the feasibility of this technology for the conditions in Klokotniza quarry, we conducted industrial tests with no sub-grade drilling and 1m air deck at the bottom of the borehole. Results have shown well-formed bench levels under the borehole plugs, reduced explosive consumption and reduced cost of drilling. Reductions were noted in the gas-dust emissions and the overall seismic effects (more then 15%) as a direct result of fewer explosives used in the blast.

Developed and industrially tested was a new technology and mechanism for sub-grade drilling in which the air deck is created with an elastic balloon and a flexible device with which the balloon is lowered to the bottom of the borehole and inflated. This new technology is effective and suitable for Klokotniza quarry.

Developed and industrially tested was a new technology and mechanism for creating the charge with water cartridge at the bottom of the borehole. This new technology is suitable for sodden and dry conditions and is highly effective.

The rationalized blasting scheme of from 3,5 by 3,5m leads to the following:

- Reduced explosive mix consumption of over 25%;
- Reduced cost of drilling by 5-7%;
- Lower the seismic effect to 17 mm/s on 65m from the blast;
- Over 25% reduction of the harmful gas-dust emission and over twice the toxic nitric gases released in extractions at Klokotniza quarry through the utilization of roughly dispersed explosive with negative 8 to negative 10 % oxygen balance.

Based on the results obtained from the performed tests we recommend that the diameter of the blast holes be increased to 127-151mm, the bench level to 14-15 meters and the spacing between the plugs to 4x4 or 4x5 meters. Furthermore, based on previously performed laboratory and industrial tests, we recommend that bulk explosives with a negative oxygen balance be used.

Implementing the discussed new technology with 1m air deck at the bottom of the borehole as well as the recommended field set up is expected to increase over 30% the effectiveness of extractions at Klokotniza quarry.

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Manufacture of explosives directly at the face and their use by pumping, relating to safety, security and productivity

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ABSTRACT: Manufacturing directly at the face is a technology which is some fifteen years old, in terms of its exploitation on an industrial scale, in underground work sites or underground mines. It has been truly and definitively established in France for 3 years, and has already replaced a purely French method, the use of assembled dynamite or slurry cartridges (pré-charges), produced in a bungalow directly on the site. This article describes the feedback from experience in which M.O.R.S.E.® (MOdule for Repumping and Sensitisation of Emulsion) technology was used for managing 5 tunnelling projects using the blast method. It will consider questions of safety, security and productivity.

1. HISTORY

1.1 Changes in the regulatory context

Bulk explosive charge technology is by no means a new invention. Since its invention in the 1950s by the French group EPC (*Explosifs et Produits Chimiques* [Explosives and Chemicals]), ANFO has always been loaded in bulk, manually in bags or mechanically by pneumatic loading units.

Due to its binary formulation (technical ammonium nitrate + fuel), nitrate-fuel can be rapidly manufactured in the sites where it is used. In rock-classified underground mines without excess water, pneumatic loading devices (jetanol, portanol, etc.) have been developed to load this explosive in bulk form in horizontal mines; in this case the energy used to convey the nitrate-fuel is compressed air at a pressure of approximately 3 bars.

In tunnel excavation sites water-based boring and the natural presence of water in the bedrock do not allow the use of ANFO under good conditions of use and safety. In addition, the toxic fumes released following the firing (incomplete decomposition due to the small boring diameters used) greatly restrict its use due to the considerable time required for good ventilation for the working atmosphere. The use of cartridges, usually placed in pre-loading rods, was then the only alternative for the companies.

The loading of (previously packaged) nitrate-fuel by pneumatic energy requires no particular authorisation except that the nitrate-fuel manufacturer must propose usage authorisation for this type of loading, and that the loading equipment must be of a type authorised by the ministry of mines; only a few examples of such equipment currently have this authorisation.

Figure 1. ANFO loader.

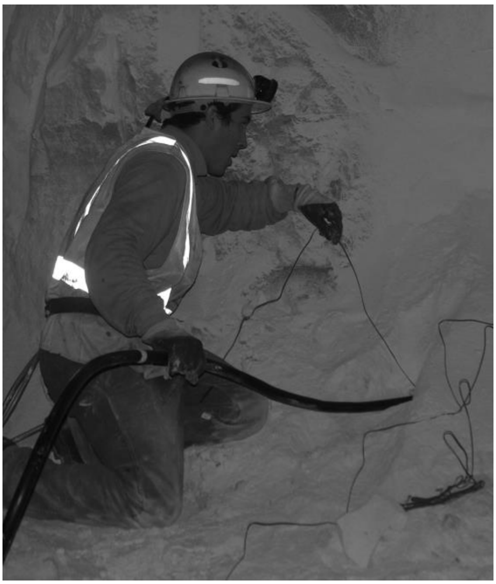

Figure 2. Pneumatic loading of the ANFO.

In respect of pumpable emulsions, a distinction must be drawn between categories:

Those which are already sensitised, and therefore explosive, and which are then re-pumped into the mine hole through a MOINEAU®-type pump. This type of technique has the disadvantage that a class 1.1 product is stored in bulk in tanks or GRVs in non-negligible quantities, on site. This process is used in certain mining countries and in certain countries where on-site manufacturing is not yet authorised systematically due to questions of national security (Spain, Italy, etc.).

Those which are sensitised at the face at the time of use by means of a module which will blend various components in order to sensitise a matrix, which initially has a 5.1 or 1.5 D classification, depending on the country. This process has the advantage of ease in terms of storage and logistics, but the idea of explosives manufacturing then comes into question. This process is far from being the most commonly used for obvious reasons of safety and security.

While in many countries (first experiments using TP in Hong Kong during the excavation of the Cheung Ching tunnel by DTP HK, a subsidiary of Bouygues Construction in the early 1990s), the use of the bulk emulsions technology had become a reality, in France it met with the problem, due to the fact that of the concept of the manufacture of explosives, of the classification of the activity in terms of classified installations, since the listing in question then required that a file for authorisation of use of an ICPE (Environmental Protection Classified Installation) be submitted. The investigation period and the requirement for a public investigation enquiry could not then be compatible with the tunnel site construction times. However, the law allowed a simplified procedure known as a test procedure for 6 months, renewable once, in order to test the technology with a view subsequently to changing to an authorisation phase. Thus, the first French experiment was able to be conducted in 2 sites:

The first in the Sinard tunnel (A51 French highway), as a test, at the very end of the site construction process (October 2005)

The second in the SALAZIE project (Réunion Island, from July 2006 to today), drive by Rivière des Pluies JV following the blockage of the tunnel boring machine.

Regulation has changed since this time, to include explosive manufacturing activity on sites where they are used under the declaratory regime, and no longer the authorisation regime. The intent of this modification was to allow industrial use of the manufacture of emulsions on site in road excavation sites, since the times for obtaining the exploitation order for each site were now short (3 weeks to 1 month after submission of the file at the Prefecture).

Use of pumpable emulsion technology consequently requires:

- An exploitation declaration file, an ICPE for the manufacture of explosives at the face (Prefecture of the place where it is to be used).
- A file for declaration to use an ICPE for storage of dangerous goods (combustive material 5.1) for the storage of matrix and gazing agents (Prefecture of the place of storage, which is generally the same as that of the place of use).

These files are generally constituted by the explosive's supplier.

1.2 Feedback of French companies

The second hindrance to the development of the pumping of emulsion in France lay in the limited feedback acquired with this technology by French companies. Except for the one having acquired export construction contracts and in countries with sufficiently liberalised regulations in the field of on-site explosives manufacturing, few companies wished to 'go through the teething troubles'. One might mention GTM (VINCI group) in the site of the Hong Kong Metro, VINCI during the excavation of the LOTSCHBEG tunnel (Mitholz window), or BOUYGUES TP, with more substantial experience in the Cheung Ching, TAIL LAM 1 and TAI LAM 2 projects in Hong Kong and LOTSCHBEG project (Ferden window) in Switzerland.

In France the first industrial experiment did not take place in mainland France but in Réunion Island, where the SPIE, BOUYGUES and RAZEL/BILFINGER joint venture used bulk emulsion technology to compensate for the failure of the tunnel boring machine during excavation of the Upstream SALAZIE project, and due to the lack of any logistical solution for conveyance and storage of class 1.1 products in the island; this experiment began in July 2006 and is still continuing; more than 1700 lm has been excavated with M.O.R.S.E® technology (see below).

As a consequence of the experience acquired by Bouygues TP in the past with this technology, and especially by the executive team with responsibility for the project (experience gained in Ferden and Hong Kong), the excavation of Grands Goulets tunnel (Drôme department in France) was naturally set to be the first in mainland France to be excavated using bulk emulsions.

Following the start of the experiment in Grands Goulets tunnel, other companies adopted M.O.R.S.E® technology and chose it for the excavation of their blast sites: one may mention:

- The Modane windows access project and the La Praz windows access project for the next LYON TURIN TGV project
- The Chavane rail tunnel for the Rhin-Rhône LGV
- The Sommand road tunnel
- The 'Galerie des bois' tunnel for hydraulic project (EDF) – started in February of 2009

2. REGULATORY OUTLINE

When use of explosives to dig a gallery is allowed, various forms of loading can be envisaged, depending on the local regulations, the goals sought, the available technologies and products, and the environmental constraints. One may mention:

- Manual loading, cartridge-by-cartridge
- Loading of pre-charging rod
- Pneumatic loading of ANFO
- Re-pumping of 'liquid' explosive
- The manufacture of explosives directly at the face and their use by pumping

2.1 Manual loading, cartridge-by-cartridge

This technique, which is used occasionally in large sites, or more systematically in small mine roads, is less and less frequently used due to the low productivity resulting from it (long loading time), and to the low level of safety resulting from it (risk of jammed cartridges, unsatisfactory continuity of the load).

Apart from the habitual rules relating to the acquisition of explosives on site (acquisition title), the competences and authorisation of the personnel (CPT, firing permit) and, if applicable, those relating to the storage of the products on site (authorisation to operate a fixed or mobile deposit), no other special administrative procedure must be followed.

2.2 Loading of pre-charging rods

This technique was the most common one until recently in all blast excavation sites. It consists in making, in a dedicated area, and as a background task, by a qualified and authorised operator, rods cut along the desired pull, filled with cartridges, and in conveying them at the time of loading directly to the face in an appropriate and approved vehicle. This method which has proved its worth for more than 20 years has the advantage that it increases productivity and systematises the loading, thereby reducing the risks of non-burned residues and also the risk of cartridges being misappropriated. This method is covered by an AFTES recommendation and is in the course of being rewritten.

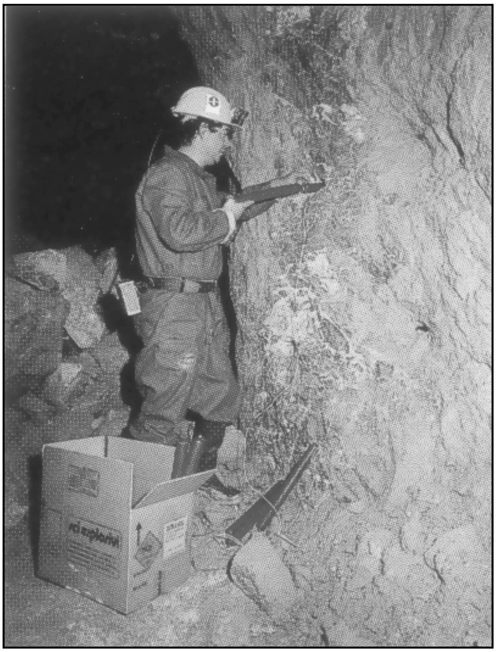

Figure 3. Loading cartridge-by-cartridge.

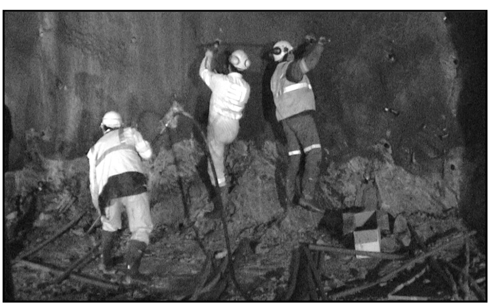

Figure 4. Placing of pre-charges.

A few uncertainties nonetheless remain relating to the classification of the pre-load location and the activity resulting from it (pyrotechnical activity, pyrotechnical location which is classifiable under the same regime as pyrotechnical installations), the consequences of which are the establishment of wide exclusion zones in the site (site floor area), and reduced activity around the site, and consequently the fact of having to obtain an administrative authorisation.

2.3 *Pneumatic loading of ANFO*

This technology is very commonly used in the extractive industry (underground gypsum, anhydrite or limestone quarry, or underground mines without risk of dust or inflammable and/or explosive gases), provided water is absent or present only in small quantities in the deposit to be exploited. It consists in loading ANFO with pneumatic energy (stainless steel receptacle at air pressure, or suction device using the Venturi effect). This technology has the advantage that it is very productive (speed of loading, bulk explosive occupying 100% of the hole), and is very low in cost.

Figure 5. Pneumatic ANFO loading device.

In regulatory terms the ANFO must be authorised for pneumatic loading, the loading equipment must be a certified model, and the operators must be trained and authorised for this.

2.4 Re-pumping of explosives

This technology allows one to benefit from certain advantage of bulk explosives method (notably filling the hole, and ease of loading). The re-pumped product must be authorised for this type of loading, and the equipment authorised by the State.

The major disadvantage of this method lies in the supply or storage of the product. This is because the product in question is class 1.1 (explosive material) and subject to the same constraints as an explosives storage (long and detailed administrative files, land area of the storage installations). This technology is used in countries where on-site manufacture is not permitted due to questions of regulations relating to security (notably in Spain).

2.5 On-site manufacture and placing by pumping directly at the face

This quite recent technology (less than 20 years old) enables an explosive product to be manufactured from so-called raw materials stored on site, using a stock emulsion sensitisation technique.

This means that it enjoys all the advantages of the loading of bulk explosives (notably filling of the hole, and ease of loading) and substantially reduces the class 1 products storage constraints (only the priming system and detonators devices can be stored on the site or delivered day-by-day by the supplier). Indeed, the products required for the manufacture of explosives are class 5.1 combustive materials, and thus are not covered by the regulations covering pyrotechnical installations (depending on the country of use).

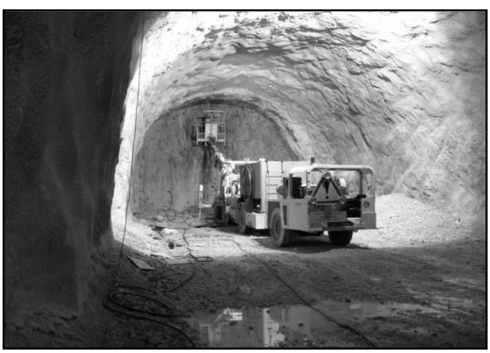

Figure 6. Pumping at the face.

From the regulatory standpoint, the manufactured product must be authorised for pumping, the equipment authorised by the State, and the personnel trained (by the manufacturer) and authorised (authorisation of the employer, shot fire licence). The storage installations must be covered by a combustive materials storage declaration.

3. FEEDBACK FROM 5 EXPERIMENTS CONDUCTED IN FRANCE SINCE 2005

Since 2005, 5 sites have used the M.O.R.S.E.® system developed by the Nitrochimie company (a subsidiary of the EPC group), in order to accomplish progress with explosives. These sites were excavated in geologically different environments, and the rock excavation sections together with the lengths of advance have constituted a diversity of experiments. One may mention:

Salazie hydraulic mine road (Rivière des Pluies drive since 2005-2007, and Rivière du mât since 2007), in Reunion island (indian ocean)

Grands Goulets road tunnel– 2005-2006

Modane LTF incline shaft (from PM1700) 2006-2007

La Praz LTF incline shaft (from PM 300) since late 2006-2009

Chavane rail tunnel on the Rhine-Rhône LGV, since mid-2007-2009

Somand road tunnel (2008)

3.1 Salazie hydraulic mine road

SALAZIE hydraulic site (Réunion Island) forms part of the project for irrigating the west coast, and contains nearly twenty kilometres of tunnel in order to convey the water from the Salazie cirque (yellow flower arm capture) to the west coast (sugar cane cultivation and tourist area). This project was awarded to the SBTPCI, RAZEL, BILFINGER, BOUYGUES TP joint venture.

In the normal course of events most of this project was to be undertaken using a tunnel boring machine, but as a consequence of the presence of quantities of pressurised water, the TBM was stopped after only 300 metres. A bypass had then to be excavated as far as the head. The decision was then taken to continue the project using drill & blast method, whilst awaiting a modification of the head of the TBM, and in order to pass through two highly water-bearing zones. 1800 lm of gallery was then created from the Rivière des pluies window drive between July 2005 and November 2006. As a consequence of the delay in the project relative to the initial schedule, a second window using drill & blast method too, was decided on the Rivière du Mât side over approximately 800 lm.

Figure 7. Rivière des pluies tunnel portal – Salazie project.

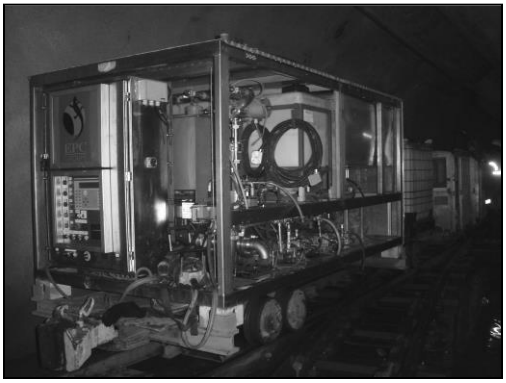

Figure 8. M.O.R.S.E. unit on lorry in the Salazie project.

The main difficulties encountered in this project relate to the supply of class 1 products (cartridges, detonating cord, detonators) from mainland France (no freight links have accepted this type of danger for delivery to La Réunion since 2006), making it necessary to charter a private cargo aircraft at a prohibitive cost, and the presence of pressurised water in the water-bearing zones. Due to the difficulties in supplying class 1 products, the on-site manufacturing solution was then envisaged with the M.O.R.S.E.® solution, using materials which were easier to convey to the site (class 5.1 combustive materials).

Characteristics:

Length: 7800 lm – 2 drives using blasting

Common section between 19 and 25 m²

Drilling length 3.20 m

Drilling diameter 45 mm

Drilling machine: manual 2-boom jumbo - Robodrill

Rock: Basalt and scoria

Initiation: HI electrical detonators

The initial firing plan with emulsion cartridges included 82 holes drilled in 48 mm. After a few test firings the M.O.R.S.E.® method rapidly enabled the number of holes to be reduced to some sixty, and the boring diameter from 48 to 45 mm, in order to reduce the consumption of pumpable emulsion per cubic meter. The specific charge remains 40% higher than that used with traditional explosives, because of the filling.

The time required to load the face with the M.O.R.S.E.® method (2 loading tubes at the face) is less than 30 minutes, representing a gain of approximately 15 minutes or more in the scoria (difficult holes to load).

To summarise, the M.O.R.S.E.® method firstly enabled the problems relating to the supply of explosives to the site to be resolved. It was the first industrial experiment in France with sensitised emulsions pumped at the face. After a one month supervisory period all the teams were able to appreciate the loading comfort using this method.

3.2 Grands Goulets road tunnel

The Grands Goulets links Valence to the Vercors plateau by a tourist route using a narrow, dangerous road made from corbels and small, narrow tunnels. After a few rock slides, in 2005 Drôme General Council decided to build Grands Goulets tunnel linking Echevis to Les Barraques in the Vercors. The contract was awarded to BOUYGUES TP. The start of the first full-section firings took place in March 2005.

The motivation which induced the company to choose the M.O.R.S.E.® method for a first industrial experiment in mainland France was the experience of its executive personnel, acquired in

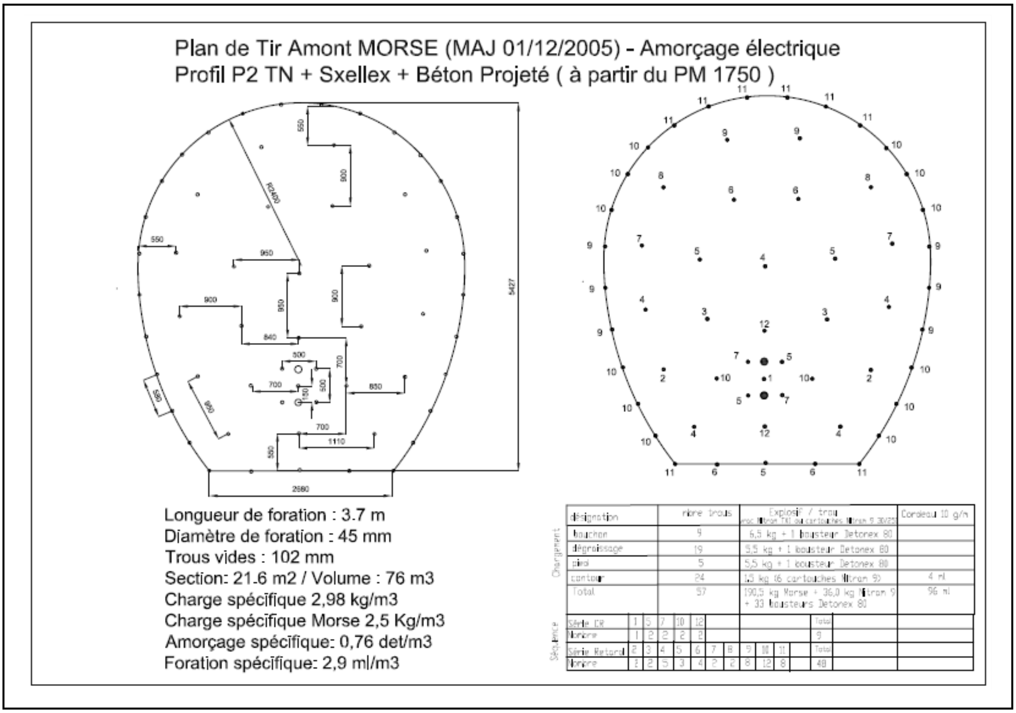

Figure 9. MORSE Upstream Firing Plan (Update 01/12/2005) - Electrical initiation Profile P2 TN + Swellex + Projected Concrete (from PM 1750).

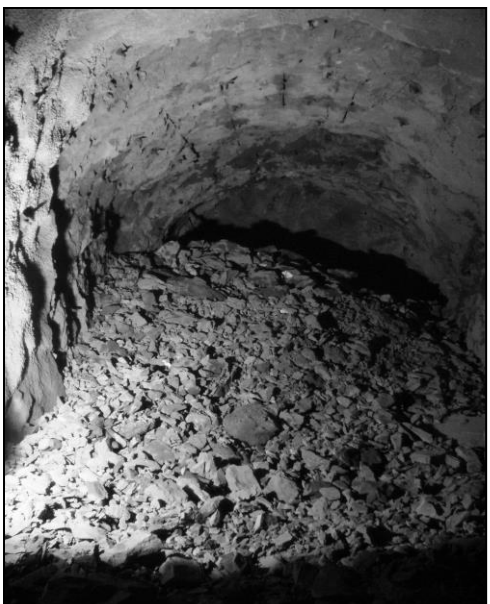

Figure 10. Result of a firing undertaken with M.O.R.S.E. in Salazie.

Figure 11. Overview of the Grands Goulets road.

export sites, and the determination of Nitro-Bickford, as an innovative company, to wish to bed down this technology in tunnel sites.

Characteristics:

- Length: 1750 lm and 800 lm for the cross passages – 1 drive using explosive

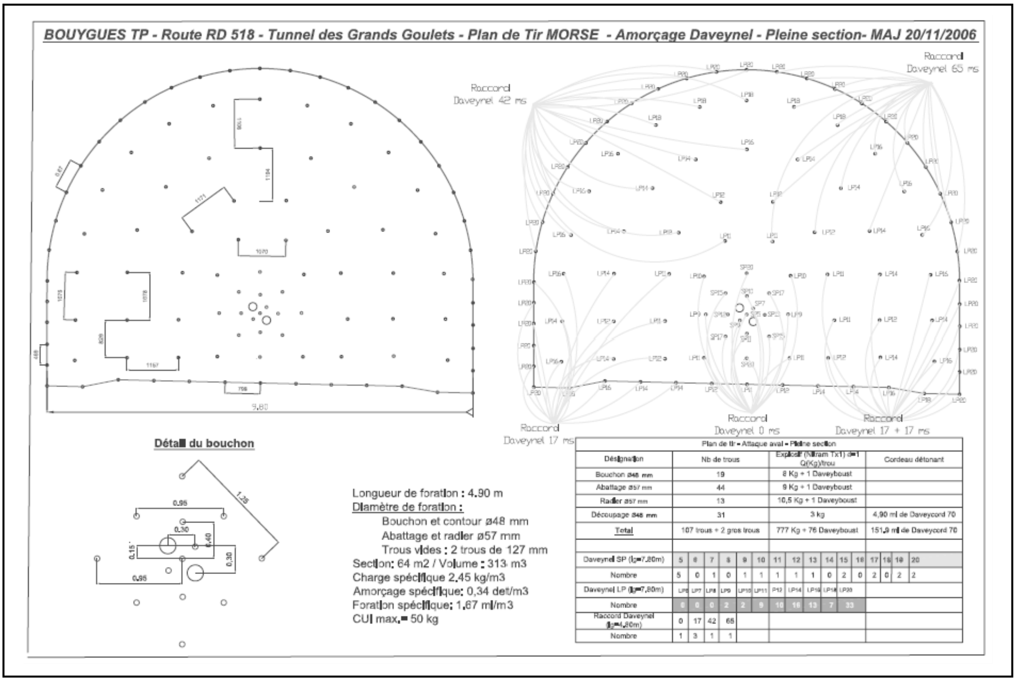

Figure 13. Firing pattern in the Grands goulets tunnel.

- Common section 67 m² and 9 m² for the safety branches
- Drilling length: 5.00 m
- Drilling diameter: 48 mm followed by 57 mm
- Drilling machine: automatic 3-booms jumbo-Robodrill
- Rock: fractured limestone
- Initiation: non-electrical detonators

Initially the pattern was designed using 48 mm holes, but as a consequence of the fracturing of the limestone bedrock leading to the frequent sealing of holes, the use of 57 mm diameter was chosen, greatly facilitating loading. The use of a larger drilling diameter did not enable the pattern to be broadened as substantially as desired, due to the relatively small section of the tunnel: the pattern is an imbrication with a geometrical profile and any widening of it rapidly reaches its limits in the average to small sections. As a consequence the specific load remained 40% greater than the one which could be foreseen with traditional cartridge loading.

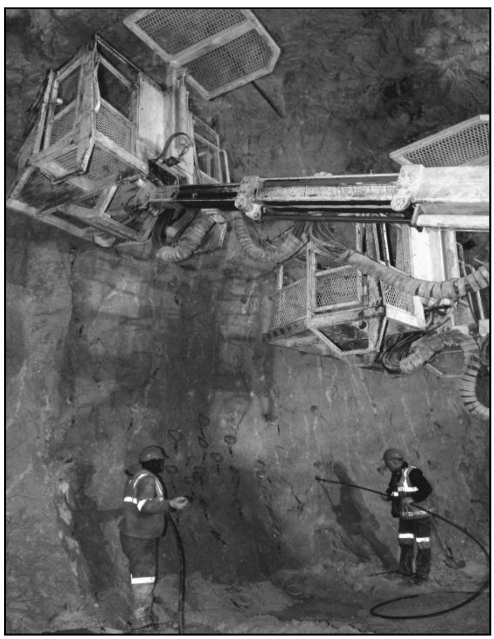

Figure 14. Loading a pull with M.O.R.S.E in Grands Goulets tunnel.

The time to load the face and connect the detonators with the non-electrical system was, on average, 80 minutes with 110 holes.

The use of the M.O.R.S.E.® system enabled constraints relating to a prepared charge shop (a site installation and a dedicated team) and to storage of class 1 products to be avoided. The time gains for the loading of a pull were, on average, 30 minutes compared to a conventional loading (prepared charge and electrical sequential firing).

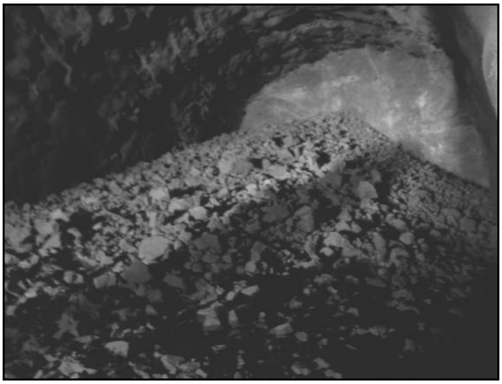

Figure 15. Result of a blast loaded with M.O.R.S.E – 4.00 m length – Grands Goulets Tunnel.

3.3 Modane LTF access

The Lyon-Turin rail project (basic tunnel twice 55 km) involves 3 reconnaissance tunnel on the French side (Saint Martin la Porte, La Praz and Modane) which will be used as an access window for the basic tunnel excavation works. In Saint Martin la Porte access it was possible for the first 1000 metres of excavation to use explosives due to the satisfactory geology encountered; from this point forward, progress was made using conventional means. The Modane access began in 2002 with a first company which built the first 1000 metres.

A second invitation to tender was then decided by the project owner, which was awarded to the RAZEL-BILFINGER-BERGER joint venture. The site director wished, as requested in the contact, to undertake a test with a bulk emulsion, and in July 2006 the M.O.R.S.E.® system started at PM1700. Since the production teams were completely satisfied with the solution it was retained as far as the bottom at PM4200.

Characteristics:

Length: 4200 lm – 1 drive using explosive

Inclination 12%

Common section 70 m² to 130 m² for the storage areas

Drilling length 5.00 m

Drilling diameter 48 mm

Drilling machine: automatic 3-booms jumbo – Atlas Copco

Rock: shales and quartzite

Initiation: sequential HI electrical detonators– non-electrical detonators towards the end of the site

Figure 16. M.O.R.S.E unit mounted on a 6x4 truck– Modane access.

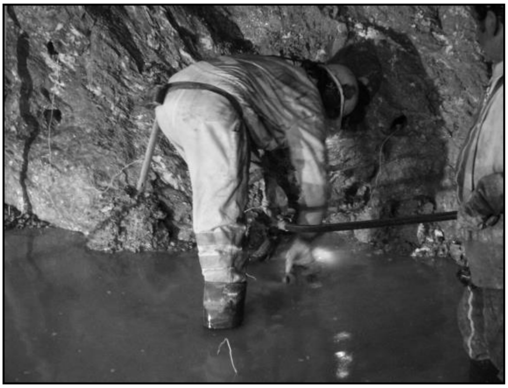

Figure 17. Pumping of the emulsion into the Modane incline shaft sole.

The M.O.R.S.E.® system was brought into service in the course of the site and the sequential electrical initiation which was then used was retained for some time. Due to the presence of water at the face, and to the consequences for the

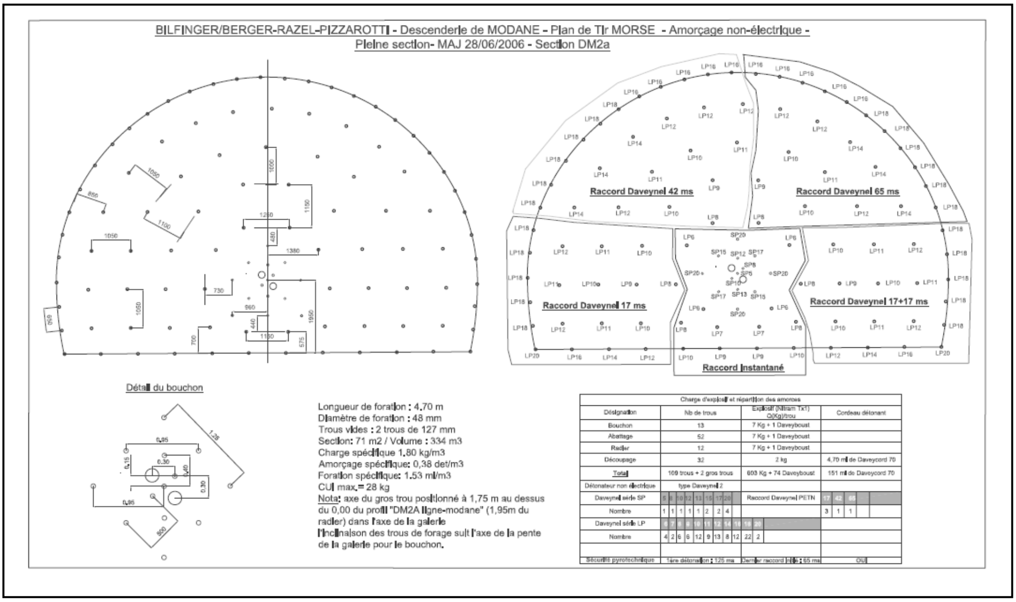

Figure 18. Firing pattern in common area.

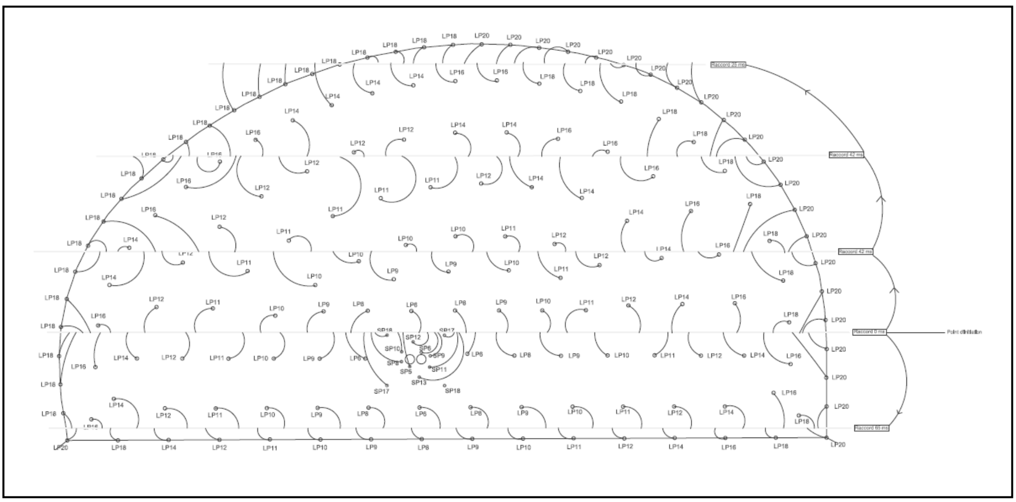

Figure 19. Firing sequence in large area with non electric system.

control of the sequential firing plan lines, non-electrical initiation was rapidly suggested to the production teams, which were able to appreciate the speed with which it could be used. In the storage sections (130 m²), non-electrical initiation also allowed full-section firing, whereas with sequential firing the high number of detonators did not permit it.

In the storage section the quantity of explosive per firing reached 1000 kg, with the consequence that there were very high volumes of gas after firing in the mine road, and the installation of a water mist-making system in front of the blowing ventilator in order to bring these gases down.

With a section of 130 m², the use of 57 mm diameter enabled the firing meshes to be tested up to spacings as great as 1.25 m, and by this means economies could be made on up to 20% of holes.

In the common section the loading, connection, firing and ventilation cycle for 5.00 lm advances did not exceed 2h30.

Figure 20. Mist production from water after firing and during mucking –Modane access.

The specific load was 30% higher compared to a traditional loading.

In this site, use from the start with the M.O.R.S.E.® system would have allowed an economy in relation to the construction of a 2t explosive depot and of a pre-load workshop, together with the personnel dedicated to these facilities.

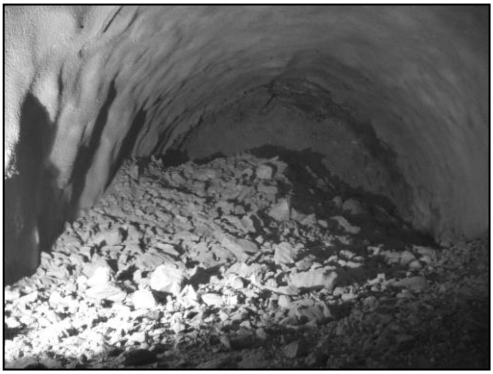

Figure 21. Result of a blast loaded with M.O.R.S.E – 4.00 m length – Modane access.

3.4 *La Praz LTF access*

La Praz access is the third incline tunnel of the LTF project on the French side. The work began in November 2005 with a pre-load workshop, and subsequently, in November 2006 (approximately PM 300), the M.O.R.S.E. ® system was installed in accordance with the company's wishes and with the requirements of the contact, in which the companies were required to conduct a trial. Since this time all the blast have been made with a bulk blended at the face, and immediately pumped into holes. The SPIE BATIGNOLES-SOTRABAS-GHELLA JV was chosen to drive this project. The geology encountered requires a heavy support method (umbrella arch, heavy arch, Swellex bolts and projected concrete) and short pull-lengths (2.50 lm).

Characteristics:

Length: 2200 lm – 1 drive using explosive

Inclination 12%

Common section 67 m² to 90 m² for the storage areas

Drilling length 2.50 m

Drilling diameter 51 mm

Drilling machine: automatic 3-booms jumbo - Atlas Copco

Rock: shales

Initiation: non-electrical detonators

The M.O.R.S.E. ® system was very quickly chosen by the site production teams, which were able to appreciate the gain in productivity obtained through the ease of loading with the rigid tubes, and also the flexibility of the system, which enables the quantity per hole to be adjusted very accurately by remote control means (start/stop), without a wire being held by each operator (for starting and stopping the pumping cycle).

Non-electrical detonators was also very quickly chosen since, compared to electrical sequential firing system, the gain in time is non-negligible (minimum 30 minutes per cycle). The time required for installing the equipment, loading, connecting the pull, firing and ventilation did not exceed two hours for a pull of 110 holes.

3.5 *Chavane railway tunnel (Rhine/Rhône LGV)*

Chavane railway tunnel forms part of the C1 batch of the Rhine/Rhône LGV line due, on completion, to link Lyon to Strasbourg. The invitation to tender was awarded to the SPIE BATIGNOLLES / CHANTIERS / MODERNES / CAMPENON / BERNARD TP Joint Venture.

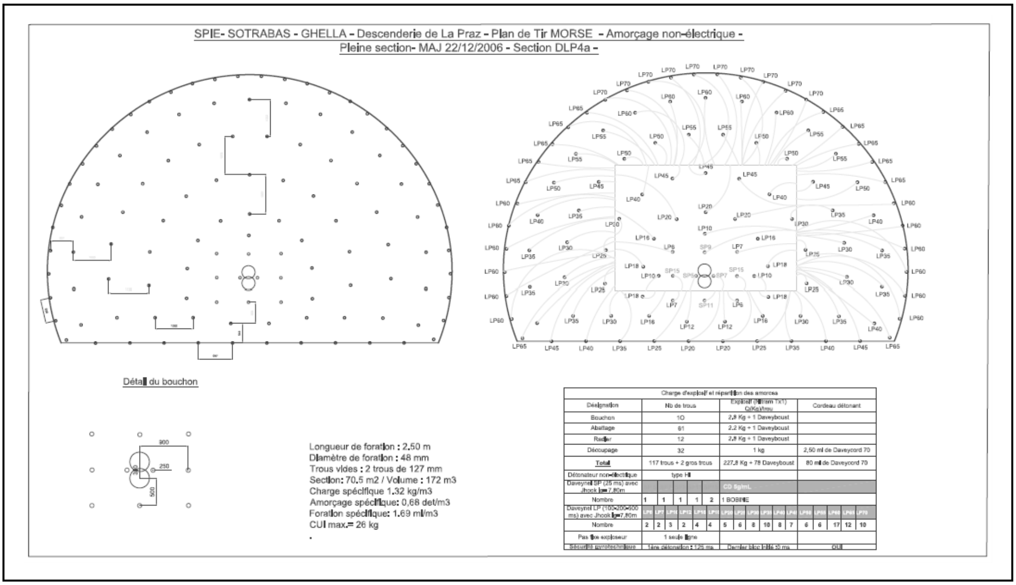

Figure 22. Blast pattern – La Praz Access.

Figure 23. M.O.R.S.E unit mounted on 4x4 truck, La Praz access.

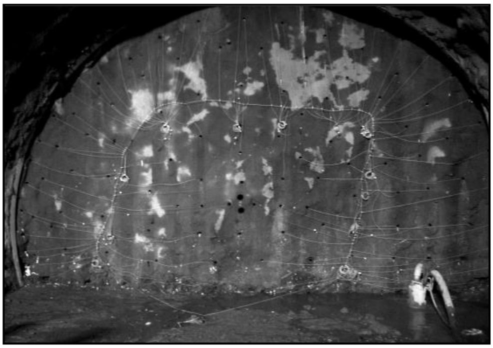

Figure 24. Non electric system at the face – La Praz access.

Figure 25. Result of a blast charged with M.O.R.S.E system – 2.50 m length – La Praz access.

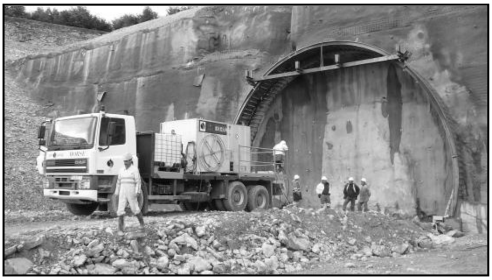

Figure 26. M.O.R.S.E unit mounted on a 6x4 truck started in the Chavane Tunnel.

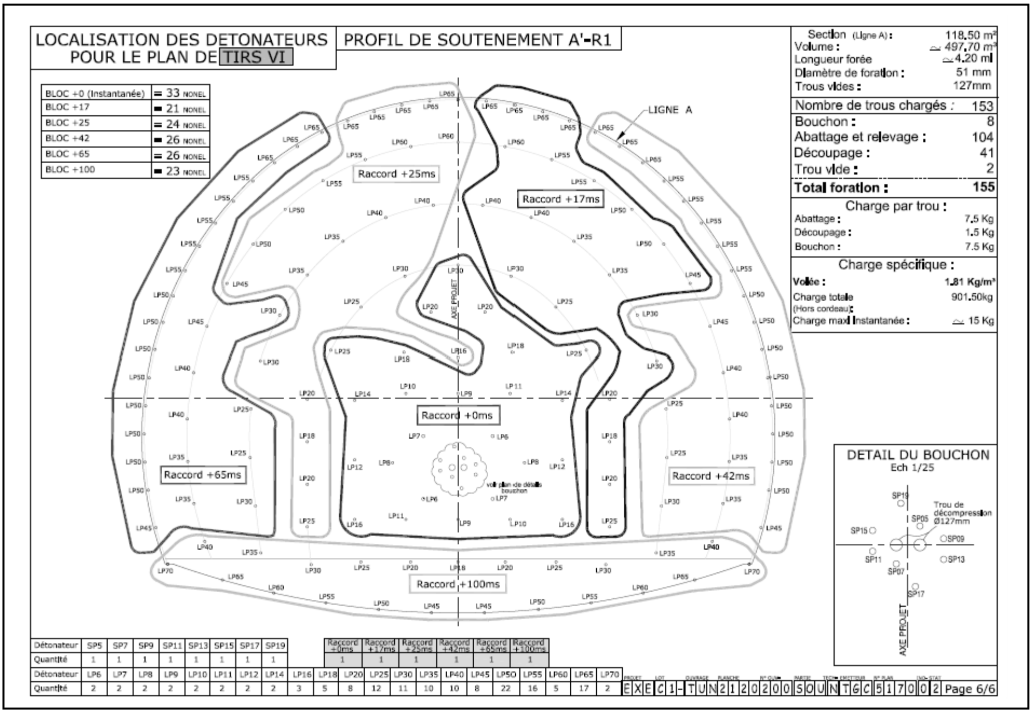

Figure 27. Blast pattern.

The first firings were done in June 2007, in the western drive, and in May 2008, in the eastern drive. 2 pumping units were brought into service in this site, one of which was latest generation, with 2 independent hoses and an increased loading capacity (3t).

Characteristics:

- Length: 1800 lm, of which 1100 lm by blasting – 2 drives using explosive
- Common section 118 m²

  Drilling length 4.20 m

  Drilling diameter 51 mm
- Drilling machine: automatic 3-booms jumbo - Robodrill

  Rock: limestone/marl

  Initiation: non-electrical detonators

The difficulty of this site relates above all to the seismic constraints imposed in relation to the final covering of the construction built in the area behind the front. The consequence of this constraint was the use of non-electrical sequential firing. The quantity of explosive per firing as a consequence of the large section is close to 1 ton and the specific load close to 1.8 kg/m3, i.e. 25% more than a cartridge-based solution.

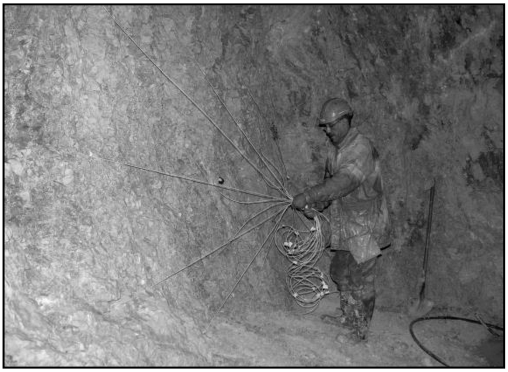

Figure 28. Use of a cluster of non-electrical tubes.

All the production teams noted the ease of loading, especially in the presence of tightened marls (smaller holes) or of debris in the holes, compared to a preload solution.

4. ADVANTAGES AND DISADVANTAGES RELATING TO THE METHOD

4.1 Advantages

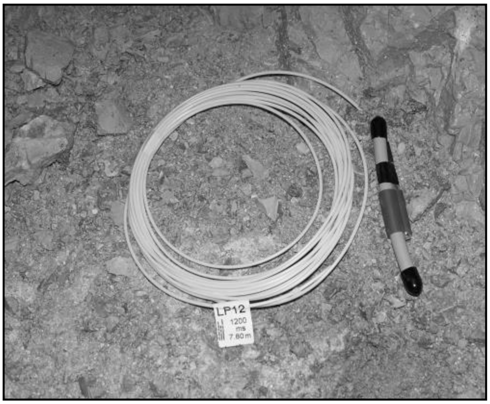

Figure 29. A non-electrical detonator connected to its Daveyboust booster.

The advantages relating to the method following these 5 experiments conducted in France since 2005 are:

Elimination of the pre-load workshop (1 installation + 2 to 4 persons, depending on the size of the site),

Simplified management in storage of class 1 products: it is limited either to the management of a small storage or a strong box for the detonators (class 1.1B), and possibly of a small storage (less than 50 kg),

Ease in managing storage of raw materials for manufacturing the bulk emulsion (an activity which is outsourced to the supplier of the method),

Increase of productivity for each cycle if the M.O.R.S.E.® method is coupled with non-electrical detonation,

Safety at the face substantially improved due to the very small quantity of class 1 products (Booster of 12 g/pcs/number of holes, flexible linear shaped charge, detonators),

Improved security due to the consistency of the product, making it difficult to transport outside the site (bulky and viscous) and to the small quantity of class 1 product,

Improved safety in mucking operations due to the lack of visible unburnt elements (if product does not function it is dispersed in the muck pile) and to the very low sensitivity to impact of the product (1000 times less sensitive than dynamite),

Simpler supply logistics.

Figure 30. Raw materials storage hangar.

4.2 Disadvantages

The disadvantages relating to the method following these 5 experiments conducted in France since 2005 are:

Systematic additional consumption compared to traditional loading due to the consistency of the product (bulk), which fills 100% of the hole. This additional consumption, estimated at between 20 to 30%, also relates to the fact of drifts observed at the face concerning the inspection of the quantities used (the miner can add product for as long as they desire to do so). This drift can be corrected by a more systematic inspection by the supervisors, and continuous training of the operators,

A release of gas of different kinds, and in larger quantities, compared to the use of dynamites (no NOx with the M.O.R.S.E.® but greater presence of CO, and much greater presence of NH3). This aspect can be corrected by correctly dimensioning the section and blowing ventilation (power level, diameter of ventilation tubes, distance to the face), and by installing a mist-making system behind the blowing ventilator once the densest gases have been pumped out.

A slightly low specific energy (MJ/kg) in certain rocks, compared to the use of dynamite. This aspect can be corrected by adjusting the volume energy (MJ/l) by setting a higher density (adjustment range from 0.8 to 1.2) and a higher boring diameter (diameter 57 mm thus enables the boring meshes to be increased).

5. CONCLUSION

Since 2005 the Nitro-Bickford company has brought 6, M.O.R.S.E.® loading units into service in 5 sites, with different environments, both in terms of the geology and of the size of the constructions. This determination as a partner supplier of underground works companies has enabled, through the competence of the personnel seconded to the sites, on-site manufacturing and pumping of emulsions in tunnels technology to become established definitively and successfully. Due to the increasing constraints relating to the logistics surrounding class 1 products, we can be sure that this trend can only increase. We now require other sites and other experiments on the part of underground works companies to take optimum advantage of this technology.

Figure 31. A new M.O.R.S.E unit with independent tubes and 3 t storage capacity.