479 Charges, 13 Decks...120 Meters Above a Crushing Plant

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Abstract

This case study shows how a unique combination of field measurements and advanced technologies allowed blasters designing, loading and firing an incredibly challenging quarry blast.

A natural limestone arch adjoined to a karstic and heterogeneous 120 meters (394 feet) high cliff, overlooked a brand new crushing plant in a quarry located in Southern France.

Several blocks already fell down and a large fracture located just behind the weakest point of the arch make site's managers fear that the worst could happen. As often the case in Western Europe, sensitive residential areas and roads surround the quarry at very close distance. Only 70 meters (394 feet) separate the first house from the top part of the arch.

The risk of an unexpected collapsing of the arch was putting personnel and installation at risk. The coming winter season and the subsequent freeze-thaw cycles could have been a triggering factor, reason why timing was also at stake.

Besides, blasting the arch without causing instability to the surrounding benches was critical for further and safe access to the deposit.

Context of the Operation

The Saint-André's quarry is located in the south of France, a few kilometers behind the town of Nice (Figure 1). It is an old quarry that is at the end of its life, after having levelled off nearly 200 m (more than 650 ft) from the mountain. The limestone site has a fault that has always complicated operations. In 1997, in the south of the deposit, the rapid erosion of a section of cliff in contact with the fault began, which in a few years revealed a natural limestone arch, overhanging SEC's crushing plant, which belongs to Jean-Lefèvre Méditerranée.

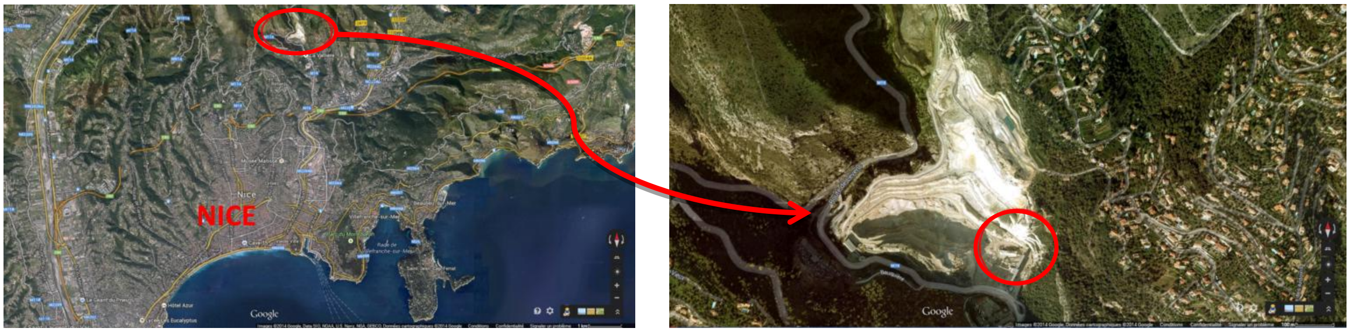


Figure 1. Location of the quarry and of the blast in the quarry

Figure 2. The limestone arch

This natural, unstable limestone bridge (Figure 2), quickly became an obstacle, preventing the operation of the site in the south east sector. Therefore, the operator decided to blast it to free the area and make it safe.

Blast the Limestone Bridge Specific: the Specific Constraints of the Site

The first constraint is the limestone bridge itself (Figure 3). This karstic geological structure, that is the result of the erosion of rocks along the fault plane, could become unstable due to continued quarrying operations, slide in one block along the fault plane and hit staff or damage the installations below. The volume was estimated at approximately 8 000 m^3 (282 500 ft^3), i.e. nearly 20 000 metric tons (44 M lbs).

Figure 3. Detailed photograph of the limestone arch

The second constraint is the presence of housing between 70 and 100 m (229 to 328 ft) behind the area. For many years now, the operator committed to the town council not to exceed a vibration level of a few mm/s, well below the regulatory 10 mm/s (0.39 in/s).

The third constraint is the presence of an industrial estate below and opposite the area to be blasted, separated by a secondary road (Figure 4).

Figure 4. The constraints around the critical area

To summarize, 8 000 m^3 (282 500 ft^3) to be blasted, perched 120 m (394 feet) above the crushing plant, without creating any vibrations, or showering flyrock either on the installations or the industrial estate opposite.

Engineering the Blasting

Although the associated risk is considerable, blasting this area was necessary for the operator. A problem with blasting could lead to the closure of the site.

In order to be successful, a multidisciplinary team was set up including: the operator (SEC), the blasting subcontractor (TP SPADA), a geotechnical engineering company (B.E. du Canal de Provence), a surveyor and a design office specialized in explosive engineering (TBT).

Calculating the Blast

The seismic constraints compelled us to use a maximum charge per delay of 2 kg (4.4 lbs), which served as the basis for the blast design. The choice of a powder factor inferior to 300 g/m^3 (0.5 lb/yd^3) was made in order to minimize flyrock. In fact, we opted for destabilizing the arch via a carefully controlled blast, leaving gravity to deal with the rest.

Geometrical Survey of the Area

The first stage of the design was an exhaustive three-dimensional survey of the area to be blasted, with 3D modelling to clearly show the difficulties due to the complex geometry of the area. The recent developments in 3D imaging for bench face profiling (Gaich et al., 2013), mostly focusing on quarrying and mining operations, were then be given a new application in this complex cliff blasting context. 3D Based on the cloud of 3D points (Figure 5), 2D face profiles spaced out every 2 m (6.5 ft) were calculated (Figure 6).

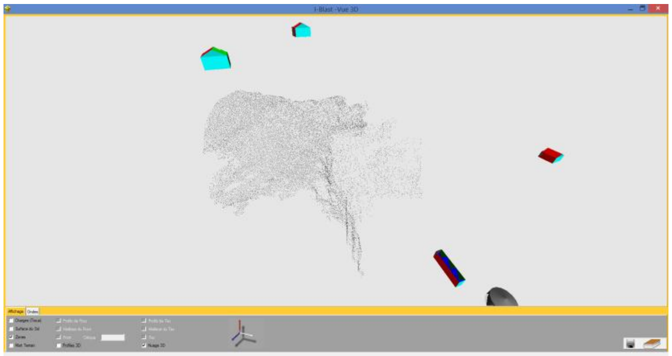


Figure 5. Cloud of 3D points

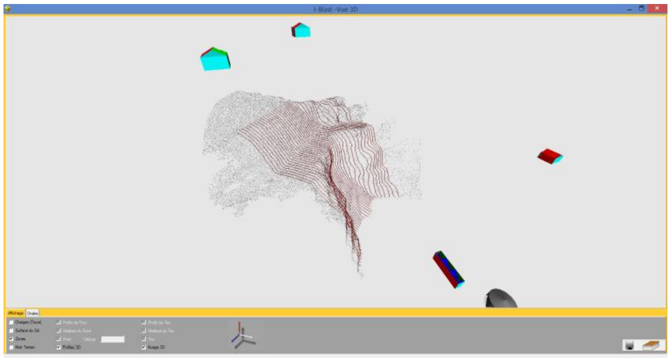


Figure 6. Cloud of 3D points with 2D profiles

In addition, the cliff was inspected by a drone to help analyze the karstic areas visible on the face.

Positioning the Holes

Based on the 2D profiles modelling using the I-Blast software, the holes were positioned to keep the burden compatible with the minimum flyrock objective, and the depth defined to avoid intercepting the fault plane (the underlying area must not be destabilized).

The geological analysis of the area to be blasted revealed that only the northern part of the blast was in contact with the fault (Figure 7). The southern part not being in contact, constant depths marking a flat berm were chosen (Figure 8).

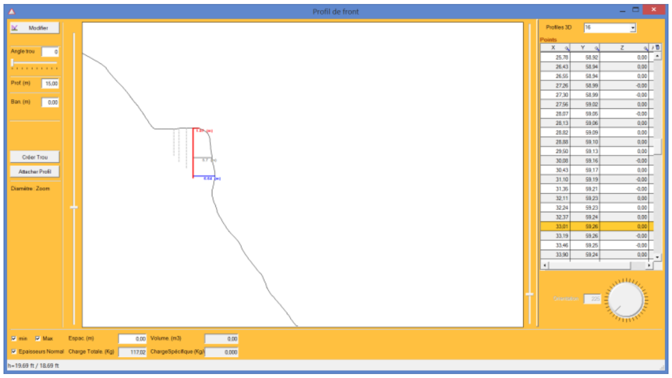


Figure 7. Positioning of a hole in the northern area

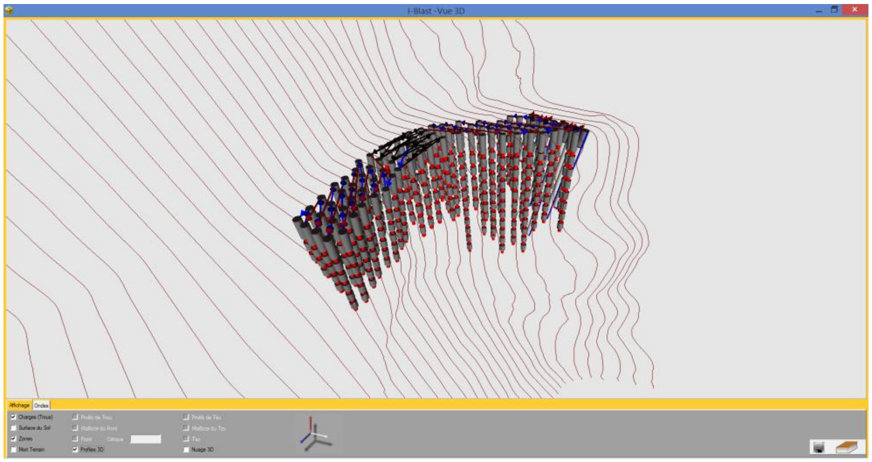
Figure 8. Positioning of a hole in the southern area

Calculation of the Charges and the Initiation Sequence

The charge per delay, as previously mentioned, was limited in this area of the quarry to 2 kg (4.4 lbs) which led to almost 20 decked charges in the deepest holes (25 m) (82ft).

In order to decrease this number, we decided to raise the charge per delay to 3 kg (6.6 lbs) and calculate the sequence with the help of the signature hole method to maintain the seismic levels to the lowest. The calculation is based on a study carried out last year on the whole site. A value of 10 ms (0.39 in/s) between charges was retained as the optimum delay (refer to Figure 11).

The 3D modelling of the blast design (Figure 9) enables us to realize the complexity of the operation. The point of initiation of the blast sequence was calculated for the center of the keystone, progressing on either side and from the top downwards. With 479 charges, the total duration of the sequence lasted nearly 5 seconds. This was considered too long, with regard to the stability of the rock, revealing a risk of moving the block before the initiation of all of the charges. A short sequence of 6 ms between charges was therefore retained to the detriment of the vibrations, but giving priority to the maximum confinement of the rock mass over its motion.



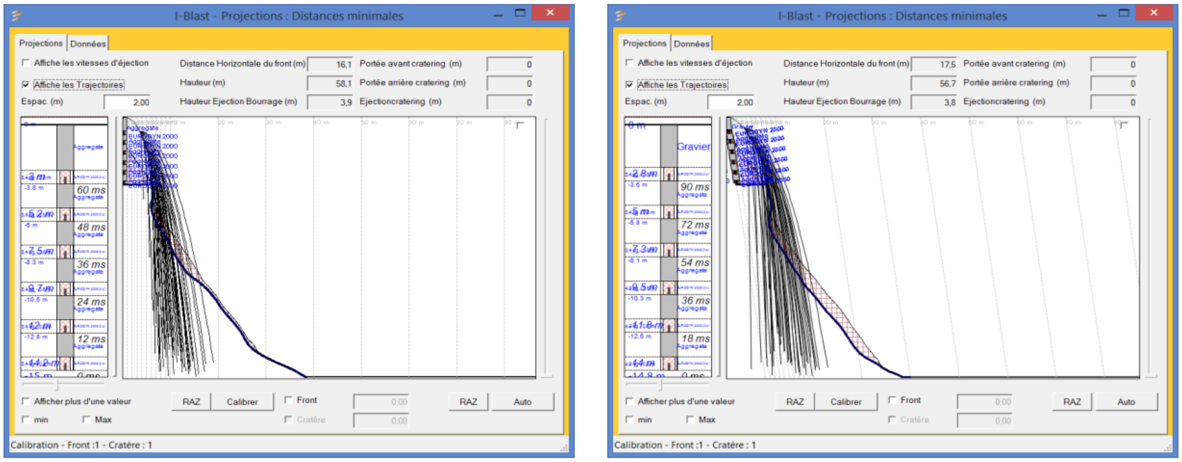
☑ Charges (Trous)
☐ Surface du Sol
☑ Zones
☐ Mort Terrain
☐ Profils de Trou
☐ Maillage du Front
☐ Front Calque
☑ Profiles 3D
☐ Profils de Tas
☐ Maillage du Tas
☐ Tas
☐ Nuage 3D

Figure 9. 3D view of the loading

Simulation of Flyrock and Vibrations

Once the 3D model was built, simulations of the effects of the blast (flyrock and vibrations) were carried out with the help of the physics-based model of the I-Blast software (Bernard, 2009). The aim was to check that the solution retained was compatible both with the seismic standard and the protection of the plant and the industrial estate.

The graphs below illustrate the trajectory of flyrock and their heave for typical profiles (Figure 10). It is to be noted that no horizontal flyrock was envisaged and that the material should flow along the fault plane.

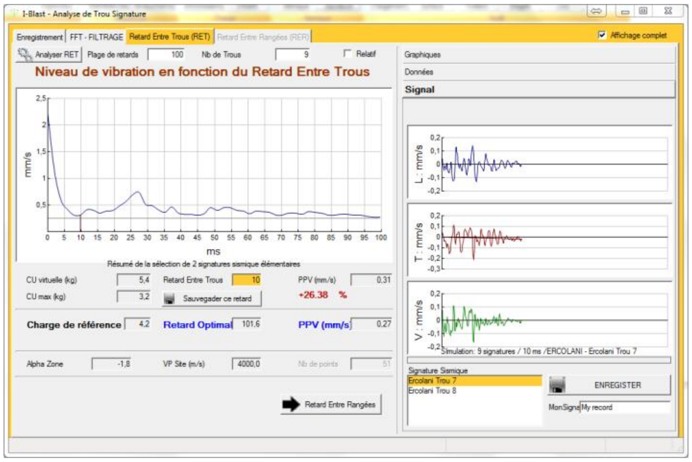


☐ Affiche les vitesses d'éjection
☑ Affiche les Trajectoires
Espac. (m) 2,00
Distance Horizontale du front (m) 16,1
Hauteur (m) 58,1
Hauteur Ejection Bourrage (m) 3,9
Portée avant cratering (m) 0
Portée arrière cratering (m) 0
Ejectioncratering (m) 0
☐ Afficher plus d'une valeur
☐ min ☐ Max
☐ Front 0,00
☐ Cratère 0,00
Calibration - Front :1 - Cratère : 1

☐ Affiche les vitesses d'éjection
☑ Affiche les Trajectoires
Espac. (m) 2,00
Distance Horizontale du front (m) 17,5
Hauteur (m) 56,7
Hauteur Ejection Bourrage (m) 3,8
Portée avant cratering (m) 0
Portée arrière cratering (m) 0
Ejectioncratering (m) 0
☐ Afficher plus d'une valeur
☐ min ☐ Max
☐ Front 0,00
☐ Cratère 0,00
Calibration - Front :1 - Cratère : 1

Figure 10. Trajectory of the material along two profiles

Seismic simulations based on a near-field approach (Yang & al., 2010) and the signature hole method (Figure 11) (Bernard, 2012) forecast that the vibration levels at the nearest housing would remain below the French regulations (Figure 12).



☑ Affichage complet
Plage de retards 100
Nb de Trous 9
☐ Relatif
Résumé de la sélection de 2 signatures sismique élémentaires
CU virtuelle (kg) 5,4
CU max (kg) 3,2
Retard Entre Trous 10
PPV (mm/s) 0,31
+26.38 %
Charge de référence 4,2
Retard Optimal 101,6
PPV (mm/s) 0,27
Alpha Zone -1,8
VP Site (m/s) 4000,0
Nb de points 51
Simulation: 9 signatures / 10 ms /ERCOLANI - Ercolani Trou 7
Signature Sismique
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Figure 11. Research for the optimum delay using the signature hole method

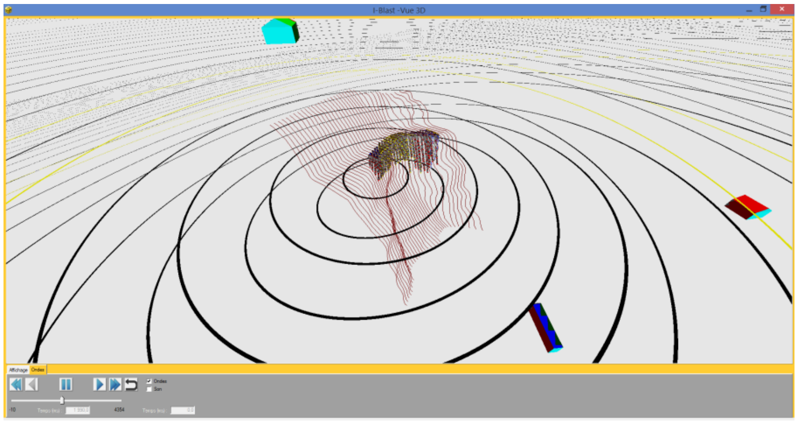


Figure 12. 3D simulation of seismic waves to forecast seismic levels

Explosive and Initiation

The choice of the explosive is absolutely essential for this type of multiple-decked charge (up to 13) blasting operation, with a small drilling pattern (2 m × 2 m) (6.5 ft × 6.5 ft). The risk of dynamic desensitization is very high. Hence, dynamite with a high percentage of nitroglycerine (40%) was retained, in spite of the explosive supplier’s insistence on using high-performance emulsions containing glass microspheres.

For initiation, due to the number of charges and decked charges, the choice of electronic detonators was obvious.

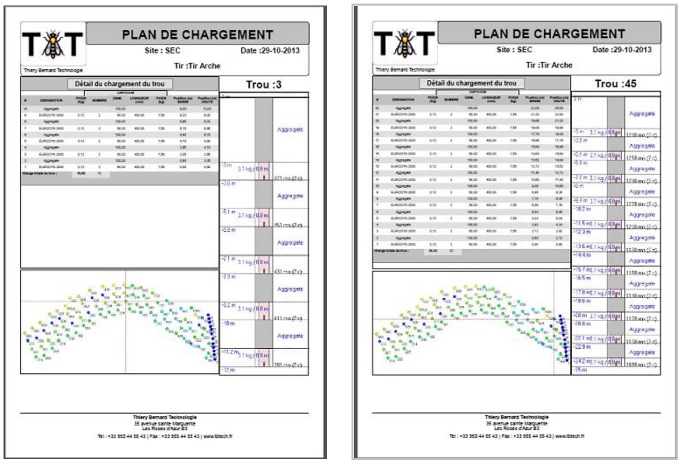
On Site: a Rock Barrier

In order to control the muck pile, a rock barrier (Figure 13) was built at the foot of the erosion area. Its volume was sufficient to contain the volume of the blast. However, one question remained unanswered: Would the material remain there considering the kinetic energy accumulated during a 120 m (394 ft) fall?

Figure 13. Bottom and top view of the rock barrier being implemented

On site: Organization

Implementing a complex blast design such as this is impossible without specific organization.Firstly, each numbered and surveyed hole on site had its own loading plan (Figure 14) specifying the quantity, and height of charges and the respective initiation timing.



PLAN DE CHARGEMENT
Site : SEC
Date :29-10-2013
Tir :Tir Arche
Thiery Bernard Technologie
Détail du chargement du trou
Trou :3

PLAN DE CHARGEMENT
Site : SEC
Date :29-10-2013
Tir :Tir Arche
Thiery Bernard Technologie
Détail du chargement du trou
Trou :45

Figure 14. Hole loading plans example. Here for holes #3 and 45

Then five teams worked, moving one after the other, from hole to hole for the following successive loading stages:

- Controlling and adjusting the hole depth;
- Preparing the charges;
- Implementing and testing detonators;
- Labeling the detonators (decks); and
- Stemming.

Figure 5. The teams loading

A final team was in charge of programming the detonators once the holes were loaded (Figure 16).

Figure 16. Programming the electronic detonators

It took 12 consecutive hours to complete the loading. The final tests to check the detonators were successfully completed as night fell. A team spent the night on site to keep an eye on the preparations and in particular the surface connections that could be damaged by wild boar!

On site: Protection

Due to the karstic type of terrain, safety meshes to protect from flyrock were installed on the free face opposite the visible critical areas.

The type of protection retained was a “sandwich” of geotextiles, and chicken wire; the geotextile was to contain the blast and small flyrock, and the chicken wire to provide mechanical resistance for the larger rocks. On principle, the implementation is simple; achieving it on a cliff face (Figure 17) in windy conditions, and with a time constraint is always a challenge for rope access workers.

Figure 67. Installing the protection on the free face

The Blast

The blast took place late morning on the second day and was a complete success. The rocks slid along the fault plane as forecast by the simulations without any horizontal flyrock (Figure 18). The rock barrier carried out its job, just a few rocks escaped the area to finish a few meters below in the piles of sand.

Figure 78. Before and after the blast

Conclusion

This blasting project with its complicated conditions and high risks was possible and successful thanks to the technical contributions, i.e.: electronic detonators, reconnaissance with a drone, 3D modelling and simulation, and above all thanks to the incredible teamwork of all the partners:

- SEC, the contracting authority for having trusted us, made the means available (surveyor, geologist, equipment) and taken part in the risk analysis;
- TP Spada, the mining subcontractor, for drilling and loading the blast as well as the overall reflection on the blast design;
- EPC France for the supply of the explosives and help with loading;
- DaveyBickford for their help in programming the detonators; and
- TBT for the engineering and supervision of loading.

References

Bernard, T. (2009). A "Holistic" Approach of Blast Vibration Modeling and Prediction. *The International Society of Explosives Engineers Annual Conference Proceedings.* Cleveland: ISEE.

Bernard, T. (2012). The Truth About Signature Hole Method. *The International Society of Explosives Engineers Annual Conference Proceedings.* Cleveland: ISEE.

Gaich A., Pötsch M., McClure R.A. (2013). Recent Developments in 3D Imaging for Bench Face Profiling and Blast Planning. *7th World Conference on Explosives & Blasting Proceedings* (pp. 110-115). Moscow: EFEE.

Yang, R., Scovira D.S. & Patterson N.J. (2010). An Integrated Approach of Signature Hole Vibration Monitoring and Modeling for Quarry Vibration Control. *Rock Fragmentation by Blasting* (pp. 53-76). London: Sanchidrian (ed.).