1. Blasting covering experience from projects

Explosives safety competence linked to UK National Occupational Standards – our experience

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ABSTRACT: The objective was to develop and maintain a competent explosives workforce using evidence measured against the National Occupational Standards for Explosives Substances and Articles. Real-world examples are presented of assessment and growth of competent individuals and a model of how a manager could use the standards to grow a Suitably Qualified Experienced Person is presented. The methodology has enabled AWE to assess the safety competence of its explosives workforce to common standards. Awe plc is contracted to the UK Ministry of Defence (MOD) through a government-owned/contractor operated arrangement. This gives the employer confidence and promotes employee pride in demonstrating a route through which staff can excel in their chosen career and be able to recognise their own value. The standards are linked to work instructions and training modules which could ultimately provide an opportunity for qualification. This activity has been seen as best practice and we will continue to share these methods with the wider community.

1 OBJECTIVE

This project set out to explore and systematically determine the required explosives safety competence of staff across all of company's explosives business areas. The project aimed to define a reliable method of recording the evidence, measuring against the National Occupational Standards (NOS) for Explosives Substances and Articles (ESA) and current company processes.

The initial objective was to identify the 'Primary' (e.g. hands-on) roles; job title, purpose, function etc., detailing the definitions against the ESA NOS and in-house competencies relevant to the role. This enabled any competency gaps to be identified, defined and development activities facilitated.

The UK ESA NOS describes levels of performance and knowledge that staff should have achieved in order to carry out their job well, in terms of outcomes. UK Health and Safety legislation states that people working with explosives *shall be competent,* meaning that the individual is able to carry out the task to a prescribed standard, but this was not clearly defined until the ESA standards were developed. This applies to all staff working with, or responsible for, ordnance, munitions and explosives. Our company has adopted the UK Ministry of Defence (MoD) stance which states;

"The competence of those working with Weapons, Ordnance, Munitions or Explosives shall be demonstrated against the standards of best practice set by the sector; these are the National Occupational Standards (NOS) for Explosives Substances and Articles (ESA)".

Competence can be described as a combination of 7 elements; Knowledge, Skill, Experience, Attitude, Aptitude, Ability and Behaviour.

2 ACTIVITIES

It was recognised that, for this project to succeed, all aspects of the explosives business would need to be consulted and energized to take part. The project team was made up from all areas of the explosives community and facilitated by an independent Environmental, Safety and Health (ESH) advisor.

The project was staffed by employees from a range of disciplines, backgrounds and outlooks who came together to form a cohesive, cross-company team. The team was able to determine a common purpose, formed during a series of workshops. They formulated an expression of what competence meant to them and the explosives community. This became the project logo, Fig 1.

"Working together to define

$C = f(KSE) \times f(A^3B)$

in ESA Management, Control and Operations at AWE"

Figure 1. Project logo – "Competence is a function of…".

It can be said that if the function of any attribute is equal to zero then competence has not been achieved and further effort is required. Zero in itself does not automatically deem an individual incompetent but rather working towards or refreshing latent competence (or new ones to be practiced, learnt or observed).

Table 1. Common competence – explosives worker practitioner / team member.

Technical competences common to this role	NOS ESA UNIT
Prepare explosives process area and equipment	4.4
Move materials within the explosives process	4.5
Prepare explosives process materials	4.6
Monitor and control explosives processing	4.8
Shut down explosives process	4.11
Move explosive substances and/or articles manually	7.1
Put explosive substances and/or articles into storage	7.3
Lift, transfer and position explosive substances and/or articles	7.18
Work effectively in a team involving explosive substances and/or articles	13.1
Hand over explosive substances and/or articles	13.11
Pack or re-pack explosive substances and/or articles	13.12
Unpack explosive substances and/or articles	13.13
Prepare and care for equipment in an explosives environment	13.15

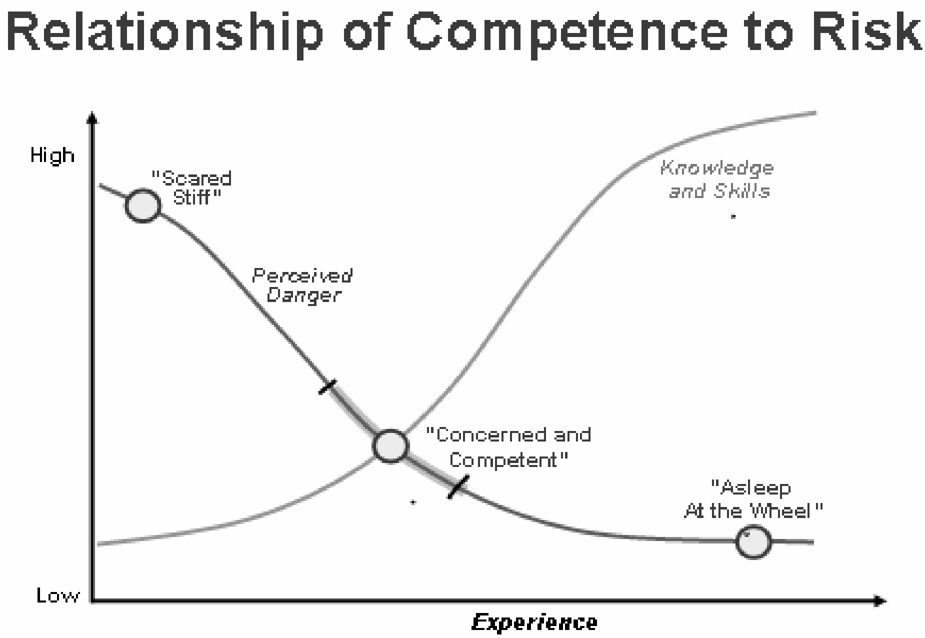

Figure 2. Relationship of experience to perceived risk.

3 METHODOLOGY

The project team were able to map the job roles and functions to ‘key roles’ of the ESA NOS. These identified the common job roles within the explosives business areas and recognised where similar tasks existed (some 43 job/roles were identified in total). This information was benchmarked against outside industry and common competence (Table 1.) was identified.

The job roles were then distilled and combined into three primary role profiles:

- explosives worker practitioner / team member
- explosives work controller
- trials conducting officer / firing officer

These were further aligned with six sub disciplines in line with the ESA standards, to subsume the majority of 43 job titles.

Separately, an additional 35 specialist ESA NOS units were identified that contribute to specific competency within the follow business areas:

- RD&D
- trials & testing
- manufacture
- assembly /disassembly
- storage /transportation
- disposal

3.1 Mapping the roles

Before mapping could take place, it was necessary to understand the relationship of experience associated with the task compared to the risks of the work being undertaken. In other words ‘where are we now?’ The model is shown in Figure 2.

This model explains that experience and growth in knowledge and skills can lead to complacency. Routine assessment is a tool to identify this behaviour.

Role mapping is a process whereby the process owner and an explosives competence assessor agree the fundamental links to the ESA NOS and tasks within the process which can be demonstrated by the work being undertaken. The following example (Figure 3) is for a team member working in a trials area. The labels across the top of the matrix indicate the separate processes, those down the side refer to the ESA NOS units. The final matrix is used to record individual levels of competence.

3.2 Using the ESA NOS

The standards are written in terms of outcomes,

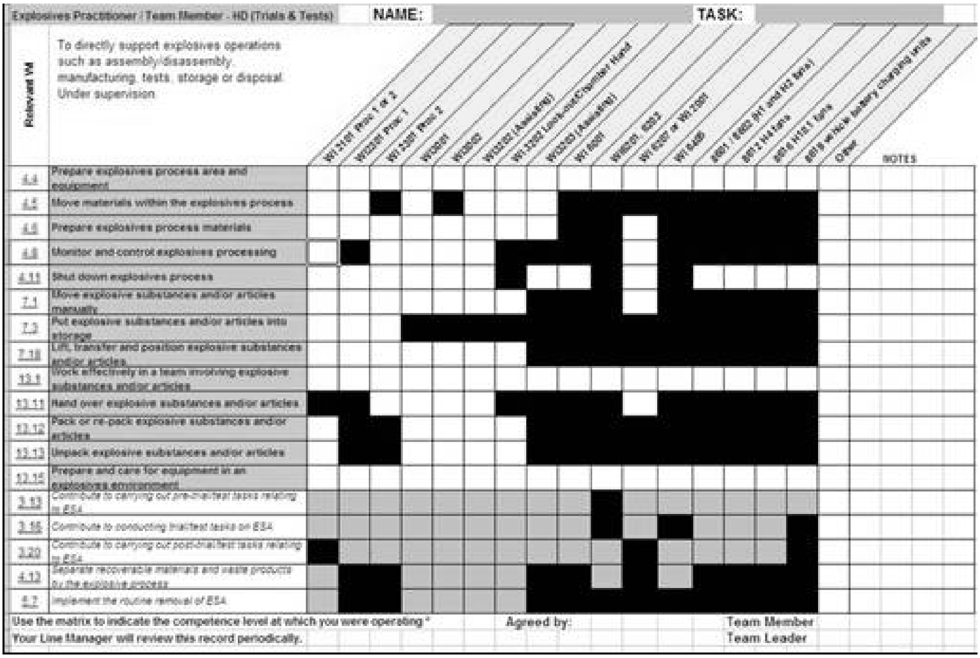

Figure 3. Matrix map of NOS ESA Units to processes.

which are measureable by assessment, and comprise of three components:

- performance – on which staff competence is judged, usually by observation.
- contexts – the parameters of the competence; routine or complex tasks.
- knowledge – the essential knowledge needed for competent performance which cannot be inferred from observation alone.

An extract from Unit 4.5 gives an example of a typical standard and the performance and knowledge requirements. It can be seen how Unit 4.5 can easily by applied to assess any process involving explosive material movement.

3.3 Work place competence / training and development using the ESA NOS

We used the ESA NOS to provide workplace training; Figure 5 shows an outline of the process. The ESA NOS was used to identify training needs and aid in self assessment, appraisal and audit. Both internal and external training has also been mapped to the ESA NOS with the view to developing a suitable qualification in due course.

Using the ESA NOS, line managers were able to assess the levels of performance by undertaking an initial assessment. The ESA NOS and their application relate principally to vocational training, either delivered in the workplace itself, or delivered in a training facility. We have found the pre and post training assessment activities to be the most beneficial use to date, including the standardisation of independent assessment as part of the training cycle (Figure 6).

Staff were assessed whilst undertaking the process, this included but was not limited to:

- process walk down
- simulated operation
- real-time operations

Assessment was recorded and is shown in Table 2:

4 CONCLUSION

Success of this project to date has been measured by completion of the initial objectives, with further addition of medium and long term gains identified. All of the ‘Primary’ hands-on explosives worker roles and post holders have been identified and the processes have been mapped against the NOS

Unit 4.5 Move materials within the explosives process

Contexts

- Explosive environments: low negative consequence; high negative consequence
- Transfer: by hand; by mechanical means

Performance Criteria	Knowledge Requirements
You need to:	You need to know and understand:
a work safely at all times, complying with health and safety, environmental and other relevant regulations, legislation and guidelines	i the health, safety and environmental and other statutory legislation, regulations and safe working practices and procedures governing explosives, and their implications for your area of work
b confirm that you have the required materials	ii the relevance of personal protective equipment (PPE)
c prepare the materials correctly for transfer and/or use in the processing	iii work area hazards
d confirm that the equipment to be used is in a safe and functional condition	iv the actions to be taken in response to an unplanned event
e deal promptly with any problems that arise, reporting any that you cannot solve	v the nature of the materials being processed
f dispose of waste, in accordance with your organisation's procedures	vi the importance of adhering to explosives compatibility procedures and explosives limits
g transfer unused materials to designated areas for reprocessing, storage or disposal, and label accordingly	vii methods of loading, unloading and transferring materials
h complete correctly the required documentation	viii the functions and uses of the different types of equipment used in moving materials
	ix how to handle equipment safely, in ways that protect yourself and others from risk.

Figure 4. Extract from ESA NOS documentation.

ESA. Staff were initially assessed by their line manager (as in the past) but this assessment was independently verified by qualified and appointed internal assessors. These assessments were available to senior managers as a guide to the health and robustness of explosives worker competence and provide an overview for skill management and forward planning.

TRAINING NEEDS ANALYSIS	An industry wide functional analysis took place to determine who needed the training, and why, outline content, sources of expertise, etc. and provided the justification for using training
TASK ANALYSIS	This included the formation of the performance standards and provided the information on and skills required
ESTABLISHMENT OF PERFORMANCE CRITERIA	The ESA NOS provides clear statements of what is expected in terms of outcomes
DEVELOPMENT OF AN APPROPRIATE TRAINING EVENT	Training was workplace based
DELIVERY OF TRAINING	Trainers used the standards to ensure that the message was consistent
ASSESSING THE PERFORMANCE	In-house assessors were appointed. It is essential to assess that the individual has gained the required knowledge and skills and that the level is standardised across the company
ASSESSING THE EFFECTIVENESS OF THE TRAINING	Ultimately, the purpose of training is to bring about a change in behaviour this leads to the desired outcome in the workplace.
REVIEW OF THE ENTIRE PROCESS	Feed back to the standards as required.

Figure 5. Outline of the training process.

An important additional benefit gained by the cross-company assessment process is that all skills are portable across the explosives business and has enabled our population of skilled personnel to be moved around as part of their career development. Also, this approach provides flexibility within the workforce to cope with the fluctuations of workload.

The output from the work has been shared with our stakeholders and the Institute of Explosives Engineers (UK) and is seen by these bodies, and our peers, to be best practice and the primary route to follow.

This project has enabled our company and its

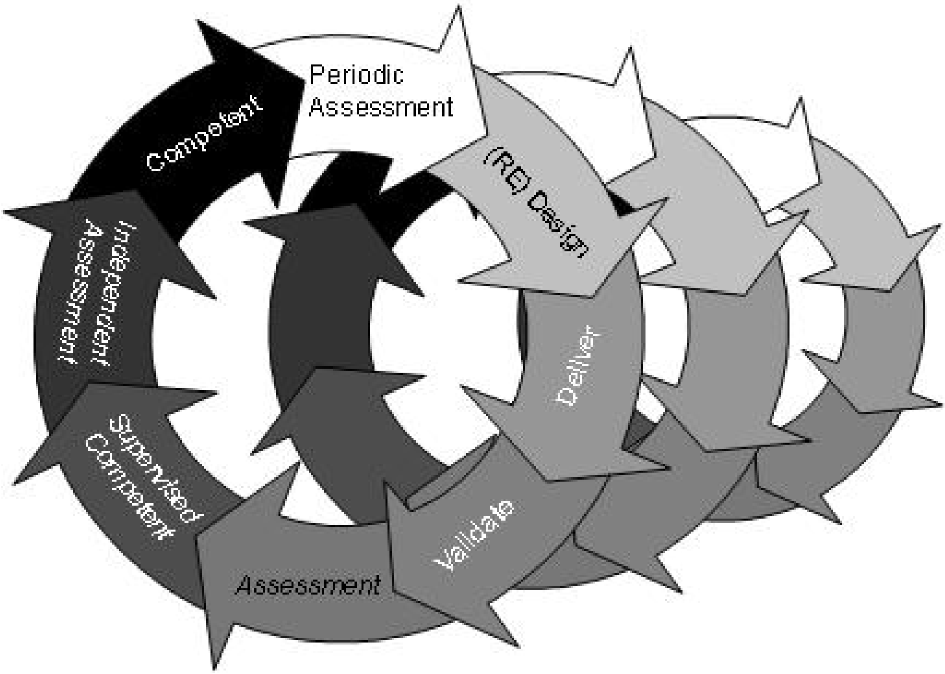

Figure 6. The training cycle of competence.

Table 2. Assessment recording.

Level	Description of activity
1	Shadowed/observed operation
2	Assisted operation, basic assistance of task and operation of simple tasks
3	Performed task mainly with authorised competent person overseeing
4	Fully competent in the task
5	Supervised others

explosives workforce to have pride in their work by demonstrating a route through which all explosives workers can excel in their chosen career and to be able to recognise their own value.

Furthermore, we can demonstrate capability. The work of this project was innovative and has been accepted as 'best in class' across the UK and will enable our stakeholders to trust that our explosives business will be safe, secure and clean. By default, our performance will ensure we are financially successful whilst retaining the brand and reputation, in keeping with the company business model (Figure 7).

Figure 7. In keeping with the company business model.

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Synchronised controlled explosive demolition of six industrial buildings at Mandoudi, Greece

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ABSTRACT: On December 19th, 2013, EXORIXI SA carried out the controlled explosive demolition of 6 buildings, inside a mineral processing plant, at Mantoudi, Evia, Central Greece. The initiation of the charges and the destruction sequence of the structures had to be simultaneous, but in a synchronised way, so that the falling movement of each building did not disrupt an adjacent one. The tallest building was 40m. What is more, a 36m tall vertical furnace at a distance of just 1.8m had to remain intact. The demolition progressed ideally, with no damage to the surrounding industrial area (even though no flyrock cover protection was used at the charging places) and very low, fully acceptable vibrations. Facts, risk parameters and useful experiences from the controlled explosive demolition project, are presented in this paper.

1 DATA AND BASIC FACTS OF THE STRUCTURES AND THE SITE

A controlled explosive demolition of 6 buildings was carried out inside a mineral (magnesite) processing plant, at Mantoudi, Evia, central Greece (Figure 1). The plant had been recently purchased by TERNA MAG SA, which was also the new investor and operator.

The main prerequisite for the decision to reopen the old magnesite processing plant and the planning of the new investment, was the demolition – removal of 6 buildings in the old furnace and briquetting complex. In their place, new facilities are planned, equipped to meet modern standards and stringent quality requirements for the finished products.

The old complex was part of a big industrial complex of almost 300,000 m^2 total area (Figure 2), constructed around 1970, and operating up to the year 2000. The old company was also engaged in primary mining activities, with its own surface and underground magnesite mines. Its processed magnesia products were known and requested for their superior quality.

The 6 buildings that were demolished (Figures 3 - 7), were regarded as heavy industrial structures - buildings of reinforced concrete (coded as K1, K2, and K4 on Figures 3 - 4), concrete silos (K3)

Figure 1. Location of demolition site in central Greece.

and concrete bases for heavy steel silos (K5, K6), with heights, ranging from 7 up to 40m. A 45m high, steel chimney (at the rear side corner of building K4) was also demolished.

Raw material (magnesite) was fed to these facilities after passing through the adjacent, initial processing complex, which included crushing, initial cleaning and beneficiation. Sizing, separation and grades production, dead burning, production of refractory bricks, etc. took place inside the complex of 6 buildings.

What is worth mentioning is the minimum distance of 1.8m between the highest building to be demolished (K1) and the closest building (CCM) that had to remain intact. The latter 36m high building had to be protected from all damage as it housed the old 7.5 m dia., 16 decks HERRESHOF vertical furnace of the caustic calcined magnesite (CCM) production line (Figure 3). This was scheduled to be repaired and gradually incorporated in the production complex of the new investment. Indeed, not only did it survive the demolition of surrounding structures, but its maintenance is now complete and it is ready for future use (Figure 11).

Other parameters evaluated in order to select controlled explosive demolition as the proposed method were:

- the necessity of minimisation of the work commencing time of the new plant, in order to expedite market re-entry of the new company
- the significant height of some buildings (e.g. 40m high for K1)

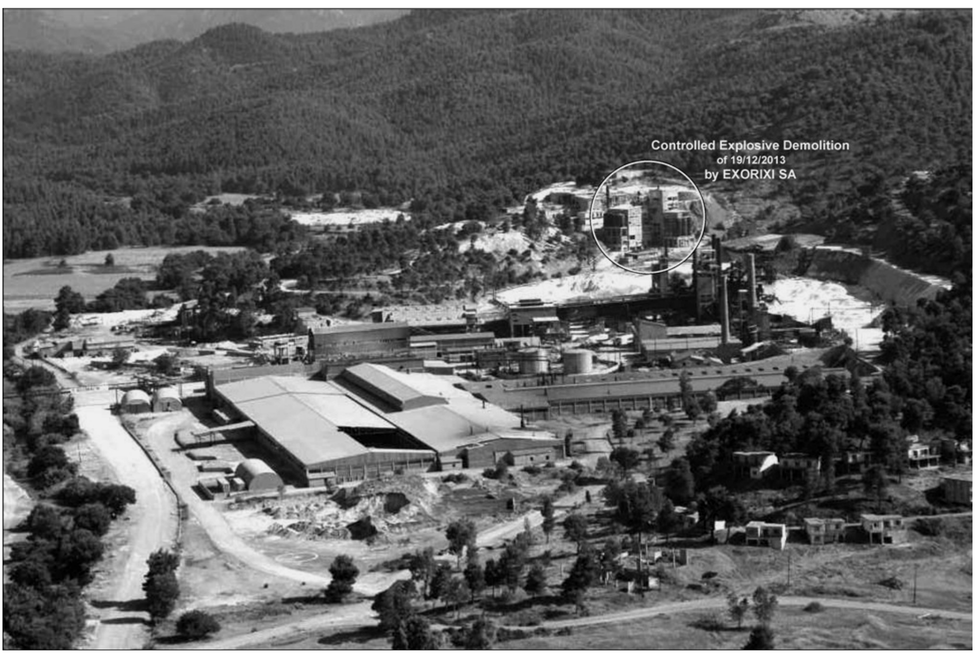

Figure 2. The wider area of the magnesite processing plant. The buildings for demolition are circled.

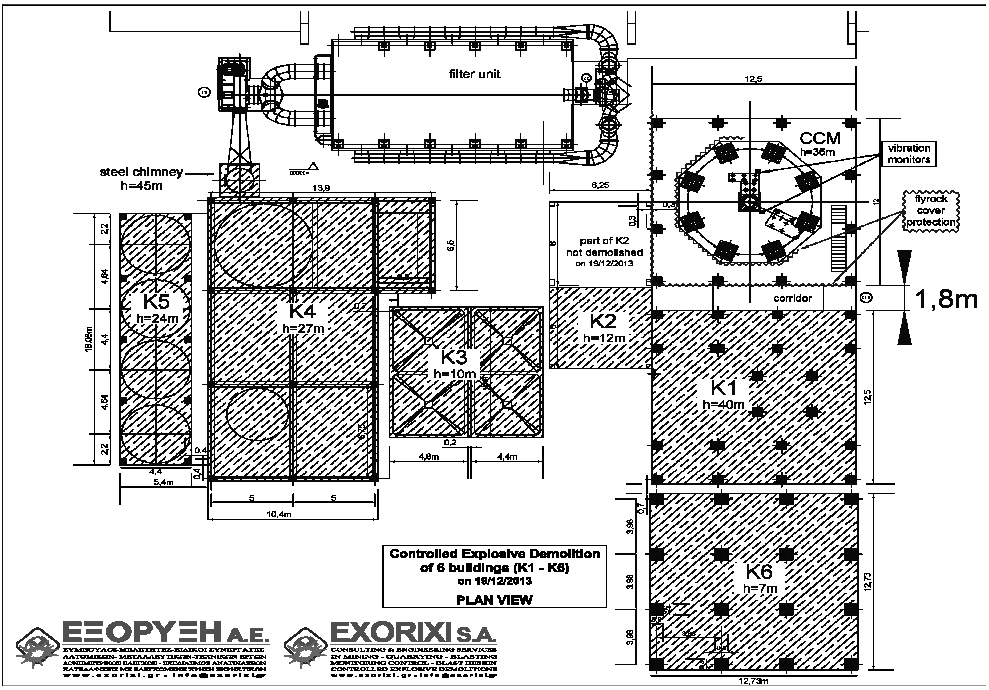

Figure 3. Plan view of the 6 buildings to be demolished.

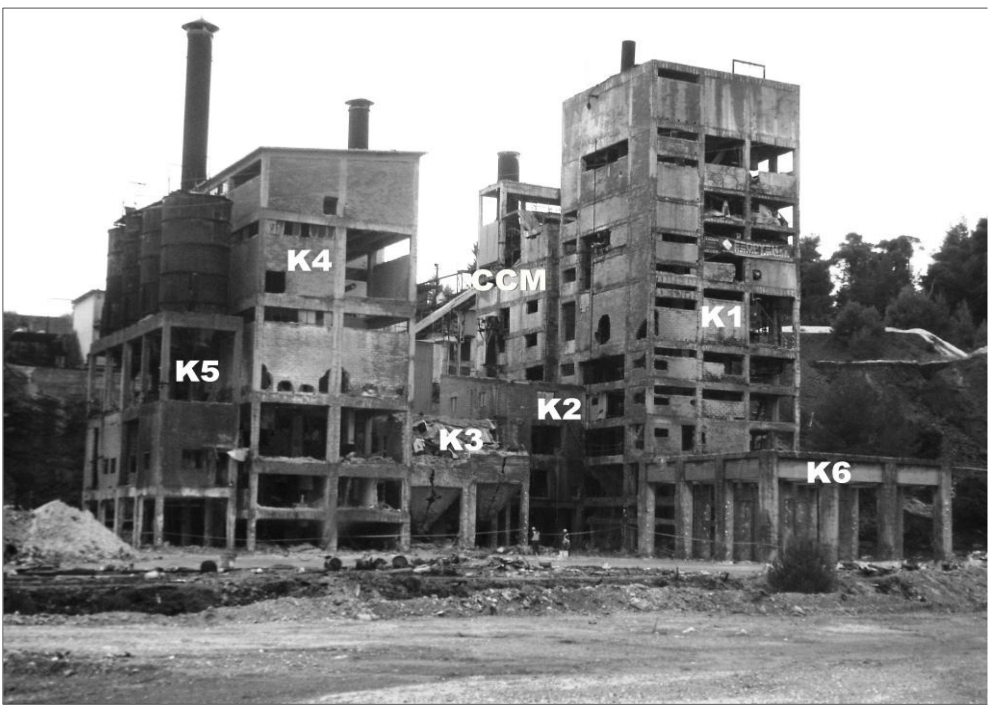

Figure 4. The 6 buildings with their coding. The CCM building had to be protected.

Figure 5. Partial view of buildings K6 and front side of K1.

Figure 6. Partial view of buildings K4 and K5 (with steel silos).

- their construction type, made of heavy reinforced concrete (e.g. support columns of 0.8 x 0.8 m in K1 and K6 buildings)
- the presence of heavy steel industrial machinery, extended networks of big pipes, equipment and accessories, as well as steel silos (externally on K5 and internally in K4).

Proper preparation of all buildings and the surrounding area preceded the demolition. Partial removal of machinery and steel parts from the buildings' interior, pre-weakening - cutting of steel parts that weren't able to be removed, as well as pre-weakening works in specific elements of the walls, stairs, etc. also took place prior the demolition.

2 DRILLING AND BLASTING

Hand-held drills were used to prepare almost 1,500 blastholes. Drilling diameter was either 41 or 45 mm, while drilling depth varied from 0.25 to 1.00 m (only a few blastholes of K6 structure were up to 1.20 m long).

Gelatin, in cartridges of 28 or 32 mm diameter, was used for charging the blastholes. The total quantity was about 400 Kg.

The initiation – firing system as well as the definition of delay times was based on non-electric detonators.

What was taken into consideration during the planning of the initiation – firing system and the definition of delay times, was the demolition of all buildings at the same time, but in a 'synchronised' way. This meant a pre-defined initiation and time sequence, as well as a pre-designed falling zone and drop direction for each structure. As all buildings were almost in contact with each other (Figures 3 - 7), what had to be assured was that none of them, when they fell, would impact on adjacent structures, and principally, that no damage risks - issues would be caused to the furnace building (CCM) that had to remain intact.

The initial planning regarded the demolition taking place in two different - separate phases, with K3, K5 and K6 structures falling first. Following further consideration, there was also evaluation of the increased risk for the remaining buildings, as the working conditions for preparation, drilling and charging works of the second phase, could be far from safe or the buildings could become 'inhospitable'.

Building K2, even though it was regarded as a structure of rather small height (approximately 12m), was considered of high risk, in terms of causing damage to the CCM building. Some of its structural elements and support columns were in contact or even connected to structural elements of one side of the CCM building. As the scenario of its demolition using mechanical means was rejected (machinery was unable to approach the critical part of K2), the following arrangement – technique was implemented: The 3 slabs and the side walls were cut using a light hand-held breaker. In this way, the part of the building that was in contact with CCM was isolated. The remaining structure, was supported by a number of steel columns for enhanced safety while working inside. It was demolished using light charges on the concrete supports, columns and connecting beams, at the same time as the rest of the buildings.

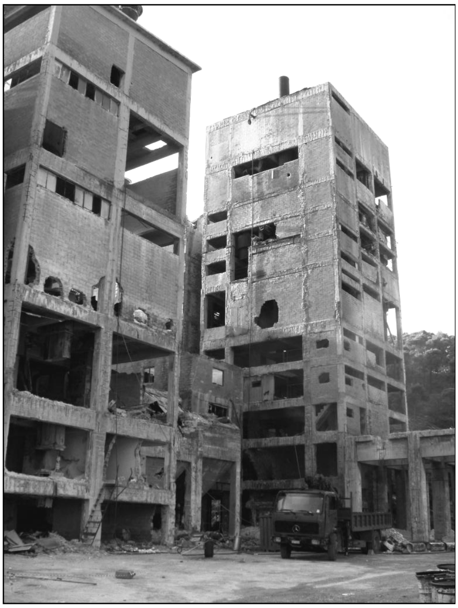

Figure 7. Partial (front and side) view of buildings K1 and K4.

3 FLYROCK RISK

Practically speaking, it was rather difficult, if not impossible, to apply flyrock cover protection. In any case, the majority of the surrounding structures were old or not scheduled for reuse or operation. The initial planning was to avoid using flyrock cover protection, and the outcome of the demolition indeed confirmed this choice!

Instead of using flyrock cover protection, there was a systematic approach and consideration for the following:

- meticulous management of each blasthole's direction during planning - definition as well as implementation – drilling. In this way, the very flyrock risk was directed towards the area of less interest regarding possible damaging effects.
- on the same principle, only light charges, and only a small number of blastholes were used in the upper parts of the buildings, especially where the concrete elements dimensions allowed so, or their quality – condition was poor.
- stemming with foam was implemented in all blastholes. Extra stemming with gypsum – plaster was applied in the blastholes of K6 structure.
- cover protection was used on the CCM building (mainly at ground level). Metal sheets and wire fencing were placed on the sides towards K1 and K2. Wire fencing and straw-bales were placed at the base of the cylindrical furnace, as well as around its rotary mechanism (Figure 3).

4 THE BLOW-DOWN DAY PROGRAM

An analytical action plan for the demolition day was formulated and presented. The detailed sequence of events, allocation of responsibilities and safety positions for everyone involved in the demolition procedure were included in this action plan, ensuring the smooth and precise completion of works. All teams that had a role in this operation were coordinated based on this action plan.

The team at the control point had the general responsibility for the implementation – progress and proper execution of the action plan, as well as the implementation and controlling of the exclusion – safety zones.

The firing time was chosen to provide sufficient time for the temporary evacuation of the area around the demolition site of workers and contractors' teams.

5 VIBRATIONS MONITORING PROGRAM

A monitoring program was implemented regarding the demolition induced vibrations, with a network of three digital vibration monitors (seismographs). The processing of the data coming from this network showed that the vibrations that the old CCM furnace structure (for which vibrations were a rather critical or even decisive parameter for the consequent maintenance – repair works) 'felt', were very rewarding. The vibration levels were so low, that they would actually be acceptable even if it was for an inhabited area.

Figure 8. Successive photos of the blow-down.

Figure 9. Seconds after the blow-down (photo from the octocopter drone).

Figure 10. After the blow-down; in-front of the debris stockpile, the part of K2 and the CCM building.

Two vibration monitors were installed in the bearing base of the rotary mechanism and the base of a main steel support column of the cylindrical CCM furnace to the side of the closest blastholes (Figure 3). Maximum ground vibration velocity values (PPV) were 8.13 and 6.73 mm/sec respectively. Particularly low PPV values (< 0.5 mm/sec) were also recorded at the nearest structures and site offices, where the demolition induced vibrations were hardly noticeable.

6 CONCLUSIONS

The controlled explosive demolition on December 19^{th} 2013 was utterly successful and progressed as designed and exactly as scheduled. Its total duration was a couple of seconds, offering a spectacular show with a highly-visible 'synchronized' pattern of demolition and differentiation of timing – movement of each structure (Figure 8).

The whole management and responsibilities of the project covered the study and design of the

Figure 11. View of the site after the removal of the structures (as on Figure 4) and the demolition debris stockpile. The CCM building, remained intact during the demolition operation.

demolition, the charging as well as the implementation of a complex firing – initiation system. Additionally, it included the management of all actions on the demolition day, the vibration monitoring and video documentation (using a great number of video cameras, among others a high-speed video camera and a camera mounted on an octocopter drone). At the same time, a significant part of the contracting works regarding the preparation of the buildings for the demolition as well as all drilling and charging works inside the structures, where working conditions were rather risky and nearly prohibitive, even for the very access of the workers, was also implemented.

An important conclusion and useful experience that can regard as a powerful tool for similar projects, is that with a detailed planning - design, effective risk management and proper implementation of preparation parameters, a number of buildings – structures can be demolished safely and controllably in a synchronised way (Figures 9 & 10).

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Electronic blasting at the Flesland Airport construction project in Bergen, Norway

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ABSTRACT: The primary purpose of blasting in construction is the excavation of rock. Often the blast performance is judged by the environmental impact (e.g. blast vibrations, air blast, flyrock, dust …) rather than the rock fragmentation. This is quite different to mining operations, where the fragmentation of rock affects all downstream processing of the raw materials and has a significant impact on the cost of the end product. The blasting contractor chose an Electronic Blasting System (EBS) as a vital part of the safety program to reduce the risk for misfires, flyrock accidents and delays in the blasting process. Through this project the contractor has verified the safety advantages of using EBS, and uses it for all their construction blasting jobs involving rubber mats covering. The work at the Bergen airport included excavation of about 1 mill. bcm of rock, all within a range from 0 m to 300 m from the airport, during a period of about 18 months. All blasts were covered with heavy rubber mats to reduce fly rock risk.

1 ELECTRONIC BLASTING SYSTEMS

EBSs have been commercially available for more than a decade. Most have the following features in common:

- fully programmable delay time in ms (which significantly reduces inventory and gives great scope to blast initiation design)
- much higher firing precision than pyrotechnic systems (leading to more predictable blasting and improved control of the environmental impact)
- safe testing of blast on the bench to ensure reliable firing of the whole blast, in particular when the blast must be covered with heavy blast mats (prevention of blast misfires due to unrecognized damage to the surface initiation).

The benefits of blasting with electronic detonators are becoming ever more widely recognised. Improved environmental control, cost savings from reducing powder factor and/or from reduced cost of operations downstream of blasting are becoming commonplace. Novel mining methods, some impossible without electronic detonators, are being tried and introduced. Plus all electronic detonators have significant safety features built into the design of the electronics inside the detonator and in the control equipment, which arguably makes EBS the safest initiation system that has ever been offered to the mining industry (Lownds *et al*. 2010).

The new generation electronic blasting system has recently been introduced into the global markets and is built on more than a decade of experience with electronic blasting systems. It has been developed for quarrying and construction as well as small open cut mines. The system is characterised by ease in use and learning and provides the flexibility and precision of electronic initiation. CE approval was granted during 2012.

A system configuration, which enables remote firing, consists of the electronic detonator, the scanner (includes test function) and a pair of blast boxes, see Figure 1.

Figure 1. Components of an electronic blasting system for remote firing.

The following features stand out for the system:

- free programmability in 1 ms steps from 0 – 10.000 ms
- unique detonator ID with 8 characters, lead wire length encoded
- 1D bar code for quick and easy scanning of unique detonator ID
- simple connection to duplex harness wire with clip connector, no tools required
- improved communication protocol, identifies detonators which are not scanned and connected to the blast
- firing precision (0.03% COV to programmed delay time)
- two-way communication for inherently safe on-bench testing
- up to 1600 detonators per blast in synchronized mode
- up to 800 detonators in a blast that is initiated via remote firing capability
- fast programming times (about ⅓ second per detonator)
- enables remote firing from a safe distance (up to 2500 m in line of sight)
- facilitates digital documentation of detonator consumption from blast box after firing facilitates easy inventory control as there is only one type of detonator.

Each detonator has a unique identification number with 8 characters, which is written to the chip during manufacture. This ID is written to the label in form of a 1D bar code, which is attached close to the clip connector. Additionally, the label includes the Track & Trace information in the form of a 2D barcode according to EU Directives 2008/43/EC and 2012/04/EU. The detonator fits into the detonator pocket of a standard booster.

Due to the new design of the printed circuit board with safety structures like spark gaps, incoming resistors and a new chip, the detonators provide the highest levels of protection against stray currents, high voltage, static electricity and electromagnetic fields.

When the blast holes are loaded each detonator is connected to a duplex harness wire with the clip connector. Additionally, a delay time must be assigned to each detonator. For this purpose the 1D barcode on the label must be scanned and a delay time assigned to the unique ID of the detonator.

Figure 2. Scanning a detonator.

Scanning can be done using a manual or an auto increment function. When all detonators are scanned and connected, the blast must be checked with the testing function which is built into the scanner. During testing each detonator is addressed with two-way communication and checked for full function. Each individual delay time can still be edited and changed on the scanner if required. Detonators which have not been scanned and are connected to harness wire are recognized by the scanner and reported to the user, so that any problem can be rectified prior to blasting.

For remote firing a pair of blast boxes is required. One blast box acts a slave and is positioned near the blast site, the other as a master and is used at the selected firing position to control the slave. After all checks are done the slave blast box is connected to the harness wire and positioned at a safe distance to the blast. The slave blast box is then activated with a digital firing key. During activation a random encryption code is generated and written along with the serial number of the unit to the digital key. This code is used for encryption of the radio communication and is only valid for one blast. The slave blast box is now in standby mode and waiting until the master blast box starts the radio communication for the blasting sequence.

For remote firing the responsible shotfirer selects a safe position with a good view on the blast after the site is cleared. To start the blasting sequence from remote and in line of sight to the slave blast box the responsible shotfirer needs to control the digital firing key. Only the encryption code on the digital key enables a radio control of the slave blast box. Before connection to the slave blast box the detonator list, containing the unique ID numbers and the assigned delay times, is downloaded via Bluetooth from the scanner to the master blast box. Once this is done the radio controlled slave blast box can start to program all detonators. The shotfirer can see on the display of the master blast box the progress in the programming sequence. When the blast is ready to fire a 10 minute countdown starts. For firing both firing buttons must be pressed. After firing all blast information (detonator IDs, delay times, detonator status, firing time) can be printed from the memory of the master blast box.

Remote firing is becoming increasingly popular in blasting practice due to the following benefits:

- increased safety distance contributes to improved safety

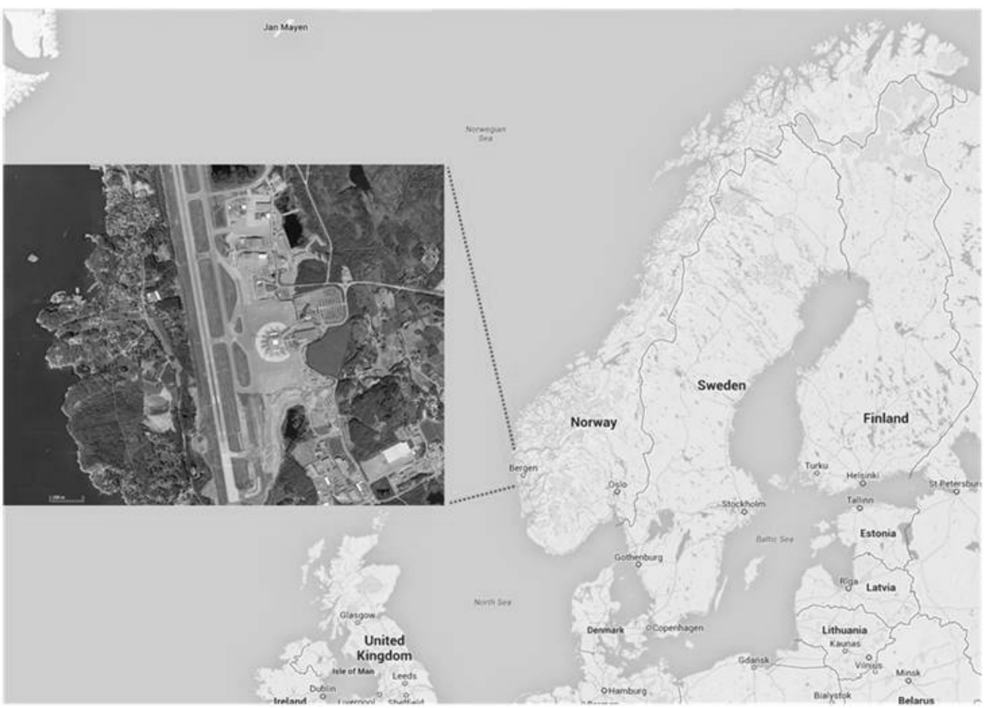

Figure 3. Geographical location of Bergen and location of the Flesland Airport and the work site.

Figure 4. Blasting under heavy mats in difficult conditions.

- responsible shotfirer has better control on blast site and approaches, no need to rely on third-party information
- removes need for running long firing cables
- improved operation efficiency due to reduced down time as haulage or access roads for moving equipment stay open until firing time.

2 PROJECT OVERVIEW

The project included a contract to blast approximately 1.1 million cubic meters of rock in preparation for the construction of a new section of Bergen Flesland Airport.

The entire blasting project lasted 14 months and consisted of over 600 blasts. Blasts were carried out over a 6 day week. About 650 tonnes of bulk explosives and close to 50,000 detonators were used in the project. At the closest point blasting was carried out in a distance less than 100 m from the main terminal building and all blasts occurred within 300 m of Norway's second busiest airport.

3 DRILL & BLAST PARAMETERS

To reduce the risk and potential of flyrock, excessive vibrations and in-hole deviation the drill hole diameter was limited to 70 mm and the bench height to 10 m. Under these conditions the contractor chose a 2.0 x 2.5 m drilling pattern. Emulsion explosive with an average density of 1.05 g/cm^3 yielded an average powder factor of 0.73 kg/m^3. Blast volumes ranged from 150 m^3 to 6,000 m^3 with an average of 3,000 m^3.

Timing designs were first planned on specific EBS blast design software by importing the surveyed drilled holes directly into the program. Generally the patterns used 10 ms between holes and 65 to 85 ms between rows.

The software was used to optimise blast designs. Drilled blast hole survey details were imported enabling appropriate hole charging and delay timing design. In some more sensitive areas it was necessary to blast with reduced charge weights.

Table 1. Basic drill and blast parameters at the Flesland project.

Diameter	mm	70
Burden	m	2
Spacing	m	2.5
Stemming	m	2
Sub drill	m	0
Hole Length	m	11
Explosive ρ	g/cm^3	1.05
Rock ρ	g/cm^3	2.7
Powder Factor	kg/m^3	0.73

Each blast required the use of blast mats to prevent flyrock events. 3 x 6 m, 1.3 ton, 15 mm cable laced steel belted truck tire mats were interlaid over every part of the pattern. In some cases a blast would require the placement over 100 blast mats, taking in excess of 4 hours.

4 BLASTING OPERATIONS

The following section will outline the details of a typical blast throughout its operational cycle. On the 12 June, 2013 a 3,000 m^3 blast was fired on the southern edge of the operations area. The blast location can be seen in Figure .

Blast #12-6 was composed of 60 holes, approximately 1,900 kg of bulk emulsion and required approximately 70 blast mats to be covered. Due to the proximity of a building

Figure 5. Beginning to charge the primed blast holes for blast 12-6.

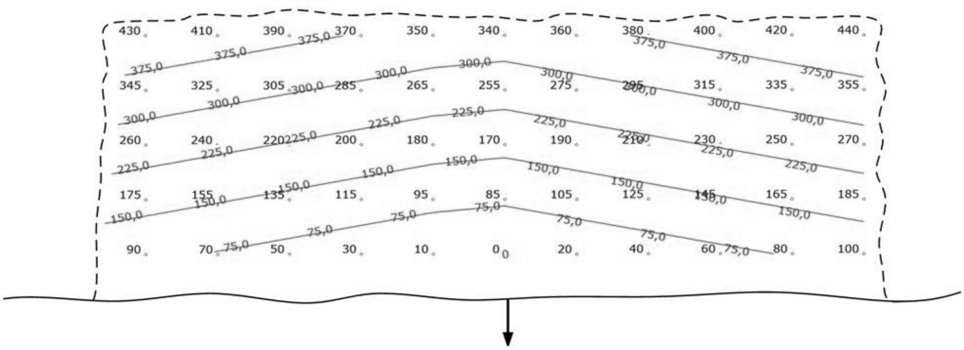

Figure 6. Opening in the middle of the front row. Sideways delay 10 ms alternating left right. Row delay 85 ms. The lines show the angle of initiation.

located approx. 50 m directly in front of the blast, fill from a previous blast was placed along the blast face to prevent any excessive rock movement. In addition there was another smaller blast located about 30 m to the south east on the level above. This second blast was fired during the same blast window with an offset of 300 ms (see Figures 4 & 5).

4.1 Priming and charging

The explosives supplier provided operators to assist the contractor with bulk loading operations. Blast hole plugs were used to ensure correct stemming lengths and the blast holes were stemmed by hand. Figure 5 shows the bulk truck and the operators beginning charging & stemming operations.

Drilling operations continued on an adjacent pattern which was fired the following day. A ‘bridge’ was left between the charged pattern and the new pattern for safety during drilling and to protect uncharged holes from blast damage.

4.2 Blast Design Timing

The initiation timing design is shown in Figure 6.

Using the timing plan in Figure single hole firing with 5 ms offset and an MIC (maximum instantaneous charge) of 42 kg was achieved for any blast size. In the planning of the project the given restrictions to drill hole diameter (max 70 mm) and bench height (max 10 m) seemed to be critical due to the strict production time plans. However, already after the first successful electronic blasts, with good blast movement and

Figure 7. Excavator placing a blast mat on blast 12-6, to the front of the pattern, fill can be seen placed along the free face to stifle flyrock.

vibration control, the blast sizes could be increased, resulting in less number of blast rounds and less unproductive time and less stops at the airport. The electronic blasting system delay accuracy and controlled on-bench blast implementation made it possible to blast large volumes at such close proximities to the airport's infrastructure.

4.3 Circuit Testing

The hallmark of the EBS is the ability to test the firing circuit after scanning and connecting is complete. The scanner or alternatively the testbox can then be set to 'endless testing' which loops the testing function for each detonator in the circuit so it runs continuously. In the Flesland Airport project endless testing was used primarily during placement of blast mats. As stated previously these mats weigh approx. 1.3 tonnes each and must be placed with an excavator in an overlapping pattern covering the entire blast. Figure 7 shows the placement process.

The placement of the mats is a challenging task for all initiation systems in order to ensure that the surface wiring of the initiation system is not damaged. The surface wiring can be easily hooked on the mats and pulled apart or crushed under the weight of the mats, resulting in possible misfires.

Endless testing was ideal to ensure that the surface wiring of the electronic blast circuit was not damaged during mat placement. Any prospective break in the circuit would have been displayed on the scanner or testbox and could have been rectified immediately.

Using electronic detonators along with the endless testing feature provided a distinct advantage over conventional shock tube initiation in the Flesland Airport project. Shock tube systems provide no feedback during mat placement and a problem is recognized only after the shot has been fired and a section of the blast misfired. Coincidently this happened at the Flesland site during the last pyrotechnic blast conducted before the electronic blasting system was introduced. A section of the blast misfired because a surface connector detonator lead was cut during blast mat placement.

4.4 Blasting

Blasting was conducted using either the remote firing function or conventionally via a firing cable with a single blast box. In the Flesland blasts the programming time averaged at about 2-3 minutes. Once programming is completed and the capacitors are charged to firing voltage the circuit is ready for initiation.

The procedure at Flesland prior to final programming required the shotfirer to contact the airport control tower for clearance to program the detonators. Once clearance was received the

Figure 8. Blast 12-6 initiated. Star shows firing location, approx. 150m away.

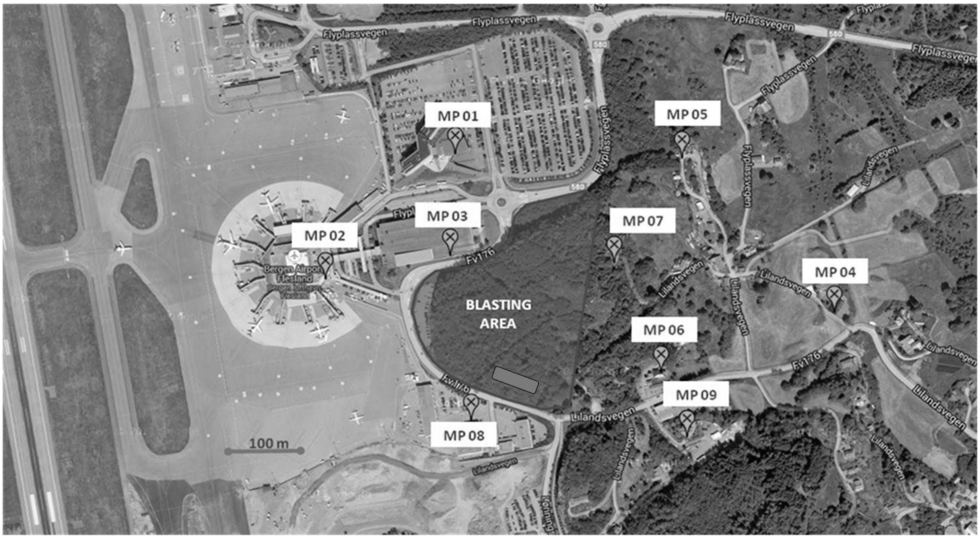

Figure 9. An overhead location map showing the placement of the 9 vibration monitors. Blast #12-6 is shown as a rectangle in the blasting area.

shotfirer initiated the programming sequence while maintaining contact with the control tower. After programming was completed the shotfirer received final firing approval from the control tower and initiated the blast.

4.5 Environmental compliance

In order to monitor blast induced vibrations the contractor employed a consultant company to install and maintain a vibration monitoring network consisting of 9 monitors. The consultant company uses a web-based vibration data management system to manage the network.

The contractor made use of web-based software to store, view and analyse vibration measurements and finally for controlling the MIC of each blast. Tables of triggered values and waveforms of the blast vibrations can be read from all monitors. Table 2 and Figure 10 show the results at MP06 for blast 12-6. It clearly shows the two separate

Table 2. Results from the 9 vibration monitoring stations after blast #12-6. Maximum allowed vibration limits and % of limits are also included.

	Max Limit	Distance to Blast	Measurement	% of Limit
MP 01	36 mm/s	350 m	-	0%
MP 02	36 mm/s	330 m	-	0%
MP 03	36 mm/s	220 m	2.25 mm/s	6%
MP 04	20 mm/s	430 m	-	0%
MP 05	25 mm/s	385 m	2.3 mm/s	9%
MP 06	25 mm/s	175 m	8.55 mm/s	34%
MP 07	25 mm/s	205 m	8.5 mm/s	34%
MP 08	36 mm/s	110 m	8.15 mm/s	23%
MP 09	25 mm/s	225 m	4.95 mm/s	20%

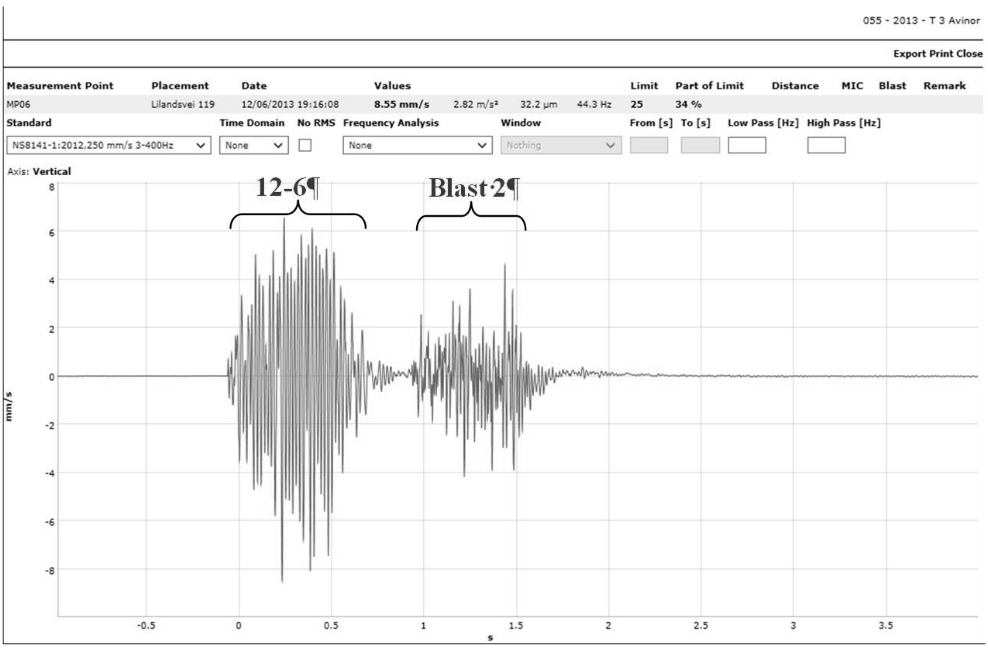

Figure 10. The waveform recorded from blast #12-6. The two blast events can clearly be seen. The first event is #12-6 and the second is a smaller blast located in the South Eastern part of the work site.

blasts with a peak vibration value of 8.55 mm/s for the first blast.

Blast induced vibration did not adversely impact on the project at any stage in the 14 month period, mostly due to far distances, relatively small drill holes and low benches. For some critical blasts the electronic blasting system contributed to control the vibrations by ensuring single hole firing. The highest recorded vibration velocity was only 52 % of the permitted level.

6 SUMMARY AND CONCLUSIONS

Over the 18 months of the project, consisting of 600 blasts, approx. 650 tonnes of emulsion and about 50,000 electronic detonators were consumed for the excavation of approximately 1.1 million m³ of rock.

The blasting operations took place under challenging environmental conditions. Smart blast design and operational excellence on the bench – starting with drilling, surveying, priming and charging and last but not least covering the blast – were prerequisite to the safe and efficient completion of a challenging construction project at Flesland airport.

The successful delivery of the critical blast performance indicators – safety and environmental compliance - was based on the capabilities of the electronic blasting system. Testability ensured no undetected misfires due to damage to the surface hook up. Timing flexibility enabled good control of rock movement and timing accuracy the strict adherence to environmental limits during all blasts.

The main blast performance improvements using the electronic blasting system were:

– safety – no undetected misfires due to surface hookup damage under heavy mats
– safety – full control of rock movement, no fly-rock
– environmental compliance – vibrations on nearby structures
– reliability – no blast delay affecting operation of airport
– fragmentation – can be loaded by excavators, no - little oversize.

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Explosives safety competence linked to UK National Occupational Standards – our experience Design for demolition of the 3.2 km Storstroemsbridge, Denmark

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ABSTRACT: In 2012 it was decided to replace the old 3.2 km Storstroemsbridge from Sjaelland to Falster in Denmark, constructed in 1937. The preparatory work on design of the new bridge and the demolition of the old bridge began in 2013, including the environmental impact assessment (EIA).

This presentation highlights the processes of planning and the assessment of applicable demolition methods, including:

- a short presentation of the bridge structure, comprising 50 span, super-structure of iron, sub-structure of concrete and a total of 250,000 t of construction materials.
- a brief state-of-the-art of demolition of multi-span bridges.
- presentation of the proposed demolition strategies:
    - demolition of the super structure in small pieces by cutting techniques or major pieces by heavy lift processes.
    - demolition of pillars in the substructure by mechanical means or blasting.
- discussion of opportunities and barriers of using blasting techniques for the demolition work.
- presentation of the most promising demolition methods, which includes blasting of the substructure.

A description of the details of blasting methods will be presented by Jorgen Schneider in a separate presentation.

The demolition of the bridge is planned to take place from 2021 to 2023 after the completion and opening of the new bridge. The tendering procedure is expected to start in 2016-2017.

1 THE STORSTROEMSBRIDGE – ONE OF THE LONGEST BRIDGES IN EUROPE

The Storstroemsbridge is an important railroad link between Scandinavia and Germany, which will be strengthened by construction of the new Femern-Belt tunnel. In 2011 it became clear to the Danish Ministry of Transport, that the Storstroemsbridge, built in 1937, did not have the capacity and strength to carry the increased

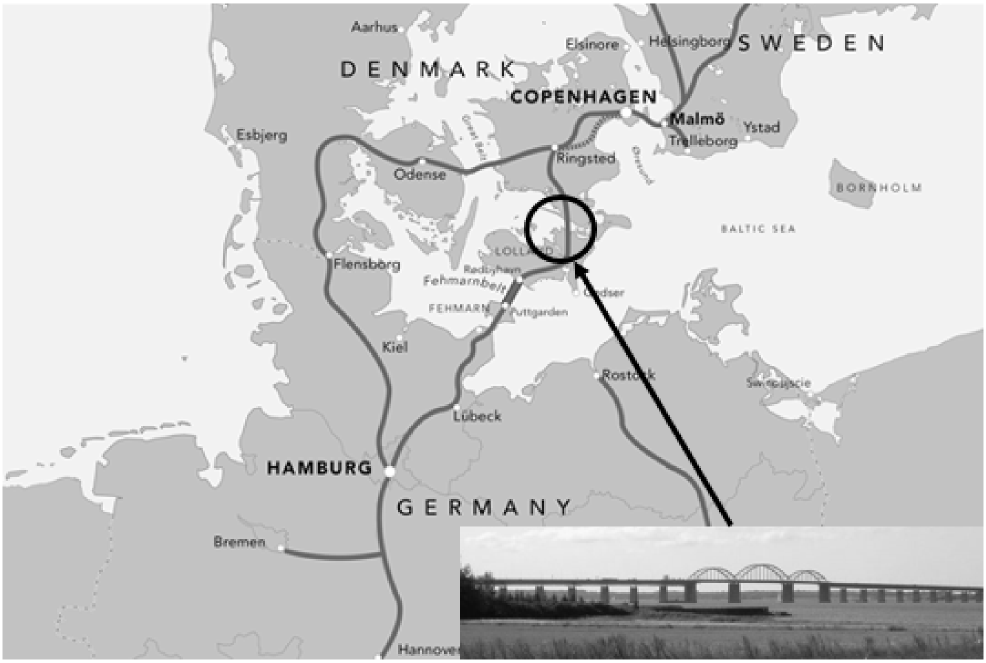

Figure 1. Map showing the major transport links connecting the islands of Denmark to Germany and Sweden.

Figure 2. Photos of the old (existing) Storstroemsbridge.

railroad traffic when the Femern-Belt tunnel will open in 2021. Based on feasibility studies of various options for strengthening and upgrading of the old bridge, it was decided to construct a new bridge and demolish the old bridge.

In 2013 the Danish Road Directorate started planning and design of the new Storstroemsbridge and the demolition of the old bridge. The Danish consulting engineering firm COWI was awarded the contract for design of the new bridge as well as the demolition design of the old bridge. NIRAS, another Danish consulting engineering company, was awarded the contract of the Environmental Impact Assessment (EIA).

2 DEMOLITION OF MULTI-SPAN BRIDGES

Design of demolition of multi-span bridges depends on the following issues among others:

– type of bridge, e.g. arch, continous girder, suspension and cable-stay, and number of spans etc.
– type of construction, e.g. steel, reinforced concrete or composite
– accessibility for demolition and collection of demolition materials

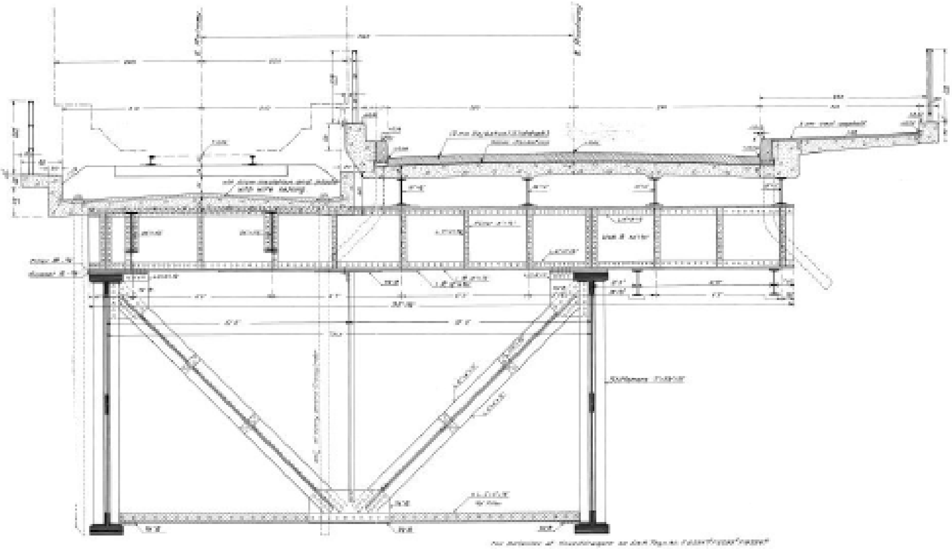

Figure 3. Cross section of the bridge.

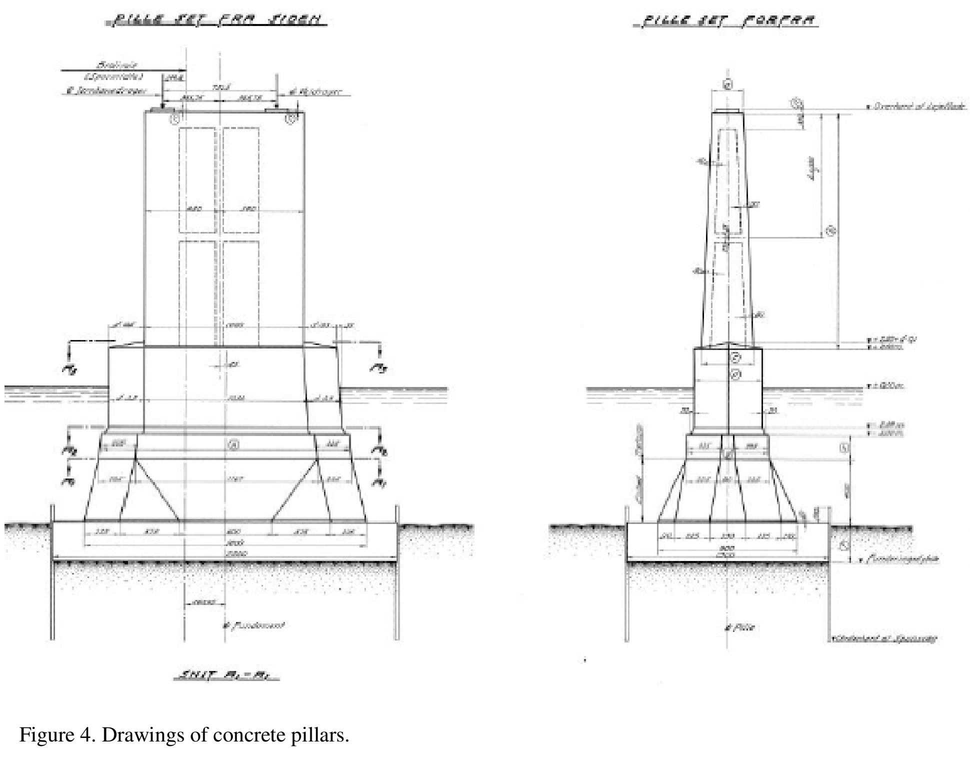

Figure 4. Drawings of concrete pillars.

– time frame for demolition, for instance critical time for demolition and clearance of debris
– special regards, e.g. traffic besides, over and under the bridge etc.
– risk and safety
– environmental constraints.

The demolition methods can be divided into following principle strategies:

Piece small - The demolition is carried out as a continous process; demolition of the structure piece by piece, followed by removal of the rubble. Traditional demolition methods with concrete crushers and pneumatic hammers are often preferred. Contionous blasting of the structures might also be used.

Dismantling - The demolition is performed by dividing the structure into suitable elements, lifted and transported to a specific demolition site for downsizing and partial demolition. The elements can be divided by mechanical means, cut by oxygen torch or blasting techniques. The lifts are performed by the means of cranes or jack-up systems. This strategy is preferred in case of in-accessible off-shore structures, structures above water, urban areas etc.

Blasting - Single and multiple span bridges can be demolished by blasting. The method is preferred for either the superstructure, the substructure or the entire brigde in case of special time constraints and opportunities for collecting the rubble after blasting. The blasting demolition can be conducted as a sequence of partial blasting operations or one integrated operation. This is the case of demolition of high rise bridges and bridges over water.

Table 1. Main figures of the Storstroemsbridge.

Feature	Data
Construction	1934 – 1937 combined railroad and motor road
Length	3.2 km
Type	Steel cantilever girder on concrete pillars
Length of spans	47 spans 60 m and 3 spans 102 – 136 m
Weight of spans	Total 891 tons – 2409 tons
Pillars	49 plus 2 abutments
Concrete	265,000 tons
Steel	20,000 tons

3 DEMOLITION STRATEGY FOR THE STORSTROEMSBRIDGE

According to the overall planning, the demolition of the old Storstroemsbridge will start after the opening of the new bridge. The requirements to the demolition methods are best possible solutions with respect to economy, safety and environmental impact. Especially, the impact on the marine environment must be controlled and fulfil public requirements. There are no specific time limit requirements. However, two years is a reasonable basic timeframe. The strategy of the bridge demolition comprises two sub-strategies:

– demolition of the superstructure
– demolition of the supporting structure (substructure).

3.1 Demolition of the superstructure

The following options for demolition of the superstructure were analysed:

– demolition of the structure into small pieces by crushing the concrete plates and cutting the steel in suitable sizes and transporting to shore for further processing
– demolition of the structure by heavy lifting of the spans one by one and transport on barge to a suitable demolition facility on shore
– demolition of the structure by blasting of the superstructure after removing the concrete decks.

The first option should start with removal of the concrete deck by crushing and retrieving the concrete by suspended containers or wire cutting and removing the concrete in suitable pieces. The design of the following removal of the steel girder is based on jack-down system on barges, enabling dismantling of the bridge in sections as it was built in 1934-37.

The second option requires a heavy lift crane with a capacity to carry a full-length span including the concrete plates. Only very few heavy-lift cranes of the required capacity are available in Europe, and the crane operations require very detailed planning and scheduling. Furthermore, crane operations for dismantling the near-shore spans require dredging of intermediate channels along the bridge close to the shores.

The third opportunity is blasting of the superstructure, which is practiced all over the world, especially in USA. Figure 5 presents an example. The blasting design is based on cutting

Figure 5. Blasting of superstructure of the Milton-Madison Bridge, USA.

Figure 6. Photo of the girder structure inside the superstructure of the Storstroemsbridge.

the girder steel members in suitable pieces by the explosive cutting charges (shaped charges). Figure 7 presents a proposed blasting design of a cross section cut.

The design is based on shaped explosive charges of NSP 711 (PETN) in DIOPLEX forms, 0.8 kg PETN pr. m (length of charge). Cutting

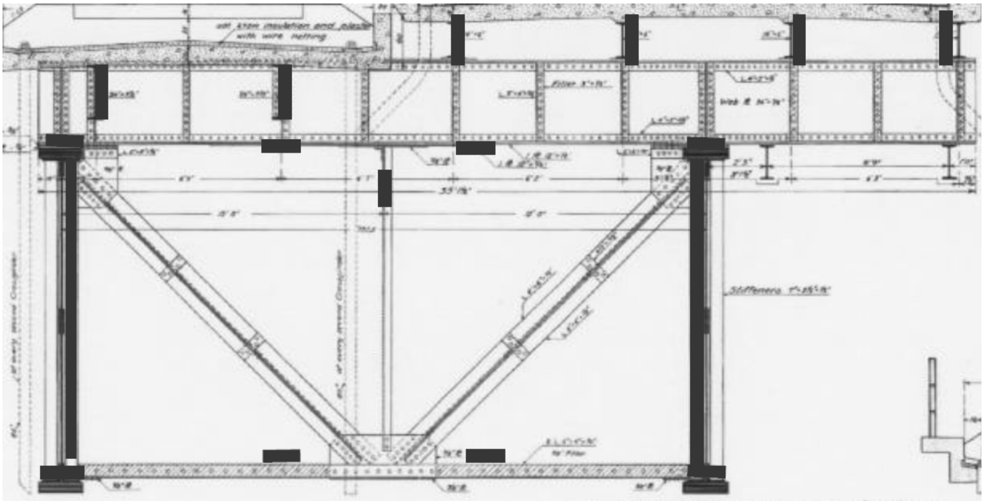

Figure 7. Proposed design of blasting using shaped charges. The explosive charges are marked black.

capacity 25 mm. Total for one cut approximately 18 kg explosives.

However, analyses of the need for resources, economy, risk and environmental impact resulted in the recommendation of the first option dismantling the steel girder by the use of jack-down systems on barges.

3.2 Demolition of the substructure

The following options for the demolition of the pillars were analysed:

- demolition of the structure by mechanical means using hydraulic hammers and concrete crushers
- wire cutting of the structure, lifting the elements on barges and transport to demolition site on shore for further processing
- blasting of the pillars in one or more sequences
- combinations of various methods, e.g. mechanical crushing of the shafts of the pillars and blasting of the bottom parts of the pillars.

The shafts of the pillars can be demolished by the use of hydraulic hammers and concrete crushers on movable work platforms. Demolition of the lower part and the foundations will be time consuming and a dry dock around the foundations might be required.

It was assessed that wire cutting of the pillars in portable sizes would also be time consuming and rather expensive.

Based on analysis of the opportunities it is decided to propose a blasting design for the demolition of the pillars. (The blasting design is presented in the paper 'Feasibility study of drilling and blasting of piers and impact on the environment' by Jørgen Schneider.)

4 OPPORTUNITIES AND BARRIERS FOR BLASTING

In Denmark demolition of structures by the use of explosives is practiced by the members of the Danish Federation of Explosives Engineers. We have a lot of experience in blasting high rise concrete and steel structures, also concrete and steel bridges, but not bridges of the size and type of the Storstroemsbridge.

Danish authorities, including the Danish Road Directorate, accept blasting demolition in line with all other demolition technologies. Therefore, the Road Directorate and COWI have assessed the opportunities and barriers of blasting technologies compared with other demolition technologies and combinations of technologies for demolition of the superstructure as well as the substructure.

The primary barrier of blasting the superstructure is the recovery of the steel members from the seabed up to the depth of 13-14 meters after blasting. We have discussed the solution of preparing lifting wires marked with buoys, which could enable the collection of steel members from the sea bottom. However, we found the recovery and lifting of steel members so complicated and risky, that the blasting of the steel girders has not been selected as one of the most preferred demolition solutions in the EIA. On the other hand, the blasting of the girders is still considered as an opportunity, which might be applicable in the future call for proposal on the demolition of the bridge.

With respect to other impacts of blasting, it should be mentioned that the nearest neighbours to the bridge are approximately in the distance of less than 100 meters, which makes it necessary to place and cover the shaped charges in order to avoid fragments. Furthermore, a safety distance and an exclusion zone should be established.

Analysis of methods for the demolition of the substructure resulted in a preference of blasting as the most preferred method. Like the blasting of the superstructure, collection of materials from the seabed is a critical issue. Recovery of concrete fragment from the seabed by crane and long-range excavators on barges are acceptable solutions. However, it is discussed whether the fragments should be recovered or it is acceptable to leave the rubble together with the foundations of the pillars on the seabed. Leaving the rubble on the seabed, depends on the maritime authorities, and presupposes that all iron bars are cut and removed and the concrete rubble masses are levelled out.

The most important barrier is the environmental protection including the protection of fish and mammals in the sea. Furthermore, cables close to the bridge must not be exposed to any risk of fragments from the blasting of the pillars.

5 CONCLUSION

By the end of 2014, COWI presented the technical proposal for demolition of the old Storstroemsbridge comprising the following methodology:

– removal of all hazardous materials such as asbestos, paints containing lead and PCB
– stripping the structure for installations, railroad materials etc.
– demolition of the land-connection spans close the abutments with mobile crane
– demolition of concrete deck
– dismantling of the superstructure spans by the use of a special designed barge and jack-down system
– transport of the bridge spans to designated site for selective demolition and recycling of materials
– demolition of pillars by blasting
– collection of concrete from the seabed and recycling of concrete, depending on the possible acceptance of leaving the concrete on the seabed
– partial demolition of the two abutments
– clearing and development of the terrain for new purposes.

The detailed planning of design and tendering proces will start after the design and tendering of the construction of the new bridge. The demolition of the old bridge is planned to be carried out in 2021 – 2023.

6 ACKNOWLEDGEMENT

The authors thank the Danish Road Directorate for the information on demolition of the Storstroemsbridge.

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Experiences with the pan-European implementation of track and trace software - challenges, solutions and prospects

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ABSTRACT: Because of terror attacks using civil explosives in Madrid (2004) and in London (2005), the European Commission introduced a range of counter-terrorism actions, which the EU identification directives are part of. The goals of the EU-directive 2008/43/EC, which was published in 2008, and its extension 2012/4/EU are the identification and traceability of all explosives from the point of manufacture, or the first introduction into the EU, up to the usage by the end user. They are also used to support the enforcement authorities in the tracing of lost or stolen explosives and prevention of their abuse. To achieve this, all manufacturers, distributors and end users of explosives within the EU are obliged to implement a tracking and tracing solution into their company processes. Regarding the latest upcoming deadline for implementation in April 2015, analyses and experiences with the already developed solutions and integrations can be done now. This paper will address the experiences and results of first implementations that show the problems developers of track and trace software had to solve and give a prospect on upcoming challenges.

1 REQUIREMENTS OF THE EU-DIRECTIVES

In addition to the traceability of explosives over the entire supply chain, manufacturers, distributors and end users need to put in place plans for the storage of the tracing data over a period of 10 years. In case of a request from the responsible authorities, concerned companies are obliged to give information about the disposition of their explosives immediately, at any time 24 hours a day and 365 days a year. The name and contact details of a person able to provide the required information outside normal business hours have to be provided to the responsible national authority. The system used has to be tested regularly to secure the efficiency and quality of stored data. The first deadline for the implementation determined by the EU-directive 2008/43/EC, the 5 April 2012 was extended by the directive 2012/4/EU to 5 April 2013. Manufacturers and importers had to ensure unique marking is labeled or printed directly on every explosive and the packaging. Goods without unique identification that have been produced or imported into the EU before 5 April 2013, do either have to be used or given back until 5 April 2015. On this date all companies possessing explosives are obligated to execute data collection and recording of all explosives.

The leading explosives manufacturers, organized in the FEEM, took three years of lead time to fulfil their new marking duty on time for the commencement of the EU regulation. In 2010 the complete industry organized itself in task forces and committees who agreed upon the two-dimensional data matrix codes ECC 200 as a FEEM standard. The developed FEEM guidance note helped the manufacturers and importers to implement the EU-directive in a standardised and easy way.

2 DEVELOPMENT OF TRACKING AND TRACING SOFTWARE

By publishing the EU-Directives the German Blasting Association began to search for a software company which was able to develop a tracking and tracing system to fulfill the requirements. Due to the experience with other track and trace solutions for the tobacco and automotive industries the association soon identified a contact. Analyses of the directives and the requirements at any part of the supply chain had to be done. In strong cooperation a tracking and tracing software for explosives was developed.

2.1 First steps in development

To develop a system it had to be clear how the requirements of the EU-directives can be achieved in practice. Considering that a unique identifier consists of up to 30-digit numbers and not only continuous numbers are used, a manual registration of data would only be possible for a very small amount of products. Even if the EU-directive does not demand it, a computer-based system was indispensable for most companies. For the first deadline (5 April 2013) a specification analyses for marking explosives had to be done and the development of a printing solution to generate labels and XML-files compliant to the EU-directive began. At the same time the company decided to found an own company for tracking and tracing of explosives.

At the EFEE World conferences in Lisbon and Moscow their Tracking and Tracing solution was presented to the public. By winning the first bigger manufacturers of explosives in 2011 and 2012, new knowledge about production processes and requirements could be collected. Since 2012 the software is has been used as an internal solution for explosives manufacturers across Europe and the USA. One of the first difficulties that the company had to solve in collaboration with the future users was the speed, and thus the profitability, of production which were not allowed to shrink due to the application of the new labels. The solution had to be implemented in already existing systems of big manufacturers.

After finding a satisfactory answer to the physical labelling, the digital data were given attention. It was supposed to be administered quickly and easily and later also be transferred in the framework of the second level of the EU-directive. Therefore the system was constructed in

Figure 1. Sample label referring to EU-directive.

a way that entire packaging hierarchies can be saved. The information of single items is summarized in small packaging units and these are assigned to a higher packaging unit. For example: all tracking numbers of single detonators are listed in the data for the single outer packaging, which again is part of an entire pallet.

2.2 *Implementation on manufacturers and importers sites*

In 2013, when manufacturers and importers of explosives already had to fulfil the EU-directive, the German Blasting Association made an analysis for the implementation. Almost half of all codes, which were produced at that time, were problematic. 20 to 30 percent of markings did not accord to the data matrix codes required by the FEEM. Furthermore, the coded data was partly erroneous: They were partially incomplete or incorrect. In total only 20 to 25 percent of the tested labels were without errors. This alarming result had an impact. By summer 2014 most manufacturers had repaired the errors identified. Some non-standard explosives still exist until April 2015. These have to be destroyed or given back by then. The main goal of the manufacturers was to remedy defects by the end of 2014 – just in time to rollout the second part of the EU-directive with due date April 2015. Therefore it was important for every party to install new hardware and software. The ambition of the tracking and tracing solutions was, and is, to make the directive achievable for every user with the lowest possible effort. Regarding this, some software vendors offer in addition to the required track and trace functionalities an electronic stock book to avoid the traditional manual paper work. Due to the time saving effect in administration of the stock book, even a practical benefit can be raised from the EU-directive.

Because of the requirements of the EU-directive, most companies had a problem with their internal organisation. The process of generating the new labels and at the same time saving data, generating XML data and delivering all information to the clients, were new tasks. To find a solution, suppliers of tracking and tracing software and the manufacturers had to engineer new process-organisations in strong cooperation to optimise the internal processes. It was necessary to keep the speed of the production on the same level, raise the quality of markings as demanded by FEEM, have alternatives for marking in case of errors and to avoid additional manual work.

For the selection of hardware, partners had to be found, which offer a variety of all kinds of devices for several areas of operation. The mobile devices had to be robust and protected against dust and rainwater. It was necessary to not only involve the manufacturers but the entire supply chain in the selection of hardware. Two worldwide suppliers became new partners to deliver handheld scanners. They offer different robust and handy devices to give the client the opportunity to choose the most appropriate one for his business. Differences can be made between price, area of operation (stock or outside) and individual requirements. At the end, the range included low-priced handheld scanners, which are connected to a PC or Laptop and small portable computers with scanner, keyboard and usually a pistol grip. They are standard in logistics and have maximal stability, longevity and are easy to use. They can be delivered in several protection classes. In a few cases robust tablet-PC´s were also requested. Due to the bigger display more information can be shown at the same time. But the display also has the significant disadvantage that the device cannot be as robust as smaller mobile devices, it is much heavier and the battery doesn’t last as long.

2.3 *European wide support – Partner network*

Originally the plan was to create a track and trace solution only for the German market, because it was assumed that other countries have similar software products. Until 2013 it turned out that very few solutions existed on the European market. That is why the work was done together with European-wide associations like EFEE and FEEM. A European Partner network was built up to provide consulting and services in local languages in every country of the EU. The benefit from this network is the local support and consulting for customers in the whole of Europe, contacts of the partners to national authorities and blasting associations to gain more information about new developments and adaption of the solution to national needs, and the exchange of experiences within the partner network.

3 FEEM GUIDANCE NOTE/XML

As already mentioned, manufacturers were the first, who had to fulfil also the requirements regarding FEEM-compliant labels and data transfer.

From 2009 until 2013 FEEM members came together to prepare the FEEM-guidance note. The aim was to outline a method to achieve a harmonized system for the implementation of the EU-Directives. The system is not binding to the FEEM members, but recommended and shall minimize logistical problems by considering the entire supply chain up to the end user.

The most beneficial solution for FEEM was the bar-coding technology. With a unique number, an item shall be traced throughout its life cycle. With a database maintained by each user of the explosives the traceability shall be achieved. Because of the high number of explosives manufacturers a harmonized system of database management is essential to prevent high effort for all users by maintaining different records of each supplier.

As a result a code structure had been designed and adopted that was flexible enough to enable the use in already existing IT systems to all companies. Mandatory fields in the bar codes on the labels enable the tracking and tracing of products. Further data is needed to keep an electronic record within the electronic stock book in accordance with national legal requirements in all EU member states. (More information can be gleaned in the FEEM Guidance Note).

4 DATA TRANSFER WITHIN THE SUPPLY CHAIN

After completing the FEEM Guidance Note, the software developer had to ensure that all requirements were fulfilled by their software. By the demands of the FEEM guidance note, information has to be sent in XML-files through the whole supply chain. An option to transfer the XML-files in a safe and fast way had to be found. There was no binding consensus in the industry on how data is supposed to get from manufacturer to the rest of the supply chain. Most of the transmission forms cause manual effort to different extents. They include data carriers like USB sticks accompanying the delivery. They are applicable almost everywhere, but cause considerable manual effort and entail, besides other security risks, the danger of transmitting viruses to the computer. Explosives suppliers may also charge extra costs for the USB-Sticks and for additional logistical effort. Data transfer can also be done by normal emails, which are used in every company. But for this, manual effort is necessary which might result in errors, loss of data, spam attacks and security holes. More security of loss and the access of unauthorized persons are offered by automatic electronic transmissions.

It was necessary to provide a platform that supports all ways of transmission and also be compatible to track and trace systems of other providers. To enable the simple and secure data transmission across Europe with all suppliers and customers, this data transfer platform is available as European standard. For the Europe-wide exchange it was necessary to have the platform available in all countries, independent from producers of explosives and from the software itself. It can also be connected to other systems. The feed in XML files are automatically audited on correspondence to the standard. This way the data transfer platform protects its users from problems in data processing and transmission. For implementing the software little effort is necessary and an internet connection has to be available. But on the other hand it is the safest and most timesaving option.

5 IMPLEMENTATION ON DISTRIBUTORS AND END USERS SITES

From 2013 also distributors and end users were supported, which had to implement a solution for tracking and tracing of civil explosives by 5 April 2015. They are not only obligated to data collection. Every single item of civil explosives has to be completely traceable over the entire supply chain from its manufacturer over the distributor or importer until the end user. The data of every single element has to be recorded in time. Afterwards the data has to be stored for a minimum of 10 years, and protected from any falsification. A special challenge was the availability of information about origin, position and disposition of the explosives for the responsible authority. Every company has to name a responsible contact person, who is available to the controller at any time of the day or week to give information at short notice. The tracking and tracing software had to regard this aspect to facilitate the permanent obligation of disclosure. It was possible to develop software, which allows one unique temporary access for the authority to check a single tracking number. This access can be closed by the customer at any time. The controller receives herewith no insight in the entire stock book, but the data of the investigated tracking number. The safe and long lasting storing of data is done in secure IBM data centers in Europe.

Due to the requirements of scanning every item, making sample scannings, and the ability to relocate and use explosives, internal work processes had to be adapted to avoid additional expense.

Also data transfer had to be included in these. Information should be provided by the manufacturers before delivery. Without these, receivers of explosives would have to register every item manually. The data transfer also has to be done in reverse directions in case of returns. The entire life cycle has to be registered and fully reproducible. As already mentioned a fast and automatic data transfer over an electronic platform can ensure that. The problem was that some manufacturers could not provide FEEM-compliant XML-data by the end of 2014.

Not only software, but also hardware had to be delivered to the customers. They had to be suitable for different environmental conditions (e.g. in queries) and weather. The techniques were new for most of the companies and employees needed to be trained. Still a lot of exception existed, which had not appeared before the use of the solution. Further trainings for several companies had to be managed.

In some countries an electronic stock book was required by law in the explosives sector. For this reason, this feature was included in the software to fulfil the national demands and EU-Directive at the same time.

The experiences when implementing the software were that every user has his own processes. Some carry their scanner from one point to another, some just need a local scanner and other companies cannot even transfer data via internet, because their site is outside of stable internet connection.

The challenge was to create a solution for all these companies, which was still flexible enough to be easily adapted to individual requirements.

6 ROLL-OUT OF TRACKING AND TRACING SOFTWARE

A big issue which especially arose in the field of explosives end users was that the EU-Directives were not well-known in the beginning. Many companies engaged themselves very late with the topic. That caused not only training for the software but training for the requirements of the EU-directives.

Due to tardy orders a late implementation into some companies systems was inescapable. An intensive usage of the system was firstly necessary in February or March 2015, because of winter break in some companies. In the first quarter of 2015 mobile devices and scanners had to be adapted to the customers' demands, but one problem was that the hardware deliverers were not able to supply so many devices right in time, because of the late orders. Processes to reduce the delivery times had to be created and the problem could be solved.

One of the main problems for all parts within the supply chain was the first inventory of all explosives, stored in their stocks. A lot of them were marked with labels, but without corresponding xml files. To use them after the 5 April 2015 they have to be scanned piece by piece. If not, all unmarked explosives had to be given back to the manufacturer or had to be destroyed by 5 April 2015 by the demands of the EU-directive. To avoid this manual effort, a possibility was found to label all the unlabeled explosives afterwards.

7 CONCLUSION (PROSPECT)

After the implementation in April 2015, when the EU-directive came into force for all companies possessing explosives in the EU, there is still a lot of work to do for track and trace software supplier.

It is necessary to increase the usability and flexibility of the software to be more adaptable to all users without losing any features of the system. For the future work between all parts of the supply chain of explosives, ways for data transfer should be expanded and even more reliable. Adaptations of the system to improve the company's processes for a faster and easier work are already planned. Better implementation into already existing systems is included in new releases of the software.

Individual adaptations of the system will follow. Many companies first notice the need for special features when they are working intensively with the system.

Over the last years since the issue of the EU-directive and appropriate papers, we developed a tracking and tracing solution for explosives for civil uses. An important fact is that knowledge in tracking and tracing and the strong cooperation with the blasting associations and selected end users were the main support to develop this solution. Feedback from the customer helped to improve the software and to find the right hardware-software combinations. Due to the new process integration additional effort may be caused but can still be kept on a low level through a tracking and tracing software. It is important to say, that this paper and the included results only concern the work and experiences of the author's companies. It may not apply to the experiences of other track and trace software suppliers.

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Transmissibility of blasting vibrations from rock to mount, Part 2

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ABSTRACT: Error in the measurement attributable to coupling has been assessed by the rock-to-mount, or coupling, transmissibility, i.e. ratio of the velocity of the sensor mount to the velocity of the ground motion – from 2 to 200 Hz, at two velocity levels, 5 and 20 mm/s. Already published data (13 trials) and new gathered tests on a vibration exciter are considered. In this new campaign free placed, sandbagged, and anchored mounts on granite were tested from 1.6 to 40 Hz at one or two vibration levels. Two more techniques, in which the sensor mounts were fixed with thermal adhesive or a combination of duct tape and gypsum plaster, have also been investigated from 2 to 200 Hz at 5 and 20 mm/s. Free and sandbagged mounts lead to a weak coupling of the mounts to rock, with accurate measurements only below 17 Hz for free mounts and 10 Hz for sandbagged in the tested conditions. Above these frequencies, ground motion in the measurement can be modified by a factor of 0.16 to 1.21. Anchored, glued and plastered mounts achieve a stiff rock-to-mount coupling, ensuring consistent measurements for the frequencies commonly found in blasting independently of the vibration level and the mount characteristics.

1 INTRODUCTION

The quality of a vibration measurement can be estimated as function of frequency f from the motion transmissibility $T(f)$, defined as the ratio of the seismograph output velocity $V(f)$ to the velocity of the ground motion $V_{gr}(f)$ (de Silva 2007). Transmissibility is a measure of the error and values around one show accurate measurements of the ground motion. If the velocity of the sensor mount is denoted as $V_m(f)$, transmissibility of vibrations can be expressed as the product of the rock-to-mount, or coupling, transmissibility $T_c(f)$, and mount-to-geophone transmissibility $T_{geo}(f)$:

$$T(f) = \frac{V(f)}{V_{gr}(f)} = \frac{V_m(f)}{V_{gr}(f)} \cdot \frac{V(f)}{V_m(f)} = T_c(f) \cdot T_{geo}(f) \quad (1)$$

The mount-to-geophone transmissibility or seismograph response is usually provided by testing the seismograph in a vibration exciter, with the sensor mount firmly attached to the plate of the exciter (Birch *et al.* 2014; Farnfield 1996; Stagg & Engler 1980). It must meet the minimum accuracy specified by design standards for blasting seismographs (DIN 1995; ISEE 2011).

Field guidelines and recommendations (most of them stemming from an already classic work by the US Bureau of Mines - Nichols *et al.* 1971) generally assume that the sensor mount follows the ground motion, i.e. rock-to-mount transmissibility $T_c(f)\approx 1$ − whenever the expected vibrations levels are lower than a certain limit. Field measurements with mounts placed close each other and coupled to the ground with some of the recommended methods suggest that some of these methods may have a coupling transmissibility different from one (Adhikari *et al.* 2005; Armstrong & Sen 1999; Blair 1995; Hutchison *et al.* 2005; Wheeler 2004; Williams & Treleaven 2003; Yang *et al.* 2014). In order to investigate this, the attachment of the geophone mount to a hard surface was simulated on a vibration exciter (Segarra *et al.* 2013, 2014, 2015). The main characteristics of ten of these trials reported preliminarily in previous EFEE conferences, in which five measuring conditions were investigated with two blasting seismographs, are shown in Table 1. It also gives the range of the resulting coupling transmissibility for each of these tests series. It was found that transmissibility for free and sandbagged mounts depends on the testing condition (motion and mount characteristics). Free laid mounts amplify ground motion up to around 60 Hz and above that frequency they damp strongly ground motion. Sandbagging leads to a complex transmission pattern; it damps vibrations at mid frequencies (around 30 Hz), and amplifies them at high frequencies. Mount characteristics, such as mass and size, affect transmissibility when the mount is free placed and sandbagged. Anchoring showed an excellent accuracy with $T_c\approx 1$ from 17 to 100 Hz irrespective of the mount characteristics and the input velocity studied.

As the memory capacity of one of the seismographs used in 2013 prevented covering low frequencies, i.e. 4 to 16 Hz, a new measuring campaign has been made to measure transmissibility for free, sandbagged and anchored mounts down to 2 Hz. In this new campaign, two more methods in which the sensor mounts were glued and plastered to granite have also been investigated from 2 to 200 Hz. This work shows coupling transmissibility from these new measurements, and studies the performance for five suggested methods to monitor vibration from blasting in a wide range of frequencies (2-200 Hz), thus including low frequencies typical of urban dwellings (Siskind *et al.* 1980).

2 EXPERIMENTS OVERVIEW

Two seismographs were tested on a vibration exciter controlled by a single-point laser Doppler vibrometer- LDV; this instrumentation was also used in previous measurements. The seismographs meet ISEE (2011) specifications for blasting devices and are formed by three orthogonally oriented geophones housed in a metallic mount and connected to a recording-sampling unit. Table 2 shows details of the monitoring devices; they are identified as Sm and Sv. Seismograph Sm has the same mount characteristics, but different electronics and mechanics than the model used in the previous set of measurements, whereas the same model of seismograph Sv was used in both measurement campaigns. Vibrations were recorded and sampled at 2048 Hz.

Figure 1 shows the layouts investigated; note the LDV pointer in the base. The longitudinal

Table 1. Summary of trials made in 2013.

Test[a]	Layout			Motion characteristics		No. of tests	Range of coupling transmissibility
	Coupling	Base	Seismographs	Peak vel. mm/s	Freq. range Hz		
FG5	Free	Granite	Sm/Sv	5	16 – 200	1/1	0.16 – 1.18
SG5	Sandbag	Granite	Sm/Sv	5	16 – 200	1/1	0.76 – 1.21
SG20	Sandbag	Granite	Sm/Sv	20	16 – 200	1/1	0.70 – 1.09
AG5	Anchored	Granite	Sm/Sv	5	16 – 200	1/1	0.98 – 1.08
AG20	Anchored	Granite	Sm/Sv	20	16 – 200	1/1	0.98 – 1.08

[a]The acronym is formed as follows: the first letter is the coupling method, the second one is the base, and the number is the peak velocity of the imposed motion.

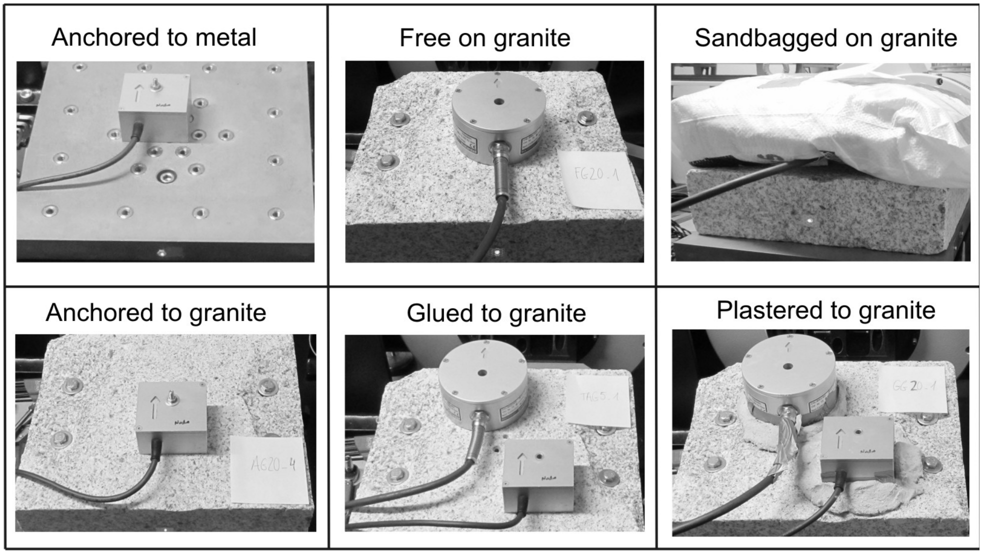

Figure 1. Test series layouts.

geophone, shown by an arrow on the top of the mount, was aligned with the motion axis of the exciter. In one layout (top left photograph, Figure 1), the sensor mount was directly anchored to the metallic plate of the exciter, whereas in the others it was placed on the granite slab coupled by means of five methods suggested by different guidelines (Instantel 2008; ISEE 2009; ISRM 1992, Konya & Walter 1991), namely: free, sandbagged, anchored, glued and plastered. The last two techniques are alternative methods of anchoring for monitoring vibrations in structures in which the surface in contact with the sensor mount should not be damaged.

Table 3 shows the main characteristics of the new tests series made in 2014; the tests series are similarly identified than in Table 1. The seismographs were tested under a horizontal sine type vibration of constant velocity and frequency shift at rate of 0.02 oct/s. The frequency was varied downwards, and the maximum deviation of the peak velocity of the base motion was fixed at 2%, and to get a stable motion at low frequencies, below 10 Hz. Seismograph Sm was analyzed first and Sv next, except in layouts with glued or plastered mounts where both seismographs were tested simultaneously. Glued mounts were tested 1 to 2 minutes after they were attached to the granite surface; the mounts were detached from the slab after they were tested at 5 mm/s, and glued again to test them at the high vibration level. Plastered mounts were tested 50 minutes after the layout was finished, using the same attachment for tests at both vibration levels.

Table 2. Characteristics of seismographs.

Characteristics	Sm	Sv
Mount density kg/m^3	2130	2690
Mount mass kg	0.905	0.508
Mount shape	Cylindrical	Prismatic
Mount base size/height cm	5 (radii) / 5	7.1 × 6.1 /4.4
Memory capacity Mb	64	200
Analog to digital converter, bits	16	16
Range mm/s	±254	±200
Resolution mm/s	0.00788	0.006

3 RESULTS

3.1 Data processing

The waveforms recorded by the seismographs in the longitudinal component were processed according to Segarra *et al*. (2015) to obtain a

Table 3. Summary of test series made in 2014.

Test	Layout			Motion characteristics	
	Coupling	Main characteristics	Base	Peak vel. mm/s	Freq. range Hz
AM5 / AM20	Anchored	Hex lag screw	Metal	5/20	1.6 – 200
FG5 / FG20	Free	No holding force	Granite	5/20	1.6 – 40
SG5 / SG20	Sandbag	23× 32× 11 cm, 4.5 kg of sand	Granite	5/20	1.6 – 40
AG20	Anchored	Plastic anchor, rod, washer, nut	Granite	20	1.6 – 40
GG5 / GG20	Glued	Thermal adhesive on the mount	Granite	5/20	1.6 – 200
PG5 / PG20	Plastered	Gypsum plaster on grey duct tape that wraps the mount base	Granite	5/20	1.6 – 200

noise-free amplitude response $V(f)$ between the onset and the end of the frequency sweep; amplitudes at these frequencies are not considered for the analysis as the use of further noise reduction or other smoothing techniques, such as the robust locally weighted linear regression (Segarra *et al*. 2013, 2014) were ruled out since they smooth in excess transmissibility at the peaks.

The spectral amplitude of the base velocity $V_{gr}(f)$ is calculated as a function of the peak velocity of the vibratory motion v_{gr} using a modified power–type formula based on Gloth & Sinapius (2004):

$$V_{gr}(f) = k\, v_{gr} f^{-1/2} = \frac{1}{t_w}\frac{1}{(S\log 2)^{1/2}} v_{gr} f^{-1/2} \qquad (2)$$

where k is a function of the waveform duration t_w and of the frequency shift, or sweep, rate S.

3.2 Mount-to-geophone transmissibility

In tests series AM5 and AM20 with the mount anchored to the metal of the exciter plate, the contribution of coupling can be considered negligible. In these conditions $V_m \approx V_{gr}$ or $T_c \approx 1$, and the motion transmissibility $T(f)=V(f)/V_{gr}(f)$ is the transmissibility of the geophone $T_{geo}(f)$ according to Equation 1. Figure 2 shows the transmissibility for both seismographs in the measuring conditions; they are estimated as the mean of the transmissibility from both tests, since differences in transmissibility at 5 and 20 mm/s are in line with the experimental errors of the test, i.e. 2%. The monitoring devices are in compliance with ISEE seismograph specifications (plotted in Figure 2 as reference).

3.3 Rock-to-mount transmissibility

The coupling transmissibility $T_c(f)$ is calculated, dividing the total motion transmissibility $T(f)$ from each trial on granite by the appropriate geophone transmissibility $T_{geo}(f)$, see Equation 1. The results are shown in Figure 3 for all individual trials; different line styles are used for trials made with the same layout but different seismograph or input velocity; ISEE (2011) bounds are also plotted.

Free placed mounts at both velocity levels (FG5 and FG20 tests; top left graph in Figure 3) lead to large distortion with coupling transmissibility ranging from 0.58 to 1.05. Free laid mounts follow acceptably well rock motion, with transmissibility within the experimental error, for frequencies below 17 Hz irrespective of the velocity of the imposed motion and the mount type. The acceleration at which this occurs (roughly estimated as $2\pi f v_{gr}$) is about 0.05g for tests at 5 mm/s (FG5) and 0.21g at 20 mm/s (FG20). The acceleration for tests at 5 mm/s is much lower than the threshold acceleration of 0.2g suggested for this technique (ISEE 2009; ISRM 1992), whereas the value for the high vibration level match relatively well the recommended value.

Transmissibility from trials at 5 mm/s (FG5) is

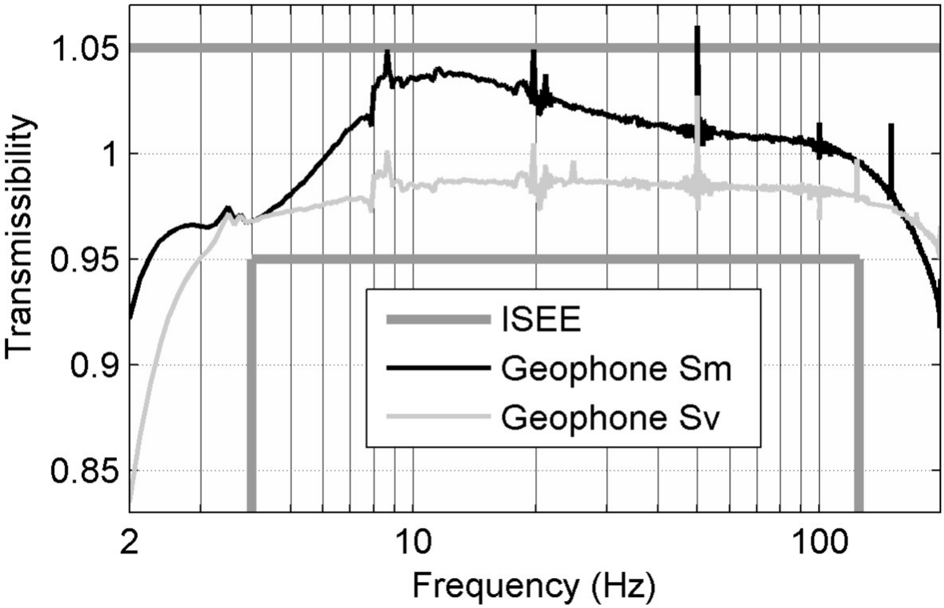

Figure 2. Geophone transmissibility from AM5 and AM20 series.

within ISEE bounds, with values close to the upper bound (1.05) at around 20 Hz for the lighter mount Sv and 40 Hz for Sm (the expected accelerations at these frequencies were 0.06*g* and 0.13*g*, respectively). Tests at the high velocity level (FG20) show a limited amplification and a strong damping with transmissibility falling steeply for frequencies above 25 Hz for mount Sv and 34 Hz for Sm (expected accelerations are 0.31*g* and 0.43*g*, respectively).

The use of a sandbag to hold the sensor mounts (SG5 and SG20 tests; central left graph in Figure 3) leads to accurate measurements in a narrow range of frequencies from 2 to 10 Hz; the expected accelerations at 10 Hz are much lower (0.03*g* for tests at 5 mm/s and 0.13*g* for tests at 20 mm/s) than the limit of 1*g* suggested for this method by field guidelines. At higher frequencies, transmissibility is complex and varies from as low as 0.59 to 1.08 depending on the frequency, velocity of the base, mount characteristics and bag planting. One of the tests (SG20) made with the smaller and lighter mount Sv lead to a damping larger than that observed for free placed sensors at the same vibration level (test FG20).

Transmissibility of vibrations for anchored (AG20; bottom left graph in Figure 3) mounts are within the experimental error (0.98-1.02) in the frequency range studied (2-40 Hz). This result is in line with coupling transmissibility measured from 17 to 80 Hz in 2013. Transmissibility of vibrations for glued (GG5 and GG20; central left graph in Figure 3) and plastered mounts (PG5 and PG20; bottom left graph in Figure 3) is within ISEE bounds with flat curves around one for frequencies below 80 Hz. Above that frequency, transmissibility increases monotonically with maximum amplification of 1.11 for glued and 1.06 for plastered mounts. All these methods provide little variability in transmissibility between trials, assuring then consistent measurements in the tested conditions (vibration level and mount characteristics).

4 DISCUSSION

Rock to mount transmissibility data shown in this work are considered to investigate the performance of seven measuring conditions from 2 to 200 Hz, namely (in brackets the acronym given to each of them): free mounts at 5 mm/s (FG5) and 20 mm/s (FG20), sandbagged at 5 mm/s (SG5) and 20 mm/s (SG20), and anchored, glued and plastered mounts at both vibration levels (AG5/20, GG5/20, and PG5/20, respectively; each of these datasets pool transmissibility from both velocity

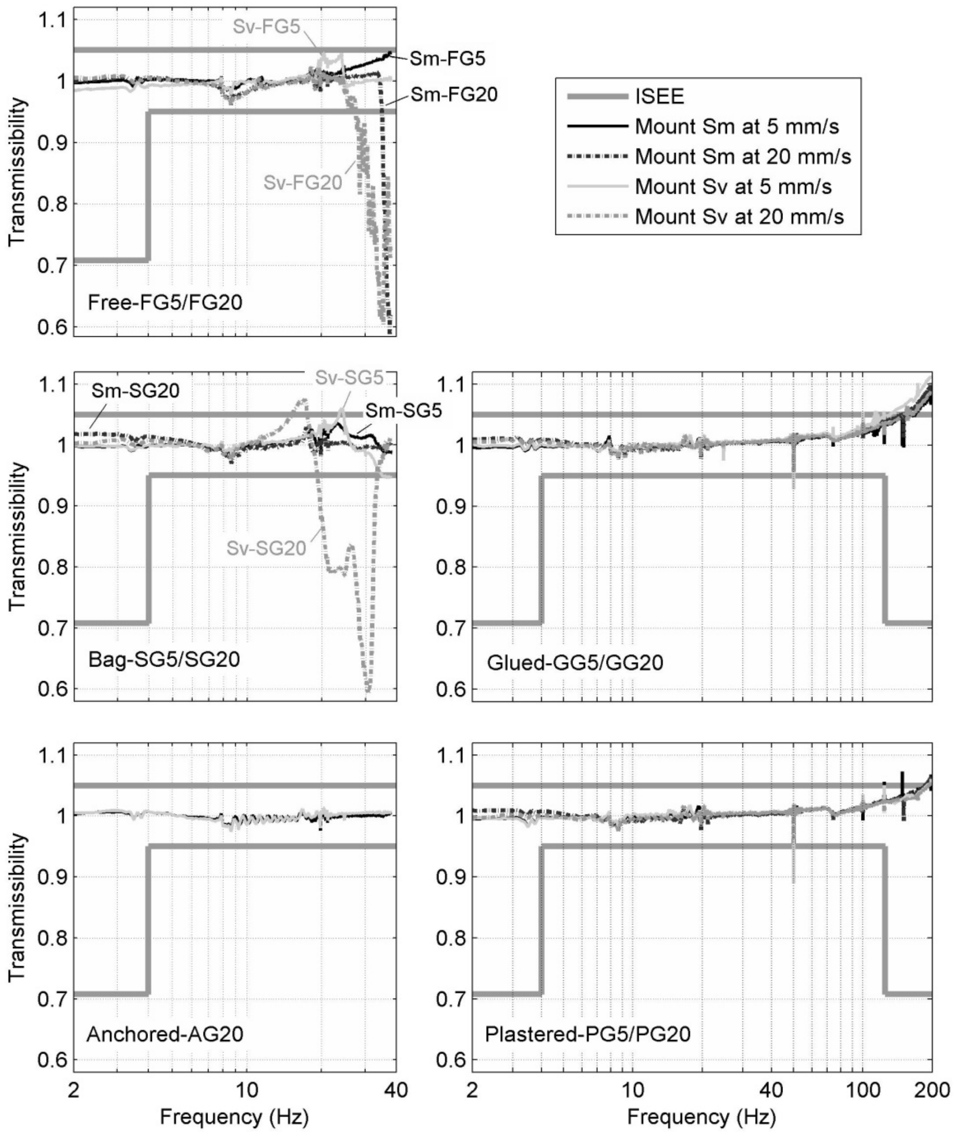

Figure 3. Coupling transmissibility for free (top right graph), sandbagged (central right graph), anchored (bottom right graph), glued (central left graph) and plastered (bottom left graph).

levels as variations between trials at different velocity are in line of the experimental errors). Although the mount characteristics (e.g. mass and size) affect the transmissibility when the coupling is poor, no such characteristics are taken into account by field guidelines. For this reason, data from both mounts are grouped together to analyse the overall performance of the coupling. In order to investigate this, and though the size of the data set at each frequency is not large (2 to 6 transmissibility values),the expected measuring error at each frequency is calculated as the mean of the absolute value of the logarithmic (gains) values at that frequency. Figure 4 shows the resulting expected errors due to coupling for each measuring condition; the maximum error at each frequency for ISEE seismographs is plotted as reference.

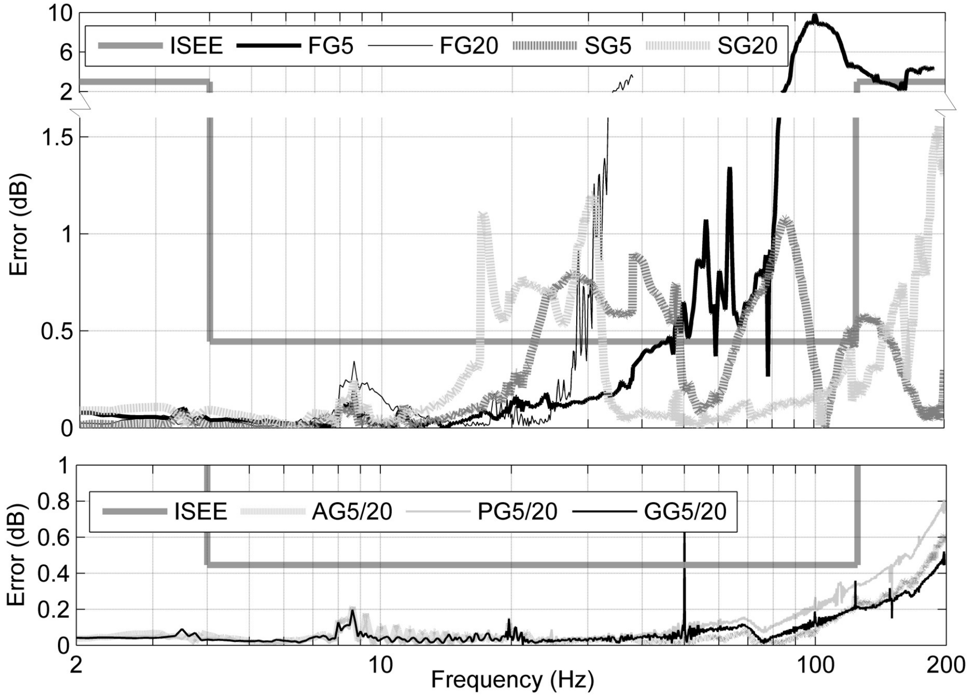

Figure 4. Expected errors due to coupling for free and sandbagged mounts (top graph; the ordinate, error, axis has been broken), and for anchored, glued and plastered mounts (bottom graph).

The performance of free placed and sandbagged mounts (top graph in Figure 4) depend on the characteristics of the base motion (i.e. peak velocity and frequency). The error is not a straight function of velocity of the base. The frequency of the first peak decreases as the peak velocity of the base increases involving a narrow frequency range where the errors are below the experimental one (≈0.2 dB). These results are in line with other works (Blair 1987; Krohn 1984), and suggest a weak coupling of the sensors mount to granite that does not prevent the mount from moving independently of the base surface even at the vibrations levels at which these methods are recommended. In order to illustrate this, note that sandbagged mounts provide an error over 1 dB at base accelerations about 0.22g (see the peak for SG20 curve around 17 Hz in Figure 3), and free laid mounts lead to a similar error at accelerations of 0.17g (see the peak for FG5 curve at 55 Hz in Figure 3). Sandbagging shifts the first peak in the error curves towards lower frequencies in comparison with free placed mounts tested at the same velocity. This implies a worse performance than free laid mounts from 18 to 48 Hz at 5 mm/s, and from 12 to 30 Hz at 20 mm/s.

Measurements with anchored, glued, and plastered mounts (bottom graph in Figure 4) have the smallest expected error across the frequency range. Differences between these methods are apparent at high frequencies, where glued mounts do slightly worse with errors up to 0.9 dB. All three methods provide a coupling stiffness high enough to ensure a good contact independently of the vibration level.

Though the coupling transmissibility for any of these methods has not been investigated in other components of the vibratory motion than the longitudinal, it follows from the results of this study that poor measurements are likely to be obtained with free and sandbagged sensors in any components of the vibratory motion. For the ‘good’ couplings – anchor, glue and plaster – their rigidity in the vertical component may differ from that in the horizontal plane, as the motion transmission in the horizontal movement is done by shear and by tensile/compressive stress in the vertical. Nevertheless, given their excellent performance on shear it is likely that their behavior be just as consistent in tension. However, the actual frequency response may show some differences; a subject for future work.

5 CONCLUSIONS

This work gives an insight to the performance of five coupling methods commonly used to monitor vibrations on a hard surface. The error in the measurement attributable to coupling has been assessed from the rock-to-ground, or coupling, transmissibility from 2 to 200 Hz at two vibration levels (5 and 20 mm/s). Free placed and sandbagged mounts lead to a weak coupling of the mount to the granite base that allows accurate measurements only for frequencies below 17 Hz for free mounts and 10 Hz for sandbagged in the tested conditions with velocities up to 20 mm/s. Above these frequencies, where accelerations are less than the recommend 0.2*g* and 1*g* for free and sandbagged measurements, transmissibility varies from 0.16 to 1.21 depending on the mount type, and characteristics (frequency and vibration velocity) of the imposed motion. Frequency and velocity should be considered together instead of accelerations to decide the coupling method but it is difficult to state peak particle velocities and frequency limits on a general basis.

Attached sensor mounts to a hard surface by means of an anchor, glue or plaster, lead to a stiff rock-to-mount coupling ensuring consistent measurements (transmissibility between 0.98 and 1.02) for frequencies commonly found in blasting irrespective of the mount characteristics and the input velocities studied. At high frequencies (above 100 Hz), these three methods still perform acceptably well with transmissibility up to 1.06 (plastered mounts) and 1.11 (glued mounts).

The results shown have important implications in vibration control studies where measurements on a hard surface are done. The worse the transfer of vibrations from rock to mount is, the higher is the error in vibration data (e.g. peak particle velocity), and the higher the uncertainty of the measurement, making it more difficult to assess changes between vibrations from different blasts or compliance with standards. Such scatter may certainly have a bearing on the usually wide prediction bands of vibration attenuation laws. Further work is ongoing to improve the quantitative significance of the results.

6 ACKNOWLEDGMENTS

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Control blasting challenges on the Bear Creek Hydro Project

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ABSTRACT: The Bear Creek Hydro Project is a 'run-of-the-river' green energy hydro project constructed in steep challenging terrain in the Coast Mountains of British Columbia, northeast of Sechelt, BC. The project involved construction of two power houses, 8 kilometres apart, with a combined capacity of 20 MW. The hydraulic head for the Upper Bear powerhouse is 500m and 125m for the Lower Bear powerhouse. Blasting challenges included underwater blasting for lake-taps at three locations as well as control blasting for the creation of intake channels, control gate structures, spillways, and a total of three plug blasts in close proximity to new control gate structures. Control of over-break for blasting of the intake channels was critical, as the channels are located within 3 metres of the edge of the stream. The project also involved control blasting for penstock pedestals underneath the tram line system. Dealing with the challenging geology on the project required extensive rock bolting, hydraulic splitting, and pressure grouting. This paper details the innovative techniques used in the underwater blasting works, as well as methods used in the design of the plug blasts for protection of the new intake gates.

1 LOCATION

The Bear Creek Hydro project is located on the west coast of Canada, approximately 100 kilometres NW of Vancouver, BC at the head of remote Salmon Inlet. Access to the site is by float plane, helicopter, or by boat from Sechelt on the Sunshine Coast. A floating base camp was established at the head of Salmon Inlet and all materials, including explosives, had to be barged into site. This area is very sensitive habitat for fish stocks and other marine life.

Bear Creek flows southerly, discharging into Clowholm Lake. The upper headwaters source is Bear Lake, located in a high elevation cirque surrounded by high peaks. Reservoir connections had to be constructed to connect Bear Lake with Bear Pond and then connect Bear Pond to the penstock feeding the Upper Bear Power House.

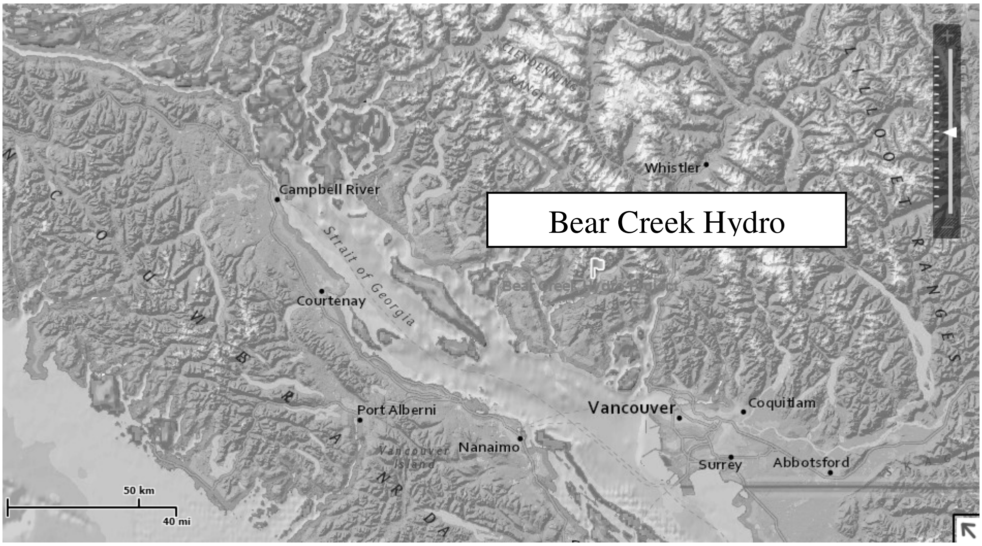

Figure 1. Location map for Bear Creek Hydro Project.

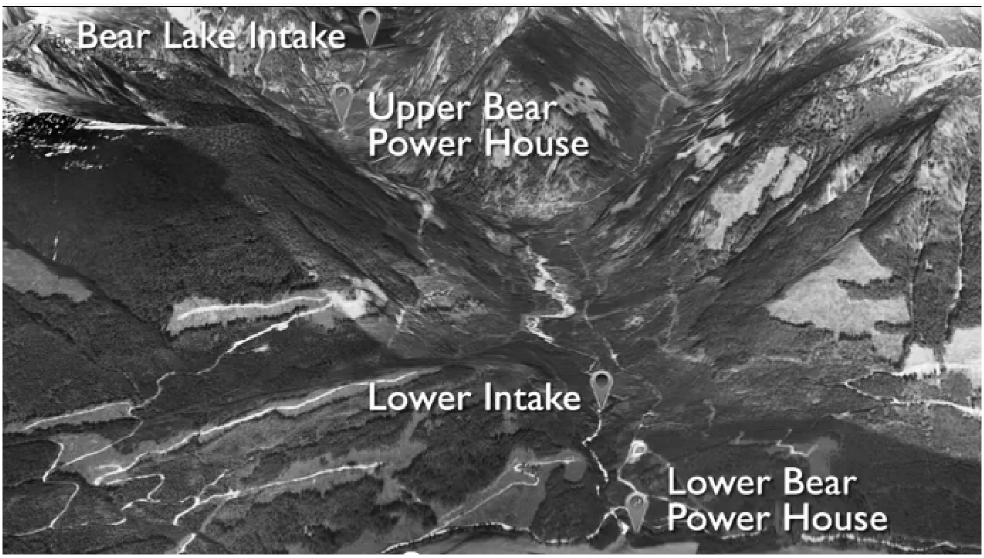

Figure 2. Powerhouse locations in steep mountainous terrain.

2 BLASTING CHALLENGES

Very challenging blasting was required for the intake channels leading to the Upper Bear penstock. Intake channel blasting with cuts of 9 to 11 metres was carried out within 3 metres of the edge of the stream. Wall control blasting was necessary to avoid any over break into the web of rock between the intake channel and the stream. The intake channels are 3 metres wide at the top and 2 metres wide at the bottom. Horizontal jointing creates problems with pulling shots to grade as some of the gas from the detonation of the explosives is lost into the open joints. Control blasting was also required for construction of slots for the installation of the control gate structures. Underwater blasting was required for the connections from Bear Lake to Bear Pond, and the connection from Bear Pond to the intake channel leading to the

Figure 3. Tamrock Ranger 700 drill being moved up the 1100 meter right of way on Sky Tram.

penstock feeding the Upper Bear powerhouse. A total of three plug blasts in close proximity to new control gates were required to finalise connections with the control gates.

3 CHALLENGING LOGISTICS

Access to the Upper Bear reservoir was achieved with the construction of a sky tram system capable of handling loads up to 39 tonnes and could carry up to eight workers in a gondola. All materials including the drills and excavators were taken up the mountain on the sky tram system. As well, all materials needed to be ordered in advance and coordinated for shipment by barge and moved overland to the site and up the sky tram system to be on site when needed.

Construction of the Upper Bear 1.2 metre diameter penstock had to be carried out on a 105% grade. Blasting for penstock saddles had to take place directly under the Sky Line system. Careful blast design and control of flyrock was critical for these shots.

4 GEOLOGY

The rock type in this area is a medium to hard, massive mid-Cretaceous quartz diorite. The rock is fairly abrasive and is characterised by sub-vertical as well as horizontal jointing with joint spacing varying from 0.3-3.0 metres. The blocky nature of the jointing can be seen in Figure 6. Horizontal stress-relief fractures located 2.5-3 metres down created cap rock problems and potential for oversize and seepage into the excavation. These stress relief fractures are common in the Coast Mountains of British Columbia and are a result of the melting of the glaciers that covered this area during the last ice age. This Fraser ice event created massive crustal loads due to the 2 kilometer thickness of ice and it was the rapid melting and retreat of the glaciers that caused the stress relief fractures to occur. Figure 5 shows a typical example of the stress relief fractures that occur throughout the Coast Mountain range in British Columbia. The resulting cap rock can create problems with oversize blocks. Fracturing

Figure 4. Drilling and blasting within 3 metres of the edge of the creek.

Figure 5. Horizontal stress relief fracture located 3 metres below surface.

Figure 6. Typical blocky jointing in Quartz Diorite for the Upper Bear intake structure.

of this zone required deck loading of explosives within the cap rock and/or the drilling and blasting of short satellite holes. Blasting of the massive quartz diorite is best achieved using high brisance explosives and high powder factors.

5 UNDERWATER BLASTING CHALLENGES

The intake channels extend out into the lake to create a proper lake-tap on grade with the intake structures. This involved creating shot rock fill pads and then drilling through the fill using steel casing and lining the holes with PVC casing. The deep water connections had to be drilled well out into the lake. We had anticipated having to drill off 'Flexi Float' sectional barges, however, the blasting crew came up with a novel solution using on-site materials. Excavator timber mats were cantilevered out over the water and engineering calculations were carried out to determine how much weight would be required to counter balance a drill located on the end of the cantilever. We determined that the 33,000 kg. excavator on site was heavy enough to accomplish this. The cantilever arrangement is seen in Figure 8. All blastholes were sleeved using 75mm ID PVC casing and loaded using 65x400mm charges of Dyno TX explosives. This explosive is formulated using high-strength microspheres and is designed for use in trench blasting with close blast hole spacing. We have experienced good success using this product on other underwater blasting projects. Even though this explosive is cap-sensitive, charges were primed top and bottom with 250g cast boosters and two Nonel detonators were used in each hole. All three lake-tap shots were designed to be fired single hole per delay. Due to its high-elevation remote location, there are no fish in Bear Lake, so use of a bubble curtain to control overpressure in the lake was not required. As the lake water eventually flows down to Bear Creek, a fish bearing stream, silt curtains and coffer dams (consisting of sand-filled 1 m^3 bags), were used to control any release of fines into the lake resulting from the blasting or excavating processes.

6 PLUG BLAST DESIGN

Blasting of the three plug blasts was critical, as

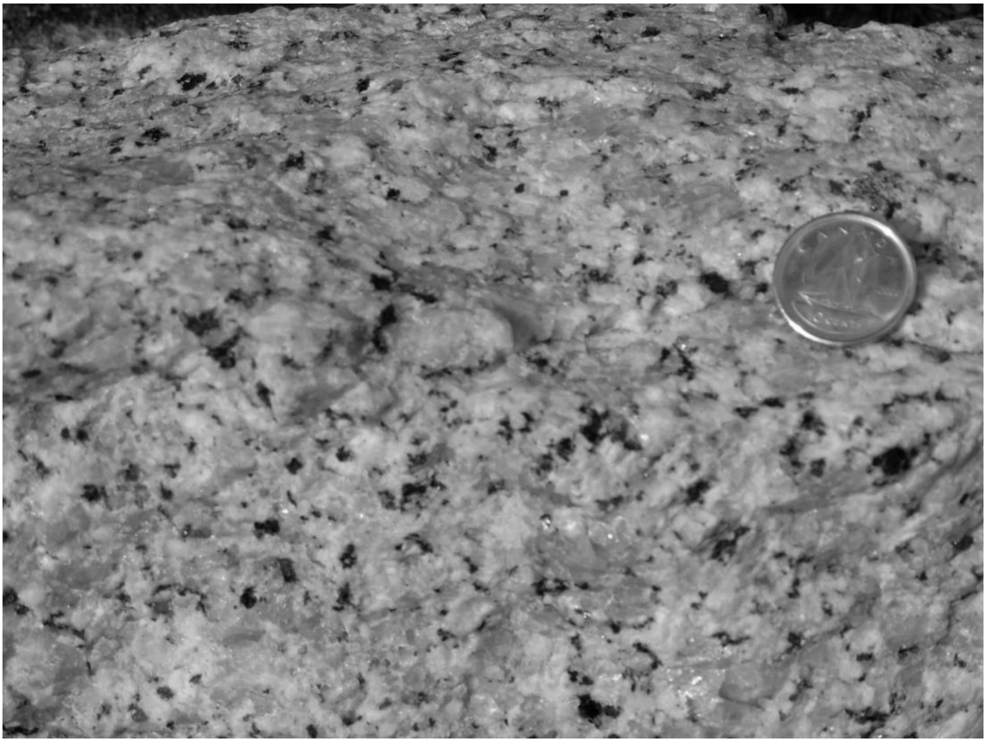

Figure 7. Quartz Diorite showing typical ‘salt & pepper’ texture.

Figure 8. Use of cantilevered pad for drilling the deep water intake channel.

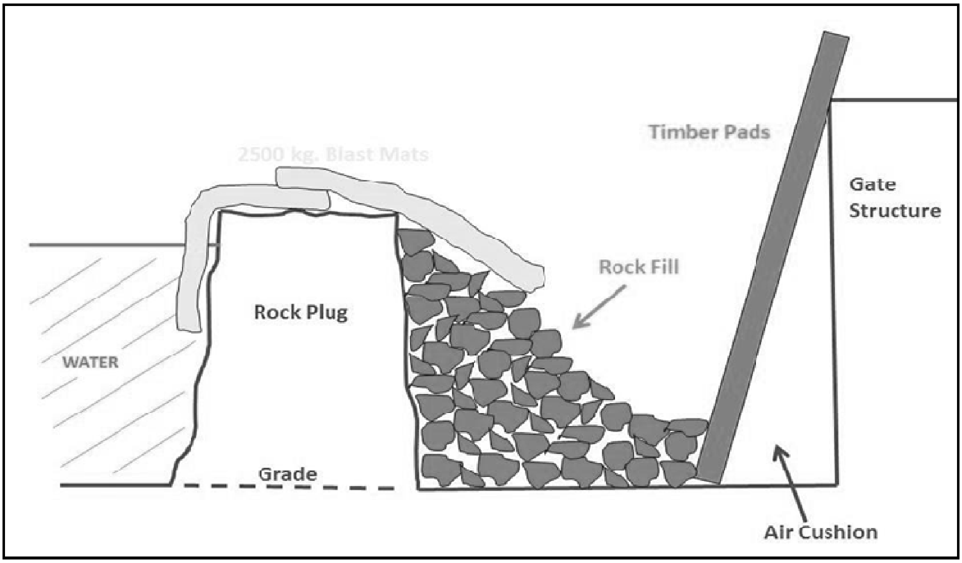

Figure 9. Plug blast protective measures.

there was only one chance to get it right. By this stage of the project, concrete work and control gates had been installed in the intake channel approximately 8 metres from the plug locations. Protection of the control gates from damage was critical. The underwater blasting areas adjacent to the plugs were excavated down to grade to ensure that we obtained a clean open face towards the open water side. In all cases, we blasted a clean vertical face with no toe present in front of the plug. This ensured that there was little back pressure on the plug during blasting and the shot would move out and away from the gate structures. We incorporated an air gap in front of the control gates to avoid hydrodynamic shock loading on the gates. We also incorporated a loose shot rock fill buffer between the control gates and the plug. This can be seen in Figure 9.

According to the project engineering specifications, if the concrete was more than seven days old, we were allowed a blast vibration limit of 150 mm/sec on the gates. If the concrete was less than 7 days old, the blast vibration limit fell to 50 mm/sec.

A calculated design powder factor of 1.91 kg/m^3 was used. This provided adequate fragmentation for the compact zero tail swing Komatsu PC 308US excavator on site. The excavator's bucket capacity was approximately 1 m^3 and the excavator was operating at its maximum reach capability, so break-out force was limited.

Meeting the blast vibration restrictions required four explosives decks per hole with a maximum charge weight per delay of 4.8 kg. This gave us a predicted maximum blast vibration level of 131 mm/sec at the control gates.

Approximately two thirds of the perimeter of the plug was presplit while blasting the slot next to the control gates. The remainder of the presplit connection was blasted in conjunction with blasting of the plug shot. Three shear line holes were drilled on each side of the plug to ensure a continuous presplit line. This is seen in the drilling layout sketch in Figure 10. Shear line holes were blasted using 85 g/m Primaflex detonating cord using a shear factor of 0.27 kg/m^2 (0.055 lbs/sq. ft.) of final wall. The 83mm diameter production holes were sleeved with 75mm ID PVC casing, as there was a delay between drilling of the plug and the actual loading and blasting of the plug. This ensured good blasthole integrity. The production holes were drilled on a 1.2m x 0.91m pattern. The design cut depth was 7.2 metres and we added 3.05 metres of subdrill to guarantee that there would be no high spots following blasting.

Based on the success of use of Dyno TX explosives in the underwater blasting, we chose the same explosive for use in the plug blasts. Four cartridges of Dyno TX 50 x 400 mm were used for each of the three lower decks and two cartridges of Unimax 40 x 400 mm were used in the top deck of each hole to break the cap rock. Unimax is an extra-gelatin dynamite having excellent water

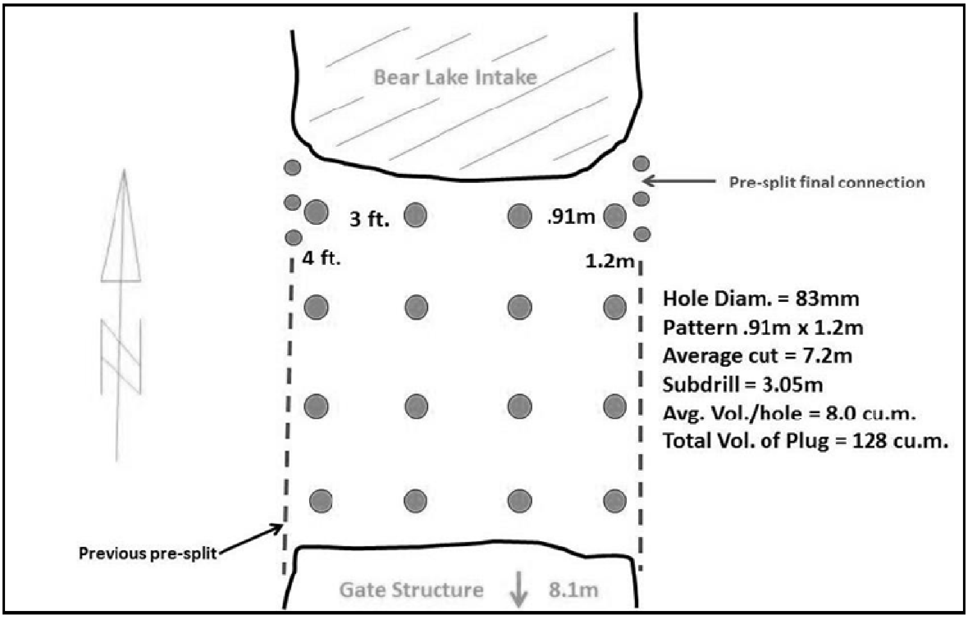

Figure 10. Plug blast drilling layout.

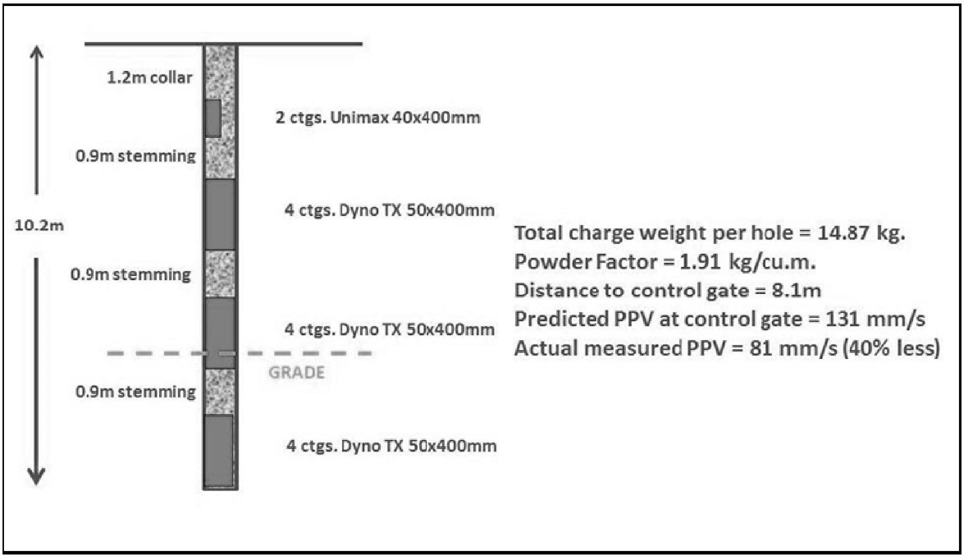

Figure 11. Cross-section showing plug blast loading details.

resistance. Each explosive deck was primed using a 250g cast booster and an I-kon electronic detonator. A cross section showing the blasthole loading is seen in Figure 11. The detonation sequence involved shooting single deck per delay from the top down as shown in Figure 12.

7 CONCLUSIONS

The results of the plug blasts were excellent. Good fragmentation was achieved and all shots dug to grade. All explosives and detonators performed exceptionally well despite the tough conditions.

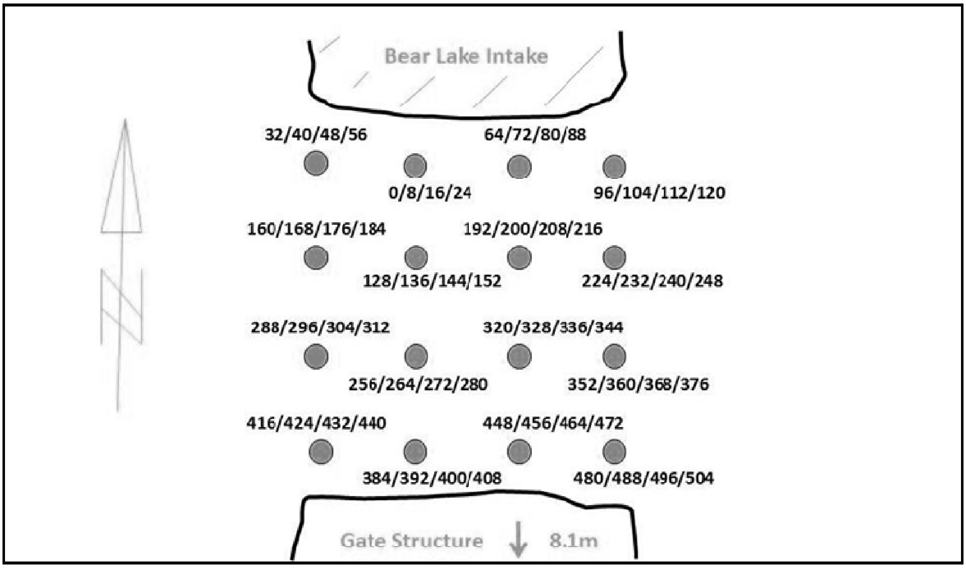

Figure 12. Upstream plug blast on Lake Structure – tie-in design with firing times shown in ms.

There was no damage to the control gates or other structures on-site. The actual measured blast vibration intensity on the control gate was 81 mm/sec, well below the 150 mm/sec limit.

8 ACKNOWLEDGEMENTS

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    - Paul Macdonald – Project Engineer
- BPR Energie – Gilles Bouchard, P. Eng.
- Regional Power Corp.

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Cliff blasting techniques for successful blasts in very sensitive areas

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DCI, Dynamic Consult International

ABSTRACT: Cliff blasting operations are amongst the most challenging to prepare and to succeed in. Working on a steep and usually very high rock face, where stability is questionable by definition, makes every single traditional step of the blasting process, starting from locating and drilling holes up to loading and timing them, more complex, more uncertain and more dangerous.

The surveying and pre-blast measurement stages are more critical than ever, as obvious risk in terms of flyrock are at stake. Despite the fact that a large clearance zone is usually defined, people around can never be considered as being out of risk, not mentioning buildings, equipment or facilities, especially when located at short horizontal and/or vertical distances.

Though every single cliff blasting operation is one-of-a-kind, this paper aims to show how a tailored combination of techniques, technologies and process can guarantee a safe and happy ending to this type of scenario.

Based on two amazing cliff blasting case studies, fired respectively between 70 and 120 metres above production facilities, and 50 to 70 metres away from residential areas in the city, the paper details to what extent, and why, high technologies, such as 3D profiling, 3D modelling and simulations combined to UAV aerial photography, thorough risk assessment, know-how and team working have been, in both cases, key factors of success.

1 SAME AREA, TWO DIFFERENT ISSUES

1.1 Context of operation, Case 1

The Saint-André's quarry is located in the south of France, a few kilometres 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 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.

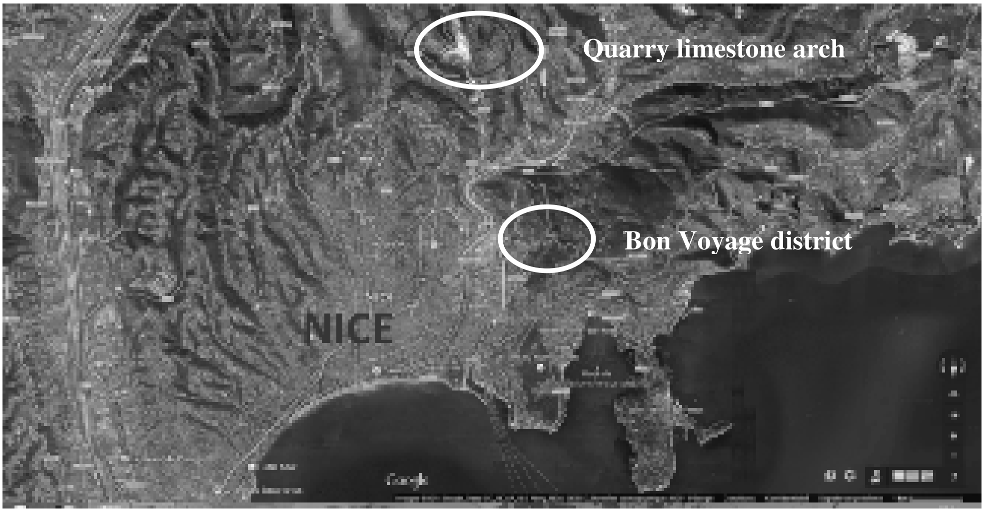

Figure 1. Location of the two sites.

This natural, unstable limestone bridge (Figure 2B), 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.


Figure 2B. The limestone arch.

1.2 Context of operation, Case 2

January 30th 2014, following recurring heavy rainfall during previous months, part of the rocky cliff located above highly urbanized district of Bon Voyage in the east of Nice city (south of France), collapsed, causing the downfall of 8000 m^3 of rock.


Figure 2A. Nice area, long shot of Case1.


Figure 2C. The cliff, operation, Case 2.

The upper part located above the collapsed area is still hanging up but very embrittled. It threatens to fall and should be treated in order to secure the area. The solution retained is cliff blasting.

The work to be performed overhangs a railway track (tunnel entrance and SNCF Nice-Drap line) that was damaged by the initial collapse. At 60

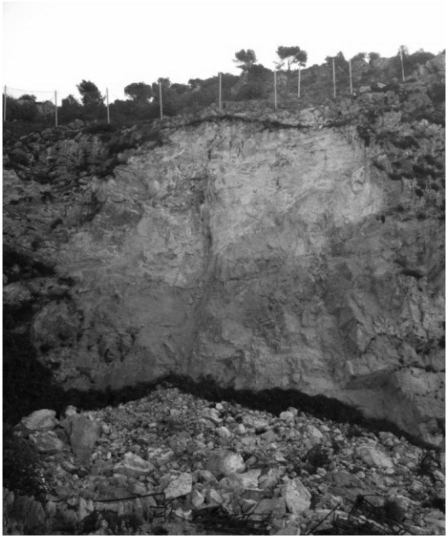

Figure 2D. The cliff after the collapse on January 30th 2014.

metres horizontally and 70 metres below is the Bon Voyage district and its residential buildings.

The unstable mass consists of two parts:

– an overhang zone of 5 to 10 m thickness and a volume of approximately 650 m^3
– a rock shell of a twenty metres high and a volume of about 800 m^3.

The bedrock consists of relatively fractured and altered limestone especially in the overhang area.

2 SPECIFIC CONSTRAINTS OF THE SITE TO BLAST THE LIMESTONE BRIDGE

2.1 Case 1, constraints

The first constraint is the limestone bridge itself. 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, i.e. nearly 20,000 tons.

The second constraint is the presence of housing between 70 and 100 m 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.

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

To summarise, 8000 m^3 to be blasted, perched 120 m above the crushing plant, without creating any vibrations, or showering flyrock either on the installations or the industrial estate opposite.

2.2 Case 2, constraints

See Figure 4:

– the blasting area itself, is still unstable and could collapse at any time
– the location of the work, with a vertical cliff 70 meters that require the use of acrobatics and

Figure 3: The constraints around the critical area.

rope access techniques with continuous personnel and equipment security
– the presence of buildings houses and a school facing the cliff and the area to be blasted. The projections risk is the main risk when firing.

The following constructions and infrastructures have some vulnerability regards to the risks associated to the blasting operation:

– houses back of the working area at the top of the cliff
– detached houses in the immediate foot of the cliff
– SNCF railway structures, track (SNCF Nice-Drap line with catenaries) and a tunnel
– residential buildings on the Route of Turin (from 2 to 8 floors)
– the fire station
– the school of Bon Voyage district
– roads - Route de Turin ((2 x 2 ways + parking), local service and the Paillon expressway (fast track 2+1 ways), high traffic
– Presence of houses behind area (100m) and respect of vibrations constraints.

3 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, NICE Métropole Nice Côte d'Azur), the blasting subcontractor (TP SPADA, GARELLI), a geology and geotechnical design office (B.E. du Canal de Provence, GEOLITHE Méditerranée), a surveyor and a design office specialised in explosive engineering (TBT, DCI).

4 CALCULATING THE BLAST

The seismic constraints compelled us to use a maximum charge per delay of 2kg for Case 1, 20 kg for Case 2, which served as the basis for the blast design. The choice of a charge per delay <300 g/m^3 was made in order to limit flyrock to a minimum. In fact, we opted for destabilising the arch via a carefully controlled blast, leaving gravity to deal with the rest.

4.1 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 understand the difficulties due to the complex geometry of the area. Based on the cloud of 3D points (Figure 5A), 2D face profiles spaced out every 2m were calculated (Figure 5B).

Figure 4. The constraints around the critical area.

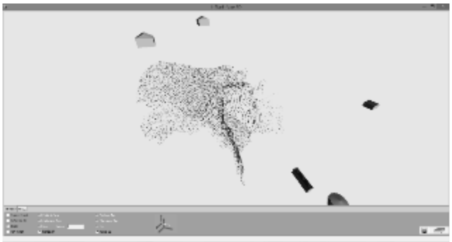

Figure 5A. Cloud of 3D points Case 1.

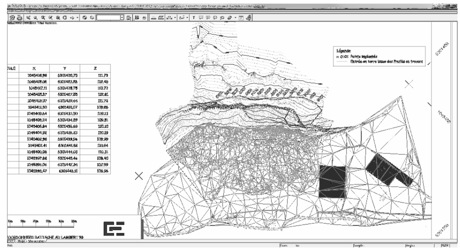

Figure 5B. 2D face profiles.

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

5 POSITIONING THE HOLES

5.1 Case 1

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 destabilised).

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 6). The southern part not being in contact, constant depths marking a flat berm were chosen (Figure 7).

5.2 Case 2

The rockshell drilling was performed with an inside angle in the rock so that the drilling plan is not aligned with the rockshell slide plan and avoid a general destabilisation of the remaining mass.

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 angle and depth defined to avoid intercepting the fault plane (the underlying area must not be destabilised):

– overhang: 27 holes in 89mm diameter, angle from 10 to 22°, depth from 4 to 10 meters

– rockshell: 14 holes in 115 mm diameter, from 13 to 15°, depth from 13 to 26 meters + 6 vertical holes in 41 mm and 4 meters deep.

Drilling was long, difficult and delicate

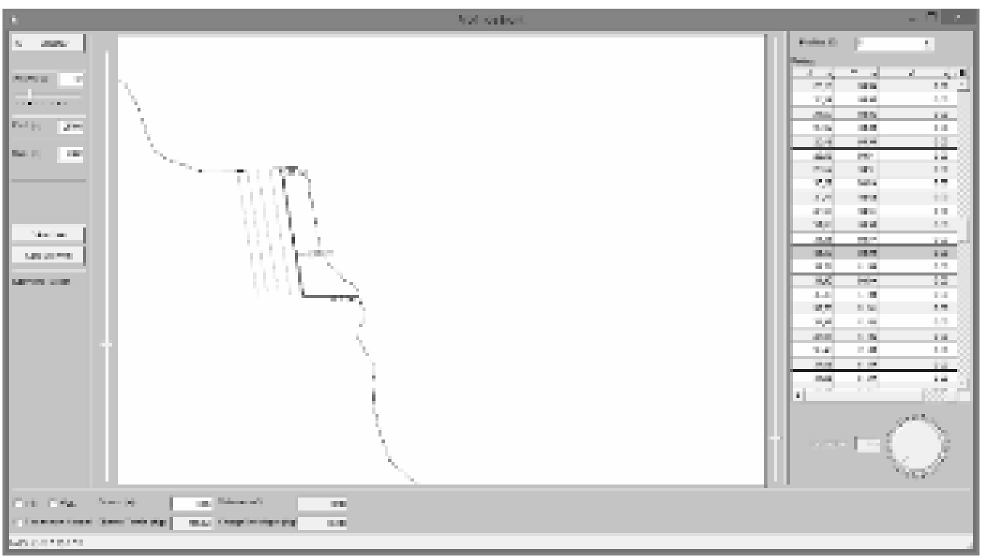

Figure 6a. Case 1, positioning of a hole in the northern area.

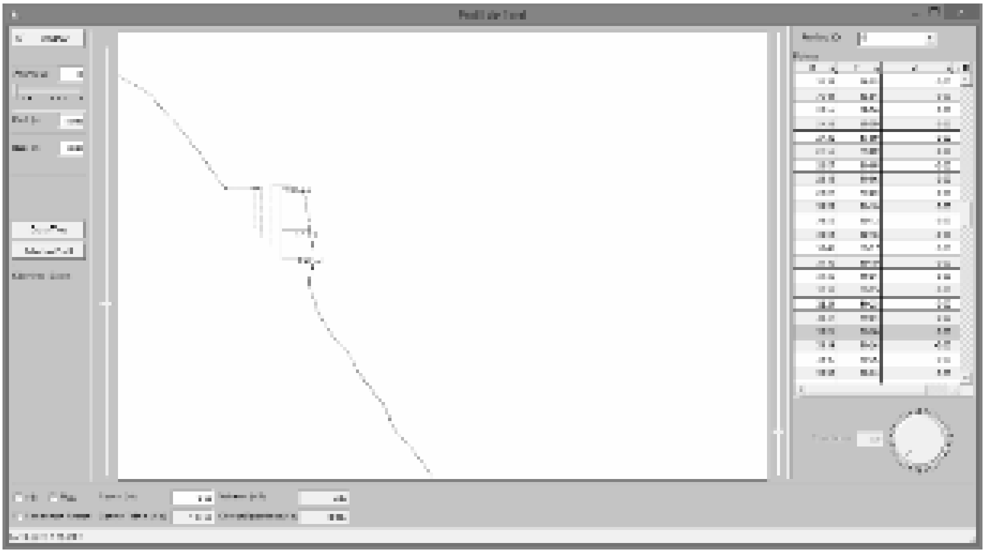

Figure 6b. Case 1, positioning of a hole in the southern area.

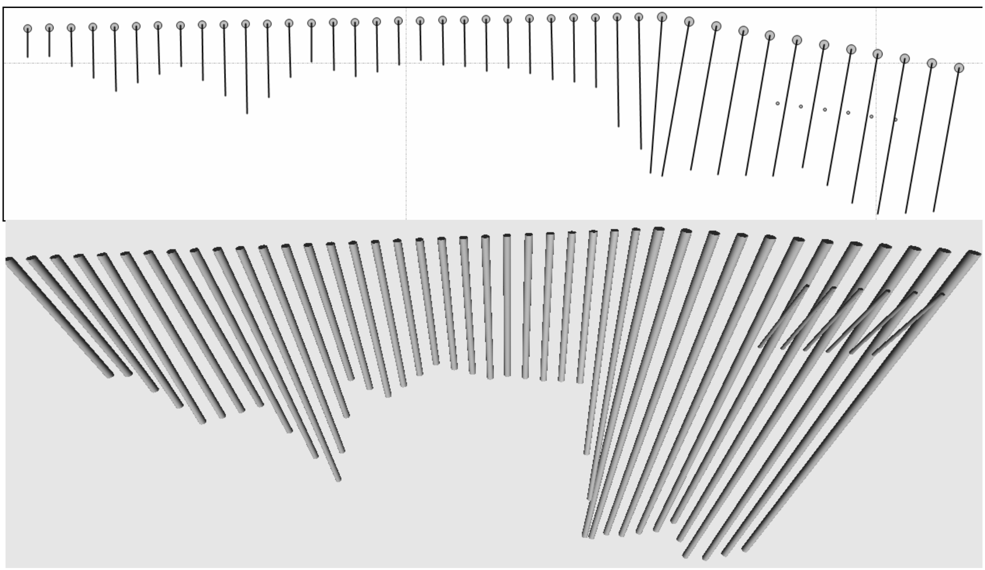

Figure 7. Case 2 3D view of the theoretical drilling.

because of working conditions and drilling depth (15-25m for the rockshell) and poor mechanical quality of the rock mass (numerous faults and discontinuities). The holes were cased.

At the end, drilling deflection measurement is carried out in all the blastholes in order to compare the actual and theoretical drilling and take into account the variances and adjust the loading hole plan accordingly.

6 CALCULATION OF THE CHARGES AND THE INITIATION SEQUENCE

6.1 *Case 1*

The charge per delay, as previously mentioned, was limited in this area of the quarry to 2 kg which led to almost 20 decked charges in the deepest holes (25 m). In order to decrease this number, we

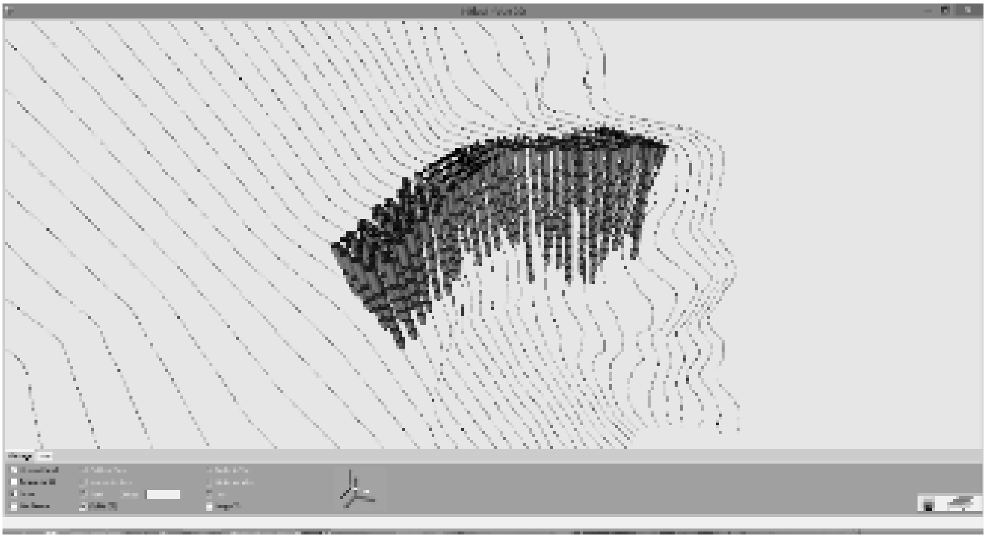

Figure 8. 3D view of the loading.

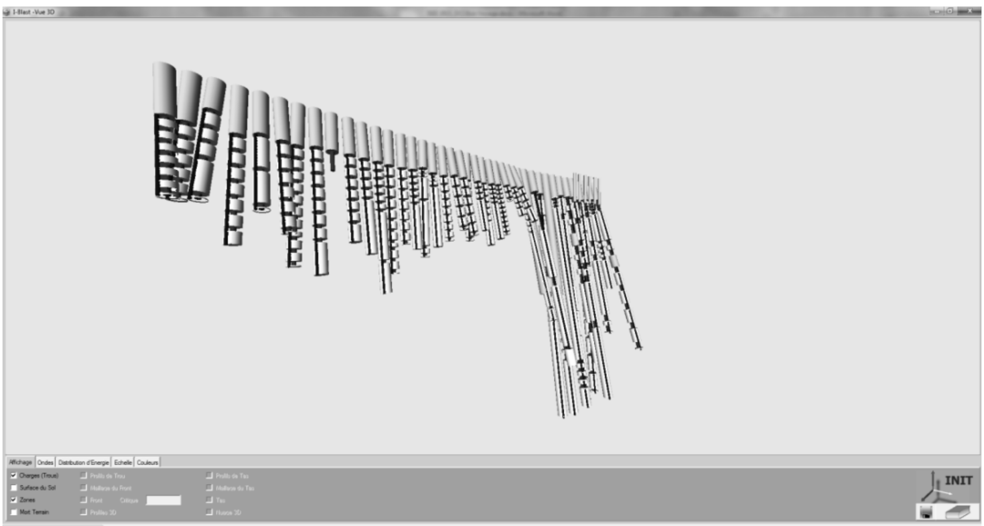

Figure 9. Case 2, 3D view of the loading.

decided to raise the charge per delay to 3 kg 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 between charges was retained as the optimum delay.

The 3D modelling of the blast design (Figure 8) enables us to understand the complexity of the operation. The point of initiation of the blast sequence was calculated for the centre 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.

6.2 Case 2

Taking account of the large heterogeneity of the blast rock mass and the real position of drilling, each hole had its own specific loading based on rock thickness and position of soft areas identified at drilling stage (i.e. karst, clay, fault).

The loading was carried out so that the blast works like a large splitting accompanied by just sufficient horizontal displacement to detach the unstable mass from the rest of the rock mass and allow it to drop by gravity and fall into the void.

The charge per hole was from 5 to 15 kg for rockshell holes and from 0.75 to 2.75 kg for overhang holes. The loading consisted of dynamite cartridge string linked by 70 g/m detonating cord.

For the overhang, holes were grouped by 4 and one by one for the rockshell. Electric detonators n 1 to n 20 were used for initiation. Initiation was carried out between the 2 mass with a homogeneous propagation of both sides (peer numbers on one side, odd numbers on the other side).

The maximum charge per delay was 15 kg. This charge is compatible with the limited vibrations level imposed on the resident sensitive structures.

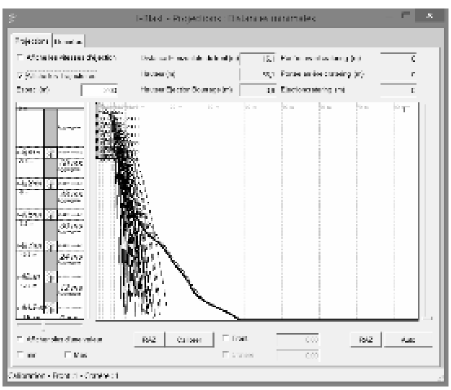

Figure 10A. Case 1, Trajectory of the material along a profile.

7 SIMULATION OF FLYROCK

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. 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.

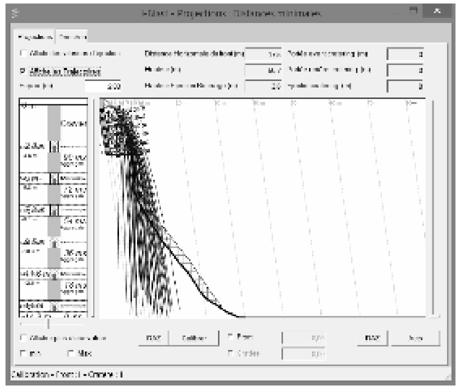

Figure 10B. Case 1, Trajectory of the material along a profile.

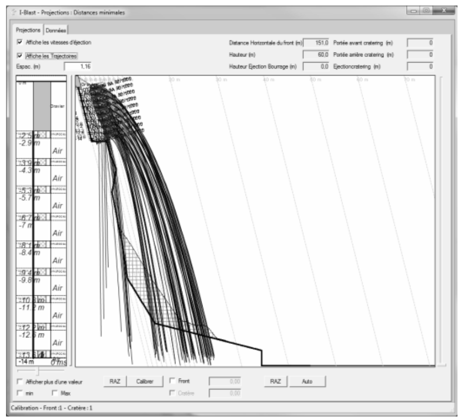

Figure 11A. Case 1, Trajectory of the material along a profile.

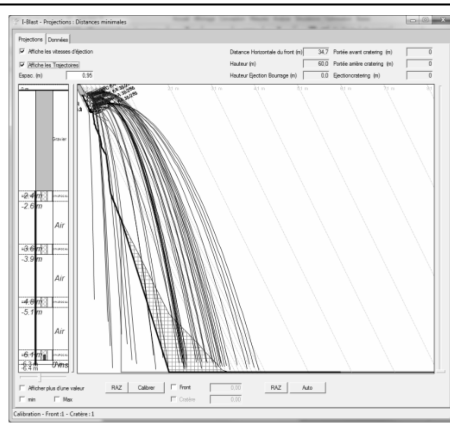

Figure. 11B. Case 1, Trajectory of the material along a profile.

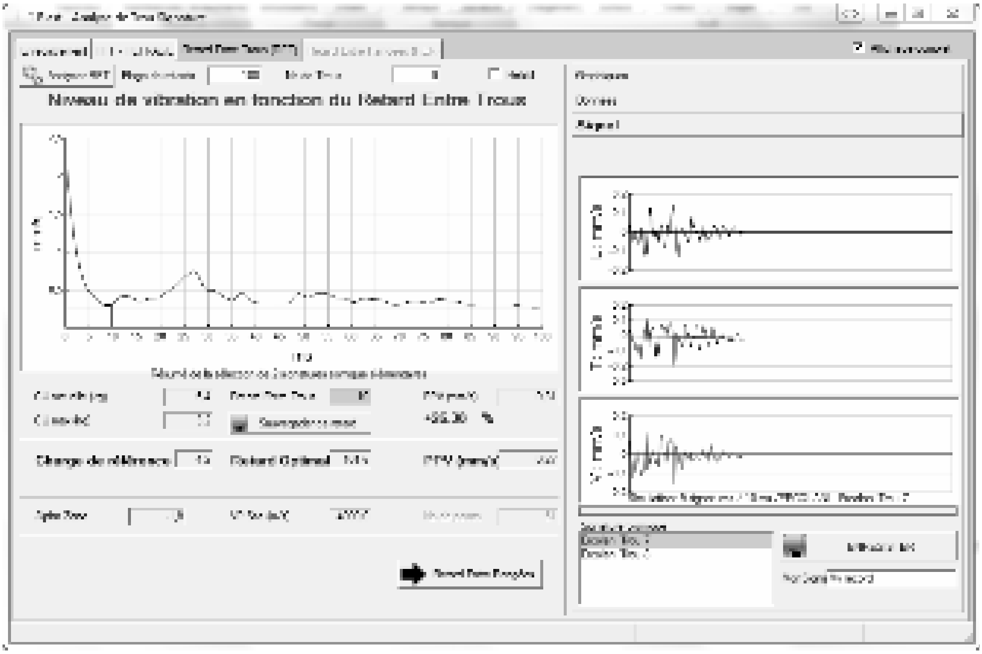

Figure 12. Research for the optimum delay using the signature hole method.

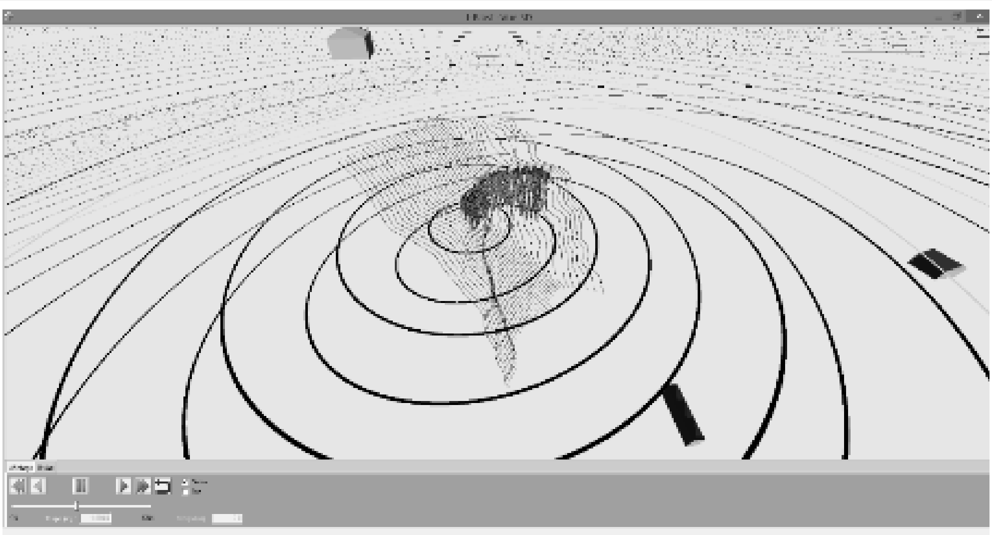

Figure 13. 3D simulation of seismic waves to forecast seismic levels.

The graphs below illustrate the trajectory of flyrock and their heave for typical profiles (Figure 10, 11). It is to be noted that no horizontal flyrock was envisaged and that the material should flow along the fault plane.

8 SIMULATION OF VIBRATIONS

8.1 Case 1

Seismic simulations based on the signature hole method (Figure 12) forecast that the vibration

Figure 14. Rock barrier.

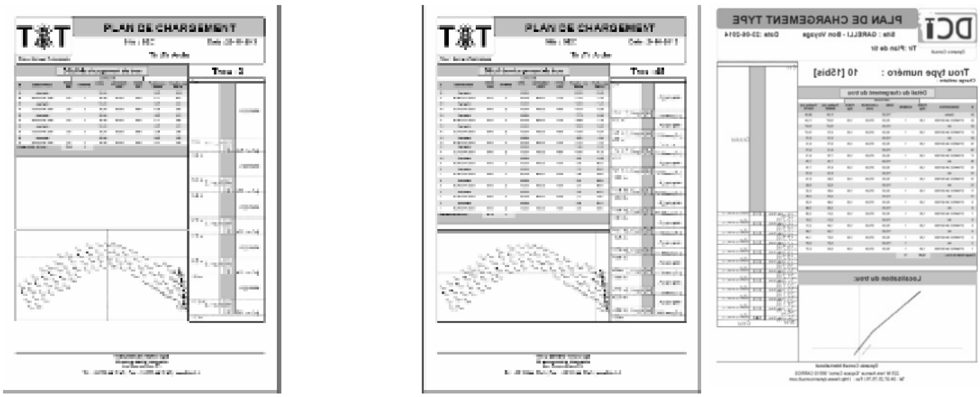

Figure 15. Hole loading plan, Case 1 and 2.

levels at the nearest housing would remain below the French regulations (Figure 13).

9 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 x 2 m). The risk of dynamic desensitisation is very high. Hence, dynamite with a high percentage of nitro-glycerine (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 for Case 1 while regular shock tube detonators were used for Case 2.

10 ON SITE: A ROCK BARRIER

9.1 Case 1

In order to control the muck pile, a rock barrier (Figure 14) 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 fall?

11 ON SITE: ORGANISATION

Implementing a complex blast design such as this is impossible without specific organisation. Firstly, each numbered and surveyed hole on site had its own loading plan (Figure 15) specifying the quantity, and height of charges and the respective initiation timing.

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
– labelling the detonators (decks)
– stemming

Figure 16. Case 1, The teams loading.

Figure 17. Case 1, Programming the detonators.

A final team were in charge of programming the detonators once the holes were loaded (Figure 17).

Case 1 - each numbered and surveyed hole on site had its own loading plan specifying the quantity, and height of charges and the respective initiation timing.

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!

Case 2 - due to poor weather conditions, loading operations, originally scheduled to start at 6 am, were delayed 4 hours and until the last moment the blast was very nearly postponed.

Figure 18. Case 2, The teams loading.

The final tests to check the detonators were successfully completed at 5pm and the blast was initiated at 5:15 pm.

12 ON SITE: PROTECTION

12.1 *Case #1*

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

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 18) in windy conditions, and with a time constraint is always a challenge for rope access workers.

12.2 Case 2

Despite all the precautions taken in the blast and loading design stage, the projection risk remained very high due to the poor quality of the rock mass and proximity to sensitive areas. To reduce it even more, protections were implemented on the blast free face and on building facades to protect from flyrock.

The type of protection retained was a ‘sandwich’ of geotextiles, chicken wire and anti-submarine wire: the geotextile was to contain the blast and small flyrock, and the chicken and anti-submarine wire to provide mechanical resistance for larger rocks.

On the loading area, protections were placed previously to the loading stage and opening made in the geotextile above the hole to allow loading.

On buildings, the protections were installed on the day of the blast after evacuation of residents.

13 THE BLAST

13.1 Case 1

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 21). 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.

13.2 Case 2

On June 25th, 2014 at 5:15 pm, almost 5 months after the first cliff collapse, the blast took place and was a complete success. The rocks slid along the cliff as forecast by the simulations without any horizontal flyrock.

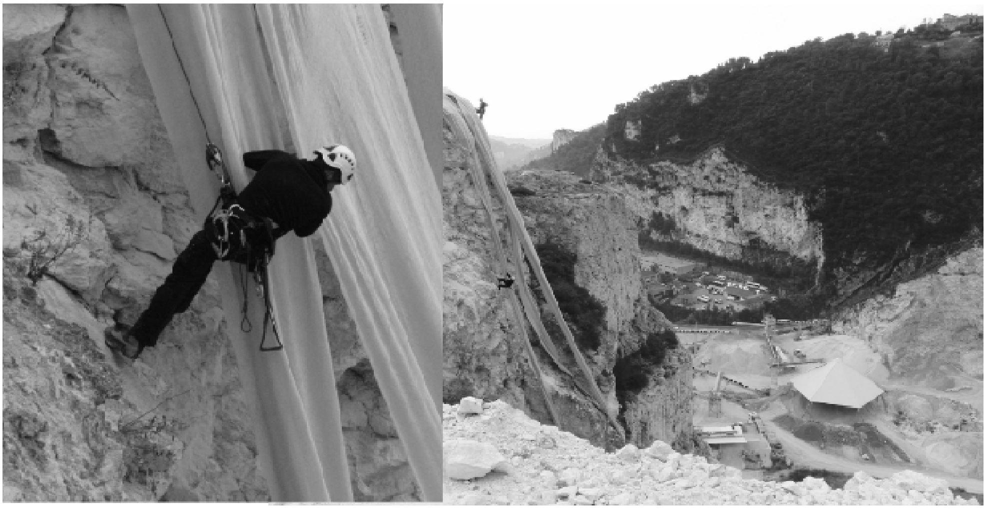

Figure 19. Case 1, installing the protection on the free face.

Figure 20. Installing the protection on the buildings and free face – Case 2.

Figure 21. Case 1, before and after the blast.

Figure 22A. Case 2, blast result - before and after looking down the cliff.

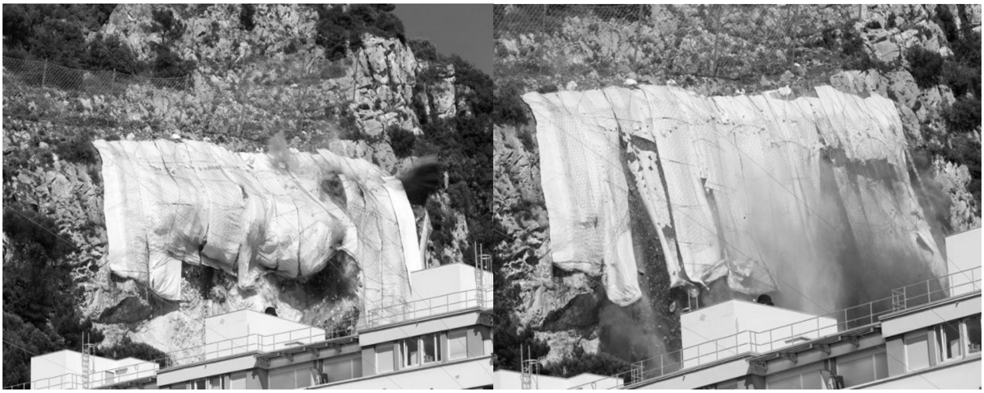

Figure 22B. Case 2, blast result - looking up the cliff.

Figure 23. Case 2, the cliff before and after the blast.

14 CONCLUSION

These blasting projects with their complicated conditions and high risks were possible and successful thanks to the technical contributions, i.e.: electronic detonators, reconnaissance with a drone, 3D modelling and simulation.

Case 1: The crusher was running 100% 1 hour after the blast and the quarry continues to operate safely.

Far beyond technology, the result is due 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
- Davey Bickford for their help in programming the detonators
- TBT for the blast engineering, simulation and supervision of loading.

Case 2: This operation was one of the largest cliff security operations carried out in France. It required the evacuation of more than 1400 people. The results were beyond the expectations since no projection was observed in the direction of neighbouring structures, or even on the railway. The cliff was purged and secure compliant with the request of the client. Less than one hour after firing, all the residents could enter their homes.

This major success is largely due to the work organisation and skills of the different partners:

- Nice Metropole : client
- Géolithe: project manager
- Garelli: leader of the consortium, in charge of all security, drilling and protection works
- EPC France: co-contractor specialising in acrobatic works
- DCI: technical consulting design office specialising in blasting engineering, in charge of blast design and explosives implementation.

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Blasting demolition of part of the Bellevue Hotel

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ABSTRACT: The Bellevue Hotel is situated in the bay of Čikat on the island of Lošinj, an important tourist centre in the region of Kvarner in Croatia. During the reconstruction and renovation process it was necessary to demolish, in stage one the south wing of the hotel and, in stage two, part of the north and west wings. Due to very fast reconstruction works it was decided that the demolition of the south wing and part of the north and west wings would be carried out by blasting. Blast design, preparation and blasting operations were completed within a week. Floor plan dimensions were 46.20 m x 15.20 m. The demolished part of the building consisted of three floors and a ground floor. The structure consisted of load-bearing walls and beams. The first phase of the demolition was carried out by blasting 16 load-bearing columns. The cut height and explosive mass necessary for concrete crushing was determined for each column. In that way static load capacity was completely eliminated resulting in kinetic energy necessary for breaking and crushing elements during free fall. Detonation sequence of explosive charges of individual load-bearing elements determined dynamic scheme of breaking the structure, as well as spatial rotation and translation in the free area. Drilling and blasting parameters were calculated for complete fragmentation of concrete elements. Boreholes of diameter 32 mm were initiated by LP detonators, with delay interval of 100-200 ms, thus resulting in planned delay of individual boreholes and the breaking of 'node' points of the structure before the fall. The columns in the south wing were immediately connected to the columns in the east and west wing, and the damage of the afore-mentioned columns had to be avoided. In the second phase of demolition parts of the north and west wing had to be demolished. Taking into account the integrity of the wing, it was a very demanding situation from the engineering point of view. The proximity of load-bearing columns that must not be damaged and short deadlines for demolishing made this project exceedingly demanding.

12 INTRODUCTION

The demolition of old structures by explosives is a method often used in the USA and Europe. The method includes the use of small quantities of explosives used for blasting load bearing structures.

Compared with conventional demolition techniques with heavy machinery, such as a wrecking ball, hydraulic hammer, excavator, hydraulic shear, hydraulic hammer, etc., the major advantages of blasting demolition are: (1) the short period of the demolition process, (2) the limited use of heavy machinery and (3) the cost effectiveness and time savings (Lauritzen & Schneider 2000). Occasionally it is not necessary to demolish the whole structure, but only a part of the structure. The blasting demolition of the part of the structure is even more demanding as the rest of the structure must not be damaged.

The paper presents the blasting demolition of part of the Bellevue Hotel in the process of reconstruction and renovation works.

2 THE RECONSTRUCTION OF THE BELLEVUE HOTEL

The Bellevue Hotel is situated in the bay of Čikat on the island of Lošinj, an important tourist centre in the region of Kvarner in Croatia. The reconstruction included the enlargement of the building and the construction of an indoor and an outdoor swimming pool. The reconstruction works were carried out partly by drilling and blasting, e.g. the foundation excavation for the indoor and outdoor swimming pools, atrium and the foundation excavation below the former hotel kitchen. The floor plan with marked spots corresponding to the hole positions on the blast design is shown in Figure 1.

The most demanding part of the reconstruction was the blasting demolition of part of the building. It was necessary to demolish the south wing and parts of the north and west wings.

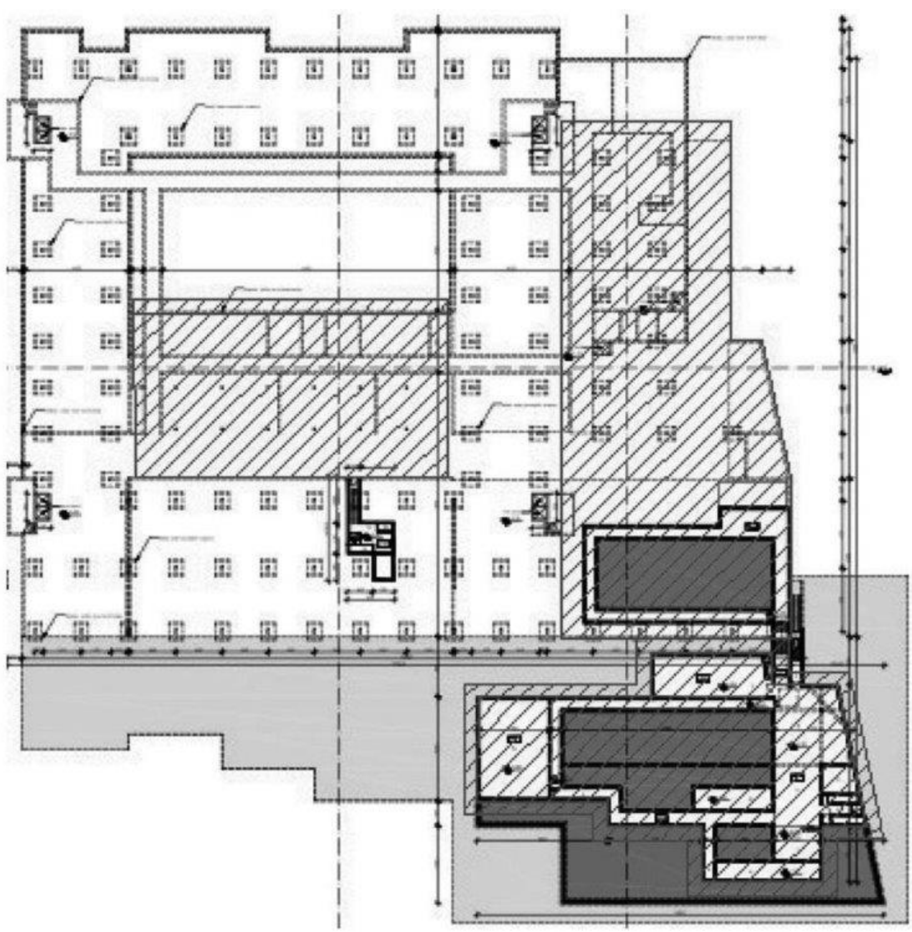

Figure 1. The floor plan with marked foundation excavation by drilling and blasting.

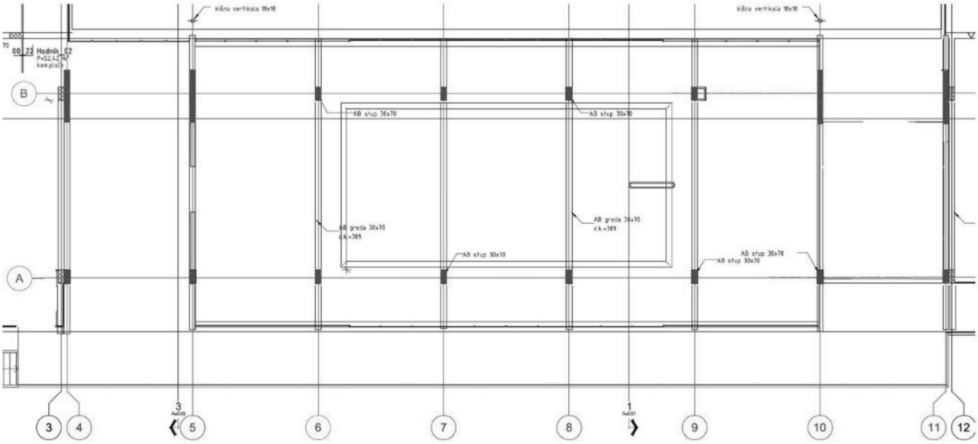

Figure 2. The floor plan of the south wing with columns (Dobrilović & Ester 2013a).

Table 1. The number of boreholes, explosive charge mass and cut heights for the south wing blasting.

Columns	Blasted columns	Cut heights m	The total number of boreholes pcs	Explosive charge per borehole kg	Total explosive charge kg	The total number of detonators pcs
7A, 7B, 8A, 8B	AB columns 30x70 cm	5.4	120	0.04	4.80	120
6A, 6B, 9A, 9B	AB columns 30x70 cm	2.4	56	0.04	2.24	56
5B, 10B	AB columns 30x270 cm	1.05	120	0.02	2.40	120
5A, 10A	AB columns 30x70 cm	1.05	14	0.04	0.56	14
4B, 11B	AB columns 30x270 cm	0.15	18	0.02	0.36	18
4A, 11A	AB columns 30x70 cm	0.15	6	0.04	0.24	6

3 BLASTING DEMOLITION TECHNOLOGY FOR PART OF THE BELLEVUE HOTEL

During the reconstruction and renovation process it was necessary to demolish in stage one the south wing of the hotel, and in the second stage parts of the north and west wings. Due to very fast reconstruction works it was decided that the demolition of the south wing would be carried out by blasting. Blast design, preparation and blasting operations were completed within a week.

3.1 The demolition of the south wing

Floor plan dimensions were 46.20 m x 15.20 m. The demolished part of the building consisted of three floors and a ground floor. The structure consisted of load-bearing walls and beams. The first stage of demolition was carried out by blasting 16 load-bearing columns. The columns in the south wing were immediately connected to the columns in the east and west wing, and the damage of the afore-mentioned columns had to be avoided. The floor plan of the south wing with columns is shown in Figure 2.

Figure 3. The columns before blasting operations.

Column dimensions were 300 x 700 mm and 30 x 270mm. The cut height and explosive mass necessary for concrete crushing was determined for each column. In that way static load capacity was completely eliminated resulting in kinetic energy necessary for breaking and crushing elements during free fall. Table 1 shows cut heights, the number of boreholes, explosive charge mass and the number of detonators for each column.

Drilling and blasting parameters were calculated for complete fragmentation of concrete elements. The explosive charge was placed in the boreholes of diameter 32 mm and of length 200 mm. A total of 344 boreholes were drilled, and the total mass of explosive was 10.6 kg. A non-electric blast initiation system (LP Detonators) with different delay intervals were used to initiate boreholes. The non-electric detonators of each column were connected in groups by a bunch connector. In order to prevent blast-generated debris from being scattered the columns were covered by geotextile fabric and chain-link fence. Figure 3 shows the columns before blasting operations.

The combination of cut heights, the proper explosive charge mass and the sequence of delay (detonation) prevented demolition of the south wing towards its central part, thus avoiding possible damage of the columns in the west and east wing. A segment of a video showing the south wing demolition is shown in Figure 4.

Figure 4. The blasting demolition of the south wing.

3.2 The demolition of the part of the north and west wings

After successful demolition of the south wing of the hotel, the investor decided that parts of the north and west wings would also be demolished by blasting.

The part of the north wing to be demolished by blasting is shown in Figure 5 (columns 13L, 14L, 13K and 14K)

The part of the west wing to be demolished by blasting is shown in Figure 6 (columns 1C, 1D, 1E, 1F, 2C, 2D, 2E and 2F).

The blasting demolition of the parts of the north and south wing was carried out in an identical manner. The only difference was the

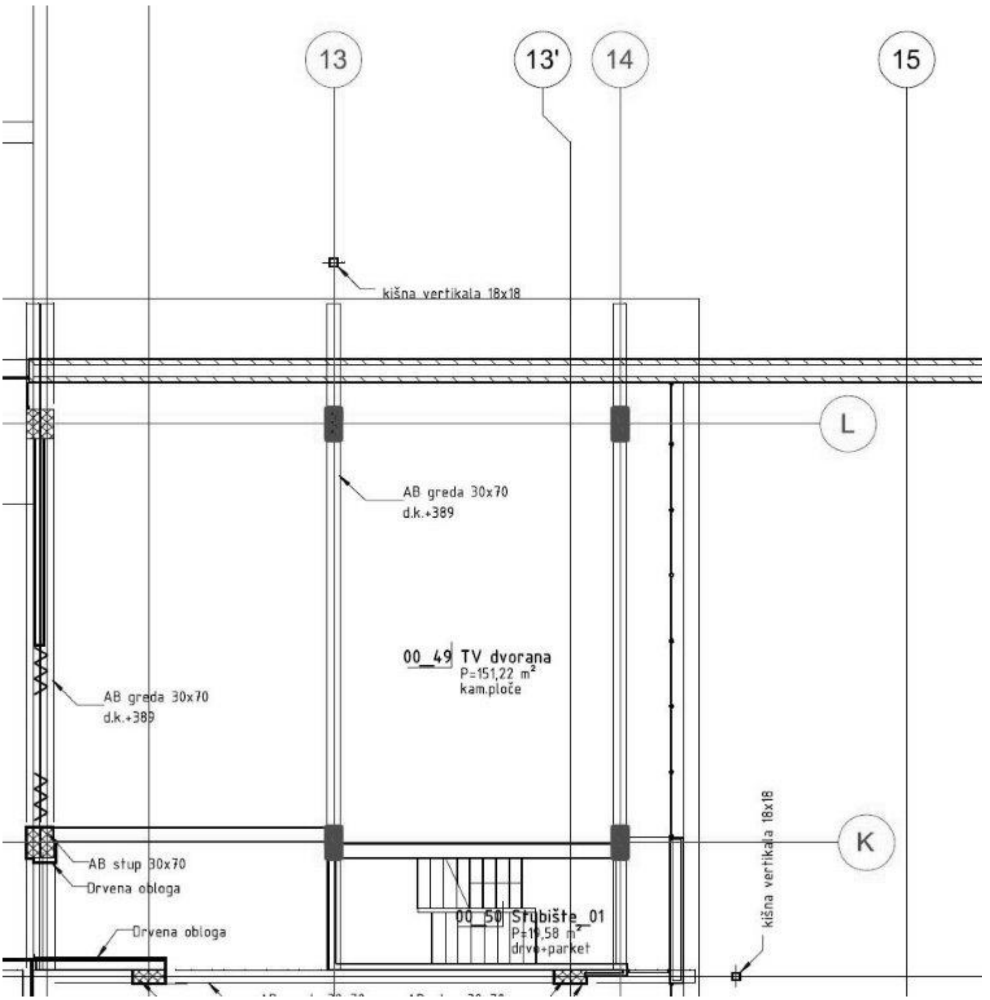

Figure 5. The section of north wing to be demolished by blasting (Dobrilović & Ester, 2013b).

Table 2. The number of boreholes, explosive charge mass and cut heights for the north wing blasting.

Columns	Blasted columns	Cut heights m	Total number of boreholes pcs	Explosive charge per borehole kg	Total explosive charge kg	Total number of detonators pcs
13L, 14L	AB columns 30x70 cm	5.4	60	0.04	2.40	60
13K, 14K	AB columns 30x70 cm	0.45	6	0.04	0.24	6

number of columns that had to be demolished. Blasting was carried out by rotation, and the axis of rotation was the line connecting back columns - axis K in the north wing and axis F in the west wing. Front columns, line L in the north and line C in the west wing were drilled and blasted to the

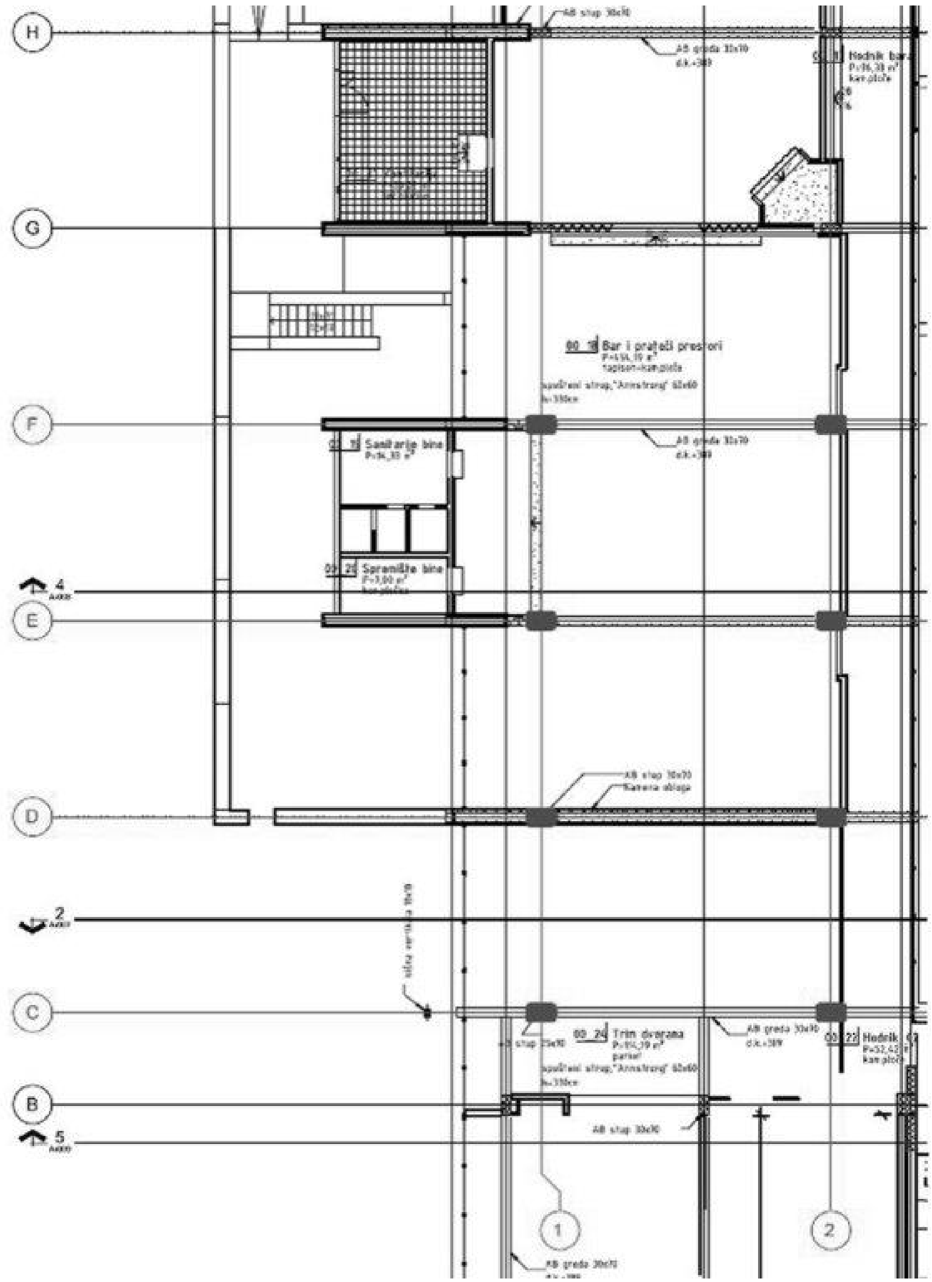

Figure 6. The section of the west wing to be demolished by blasting (Dobrilović & Ester, 2013b).

length of 5.4 m. There were 30 boreholes per each column. In the back columns, line K in the north wing and line F in the west wing, there were 3 boreholes per column. The number of boreholes for blasting the part of the north wing is shown in Table 2, and the number of boreholes for blasting the part of the west wing is shown in Table 3.

Before the demolition of part of the west and south wing it was necessary to separate the parts of the wing to be demolished from the rest of the

Table 3. The number of boreholes, explosive charge mass and cut heights for the west wing blasting.

Columns	Blasted columns	Cut heights m	Total number of boreholes pcs	Explosive charge per borehole kg	Total explosive charge kg	The total number of detonators pcs
C1, C2	AB columns 30x70 cm	5.4	60	0.04	4.80	120
D1, D2	AB columns 30x70 cm	2.4	28	0.04	1.12	56
E1, E2	AB columns 30x70 cm	1.05	14	0.04	0.56	14
F1 I F2	AB columns 30x70 cm	0.15	6	0.04	0.24	6

wing, i.e. to construct dilatation. In that manner it was possible to prevent demolition of the rest of the north and west wing during blasting demolition of the building. Connecting and initiating boreholes was carried out in the same manner as in the demolition of the south wing. Figure 7 shows the demolition of part of the north wing and Figure 8 the demolition of part of the west wing.

Figure 7. Blasting demolition of part of the north wing.

4 CONCLUSION

The reconstruction of the Bellevue Hotel included the demolition of parts of the existing hotel. During the demolition work two basic preconditions had to be fulfilled. Demolition had to be carried out within a very short period, and during the demolition the rest of the structure, as well as other objects in the vicinity had to be free from damage. The investor decided to use blasting demolition. It turned out to be the best method taking into account the cost and duration of the demolition. The whole project was completed within a week, and the remaining parts of the structure, as well as the structures in the vicinity, were not damaged after blasting operations.

Figure 8. Blasting demolition of part of the west wing.

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Effect of non-accurate drill depth on the cost analysis of a foundation excavation blasting

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ABSTRACT: Fracturing the rock mass outside its predefined boundaries or not achieving enough fracturing within a defined boundary may lead to severe problems. This study explains drill depth errors and their effects on foundation excavation blasts done for the construction purpose of a 15,000 m^3 water tank. At the final stage of the excavation an additional secondary blast is required due to non-accurate drill depths. To locate hole collars for the secondary blasting, detailed surveying of the area was carried out and this survey information was used for DTM creation. By using the information from DTM, blasthole depths were determined and 720 holes having depths between 0.5 m and 2.8 m were drilled and blasted. This additional blast resulted in an extra 15 work days and additional cost to the project. Cost analyses indicated that drilling and blasting costs of the levelling work were 6 to 7 times higher than those of regular production blasts.

1 INTRODUCTION

Rock fragmentation by using explosives is comprised of two different tasks which are drilling and blasting. Although these two tasks are independent from each other, how well the holes are drilled has a great impact on the performance of the blasting operation and accurate drilling can be considered to be as the key to success. Inaccurate hole drilling may stem from not drilling the hole at the desired collar, not reaching to the desired depth, deviation in the borehole and errors made in drill angle (Harris 2001). Most of these problems actually arise from giving insufficient importance to accurate drilling since the time spent on accurate drilling is thought to be a loss in production. However, the time and money losses which are thought to be caused from the effort spent on drill accuracy may be nothing in comparison to the problems encountered and time and money losses due to blasting of inaccurately drilled holes. Effort spent on drill accuracy is comprised of the effort of drill and blast engineers, surveyors and the drilling operators. Unless these three work as a team, it is likely that there is a loss in the performance of the blasting operations and the minimum achievable cost of blasting cannot be attained. Forsyth *et al.* (1995) states that the most influential factor on blasthole location is people.

The purpose of this research is to investigate effects of inaccurate drilling practices caused by not paying so much attention to surveying work after blasting or wrong calculation of blasthole depths required on cost analyses of a foundation excavation blasting.

2 NON-ACCURATE DRILLING RELATED PROBLEMS AND SOURCES

There are many factors which can be considered to be the source of inaccurate drilling. Some of them are related to human factors and some are related to the geology of the area. Harris (2001) presents four factors which affect the drill accuracy and they are positioning accuracy, depth accuracy, borehole path accuracy and angle hole drilling. Positioning accuracy is the beginning of the drill accuracy. If the hole cannot be located at its planned collar location, planned drill pattern cannot be achieved. This can change the actual burden-spacing lengths planned and a change in blast pattern may result in toe problems unless the drill depth is not modified for the actual collar position. Depth error can be stated as the blasthole depth not reaching to a desired level or drilling more than to a desired level. Depth errors create uneven floors and this can bring about some other problems. Uneven floors, on how large the area is, may require secondary drilling and blasting operations. These secondary drilling and blasting operations are of higher costs when compared to regular production blasting and it may take much longer time to drill and blast a certain volume of rock.

3 WORK AREA

The foundation excavation was planned to be done for the purpose of a water tank construction in Yozgat, Turkey. The dimensions of the water tank are 65.50 m x 49.10 m, water height is 5.25 m and depth of the foundation is 4.50 m. The base elevation of the water tank, as shown in Figure 1, is 1470.75 m and the maximum topographical elevation in the excavation area is 1,486.00 m. The maximum depth of excavation is 15.25 m. Three benches were planned to be constructed at the northern part of the excavation area.

4 PRODUCTION BLASTING

Since there was a sensitive structure nearby, which was a gas transmission pipeline, some test blasts were carried out previously in the site and it was understood that 25.5 kg per delay was a safe amount. Considering the vibration limitation, two different blast designs were suggested for two different bench heights, which were 5 m and 7.5 m bench heights.

In production blasting operations, 0.5 kg (Nova 70) emulsion type of explosive as a primer, ANFO or emulsion type of explosives (65 % Heavy ANFO) depending on the water condition of the hole as a column charge and non-electrical detonators as in-hole detonator and hole to hole connector were used. Rock types existing in the site were basaltic andesite and andesite. Since the rock mass was jointed and weathered at some parts, powder factor values were between 0.300 kg/m^3 to 0.330 kg/m^3. Applied blast design parameters for 7.5 m and 5.0 m bench heights are given in Table 1 and Table 2 respectively.

The construction area was far away from where consultants were residing. So, it was not always possible for the consultancy group to go to the site and mark the collars of the blastholes. For this reason, prior to each blast, the coordinates of the boundaries of newly formed bench face were measured, drawn on a CAD software and sent electronically to the consultancy group by the surveyors working on-site. Example CAD file sent by the surveyors is shown in Figure 2. Having

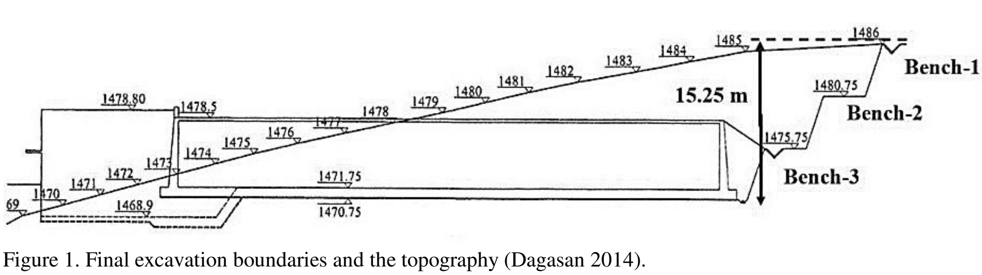

Figure 1. Final excavation boundaries and the topography (Dagasan 2014).

Table 1. Applied blast design parameters for 7.5 m bench height.

Parameters	Values
Diameter (mm)	89
Bench Height (m)	7.5
Bench & Hole Angle (deg)	90
Burden (m)	2.9
Spacing (m)	3.5
Subdrill (m)	0.9
Depth of Blasthole (m)	8.4
Charge Height (m)	5.2
Stemming (m)	3.2

Table 2. Applied blast design parameters for inclined 5 m bench height.

Parameters	Values
Diameter (mm)	89
Bench Height (m)	5.0
Bench & Hole Angle (deg)	72
Burden (m)	2.5
Spacing (m)	3.0
Subdrill (m)	0.75
Subgrade (m)	0.63
Depth of Blasthole (m)	6.0
Charge Height (m)	2.7
Stemming (m)	3.3

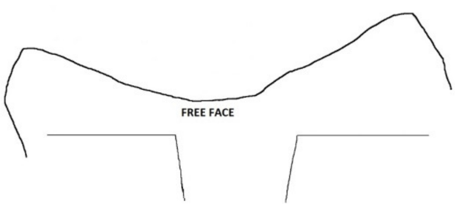

Figure 2. Example CAD file sent by surveyors.

received the boundaries of the free face, hole collars were located on the same file and sent back to the surveyors (Figure 3). Surveyors extracted all the coordinates of the hole collars and marked them on the ground. Due to uneven and sloping terrain existing in the site, different hole depth for each unique hole, depending on the elevation at the planned hole collar, was assigned instantly by the surveyors.

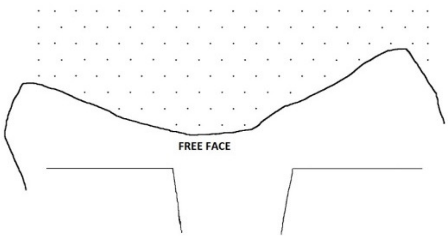

Figure 3. Hole collars marked on the CAD file.

5 LEVELLING BLASTING

As mentioned before, the excavation was done by dividing the total excavation depth by two. To do this, the excavation was scheduled in such a way that the upper 7.5 m part of the excavation depth was drilled and blasted first. Then, the lower 7.5 m part was drilled and blasted. When the blasted pile of lower part was removed from the site, it was revealed that there was an uneven floor covering an area of 2170 m^2. This needed a levelling work either to be done by drill and blast operations or hydraulic hammers. Since there was not a hydraulic hammer available at the site and it was difficult to bring one to the site, levelling work was decided to be done by further drill and blast operations. The main cause of this secondary blast was the mistake done by the surveyors. When the surveyors were determining the depth of the hole, they just subtracted the desired elevation level from the measured collar elevation. Since they didn't add any sub-drill amount into the blasthole length, desired floor levels were not achieved.

After facing this situation a detailed survey of the area was requested to analyse the situation in more detail. A couple of days later, the surveyors completed the task and sent the detailed surveying information. This survey information was converted into a Digital Terrain Model (DTM) on a mine design software. This model is shown in Figure 4. Areas that need to be levelled are shown in Figure 5 as dark regions.

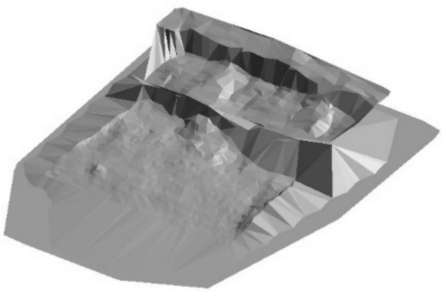

Figure 4. DTM of the area to be levelled by secondary drilling and blasting.

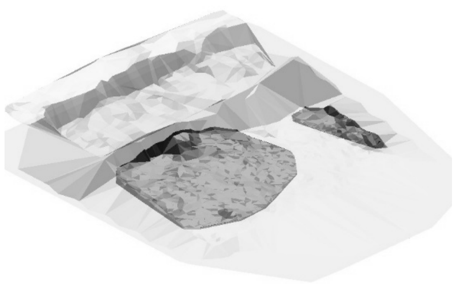

Figure 5. Darkened regions show the areas that need to be levelled.

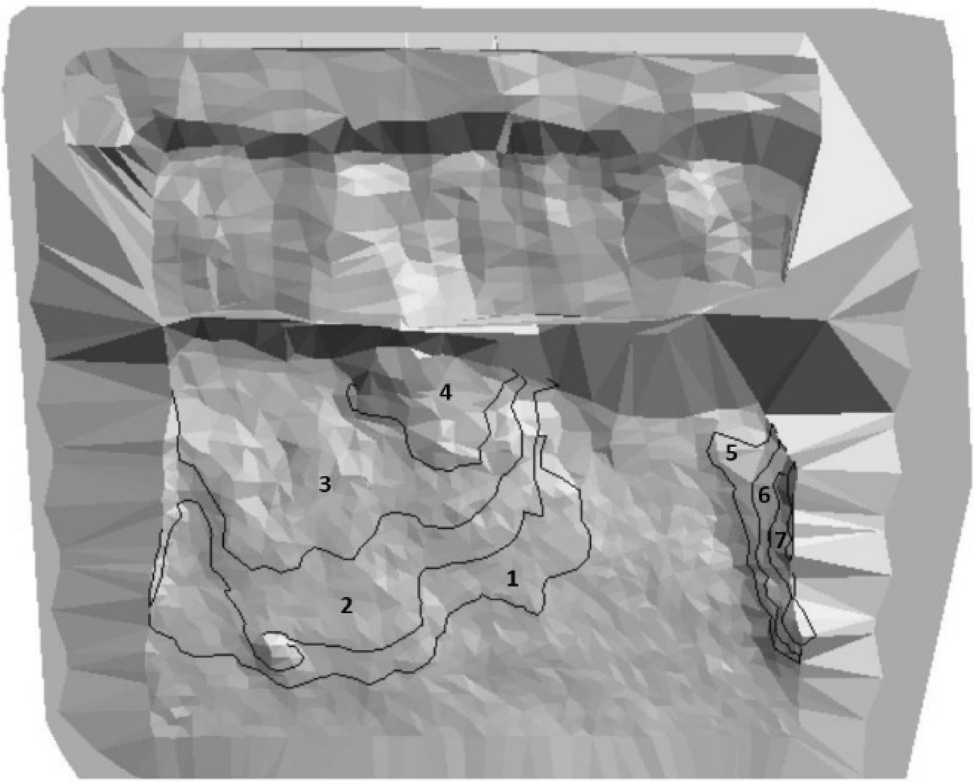

Figure 6. Different regions were determined depending on the drill depth required.

By using the DTM model, it was understood that an additional excavation depth ranging from 0.7 m to 2.8 m were needed. It is clear that 2.8 m cannot stem from a non-accurate drill depth. This part of the area to be levelled caused from a misfire incident occurred in previous production blasts due to row-by-row delaying instead of echelon type of tie-up.

The total volume of the rock to be removed from the site within levelling work was 1,615.25 m^3. In some part of the area to be levelled there was no need for levelling blasts. For this reason, no drill plan was prepared for this region. Other parts of the area to be levelled separated into different regions depending on the depth of excavation required and different drilling and loading plans were prepared for each region. These regions can be seen in Figure 6. Blast patterns designed for each region are presented in Table 3.

Table 3. Blast patterns used in levelling blast.

Region	Hole Depth (m)	Burden (m)	Spacing (m)
1	0.7-1.0	0.80	1.00
2 and 5	1.1-1.5	1.00	1.25
3 and 6	1.65-2.05	1.20	1.50
4 and 7	2.15-2.8	1.30	1.60

By using the burden and spacing values indicated in the prepared blast patterns, hole collars were located for each region (Figure 7). This drill plan was converted into a CAD file and sent to the surveyors. Blastholes were drilled according to this drill plan.

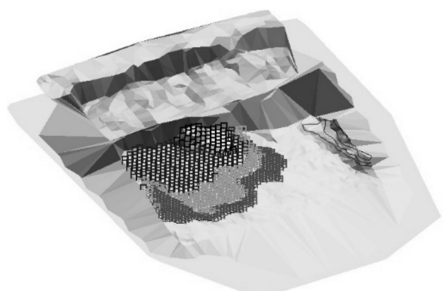

Figure 7. Area to be levelled with placed hole collars.

6 RESULTS AND DISCUSSION

In total, 720 holes were drilled and blasted within the secondary blasting work. 720 dual type of detonators (6 m 25/500), 520 kg emulsion type primers, 280 kg emulsion type of explosives were used. All in all, 800 kg of explosives were used to blast 1,615.25 m^3 rock and this made the powder factor used in the levelling work as 0.495 kg/m^3. This is 65 % higher powder factor than used in a regular production blast.

This work, including the surveying time, cost the company an extra 15 workdays and amounted to $14,200. Considering the volume of rock broken by an individual production blasthole in 7.5 m bench height, which is 7.5 x 3 x 3.5=78.75 m^3, excavation of the exactly the same volume of rock could have been done by blasting a group of 21 production blasthole. To drill 21 production holes, considering the blasthole depth of 8.4 m, 172.3 m length of drilling is required. This length of drilling can be completed the same day the drilling work started. The drilling and blasting cost of this work would be about $2,200.

The cost caused by this additional blast is of 6.4 times the cost of production blast with emulsion type column charge and is of 7.5 times the regular blast with the usage of ANFO as column charge.

7 CONCLUSION

Generation of a DTM by detailed surveying work before and after blasting and making use of mine design software in determining the locations and depths of drill holes increases drill precision, prevents errors and reduces loss of time and money caused by the need for secondary blasting works. Although time and effort spent for obtaining accuracy seem, most of the time, a loss from the production, it may save one from thousands of dollars depending on the size of the work. If the blast area in this work was converted into DTM after each production blast and locations of the collars of the holes and depths were determined accordingly, this levelling work wouldn't have been needed and $10,000 would have been saved. Not spending at most a work day for detailed surveying caused a loss of 15 work days in this work. Especially in an area where the terrain is sloping, use of DTM in blasting operations would be a very good approach. Besides, if the drill design is done on a DTM, neither the driller nor the surveyor would be in need of the determination of the sub drill amount and cause an error.

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