EFEE

NEWSLETTER

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Blasting technology for removing a part from the northern tower of Zagreb cathedral

Optimising blast layouts by aerial imagery and automatic placement of boreholes

BAF - Baltic Aggregate Forum photoreportage

...and much more!

NEWSLETTER

SEPTEMBER 2020

We in EFEE hope you will enjoy the present EFEE-Newsletter. The next edition will be published in November 2020. Please feel free to contact the EFEE secretariat or write to newsletter@efee.eu in case:

- You have a story you want to bring in the Newsletter
- You have a future event for the next EFEE Newsletter upcoming events list
- You want to advertise in an upcoming Newsletter edition

or any other matter.

Doru Anghelache, Chairman of the Newsletter Committee and the Vice President of EFEE

and Teele Tuuna, Editor of EFEE Newsletter - newsletter@efee.eu

Dear EFEE members, the President´s voice

I am delighted to introduce the latest issue of EFEE Newsletter to all our members and other explosives and blasting professionals! I hope that you find our technical articles of various topics interesting.

All over Europe COVID is raising its ugly head again after a calmer summer period. Luckily, we are still far from spring statistics and it is unlikely that the situation will escalate that far again. Both us and the virus have learned from past mistakes. Average symptoms caused by the virus seem to be milder now as it needs us to survive so it can spread wider. We also have a better understanding of Covid's spreading mechanisms which helps us to avoid unnecessary hard restrictions and panic. At the same time, deaths, caused by other viruses, have reduced significantly thanks to increased social distancing, carefulness and hygiene. This development is a good example of how things balance up, all living things fight and evolve to survive, and extreme hardships are boosting our efforts.

Our industry has also started to evolve. We have come to terms with the fact that this is the new normal and current restrictions will not be lifted in a while, not even soon after a possible vaccine comes available. We need to find new ways to handle our businesses and live our lives safely and effectively.

Meetings have been held remotely over internet successfully for half a year now and many people work totally or partly from home offices. These solutions have been fairly easy to adopt. The next phase is to introduce new online solutions for organizing more complicated and larger events, like training courses and conferences. This development has been driven by two major reasons. Firstly, in safety driven explosives industry, authorities and regulations are setting minimum requirements for updating training. Our licences require regular updating in most countries. The other reason is the current way of living surrounded by data, which we have adopted successfully during last decades. Already 6 months without normal possibilities to network makes many of us feel like we are missing out from something important – a fuller picture.

Many training providers are now planning to offer training in form of e-learning or webinar. Our fellow organization ISEE is one of them. At the moment larger events like conferences are being cancelled or postponed. However, the technology is being developed to arrange even this kind of events over web, including coffee rooms, exhibition booths, one-on-one talks, etc. They tell the only thing you miss is the long flight and poor nights at the hotel. Well, maybe you would still miss a little bit more than that. Nothing really compares to meeting old friends and colleagues over a glass of wine.

The constitution of EFEE expects us to arrange an annual general meeting once a year. We could not do that in the spring as normally. We had all meeting arrangements already booked for Istanbul, but they had to be cancelled – or hopefully only postponed until next year. EFEE board has now decided that we need to continue normal operation in our committees and Council. We are therefore continuing with normal Committee work immediately. Most Committees will meet in the beginning of October by using standard remote meeting applications. Council meeting and AGM will then be held on 20th of November by using a special application designed for larger meetings including voting. This means that the prolonged term of the current board will also soon come to an end and we can introduce the new EFEE board, where I will continue serving our federation as the immediate past president.

These special arrangements offer an opportunity for those interested in EFEE work but who are normally not able to join in due to requirement to travel on a weekday. Committee, Council and AGM meetings are open for all EFEE members to participate according to EFEE Constitution, but only delegates with voting rights are eligible for voting. Please inform our Secretary General by email if you wish to join a Committee, Council or Annual General meeting this fall, and he will forward your request to Committee Chairmen or our Council & AGM meeting organizer to send out invitations.

I am looking forward to some new active members in our meetings this year!

Jari Honkanen, President of EFEE


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Collapse of a cooling tower - a successful demolition project

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Abstract. From the point of view of demolition, one of the most interesting construction categories is the hyperboloid shape cooling towers. These seemingly fragile structures support at the base on a reinforced concrete belt and pillars. An important element to be taken into account when choosing the demolition solution is the slope of the tower. As this ratio between tower height and base diameter is greater (4-5), the easier is the demolition of the tower by overturning, respectively by moving the centre of gravity of the construction away from its base. In the case of the cooling tower described in this article, its height was 72.00 m and the base diameter of 52.00 m - the slope ratio index being less than 2, which was why the chosen solution of demolition was that of partial lateral collapse followed by a total crash of the tower on its position. The article describes how to perform the demolition of the cooling tower, the technical and safety solutions adopted for its successful collapse in the intended direction, in very sensitive location conditions regarding the constructions and installations in its immediate vicinity.

1 Introduction

At the present stage of greening of the old productive units, the demolition process using blasting works have an increasing application due to the reduced time consumption, labour and expenses. A large number of demolition works by using explosives are characterized by a high degree of difficulty, have shown that the use of the blasting technique is a proper alternative from the point of view of efficiency and security.

The basic idea when performing a building demolition is that the destructive effect on the neighbouring objectives to be protected has to be negligible, the number of elements destroying by blast has to be as small as possible, as well as like the explosive quantities that are blast at once. One of the interesting construction categories, from the point of view of demolition, is the hyperboloid - shaped cooling towers. The towers are constructed of a freely supported structure of reinforced concrete of hyperboloid shape. This apparently fragile structure is rest on the base support consisting of a reinforced concrete ring belt and pillars. If a comparison is made on a scale between the thickness of the tower shell and that of an egg's shell, then the egg shell should have a thickness of only 0.10 mm. From this perspective, the cooling towers possess a "shell" much thinner than that of an egg. Such constructions take very well the external - induced shocks, their own weight and those of the temperature variations. A higher unilateral stress may, however, be fatal to the stability and integrity of such a construction (1). The article describes how to perform the demolition of the cooling tower, the technical and safety solutions adopted for its successful collapse in the intended direction, in very sensitive location conditions regarding the constructions and installations in its immediate neighbouring.

The location of the cooling tower on the refinery platform is shown in Fig.1.The cooling tower had a height of 72.00 m, with a basic diameter of 52.00 m, respectively 33.00 m at the crown. The role of such towers is the recirculation and cooling of industrial water which is then used to cool the installations from the platform. In the immediate vicinity of the cooling tower that is being demolished, there are the following objectives (Fig. 2):

Fig. 1. Cooling tower site location marked with a red ring

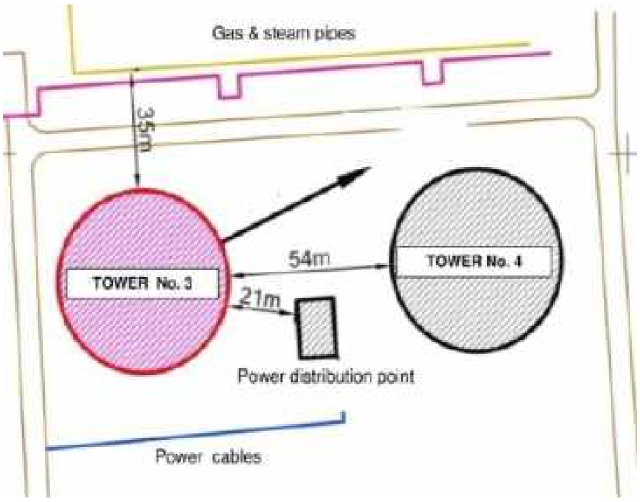


Fig. 2. Location of neighbouring objectives.

2 Cooling tower construction description

The cooling tower was located inside a large Romanian oil refinery, being in the form of a rotating hyperboloid made of reinforced concrete, by sliding with variable section.

- to the north, at 35.0 m, gas and steam pipes;
- to the east, at 54.0 m, cooling tower no. 4;
- to the south-east, at 21.0 m, power station 6 kva;
- to the south, at 19.0 m, power cables.

The structure of the tower consists of the following component elements (Fig. 3 and Fig. 4):

- inclined pillars supporting the tower body;
- vertical pillars supporting the console of the outer ramp;
- the circular belt located at the top of the inclined pillars;
- rotary blinds, in the access area at the bottom of the tower;
- the tower body itself, in the form of a hyperboloid;
- coronation (ring belt) at the top of tower;
- central water distribution room located at the base, inside the tower;
- structure of the cooling and distribution system located at the base, inside the tower.

The **inclined pillars** of the tower are prefabricated of reinforced concrete with octagonal section, having the main dimensions of 0.45 x 0.40 m. The tower rests on 36 pairs of "Λ" shape of inclined pillars, with a height of 4.45 m.

The **vertical pillars** supporting the console - the outer ramp, are rectangular in shape, with dimensions of 0.40 x 0.18 m and a height of 4.0 m. The **ring belt** is the main element of resistance and support of the tower. The belt has a height of 1.40 m and a variable thickness with an average of 0.55 m. The **tower body** is the second element of resistance of the construction. The hyperbolic tower body has a variable thickness on height, ranging from 0.47 m starting from the level + 7 m and 0.14 m up to the level + 28 m, from where the thickness of the body remains constant at 0.12 - 0.10 m, up under the belt from the topside of tower.

Fig. 3. Cooling tower body.

Fig. 4. Cooling tower at the base side.

3 Cooling tower blast demolition

3.1 Considerations on demolition by blasting works

The basic idea of a demolition is that the destructive effect on the neighbouring buildings needed to be protected is negligible, the number of the elements that are destroyed by the blast must be as small as the explosive quantities that are blasted at once. Each construction creates a special case, separately, the calculation of the blasting parameters adapting according to each situation.

The explosive load required for the dismantling of a certain constructive part, is dependent on the type of explosive used, the material being shot, the type of construction being demolished and the geometry of the location of the blasting holes. The choice of a demolishing method by blasting variants is conditioned by the physical state of the construction, by the existence of objectives in the vicinity of the demolition construction, by the possible effects of the demolition on these objectives (2).

The demolition process chosen must meet the following requirements:

- directing the fall to protect the nearby active constructions and maintain the production/activity process;

- protecting buildings near the target, against seismic action, shock wave, and throwing concrete or metal pieces under the effect of the explosion;

- destroying the integrity of the construction, so that the dismantled elements can be transportable or loaded with mechanical means.

3.2 The cooling tower demolition process

One of the interesting categories of construction, from the point of view of demolition, is the cooling towers of hyperboloid form. An important element to be taken into account when choosing a demolition solution is the slenderness of the cooling tower. In this context, the slenderness is the ratio between the height of the tower and its diameter at the base. As this ratio is greater (4-5), the easier is the demolition of the object by overturning or by moving the centre of gravity of the building outside from the plan of its base.

In the case of the cooling tower described in this article, the slenderness index is less than 2, which is why a combined demolition variant was chosen - the partial lateral collapse followed by a total crash of the tower on its plan position.

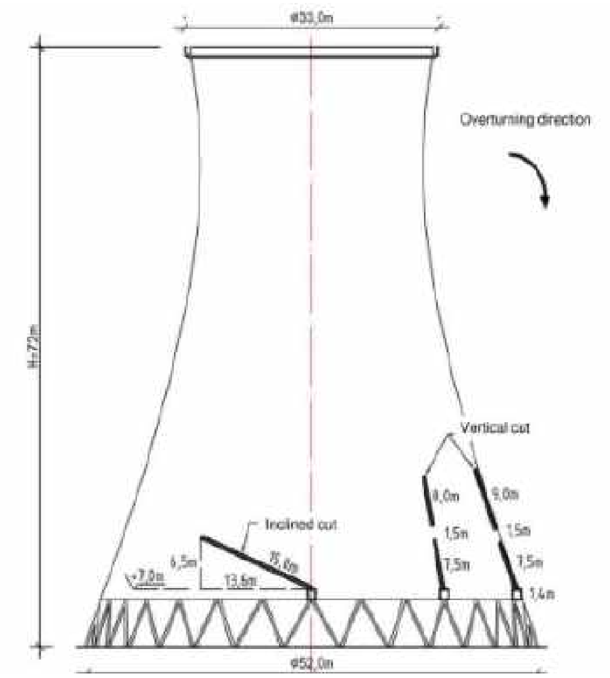
This has been done by blasting at least half of the support legs (pillars) and parts of the ring belt in a selected direction, followed by a crash on the tower itself, facilitated by the pre-created cuts in the tower jacket.

The un-blasted support pillars, opposite the tipping direction, functioned as a "hinge", allowing the creation of a striking energy by collapsing the other half of the tower. This striking energy was indispensable to induce a dynamic tension in the hyperboloid of the tower and to make it slip along the cuts previously created in its body.

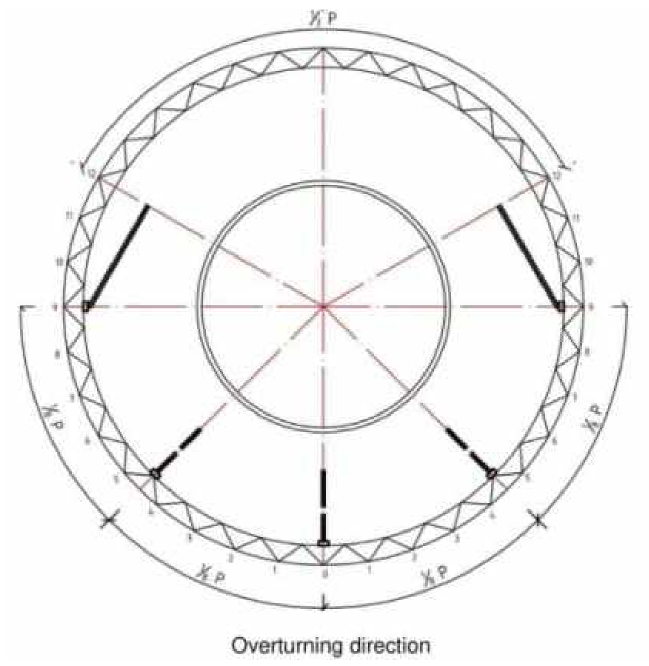
4 Preparatory stages for demolition of tower structures

In order to demolish the cooling tower, the following phases have been completed (3) (4):

- decommissioning and sectioning of the elements of the cooling and distribution system inside the tower (beams and pillars supporting cooling system, water collection system resulting from condensation) and of the connections between them and the ring belt of the tower body on at least 1/3 of the surface from the overturning direction;
- creation of a discontinuous vertical cut in the position of overturning axis and above the ring belt (level +7.0 m). The cut with the width of approx. 0.30 m will have a first section of 7.5 m long (between level +7.0 m and +14.5) and a second section of 9.0 m long (between level + 16.0 m and + 25.0 m) with a discontinuity of 1.5 m between the two sections (Fig. 5);
- creation of 2 vertical discontinuous cuts, above the ring belt (level +7.0 m) and placed on both sides, at 1/8 of the perimeter with respect to the overturning axis. The cuts with the width of approx. 0.30 m will have a first section of 7.5 m long (between level +7.0 m and +14.5 m) and a second section of 8.0 m long (between level +16.0 m and +24.0 m) with a discontinuity of 1.5 m between the two sections (Fig. 5);
- creation of 2 inclined continuous cuts and towards the tower back side, starting above the ring belt (level +7,0 m) and placed on both sides, at ¼ of the perimeter with respect to the overturning axis. The cut with a width of 0.30 m and a length of 15.0 m between the height of +7.0 m and +13.5 m has a horizontal projection length of 13.60 m and a vertical projection of 6.5 m (Fig. 5);



side view



top view

Fig. 5. Location of the cuts on tower body.

- creation of breaking sections by blasting works, in the inclined supporting pillars from the half of the perimeter placed in the direction of tower overturning, respectively 19 pairs of inclined pillars;
- in order to make the breaking sections, 5 holes are drilled in each pillar, starting from +2.0 m distance above the ground level (Fig. 6);
- creation of breaking sections by blasting works, in the ring belt next to the each cut need to be executed in the tower body. To create these breakings, in each section were drilled 18 holes placed on 5 rows (Fig.7).

a) vertical cut in the position of overturning axis:

- number of horizontal rows, N_R= 80;
- total number of holes per cut, N_H= 160 holes;
- total explosive charge, Q_T =7,8 kg and 90 lm of detonating cord.

b) vertical cuts placed at both sides at 1/8 of the tower perimeter:

- number of horizontal rows, N_R= 2 x 74 = 148;
- total number of holes per cuts, N_H= 2 x 148 = 296 holes;
- total explosive charge, Q_T= 2 x 7,5 kg = 15 kg. and 2 x 84 lm = 196 lm of detonating cord.

c) inclined cuts placed on both sides, at ¼ of the tower perimeter:

- number of horizontal rows, N_R= 2 x 26 = 52;
- total number of holes per cuts, N_H= 2 x 52 = 104 holes;
- total explosive charge, Q_T = 2 x 3,6 kg = 7,2 kg. and 2 x 30 lm = 60 lm of detonating cord.

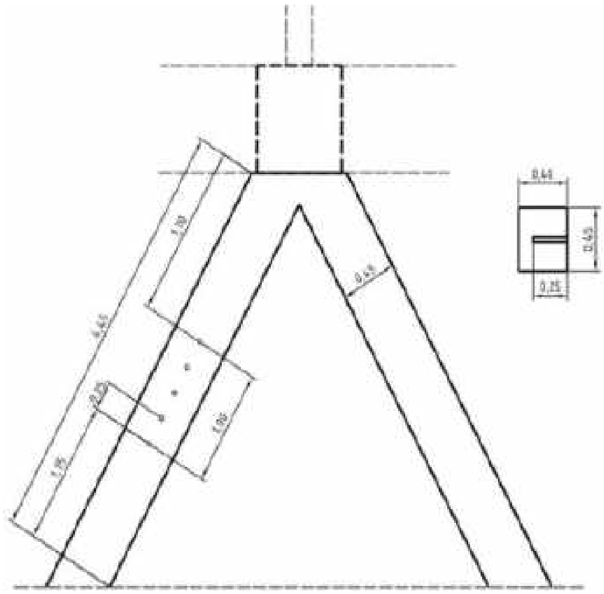


Fig. 6. Blasting holes position on inclined pillars.

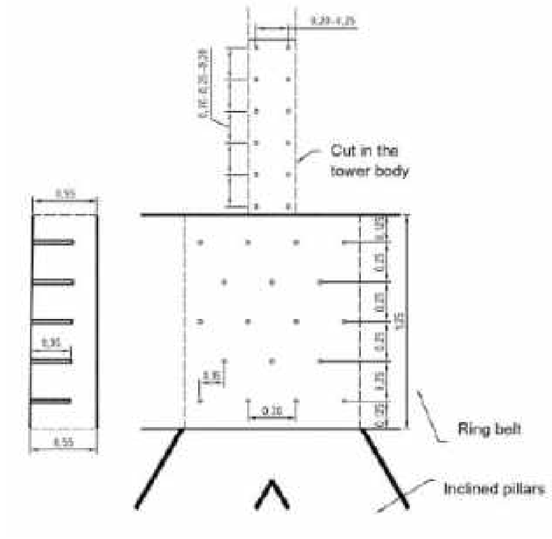


Fig. 7. Blasting holes position on ring belt and cuts.

Dynamite type explosive loads were placed in holes drilled in supporting pillars, ring belt and cuts on the tower body. The explosive charges were connected with detonating cord and initiated with non-electric detonators and connectors. The order of detonation of explosive loads it is presented in the Fig. 8.

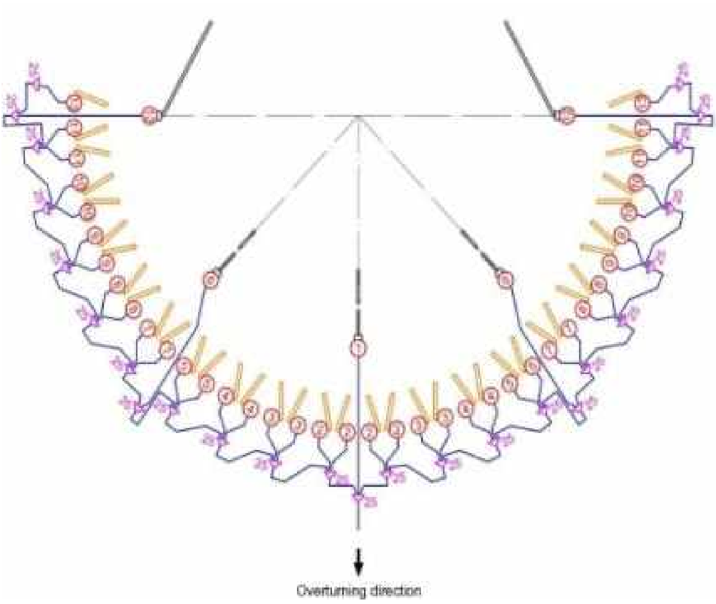


Fig. 8. Initiation network and the delay order.

Fig. 9. External protection against throwing effect.

The total amount of explosive used to demolish the cooling tower is as follows:

- Q_{Te}= 43.00 kg dynamite;
- Q_{Tdc}= 500.00 lm detonating cord;
- N_{d}= 45 pcs of nonelectric detonators;
- N_{c}= 25 pcs of nonelectric connectors, (25 ms delays).

6 Evaluation of the risks generated by the demolition works

The ***throwing of small material under the effect of the explosion***, is diminished by the installation of local means of protection made of rubber band, wire net, as well as by mounting an external protection around the construction, from materials such as textile cloth, at the level of openings where explosive charges are located. (Fig.9).

The ***seismic effect due to the detonation of the explosive charges*** at the demolition works of the cooling tower is negligible due to the distribution of the total load on a number of small loads (0.050 - 0175 kg dynamite / hole) placed in the structure in areas above the ground and initiated on groups with delay of the order of tens of milliseconds.

Seismic effect on the impact of falling on the ground of the structure that is being demolished (5,6) can result seismic effects whose size depends on the energy released to impact. This energy depends on the mass of the structure being demolished, the height of its centre of gravity and the strength of the land it falls on. Considering the constructive type of the cooling tower and the mechanism of its collapse, the impact with the soil generates low values of the seismic waves.

For the objectives closest to the cooling towers, respectively the power station and the cooling tower 4, the value of the propagation velocity of the seismic waves, possible to be generated when the cooling tower collapses, is estimated to be lower than the one which can be considered admissible, of 2.10 cm/s.

The ***overpressure of the shock wave*** also has very low values, due to the distribution of the total explosive loads over a large number of holes with small loads, having an estimated value of 0.0293 kgf / cm_2. This value is not dangerous for the buildings and human bean safety.

7 Conclusions

At the present stage of greening of the old productive units, the demolition process using blasting works have an increasing application due to the reduced time consumption, labour and expenses. A large number of demolition works by using explosives and characterized by a high degree of difficulty, have shown that the use of the blasting technique is a proper alternative from the point of view of efficiency, quality and security.

Each construction creates a special case, the calculation of the blasting parameters are adapted according to each specific situation. Blasting parameters and explosive charges are dimensioned according to the type of material and section of the construction elements to be blasted. The most commonly used method of demolition is the collapse of the construction itself or its overturning in a given direction.

For this purpose, numerous works of structural preparation, removal or reduction of the section of constructive elements are made beforehand. All this approaches are described in this article. Based on the blasting concept and risk assessment needed to take in consideration, it is presented the practical way of realizing with success the demolition by blasting works (Fig.10 and Fig. 11) of a hyperboloid cooling tower located in the immediate vicinity of sensitive objectives.

Fig. 10. Tower after demolition - back view.

Fig. 11. Tower after demolition - lateral view.

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BLASTING TEHNOLOGY FOR REMOVING A PART FROM THE NORTHERN TOWER OF ZAGREB CATHEDRAL

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ABSTRACT

Zagreb Cathedral was seriously damaged in the earthquake that hit Zagreb. The top of the southern tower broke and crashed down, and the northern tower was also badly damaged. Because of high risk of collapsing and causing even greater damage to the Cathedral and surrounding buildings, it was necessary to remove the damaged part. This paper describes how the removal, especially the blasting part, was performed.

ZAGREB CATHEDRAL

Zagreb Cathedral is the most famous and tallest Croatian religious object and one of most valuable objects of Croatian cultural heritage. It is dedicated to the Assumption of Mary and to kings Saint Stephen and Saint Ladislaus. The construction of the cathedral in transitional Romanesque -Gothic style began around 1904. The construction of the cathedral lasted for a very long time and it was not completed and dedicated until 1217. Cathedral has been reconstructed many times during the past. The first reconstruction, in Gothic style, was done by bishop Timothy (1263-1287) because cathedral was severely damaged in the Tatar invasion. The reconstruction continued in the 14th and 15th century. In the 16th century the cathedral was fortified by walls and towers and in the 17th century the cathedral got its massive renaissance tower. [1]

The fires and enemy attacks have damaged the cathedral several times but it suffered its hardest damage in the 1880 earthquake. After the earthquake the cathedral underwent a major reconstruction in neo-gothic style (1880 -1906) under supervision of Herman Bollé and by designs of F.Schmidt. It was then when the Zagreb cathedral got its present form with two slim towers, high roof, new pillars in the sanctuary and altars which replaced the 18th century baroque one. [1]

Renovation of the cathedral's two towers began in 1990. It was at this time that scaffolding was first erected around the towers. The restoration they required was a painstakingly slow process, hampered by the brittle, porous stone with which Herman Bollé had chosen to build them and by restoration funds relying solely on contemporary donations. The towers have not been completely free of this scaffolding for three decades which mean that some of citizens of Zagreb and Croatia has never seen cathedral without scaffolding.

Figure 1. Cathedral before earthquake 1880

Figure 2. Cathedral before earthquake 2020

ZAGREB EARTHQUAKE

At approximately 6:24 AM CET on the morning of 22 March 2020, an earthquake hit Zagreb, Croatia, with an epicentre 7 kilometres north of the city centre. The earthquake had a magnitude of 5.3 Mw and a depth of 10 kilometres according to Advanced National Seismic Systemand 5.5 ML according to the Seismological Service of Croatia. The maximum perceived intensity was VII (very strong) on the Modified Mercalli intensity scale (MMI). It was the strongest earthquake in Zagreb since the earthquake in 1880 [2]. To make situation was even worse as the earthquake happened during Zagreb being in corona lockdown.

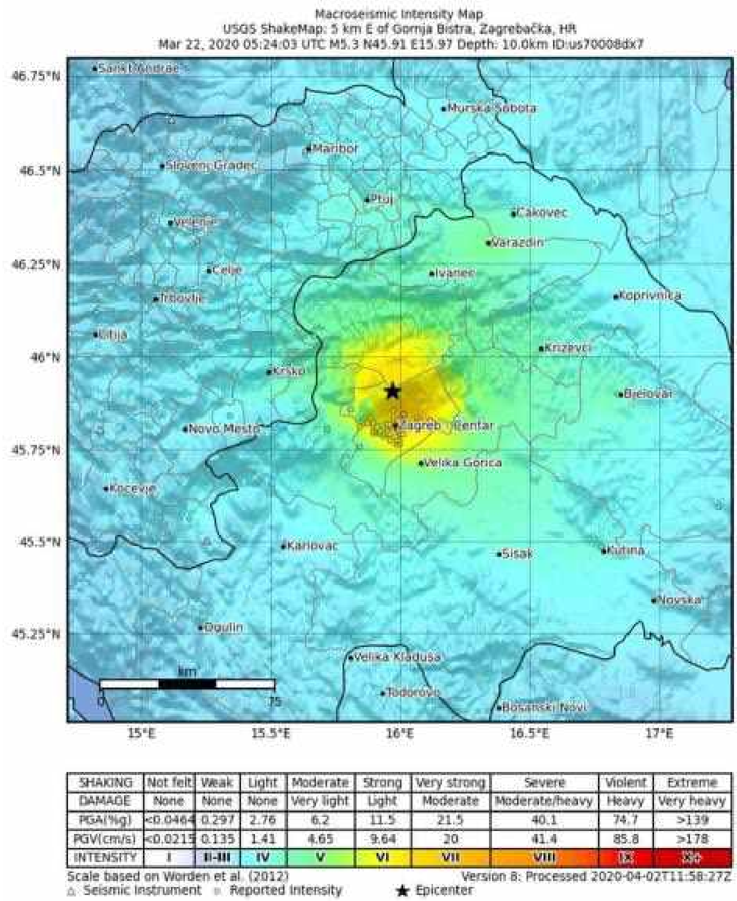

Figure 3. Epicentre and intensity of earthquake made by USGS

Citizens of Zagreb had got instructions to leave the buildings and go to open space area along with need to take care of social distancing. More than 30 aftershocks were recorded within seven hours of the main earthquake. Anamarija, 15 year old girl, was the only victim and 27 other persons were injured. Material damage was quite high; 26,197 buildings are reported to have sustained damage, 1,900 of which are unusable. Some neighbourhoods were left without electricity and heat, and in some areas without internet. Most of the damaged buildings were built in the 18th and 19th centuries and those buildings are in the historic centre of Zagreb. Most of the museums in the city's centre were damaged by the earthquake, including the Museum of Arts and Crafts, the Croatian History Museum, and the Schools Museum. Two buildings of the Komedija Theatre reported significant damage. Other theaters, minor damage was also registered on the Faculty of Law, the Croatian Music Institute [2]. One of the buildings with mayor damage was Zagreb cathedral.

Figure 4. Consequences of earthquake in Zagreb

DAMAGE ON ZAGREB CATHEDRAL AND DECISION ON NORTH TOWER REMOVAL

Immediately after the earthquake it could be seen that Zagreb cathedral doesn't have the upper part of southern tower anymore as shown on figure 5.

Few days after the earthquake, cathedral renovation designer and supervising engineer Mr. Damir Foretić made detailed report where all damages on cathedral were reported. Southern tower broke down at height of 92m, where the 10,3 m long part fell down and made significant damage on Cathedral during the fall. One part of the tower fell on the roof of the cathedral which was also damaged and pierced in several places, and most of the stone elements fell into the courtyard between the cathedral and the Archbishop's Palace [3]. There were a lot of other positions with damages on cathedral and all of them had been marked and damages were described in report.

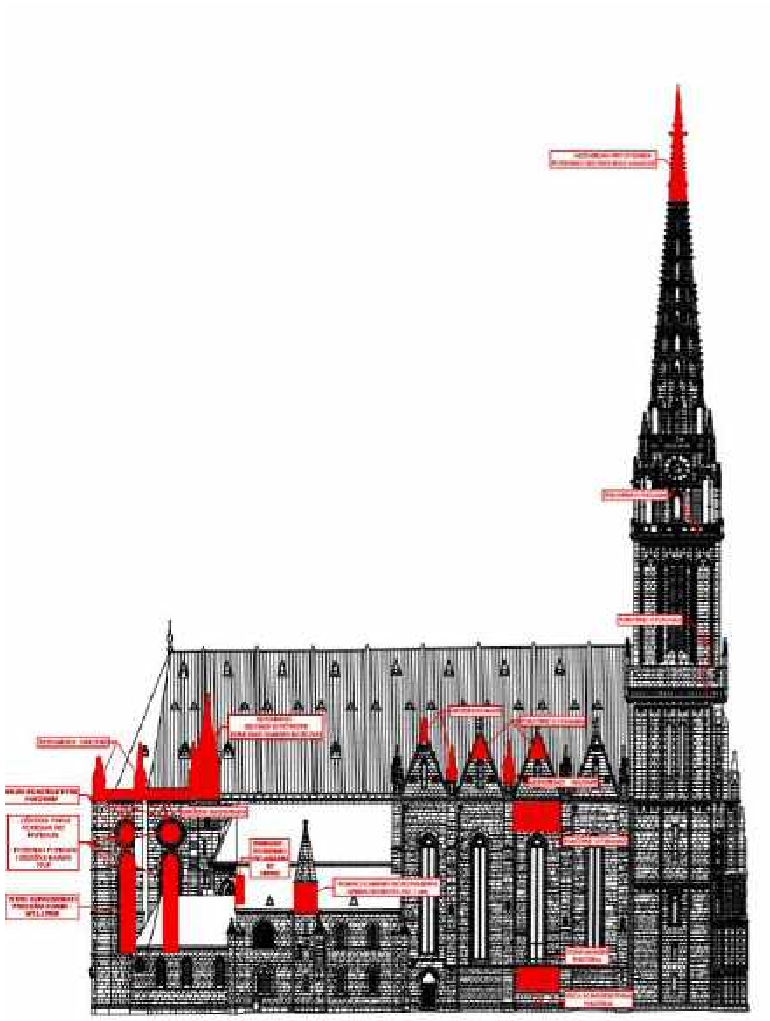

Figure 6. Damages on Zagreb cathedral [3]

During the prospection drone had been used in order to take pictures of northern tower. After reviewing the videos from the drone, significant damage was confirmed, and after another recording by drone the conclusion of members of expert commission and colleagues from the working group was unanimous - part of the north bell tower should be removed as it threatens to collapse on the cathedral side! [3] The part of the bell tower that could collapse was about 36 tons, with a total height of 13.47 meters together with a cross. Damages parts are shown on figure 7.

Figure 7. North-east and north part of northern tower (photo by Josip Ninković)

Immediately, the first plan for northern tower removal was made by Mr. Foretić and other members of working group. The plan was to lower the tower using a 500-ton crane and the tower was to be prepared according to the plan shown in the figure 8.

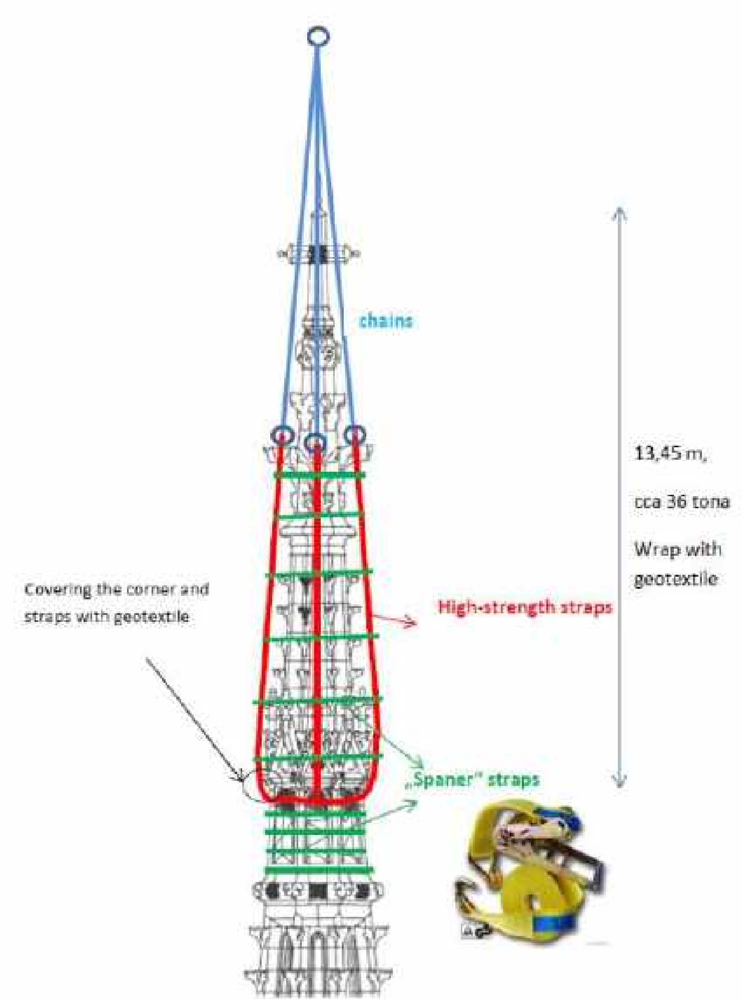

Figure 8. Preparation of northern tower for lowering by 500-tons crane [4]

Prior to the descent, it was necessary to separate the top of the tower from the rest of the building. The northern tower of cathedral was badly damaged and statically disturbed and represented a threat to the people who will work on removing. Solution for safe way of separation was controlled blasting.

PREPARATION FOR BLASTING

On behalf of Cathedral Restoration Committee Mons. Ivan Hren, the curator of the Zagreb Cathedral and chairman, contacted University of Zagreb, Faculty of Mining Geology and Petroleum Engineering and asked for help in calculation of blasting parameters and executing of blasting. Professor Mario Dobrilović and Assistant Professor Vječislav Bohanek from Department of Mining Engineering and Geotechnics are named on behalf of the Faculty of Mining Geology and Petroleum Engineering to perform these difficult tasks. Conclusion after the first meeting of working group was that the Croatian Army force should conduct the blasting deigned by faculty.

Figure 9. Blasting team with Cardinal Bozanić

Members of Engineer Regiment from Karlovac; Colonel Miroslav Car, Sergeant Krešimir Marjanović and Sergeant Damir Vulaković became part of the blasting team.

In order to remove upper part of north tower, blasting team had two main tasks to solve. First task was explosive cutting a 15 mm diameter steel rope that connects the top of the tower and connects it to a counterweight of about 4 tons. The role of wire rope was to stabilize upper part of tower. Second, even more complicated part, was to perform a blast that would release the metal wedges that connect the two rock segments of the cathedral. There were four rock segments and each of them had three metal wedges. As can be seen in figure 7 some of them were already released as a result of earthquake. Both tasks must be performed simultaneously. Steel wire rope and metal wedge are shown and on figure 10 and positions of metal wedges cros section of tower on figure 11.

Figure 10. Steel wire rope and metal wedge.

The second task was much more difficult than the first one because there was no available data in literature to be used as guideline. Also, there was no data at all that someone did blasting in this type of rock. Cathedral was built from lithothamnian limestone called Bizek, which is the autochthonous stone in the Zagreb area. The basic characteristics of the Lithothamnian limestone are porosity, love density and perforated texture [5].

In order to perform blasting successfully, it was necessary that calculation about quantity of explosive and positioning of explosive charge must be empirically proven. All tests were done on samples taken from parts of southern tower of cathedral. We used stone samples different in shape, size and mass and steel wire rope in different lengths. The first tests are done on steel wire rope.

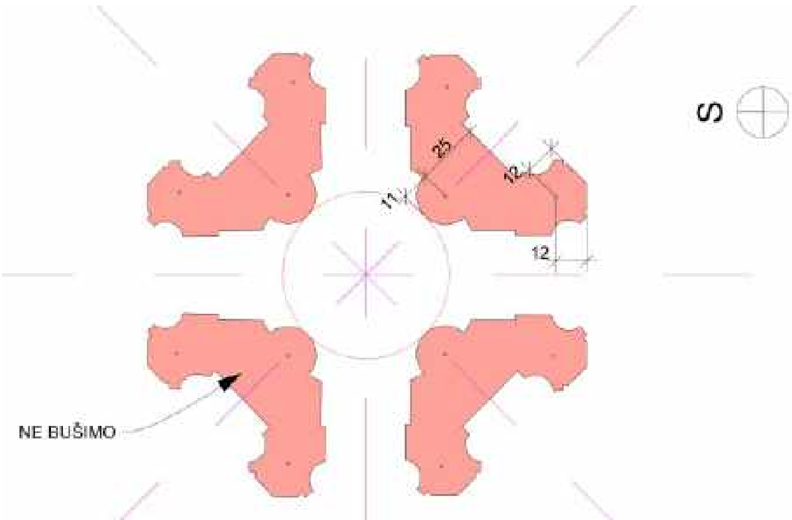

Figure 11. Positions of metal wedges

Quantity of explosive and shape of explosive charge had to be determined for successfully cutting. Tests were performed in Laboratory for testing explosive at Faculty of mining Geology and petroleum engineering.

PETN explosive were used for testing and charges were made different by shape and mass. Also positions of the charges were different and one or two charges setups were used. After each shoot inspection was made on steel rope and measured the efficiency of cutting by explosive.

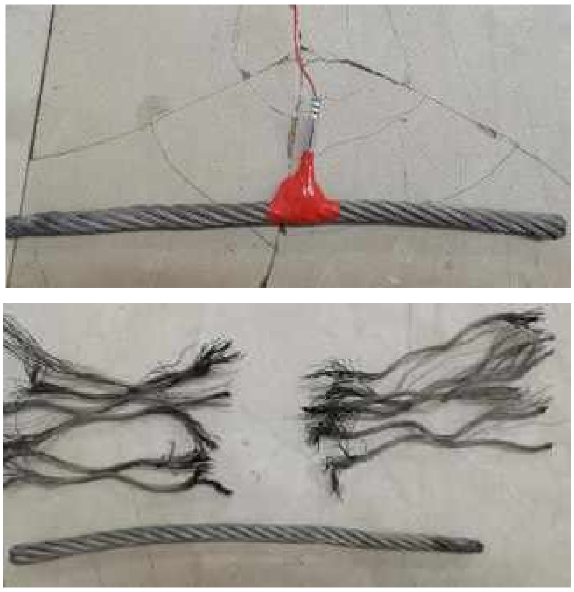

Figure 12. Wire rope explosive cutting test

Taken samples of stone were smaller than those on which blasting should be performed. The quantity of explosive and position of explosive charge were calculated in order to make fragmentation on the place where metal wedges are, but not to damage rest of stone block. Also, different materials had been tested in order to prevent fly rock or debris damage during the blasting.

Report of laboratory testing was analysed and afterword the polygon tests were performed in the courtyard of the cathedral. Tests were done together with members of the Croatian army responsible for the blasting. During this testing bigger samples of stone were used in order to make all testing more realistic. The aim of these tests was to confirm results of laboratory testing and to:

- determine the optimal amount of explosive charge for fragmentation of stone blocks
- determine the optimal amount of explosive cutting of steel rope
- determine the initial means and manner of initiation
- determine the method of protection against scattering of fragmented material during blasting.

All blastings were recorded by high Chronos High-speed camera. These recording were very useful for evaluation of blasting results. The testing setups for the stone block and steel wire are shown on figure 13, results on blasting on figure 14 and protection on figure 15.

Last trial blasting was done on 16th April and final conclusion was made. Quantity of explosive for cutting of steel wire rope is 15 g and for demolition of metal wedges two different charges will be used, 5g for middle wedges and 3 g for side wedges of each element. Chosen explosive was PEP 500 plastic explosive and electric detonators were used for initiation. After the last trial blasting, team was lifted again by crane to the upper part of the cathedral to check once again number of holes and position for drilling.

Figure 13. Stone block testing [6]

Figure 14. Stone block and steel wire test setups

Figure 16. Protection against debris and fly rocks (record of high speed camera)

BLASTING

Preparation for demolition was planned to start about 8 o clock on April 17th but it was postponed to 11 o'clock. Reason for delay was very strong wind in the morning and because of safety reason it was not possible to lift the blasting team on the top of cathedral. Blasting team was divided into two groups. The first group was in charge of drilling the holes and setting the explosives in stone block of cathedral and the second one for placing the explosive charge on steel wire rope inside the cathedral. Together with the blasting team in the crane basket was Mr. Tomo Capan who gave information about the position of the basket to the crane operator.

Whole process was supervised by Seven members of the Military Intelligence unit and three aircraft led by the Commander of the Military Intelligence Major Mario Maslov. Videos from drones were visible in real time on display at command centre. It was extremely important to have all information in real time especially information about effect of blasting. Immediately after the blasting clean cut on steel wire rope was visible.

Figure 17. Preparation for blasting

After the placing of the explosive charge, big role was played by alpinists who set up the cables and attached them to the crane. Also, police had to remove all the people and journalist to secure area and to secure perimeter. Finally, after the long preparation, everything was ready for blasting and about 18 o'clock Colonel Car gave the order for blasting.

The removal began several minutes later after drones made sure the blasting had released the metal wedges so that the part of the tower could be lowered in one piece by 500-ton crane. Few minutes after the blasting northern tower was landed in front of Zagreb Cathedral. Many people felt a big relief especial those who directly participated in project.

Figure 18. Blasting and lowering of northern tower (Photo: MORH/F. Klen)

Figure 19. Joint picture after blasting (Photo: MORH/F. Klen)

CONCLUSION

The project was carried out in unusual times, after the earthquake and during the corona lockdown on a building that has a special significance for most residents of Zagreb and Croatia. It is not surprising that media interest for this project was extremely high and Croatian citizens were able to watch the removal of the tower online in real time. Although all member of blasting team participated in many different blasting projects this one was something special and we are all very proud for having participated in this project.

For the end, it is an interesting fact that the northern tower was removed on the same date (17th of April) when the main architect of this gothic cathedral towers, Mr. Herman Bollé, had died.

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Optimising blast layouts by aerial imagery and automatic placement of boreholes

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ABSTRACT

The paper presents a new concept for designing surface blasts. It is a pure geometric approach relying on comprehensive and accurate 3D surface models of the entire area to blast. Photogrammetric 3D models from aerial imagery are used as for that purpose. The new approach uses the minimum burden concept and extends it with so-called minimum burden surfaces that form the basis for an automatic placement of the boreholes. The concept is especially useful at more complex or irregularly shaped blast sites as shown in the contribution.

1. INTRODUCTION

Remote-controlled camera drones have reached a level of maturity which allow their routine application in surface mining and quarrying for acquiring aerial imagery at high quality and resolution. Ongoing development in digital photogrammetry allows for a rapid and consistent processing of large sets of overlapping photos to registered 3D models. By using such 3D models several surveying and assessment tasks in surface mining are addressed such as stockpile measurements, mine planning, or stability assessments. This contribution deals with the design of surface blasts based on 3D models.

Pro-active blast design includes the adaptation of the borehole locations according the actual shape of the bench face (Moser et al. 2007). By doing so blasting results are improved, fly-rock is omitted, and production costs may be significantly lowered (Stewart 2017).

A new approach for placing boreholes under special consideration of geometric constraints is used to provide an automatic pro-active blast design pattern. It uses the novel concept of so-called minimum burden surfaces, i.e. the sum of locations where the minimum burden constraint is fulfilled.

The presented procedure shall not replace the responsibility and the experience of the shotfirer but rather support tedious adaptation work when having complex blast sites.

2. 3D MODEL GENERATION

2.1 Structure from Motion

Photogrammetry enables to generate three-dimensional models from a series of overlapping photographs. The introduction of the Structure from Motion concept (Snavely et al. 2014) as well the broad availability of drones brought a renaissance of this technology. Structure from Motion includes a series of processing steps that allows computing a comprehensive set of 3D surface points that are combined to a surface description (a mesh) in photo-realistic style. Due to high redundant information, always present geometric deviations of the used camera (lens distortion) are compensated while generating the 3D model. This auto-calibration ability makes modern photogrammetry algorithms capable to produce accurate 3D models even from low-grade cameras, so even low priced off-the-shelf drones can be used to generate 3D models at sufficiently high accuracy (see also next section).

Several commercial software products are available (e.g. Agisoft, Pix4d, ShapeMetriX). All work in a similar way and provide comparable results. In this case the ShapeMetriX software has been used as it also includes tools for blast design.

Figure 1 shows a resultant 3D model generated from 240 photographs. The model computes in less than 1 hour on a mobile workstation (Dell Precision 7520). In this case it consists of 3 million surface points and has a ground sample distance (GSD) of 1 cm/pixel. The used drone was a consumer grade DJI Phantom 4 equipped with a 12 Mpix camera. The 3D model was referenced using surveyed ground control points.

Positional accuracy is best if there are some reference points (ground control points GCP) in the captured area. The GCPs are locations with surveyed co-ordinates. The referencing mechanism transforms the model to the location of the GCPs with remaining residuals in the sub-cm range if GCP bundling is used. GCP bundling refers to a method where the GCPs are included while the

Figure 1. Comprehensive 3D model of a blast site and adjacent area

2.2 Model accuracy

Accuracy in that context needs to be looked at in two ways: (i) *positional accuracy*, i.e. the correct location of the 3D model in a given co-ordinate grid and (ii) *shape accuracy* that reflects mainly if all the details of the rough surface are rendered by the 3D model. Both are linked to the GSD and the latter also to the spacing of the 3D surface points. For 3D models that reside in local co-ordinates the correct orientation and scale of the model is taken as quality measure instead of the positional accuracy.

entire camera arrangement is computed. It may increase the positional accuracy compared to normal referencing (see Table 1). The residuals refer to the overall distance vector in 3D between GCP and according point on the 3D model.

Table 1. Typical accuracy (overall error in 3D) of geo-localisation when using ground control points; GSD: 0.5 cm/px

Flight date	No. images	No. GCPs	Residual [cm] mean/stddev/max	Note
09.08.2018	289	11	4.8 / 2.5 / 8.9	No GCP bundling
09.08.2018	289	11	**0.3 / 0.3 / 1.2**	With GCP bundling
18.10.2018	302	11	3.5 / 1.9 / 6.9	No GCP bundling
18.10.2018	302	11	**0.2 / 0.2 / 0.6**	With GCP bundling

In some cases, the installation and survey of GCPs is seen to be too time-consuming and costly. In such cases the 3D model might be referenced (scaled and oriented) based on GPS information that is recorded while taking the images. Such models show larger deviations from the ground truth - depending on the quality of GPS and the used flight path, the absolute localisation might be some metres off. Such pure GPS referencing is improved by using real time kinematic (RTK) or post processed kinematic (PPK) GPS. Both lead to better absolute geo-localisation of the 3D model without needing GCPs. However, final models are not guaranteed to have a certain positional accuracy.

A comparison of pure GPS-referenced 3D models with GCP-referenced ones showed that the scale of the 3D models deviated between 1 – 2 % and the angular difference (e.g. inclination of bench faces) differed by about 1°. Note that positional accuracy is not guaranteed to stay at the stated figures as the results depends on actual GPS availability and the used flight path.

3. THE MINIMUM BURDEN CONCEPT

3.1 Minimum burden diagrams

In order to describe burden as the distance from a borehole to the free surface usually the term *profile* is used. The profile provides the information what is “in front of the hole” at a certain depth. Mathematically, the profile is the intersection of a vertical plane in front of the borehole with the surface description of the free face. This concept becomes improper if a hole is at a corner since it is not uniquely defined in which direction (azimuth) the intersection plane shall point (Figure 3 left). But also for regular boreholes the intersection plane does not necessarily hit the locations where the distance between the borehole and the surface is minimal (Figure 3 right). Also in the case of an irregular bench face the resulting profile might show significantly larger values than the real shortest distance to the free face is.

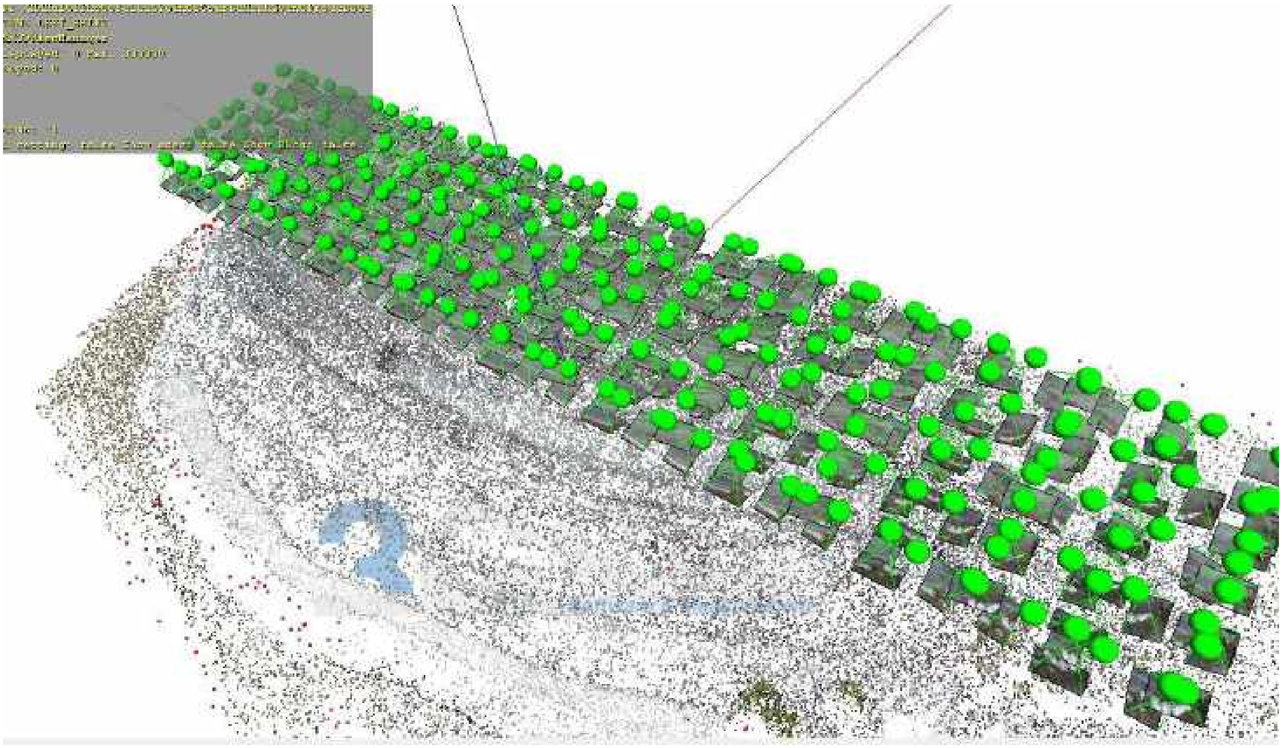

Figure 2. Analysis of deviations between camera locations from GPS recording (spheres) and photogrammetry-determined (pyramids).

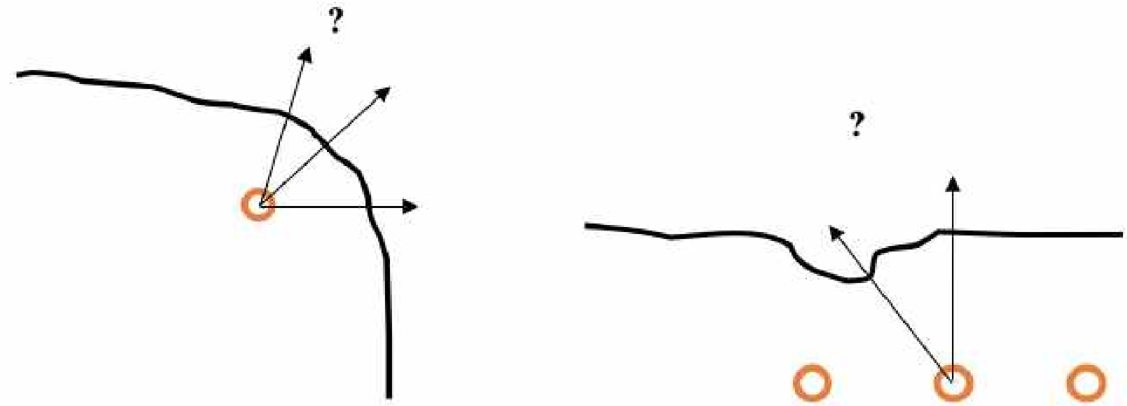

Figure 3. In which direction shall the profile measure in case of a corner hole (left) or a face irregularity (right)?

In order to overcome this, the minimum burden diagram is used. This entity provides the minimum distance at a certain depth anywhere around a borehole. For its generation, a spherical search around a certain point along the borehole is performed and the shortest distance to the surface determined. This search is repeated for all points along the borehole, typically done in small, discrete intervals. This way it is ensured that face irregularities, corner situations, or simply angular misalignments in azimuthal direction are treated correctly.

The advantage of the minimum burden diagram becomes obvious if the burden numbers obtained by the profile and the minimum burden diagram are compared for the same borehole. In this case the face has an irregularity in front of the borehole (see Figure 4). The resulting profile shows significantly larger values than the minimum burden diagram (Figure 5). Such difference if incorrectly taken into account might be responsible for improper hole loading and all related consequences therewith.

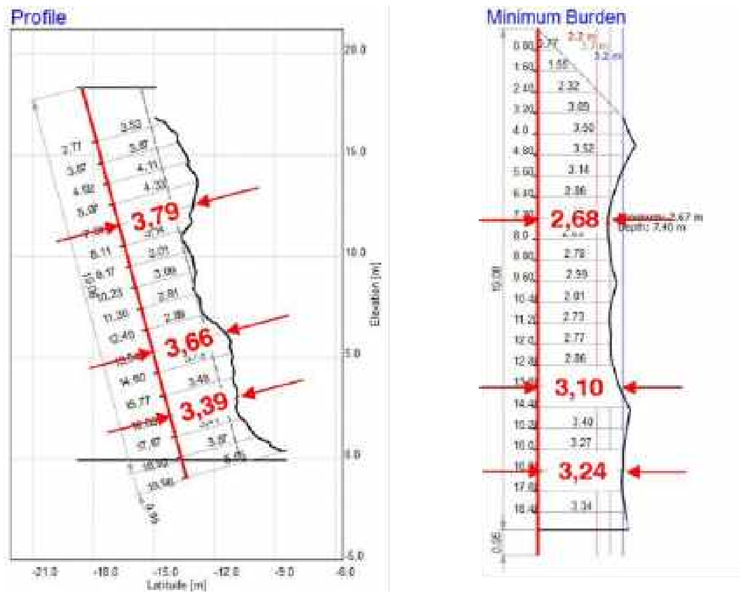

Figure 5. Profile and minimum burden diagram for the same borehole; note the significant differences at the indicated hole depths

Another characteristic is that a minimum burden search also works properly with deviated boreholes which, for example, have been surveyed by a down-the-hole-probe. Mathematically, a profile as a planar intersection is not even defined for a deviated borehole. In contrast, the minimum burden diagram computes the very same way as for straight boreholes.

Figure 4. 3D model with a single profile; circle marks an irregularity (remainder of a detached block)

3.2 Minimum burden charts

For the minimum burden diagram the shortest distance from a borehole to the free surface is looked for in a spherical search. A minimum burden chart results from searching in the opposite direction as with minimum burden diagrams, i.e. from the surface to the boreholes. Figure 6 depicts an example: for each surface location the distance to the nearest borehole is determined. Depending on the result the surface location is coloured. In this case green colour reflects design burden, red colour indicates light burden, and blue areas depict heavy burden situations. The coloured representation provides straightforward help in identifying problematic areas. The concept has been described by Gaich et al. (2009).

3.3Minimum burden surfaces

An extension of the minimum burden charts leads to the computation of minimum burden surfaces. The minimum burden surface is a geometric entity that consists of those locations where a borehole *should* be in order to fulfil the minimum burden criterion. So any borehole that is placed on the minimum burden surface therefore leads to a best possible minimum burden diagram.

The minimum burden surface is computed starting from the free face and identifying locations that are at design burden away from it. This is done for several sample point over the free face (see Figure 7). The sample points define the basis for the according minimum burden surface.

A minimum burden surface turns out to be a kind of smoothed copy of the free surface it belongs to. It is a general surface, i.e. it is not necessarily flat.

The whole process is applied repeatedly if several rows are sought. The minimum burden surface on the first row serves then as the free surface for the second row and so on.

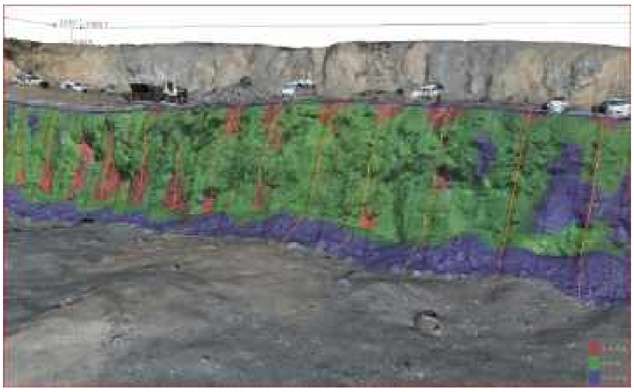

Figure 6: Minimum burden chart with indicated location of boreholes; green colour shows design burden, red: light burden, and blue: heavy burden

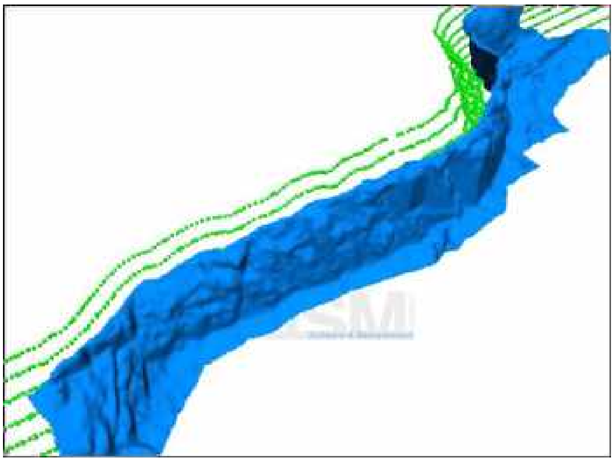

Figure 7. The computation of the minimum burden surface starts with the determination of according sample points (green)

4. AUTOMATIC BOREHOLE PLACEMENT

The components as described in the sections before, i.e. a comprehensive 3D model and minimum burden surfaces are the elements for the automatic borehole placement routine. Boreholes are arranged along the minimum burden surface for the first row. Several boundary conditions resp. degrees of freedom are possible during this process which influence the final output including:

- Inclination: fixed value or variable
- Azimuth: fixed value of variable
- Side spacing: constant or variable;
- Side spacing: fixed minimum inter-hole-distance e.g. at the bottom

The algorithm is able to follow any irregularly shaped crest and places the boreholes while simultaneously trying to keep the minimum burden constraint valid. The more reduced the degrees of freedom, the more the minimum burden constraint may be violated. Figure 8 shows a 3D model that includes a curved bench as well as the result of the algorithm.

The layout clearly follows the crest and in this case also inclination and azimuth were allowed to vary. The resulting minimum burden distribution is shown in Figure 9.

The application of the algorithm in a multi-row design is depicted in Figure 10.

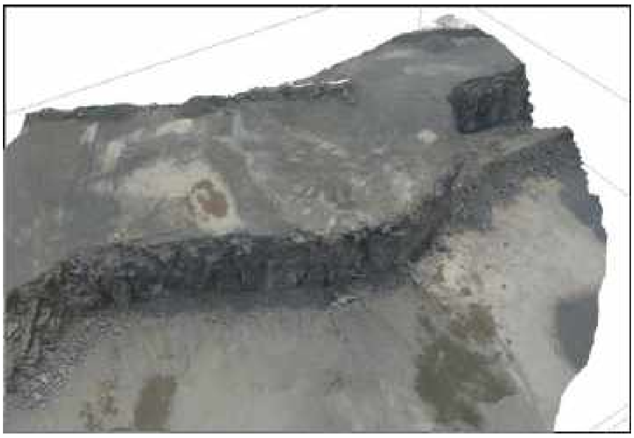

Figure 8. Left: 3D image of a curved blast site; right: plan view of automatically placed boreholes using minimum burden surfaces; the boreholes follow the crest

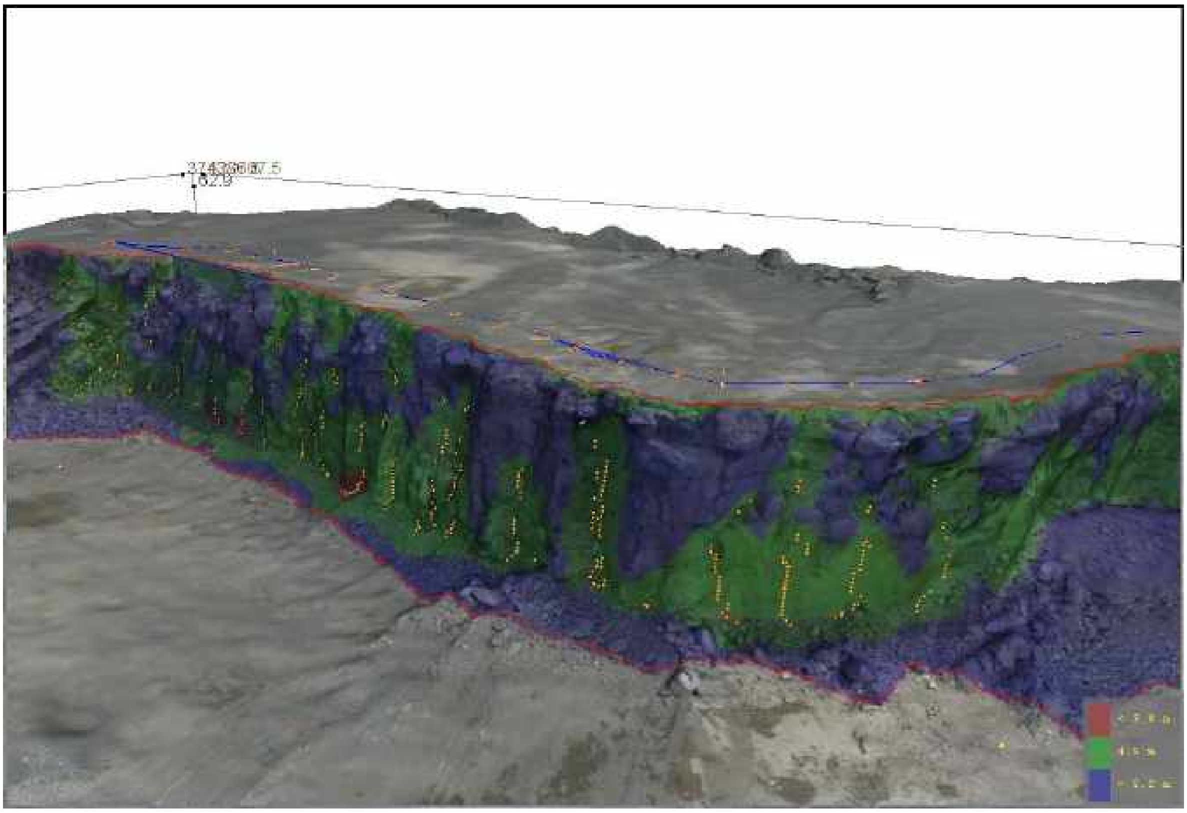

Figure 9. Minimum burden chart for automatically placed boreholes on a curved corner blast; bright dots indicate locations of minimal burden.

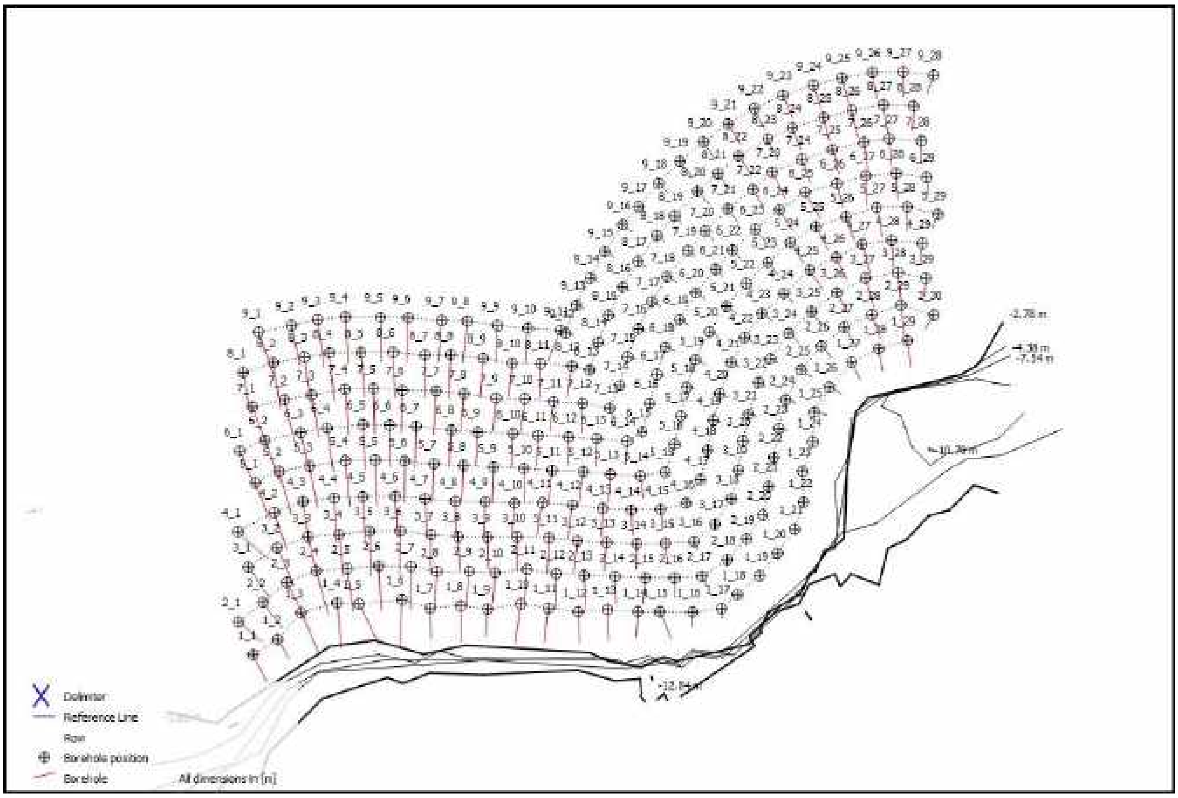

Figure 10. Automatically placed boreholes with loose constraints in azimuth and inclination

5. CONSEQUENCES AND CONCLUSIONS

3D models from photogrammetry acquire blast sites of surface blasts comprehensively and accurately (cm range). Together with the minimum burden concept real burden information instead of profiles gets associated to boreholes.

Minimum burden surfaces are an extension to existing minimum burden calculations. They reflect the sum of locations where design burden is met taking the entire blast site into account.

If boreholes are placed along minimum burden surfaces, they will follow the shape of the crest. The used algorithm is able to provide a blast pattern for highly irregular shaped blast sites.

The presented approach works purely geometric. Further work includes the automatic placement of boreholes according to associated volumes to be blasted.

ACKNOWLEDGEMENTS

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Who are the EFEE Members:

Forcit – almost 130 years on the leading edge of Nordic explosives industry

Forcit Group – explosives related expertise since 1893

FORCIT is a privately owned and independent player in explosives branch with a strong Nordic value base and presence. Reliability in all our undertakings, and enthusiasm to get results, combined with the knowledge of Nordic conditions, give us a solid base for succeeding together. Forcit was founded 1893 in Hanko, Finland, and has grown its expertise since. The origin of the company was manufacturing dynamite. Nowadays Forcit Group provides expertise for construction, excavation and blasting related operations, as well as for the defence industry. Around 450 Forcit professionals across the Nordics work every day to help and to serve.

Forcit dynamite production and headquarters has been in Hanko, Finland since 1893.

The Group consists of three business areas: Explosives, Consulting and Defence. Forcit Explosives is the leading partner for civil explosives and related services in Nordics and in selected projects worldwide. Forcit Consulting is the leading consulting services partner offering a wide range of expertise, services and training for construction and excavation and its operations are centralized in Northern Europe. Forcit Defence is a trusted partner for high class insensitive munitions-based defence systems for global markets. Forcit Explosives and Consulting co-operate closely with the mining industry and companies in the excavation and construction sectors. Forcit Group turnover is approximately 130 million euros. Explosives is the largest business area with sales around 100 million euros. Consulting and Defence sales are equal and growing steadily.

Forcit Explosives

Forcit Explosives provides comprehensive blasting services for mining and construction. Company's range of services consists of locally well-known products suited for Nordic conditions and users. The modern technology charging trucks together with recognized and high-quality products ensure that projects succeed with their objectives. Forcit's employees are distinguished experts on the Nordic market. Service network is widespread and growing. Flexible customer service enables us being close to customers wherever and whenever.

Forcit has been in close co-operation with O-pitblast to create the software for blasting operations. Our surface charging trucks interact seamlessly with the O-pitblast platform. Individual charging data can be viewed in 3D. Similar setup is under construction for underground operations and it will be launched soon. Other focus areas in addition to digitalization and big data are remote charging underground, minimizing nitrogen emissions of blasting operations and improving working conditions in underground mines through less and more friendly blasting fumes.

Forcit Consulting

Forcit Consulting has provided expert services like consulting, measurements and training for mining and construction industry for 50 years. There are currently 20 office locations and over 120 experienced professionals. Our fleet of monitors consists of over 2500 remote controlled measuring units for monitoring all environmental effects in a top-of-the-art on-line measurement system, which enables thorough analysis and reporting of results.

Forcit Consulting has full selection of necessary services for works like blasting, demolition, ground excavation and piling, which often include some structural risks and unwanted environmental effects like vibration, air-pressure, noise and dust.

Consulting is people business and majority of employees are engineers and professionals in construction, mining and blasting work.

In order to enable the best possible customer experience and growth strategy for the coming decades, the names of all our three national companies have been changed in September - Finnrock (FI), Bergsäker (SE) and Bergcon (NO) have been renamed under one leading common brand, Forcit Consulting. This has provided us with a new common platform for future business development. Main positive effect from this will be a wider service offering and area by placing all our special international expertise and resources more easily available throughout our operating area.

Forcit provides also consulting, training and expertise for safe and environmentally friendly use of explosives for all purposes

Forcit Defence

Forcit Defence is one of the leading manufacturers of Insensitive Munition Defence Systems. Forcit Defence has been developing and manufacturing innovative Defence products since 1920's and today is a global supplier that operates as a prime contractor for our own systems and as a partner for other international system providers in the Defence business.

We provide our customers with special services like product design, explosives, loading, assembly and system integration on land, air and naval domains. Our product range includes Anti-Access/ Area Denial and Counter mobility systems, AT-munition, precision fragmentation charges and next generation sea mines for shallow waters.

Company cooperates in development and manufacturing of warheads for all types of payload delivery vehicles and serves as a strategic manufacturing partner.

Forcit has the second largest Cast Cured Plastic Bonded Explosives manufacturing capability in Europe and we can Load-Assemble-Pack warheads, from the smallest charges up to large warheads/bombs.

Strongly sustainable

Group aims to achieve the position of industry leader in sustainability. Business is based on a responsibility with high ethical standards, strong financial performance and top priority on health and safety. Company strives to minimize the environmental impact. Focus areas are increasing safety, and reducing of emissions, waste and energy usage.

Forcit Group consists of three business units: Explosives, Consulting and Defence

Being responsible actor gives company social license to operate. Occupational safety is improved by continuous information gathering, development and monitoring. Increasing security of our warehouses and the logistics is also part of Groups continuous safety work and risk management.

Group increases emphasis on optimizing the material flow and having sustainable raw material sourcing. Finding innovative waste handling methods by exploring different ways of reusing the waste produced from raw materials and production also reduce emissions originating from waste handling. The share of renewable energy has significantly increased due the active work on sustainability resulting in considerable decrease on CO_2 emissions. Forcit has applications that help customers to optimize the amount and the charging of explosives, which results minimizing the nitrogen load to the environment. R&D department is investing developing sustainable products.

Life Cycle Analysis and Environmental Product Declarations

A Life Cycle Assessment (LCA) study was performed during 2019-2020 for several Forcit products to provide information for Environmental Product Declarations (EPDs). Altogether eleven EPDs were created in the first phase.

An LCA study means evaluating the environmental impacts of a product (or service) from cradle to grave. The study was performed following the requirements of International LCA standards (ISO 14040 and 14044), Product Category Rules (PCRs) for Explosives and Initiation systems (NPCR 024:2016 version 1.0), and EN 15804:2012. The LCA and the EPDs have been verified by a third party.

This comprehensive study is a good way of gathering information for ourselves on life-cycle accountability. It is a tool for process improvement, product design, strategic planning and procurement of raw materials. It also gives information to our customers while increasing transparency and credibility.

The EPD's can be found on the Norwegian EPD Foundation's site under EPDs. Direct link is here .

The life cycle stages (modules) included in the study are:

A1	Extraction and processing of raw materials. Production of electricity and heat, water flows.
A2	Transportation of raw materials and packages to Forcit, internal transportation of products and semi-finished components. The emissions occurred in the combustion process (engines) and during the production of fuels used in this transportation stage.
A3	Manufacturing of products at Forcit. Manufacturing of packaging.
A1-3	Treatment of final residues and waste streams onsite.
A4	Transportation of products and semi-finished components to use site.
A5-1	Installation stage of explosives at use site. Transportation and treatment of packaging waste.
A5-2	Use stage of the explosives; detonation emissions.

Presented together in EPD document as A1-3.

BAF – The Baltic Aggregate Forum Photoreportage

Teele Tuuna
Gaia Grossfeldt

"Third time is a charm", even in 2020. Against all odds, the Baltic Aggregate Forum - BAF took place on 27-28th of August, 2020, after being delayed from May 2020, and in the end it was really a success. BAF is an event created for aggregates associated businesses, organizations and individuals from the Baltic States - Lithuania, Latvia and Estonia. It has been organized two times before, with a 3 and 5 year cap, in Estonia. The event consists of a demo area, trade fair of mining and roadworks machinery and a conference – all in one place and this year as an open air event suitably in a bottom of an active quarry, the Paekivitoodete tehase OÜ Väo quarry. Countries represented in BAF 2020 were Latvia, Lithuania, Austria, Belgium, Germany, Finland and Estonia.

Of course, organizing such an event during the pandemic is a real challenge. Since the beginning of summer 2020, Estonian government prohibited events with over 1000 participants indoors due to coronavirus threat. BAF, on the other hand, was held in a quarry on the edge of Tallinn. All together there was 441 registered participants, but many of them could not come eventually, due to restrictions from their home countries or within their organisations. But problems are to be tackled, and all the scheduled presentations took place, even, if the presenter could not be in Estonia, so in the end there was 4 live video bridges, coming to the audience through smooth and well set systems with no hiccups via wi-fi. Apparently a new normal.

Having such an event in a quarry may sound a bit robust but the organisers seemed to have been thinking of every detail. Shuttle buses took quests from their hotels and back all day and conference presentations were held inside a great big tent, with multiple screens set around the area and speakers outside of the tent – so even the exhibitioners could listen to the presentations. The weather cooperated beautifully and good feedback was sent about the demo, exhibition area and conference for being in one place. The quests new ahead to wear suitable footwear, freshly grilled food was served on site and the open space of a quarry actually gave a really good vibe to the whole event. like the aggregates people felt very comfortable in a quarry.

The three small Baltic states have been eager to cooperate in many ways starting with being independent democratic countries and ending with shared tourism, so it is understandable, that these countries should have a united way of transportation to the heart of Europe. It is only logical that the most heated and interesting subject in BAF also was the building of Rail Baltica. The hardest question seems to be where to get enough material to build it and the best way to find answers is to get together, present ideas and case studies and share solutions for architectural problems. In the end all heat will be solved in a glass of wine while cabaret dancers bring sparkle in the Gala dinner evening.

Life needs to go on, projects need to be kept going and positive thinking is a major role player during these uncertain times. And we have to say a big thank you to those, who are not afraid to move forward, like the organisers of BAF - the Estonian Society of Mining.

More information www.baf.ee


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Upcoming International Events

15TH INTERNATIONAL CONFERENCE ON
DRILLING AND BLASTING TECHNOLOGY–2020
Cancelled and moved to spring 2021
Velence, Hungary
http://www.mare.info.hu/en

MINExpo INTERNATIONAL 2020
Postponed Until Sept. 2021
Las Vegas, Nevada, USA
https://www.minexpo.com/

ISEE 47th Annual Conference on Explosives and Blasting Technique
Cancelled and moved to 2022
Orlando Florida, USA
https://www.isee.org/conferences/2021-conference

SME Annual Conference
1-5 March 3, 2021,
In virtual format
www.smeannualconference.com

SAFEX International Congress
New date 5-10 September, 2021
Salzburg, Austria
https://www.safex-international.org/safex/news-safex-congress-xx-in-salzburg.html?sid=1580472102

WORLD TUNNEL CONGRESS 2021
UNDERGROUND SOLUTIONS FOR A WORLD IN CHANGE
Postponed to 2022
Bella Center Copenhagen, Denmark
https://www.wtc2021.dk/

HILLHEAD 2021
June, 22-24, 2021
Hillhead Quarry
Buxton. UK
https://www.hillhead.com

EFEE 11th World Conference on Explosives and Blasting
September 12-14, 2021
Bucharest, Romania
www.efee2021.com

FRAGBLAST 13
October 17-22, 2021
Hangzou, China
www.fragblast13.org.cn

World Mining Congress
June 27-30, 2022
Brisbane, Australia
https://wmc2022.org/