EFEE

NEWSLETTER

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May 2020

We in EFEE hope you will enjoy the present EFEE-Newsletter. The next edition will be published in August 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

It is time for the next issue of EFEE Newsletter again! As always, we have several interesting technical articles for you to read. Understandably, the list of upcoming events is unfortunately shorter than normally.

I could hardly imagine what the next couple of months would bring when I last wrote the foreword to the previous EFEE newsletter. The quick and overwhelming COVID-19 development, dramatic health consequences and strict national and global restrictions have left an unforgettable memory of this spring for everyone. I truly hope that all of you EFEE members have remained healthy or gone through a mild version of the virus at most. Other options have not been pleasant as we now know.

Safety has always been first in the blasting industry. Perhaps this mindset has also helped us through these dangerous times. As far as I have heard, construction and mining are among those businesses which have suffered least of COVID problems and restrictions so far. Most organisations have been able to keep their personnel safe and healthy and operations running. All international operators have of course had challenges due to travelling restrictions and quarantine periods.

Two months of social distancing has been an ordeal but brought also some positive issues. I am sure that many of us have had a possibility to spend more time with their families. Many people have worked remotely from the safety of their homes. I believe this has brought some new balance and priorities in life for many people, like myself. In stead of flying off every week to meet with clients and colleagues abroad, my meetings have been handled mostly over internet from home. A lot of saved travelling time and carbon footprint. The air is cleaner than in decades. At the same time, we have had to learn to master remote meeting tools and adapt these techniques quickly. Some of these new habits will probably stay in our ways even after the virus is gone.

EFEE has also had to postpone its normal April annual general meeting at least until October, probably even further or hold it over internet instead. This foreword would have normally been the last I wrote as the President of EFEE but now there will be at least one more until the new board and president will be elected. The whole board is committed to continue until the election can be arranged and thus EFEE is managed normally. Only committee work has been affected by these restrictions but even that is now planned to be restarted by using remote meeting tools. Luckily EFEE did not have a conference booked for next fall and we are hoping to be able to arrange the next conference as planned 13-15 September 2021 in Bucharest.

The aftermath of COVID remains to be seen. Nobody knows if it will blow over during the summer or will there be a second wave in the fall and when will the vaccine be available – or will there be a vaccine. Hopefully this is not the beginning of the new normal at least, as some predict. Economical consequences remain also still to be seen. Despite uncertainty we can all rest assured that sooner or later the virus will be conquered, and life will find its way again. Our job is to stay safe and to keep our families safe until then.

I wish all of us a good and safe summer – let´s have a blast and stay healthy!

Jari Honkanen, President of EFEE

Vibration monitoring standards connected to the use of explosives in different countries

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Abstract

The paper is part of the ongoing work of the Environmental committee of EFEE. To assist the European experts working with explosives one of the aims is to improve the common knowledge of similarities and differences between national legislation, standards or guidelines on vibration monitoring and other environmental monitoring during blasting in Europe and abroad.

This has been done by use of an online survey through the most of 2018. Questions have been asked on issues regarding vibration monitoring during blasting. The existence of norms, guidelines or standards and how they are used. Even though the questions were kept at a simple level they were formed to try to map the different national standards use of such things as frequency, guidance on monitoring position, distinction between different types of structures, requirement to the equipment and more. Furthermore a few initial questions were asked on other types of environmental monitoring relevant for blasting.

The respondents are national, cooperate or individual members of EFEE. The respondents are experts in the use of explosives and vibration-monitoring in their respective countries. More than 60 persons have answered the questionnaire from 29 different countries. Mainly European but also other nations including India, Israel, Nigeria, Saudi Arabia, UAE, USA, Greenland and Hong Kong.

By analysing the incoming answers, the differences and similarities between different countrieshas been clarified and mapped. Where needed the different guidelines, standards and regulations have been visited to verify the answers and further elaborate on the comparison.

Introduction

The survey on vibration monitoring standards connected the use of explosives has received answers from most of the national associations of EFEE and other EFEE members which have enrolled national experts to answer the survey.

The answers have led to an insight in some relevant differences and similarities of the use of standards for vibration monitoring connected to the use of explosives mainly in European but also other national standards has been included. The gained insight in the standards has not the least given the EFEE environmental committee a great setoff for conducting further work that will perform a more detailed examination of the use of standards in the EFEE member nations. EFEE is centred around Europe but also include members from around the world. This of course combined with EFEEs long cooperation with ISEE.

The questionnaire

Through most of 2018 the members of EFEE, or experts enrolled by the respective national member of EFEE, was given the chance to answer a questionnaire on environmental monitoring during blasting. The questions focused on vibration monitoring during blasting. The existence of norms, guidelines or standards and how they are used. In the following the questions are described.

Is there a standard?

Initially the respondents were asked if their country makes use of a standard for blast vibration. Based on the answer the respondents were further asked to list the standard(s). If the answer is that there is no standard, they were asked to elaborate on how the issue is then solved. The respondent was also asked to upload further information regarding the standard used in their country, if possible. If the respondent states that there is a standard, "yes", they are asked additional questions on the use of the standard, as listed below. If the answer was "no" they were asked how they then solve the issue and not asked any further on details of a standard but rather led to the questions on whether "monitoring is mandatory" and if they have any "additional comments". These two questions are elaborated further down.

What about frequency?

If the respondents have confirmed the existence of a standard in their country, they were asked on how frequency is taken in to account e.g. higher Hz = higher ppv. If the answer was "no" they were asked to elaborate on how they then deal with frequency. If they answer was "yes" the respondent was asked if the standard allows higher limits on higher frequencies. As the last question on frequency the respondent was asked on the use of filtering on the signal due to frequency. If the answer here were "yes" the respondent was asked to elaborate on the range of this filtering.

Components for consideration thresholds?

Different standards use different ways to evaluate the ppv monitored during a blast. Therefore, the respondent were asked which components are considered in the used standard. Namely; vertical, transversal, longitudinal (radial), resultant or the largest component. After the respondent have been elaborating on the components which are considered, the respondents were asked about thresholds. Specifically, if the thresholds are dependent on the structures which are being monitored on. If the respondent answers "yes" they were asked to elaborate.

Practical requirements to the monitoring

The question is asked if the used standard sets requirement to the monitoring equipment used for monitoring during blasting. If the answer were "yes" they were asked to elaborate and given the chance to upload relevant documentation. Equally the respondents were asked if the used standard has requirements to the way (procedure) the monitoring must be carried out during blasting? e.g. position and orientation of the sensor or pre-monitoring of background level. If "yes" the respondent was given the chance to elaborate.

Is monitoring mandatory blasting?

The respondent were asked if monitoring is mandatory during blasting work. This with variations from a clear "yes" to "no" or other. This question were raised independent of the respondent's initial answer on; whether there is a standard used for blasting in the respective countries.

Additional questions on environmental monitoring

When the questions on vibration during blasting were answered the respondent were given the chance to answer additional questions on environmental monitoring during blasting. The subject were only touched very briefly; as the respondent were asked to confirm if there exist standards on the different subjects followed by some follow-up questions. The additional questions are described in the following.

Human exposure to blast

The respondent were asked if the country has a standard for human exposure to blast induced vibrations. If the answer was 'yes' they were given the chance to elaborate.

Air-blast

Does there exist a standard on air-blast (air-over-pressure) control and limitation during blasting works in the respective countries. Again, the respondent were given the chance to elaborate if the answer was 'yes'. If the respondent answers 'no' they were equally asked to elaborate by answering the question, how do you then control air-blast effects?

Noise control

The respondent were asked on the existence of a standard for noise control during blasting. If the respondent answered 'yes' they were asked to further describe these requirements and limit values for noise control.

Dust control

Control and limitation of dust during blasting through a standard, was also included in the questionnaire. If the respondent confirmed the existence of a standard they were asked to elaborate on requirements and limit values for dust control.

The answers

The text below is an attempt to discuss the answers from the questionnaire. Each question is quoted, discussed and commentated. It should be noted that the amount of information from the different respondents varied a lot and it has not been possible to draw conclusions for all individual questions. The answers are however enough to identify some general differences and trends in how these issues are treated in different countries. Equally the survey has given an insight in the respondents' knowledge, use and experience with their respective standards.

Do you use one or more standards/guidelines for blast vibration control and limitation in your country?

All respondents answered 'yes' on this question, however the way it works differs from country to country. Most commonly the country have a national standard (41%), in some countries its regulations are from authorities (21%) and in some countries the praxis is to use standards from other countries (38%), se table 1.

Table 1 Standards and regulations used in different countries.

Country	National standard	National regulations	Other countries standard
Austria	Austrian Standard S 9020 - 2015		
Belgium			DIN4150
Bulgaria			DIN 4150
Czech Republic	ČSN 730040		
Denmark			DIN 4150 for hard rock, SS 460 4866 is used
Estonia		National regulation	
Finland		Tärinänormit/ Finnish Vibration normes	
France		Decree of 22 September 1994 Circulaire du 23/07/86	
Germany	DIN 4150		
Greece		Greek Mining Regulation	
Hungary			DIN and some inner std. (ex. customer, authority)
Hong Kong		Limits by Authorities	
India			Australian standards
Ireland			British Standards
Italy	UNI 9916		(UNI 9916 refers to both DIN 4150 and BS 7385)
Israel			DIN 4150
Netherlands			DIN 4150
Nigeria			Use of consultants
Norway	NS8141, 2. Ed., 2001, NS8141-3, 2014		
Poland	PN-B-02170:2016		
Portugal	NP 2074:2015		
Saudi Arabia			BS7385:2, USBM RI8507
Slovakia	STN EN 1998-1/NA/Z1 STN ISO 4866+Amd 1+Amd		
Spain	UNE 22-381-93		
Sweden	SS 4604866:2011		
UAE		Ministerial Dec. 567: 2014	
United Kingdom	BS 5228; BS 6472; BS 7385		
USA	USBM RI 8507		

Does your vibration standard take frequencies into account (e.g. higher Hz = higher PPV)?

In principle, there are 3 types of standards named A, B and C below:

Type A: These standards are based on frequency where the shape of the curve is step-shaped in order to allow different vibration levels in different frequency ranges. These frequency ranges are connected either via "vertical steps" (France, Switzerland, Portugal), by diagonal lines through a displacement condition between different ranges (USBM, UK, Spain) or via "other" diagonal lines (Germany). This is done because there is a risk of amplification/ resonance at low frequencies which is not present for high frequencies. This type of standard is the most common type (see figure 1).

Type B: Theses standards relates the allowed value based on the distance and/or type of ground under the building. OSM(USA) uses a distance dependent value as an alternative to the frequency based USBM. Sweden, Finland, Norway and Estonia include both distance and the type of underground. In principle lower levels of vibration are allowed at longer distances and/or softer ground (see figure 2).

Type C: Standards that uses specific vibration values independent of frequency, distance and/or ground material, example Austria: 1,24 in/s (31,5 mm/s), if the duration of the vibration is less than 2 seconds.

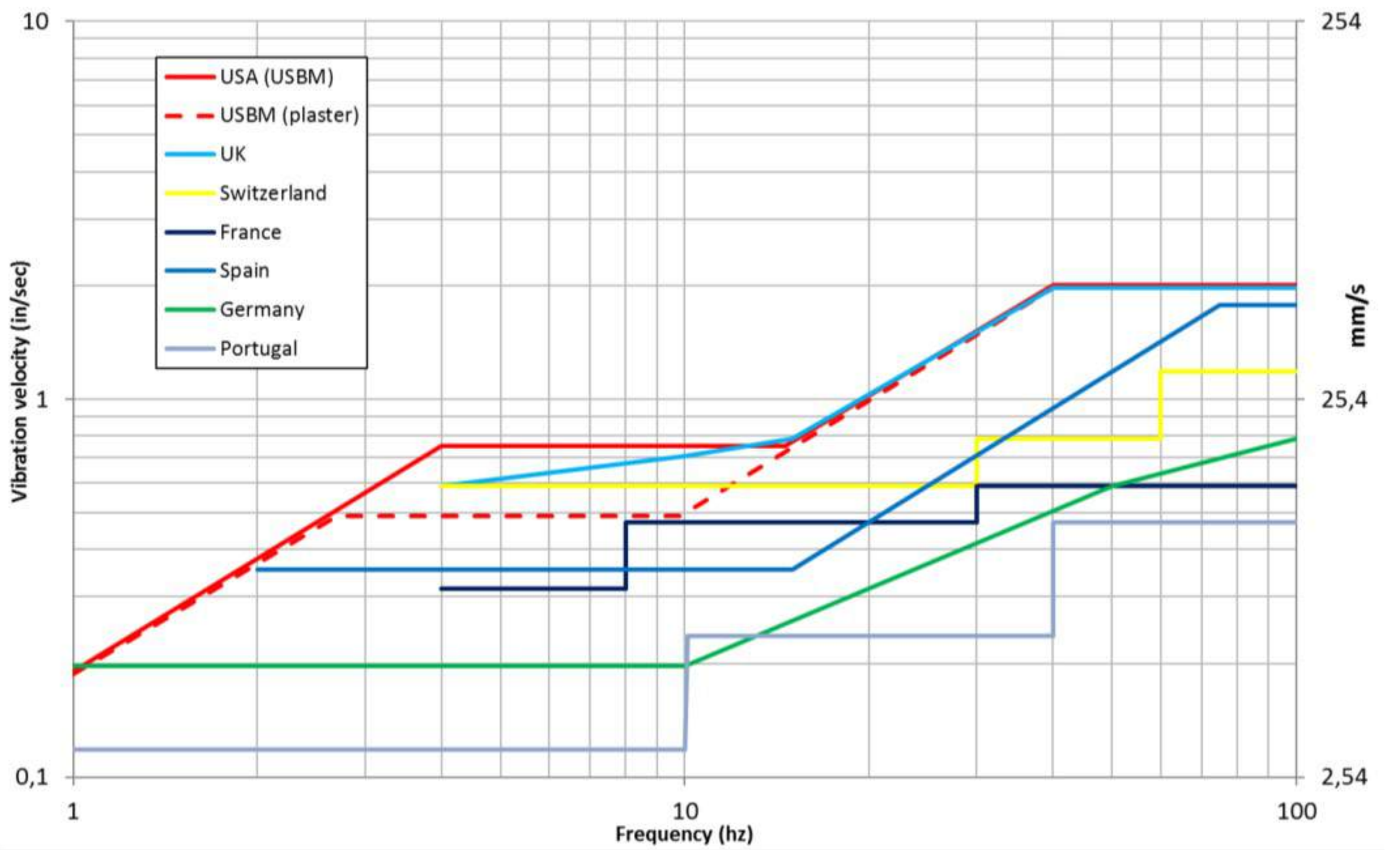

Figure 1. Vibration limits for residential houses. The different standards that are based on frequency included in the survey (Type A).

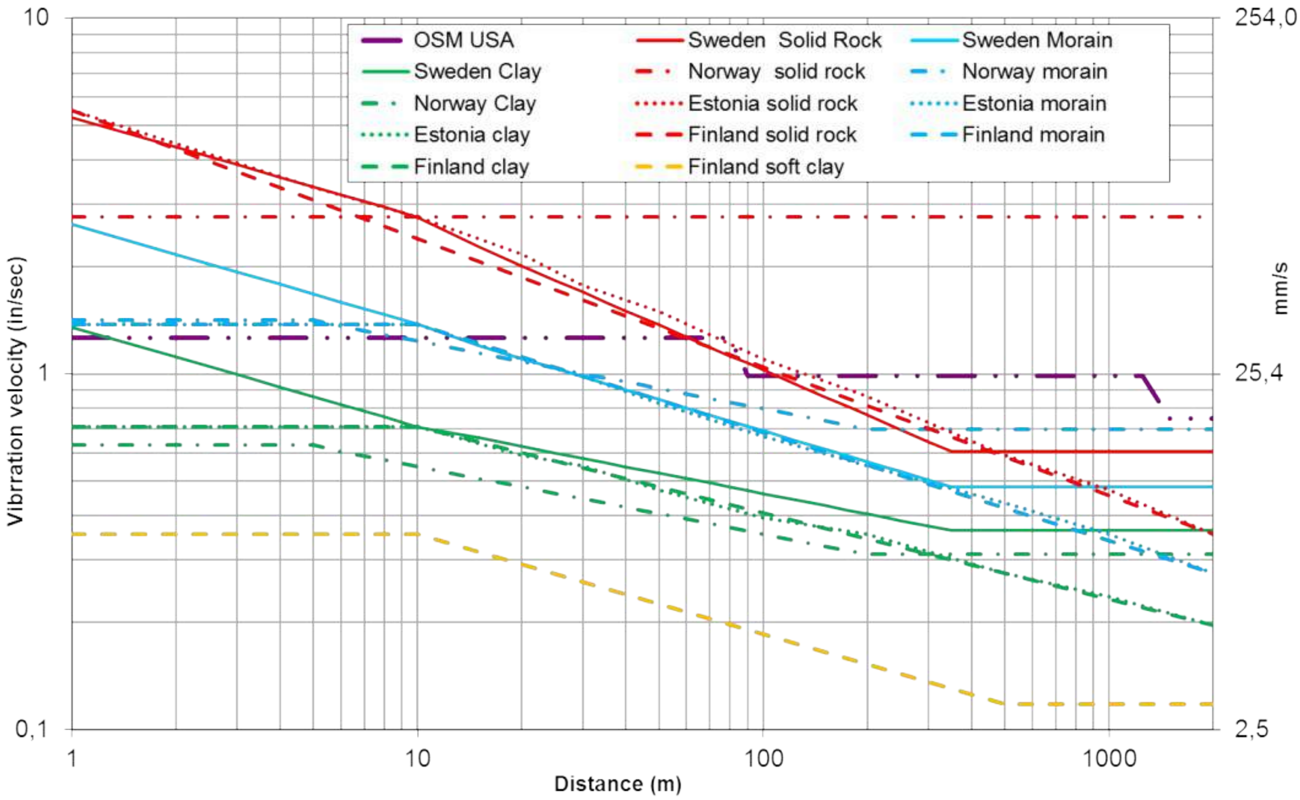

Figure 2 Vibration limits for residential houses. The different standards that are based on distance and underground included in the survey (Type B).

Does your standard require filtering of the signal due to frequency?

This was a difficult question, mainly since it mixes two different issues where the first part is the bandwidth that you must measure over and the second is if the sensitivity is different at different frequencies. For bandwidth; it differs significantly between different standards, see table 2. For sensitivity; no standard seems to have such filtering, even if the German DIN 4150-3 in its latest version offers such an option.

Which components are considered in the used standard?

According to the survey PCPV (Peak Component Particle Velocity) is the most common parameter to monitor, PCPV is defined as the maximum value of any of the 3 monitored directions. Portugal and Estonia use the VPPV (vector sum, Vector Peak Particle Velocity). In Sweden and Norway, only the vertical direction is monitored. Poland focuses mainly on the horizontal directions.

Table 2. Frequency ranges according to different standards

Country	Standard	Frequency range
Austria	ÖNORM S 9020	2-250 Hz
France	Circulaire du 23/07/86	4-150 Hz
Germany	DIN 4150-3	1-315 Hz
Italy	UNI 9916-2004	1-300 Hz
Norway	NS 8141-1:2012	3-400 Hz
Poland	PN-B-02170:2016	1-100 Hz
Portugal	NP-2074	3-80 Hz
Schweiz	SN 640 312a	5-150 Hz
Spain	UNE 22381:1993	2-200 Hz
Sweden	SS 460 48 66	5-300 Hz
UK	BS 7385-1:1990	1-300 Hz
USA	ISEE	2-250 Hz

Are there different threshold values depending on the type of structure to be protected?

All Countries besides France answers 'yes' to this question, the way the threshold value is determined varies a bit though. In principle Austrian, Estonian and Nordic standards decide threshold value from an equation where building type, building material etc. are included, while the standards that uses frequency as a parameter divides buildings info different classes, typically: sensitive buildings, "normal" residential buildings and industry buildings. This combined with a defined curve for each category in a vibration velocity-frequency diagram.

Does/do your standard set requirements to the monitoring equipment, for monitoring during blasting?

The answer 'yes' coincides to a large extent with countries that have their own national standard, countries without a national standard have normally not defined this.

Does your standard have requirements regarding the way (procedure) the monitoring must be carried out during blasting?

Most countries have a requirement regarding where to monitor and most commonly the requirement is that the sensor should be placed 'on' or 'in' the building. In Hungary, Spain and USA measurements should be done in the ground in the direction of the blast. Respondents from Belgium, Denmark, Estonia, Hong Kong, Netherlands, Saudi Arabia reply that there are no requirements. Some examples can be seen in table 3:

Table 3. requirements regarding where monitoring should be made

Country	Position of Monitor
Austria	Basement
France	Basement, parallel to the wall
Hungary	Define direction at front of the building
Ireland	Placed at base of building facing the source of vibration. Refer to BS 7385-2:1993
Norway	Sensor on the foundation or near the foundation, where vibrations enter into the structure
Poland	Using the SWD scale, one should use vibrations of horizontal vibrations, i.e. in x and y directions recorded at the source point of vibrations, in a rigid structural node -- at the intersection of load-bearing walls in two directions --located on the foundation of the building or in a rigid node on the wall underground level in the ground level.
Portugal	Transducer must be fixed to the base of structure or foundation according ISO 5348, max up to 0.5 m from the level of the ground
Slovakia	The sensors must be stored at the reference point on the foundations of the building.
Spain	On the ground, near to the structures
Sweden	Vibrations should be measured at a point where they enter a building or structure. The sensor should be attached to the load bearing part of the foundation.
USA	Monitors should be buried in undisturbed soil or bolted to rock

Is monitoring mandatory for any blasting work in your country?

More than half of the respondents answered 'Yes; depending on the situation.' or 'Yes, always' to this question. Namely respondents from UAE, Hong Kong, Portugal, Sweden, Belgium, Ireland, France, Hungary, USA, Czech Republic, Austria and Israel. When elaborating on the 'situation' the requirement for monitoring is explained for blasting close to buildings/structures, for quarries, if the national or local authorities finds it suitable and finally if insurance or public complaint requires it. Some of the respondents explain how the experienced and responsible engineer decides if monitoring is needed and some companies always monitor to be sure to have the data if needed later. The rest of the respondents answered 'No; but monitoring is normally performed anyway.', 'No; monitoring is seldom performed. 'and 'Other'. Namely respondents from; Italy, Norway, Estonia, Germany, Slovakia, Netherlands, Denmark, Poland, Saudi Arabia and Spain. However, when this group of respondents elaborates on the answers there is still several situations where monitoring is required by authorities, insurance or dwellers. This group of answers still requires monitoring though with less strictness than for the 'Yes' category. In a single case the standard instructs when it is required. The summary for this question is that there are very few countries where monitoring is always required. Monitoring is required in several countries for special situations or if the authorities, dwellers or insurance requires it. Blasting close to structures almost always requires monitoring.

Do you have a standard for human exposure to blast induced vibrations in your country?

Seven counties answered 'yes' to this question: Bulgaria, Germany, Greece, Hong Kong, Italy, Slovakia, and UK.

Does your country have a standard for air- blast (air-over-pressure) control and limitation during blasting works in your country?

Seven countries answered 'yes' to this question: Czech Republic, Estonia, Hong Kong, Hungary Slovakia, Sweden and USA.

Do you have a standard for noise control and limitation during blasting in your country?

Almost half of the respondents answered 'yes' to this question, there is however a problem interpreting this question. It could be referred to include monitoring during the actual blast, or it could also include the surrounding activities. Its consequently difficult to draw any conclusions from this question.

Do you have a standard for dust control and limitation during blasting in your country?

Bulgaria, Estonia France, Hong Kong and USA and answered 'yes' to this question

Comparison of Type A and B vibration standards

To further describe the difference between frequency-based standards and distance/underground based ones, data from a Swedish comparison (Jern et al., 2018) has been included. However, the Swedish standard only monitor the vertical direction why the value from the British and German standards might be a bit underestimated.

The test was made by choosing events were the values was close to the allowed vibration level according to the Swedish standard (50-150%), then the data from the vibration curve was re-filtered according to British and German standards and the values was compared to the allowed level of the two standards respectively, then the data has been normalized to the British standard, i.e. in the graphs all events are plotted to be 100% of the allowed value according to British standard, this is then compared to the Swedish and German standards. The graphs show (in %) how the results differ, if the value is less than 100% the vibration level is within limits according to the standard and vice versa.

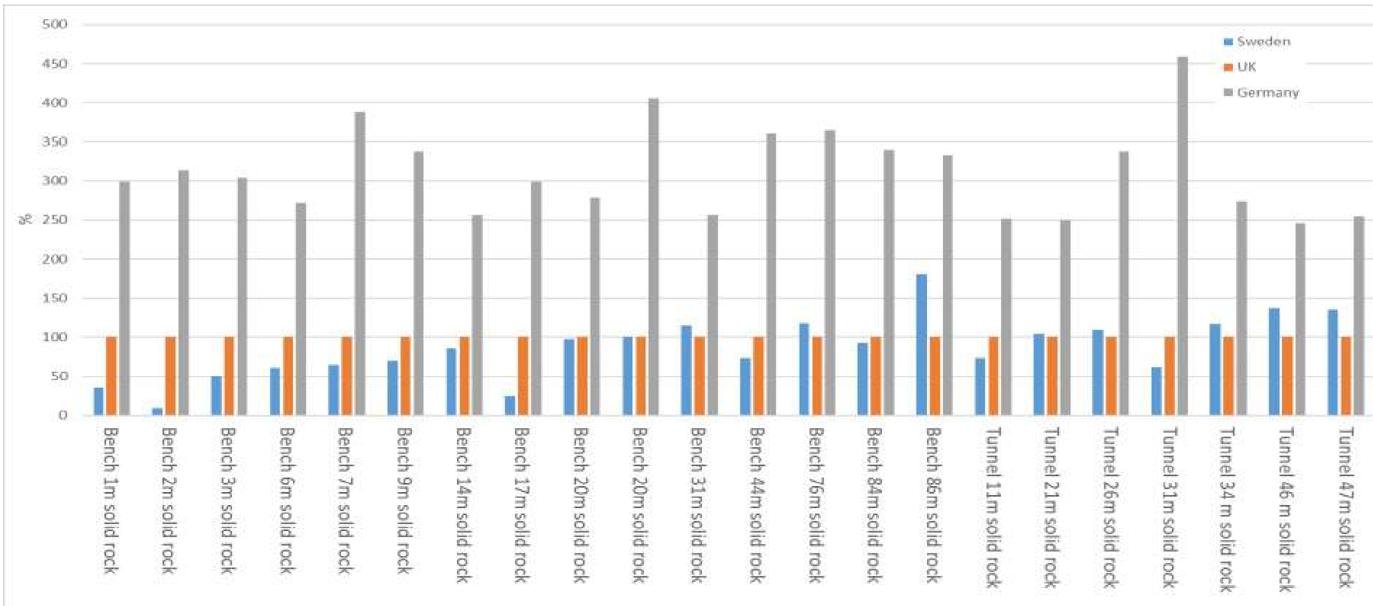

Figure 3. Comparison of the British, German and Swedish standard, examples from buildings constructed on solid rock.

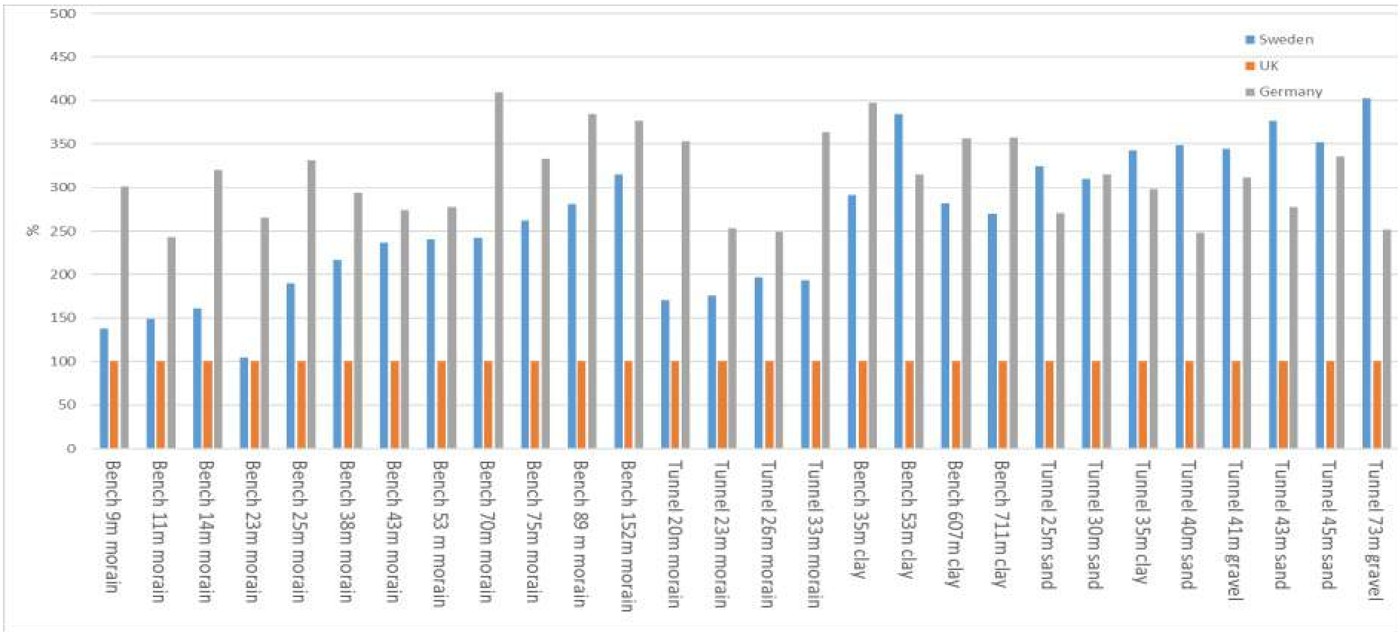

Figure 4. Comparison of the British, German and Swedish standards, examples from buildings constructed on soil.

Noted is that the Swedish standard allows the highest levels (the lowest staples in the diagram) when blasting above ground and when the building is placed on solid rock and the distance is short. In most other cases the British standard allows higher values. In soft soils (clay, sand, gravel) and especially in tunnel blasting. German standard equally allows higher values than the Swedish standard. The reason why tunnel blasting is important is that underground blasting in general gives higher frequency's due to the lack of a well-developed Raleigh-wave.

No comparison with the USBM (USA) standard was made because the positioning of monitors is different i.e. in USA monitors are placed in soil while other standards position monitors on buildings. However; the British and the USBM standards are very similar and a simple comparison can be done by comparing with British standard.

It should be noted that different standards vary very much between different countries. It's obvious that the reason for this is not that the risk of damaging a building varies that much. The reasons for the big variation are probably more due to practical reasons than anything else. In some countries the standards are more likely to take human comfort rather than the risk of damage into account, especially when standards are used mainly for blasting in mines and quarries the levels can be kept low even if it's obvious that the risk of damage is extremely low. However, in countries with hard rock where a lot of blasting must be done close to nearby buildings, levels must be higher in order to allow construction projects in the urban environment.

The only standard that seems to be based on real data is the USBM standard (Siskind et al. 1980) but the study mainly investigated the frequencies between 4-12 Hz. Even if the standards that includes distance and underground lacks a solid theoretical base it's clear that they gives the opportunity to allow higher values when blasting at short distances it's also proven by many years of experience that damage is extremely rare even at levels above 4 in/s (100 mm/s) at a few meters distance. Frequency based standards have difficulties handling blasting at short distances.

Conclusion and Discussion

According to the respondents, all the countries that we received answers from, either have a national standard, regulations from authorities or make use of standards from other countries. Monitoring during blasting is only mandatory in one of the responding countries. However, several others preform monitoring even if it is not mandatory and a big group do vibration monitoring depending on the specific case. A few respondents answer that monitoring in their country is seldomly preformed, and some countries have just not bothered to answer the question which could be a sign that vibration monitoring is not really in focus in these countries.

Most of the standards include frequency in the standard, where a higher frequency gives a higher allowed vibration level. The exceptions are the Nordic countries and Estonia were distance and underground are used to decide the allowed vibration level and Austria where the allowed vibration level is independent of other parameters.

Regarding vibration velocity, most of the answering countries replies that the maximum value of the three monitored directions are considered, two countries (Portugal, Estonia) uses the vector sum and further two countries looks only on the vertical direction (Sweden, Norway) and a single country (Poland) only looks at the horizontal direction. All the countries responding, besides France, have answered that they have different values depending of the type of structure, which is being monitored on. In some of these countries they include frequency and allow higher vibration velocity depending on the frequency. It is noted that countries that have a standard also seems to be the once that has a requirement to the monitoring equipment. Seven countries reply that they have no requirement to the position of the monitoring equipment. The rest of the responding countries either place the equipment on the building or on the ground in the direction of the building.

On the question of other environmental standards during blasting seven countries informed that they have a standard for human exposure. Six answered yes to having a standard on air-blast. Half answered that there is a standard for noise control. Only few answered that they have a standard for dust control.

Something that should be noted is the large difference in standards especially when it comes to vibration level. The accepted vibration level varies vastly between different countries. Furthermore, the way monitoring is performed also varies (frequency content, monitored direction, position of monitor etc) which makes comparisons difficult.

Future work

Both the conducted survey and the papers presented in EFEE and ISEE is part of the ongoing work of the Environmental committee of EFEE. This to assist the European and international experts working with explosives. One of the aims is to improve the common knowledge of similarities and differences between national legislation, standards or guidelines on vibration monitoring and other environmental monitoring during blasting in Europe.

The mentioned conclusions above are the direct conclusions based on the answers of the survey. However, there is other conclusions that cannot be answered fully with the present data but requires an additional interview of the respondents. The further work should also try to ensure that the once that are users of the standard in a higher degree have the possibility to answer the survey questions.

The future study will also include calculations of a few defined cases combined with a test setup. The calculations and test will be done with the different standards, to see how the results differ and if there is a difference in the conclusions from the different standards. The future work will try to include working groups from outside Europe for instance ISEE and SAFEX.

Acknowledgments

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3D characterisation of ammonium nitrate powders by X-ray computed tomography

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Abstract

The mixture of ammonium nitrate (AN) prills and fuel oil (FO), usually called ANFO, is extensively used in the mining industry as a bulk industrial explosive. One of the major performance predictors of ANFO mixtures is the fuel oil retention, which is itself governed by the porosity of the AN prills. Standardised tests routinely used to assess oil retention face several important limitations; the first being the difficulty to cover the wide range of porosity contents and morphologies from different types of ammonium nitrate prills; the second being the inability to evaluate the closed porosity, which is an important factor regarding the sensitivity of the explosive to detonation. In this study, we present how X-ray computed tomography (XCT), and the associated advanced data processing workflow, can be used to fully characterise the structure and morphology of AN prills. We show that structural parameters such as volume fraction of the different phases and morphological parameters such as specific surface area and shape factor can be reliably extracted from the XCT data, and that there is a good agreement with the measured oil retention values. XCT can therefore be employed to non-destructively and accurately evaluate and characterise porosity in ammonium nitrate prills.

1 Introduction

In the mining industry, the term ANFO for ammonium nitrate / fuel oil specifically describes a mixture of solid ammonium nitrate prills (see Figure 1a) and diesel fuel (commonly AN 94.5 % / FO 5.5 % in weight [1]), widely used as a bulk industrial explosive. While the worldwide production of AN for fertilizer is around 40,000 tonnes per day [2], the global ammonium nitrate market is expected to reach USD 6.18 billion by 2025 [3]. One of the major performance predictors of the ANFO prills is the fuel oil retention, which is itself governed by the porosity of the AN prills. Presently, the oil retention capacity of ammonium nitrate in prilled and granulated forms is determined by means of a standardised test in the EU [4]. However, this method faces technical difficulties, mainly because the porosity from different types of ammonium nitrate prills varies significantly. The porosity connected to the prill surface, open porosity, is available for oil retention. The pores not connected to the prill surface, closed porosity, are not available for oil retention but are however important for the explosive sensitivity. The current test methods cannot account for the closed porosity, which explains some of the technical limitations of such test.

One way to investigate and characterise the porosity of AN prills in a more accurate and differentiating way is to use X-ray computed tomography (CT). We believe that CT could be an invaluable tool to the explosives community, by providing qualitative and quantitative measurements of both the open and closed porosity, and the total surface area of AN prills.

In this paper, a data processing workflow was developed to extract these measurements from the high resolution scan of a single AN prill. However, to obtain more representative data, the workflow was amended to extract the same data on a lower resolution scan covering around 20 AN prills, i.e. to extract the measurements for each individual prill grain whilst performing the segmentation on the entire 3D volume only once.

2. Material and method

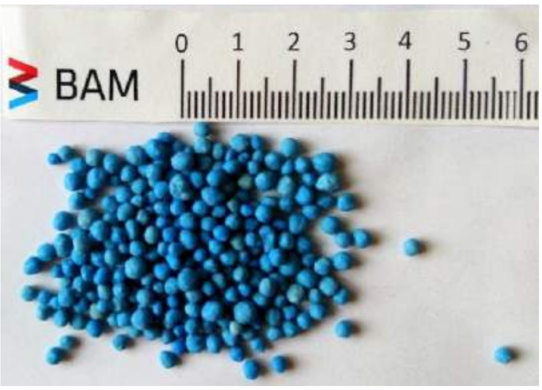
Two types of AN prills were CT scanned, the type labelled hereafter *type E* used in the mining industry as a constituent in ANFO mixtures, and the type labelled *type F*, used as a fertilizer in farming. A first scan was performed on a single prill glued onto a carbon fibre rod (see Figure 1b), to obtain the best voxel size possible (around 2.5 µm) and assess the dimensions of the porosity. A second scan was performed on several prills contained in a polyimide tube of 4.2 mm diameter, so that a good compromise between voxel size (around 5 µm) and field of view (number of grains scanned) was attained.

2.1 AN prills

Four different types of AN prills were under investigation in this study. Two were fertilisers (F1 and F2) used in farming, and two were explosives (E1 and E2) used in the mining industry as a constituent in ANFO mixtures; the two types are displayed in Figure 1. Type E1 and E2 are similar, as E2 prills are crushed E1 prills. Therefore, the structural parameters between E1 and E2 should be similar, whilst the morphological parameters are expected to show significant differences. These two materials were selected in order to assess the sensitivity of the data processing.

2.2 Laboratory X-ray computed tomography

Two type of scans were performed to assess the AN prills (see Figure 2). A first scan was performed at the highest possible magnification on a single prill glued on top of a carbon fibre rod, so that the features of the AN prills could be evaluated with the highest resolution possible (voxel size around 2.5 µm) and the CT data processing workflow could be developed (see section 2.3). Then, a lower resolution scan was performed so that a more significant number of

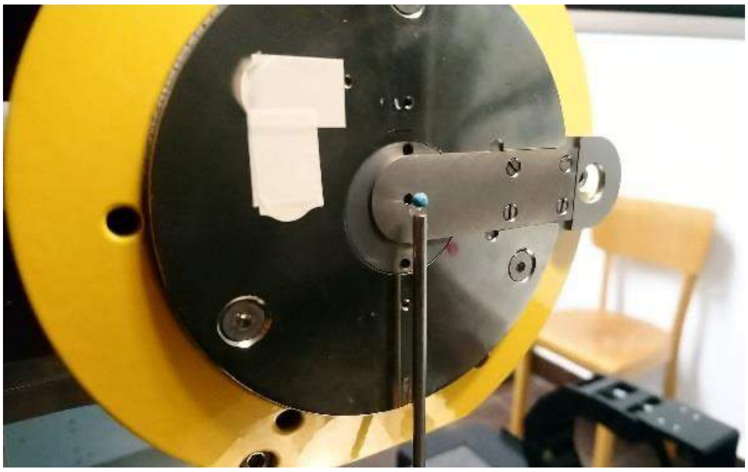


a) F1 fertiliser prills

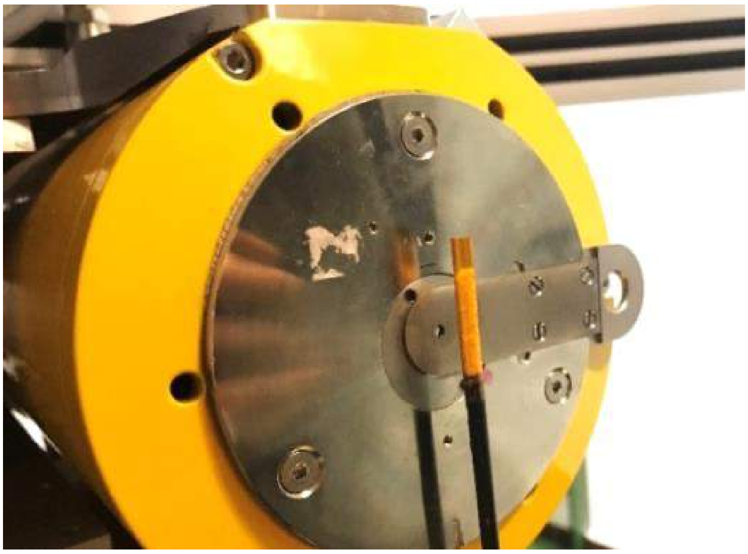
b) E1 explosive prills

Figure 1. Examples of AN prills under investigation.

AN prills could be assessed (voxel size around 5.0 µm). The AN prills were scanned on a *GE V|Tome|x L 180/300* system [4] equipped with a 180 kV source, a tungsten transmission target (actual focal spot size below 2 µm as determined with JIMA test pattern RTC02), a diamond window, and a GE 2000 × 2000 pixel DXR-250 detector. The voxel size was calibrated after the scans were performed, by scanning a ball bar consisting of 2 rubis spheres glued onto a carbon fibre rod and separated by a calibrated distance of 2.273 mm +/- 0.001 mm. The calibrated voxel size was determined by comparing the calibrated distance to the distance between the 2 spheres in the volumetric XCT data using *VGstudio MAX version 3.2* [5] (Surface determination then 2 spheres were generated by fitting 25 points to the surface of the rubis, then the distance between the spheres' centres was measured). The calculated value was then employed as voxel size for each XCT scan during the data processing step. The data visualisation, processing and quantification was performed using *Amira ZIB Edition version 2019.03* [6].



a) Single AN fertilizer prill glued onto a C fibre rod



b) Multiple AN prills into a polyimid e tube

Figure 2. Example AN prills (a) and single prill mounted on carbon fibre rod (b).

2.3 XCT data processing

The data processing workflow presented Figure 3 was developed for the prills scanned individually. The single prill scans served as a starting point in understanding the challenges in segmenting a complex open pore network in contact with the air outside the prills. Taking a single prill allowed optimizing the entire processing workflow by getting rid of the contact points between the several prills, and the presence of the container (polyimide tube).

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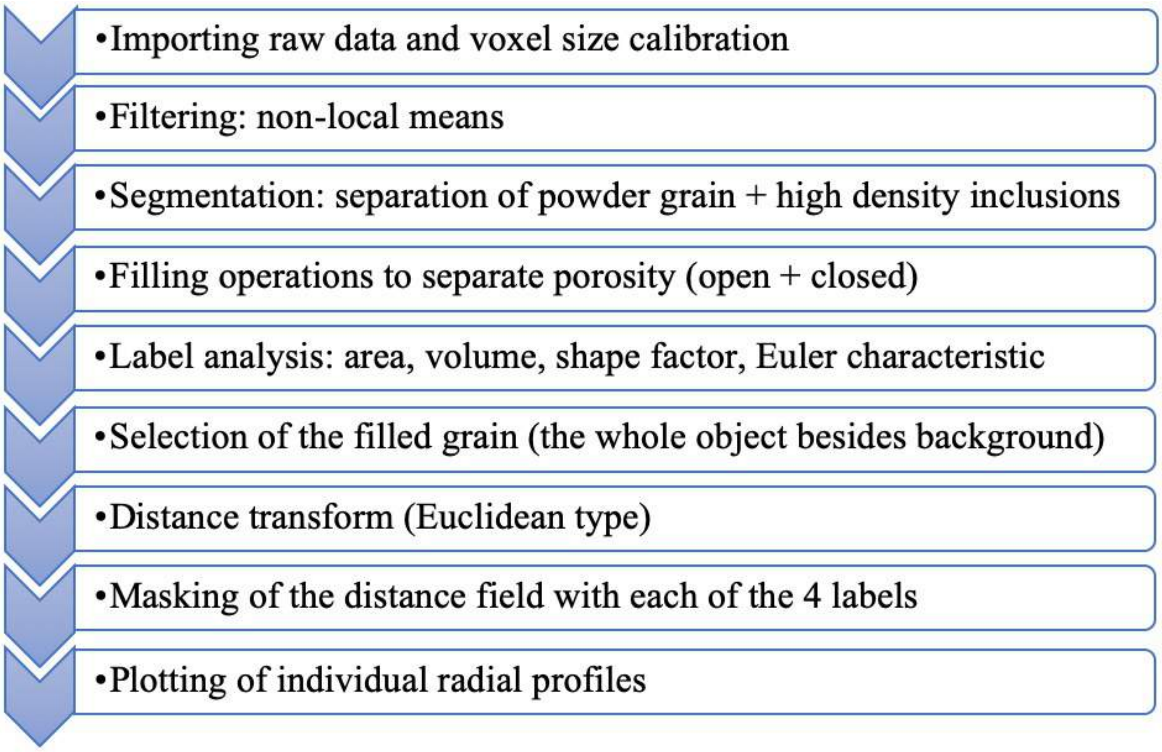
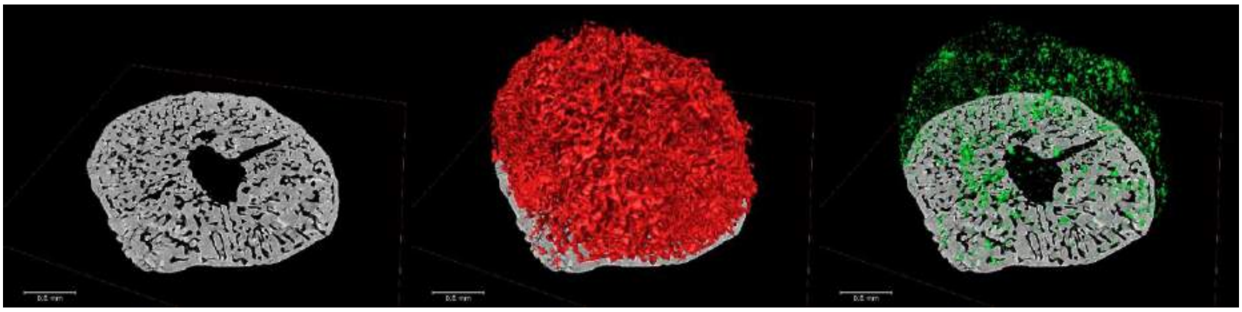


Figure 3. Overview of the data processing workflow for single prills.

Regarding the data processing of the prills in the polyimide tube, the entire data processing workflow is fully detailed in [9]. A watershed segmentation is used to select the AN, air and polyimide tube materials. The individual materials (AN, open porosity, closed porosity and high-density inclusions) are then separated before the prills are separated. The determination of the structural and morphological parameters of the prills are based on the same metrics presented before. Examples of 3D renderings of the open porosity and the closed porosity are given Figure 4.

3. Results & discussion

Examples of 2D slices from the 2 prill types presented in Figure 5 qualitatively show the differences in porosity and overall structures. Both fertilizer prills contain high density inclusions, whilst the explosives contain none. The porosity contents also appear to be significantly different. F1 prills have a limited amount of porosity, whilst more extensive porosity contents are visible for F2, E1 and E2. The porosity is quite rounded for F2 whilst for the explosive materials, there is often a large round cavity in the centre of the prills and more elongated, or crack-like pore channels, running radially. These observations are in good agreement with the structural features of the prill porous network described in [10].



a) 2D slice

b) 3D rendering of open porosity

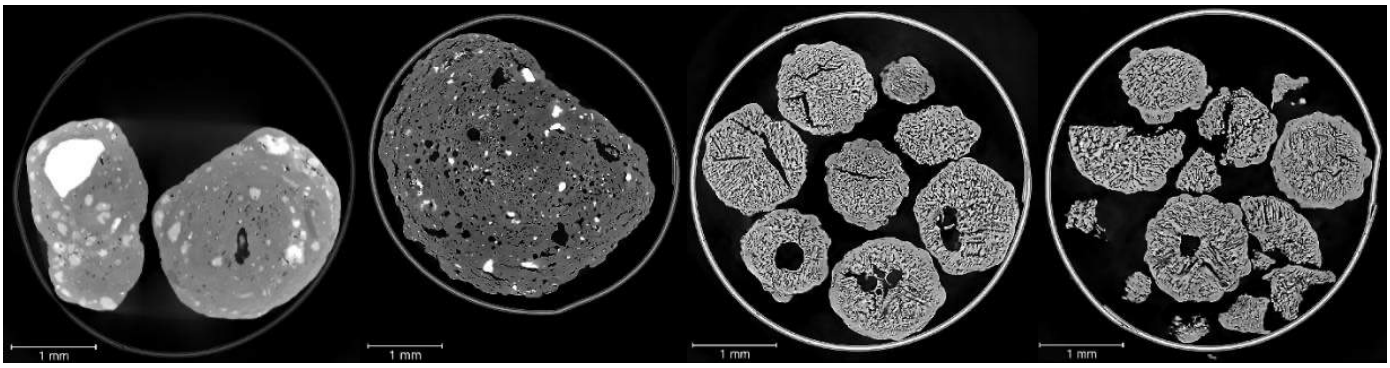
c) 3D rendering of closed porosity

Figure 4. Example of segmented data for sample E1 (0.5 mm scale bar)

However, it is impossible to distinguish the open porosity from the closed porosity from the 2D slices. It can also be noticed the significant differences in terms of size of the prills, the explosives materials have much larger prill sizes, whilst the fragmented prills from E2 have much sharper edges, compared to the fully round E1 prills.

The data processing workflow developed here was aimed at extracting the most relevant structural parameters of the AN prills, both on a global and a local scale, and in a quantitative fashion. The structural and morphological results obtained are gathered in Figure 6.

First, the volume fraction measurements (Figure 6a) show that material F1 is significantly different from the other AN prills, with a much greater AN content (above 95 %). This is associated with virtually no open porosity, and 1 % closed porosity and 2 % high density inclusion. Only F2 also contains high density inclusions (around 1 %) but a much greater porosity content, both closed (3 %) and open (18 %). As expected, materials E1 and E2 are very similar, and for each constituent, the variations between E1 and E2 are within the measurement errors. In particular, the closed porosity contents are similar, whilst the open porosity content is lower for the cruched prills E2. From the 2D slices, crushed prills will likely not include the inner cavity, which is consistent with a lower open porosity content.



a) F1 prill**s** b) F2 prill**s** c) E1 prill**s** d) E2 prills

Figure 5. Examples of 2D slices for each material under investigation.

Second, the morphological aspects are presented in Figure 6b, where the AN and the open porosity are assessed. The analysis of the AN yields more representative results, but it is also of interest to consider the open porosity itself, as it is a true representation of the volume available for the fuel oil to soak into. There are clear differences between E1 and E2, with E1 shape factor being a factor of 2 higher than that of E2, and E1 Euler characteristic being a factor of 3 higher than that of E2. Those differences reflect the smaller prill fragments from E2 compared to E1 (resulting from crushing), thus having less complex structures per unit of volume (also resulting in greater measurement deviation).

Figure 6c shows the correlation between AN volume and surface area for each prill of the XCT volume. There is a linear relationship for all the materials under investigation. There is a good agreement between E1 and E2 over the entire range of surface areas, with E2 having more data points towards the low AN volumes, corresponding to the prill fragments. The fertilisers have much greater AN volumes, due to the larger prill size, but E1 has associated low surface areas (< 100 mm^2), whilst E2 has associated large surface areas (> 150 mm^2). To be able to better compare the materials, the specific surface area values, defined as the surface area of AN per unit of AN volume, were calculated. Figure 6d shows the linear relationship between the specific surface values determined by X-ray computed tomography and the oil retention values determined according to the European regulation [3]. With this result, we demonstrate that XCT could be used to predict the performance of explosives over a very wide range of porosity content.

Based on a distance transform operator, the radial volume fraction of each phase can be determined. The plots for each material are gathered in Figure 7. For sample F1, the AN content decreases radially when moving inwards the grain, whilst the closed porosity increases, particularly in the innermost 20 % of the grains, to reach a volume fractions as high as 20 %, whilst the average closed porosity content is only 1 %. The high-density inclusions are mostly present in the outermost 10 % and innermost 50 % but are relatively well distributed. Both explosive materials exhibit similar radial distribution profiles for each of their phases. The AN content drops rapidly in the

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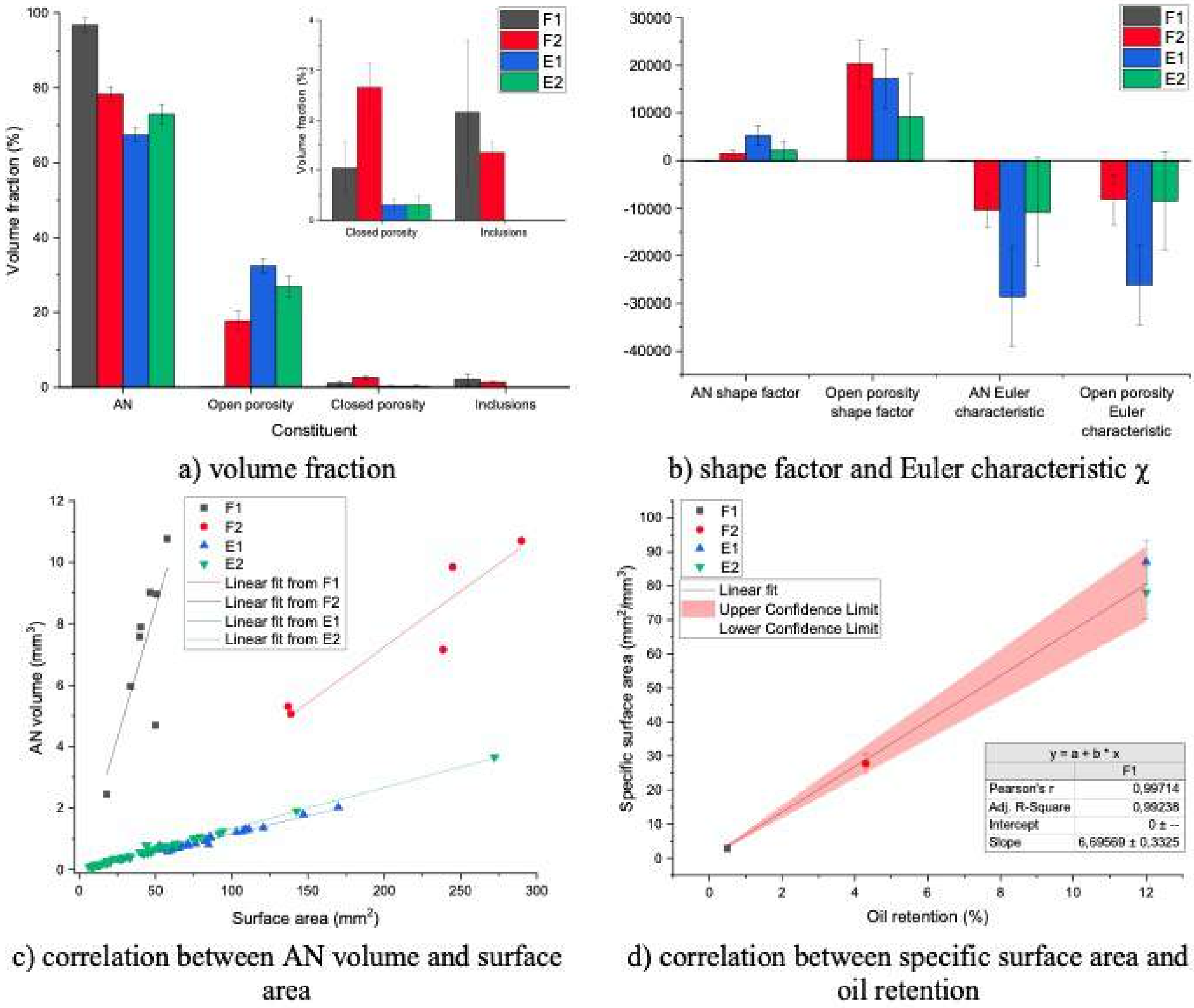

Figure 6. Overview of the structural and morphological prill parameters.

The effect of the crushing can be seen close to the centre of the prills, with E1 having an open porosity content plateauing at 100%, corresponding to the central cavities observed in Figure 4 & 5. F2 is somewhat of a mix between F1 and E materials, with a sharp increase in open porosity in the outer 20 % of the prills but the content then stabilises around 25 % over the remainder of the prills.

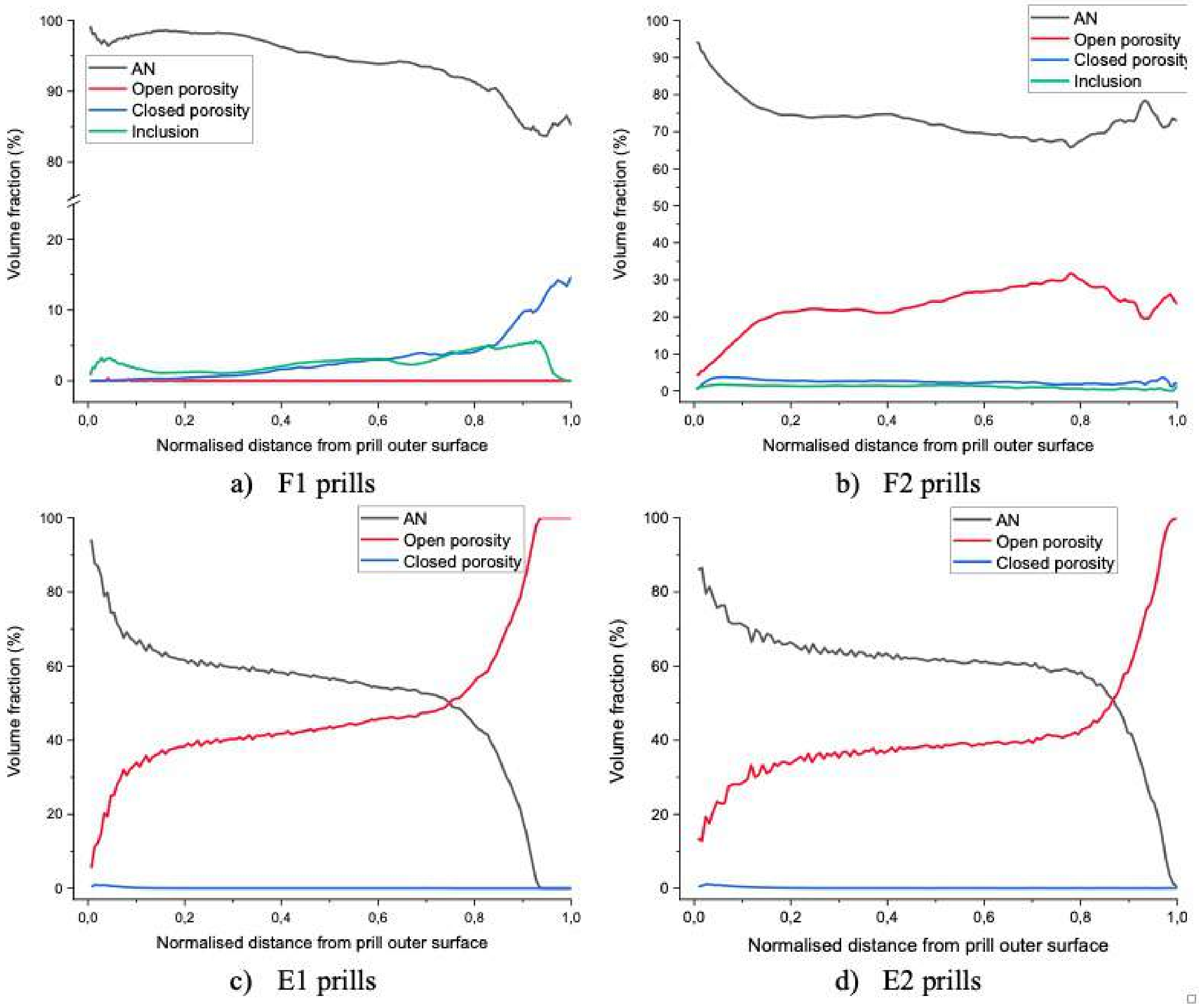

Figure 7. Radial profiles of AN prills.

4. Conclusion

Overall, the results presented here demonstrate that XCT can be successfully applied to the structural and morphological characterisations of AN prills in a non-destructive manner, as a wide range of morphological parametars can be extracted, in addition to overall volume fraction values. The workflow developed was capable of quantifying the morphological differences between E1 and E2 samples, whith E2 being crushed E1 prills. The differences in shape factors and Euler characteristics are consistent with the morphology of the fragments (E2) versus the spherical prills (E1).

Clear differences were also evidenced between the fertilisers and explosive materials. Being able to differenciate between explosive and fertilizer AN prills is extremely important for safety reasons and this is one of the core missions of BAM (Bundesanstalt für Materialforschung und -prüfung). No high-density inclusions were found in the explosive materials. If no open porosity was found in F1, around 20 % was found in F2, which is a level similar to some explosive prills. However, when looking at the specific surface values, the F2 value is much smaller than what was found for E1 and E2.

A linear correlation was found between the specific surface area values extracted from the XCT data and the oil retention values, similarly to other results [9], demonstrating that XCT can be used to predict the performance of AN prills.

The future work will focus on comparing the present XCT results to those of conventional techniques such as BET and mercury porosimetry, as assess which morphological parameter are most relevant to the mining industry. The workflow developed here can also be applied to a broad range of small porous parts and porous powders (propellants...).

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Blast design and analysis from aerial imagery

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ABSTRACT:

Remote-controlled camera drones have reached a level of maturity which allow their routine application in mining and quarry for acquiring aerial imagery at high quality and resolution. Further developments in computer vision science allows for the rapid and consistent processing of a large set of highly overlapping pictures to registered 3D images. With 3D images several surveying and assessment tasks in surface mining are addressed. The use of aerial imagery from drones increases these possibilities and allow for the determination of several parameters (key performance indicators) that are utilised to benchmark and audit the results of drill and blast works in mining in surface operations.

1. INTRODUCTION

Drones (so-called unmanned aerial vehicles) have experienced a rapid development and maturity and are applied today by a broader user base. Remote-controlled and GPS-tracked devices are frequently used not only by consumers but also surveyors and related professionalists. In particular the attachment of cameras to drones (fixed or with gimbal) enhances their use for 3D imaging technology from aerial imagery. Nowadays, 3D imaging from drones has found its way to surveying tasks in surface mining and quarrying.

3D images have been used in the past for specific task related to surface mining and quarrying, mainly originating from terrestrial imagery. The tasks included 3D bench face profiling and designing of blasts, and also geometric rock mass characterisation. This article reviews and addresses the various possibilities utilising aerial 3D images in surface mining showcasing that a single data set is useful for several applications such as:

- Blast design and analysis
- Volumetric measurements
- Excavation planning
- Stability assessment
- Fragmentation analysis
- Updating mine maps
- General documentation purposes

In the following section a brief overview on 3D image generation is given as well as the application of 3D images for surface mining which is addressed by various examples.

2. 3D IMAGE GENERATION

Photogrammetric reconstruction of surfaces recover 3D information using at least two photos from different angles where the photos show the same part of a "scene", e.g. a rock surface. The technology behind is called photogrammetry and dates back to 1850 (cf. Slama 1980).

In the 1990's upcoming digital imaging and availability of computing power brought new algorithms and new applications to image based stereoscopic measurement and led to the introduction of the term Computer Vision (cf. Faugeras 1993). This technique has been used mainly in robotics but also for geometric rock mass characterisation (Gaich et al. 2003).

A more recent approach handles multiple photographs simultaneously in order to perform a fully automatic 3D reconstruction. This technique is known as Structure from Motion (Snavely et al. 2008). Structure from Motion has reached maturity in the Computer Vision domain but the number of applications using the technique remained rather low.

Although the geometrical principles have been developed in the 1990's it took till the 2010's where an application to high resolution input photos has been realised mainly for the reconstruction of objects from unordered image collections obtained from Internet user photo galleries (Snavely et al. 2008). Photogrammetry and Structure from Motion have merged then which brought Structure from Motion also to measuring and surveying tasks (cf. Pollefeys et. al. 2001, Hoppe et al. 2012).

In parallel to the evolvement of photogrammetry the availability of small lightweight drones highly rose. The broad utilisation of drones increased the abilities of photogrammetry especially in surface mining. The better angle of the camera to the areas of interest overcame potential occlusions that often occurred in sole terrestrial imaging. Terrestrial imaging, however, is still beneficial for vertical walls and high image resolutions and might be nicely combined with aerial imagery.

An important requisite for comprehensive and accurate 3D models in this context is redundancy in form of having the same part of the surface visible in several images. This redundancy allows to close gaps that pure stereoscopic photogrammetry may deliver and it has the potential to increase the accuracy of single 3D surface points. It furthermore enables the determination of the camera distortions on the fly, i.e. it allows to calibrate the camera while doing the project (auto-calibration).

Applying the principles of the Structure from Motion, 3D images are processed immediately on site or off-site using a cloud based service. The first requires according computing power on site, the latter needs a transfer of potentially large amounts of data over a network in order to send the photos and receive the results. Several software packages exist that allow for a close-to-fully automatic processing of image data to consistent 3D models.

Figure 1 left shows a picture of a drone in a surface mine. It carries an off-the-shelf SLR camera and in this case flew the bench face and the muck pile before hauling. On the right side a stack of images is displayed, the overlap between the images was approx. 85%, i.e. each part of the surface is visible in at least 5 images.

Figure 2 showcases a crucial step for reaching accurate results in multi-photo reconstruction – the determination of the camera locations based on identified correspondences between the photos. In the example the drone flew operator controlled hence the "grid" of camera locations is not regular.

Figure 3 presents a snapshot of a 3D image taken of deposited tunnel excavation material in order to document the heap and to measure its volume. The computation of the 3D image requires the user to define a region of interest for the 3D measurements (optional), all other computation steps perform automatically.

Figure 1: Drone ready for take-off in a surface mine (left) and stack of highly overlapping images (right).

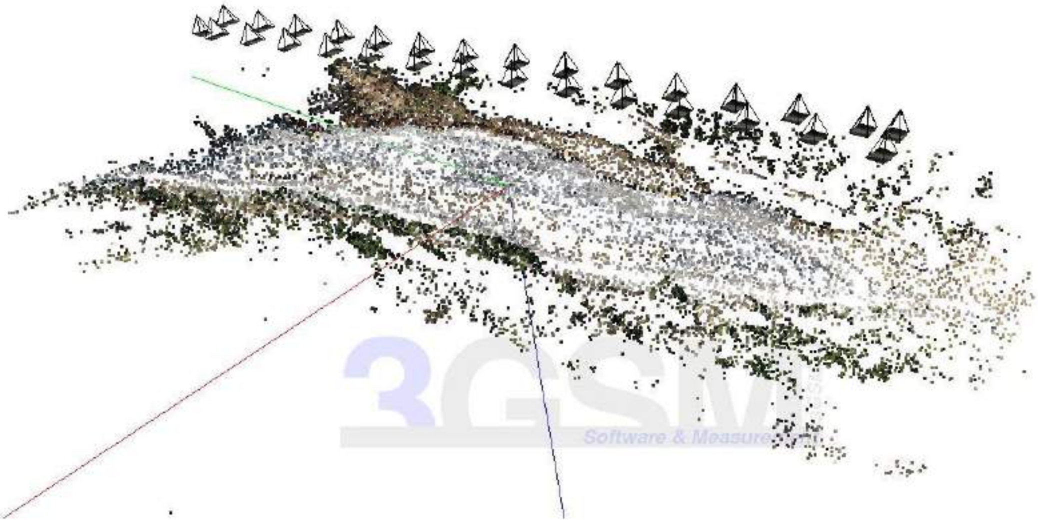


Figure 2: Intermediate result during 3D image generation: the small pyramids indicate recovered camera locations based on a subset of 3D surface points.

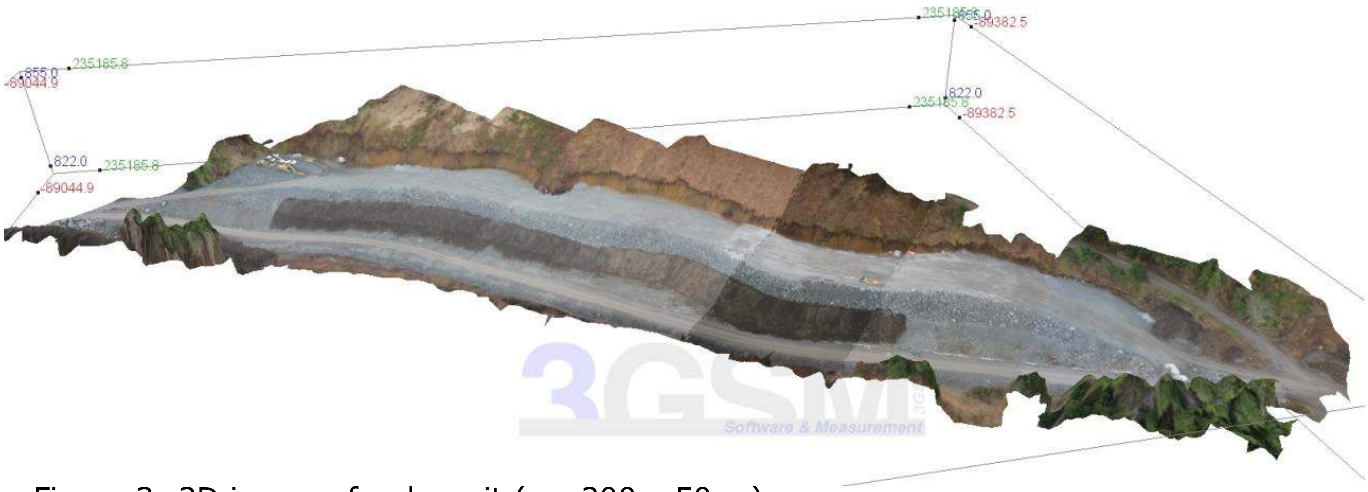


Figure 3: 3D image of a deposit (ca. 300 x 50 m)

3. THE APPLICATION OF IMAGES IN SURFACE MINING

There are several reasons why aerial 3D imagery fits so well to surface mining sites: (i) large areas need to be acquired (surveyed), (ii) several parts are difficult to access or not accessible (e.g. highwalls), (iii) usually no vegetation obstructs the rock surface, (iv) drone flights over uninhabited areas are easier to perform from the legal point of view. The following sections showcase examples for 3D image generation from drone imagery applied in a surface mine and thus demonstrate its fields of application.

3.1 Blast design

Incomprehensive knowledge on the geometry of a blast site and especially the face may lead to unexpected blasting results (Moser et al. 2007). Economic consequences of poor blasting in a surface mine or quarry include:

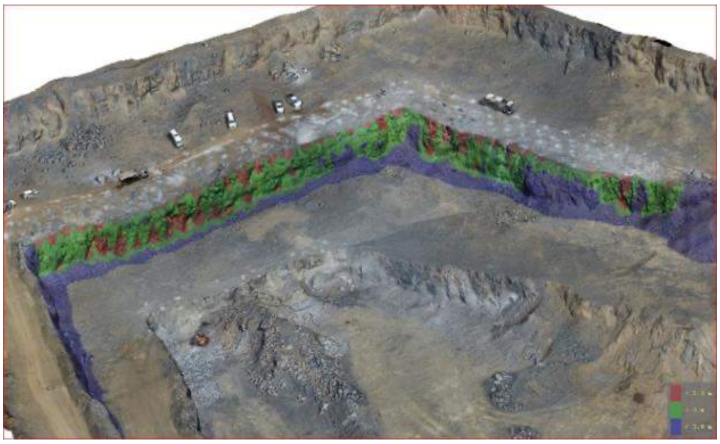
- Additional efforts for loading and hauling
- Efforts for secondary breakage
- Too much fines
- Reduced crusher performance
- Additional wear of equipment due to uneven floors

More importantly, safety-related issues are also associated with:

- Fly rock incidents
- Excessive vibrations
- Air blasts
- Excessively damaged rock walls and floors leading to safety hazards

3D images provide a straightforward data basis for improving blasting results as they provide both (i) detailed information on the geometry of the blast site and (ii) a visually clear and detailed representation of the rock mass conditions. They enable to proactively design and optimise the drill pattern and loading according to the actual bench face geometry. This becomes a particular evidence at irregular bench faces, blasts with several free faces, or very large blast sites. The comprehensive data set from an aerial 3D image enhances the information of a face profile. It additionally provides the detailed geometry of the top of bench and in particular the conditions along the crest line.

Once the 3D image is generated and the drill pattern specified, real burden information is available, i.e. the distance from the borehole to the closest location of the free surface in any direction (360° spherical search). The 3D image may be colourised according to the current burden situation with reference to the design burden and a site-specific corridor of acceptance. Current burden values within the corridor of acceptance are coloured green while burden values below or above are the coloured red or blue, respectively; hence making problematic areas obvious. By overlaying the colour codes to the 3D image, a self-explaining representation of the burden situation results (see Figure 4). In a proactive design approach, this information is used to adjust the location and/or the inclination of certain boreholes in order to adapt to the bench face geometry. Adjustment criteria may include minimisation of light and heavy burden areas or avoidance of (too) small borehole spacings. The so-called minimum burden is the key information for the optimisation of a drill pattern (cf. Moser et al. 2007). Since aerial 3D images provide detailed information on the top of bench, borehole length can be easily designed to match a horizontal plane or ramp. The result is a borehole map with co-ordinates for each borehole collar, the length, inclination, and bearing for each hole, as well as corresponding profile/burden data.



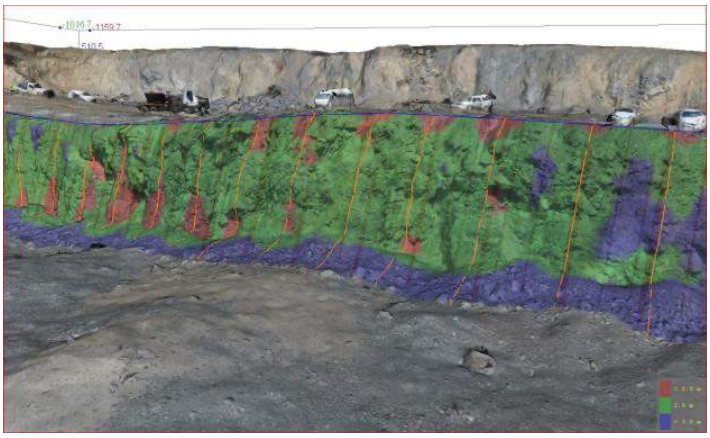


Figure 4: 3D image of a blast site including colour-coded visualisation of burden over the bench face area (left); detailed view with borehole profile locations (right). Green: design burden; Red: light burden; Blue: heavy burden

A complete blast design requires to audit the pattern as drilled, i.e. each borehole location and its course. Several sophisticated possibilities exist such as GPS with rover receiver, drill rigs with included GPS, down-the-hole probes, and drill rigs with such measurement possibility included. A basic method to audit as drilled borehole collars is the use of a tape measure along and across a predefined reference line. Aerial 3D images of blast sites with already drilled holes also allows to audit the collar positions directly (see Figure 5 left). In such cases neither a rover receiver nor GPS on the rig is required.

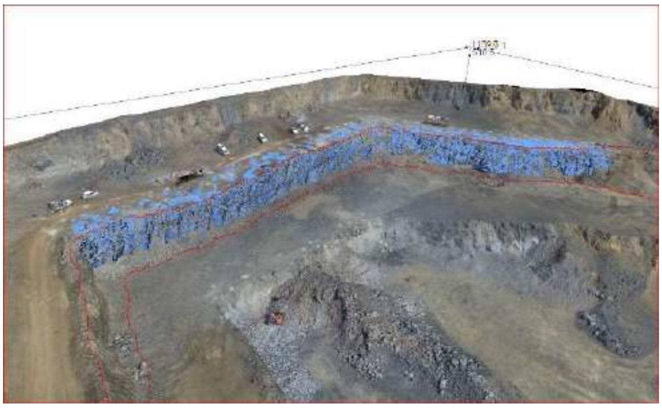


Figure 4: 3D image of a blast site including colour-coded visualisation of burden over the bench face area (left); detailed view with borehole profile locations (right). Green: design burden; Red: light burden; Blue: heavy burden

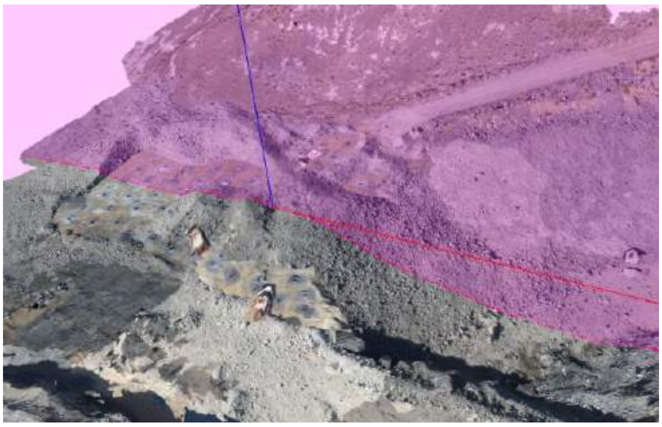
Figure 5 right shows the bank volume of the readily designed and audited blast. Together with the updated burden charts from the audit and the according profile plots, this provides information for an adequate loading of the holes.

(Stewart 2017) describes the geometric and economic impacts of proactive blast design including auditing using 3D images: Production time was reduced by 10% and the efforts for secondary breakage went down significantly.

3.2 Post-blast analysis

The 3D image survey of section 3.1 includes information before executing the blast (pre-blast survey). A drone flight after the blast allows for the analysis of the muck pile and its fragmentation (post-blast analysis). The post-blast 3D surface needs to be registered in the same co-ordinate system in order to enable comparative analyses. This is usually accomplished by geo-referenced surveys. If geo-referencing is not available, it is still possible to register the 3D models in a common local co-ordinate system based on common parts in the pre- and post-blast survey that remain unchanged in the 3D images.

Figure 6 depicts an overlay of two 3D images (pre- and post-blast) as well as a vertical section through the model. The resulting graphs visualise the shape of bench face and muck pile at this location. The power trough becomes obvious. Its location and depth is determinable simply from the data.



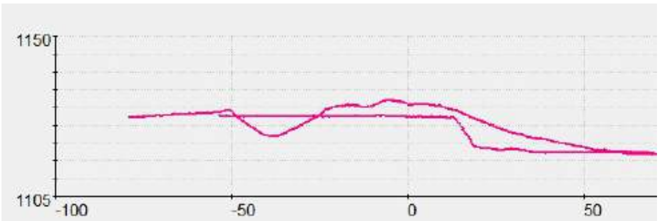


Figure 6: A section through 3D surfaces pre- and post-blast reveals the shape of the muck pile and allows the determination of depth and location of the power trough (arrow).

The volume of the muck pile is determined by the comparison of the two surfaces pre- and post-blast. The embedded volume between the surfaces corresponds to the volume (see Figure 7). Note that the precise volume of the muck pile is available once the whole muck pile has been cleared from the new free face. So, only a third drone flight after mucking (post-mucking survey) enables the precise determination of the blasted volume, the real bank volume, and the accurate volume of the muck pile. With this information at hand the swell as the ratio between the muck pile volume and bank volume is determined.

Another key parameter for describing blasting results is the distribution of particle sizes (fragmentation). Several software solutions are offered on the market. Some rely on the segmentation of particles by 2D image analysis (e.g. Split, WipFrag). The required scale information is introduced either by objects of known size in the photos or by basic stereoscopy with known camera distances (Motion Metrics). Also geometric approaches exist (Thurley et al. 2015) performing an analysis of the shape of the muck pile. Using 3D images, both ideas nicely combine and enable taking out the best of both approaches. Figure 8 shows a section of a 3D image from a muck pile and the resulting delineation of particles. The applied algorithm analyses the shape of the surface and combines the result with image processing algorithms.

Figure 7: Volumetric description between two arbitrary shaped surfaces.

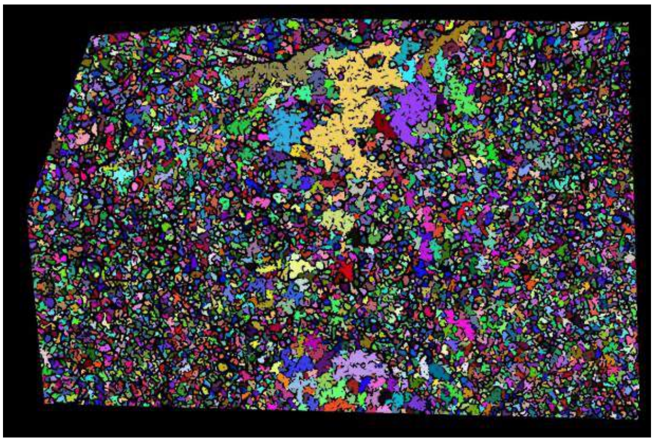



Figure 8: 3D image of a muck pile (left) and automatic particle detection based on the combination of geometric analysis and image processing (right).

3D images form a self-explaining type of documentation. Whenever an incident occurs, the presence of data that is easily communicated also to non-experts in the field is beneficial. In addition to the 3D images the generation of a video document of the blast is useful. The video additionally enhances the means of communication as mentioned.

Topographic maps are inherently generated from 3D images and are available for free when performing blast design or blast documentation. Figure 9 shows a topographic map from a part of a surface mine where a blast site has been designed.

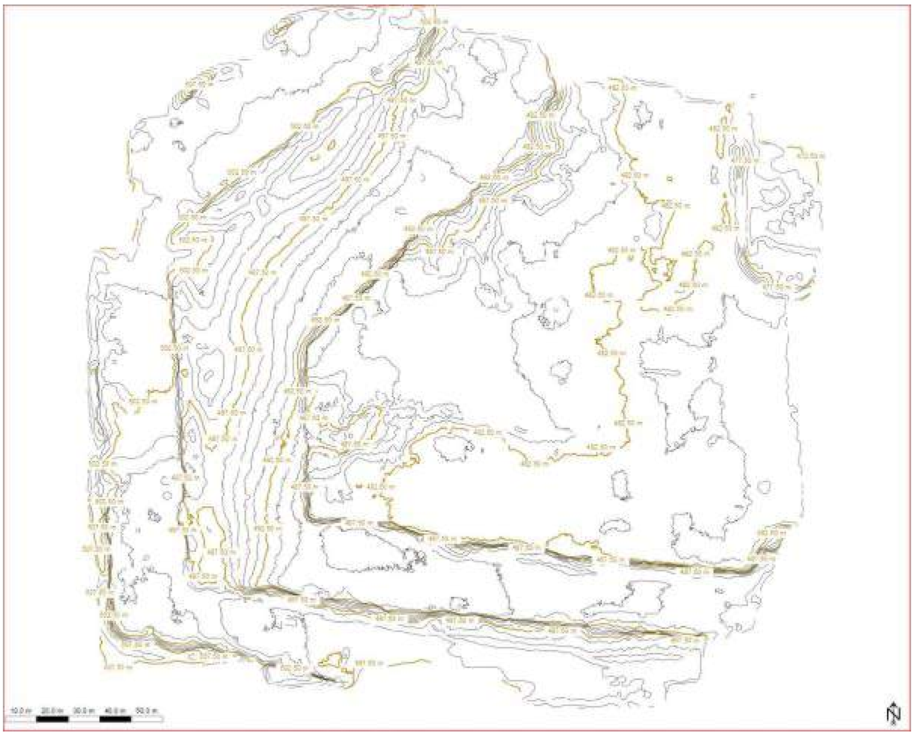


Figure 9: Topographic map of a surface blast site and its adjacent benches and ramps.

3.4 Geometric rock mass characterisation

The natural representation of the rock surface with a 3D image allow for qualitative and quantitative assessments. Qualitative assessments include the face quality in general and the presence of open and/or large joints, cavities, or weak zones, e.g. mud seams or faults.

For a quantification of (geometric) rock mass properties spatial measurements are required. Software tools exist that enable the determination of joint orientations, joint sets and their spatial variation, as well as quality parameters such as joint frequency, or joint spacing. Such characterisation of the rock mass may also happen automatically or semi-automatically. Approaches as described by (Slob 2010, Riquelme et al. 2014) aim to identify planar regions in 3D point clouds. Figure 10 and Figure 11 outline the principle of a topographic analysis of a 3D surface.

The basis is the set of normal vectors over the surface. Their spatial distribution resp. their density lead to clusters of the normal vector's orientation. The clusters are then used in a second processing step for the generation of areas that may correspond with joint surfaces (see Figure 11).

The possibilities within quantified rock mass characterisation provide a profound data basis for defining the geometric parameters of a fractured rock mass such as the number of joint sets, joint set orientations and its variation, joint set spacing and its variation, joint set persistence, etc. High resolution surveys also enable the measurement of the waviness and roughness of the exposed joint surfaces. The basic input parameters for stability assessments of benches, inter-ramp slopes and overall pit slopes are quickly available, and can be easily audited additionally.

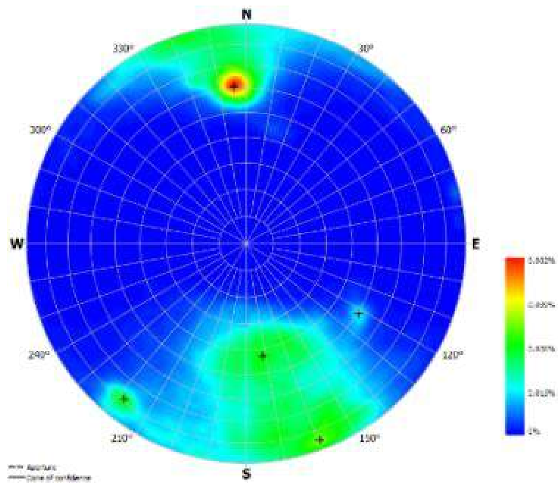
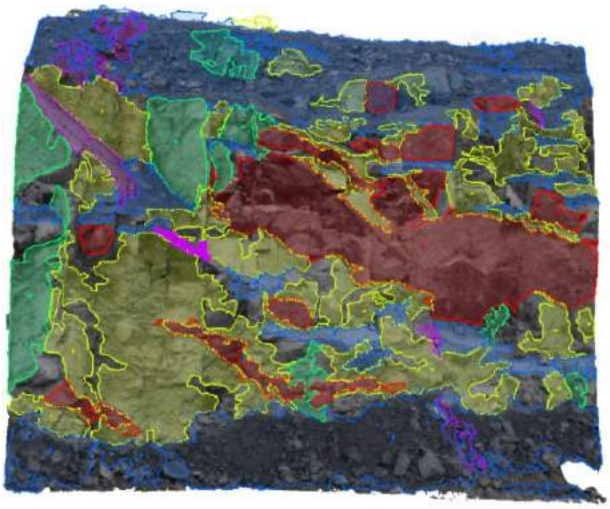



Figure 10: Section of a bench face (left) and automatically analysed orientations of surface normal including colour-coded density distribution (right)

BACK TO TOP



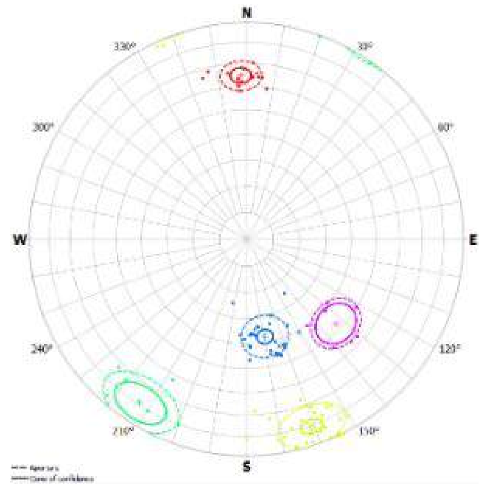


Figure 11: Automatically determined surface areas, clustered according to their spatial orientations (left) and according plot in the stereo net (right).

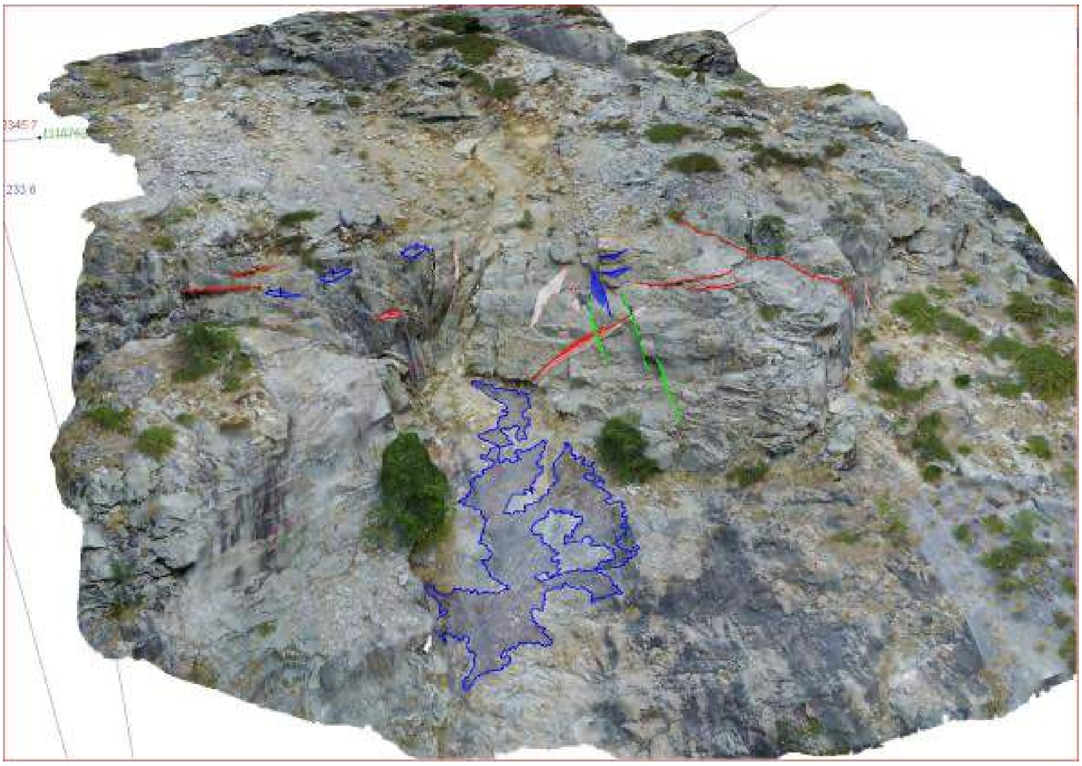


Figure 12: Basic geologic mapping of a rock wall area with difficult access forms the basis for stability assessments.

4. CONCLUSIONS

The use of aerial 3D imagery taken with drones allows for performing several surveying and assessment tasks in surface mining and allow for the determination of several key performance indicators. The consequent determination of such parameters lead to comparable results between different blasts and shall help to improve the quality of drilling and blasting works in terms of productivity and efficiency while still preserving high safety standards. Surveying and assessment tasks related with the application of aerial 3D images include:

- Surveying of bench face, top, and floor
- Face profiling – pattern, profiles, minimum burden
- Blast design
- Post-blast analysis
- Rock mass characterisation - geological mapping
- Mine plan update
- General documentation

Key performance indicators determined from 3D images:

First drone flight (pre-blast):

- Pre-blast volume – as designed (prediction)
- Pre-blast volume – as drilled (prediction)
- Location of hole collars
- Thickness of seams, orientation, location (geological mapping)

Second drone flights (post-blast before mucking):

- Volume of the muck pile (estimation)
- Bank volume (estimated)
- Height and width of the muck pile
- Power trough volume
- Power trough cross sections – location of minimum
- Fragmentation distribution
- Visible half barrels – Number, average length, total length

Third drone flights (after mucking):

- Volume of the muck pile (real)
- Bank volume (real)
- Percent cast as a volume ratio
- Swell of the muck pile volume
- Back break – Distances, Volumes
- Number and length of half barrels and burn cuts

Using aerial 3D imagery from drones covers a wide range of application in surface mining making this technology a viable standard operating procedure.

5. ACKNOWLEDGEMENTS

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WipWare Inc. http://www.wipware.com

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FYI New Date! October 12-14, 2020

HILLHEAD 2020
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FYI Postponed to 22–24 June 2021

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Official language: Czech (foreign presentations in English)

Website/Contact info regarding the conference: www.sttp.cz