REPORT

Explosion Accident during Mobile Production of Bulk Explosives

Report by DSBs project committee on the follow up of the accident in Drevja on the 17th of December 2013

Norwegian Directorate for Civil Protection

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01

Abstract

1.1
COURSE OF EVENTS

In relation to blasting operations conducted as a part of road construction project Fv. 78 Arm Ømmervatn, the mobile unit for on-site production of bulk explosives owned by Maxam, MEMU F-114, arrived at Drevja on 17th December 2013 at approximately 12:00, after a 160 km transfer from the depot at Brønnøy Kalk, Norway. F-114 was carrying precursors for production of bulk explosives, and the main components being ANPP and ANE.

The production was initiated and at approximately 13:00, a fire was identified on the right side at the front of the vehicle. After ending an unsuccessful attempt to extinguish the fire, the construction site and residential homes in the immediate area were evacuated. The police and the fire brigade were alerted and arrived at the site.

The duration of the fire was approximately 2.5 hours. It is likely that after about 1.5 hours, the fire had spread to the ground beneath and in front of the vehicle. After about 2 hours, the fire had enclosed the entire vehicle and it is likely that the cab had burned out. The final 5 minutes, after about 2 hours and 21 minutes up to the moment of explosion, the fire intensified significantly.

There were considerable material damages to the surrounding environment after the explosion. A residential home burned to the ground, several buildings had structural damages and broken windows, and construction equipment in the area was damaged. No persons were injured.

1.2
APPROVALS, CERTIFICATES OF CONFORMITY AND AUTHORISATION FOR MANUFACTURE

The Norwegian Public Roads Administration (NPRA), Risløkka Traffic Services Office, approved F-114 after an initial inspection in accordance with ADR on 17th June 2010. After this, the vehicle was subject to periodic inspections. The last inspection took place on 12th February 2013. The tanks with associated equipment were ADR approved by DNV on 11th May 2010.

The MEMU approval and the authorisation for manufacture under the Regulations on Explosives for F-114 were granted synchronously by DSB, in the decision dated 8th June 2010. The authorisation is valid for products in the Riomex series.

According to ADR, UN 3375 must be approved by the competent authority. Carriage of UN 3375 in tanks is further subject to a special requirement on suitability of the substance for carriage in tanks, and must be tested with a method approved by the competent authority. Maxam has submitted documentation from BAM concerning the approval of UN 3375, and the suitability of the product for carriage in tanks. The traceability in the documents is not satisfactory.

The provisions of the Regulations on Explosives define specific requirements for the conformity assessment and the certificate of conformity including accompanying documentation for explosives. BAM has certified that a prototype of Riomex SC 7000 meets the basic safety requirements of Directive 93/15 EEC, which is implemented through the Regulations on Explosives.

1.3
MOBILE PRODUCTION OF EXPLOSIVES ON MEMU F-114

The explosive Riomex SC 7000 manufactured by F-114 is a mixture comprised by several components. Riomex SC 7000 is prepared through a process, of which ammonium nitrate porous prills (ANPP) and diesel is added to emulsion (ANE), before the mixture is sensitized. This type of bulk explosive is intended for use above ground only. Riomex SC 7000 is sensitized through chemical gassing, and the formation of gas is catalysed by the addition of acid at the outlet of the product pump. The capacity of F-114 was about 13 tonnes.

1.4
ANALYSIS OF THE COURSE OF EVENTS

Throughout the working process, the project committee continually assessed which information was possible to obtain in order to analyse the incident in Drevja. Three surveys were conducted; photo material from the incident was collected, the persons involved were interviewed and key documentation from Maxam was obtained.

Based on statements from witnesses and photos, it is most likely that the fire started in the electrical system on the lower right side of the chassis. A correlation between faults in the electrical system and the fire is considered likely by the committee.

During the inspection conducted immediately after the accident, it was observed that the MEMU was highly fragmented, no clear impact crater had formed, cartridged explosives were found intact close to the blast area and immediate surroundings were apparently little affected by the pressure wave. The project committee suggests that the given geological conditions on the site may be the main explanation as to why no impact crater was formed.

Given a 2.5 hours duration of the fire, involving a significant fire impact and estimated temperatures of more than 1200 °C, the project committee considers it most likely that the ANPP had melted, and that both ANPP and ANE had started to decompose. It cannot be excluded that the detonation characteristics of the chemicals to a large extent may have changed, as high temperatures and possible contamination by organic material are among the factors which increase sensitivity.

The project committee does not consider the findings of molten aluminium fragments as sufficient proof on its own that the tanks melted, but it does indicate a weakening of the aluminium that may have caused the tanks to burst. FFI's (Norwegian Defence Research Establishment) simulation of the engine block's trajectory indicates that a considerable force has emerged from the ground, very close to or from partially below the engine. Hence the committee deems it most probable that at least one tank had bursted, causing the chemicals to leak and drain into the ground. The committee is further of the opinion that the basis for concluding how the materials were distributed and spread on the ground, is insufficient.

The intention of using aluminium tanks has been to reduce the likelihood of a fire causing an explosion. This incident demonstrates that the use of aluminium tanks as a means to prevent explosion in a MEMU on fire, is not sufficient.

Explosive yield calculations have been performed based on the extent of damage to buildings, the trajectory of the engine block and registered vibrations in the ground. It is not possible to conclude accurately on the size of the detonated charge, but the project committee estimates that an amount corresponding to 500–1 000 kg TNT is probable. The committee has further judged the basis for estimating the TNT equivalent amount of ANPP and ANE involved in the blast to be insufficient, as it will provide uncertain and not constructive numbers.

Findings of vital parts substantiates that the explosion was not initiated in the pump, and in neither the vertical nor the horizontal auger. Beyond this, it is very difficult to determine what initiated the explosion.

FFI's analysis of the extent, size and dispersion of the aluminium fragments substantiates a detonation in both aluminium tanks. At the same time, the committee believes it is relatively certain that the original amounts of both ANPP and ANE present before the fire broke out, were not involved in an ideal detonation. This would represent a much larger explosive potential than what was observed in Drevja.

Despite considerable amounts of information gathered and analyses performed by, it is still difficult to outline a complete course of events. Hypotheses are introduced to illustrate possible course of events and the needs for specific knowledge. The hypotheses include the possibilities of the explosion occurring in the ANPP tank or the ANE tank and on or above the ground.

1.5 PREVENTIVE MEASURES

After an accident like the one in Drevja, a thorough evaluation to assess whether safety levels are good enough during mobile production of explosives, is a matter of course. The overall objective for the government and the industry is to minimise the risk of similar incidents happening again. Measures which shall improve safety of mobile production of explosives even further must be considered in a holistic safety perspective, and with the recognition that handling of explosives and other dangerous substances will always be associated with risk.

The project committee generally assesses the risks related to mobile manufacture of explosives to be acceptable, despite the accident in Drevja. However, we believe risks are not assessed appropriately for a fire scenario. There may also be other scenarios or conditions present which change the risk situation. In the process of assessing which measures need investigation, the committee has worked towards the objective of looking holistically at risks related to mobile manufacture of explosives. We recommend measures that highlight the possibilities for further risk reduction under normal conditions as well as in extraordinary situations.

The project committee in DSB proposes a package of measures comprised by the following:

- Changed procedures for applications for manufacture.
- Follow up on non-conformances identified through document audits.
- Assess the need for regulatory changes.
- Evaluate possible fire prevention and firefighting actions.
- Assess the need for a comprehensive assessment of the risks related to mobile production of explosives.
- Acquire specific knowledge.

Non-conformances identified through work conducted by the project committee will be followed up with Maxam as they would subsequent to a regular audit. Non-conformances identified are not considered to have had direct consequences for the incident.

DSB will during 2015 revise the Regulations on Explosives, and initiate and maintain the progression of the work involving the proposed measures.

CHAPTER

02

Introduction

2.1 AUTHORISATION AND ORGANISATION

After the explosion in Drevja, a project committee was assembled in DSB and given the following commission:

> *"The project committee has been commissioned to make an independent assessment of the accident that took place in Drevja on 17th December 2013, to seek to clarify the cause of the fire in the vehicle, the reason the fire evolved and why the fire led to an explosion.*
>
> *The project committee shall propose any necessary measures to prevent similar incidents, as well as identifying any violations of the regulations enforced by DSB.*
>
> *The project committee shall involve the industry and identified measures must have strong ties to a joint industry. DSB has already informed the industry that there may be a need for conducting full-scale tests. The committee shall make recommendations as to whether tests are necessary, and if that is the case, which tests."*

The project committees' specific objectives were to:

- Provide a detailed description of the course of events.
- Provide a description of the scene of the accident and the discoveries made there.
- Assess the blast effects.
- Create a probability assessment of potential causes.
- Seek to provide a conclusion.
- Propose appropriate measures in order to reduce the risk of similar incidents.
- Provide input to the further developments of the regulations.
- Arrange a theme day with the suppliers of explosive materials.
- Assess the need for full-scale tests.
- Identify any violations of the regulations.

The project owner was the Head of Department Siri Hagehaugen from the Unit of Explosive Safety (EKS), and project managers were Gry Haugsnes and Axel Proet-Høst. Project committee members were Olav Jacobsen, Jan Øistein Kristoffersen, Bente Tornsjø, Maria Elisabeth Due-Hansen and Odd Arne Grøvo. Project owner Siri Hagehaugen reported further to Torill Tandberg, the Director of the Department for Business, Products and Hazardous Substances (NPF).

The project committee was authorised to recruit external expertise. Important collaborating partners have been the Defence Research Establishment (FFI), Norwegian Geotechnical Institute (NGI), the Norwegian Public Roads Administration (NPRA) and the Norwegian Defence Estates Agency (NDEA). A dialogue meeting with suppliers of explosive materials has also been conducted during the process.

2.2 BACKGROUND

MEMU is an abbreviation for Mobile Explosives Manufacturing Unit.

The definition of a MEMU in ADR is as follows:

> *"A unit or a vehicle mounted with a unit, for manufacturing and charging explosives from dangerous goods that are not explosives. The unit consists of various tanks and bulk containers and process equipment as well as pumps and related equipment. The MEMU may have special compartments for packaged explosives."*

As of today, approximately 80% of all explosives used in Norway are bulk explosives and an increase is expected in upcoming years also for smaller blast operations. Worldwide, there are many different ways to produce and charge bulk explosives. MEMUs are used for blasting operations both above ground and underground. Primarily units blending emulsions and gassing agents are being used underground. New and better charging units are continually being developed. Today MEMUs are used above ground for both larger and smaller blasting operations.
A MEMU intended for larger blasting operations typically has a capacity of 7-14 tonnes and a MEMU

intended for smaller operations has a capacity of 1-3 tonnes.

Previously there have been no major accidents involving a MEMU, but ammonium nitrate and ammonium nitrate-fuel oil have been involved in a number of accidents.

DSB decided during spring 2013 to investigate the governing of explosives including the on-site production of explosives using mobile manufacturing units. An internal working group was established to obtain necessary information and make recommendations concerning the future regulations and governing of the field.

External consultancy support was employed to investigate the following:

1. A description of the technical and practical developments of bulk explosives and handling on-site, and an analysis of future development.
2. A description of the on-site production process of emulsion and bulk explosives.
3. A description of good practice in the industry.

The internal working group should have delivered the recommendations by February 2014, but due to the review of the accident in Drevja, the deadline was postponed pending the report of the Drevja accident.

2.3
RELEVANT REGULATIONS

Act No. 20 of 14 June 2001 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (The Fire and Explosion Protection Act) is the act that maintains safety and the handling of explosive precursors and the manufacture of explosives. The law is elaborated through a number of key regulations.

In relation to the Drevja accident, the following regulations issued pursuant to the Fire and Explosion Protection Act, the Working Environment Act and the Product Control Act respectively, are relevant:

- Regulations No. 384 of 1 April 2009 concerning the inland carriage of dangerous goods (the Inland Transport Regulations)
- Regulations No. 544 of 20 May 2009 concerning machinery (the Machinery Regulations)
- Regulations No. 1357 of 6 December 2011 concerning performance of work
- Regulations No. 602 of 8 June 2009 relating to the handling of flammable, reactive and pressurised substances including requisite equipment and installations (the Regulations on the handling of Hazardous Substances).
- Regulations No. 922 of 26 June 2002 concerning the handling of explosive substances (the Regulations on Explosives).
- Regulations No. 1127 of 6 December 1996 relating to systematic health, environment and safety activities in enterprises (the Internal Control Regulations).

CHAPTER

03

Course of Events

The description of the course of events is based on reports and logs from the fire department, questioning performed by the police, interviews performed by DSB and on photos taken by the contractor, fire department, police and Maxam Norge AS.

The Norwegian Public Roads Administration Region Nord was the owner of the road construction project Fv.78 Arm Ømmervatn-P1304. Johs. J. Syltern AS was the main contractor in this project while RockNor AS was the blast contractor. The project was expected to finish in October 2014. Maxam Norge AS (Maxam) was responsible for the delivery of bulk explosives.

In connection with the project Fv.78, a quarry was constructed. On December 17th 2013, MEMU F-114, owned by Maxam, arrived at approximately 12:00 to charge blast area number 50. F-114 arrived after driving 160 km from Maxams' storehouse at Brønnøy Kalk. After its arrival, the Maxam operator prepared F-114 for production/pumping. The MEMU was placed in a slope with its rear end pointing uphill towards the blast area, thus situating its ANPP tank at a lower point (Figure 2).

The production commenced at approximately 12:00. When initiated, the production starts first followed by product pumping. At this time the operator of the pump was situated by the cabinet on the left rear side of the truck, where the operator console for the production unit was placed (Figure 1). During production/pumping, the engine was running and the lights were turned on. Two RockNor employees were situated at the rear end of the vehicle close to the blast area, when the fire was discovered.

At approximately 13:00 the power supply shut down. The operator heard the characteristic sound of "(compressed) air leakage" whereafter the engine shut down immediately. The operator walked up to the cab and discovered white/grey smoke coming from the right front side of the vehicle. Subsequently, the operator went over to the passenger side and turned off the main power supply. When the operator opened the passenger door, the cab was filled with black smoke and visible flames were seen both on the in- and outside of the vehicle. The flames blazed towards the operator from the dashboard from the floor and up.

FIGURE 1. Where the operator stood in relation to the fire.

FIGURE 2. Picture of where the fire started.

The three people on site tried to extinguish the fire with dry powder fire extinguishers from F-114 and from other vehicles in the area. At the beginning, the extinguishers were directed towards the fuse box on the lower right side of the dashboard. Later on, they were directed from the outside onto the right side of the cab. The flames reappeared every time and finally all extinguishers were empty. Thus, it was decided to discontinue the extinguishing and rather commence an evacuation. The operator manually set off the automatic fire extinguisher in the engine compartment before he left the vehicle. At approximately 13:11, the operator called 110 (the fire brigade). Shortly after this, all the people working in the area (40 persons) were evacuated approximately 500 meters. The road was also closed in both directions. In addition, all residents in the range of 500 meters were identified and evacuated.

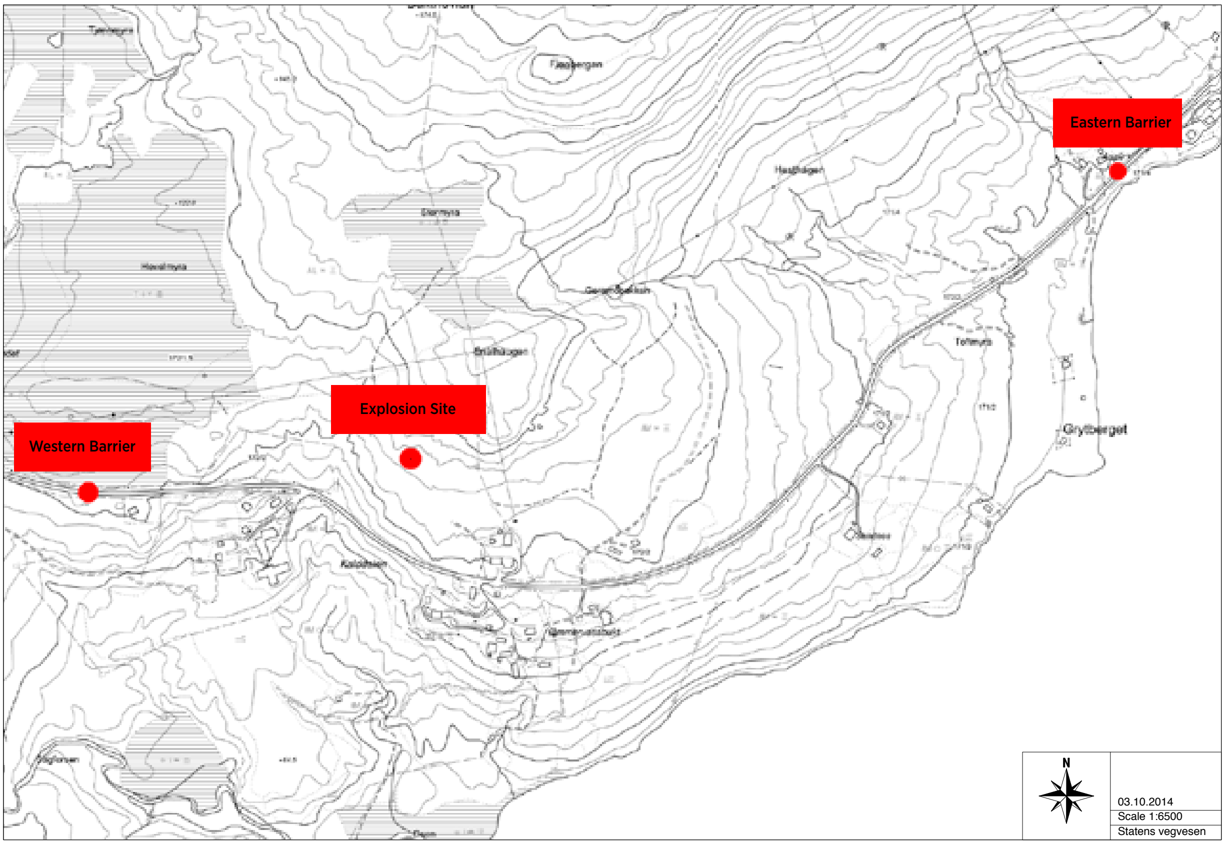


FIGURE 3. Map displaying the position of the MEMU and the eastern and the western barrier.

During the evacuation, there was a continuous dialogue between the Maxam operator and the police concerning the chemicals on board of the truck. The police was also in dialogue with DSB concerning evacuation zones. The police executive arrived at approximately 13:40 and the fire brigade arrived at approximately 13:50. At 14:21 the evacuation zone was expanded to 1 000 meters, however, to the best of our knowledge it seems that the eastern barrier ended on 1 000 meters while the western barrier was placed at approximately 500 meters. The eastern barrier was moved during the fire due to smoke.

The map (Figure 3) displays the position of MEMU F-114 and the eastern and western barrier. The police executive, employees at the NPRA and the Maxam operator were situated at the eastern barrier, while employees from Johs. J. Syltern, the police, NPRA and the fire brigade chief was located at the western barrier.

Both fire and production of smoke varied in intensity. Briefly before the explosion, the fire intensity increased considerably. After approximately 2.5 hours on fire, F-114 exploded at 15:24. The material damages in the area were of great extent. A private house burned to the ground while several other buildings suffered from structural damages and broken windows. Construction machines in the area were also damaged. There were no casualties.

The explosion was recorded on a mobile phone camera approximately 3 km from the site. After the explosion, the area was closed until the next day. In the afternoon on December 18th, representatives from Maxam and the contractor of the project entered the area to collect cartridged explosives and initiators remaining on the surface of the area. The ones lying closest to the truck were affected by the fire to some extent. The amount of collected explosives was the same as the initial amount before the fire was discovered.

On December 20th, blast number 50 was detonated.

CHAPTER

04

Certain Relevant Requirements for MEMUs and On-Site Production of Bulk Explosives

4.1 REQUIREMENTS FOR RISK ASSESSMENT AND EVALUATION OF DOCUMENTATION PRESENTED

The Fire and Explosion Protection Act § 19 and § 20 are relevant provisions for any business which handle hazardous substances. The company shall ensure that the level of safety is good enough and safety considerations should be integrated in all business phases including planning, design, establishment, operation and decommissioning.

Risks should be reduced to a level that can be reasonably achieved (the ALARP principle). There will always be a residual risk associated with the handling of explosive substances which normally has to be accepted in society. Such an acceptable level can be determined in several ways, for example as a quantified level of likelihood of a given type of accident and its consequences, or as a qualitative description. What can be reasonably achieved expresses a principle where the costs associated with the reduction of risk must be compared with the safety benefits that can be achieved.

The provision of the Regulations on Explosives § 2-2 on requirements for businesses stipulates that the business should identify hazards and problems that can arise when handling explosive substances, and implement compensatory measures. This provision has a content corresponding to the Regulations on the Handling of Hazardous Substances § 10.

§ 5-6 of the Internal Control Regulations states that a business shall identify hazards and problems, and based on this assess risks as well as establishing accompanying plans and measures to reduce the risk factors. It is required that must shall be documented in writing. The requirement to document risk assessments within the business, and that this should result in plans and measures to reduce the risk to an acceptable level, is therefore rooted in several regulations.

Understanding of risk is something a person, industry or business may have, partially have or not have. The prerequisites for a good understanding of risk are that a risk assessment has been conducted, that the risks are recognised and endeavoured minimised, and that a plan exists for managing the remaining risk. Achieving a good understanding of risk within an organisation requires interdisciplinary processes and good training/rehearsals.

A risk assessment should include a system description (what will be analysed), hazard identification as well as consequence and probability assessments for identified hazards. For identified hazards, technical and organisational measures should be implemented in order to reduce the risk to a satisfactory level, and contingency plans should be prepared if necessary.

The project committee has inquired about which risk assessments Maxam has developed of the project design and commencement using MEMUs, including a HAZOP analysis for on-site production. Associated with the fact that MEMU F-114 was involved in a collision, an explanation of how Maxam assessed whether the collision affected the risk situation was also requested.

According to Maxam, a risk assessment was conducted, but this is not documented. The project committee is of the perception that risk assessments within the business are insufficiently documented.

The project committee has received Maxam Europe's HAZOP for on-site production. HAZOP (Hazard and Operability) is a qualitative method suitable for identifying hazards of processes and operating terms, and can be a supplement to a risk analysis. When hazards are identified, measures shall be implemented to prevent these situations from arising. The document provides an overview of the elements to be analysed. Non-conformances and causes for non-conformances are well documented, but we question how consequences, security measures and corrective actions are described in the document and how they are implemented.

Concerning the question of whether the collision affected the risk situation, it is Maxam's view that a full restoration at an authorised garage did not affect the risk situation, and Maxam's Management of Change procedure was therefore not implemented.

The project committee is in principle of the opinion that a significant reconditioning of the electrical system on an ADR vehicle should call for a raised alertness until it is certain that the repair was satisfactorily performed. The committee has not taken a decision on what this extra alertness should entail.

After the repair following the collision with the elks, a bull bar (frontal protection system) was mounted at the front of the vehicle. The bull bar restricts the access to the engine compartment. This report does not claim that the bull bar was the reason that the fire could not be extinguished. What the project committee however does question, is whether Maxam should have implemented the Management of Change procedure for mounting the bull bar. The committee assesses the risk situation of a fire in the engine compartment to have changed when the opportunities for extinguishing the fire has changed. The assembly of new equipment is a change, and any need for communication to employees regarding new risk factors, training etc. should be carefully considered.

4.2 APPROVAL OF F- 114 BY THE NPRA

The Inland Transport Regulations apply to the carriage of UN 1942 ammonium nitrate, UN 3375 emulsion and other dangerous substances which are considered dangerous goods according to the UN Recommendations on the Transport of Dangerous Goods. The annexes to the European Agreement concerning the International Carriage of dangerous goods by Road (ADR), which is an integral part of the Inland Transport Regulations, did from 1st January 2009 introduce specific provisions for the transport of dangerous goods on MEMUs. This includes provisions for the construction of tanks, bulk containers and special compartments for these units in Chapter 6.12, and provisions concerning the construction of MEMUs in Part 9.

The purpose of the provisions of ADR is to maintain safety during carriage of dangerous goods by road. The various technical requirements, design specifications etc. in ADR also have a positive impact on safety at the moment the production of bulk explosives is initiated, i.e. after the transport operation has ended. Hence the provisions of ADR have been considered in the report compiled by the project committee.

Approvals of MEMUs are performed by NPRA according to ADR Section 9.1.2, which issue certificates of approval in accordance with ADR Section 9.1.3. In order to have the certificate of approval issued, the vehicle's compliance shall be verified through an initial inspection. Subsequently, an annual technical inspection is required in order to extend the validation of the certificate of approval. This annual inspection shall cover the relevant provisions of ADR as well as the general technical requirements for vehicles. Only the part of the annual inspection concerning ADR must be conducted by NPRA. The remaining part of the examination can be performed at a garage approved by NPRA for such inspections.

MEMUs must fulfill the requirements for relevant base vehicles as specified in Chapter 9.2. This include requirements for wiring, battery master switch, batteries, permanently energised circuits, electrical installation at rear of cab, braking equipment, antilock braking system, endurance braking system, fuel tanks, engine, exhaust system, prevention of fire risks, combustion heaters, speed limitation device and coupling device of trailers.

Chapter 9.8 applies additional requirements concerning complete or completed MEMUs. Listed here are the requirements for tanks and bulk containers, earthing systems, stability and protection against rear impact. Included in this chapter is also the requirement for an automatic fire extinguisher system for the engine compartment.

Provisions on firefighting materials are given in ADR Section 8.1.4. The provisions specify the quantities, types and locations of hand extinguishers to be placed on the vehicles.

With regards to the initial inspection under ADR, F-114 was approved on the third attempt on 17th June 2010 by NPRA, Risløkka Traffic Services Office. All non-conformance remarks noted under the first inspection had then been rectified. The vehicle had since been subject to periodic inspections, the final time on 12th February 2013. An extension of the ADR certificate of approval requires that the vehicle has additionally passed the general EU inspection.

4.3
DESIGN, CONSTRUCTION AND TESTING OF TANKS

Concerning design, construction, testing of tanks etc., ADR Chapter 6.12 applies. The chapter specifies or directs to the technical construction requirements for tanks, bulk containers and special compartments for explosives of MEMUs.

Tests, inspections and checks shall according to ADR sub-section 6.8.2.4.5 be conducted by an expert approved by the competent authority. Under ADR sub-sections 6.12.3.1.3 and 6.8.2.4.5, new MEMU tanks shall also be approved by an expert. DSB has delegated this authority to DNV (Det Norske Veritas).

According to a letter from DNV to Maxam dated 11th May 2010, the tanks with associated equipment are approved in accordance with ADR 2009, Chapter 6.12.

The tank was due for periodic inspection in January 2013. The final tank inspection was performed by DNV on 7th February 2013. DNV has explained that when this inspection was about to take place, the tank had not been cleaned, and an internal examination was therefore not possible.

Rather than a periodic inspection, an intermediate inspection with no requirement of an internal examination was conducted. A pressure test was performed in place of the leakage test normally required for an intermediate inspection. Carriage of dangerous goods in a tank which is overdue for periodic inspection is not permitted. NPRA renewed the vehicle certificate of approval under ADR sub-section 9.1.2.3, although the main inspection of the tank was not performed, and only an intermediate inspection was reported.

4.4
CARRIAGE OF UN 3375

According to ADR Sections 3.1.1, 3.2.1, Table A of 3.2 for UN 3375, 3.3.1, special provision no. 309 final paragraph, UN 3375 shall pass Test Series 8 in the UN Manual of Test and Criteria, and be approved by the competent authority. In addition, ADR Section 4.3.5 TU39 requires that "The suitability of the substance for carriage in tank shall be demonstrated. The method to evaluate this suitability shall be approved by the competent authority. One method is test 8 (d) in Test Series 8".

This entails that the substance according to SP 309 must be approved by test (a), (b) and (c) in Test Series 8, and that the suitability of the substance for carriage in tank according to TU39 shall be tested in a manner that is acceptable to the competent authority.

Maxam has presented "BAM Bescheid No. II.3/3440/06" for Maxam's "AN/SN Emulsion" as approval of the substance as UN 3375, and the suitability of the substance for carriage in tanks. The approval was granted in relation to a name change of the emulsion. The former name was Dyno Emulsion. However, it is not clear from this document that the emulsion has passed Test Series 8 as referred to in SP 309 and TU39. Neither does it contain any information which makes it possible to identify which substance has actually been approved. The project committee has subsequently received a test report for Test Series 8 (a), (b) and (c) for the emulsion from Germany. The emulsion has also been subject to a "modified vented pipe test" 8(d) to demonstrate the suitability of the substance for carriage in tanks, cf. a letter from BAM to Maxam dated 16th July 2014. The traceability between the documentation received and the name which applies for the emulsion used by Maxam today, is not satisfactory.

DSB has to date not granted any approvals in accordance with SP309 in ADR. There are no comprehensive national regulations in place concerning the acceptance of other authorities' approvals. DSB's practical approach has been that demonstrating suitability for carriage in tanks is not necessary, when the substance is carried in tanks of aluminium or fibre-reinforced plastic. Neither are there any general national regulations in place on which test methods acceptable.

4.5 APPROVAL OF MEMU F-114 AND AUTHORISATION FOR MANUFACTURE

According to the Regulations on Explosives § 2-7, the machine, apparatus, container or other appliance particular for the handling of explosives, shall be approved by the regulatory authority before it is placed on the market or used. The provision applies to the approval of the actual appliance. The purpose of the provision is to ensure that all safety requirements for consumers and the surroundings related to any handling of a device intended for the use for handling explosives, are fulfilled.

As the substances handled in a MEMU become explosive through the manufacturing process, the general practice has been to consider both raw materials and semi-finished products to be explosive, hence the Regulations on Explosives § 2-7 applies.

Pursuant to § 6-1 of the Regulations on Explosives, an authorisation from a regulatory authority must be obtained in order to manufacture explosives.

For MEMU F-114, the approval under Regulations on Explosives § 2-7, and the authorisation for manufacture according to the Regulations on Explosives § 6-1, were granted synchronously through DSBs decision dated 8th June 2010. The authorisation applies for products in the Riomex series.

A condition was set: The chassis should be approved according to the applicable requirements for the chassis and the additional requirements for completed MEMUs cf. Chapter 9.8 of ADR. The authorisation for manufacture from DSB is granted on the condition that the truck operator receives the necessary training in accordance with the organisation's instructions. Safety instructions and instructions for operating the manufacturing and charging unit shall be complied to.

Maxam's operator held a valid driver training certificate including a specialisation for carriage of explosive substances and carriage in tanks. Additionally, Maxam has reported that the operator in question has completed the internal training.

4.6 REQUIREMENTS FOR MAINTENANCE ON MEMUS

There are no specific requirements for maintenance on vehicles in ADR, but dangerous goods shall not be transported if the equipment is not in order, see ADR sub-section 1.4.2.2. The Inland Transport Regulations § 5 requires that the owner and the operator of the vehicle and other materials, shall keep this in a proper condition through systematic performance monitoring and maintenance. What is considered a safe general maintenance level, must be decided in relation to what the manufacturer of the vehicle/material deem necessary based on the use of the equipment.

MEMU F-114 and the tanks have been through the imposed periodic inspection under the direction of NPRA and DNV. NPRA should not have renewed the certificate of approval for the vehicle under ADR sub-section 9.1.2.3, as the main examination of the tank was not performed.

ADR lays down provisions on the use of fixed tanks for UN 3375 in 4.3.5 TU 39 which intends to prevent solidification, accumulation and packing of materials. 4.3.5 TU3 specifies that the inside of the tank and all parts that may come in contact with the substance shall be kept clean. To meet these provisions, as well as the prohibition on hoppers and discharge pipes containing premixed materials during transport, MEMU operators must have procedures for cleaning and cleansing of the equipment. Such cleaning procedures of the equipment is an essential prerequisite for the equipment to function as intended and it also affects the safety during production and charging, although the provisions are established for safe carriage. Maxam has not documented that they have a routine for regular cleaning of the tanks.

According to the Norwegian Labour Inspection Authority's Regulations concerning Performance of Work § 10-5, the employer must ensure that only work equipment compliant to the relevant regulatory requirements, and the technical requirements of the Regulation concerning Machinery, is used.

According to the regulations listed, F-114 should have been maintained in order to meet the technical requirements of the Regulations concerning Machinery. No verifiable information has been presented on F-114's potential compliance with the above listed technical requirements, at the time of the accident.

CHAPTER

05

Mobile Manufacture of Bulk Explosives with F-114

5.1
HISTORY OF THE VEHICLE

MEMU F-114 was registered with registration number VF 62363 in Norway in 2010. F-114 had a chassis of type FH12 8*4 produced by Volvo in 2004 with chassis number A 587997, and was acquired by Maxam in 2010. The F-114 production/pump unit was produced by Talleres Cobo Hermanos S.L. with serial number C/0200/06 in 2006. The unit was first delivered to Maxam UK and was in 2010 transferred to Norway, where it was mounted onto unit F-114.

F-114 was brought into use in Norway in June 2010. The unit has subsequently traversed a stretch in the order of 220,000 km, delivered more than 5,300 tonnes of explosives and the engine has been in operation for more than 6,000 hours.

On 20th November 2013, F-114 was involved in a collision with three elks. The chassis received damages which were rectified in authorised garages, Volvo Car TTS and Dekksenter AS. There were damages related to the headlights and cables on the right side, to the car body and grille. Additionally a bull bar was fitted. The repairs were relatively comprehensive and in the order of 200,000 NOK. After the repairs, F-114 performed different charging missions. During these three charging missions, F-114 pumped a total of 26,895 kg without any non-conformances.

FIGURE 4. Picture of damages on MEMU F-114 after collision with the elks.

5.2
MANUFACTURE OF RIOMEX SC 7000

5.2.1 RIOMEX SC 7000

The explosive Riomex SC 7000 that was manufactured by F-114 is a mixture consisting of several components. Riomex SC 7000 is manufactured by adding ammonium nitrate porous prills (ANPP) and diesel to emulsion (ANE), before the mixture is sensitized. This type of bulk explosives is intended for use above ground only.

All types of emulsion explosives must be sensitized. Riomex SC 7000 is sensitized through chemical gassing. The gassing is catalysed by the addition of acid at the outlet of the product pump.

The table below provides an overview of the amounts of chemicals the MEMU could carry and use for manufacture.

CHEMICAL	UN	LOADED [KG]
ANPP (NH_4NO_3)	1942	5 000
ANE	3375	8 000
Oxidizing Agent (Gassing Agent)		90–100
Acid		90–100
Diesel		450 L

FIGURE 5. List of chemicals in unit F-114.

Maxam's emulsion, OM12, is produced by Maxam in Sweden. The emulsion loaded on F-114 prior to the accident was produced in Enköping on 20th November and carried to the depot station at Brønnøy Kalk in Norway on 21st November.

5.2.2 MANUFACTURING PROCESS IN F- 114

The ANPP tank was constructed of aluminium and had a capacity of 6,600 litres. An auger was assembled to the bottom of the tank to take the ANPP to the vertical auger leading ANPP further up to the horizontal mixing auger. The emulsion tank equally had a capacity of 6,600 litres and was also constructed of aluminium. The emulsion is pumped through a hose to the horizontal mixing auger, and is the first addition to the auger. It is the project groups opinion that this process layout not is in accordance with best practice in the industry. A lay out where ANPP is mixed with diesel before ANE is added to the process, is considered best practice. This because the ANPP then better absorbs the diesel.

The capacities of the diesel tank and the tank for gassing agent were 430 and 150 litres respectively, both constructed of aluminium. The diesel tank (for production) was attached to the chassis on the right side at the back (behind the emulsion tank, beside and under the hose reel). The tank containing the gassing agent was mounted onto the vehicle's right side behind the second rearmost cabinet door. During production, diesel and then gassing agent are added into the horizontal mixing auger. Despite the fact that the gassing agent is added into the auger, the gassing will happen slowly due to the relatively high pH of the mixture. Without the addition of acid, this mixture would reach a bulk density of 1.2 kg/dm3 after approximately 45 minutes at 25 °C. After the mixing, the mixture is transferred to a container for finished product with a capacity of 275 litres. The production starts and stops depending on the level of the finished product container.

In a scenario where the horizontal auger is exposed to heat the emulsion will be sensitised through gassing even if the pH is high. Acid is only a catalyst to increase the speed of the gassing process because of the relative high pH in the emulsion and cold conditions. It is the project groups opinion that a better lay out would be to introduce the acid at a later stage in the process. This to reduce the risk of gassing of the emulsion before it enters the drilling hole.

When the operator starts charging a borehole, the water pump and the pump that dispenses acid are also activated. The water tank of 800 litres capacity was placed between the two major product tanks. The acid tank of 150 litres capacity was placed on the vehicle's right side behind the rear cabinet door.

The capacity of F-114 was about 13 tonnes.

5.2.3 CONFORMITY ASSESSMENT

According to the provisions of the Regulations on Explosives Chapter 3 and Annexes I and II, specific requirements are laid down for the conformity assessment, declaration of conformity including accompanying documentation for explosive materials. These regulations are the implementation of Directive 93/15/ EEC concerning marketing and control of explosives for civil use.

According to the Regulations on Explosives § 3-4, a technical inspection body must certify that the explosives are in conformity with the provisions of the directive prior to a release to the market.

The project committee has received the "EF type examination certificate No. 0589. EXP. 2443/02" issued by BAM on 17th December 2003. The certificate confirms that a prototype of the explosive Emulgit AN RP meets the basic safety requirements of Annex I of Directive 93/15/ EEC. The project committee has also received the first appendix to the "EF type examination certificate No. 0589. EXP. 2443/02" issued by BAM on 14th July 2009, upon request from Maxam Deutschland GmbH. The document verifies the amendments to certificate no. 0589 concerning the manufacturer's name and address, which were changed from West Blast Gmbh to Maxam Deutschland GmbH. That RIOMEX SC 7000 shall be added as an alternative trading name for the explosive Emulgit AN RP, is also covered.

CHAPTER

06

Precursors for On-site Production of Explosives

The following chapter gives an introduction to the physical and chemical properties of the chemicals transported by F-114 at both ambient and elevated temperatures.

6.1 AMMONIUM NITRATE, TECHNICAL GRADE

The explosives produced on MEMU-114 used ammonium nitrate as porous prills (ANPP). ANPP is of a characteristic porous quality (density of 0.8 g/cm³) which is especially suited for the production of ammonium nitrate based explosives. ANPP is classified as dangerous goods class 5.1 oxidizing substances, UN1942. Ammonium nitrate (AN) classified as UN1942 must not contain more than 0.2 % combustible material. ANs thermal conductivity is extremely low and its heat capacity is relatively high, implying that quite high amounts of heat must be applied to melt it. ANPP consist of pure AN and the chemical properties of ANPP will be equivalent to those of AN.

6.1.1 DECOMPOSITION OF AMMONIUM NITRATE

At elevated temperatures several alterations can be observed with AN. First of all, the crystal structure of AN changes at 32 °C going from porous grains to a more powder-like form. This can have a sensitizing effect. ANs melting point is approximately 170 °C, however, an extremely slow endothermic decomposition can be observed from 80–90 °C.

The products forming from this decomposition is ammonia and nitric acid:

$$NH_4NO_3(s) \rightleftharpoons NH_3(g) + HNO_3(g)$$

When the temperature exceeds ANs melting point and approaches its boiling point (210 °C), a second exothermic decomposition can take place, yielding nitrous oxide and water:

$$NH_4NO_3(l) \rightarrow N_2O(g) + 2H_2O(g)$$

Temperatures above the boiling point accelerate the decomposition of AN. Furthermore, poisonous red/brown NOx gasses can be formed. This decomposition can be of explosive nature.

6.1.2 EXPLOSIONS ORIGINATING FROM AMMONIUM NITRATE

Explosions in AN can be caused by one of the following three mechanism: heating under confinement, run-away reaction or detonation. The ability of AN to detonate depends on several conditions e.g. the chemical and physical properties of the ammonium nitrate involved (technical grade, fertilizer grade, melted etc.), the surroundings, contaminations, temperature and pressure.

When AN is confined and heated, the decomposition rate increases considerably and the pressure can reach extremely high levels, thereby initiating an explosion (4,6,7). There is a broad consensus in litterature about the theoretical possibility of an explosion occuring in large amounts of pure AN during fire caused by local heating and an inner collapse, thus leading to a local surge of pressure. The areas with elevated temperatures and low density (due to melted AN) can have a sensitizing effect thereby creating local confinement and pressure build-up which can lead to an explosion.

A rapid increase in pressure which is high enough to initiate melted AN is also a theoretical possibility with the earlier mentioned inner collapse in large piles of AN.

Several experiments have been performed on both large and small amounts of AN. Whereas small-scale tests (gram scale) using rapid localized heating have shown that pure AN has the ability to detonate (7c), it still remains to prove that AN can detonate during fire due to local pressure build-up in large-scale tests. It has proven to be extremely difficult to perform and reproduce results from these types of large-scale experiments. On the other hand, it has been possible to get large amounts of AN to detonate during fire with small amounts of sensitizing compounds (e.g. diesel). (4)

A run-away reaction in a compound happens when the overall elevation of temperature leads to an increase in reaction rate leading to a larger heat input than output to the surroundings. Thus, the heat originating from the reaction/decomposition will increase the reaction/decomposition rate in addition to the externally applied temperature. This run-away reaction can lead to an explosion.

The phenomenon deflagration-to-detonation transition is often mentioned in literature on explosives. As the name implies, this phenomenon is observed when a deflagration (combustion) in a potentially explosive compound transforms into a detonation. The exact mechanism concerning this phenomenon is not completely understood; however, it is believed that both confinement and run-away reactions can lead to such a transition.

There is a variety of impurities that can increase the explosive potential of AN. Amounts as low as 0.2 % organic material such as diesel, cellulose etc. or metals such as aluminum, can increase the sensitivity considerably. (8)

6.1.3 RELEVANT RESEARCH ON THE EXPLOSIVE PROPERTIES OF AN UNDER FIRE EXPOSURE

Ammonium nitrate has been involved in several accidents over the last century, usually due to fire exposure. Consequently, a large amount of literature on the explosive behavior, especially at elevated temperatures, can be found. It is generally believed that AN is of low sensitivity and requires a powerful initiation to be able to detonate. Still, there are certain conditions and scenarios that seem to increase the probability of detonation; however, they are usually difficult to reproduce. A common reason for this is that most of these experiments are performed in a small scale due to safety and convenience. The following examples represent large-scale tests and experiments.

In the report “Explosion Hazards of Ammonium Nitrate Under Fire Exposure”(4) the explosive hazards of AN under fire exposure is investigated. The report concludes that AN, at ambient conditions, is of extremely low sensitivity and requires a large charge and a powerful explosive donor. However, the critical diameter of AN will decrease significantly at higher temperatures and thus be of higher sensitivity. This observation has been thoroughly investigated.(5) Still, even at heavy confinement and elevated temperature, no detonation in pure AN was observed.

AN mixed with different types of combustible materials was also investigated. Detonation was observed, but only when confined. The heated mixtures were also investigated for projectile sensitivity. With these experiments, both contaminated and pure AN was able to detonate at temperatures close to the melting point of AN.

Projectile sensitivity was also investigated in the report “The Sensitivity of Ammonium Nitrate Melts and Solutions To Projectile Impact”. (6) These tests showed that when elevating the temperature to 260 °C, molten AN could be detonated by projectiles with sizes above 50 mm, even in an unconfined state. The critical shock velocity was found to be 190 m/s. Furthermore, it was shown that the projectile sensitivity was diminished at lower temperatures and when diluting with water. This report was part of a series of reports published over five years by “The Department of Mining Engineering at Queen’s University” in Canada. (6,7) Several tests were performed on both solid and liquid AN mixtures, to investigate its ability to detonate under different conditions. The main conclusion was that the shock sensitivity of pure AN, both as a solid and liquid, was a direct function of temperature. At high temperatures the density of AN decreases and this lower density correlates to higher shock sensitivity. In addition, it was observed that the increase in shock sensitivity at high temperatures was dependent on the amount of AN.

Additives or impurities can have a great impact on the sensitivity of AN. (8) Combustible materials in amounts as low as 0.2% (e.g. diesel, cellulose etc.) or metals (e.g. aluminium) can increase the shock sensitivity considerably, especially at high temperatures. (10). Chloride salts such as $CaCl_2$, NH_4Cl, $AlCl_3$ and $FeCl_3$ in amounts as low as 0.1% are also known to cause an increase in sensitivity by lowering the decomposition temperature. (10) In addition, acidic conditions can also cause higher sensitivity and increase the explosive hazard. (11)

6.2 AMMONIUM NITRATE EMULSION

The ammonium nitrate emulsion (ANE) used on F-114 consisted of a hydrous AN solution mixed with an oil. By the means of emulsifiers, this creates a petroleum jelly-like mixture. The emulsion is oil continuous and thus is not miscible with water. AN is classified as class 5.1 oxidizing agent and is transported as dangerous goods UN3375.

ANE mostly consists of diluted AN and can, when heated, theoretically lead to similar decomposition patterns as described for pure AN. If the water in ANE is able to evaporate, the resulting mixture will be similar to that of ANFO. This could have a greater explosive potential under fire exposure than ANPP alone. Thus, by heating ANE, especially under confinement, the explosion hazard will be greater. If the AN in this mixture starts do decompose, the mixture can basically sensitize itself by "self-gassing" leading to a mixture with lower density and greater sensitivity. Contaminations in ANE will have similar effects on ANE as described for ANPP.

6.2.1 RELEVANT TESTS ON THE EXPLOSIVE PROPERTIES OF ANE

Several requirements in the regulations for transportation of dangerous goods (ADR/RID) must be satisfied to allow a compound to be classified and transported as UN3375. Several empirical tests must be performed and passed for an emulsion to be approved. These tests are thoroughly described in the UN test manual and investigate the following properties:

- Thermal stability
- Shock sensitivity (GAP test)
- Sensitivity at high temperatures and confinement (Koenen test)

In addition to this, the compounds need to be proven suitable for transportation in tanks by a method that is found acceptable by the local authorities. A frequently applied method for this is The Modified Vented Pipe Test (MVPT). By burning the compound in a steel pipe of defined dimensions, the method indicates how the compound behaves under fire exposure and ventilated confinement. This MVPT has also been performed on emulsion using an aluminum pipe. This test showed that the aluminum melts and rips under the influence of elevated temperatures, thus preventing a pressure build-up.

Usually, when performing the MVTP on emulsion, a violent reaction can be observed and the emulsion is thrown out from the steel pipe. The diameter of the ventilation has proven to be of great significance for the explosive behavior of ANE in these types of test.

Three large-scale results have investigated the consequence of a fire when ANE is transported on ADR approved steel and aluminum tanks, respectively.(2,3) The steel tank produced a rapid pressure build-up and decomposition of the ANE and finally a powerful blow-out, while the aluminum tank quickly weakened by the heat and ruptured. In the latter, the ANE poured out and burned until it extinguished by itself. Two large-scale tests were performed on aluminum tanks. In both, 25-40% of the emulsion was left after the fire extinguished.

An important note is that these large-scale tests were prepared in ways that are not completely representative for a fire in a MEMU with regards to the heat distribution, fire origin, truck construction etc.

6.3 DIESEL OIL

F-114 had two diesel oil tanks used for truck fuel and explosives manufacturing, respectively. Diesel oil is a petroleum based fuel consisting of both saturated and aromatic hydrocarbons. The diesel used for manufacturing purposes had a boiling point at 190–370 °C, flash point at 65 °C and was classified as a flammable liquid. The truck fuel had a lower flash point at 60 °C. The safety data sheet for the diesel used as a part of the explosives production has been provided.

6.4
SODIUM NITRITE SOLUTION

Sodium nitrite is a colourless to white salt and is classified as oxidizing, toxic and environmentally damaging. Sodium nitrite is used as a sensitizer due to its reaction with AN which produces nitrogen gas. The explosive hazard of sodium nitrite is much lower than for its corresponding nitrates; however, explosive mixtures can be formed when combined with ammonium salts, pulverized metals or combustible materials. The melting point of sodium nitrate is 280 °C. When temperatures exceed 320 °C, sodium nitrate becomes unstable and starts to decompose producing sodium oxide, nitrogen(II) oxide and nitrogen dioxide:

$$2NaNO_2\ (l) \rightarrow Na_2O\ (s) + NO\ (g) + NO_2\ (g)$$

The safety data sheet for sodium nitrite in 25 kg bags has been provided. Here, the compound is described as flammable in contact with combustible material and it must not be exposed to heat. It is non-compatible with other oxidizing agents, acids and ammonium salts. In this case, the sodium nitrate was transported as a hydrous solution. Even though sodium nitrate does possess the described properties, it should be accounted for that these do not directly correlate to a 25 % solution.

6.5
ACETIC ACID SOLUTION

Acetic acid is a carboxylic acid which is weak acid with a boiling point between 118-119 °C. Acetic acid above 10% is classified as a corrosive, flammable liquid. The acetic acid on board F-114 has a flash point at 69 °C. The acetic acid functions as a catalyst in the sensitizing process in the explosives mixture, providing the desired density. This process is more thoroughly described in the next chapter.

The safety data sheet for the acetic acid transported on F-114 has been provided. The data sheet describes the compound as non-compatible with oxidizing agents, high temperatures and open flames should be avoided. Heating can produce flammable gasses.

CHAPTER

07

Relevant Accidents

7.1
AMMONIUM NITRATE RELATED ACCIDENTS

AN is produced in large quantities world-wide. In 2012, it was estimated that the production exceeded 57 million tonnes. Approximately 75 % of this is used in fertilizers, while the remaining 25 % includes civil explosives such as ANFO (ammonium nitrate-fuel oil) and emulsion explosives, which are a safer alternative than other more sensitive explosives with the same explosive effects.

During the last century, several accidents involving AN have been reported. One of the best known is the factory accident in Oppau, Germany in 1921 where a 4,500 tonnes mixture of ammonium sulfate and ammonium nitrate exploded due to the expired method of using dynamite to crush caked ammonium nitrate. Next, the accident at the harbor of Texas City, USA, in 1947 is to date the largest industrial accident reported in the US. To ships carrying 2,280 and 961 tonnes of AN fertilizer caught fire and eventually exploded. At that time, the AN beads were coated with a wax to protect the AN from moisture and prevent caking. Now it is known, that this sensitized the AN. In addition, the fertilizer was stored in paper bags at relatively high temperatures, adding further hazardous explosive conditions. One of the more recent accidents involving AN happened in West, Texas, USA in 2013 where a fire in a fertilizer factory lead to an explosion. It is believed that the fertilizer was stored together with combustible materials, which is probably the main cause for this event.

7.2
FIRE AND ACCIDENTS INVOLVING ROAD TRANSPORTATION OF AMMONIUM NITRATE

The following description of accidents will focus on fires in engine-driven vehicles carrying AN and/or emulsion since this will be of greatest concern for the accident described in this report. There have been no earlier reported accidents involving MEMUs neither nationally nor internationally.

On-site production of liquid explosives has been carried out in Norway since the 60's. During this time, only one accident has been reported, in 1999. However, this did not involve the mobile production unit directly. During the construction of the Ibestad tunnel, a fire started in the drilling rig. The tunnel and area close to the tunnel was evacuated for 24 hours. However, the fire did not lead to an explosion. Several accidents involving the transport of AN and AN based explosives have been reported internationally. Some of these are described in the following table.

WHERE	WHEN	CARGO	COURSE OF EVENTS	DAMAGES
Walden, Canada	1998	18 tonnes with AN based explosives, e.g. ANFO.	A tractor and trailer went off the road and hit a rock wall. The vehicle caught fire and after 35 minutes with intensive fire, the vehicle exploded.	Two persons hurt. Major property damages.
Usmanka, Russia	2004	Unknown amount of ANE.	The vehicle went off the road, caught fire and exploded.	Only material damages.
Mihailesti, Romania	2004	23 tonnes of AN fertilizer.	The vehicle went off the road, turned over and caught fire. The driver unsuccessfully tried to extinguish the fire. The fire lasted for 1 hour until the vechicle exploded.	18 people died (the driver, 7 firefighters, 2 journalists and 8 spectators) and 13 were hurt.
Barracas, Spain	2004	25 tonnes of AN fertilizer.	The vehicle crashed with a car, turned over and caught fire. After approximately 30 minutes of fire, the vehicle exploded.	2 people died and 5 were hurt.
Shengangzhai, China	2005	19,5 tonnes of AN of unknown quality.	Unknown.	12 died and 43 people were hurt.
Charleville	2014	50 tonnes of AN of techical greade.	The vehicle went off the road and caught fire. The fire lasted for approximately 1 hour until the vehicle exploded.	8 people were hurt.

FIGURE 6. Relevant accidents involving fire in a truck and/or emulsion.

The accident in Walden is perhaps less comparable to the Drevja accident than the other examples, since the Walden vehicle contained prefabricated AN explosives; however, it is mentioned in this connection due to the large amounts of literature and tests that have been produced based on this event.

CHAPTER

08

Collecting Documentation

The project committee continuously evaluated which kind of information that could analyse the accident in Drevja, and if it was possible to obtain. The following initiatives were implemented to collect useful information:

Immediate site inspection
On December 19th 2013 the police, Maxam, contractors and DSB inspected the site of the accident with the motive of understanding the incident and observing the extent of the damage.

Photos, videos and testimonies
Several pictures were taken throughout the course of event. Pictures have been provided by Maxam, the fire brigade, NPRA and Johs. J. Syltern. The project committee has conducted written interviews with Maxam, NPRA, the police, the fire department and Johs. J. Syltern. All documents have been shared with the police and Maxam. Both pictures and interviews have been analysed and evaluated as possible input for the event. In addition, the explosion was recorded on video at the military camp HV-14 approximately 3 km away. This video has also been analysed.

Survey on the extent of damage on buildings
The project committee carried out an inspection at the site in Drevja on February 24th–25th 2014. The aim was to survey the damages that the accident had caused on the buildings in the area. The observation from this survey was used later on in explosive yield calculations performed by DSB.

Survey of fragments
From June 2nd–4th 2014, Maxam and the project committee carried out an extended investigation at the accident site. NPRA and the Civil Defense supplied additional assistance while supplementary scientific competence was obtained from FFI. The aim was to survey the scattering of fragments as extensively as possible. This was to obtain the necessary data to perform calculations on explosive yield, identify the cause and point of initiation.

The following searches were organised:

- A search for big fragments in a range of 0-200 meters since FFI had a hypothesis that the engine block and other low-lying heavy fragments should be found in this proximity of the site. The position and weight of these fragments would provide data for explosive yield calculations and the evaluation of where on the MEMU the explosion was initiated.
- A search for larger fragments further from the zero point in a range of 250-700 meters. These would provide data for explosive yield calculations performed by Maxam.
- A search for aluminum fragments in a radius of approximately 700 meters. This would provide evidence for the evaluation on the possible melting of the aluminum tanks and the course of the explosive event.
- A search for vital parts. Vital parts are defined as pump, angers, but also fragments that can reveal the casue for the explosion.

Collecting data from vibration measurements
On a farm in close proximity to the accident, Multiconsult had, on behalf of NPRA, installed a meter to monitor the vibrations from the quarry. The meter was installed on the foundation of the piggery and measured vibrations in vertical direction. Values above a predefined trigger value were automatically saved.

Order to submit documentation
Maxam have been ordered to submit several types of documents. These have been provided.

Additional information
The project committee has collected additional information from a geologist from the NPRA. NPRA has inspected the garage that performed the repairs on MEMU F-114 after it had collided with the elks. This information was subsequently handed over to the project committee. Volvo was contacted regarding the amount of aluminum present in a Volvo FH cab.

If the project committee had had the knowledge we have to date and had had more resources, even more extensive information could have been collected. The comittee is in particular pointing to metallurgical and chemical analysis of the aluminum fragments which could probably have revealed more about whether the tank(s) melted and which tank the fragments originated from, based on e.g. the presence of hydrocarbon residues. Furthermore, the engine block could have been investigated more thoroughly. A more thorough search of chemical residues in the area after the event could have high-lighted if any chemicals had been thrown out of the tanks during the event. A better analysis of the quality of the windows in the buildings used in the earlier mentioned calculations could also have given a more precise figure in the explosive yield calculation. Finally, an even more exhaustive search for fragments could have been performed thus reducing the uncertainties in the fragment analysis. This additional information could have contributed to a more detailed analysis; however, it is uncertain if this would have influenced the evaluations or have made the description of the course of event more evident.

CHAPTER

09

Analyses and Evaluations

The project committee and external qualified academic specialists have independently performed several analyses and evaluations. These will be presented in the following sections and are contributions from the DSB project committee in cooperation with The Norwegian Defence Estates Agency (NDEA) and FFI, NGI and NPRA.

Additional calculations on explosive yield could have been performed on other fragments than the engine block by using the obtained information on the scattering of fragments. This could have provided supplementary information to the analyses on the engine block; however, it is important to stress that the uncertainty of these calculations increase when the size of the fragment decrease.

The video recording of the explosion could possibly have been used in a calculation on explosive yield based on the size of the fireball caused by the explosion. This has not been pursued since the analysis described in the following sections already provides three independent calculations.

9.1 ANALYSIS OF THE CAUSE OF THE FIRE

When analysing the depositions and photos from the accident, it appears to be highly likely that the fire started in the electrical installation down on the right side of the chassis. In this area, wires are connected between the headlight and the fuse box which is placed down on the right side of the cab. This was the area which was damaged when the vehicle crashed with the elks. Seeing that the fire extinguishing was not successful indicates that the origin of the fire was difficult to locate and reach. The project committee believes that it is quite probable that there is a connection between a failure in the electrical installation and the fire; however, this is not possible to document. NPRA inspected the garage which conducted the repairs after the collision with the elks, and support this assumption.

9.2 ANALYSIS OF THE SITE OF THE EXPLOSION

At the inspection of the site of the explosion, the most important observations were that the MEMU was considerably damaged and fragmented. Furthermore, no visible crater was seen and both cartridged explosives and initiators which were left at the site were still intact. Additionally, a pile of crushed stones which was lying next to the truck before the event seemed untouched, no apparent visible chemical residues were found in the area and the charging hose used for charging the boreholes was found close by the site relatively intact.

According to “Introduction of the technology of explosives” by Paul W. Cooper and Stanley R. Kurowski, a charge which is set off on a surface will create a crater. The size of this crater will depend on the size of the charge. The radius is quite predictable if the properties of the soil type/rock, the properties of the explosive, the shape and geometry of the charge, the distance above the surface and/or how deep underground the charge is buried. In relation to Drevja, few of these are known in detail.

If a charge is set off above ground, the size of the crater will decrease if the distance from the surface increases. If the center of the charge is three times the diameter of the charge itself, the diameter of the crater will be reduced to 5 % of what it is compared to an explosion on the surface.

Calculations performed by CONWEP (microcomputer program) results in a crater approximately 41 cm deep and with a volume of 0.9 m^3 when detonating 900 kg TNT on a surface consisting of massive, reinforced concrete or solid rock. The reason why no apparent crater was formed after the explosion in Drevja can have several explanations.

The geologist at NPRA associated with the earlier described road construction has performed a mapping of the geological properties of the rock types found in the area of the accident site. The type of rock at the explosion site is mica schist. Mica schist can tolerate higher pressure (is difficult to blast) than e.g. gneiss. This is due to a certain porosity found in this type of rock and because it can be deformed under pressure (ductility). The geologist is of the opinion that an explosion on the surface or close to a surface (< 0.5 m) which consists of mica schist will not affect the rock surface more than causing superficial cracks.

See Appendix 1 for a more thorough analysis.

In general, an explosive with low brisance will have poorer shattering capabilities than an explosive with high brisance. TNT is normally used as an internal standard when measuring brisance. Seeing that there were few damages on the rock surface at the explosion site, it is highly likely that the compound that exploded was of low brisance.

The absence of a crater could also point towards the explosion taking place above ground level, that the energetical material had a relatively large surface or that a possible formed crater was so small that it was difficult to identify.

The effect of an explosive is dependent on confinement. Thus, the effect will be different if the explosive is placed in a borehole or on a surface. No tests, experiments or accidents have demonstrated a formation of a crater when detonated on a surface consisting of mica schist.

FIGURE 7. Picture illustrating the field of mica schist.

FIGURE 8. Explosion site before the explosion.

FIGURE 9. Explosion site after the explosion.

Figure 8 and 9 clearly demonstrates that the MEMU was considerably fragmented and that these fragments were immensely scattered by the explosion.

Before the explosion, the MEMU was placed approximately in the middle of Figure 9.

FIGURE 10. Picture that illustrates the effect of the blast on the crushed stones.

In Figure 8, a pile of crushed stones is seen to the left, next to and in front of the MEMU. During the first inspection on December 19th 2013, it was observed that this pile was less affected by the shock wave than what could be presumed. Figure 10 also illustrates this; however, it is difficult to give any accurate evaluations on these effects due to uncertainty in the distances at the site.

Of the cartridged explosives, initiators and borehole plugs that were left behind on the blast area, only the borehole plugs in close proximity to the truck were affected by the fire. The remaining explosives were collected and counted. All explosives placed on the blast area before the accident were retrieved, and none of the boreholes had detonated.

The hose which contained the mixed explosive material was found more or less intact approximately 40 meters from where the MEMU had been. The hose had a length of 84 meters in total where the first 60 meters starting at the outlet from the truck consisted of 1″ reinforced rubber while the remaining 24 meters consisted of a 3/4″ plastic charging hose which is lowered into the borehole. The content of the retrieved hose piece was sent to LOM (technical controlling authority) for analysis. The composition of the product was analysed, the sensitivity was tested according to the UN test series 3a and 3b and the thermal stability of the product was evaluated. The results were in conformity with the statement of compliance for the explosive RIOMEX SC 7000.

FIGURE 11. What it looked like on the blast area after the explosion.

FIGURE 12. Picture of the hose with explosives.

No other residues of ANPP, ANE or other chemicals were identified at the explosion site.

Figures 13 and 14 show that the rock surface at the explosion site had a distinct red coloring. The geologist from NPRA states that it is highly likely that this was caused by the incident.

FIGURE 13. Picture that demonstrates the red coloring on the rock surface.

FIGURE 14. Close up of the coloring.

9.3 EXPLOSIVE YIELD CALCULATIONS BASED ON STRUCTURAL DAMAGES

This analysis is based on the estimated pressure and impulse from the explosion by evaluating the extent of damage on buildings in the area of the explosion site. If a pressure level at a certain distance can be estimated by evaluating the destructive damages, an explosive yield in TNT equivalent can be calculated. To estimate the pressure level, an evaluation of the number of broken windows in a wall is central.

The positioning and angle of the facade towards the explosion site is important in order to be able to calculate the reflected pressure.

By such an evaluation, a pressure-impulse curve can also be created. Different types of calculations for such types of curves can be performed depending on the dimensions, thickness and quality of the glass. NDEA have provided the project committee with the necessary curves representative for the case in Drevja.

The damages on the windows were only evaluated by taking pictures of the houses in the area. The sizes of the windows were not measured and the quality of the glass is not determined. Based on the pictures, the windows where roughly divided into large and small windows and it was assumed that the glass was of a non-hardened quality (old windows).

The pictures were analysed to find facades with several windows of the same type where only some of them were broken, since this indicates that the pressure and impulse values have been on the limit of what the windows can tolerate. The area and quality of the windows must then be evaluated in order to be able to estimate the pressure and impulse that the specific facade has been exposed to. A lateral pressure of 5 kPa can in most cases represent the pressure where windows can be broken. However, in some cases the pressure must exceed 10 kPa to achieve broken windows and some facades can even withhold pressure up to 15 kPa before 50% of the windows break.

FIGURE 15. Yellow house-wall facing south.

The damages on the windows seen on “the yellow house” will in this case represent a lateral pressure of 5 kPa. The distance between the house and the explosion site is approximately 210 meters and the reflection angle to the southern wall is approximately 76 degrees. Some of the windows are broken while others are pushed in. Corresponding evaluations have been performed for several other buildings in the area and the explosive charge which is needed to cause these observed damages have been calculated by CONWEP and PI-curves.

The calculated values correspond well with each other and this analysis provides values for the explosive yield at this particular event between 500 and 1,000 kg TNT.

Appendix 2 provides additional details on the extent of damage and the described calculations of explosive yield.

9.4

EXPLOSIVE YIELD CALCULATIONS BASED ON SEISMOGRAPHIC MEASUREMENTS

The interpretation of the seismographic measurements was assigned to the Norwegian Geotechnical Institute, NGI, by the project committee. The aim of this was to provide an estimate of the explosive yield of the explosion in TNT equivalent.

The measurements recorded during the explosion show two clearly separated phases – designated as

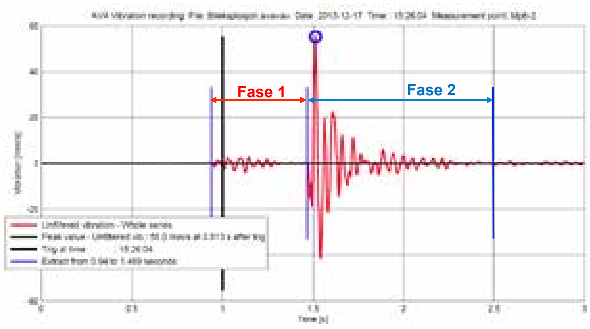


FIGURE 16. Registered seismographic measurements from the explosion in Drevja.

phase 1 and 2, respectively. NGI interoperate phase 1 to be vibrations which are transferred as mechanical waves from the explosion through the ground. Phase 2 are vibrations which are induced directly in and around the foundation when the air pressure from the explosion passes by.

Phase 1 and phase 2 were analysed separately. NGI has in addition to this performed a simplified calculation of the time of arrival for the two different types of vibrations, and also from the pictures of broken windows, which were described in the previous section. A more thorough description of these analyses can be found in Appendix 3.

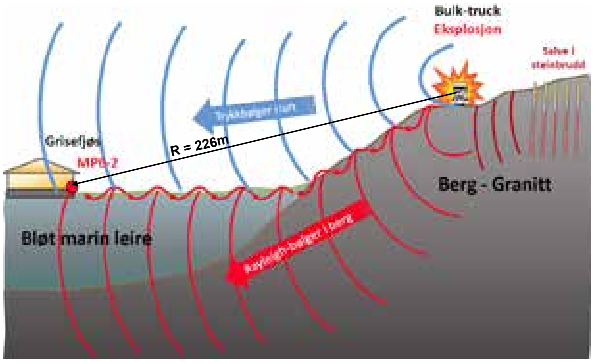


FIGURE 17. Situation – schematically.

The calculated estimates found for the described methods can be found in the following table.

Based on these results, NGI concludes that the amount of explosives that went off during the Drevja accident were equivalent to approximately 750 kg.

The described calculations are based on a site-specific propagation model for vibrations through the ground which has been established by NGI via collected vibration and blast data from previous blasts in the same quarry. This provides a more empirically based calculation method. The shortcoming of this method is that it is dependent on a coupling factor in order to be able to collate vibrations from a confined charge and an explosion in direct contact with the surface. The variation of the degree of contact with the surface and thus the size of this coupling factor can provide a variation in the estimated charge with a factor around two. This method provides low-area charge estimates.

	METHOD				
PARAMETER	ESTIMATE	DIRECT VIBRATION	PRESSURE INDUCED VIBRATION	ARRIVAL TIMES	BROKEN WINDOWS
Pressure	Best estimate	–	4.9 kPa	5.0 kPa	5 kPa
	Upper limit	–	7.4 kPa		10 kPa
Yield	Best estimate	630 kg	775 kg	775 kg	775 kg
	Upper limit	321 kg	1 700 kg	–	3 570 kg

The method utilizing the pressure wave induced vibration estimates the peak value at the piggery which is subsequently used to calculate backwards to what the size of the charge must be to provide the observed pressure wave at that distance. The link between the pressure wave and the seismographic measurements is quite complicated and is based on simplifications and empirical data. The coupling factor between the shock wave and vibration can also in this case have great impact on the estimated values which can change the estimated pressure with a factor of at least 1.5. By analysing the pictures of the broken windows, an estimated peak pressure value can be estimated. With this method, the greatest uncertainty is found when calculating backwards, since the link between the shock wave arriving at the piggery and the charge is non-linear. This means that even small variations in the estimated pressure can cause large variation in the estimated charge.

The estimated charge calculated from the arrival time of the two phases is also found by the estimation of the shock wave arriving at the piggery. It seems that this method provides a quite clear indication of the pressure and thus the size of the charge.

9.5 ANALYSING THE SCATTERING OF FRAGMENTS AND VITAL FINDINGS

The search for fragments was resource-draining; however, the result was a total of almost 350 registered fragments. Even more fragments were identified in the area; however, all of them were not registered as they were not important for the aim of the inspection. All of the registered fragments were registered with the appropriate coordinates, weight and a picture. An engineer from Maxam, Spain, has evaluated where on the truck the fragments originated from.

The fragments were found at distances from approximately 50 meters to around 500 meters. The map seen in the next figure shows a plot of all the registered fragments. The retrieved fragments varied considerably in weight, from aluminum fragments of a couple of grams to the engine block weighing around 900 kg.

Maxam has performed their own analyses based on the retrieved fragments as a part of their own individual report on this accident. Around 3,000 kg of the 9,000 kg of non-combustible material on the truck has been identified. Of these, around 30% of the total fragment count is aluminium, even though aluminium accounts for only 5% of the total weight. The remaining fragments are mainly of steel.

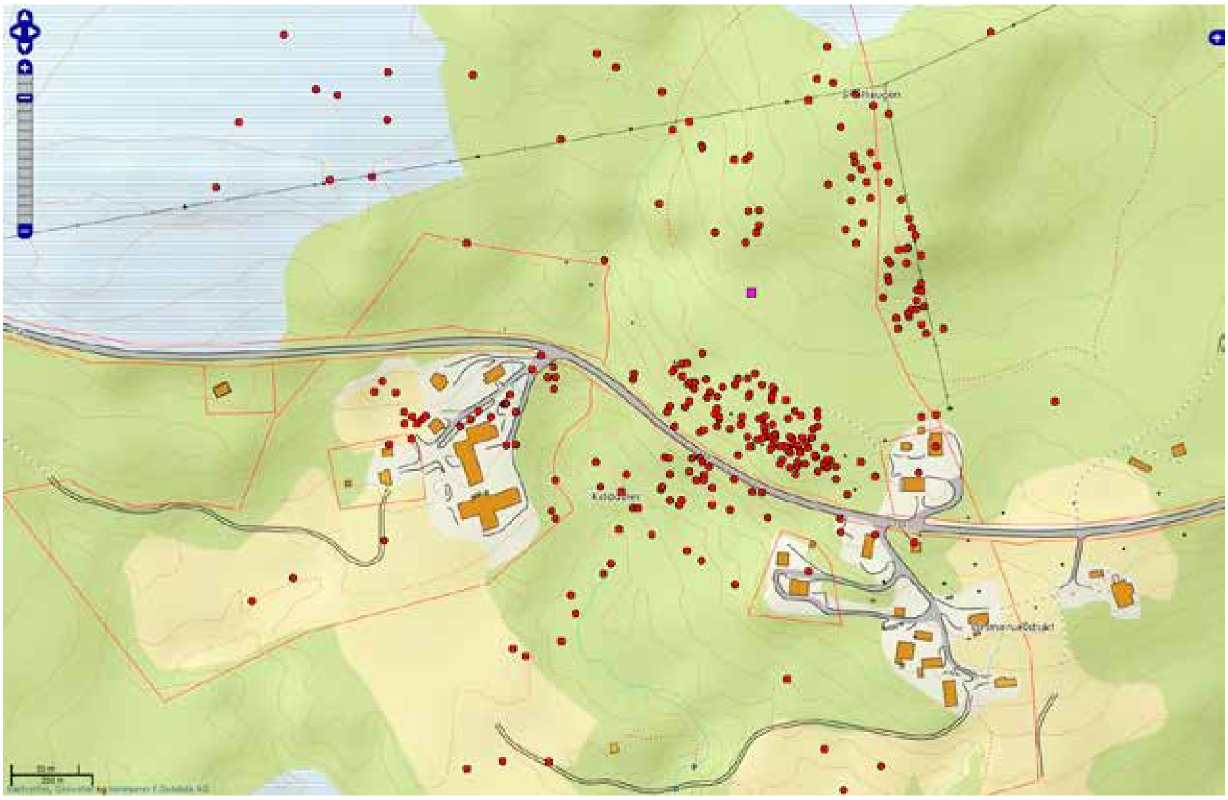


FIGURE 18. Map with plots of all the fragments. The pink square indicates the position of the MEMU.

9.5.1 ANALYSIS OF THE TRAJECTORY OF THE ENGINE BLOCK AND CALCULATION OF EXPLOSIVE YIELDS

The engine block was found approximately 200 meters from the explosion site in a south-western direction. This point was about 30 meters lower in altitude than the zero point. The trajectory of the engine block has been simulated by FFI with the intention of identifying the starting point and size of the force that is necessary to provide such a trajectory. The analysis can be found in detail in Appendix 4.

The initial speed of the engine block can be roughly estimated by using simple ballistic calculations neglecting air resistance (the effect of air resistance on a body as in this case will be quite small). These calculations indicate that the engine block had an initial speed of at least 40 m/s.

The simulation of the trajectory of the engine block was performed by modeling the engine as a rigid and homogeneous block with dimensions 1.1, 0.8 and 0.5 meters (l×h×b) and a weight of 900 kg. The engine block was situated approximately 0.5 meters above ground in the vehicle and the distance between the far back of the engine and the front of the ANPP tank was about 1.2 meters. This was also taken into account in the simulations. The reference explosive used in the simulation was TNT. In total, 37 simulations were performed differing in the configuration of the amount and shape of explosive and its distance above ground. In some cases, the explosive was placed directly underneath the engine block.

In the following figure, four different configurations can be seen where the combination of the shape, amount and positioning of the explosive and initial velocity and engine of the engine block provides the observed trajectory from the accident.

FFI specify that the simulations employ ideal shapes of the explosive and if more factual conditions had

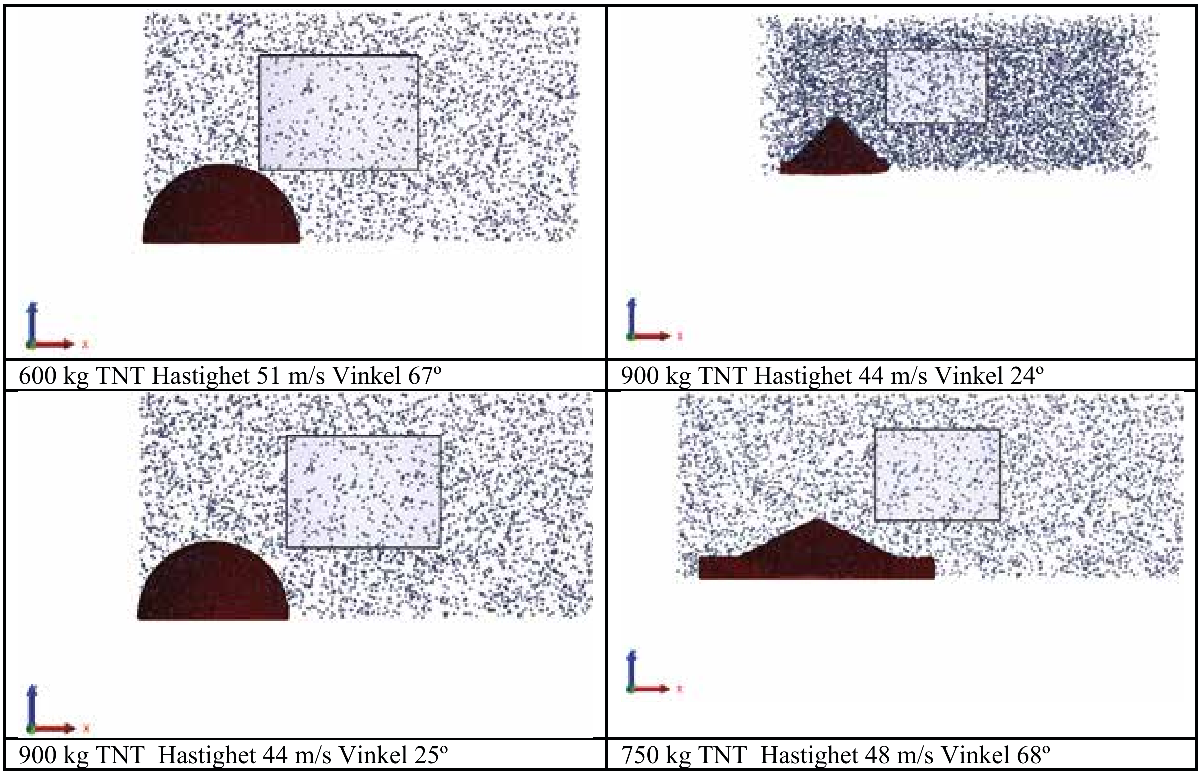


FIGURE 19. Four possible configurations that can result in the observed trajectory.

been used another outcome could be likely. A different configuration and positioning of the explosive could have shown different explosive yields. As an example, smaller amounts of explosive could have provided the necessary force if the explosive was partly placed directly beneath the engine.

However, the results of these simulations point towards that the positioning of the explosive charge must have been very close to or partly placed beneath the engine. This means that the explosive force must have originated from ground level.

FFI also estimates the size of the explosive charge that is necessary to give the engine block its observed trajectory, but specify that the uncertainty is of greater concern in these figures.

The estimated explosive yield:

- If the distance between the engine block and the explosive charge was between 0.5 and 1.0 meters, it is probable that the explosion was equivalent to more than 900 kg TNT.
- If this distance was shorter than 0.5 meters, an equivalent of 600 kg TNT is sufficient.

When discussing these results with FFI, it was stressed that a considerable amount of explosive must have been initiated at ground level. If the explosion had taken place inside the ANPP tank alone, the engine block would have had an initial angle lower than horizontal and would have hit the ground at an earlier stage. This scenario is also unlikely when looking at the trajectory of the gear box, which is situated directly behind the engine block. The gear box was found at approximately 430 meters in the same direction as the engine block.

Where the detonation was initiated is not crucial for the trajectory of the engine block since the detonation velocity is large compared to the initial speed of the engine block.

9.5.2 ANALYSIS OF THE SCATTERING OF THE ALUMINUM FRAGMENTS

A relatively large amount of aluminum fragments were found at the inspection in Drevja. The size of the fragments varied from a couple of grams to several kilograms. The following analysis is associated with some uncertainties, since the total amount of collected fragments only constitute a small part of the total amount of aluminum originating from the production tanks, cabinet doors, cab and the plate beneath the production unit.

Small aluminum fragments, usually with a weight under 50 grams and an area down to 10 cm², were found up to 200 meters away from the explosion site. Fragments of such a small size, will only travel this far if the metal has been in direct contact with the explosive, as stated by FFI. It is only possible to reach the necessary initial velocity for such a trajectory if the metal and explosive is in direct contact during the detonation. The initial velocity must have been close to 100 m/s, which corresponds to the Gurney velocity which is approximately 30% of the detonation velocity.

FIGURE 20. Small aluminum fragments found at approximately 150 meter in easterly direction.

FIGURE 21. Big aluminum fragment found at approximately 170 meter in easterly direction.

The summary done by FFI after the inspection provides a clear impression of that most of the aluminum fragments were found on back side and on both lateral sides of the vehicle's original position. Very few aluminum fragments were found on the front side of the vehicle's original position. An explanation to this could be that the cab and the engine block have functioned as a barrier. However, this could also indicate that the detonation has taken place quite close to the cab, as a detonation further behind the cab would have led to more fragments being shot forwards. Aluminum fragments recovered on the back side of the truck's original position can originate from the top of the front tank or even more likely from the rear tank. The complete version of this analysis can be found in Appendix 4.

Very few large aluminum fragments were found. This could be an indication of a detonation in both tanks. Direct contact between an explosive and metal will lead to a considerable burst of the material. However, none of the tanks were completely full, and the top part of the tanks would therefore quite certainly be in no contact with the explosive and thus be less affected by the earlier described burst effect. The picture in Figure 20 illustrates this.

When discussing these results with FFI, it was stressed that if a detonation did not take place in the rear tank, fragments up to 2 m² should have been found at the inspection. No such fragments were found at the inspection, but it cannot be excluded that they have been overlooked.

9.5.3 ANALYSIS OF THE FINDINGS OF VITAL FRAGMENTS

The augers and pump in the production unit is associated with explosive hazards if a pressure build-up caused by confinement is present. The product pump, the vertical auger and the horizontal mixing auger were all retrieved in a more or less intact condition and did not seem to have been exposed to any internal explosions.

FIGURE 22. Product pump.

FIGURE 23. Horizontal mixing auger.

The product pump (approximately 80 kg) was found about 330 meters in a northwestern direction and the mixing auger (approximately 100 kg) was found around 500 meters in a southwestern direction from the explosion site. Even though the product pump in this case was not the cause of initiation, the project committee finds it important to stress that decomposition and pressure build-up in the pump when exposed to extreme heat could in theory lead to a detonation.

FIGURE 24. Part of the vertical auger.

FIGURE 25. Fragment from the production diesel tank.

Parts originating from the vertical auger (around 18 kg) was found at approximately 210 meters in a southwestern direction from the explosion site.

The picture seen in Figure 24 shows a fragment from the production diesel tank. This was situated at the far back of the MEMU truck. This fragment does not seem to have been affected much by the heat from the fire.

As mentioned earlier, roughly 115 aluminum fragments were identified (around 90 kg) originating from the tanks, cabinet doors, cab and the plate beneath the production unit. This is a small fraction of the total amount of aluminum that could be found on a MEMU. The tanks and the plate both had a thickness of 5 mm. Some of the fragments appeared to be unaffected by the heat from the fire while others were melted into aluminum cakes (28 were found in total). The evaluation on the heat influence on the aluminum fragments have been performed by engineers from DSB and an engineer from Maxam, Spain. Metallurgic expertise has not been performed.

FIGURE 26. Melted aluminium.

The melting point of the aluminum alloy used in the tanks and vehicle lies between 600–720 °C. It is difficult to say anything certain about the origin of the aluminum cakes; however, they do confirm that the temperature of the fire was above the melting point of aluminum. The project committee presumes, based on the course of the fire and by exterior analysis of fragments, that it is highly likely that the aluminum in the cab and first tank was affected by the fire to a higher extent than the rear of the vehicle including the rear tank, production diesel tank and the hopper. The heat from the fire will weaken the aluminum thus increasing the probability of the tanks rupturing due to pressure build-up caused by the formation of gas, the weight of the chemicals in the tank or by collapse of carrying constructions such as the mixing auger.

Full-scale tests involving fire and aluminum tanks carrying ANE has shown that a prolonged fire quickly leads to a weakening of the tank material followed by a rupturing of the tank.

The endothermic decomposition of AN which slowly starts at 80–90°C can have delayed this weakening of the tanks, but the project committee presumes that the external heat still will affect the metal seeing that aluminum possesses a high heat conductivity.

The intention of using aluminum tanks has been to reduce the probability of a fire leading to an explosion since the heat will weaken the aluminum tank, thus leading to rupture releasing the chemicals and relieving the pressure build-up. This incident does underline that the use of such aluminum tanks are not sufficient to prevent an explosion when exposing a MEMU to fire.

FIGURE 27. The engine block.

Finding the engine block has been central to this investigation as it has provided the possibility to identify the starting point of the force leading to its projector. As mentioned, the engine block was retrieved about 200 meters from the explosion site. It had to be excavated by an excavator since it was covered with soil. At a glance, the engine block seemed more or less intact; however, no additional analyses where performed (e.g. shattering effects by the detonation etc.).

NDEA has performed a reconstruction of the bomb that was set off in the Norwegian government's quarter. Here, the engine block was observed to be shot out at a considerable distance and staying intact. In this reconstruction the engine block and explosive were not in direct contact.

9.6 ANALYSIS OF PICTURES, INTERVIEWS AND THE VIDEO RECORDING

In Appendix 5, the project committee has collected pictures illustrating the course of the fire. The main findings from this analysis is that it is quite likely that the fire had spread to the ground after about 1.5 hours, that the fire after approximately 2 hours had surrounded the vehicle and that the fire in the cab had ceased. After 2 hours and 21 minutes the fire intensified until the time of explosion. It is not possible to tell how long the fire had been burning when it was discovered. Observations done by the crew at the site correlate with the descriptions above.

The interpretation of the pictures is associated with great uncertainties and this analysis will not be of great influence in this investigation.

FFI has performed an analysis of the video recording which is recorded at a distance of approximately 3 km. This analysis indicates that recordings show steel fragments with a weight of at least 300 grams and an initial velocity of around 700 m/s. Steel fragments glow and provides the characteristic effect that can be observed in the video. It cannot be lumps of ANE since the density of ANE is too low to obtain the observed altitude. Fragments which are thrown out at a visibly lower speed are heavier fragments and fragments originating from a lower position where the detonation was initiated. See Appendix 4.

9.7 ANALYSIS OF THE ENERGETIC YIELD CARRIED BY THE TRUCK

In the report by the Accident Investigation Board Norway from the accident involving a fire in a lorry in the Oslofjord tunnel the report "Räddningsinsatser i vägtunnelar" is cited. The latter provides an overview of the heat release rate produced by fires in these vehicles related to the size of the vehicle and its cargo. Figures from this report indicate that the heat release rate provided by a fire in a lorry/truck can be between 66-202 MW. This variation is due to the differences in course of the fires, where the fire started and cargo.

A diesel tank of 450 L represents an effect of approximately 17 MW. Depending on the total heat release rate of a MEMU (assumed to be 66-202 MW), the mentioned diesel tank can represents an increase of 10-25%.

Another relevant issue is that diesel burns more intensively than e.g. rubber or plastic. This intensive burning will produce extremely high temperatures.

FIGURE 28. Fragment that illustrates deformation of steel due to heating.

The metallurgic analyses performed on the steel fragments from the explosion in Walden indicated that the temperatures had been around 1100 °C. Other tests performed in relations to this accident have shown temperatures of around 1200 °C.

The picture in Figure 27 illustrates that the fire in Drevja must have had these high temperatures, since the fragment which originates from the beam frame and show that the temperature has been high enough to make the metal soft enough to be folded around the logs.

9.8 CHEMICAL PROPERTIES AT THE TIME OF THE EXPLOSION

When exposing ANPP for such a prolonged and intense fire, the project committee considers it to be highly likely that the ANPP, despite its low thermic conductivity and high heat capacity, at least would have been partly melted and that decomposition of the compound had commenced.

It is difficult to say in this case if or to what extent the ANPP was sensitized, if any contaminations were present and which mechanism led to the explosion. But, it is highly likely that the detonation characteristics were altered.

This also applies for ANE. AN will start to decompose and cause a similar sensitization process of ANE as in pure AN. The main difference is that both water and fuel is present in ANE. Both of these can influence the behavior of ANE during exposure to heat compared to AN, especially when comparing heat capacity and density. The detonation characteristics of ANE in this case will also be similar to those of AN, but will depend on the degree of sensitization.

9.9 CONVERTING TNT EQUIVALENT TO ANPP AND ANE QUANTITIES

The concept of TNT equivalent is frequently used to be able to quantify the amount of energy which is released during an explosion. This method compares the released or potential power of a given explosive/explosion with the amount of energy that is released by the detonation of TNT, which is 4.184 gigajoule per tonne. Thus, if an explosion releases 4.184 GJ the energy release is equivalent to 1 tonne of TNT. For different types of explosives, a conversion factor is frequently applied to compare a given explosive directly with TNT. E.g. if a known amount of explosives has a release of energy that is 10 times less than the same amount of TNT, the conversion factor to TNT equivalent will be 0.1. In this way explosive yields found by different calculation methods and also different types of explosives can be compared through a common unit. However, it is important to take into account when using explosive yields that most of these figures are estimates, especially if the figures are from a non-empirical method or source. This also applies to the three estimated explosive yields provided by DSB, NGI and FFI.

Regarding the accident in Drevja, ANPP and ANE are the most relevant chemicals to look at when discussing what contributed to the explosion. A great amount of literature can be found on the TNT equivalent of ammonium nitrate. However, these figures seem to be under much debate since they are heavily dependent on conditions such as available fuel, temperature, density, pressure, contaminations etc.. To the best of our knowledge, AN is reported to have conversion factors ranging from 0.05-0.60. This interval represents AN of different qualities, amounts, additives/contaminations and at different conditions. Pure AN is often reported with conversion factors ranging from 0.32-0.57. The conversion factors of ANE are under the same debate; however, numbers ranging from 0.5-0.7 are often mentioned in reports from the industry. Higher and lower values can be found in the literature, but they do depend on the type of emulsion, if it is gassed (sensitized) and at which type of conditions the experiments have been performed.

The conditions present at the accident in Drevja were of a unique character. We do not know much about what kind of temperatures the AN was exposed to, the homogeneity in the chemicals (melted, solid, a mixture of these etc.), which types of contaminations was present and if any confinements were present. Furthermore, it is also unknown which amounts of ANE and AN were left before the explosion. Since the conversion factors still are under much debate in the literature, the details of the conditions at Drevja are more or less unknown and the provided explosive yields are already based on estimates, the project committee will claim that a conversion from TNT equivalent to amounts of AN/ANE in this case provides figures with so much uncertainty that they will be unrepresentative for this event. What we can say; however, is that if the original amounts of ANPP and ANE present before the fire started had been ideally detonated, the resulting explosive potential would have been excessively larger than the explosion observed in Drevja.

CHAPTER

10

Summary and further Discussions

Unfortunately, when evaluating the available information from the accident and the academically based analyses, no conclusive explanation on the course of the fire can be derived. Nevertheless, the performed analyses still provide a basis for assessing which scenarios that are the most likely to have happened. The following chapter summarises and discusses what the project committee finds to be most probable.

The most important issues, especially for the future regulations on MEMUs, are whether the tanks ruptured or not, which chemicals were involved in the explosion and if the explosive product and process equipment initiated the explosion.

10.1 EXPLOSIVE YIELD

The charge that exploded was most likely in the range of 500–1,000 kg TNT. Three independent analyses based on the extent of the damages on buildings, trajectory of the engine block and seismic measurements respectively, have estimated explosive yields within this range.

The project committee has concluded that it will be of little use to try to calculate the amount of chemicals (kg) that could have been involved in the explosion. When converting the estimated explosive yield in TNT equivalent to another known chemical/explosive, the result will depend on the applied conversion factor. These are standardised numbers which, amongst others, depend on the properties of the chemicals (melted, homogeneity, contaminations etc.) and the surrounding conditions (pressure, temperature etc.). Due to the uniqueness of the Drevja accident, we know little about the actual conditions and circumstances. Such a conversion will therefore only provide figures with great uncertainties, thus being unrepresentative.

However, the project committee does find it highly likely that the explosion did not comprise the total amount of ANPP and ANE that were present before the fire commenced. The total amount of chemicals (approximately 13 tonnes) represents a much greater potential explosive yield than what the immediate observed damages in Drevja did. It is also considered likely that an unspecified amount of the chemicals decomposed during the fire and that the explosion was of a non-ideal character.

10.2 EXPLOSION ON THE GROUND

Findings of both melted aluminum and aluminum affected by heat probably originating from the tanks and the cab were retrieved. These indicate that the temperature during the fire must have been above the melting point of aluminum. The project committee considers that it is highly likely that the front tank was heat affected to such an extent that it could have ruptured due to a pressure build-up, the weight of chemicals and/or collapse in the bearing structures. In such a scenario, it is also believed that the chemicals have poured out from the tank. It is not possible to conclude if both tanks could have ruptured solely based on the findings of melted and heat affected aluminum.

The simulations and analyses of the trajectory of the engine block performed by researchers at FFI, underline the probability that a considerable amount of the chemicals detonated on the ground, relatively close to the engine block. The course of the simulated trajectory is also supported by the trajectory that the gear box (situated right behind the engine block) must have had to be found at approximately 430 m in the same direction as the engine block.

It has also been discussed if the engine block could have had a similar trajectory if the explosion force had a different origin. This is highly unlikely as the engine block would have had an angle less than horizontal if the explosion had happened e.g. in the ANPP tank. The engine block would therefore have hit the ground at a much shorter distance from the zero point. The simulations also demonstrate that a reflection of the explosive force into the ground would not give the observed trajectory, thus being quite unlikely.

The fact that no crater was formed, weigh against a detonation taking place directly on the ground. Normally, the lack of a crater argues towards an explosion taking place above ground or the explosive compound having a large surface. However, the geologist from NPRA states that due to the geological conditions it is not unlikely that no distinct crater was formed.

10.3 INITIATION OF THE EXPLOSION

During the search for fragments a special effort was made to retrieve vital parts of the process equipment such as pumps and augers. Both the horizontal and vertical augers were found as well as the product pump. None of these had any signs of an internal explosion. Thus, the project committee believes it to be highly unlikely that the explosion was initiated in the process equipment.

In addition to this, it is difficult to directly substantiate whether the explosion started in chemicals on the ground or in one of the tanks. The chemicals may, for example, have been driven to detonation in one of the tanks as a result of heating, melting, decomposition, and sensitization or even by confinement. This may then have induced a detonation of chemicals on the ground. The latter is underlined as likely with the earlier described simulations performed by FFI.

Although it cannot be excluded that a confinement of the chemicals may have led to the explosion in Drevja, the earlier described results from literature suggests that a detonation in ammonium nitrate as a result of varying amounts and types of contaminants is possible. In addition, ammonium nitrate possesses the ability of “self-gassing” during decomposition. This increases sensitivity and the likelihood of explosions. This supports the scenario derived from the FFI experiments of an explosion taking place directly on the ground as plausible.

10.4 DETONATION IN BOTH TANKS

The collection of small fragments (50 grams, 10 cm^2) at a long distance (200 meters) found during the search and the lack of large fragments (up to 2 m^2) substantiates that a detonation took place in both tanks. Such small fragments could only travel such a large distance if the metal was in direct contact with the exploding compound. Larger retrieved pieces can originate from parts of the tank that were not in direct contact with the exploding material and the tank wall.

Based on these findings, the FFI researchers suggest that if the content of the ANE tank had been kept intact and not contributed to the explosion, this would have functioned as a large buffer due to the size of its mass. The front wall would have been extensively fragmented; however, the rear wall would probably have been found relatively intact close to the zero point. It is also their assumption that under these circumstances the product pump and hose reel would not have gotten the necessary initial velocity to travel the observed distance. To achieve this, a detonation in the ANE tank is essential; however, no computational experiments have been performed on this.

It has previously been considered that the amount of chemicals initially present in the tanks would represent a much larger potential explosive power than the damages in Drevja indicates. Thus, a large amount of these cannot have been directly involved in the explosion, but either have decomposed during the course of the fire or have been thrown or poured out.

10.5
SHOCK WAVE DAMAGES ON CLOSE SURROUNDINGS

The pressure wave from the explosion had seemingly little effect on the immediate surroundings, but greater effect on residential houses further away from point zero. It is of course difficult to say specifically how the shock wave from the explosion has propagated in this case; however, it is known that it is significantly influenced by the surrounding environment. Factors such as the shape of the tank and the shape and angle of the surface where the explosion took place can affect the shape and direction of the shock wave, especially if the latter is reflected on the surface. This suggests why the shock wave of a given explosion does not necessarily provide a uniform representation of the extent of the damages.

CHAPTER

11

Preventive Measures

After an accident like the one in Drevja, a thorough evaluation to assess whether safety levels are good enough during mobile production of explosives, is a matter of course. The overall objective for the government and the industry is to minimise the risk of similar incidents happening again. Measures which shall improve safety of mobile production of explosives even further must be considered in a holistic safety perspective, and with the recognition that the handling of explosives and other dangerous substances will always be associated with risk.

The project committee generally assesses the risks related to mobile manufacture of explosives to be acceptable, despite the accident in Drevja. However, we believe risks are not assessed appropriately for a fire scenario. There may also be other scenarios or conditions present which change the risk situation. In the process of assessing which measures need investigation, the committee has worked towards the objective of looking holistically at risks related to mobile manufacture of explosives. We recommend measures that shall highlight the possibilities for further risk reduction under normal conditions as well as in extraordinary situations.

The project committee in DSB proposes a package of measures including a change of procedure for applications for manufacture, bringing identified non-conformances to a close, assessing the need for regulatory changes and initiating a process of evaluating fire prevention and firefighting measures, conducting risk assessments of the risks related to mobile manufacture of explosives in a holistic perspective, and acquiring knowledge that is essential for the understanding of the different methods for mobile production.

The project committee has not been requested to thoroughly investigate economic, administrative or other significant consequences of measures proposed. This must be done in the further work process and preferably in cooperation with authorities in several countries and the industry.

11.1 CHANGED PRACTICE FOR APPLICATIONS FOR MANUFACTURE OF EXPLOSIVES BY THE USE OF MEMUS

DSB already started a project in May 2013 to develop a comprehensive governing of all aspects of mobile manufacture of explosives. This work was put on hold pending the follow-up of the accident in Drevja.

In June 2014 DSB changed their practice related to applications for authorisation for manufacture. This as a consequence of the Directorate having concluded, after a review of the regulations and the practice, that a specific authorisation of the manufacturing unit (MEMU) is not necessary under the Regulations on Explosives § 2-7. The Directorate is of the opinion that MEMUs are covered by the Machinery Regulations, and therefore there is no need for any individual approval, cf. the Regulations on Explosives § 2-7.

According to the Regulations on Explosives § 2-11, the applicant for an authorisation under this Regulation shall give the supervisory authority the necessary information, and submit the documentation and risk assessments needed, in order to assess whether the authorisation should be granted. Pursuant to the same regulation § 2-12, special conditions may be established to prevent the risk of fire or explosion, or that the goods goes missing or falls into the wrong hands.

The Directorate has on this basis amended the instructions on processing of applications related to the manufacture of explosives, in anticipation of the new legislation.

The following information/documentation, which is considered to lie within what may be required by the Regulations on Explosives § 6-1, must be submitted in connection with applications for manufacture of explosives by the use of MEMUs.

Basic requirements:

- Documentation confirming that the unit is in conformity with the Machinery Regulations – Declaration of Conformity.
- Documentation confirming that the vehicle/load carrier is EX III approved in accordance with ADR Chapter 9.1.2.
- Documentation confirming that the tanks are approved according to ADR Chapter 6.
- Name of the appointed competent person as laid down by the Regulations on Explosives § 2-1, and a satisfactory Certificate of Good Conduct for this person issued by the police, not older than 3 months.
- Information about which eligibility requirements are set for the operator of the unit.

Risk analyses, procedures and plans:

- Risk analysis for manufacture on MEMUs, including the on-site placement of the vehicle/unit.
- Procedures in Norwegian for production and charging of bulk explosives.
- Procedures in Norwegian for maintenance, including cleaning, of the unit.
- The organisation's security plan with regards to the substances on board the unit according to ADR sub-section 1.10.3.2.
- Information about how or in which area the unit will be used.
- Emergency response plans, including a list of emergency equipment on the unit.

Information about the unit and explosive goods etc.:

- Drawings of the unit with specifications of tank volume and tank materials.
- Trade name and the Declaration of Conformity for the bulk explosives to be manufactured.
- SDS's for the substances and mixtures on board the unit.
- Flowchart describing the manufacturing process.

The project committee recommends that DSB becomes stricter in the process of handling applications for mobile manufacture. New documentation requirements/information as well as other requirements applied through the current regulations will be followed up more closely. Depending on the resource situation, DSB wants to prioritise audits and supervision in the field to a larger extent.

11.2 FOLLOW-UP OF THE NON-CONFORMANCES

In connection with the submission of this report, Maxam is requested to prepare a plan for when and how they will rectify the non-conformances identified. Based on the character of the non-conformances, the committee's judgment is that they did not have direct consequences for the incident, and will therefore be pursued as non-conformances from a regular audit.

11.3 MEASURES FOR INVESTIGATION

11.3.1 CHANGES OF REGULATIONS

The Regulations on Explosives are governing the manufacture of explosive goods. The regulations are in principle established to govern industrial production of explosives at specific locations, and are not necessarily well adapted to the developments in the industry with an increasing use of mobile charging and manufacturing units.

The Directorate aims to always manage the field in a manner that is adapted to the technical and practical developments. The purpose of the Regulations on Explosives is that all handling of explosives must be safe for consumers and the surrounding environment, and that there is a high degree of certainty that the explosives do not go missing or fall into the wrong hands.

In addition, there has been a need for evaluating the relationship to the Machinery Regulations and the Directorate's practice of single approvals of MEMUs.

The provisions of the Machinery Regulations do to all appearances represent a limitation to the Directorate's possibility of granting single approvals for a machine.

On this basis, a project was initiated in May 2013 to review the regulations for mobile manufacture of explosives.

Besides provisions established in order to maintain safety and securing related to the storage of AN for production of bulk explosives, it is considered to implement a number of changes to the Regulations on Explosive relating to the requirements for the manufacturing process, the use of MEMUs and other production equipment.

The provisions on the authorisation for manufacture is under revision. The various participants' responsibilities should be specified more clearly in the regulations, and the Directorate wants to look at the opportunities for establishing a more comprehensive responsibility for the manufacturer.

Future regulations on the field shall protect against unwanted incidents and ensure safety, the securing of hazardous substances and meet the Directorate's need for an overview of risk and vulnerability in society.

The following specific factors are under review for further control:

- Total liability for manufacturers.
- Specific requirements for the information to be submitted and evaluated by DSB in connection with an application for manufacture.
- Specific requirements for the qualifications of personnel participating in the manufacturing process.
- Electronic notifications to DSB of all MEMUs in use, along with the names of the operators who have been trained.
- Provisions regarding the manufacturer's responsibility for a satisfactory maintenance and cleaning of equipment.
- Monitoring of the manufacturing process.
- Rules for the leasing of MEMUs.
- Requirements for safety distances.
- Risk analysis of the placement of AN on-site.

11.3.2 COMMUNICATION TO THE FIRE AND RESCUE SERVICE REGARDING AMMONIUM NITRATE HAZARDS

The Safety Data Sheets (SDS's) for both ANPP and ANE communicates a significant explosion hazard.

In the SDS for ANPP it is emphasized that the substance has oxidizing properties, that it may emit toxic gases when heated and that heating in a closed container or closed compartment can lead to explosion. Firefighting crew are advised to extinguish with large amounts of water, not to use chemical extinguishing agents or attempt to curb the fire with steam or sand. It is recommended that the container is cooled with water. The importance of avoiding contamination from any source including metals, dust and organic materials is also emphasized.

In the SDS for the emulsion, the importance of keeping the emulsion away from combustible materials is highlighted, as the emulsion may become explosive when mixed with combustible materials. Firefighting crew are further advised to use water to cool tanks, containers and reservoirs near the heat source of the fire. It is also communicated that dangerous combustion products such as carbon monoxide, carbon dioxide and nitrous gases may be formed. In the ingredients and composition section of the SDS, AN is listed as the main ingredient. For this component, risk phrase R9 is given - explosive when mixed with combustible materials.

The project committee recommends that immediate action is taken to inform the fire and rescue services about the risk of explosion in the event of ammonium nitrate on fire, and that this should be communicated within the third quarter of 2015.

11.3.3 HAZARD LABELLING OF AMMONIUM NITRATE

An evaluation of the possibilities for changing the hazard labelling of ammonium nitrate is recommended. By *ammonium nitrate*, the project committee refers to UN1942, UN3375, UN2067 and UN2426.

Hazard markings on vehicles consists of hazard placards and other vehicle signs. Additionally, the instructions in writing for the vehicle crew shall accompany the transport. There are 13 different

FIGURE 29. Hazard placard for Class 5.1.

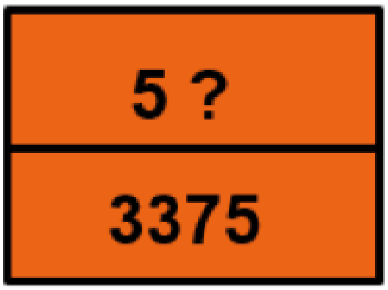


FIGURE 30. Illustration of a vehicle sign.

hazard classes of which each class has a corresponding placard highlighting the hazard of the particular chemical. The placard for 5.1 oxidising is illustrated in Figure 27. The orange vehicle sign has two fields - an upper field for the hazard identification number, and a lower field for the UN number. The hazard identification number is made up of 2-3 digits which together communicate the substance hazards. The intention of the instructions in writing is to provide supplementary information that the vehicle crew can communicate in the event of an accident.

For UN 1942, the use of the hazard placard as illustrated in Figure 28 and hazard number 50 which also indicates that the substance has an oxidizing effect (fire promoting effect), is required. The instructions in writing to the vehicle crew communicates the following: *"risk of vigorous reaction, ignition and explosion in contact with combustible or flammable substances"*. No additional guidance further to this is provided.

When hazard markings are reviewed, one should consider the basis for classification, what can be communicated through hazard identification numbers and as a minimum, what should be communicated from the instructions in writing. As classification and hazard labelling is based on international regulations, it is not possible to create national hazard labelling standards.

It is recommended that DSB initiates a process during 2015 in order to raise the issue in relevant international fora.

11.3.4 INVESTIGATE FIRE PREVENTING AND FIRE COMBATING MEASURES

Fire preventing measures will reduce the likelihood of a fire developing regardless of what the source of the fire is.

The project committee recommends that a review of the requirements for electrical installations in the Inland Transport Regulations (applicable for vehicles carrying explosives and tank vehicles) is conducted to assess whether they promote a sufficiently high level of safety. Areas in particular need of evaluation are whether requirements for repairs and modifications of electrical installations in ADR vehicles should be introduced.

For vehicles in which it is especially critical to avoid fire, unnecessary sources of ignition should be removed. Sources that could escalate a fire should be avoided or placed as far as possible from a potential starting point for a fire.

Early discovery of a fire is also a critical factor. During transport, the driver/operator will on an early stage detect a fire in the engine or the electrical system. During production, the operator will be positioned behind the vehicle, without a chance of detecting the fire. The fire will be discovered earlier if a signalling fire alarm is installed into the control panel, alternatively if the vehicle is monitored during manufacture.

The possibility for efficient firefighting is important to reduce the risk of a fire ending in explosion. In addition to the automatic fire extinguishing system in the engine compartment and requirements for fire extinguishers on the vehicle, the committee recommends that further actions are considered. The committee recommends a broad view to alternative fire extinguishing methods in the wheels/brakes, electrical systems and engine/fuels. Extinguishing agents as well as access to the area of fire origin must be evaluated.

It is recommended that DSB initiates a process during 2015 in order to raise the issue in relevant international fora.

11.3.5 THE NEED FOR A COMPREHENSIVE RISK ASSESSMENT OF MOBILE MANUFACTURE OF EXPLOSIVES

The handling of finished explosives is well regulated. Any type of handling is strictly regulated through requirements for permits, and the competency requirements for rock blasting are strict. The regulations are based on good and detailed knowledge of risk when handling finished explosives. As previously mentioned, DSB has acknowledged that the current regulations on explosive substances are not designed for mobile production of bulk explosives. It is DSB's intention to revise the regulations in such a manner that the governing of mobile production of bulk explosives becomes risk-based. In order to achieve a risk-based governing, a comprehensive assessment of risk of mobile production of explosives is necessary.

The project committee is of the opinion that a comprehensive assessment of risk comprises risk assessments of the entire handling chain as well as extraordinary events such as fire. The assessment should also address the complexities arising from using different methods on a given location based on varying motives.

The project committee presumes that the different methods represent different risks, and that these dissimilarities are potentially highly affected by the risks during fire. The dissimilar risks may potentially lead to different regulations and different requirements for risk mitigation measures.

Based on a highly simplified risk assessment, one may suggest that the risk related to bulk explosives is generally lower than for finished explosives. The committee wants the development of mobile production of explosives to continue, but recommends that the risks of the methods are assessed further in a holistic perspective.

The risks of mobile manufacture of explosives may be a function of risks during transport of the precursors, storage of the precursors in depots, which chemicals are used in the production, the actual production on-site and the manufacturing equipment and conditions on-site. The risk of explosives or precursors for explosives going missing should also be taken into consideration. Evaluating how the different factors should be weighted will be important in the work going ahead.

The project committee therefore recommends that DSB initiates a project to carry out a comprehensive risk assessment on mobile production of explosives. The project should have representatives from governments (e.g. Nordic), the explosives industry and research (preferably international).

The results of such an assessment will form the basis of a risk-based governing of mobile manufacture of explosives, and evaluate whether it is possible to set criteria for acceptable risk. The assessment and the work behind it will hopefully also provide a better understanding of risk of mobile production of bulk explosives, identify any hazards that are not currently identified or reduced to a level that can be reasonably achieved, and provide input regarding risk mitigation measures for hazards already known. It should also offer a tool for businesses in the process of conducting their risk assessments for existing and new methods, deciding on which level of risk they want to operate on, and which measures must be implemented.

11.3.6 THE NEED FOR SPECIFIC KNOWLEDGE

The project committee is of the opinion that specific knowledge is needed in order to assess the risk level, especially in connection with fire in a MEMU.

A considerable amount of information is already available on the behaviour of ammonium nitrate during fire, but this is generally focused on storage and fire risk of AN of fertilizer quality or as finished explosives (ANFO). The empirical foundation to perform risk assessments on is poorer when it comes to carriage of AN and ANE, and especially in connection with a MEMU vehicle.

Based on this, the project committee recommends that the first phase of the new project will define the knowledge that should be obtained in order to perform a better risk-based assessment. The committee suggests that the following areas may be relevant:

- Investigate properties such as decomposition rate and sensitization for ANPP and ANE during a course of fire and which parameters affect these (e.g. time, temperature, contamination, containment, etc.).
- Examine which impacts a fire has on the properties of prills in large quantities and whether prills in aluminium tanks is safe with regards to fire.
- What the direct effects on the aluminium tanks on a MEMU during fire are. How fast they deteriorate, where they crack etc.
- Investigate possible causes of detonation by fire in ANPP and ANE separately and by coinciding storage (run-away, projectiles, molten metal, collapse, etc.).
- Examine whether layers of ANE on tank walls (poor cleaning) during a fire course can cause detonation, and whether this can be initiated by another detonation.
- Large-scale test on MEMUs where the whole process is monitored (temperatures inside the tanks, fire development etc.)
- Large-scale tests with ANPP and ANE examining the characteristics of different types of tanks and tank materials during fire.
- Investigate whether the construction of the tank or the properties of the chemicals in the tank can cause a directed charge.
- Examine the impacts of a pressure wave created by explosion in ammonium nitrate on the close surroundings, including a crater.

The project committee recommends that the team which will be put together to conduct a comprehensive risk assessment of mobile production also aim to outline which needs for knowledge exist, and how potential gaps may be covered. Any costs of minor or full-scale testing will be identified in the first part of the project.

Appendix List

APPENDIX LIST

Appendix 1: Notat fra SVV – Fv. 78 Arm Ømmervatn – Bergarter i masseuttak og deres egenskaper.

Appendix 2: Analyse fra DSB – Ladningsberegninger basert på avstander og skadde objekter.

Appendix 3: Teknisk notat – Ekvivalent detonerende ladning estimert ut fra målte vibrasjoner.

Appendix 4: Notat fra FFI – Sprengningsulykke i Drevja 17. des 2013.

Appendix 5: Bildeanalyse fra DSB.

The appendixes are unfortunately not translated into English.

VEDLEGG 1: NOTAT FRA SVV – FV. 78 ARM ØMMERVATN – BERGARTER I MASSEUTTAK OG DERES EGENSKAPER

Statens vegvesen

Notat-1

Til: Gry Haugsnes, DSB
Frå: Mikael Bergman, SVV
Kopi: Rainer Smedseng, SVV

Sakshandsamar/innvalsnr:
Mikael Bergman - 95419715

Oppdrag:	**Fv. 78 arm Ømmervatn – Bergarter i masseuttak og dess egenskaper**		Dok. nr. i Sveis:		
Oppdragsgiver:	**Direktoratet for Samfunnssikkerhet og Beredskap**		Dato: 2014-10-15		
Planfase:	**Byggefase**	Arkivkode:	Ant. vedlegg:		
Kommune:	**Vefsn kommune**	Vegnr.: **Fv. 254**	HP: **01**	Km: **4,000-4,700**	
UTM 33 ref.:		EUREF 89	Geoteknisk kategori:		
Utarbeidet av:	**Mikael Bergman**	Sign.: Mikael Bergman			
Kontrollert av:	**Per Nyberg**	Sign.:			

FV. 78 arm Ømmervatn – Bergarter i masseuttak og dess egenskaper.

Innledning
På oppdrag fra Direktoratet for Samfunnssikkerhet og Beredskap (DSB) er det gjort en oppsummering av bergartstyper i masseuttaket og dess egenskaper i prosjekt Fv78 arm Ømmervatn.

Bakgrunnen til dette, er eksplosjonen av slurrybil den 17. desember 2013. Ved befaring av DSB etter ulykken vært det observert porøse steiner liggende spredt ut i omliggende terreng.

Befaringen av stedet ble utført den 25. september 2014 av ingeniørgeolog Mikael Bergman.

Geologi
I forkant av ulykken ble det gjort en befaring av stedet den 10. september 2013, for å evaluere berget i området. Dette ble gjort i og med avdekking av løsmasser ned til fjelloverflate. Fra denne befaringen ble det notert en svakhetssone i form av skifer og marmor, som gikk tvers igjennom masseuttaket. Skisse fra befaringen kan ses i vedlegg 2. Denne sonen hadde en bredde på opp imot 30 meter. Resterende masseuttak var i form av bergarten granitt.

Fra befaring den 25. september 2014 ble det notert at svakhetssonene var i form av bergarten glimmerskifer med innslag av både kvarts, pyroksen og amfibol mineraler.

Bergartenes egenskaper
I masseuttaket var det hovedsakelig bergarter i form av granitt og glimmerskifer. I tillegg finnes det kvarts.

Postadresse
Statens vegvesen
Region vest
Askedalen 4
6863 Leikanger

Telefon: 02030
Telefaks: 57 65 59 86
firmapost-vest@vegvesen.no

Org.nr: 971032081

Kontoradresse
Askedalen 4
6863 LEIKANGER

Fakturaadresse
Statens vegvesen
Regnskap
Båtsfjordveien 18
9815 VADSØ
Telefon: 78 94 15 50
Telefaks: 78 95 33 52

Granitt er en magmatisk bergart, som dannes fra størknet magma. Bergarten danner oftest større og mer rundkornete krystaller. Den er i tillegg litt porøs. Granitt er en sprø bergart og er relativt lettsprengt. Granitt har en densitet på 2 760 kg/m^3. Granitt består av mestedels kvarts og feltspat og har en smeltepunkt på ca. 1 400 °C.
Glimmerskifer er en sedimentær/metamorf bergart som dannes fra leire som utsettes for trøkk og/ eller varme. Bergarten danner oftest finkornete mer flate krystaller, som klyves lett langs skifrighetsplaten. Bergarten er mer porøs en granitt. Beroende på hvordan bergarten er dannet kan den være alt fra lite porøs til svært porøs. Glimmerskifer er en duktil bergart og er relativt tungsprengt. I og med at glimmerskifer består mestedels av glimmer (biotitt og/eller muskovitt), som er mineraler med lav hardhet, skapes det lett avskalinger. Det kan i noen tilfelle til og med ripes eller knuses med hendene. Glimmerskifer har en densitet på 2 800 kg/m^3. Glimmerskifer består av over 50% glimmer som har en smeltepunkt på ca. 1 200 °C.
Kvarts/Kvartsitt er et mineral men også i seg en bergart bestående av 90-100% kvarts. Kvarts er et hardt mineral som har en høg smeltepunkt på 1 650 °C. Kvarts er et mineral som klarer av store trøkk og er derfor tungsprengt. Kvarts/kvartsitt har en densitet på 2 800 kg/m^3.

Sprut fra eksplosjon
Fra eksplosjonen ble flere steiner slengt lang i lufta. DSB legger frem spørsmål om trykket fra eksplosjonen kan ha sprekket opp omkring liggende berg som senere ble sendt i luften.
I og med at eksplosjonen utspelte seg i dagen (over terreng) har trykket ikke påvirket berget under, mer en at det kan ha sprukket opp overflaten litt. Denne då sprenging av berg trenger innspenning for å sprenge det ut.
Rundt slurrybilen ved ulykken vart det liggende stein/pukk, se foto 1 i vedlegg 1. Disse steinene er trulig de steinene som vart flyet i lufta og som truffet nærliggende byggen. Steinene hadde forskjellige størrelser og form, i og med at det vart arbeid i alle led i masseuttaket som bestod av både granitt og glimmerskifer.

Ulykkens påvirkning på berget
Ulykken startet med brann fra slurrybilen. Varmen som skapes ved brann er opp mot 900 °C. Ved langvarig påvirkning av slike høge temperaturer gjør den bindingen mellom kornene i glimmerskifer svakere (som har en smeltepunkt på ca. ca. 1 200 °C). Dette bidrar til økt porositet og på den måten, trenger seg varmen lengre inn i berget. Resultatet blir en mer porøs og svakere berg.

Konklusjon
Masseuttaket består av glimmerskifer og granitt. Der ulykken skjedde var det underliggende berg i form av glimmerskifer. Eksplosjonen skjedde ute i dagen og har ikke påvirket kring liggende fast berg. Ved siden av slurrybilen ved ulykka vart det lagret stein/pukk. Di vart utsatt for høg varme som i sin tur har gjort dem svakere. Det er trulig disse som vart slynget i lufta ved eksplosjonen og som truffet nærliggende byggen.

Ingeniørgeolog, Mikael Bergman
Mosjøen den 15. oktober 2014.

Vedlegg
1 – Fotoen
2 – Skissert bergartsgrense 2013-09-10
3 – Skissert bergartsgrense 2013-10-09

Foto 1: Slurrybil før eksplosjon den 17. desember 2013. Bilde mottatt fra DSB.

Foto 2: Bilde visende fjellparti rett bak der eksplosjonen skjedde. Bilde tatt av DSB den 18. desember 2013.

FOTO		Vedlegg 1 - Foto
Fv. 78 arm Ømmervatn		
Statens vegvesen - Region nord - Fv78 Halsøya-Leirosen, Prosjektavdelingen		

Foto 3: Sett mot gården (mot sørvest) fra eksplosjonssted. Bilde tatt av DSB den 18. desember 2013.

Foto 4: Bilde av masseuttak tatt den. 25. september 2014.

FOTO		
		Vedlegg 1 - Foto
Fv. 78 arm Ømmervatn		
Statens vegvesen - Region nord - Fv78 Halsøya-Leirosen, Prosjektavdelingen		

Foto 5: Bergvegg rett nord for der eksplosjonen skjedde. Hammer i nedre delen av bilde viser ca. hvor eksplosjonen vart. Bilde tatt den 25. september 2014.

Foto 6: Sett fra eksplosjonssted mot fjellvegg i nordøst. Mørke fjellet er svakhetssonen som korse masseuttaket. Bilde tatt den 25. september 2014.

FOTO		
		Vedlegg 1 - Foto
Fv. 78 arm Ømmervatn		
Statens vegvesen - Region nord - Fv78 Halsøya-Leirosen, Prosjektavdelingen		

Foto 7. Bilde tatt fra pel ca. 4 810 mot nordøst. Fjellveggen sett på venstre side av bilde er av samme type berg som svakhetssonen sett på avstand, se foto 6. Stedet for eksplosjonen er omtrentlig innringet med rødt i bilde. Bilde tatt den 25. september 2014.

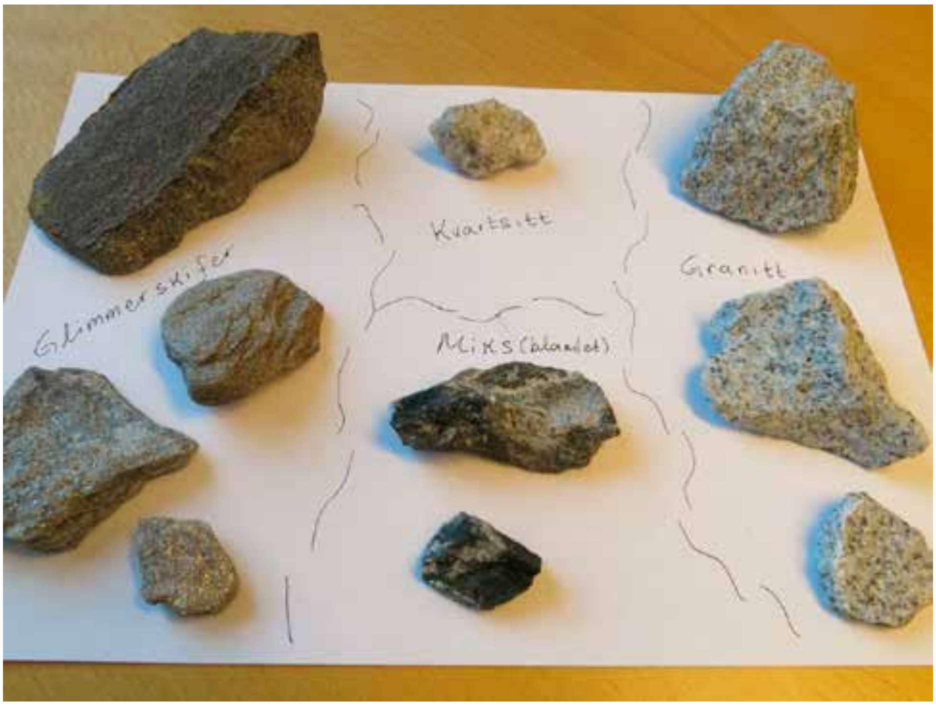
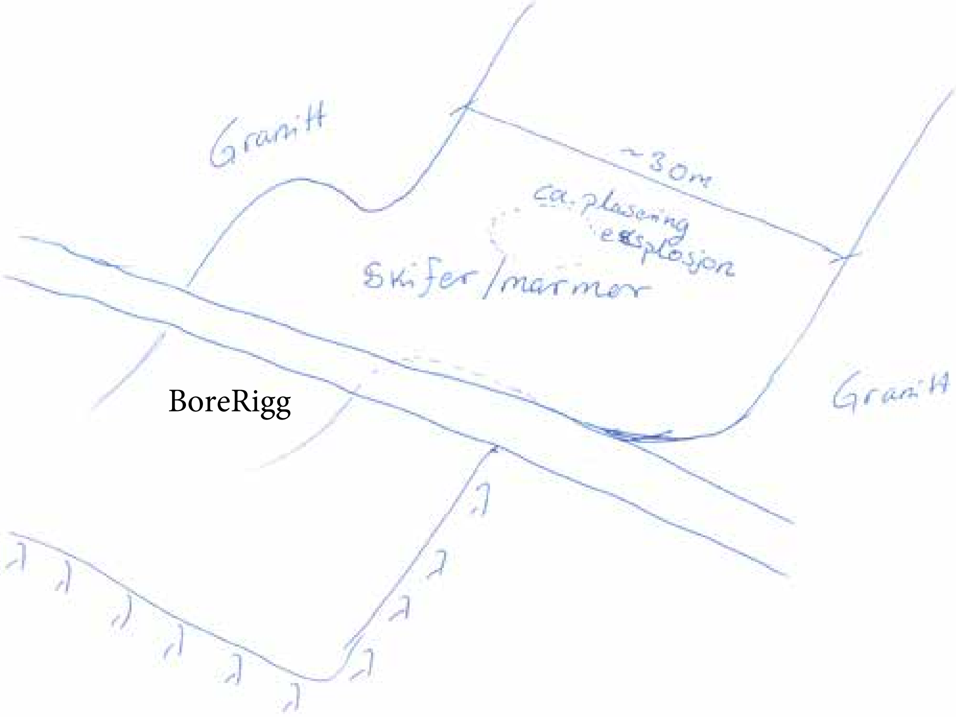


Foto 8: Stuffer (steiner) fra masseuttaket som viser på variasjonen av bergarter.

FOTO		
Fv. 78 arm Ømmervatn		Vedlegg 1 - Foto
Statens vegvesen - Region nord - Fv78 Halsøya-Leirosen, Prosjektavdelingen		

Vedlegg 2
Skissert oversikt fra befaring den 10. september 2013




Vedlegg 3
Bilde fra Rainer Smedseng, tatt den 9. oktober 2013
Granitt
Granitt
Ca. plassering av
eksplosjon
Ca. 30 meter
Glimmerskifer

VEDLEGG 2:
LADNINGSBEREGNING BASERT PÅ AVSTANDER OG SKADDE OBJEKTER

Odd Arne Grøvo, senioringeniør DSB
1/7-2014

Innhold

1 Sammendrag

Analysene gir holdepunkter for å hevde at eksplosjonen har hatt effekt av mellom 500 og 1000 kg TNT. Mengde omsatt AN/ANE kan ha vært under 3.000 kg.

Dette gir følgelig ingen holdepunkter for å fastslå at det var innholdet i den ene eller den andre tanken har gikk til detonasjon. Det kan imidlertid fastslås at langt fra hele totalmengden har gått til detonasjon.

2 Innledning

Dersom man ut fra vurderinger av raseringsnivå kan anslå/estimere et trykknivå på en gitt avstand, så er det mulig å beregne ladningsstørrelse i TNT med for eksempel programmer som CONWEP, evt BlastCalc (App). Ved å legge til grunn en TNT ekvivalent på AN og ANE så kan man så anslå mengden AN og/eller ANE som bidro i eksplosjonen.

Den store utfordringen er å estimere trykk og impuls fra eksplosjonen ut fra vurderinger av skadeomfang på ulike bygg. Sentralt her er vurdering av vinduer; hvilke som er knust og hvilke som ikke er knust. Fasadenes orientering i vinkel mot eksplosjonsstedet er viktig for å beregne reflekterte og reelle trykk.

I en slik vurdering kan også PI kurver (Trykk-Impils kurver/plott) legges til grunn. Det finnes eller kan beregnes ulike kurver for ulike glassdimensjoner, glasstykkelser og kvaliteter. Vi har fått støtte fra Forsvarsbygg med å finne frem et par slike kurver.

Vi har ikke mål på verken vindusarealer eller glasstykkelser. Vi kan imidlertid ut fra bildene kunne skille grovt mellom store eller små vindu. For de fleste bygg må glasskvaliteten regnes som dårlig (gammel), ikke herdet.

Øvelsen blir å finne fasader med flere vinduer av samme type hvor noen, ikke alle, er knust. Man er da på grensen av hva vinduene har tålt av trykk og impuls. Areal og kvalitet på vinduene må så vurderes for, ut fra erfaringer, å kunne anslå trykk og impuls den konkrete fasade har vært utsatt for. Heldigvis for hendelsen, men uheldigvis for grunnlaget for å vurdere omsatt mengde, skjedde hendelsen i et område med få hus og med begrenset variasjon i avstand til eksplosjonssted. Statistikk på om hhv 10%, 50% eller 90 % av vinduene var knust er dermed begrenset som grunnlag for beregninger og avlesninger i PI kurver. De hus som ble eksponert ligger imidlertid i grenseområdet for trykknivåer der vinduene knuses.

Sidetrykk på 5 kPa kan i mange tilfeller representere trykknivå der vindusskader oppstår og kan gi knusing av vinduer. Noen ganger bør man opp i 10 kPa for å oppnå knusing og det kan være fasader som tåler opp mot 15 kPa før 50 % av vinduene "går".

Vinkelen på fasaden må også vurderes i forhold til trykkbølgens retning og refleksjonsvinkel.
Med de ladningsstørrelser og avstander det her er snakk om 500 – 2500 kg TNT og bygninger i avstand fra eksplosjonssted på 140 – 360 meter kan man noe forenklet legge til grunn at reflektert trykk (fasade vendt mot eksplosjonssted) er det dobbelte av sidetrykk eller hendelsestrykk (fasade vinkelrett på trykkfront). Reflektert impuls for tross alt en så liten eksplosjon vil ha en enda lavere faktor.

Fasader vent noe bort fra å ha flate rett mot eksplosjonssted vil få et med vinkelen avtagende reflektert trykk. På sidefasader som er vent noe mot eksplosjonssted må man også regne inn at noe av sidetrykket reflekteres. Her kan man legger jeg til grunn refleksjonstrykk med en faktor 2 mhp sidetrykket opp til 40 grader. Et sted i området 40 – 80 graders refleksjonsvinkel får man, sektor avhengig av trykket på stedet, en økning opp mot tre ganger sidetrykk før denne avtar til rent sidetrykk på 90^{o}.

Takk til Forsvarsbygg for faglige innspill!

2

3 Nullpunkt / eksplosjonssted (ES)

Fastsettelse og klar definisjon av stedet der MEMUen stod da den eksploderte er helt nødvendig for å kunne vurdere avstander og videre beregne de mengder stoff som har dekomponert/detonert.

3.1 Grunnlag for denne analyse

Nullpunkt (UTM 33), målt av Statens vegvesen (SVV) med landmåler GPS:

Ø: 0425637
N: 7319534

DSB mottok en rekke koordinater i SOSI filer. Disse er konvertert av Karen Lie/DSB.

Kontroll med konverteringen fra SOSI:
SVV viser i sin oversikt til følgende avstander:
Senter bil – nærmeste hjørne gult hus: 202,547 m
Senter bil – fjøshjørne (der rystelsesmåler stod): 223,257 m

Test til gult hus: Resultat i kart 202 m.

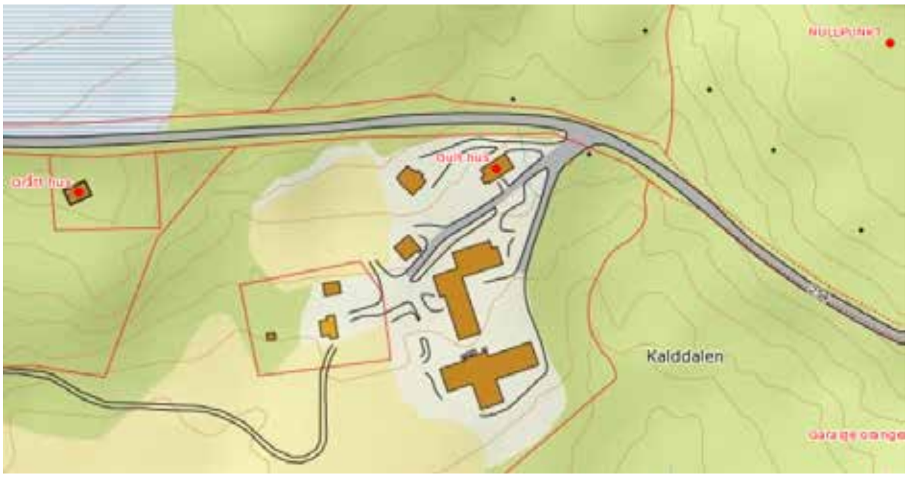
Test til fjøshjørne: Avstand i kart 225.

Vi fester lit til konverteringen og legger (UTM 33): Ø: 0425637, N: 7319534 til grunn for analysen.

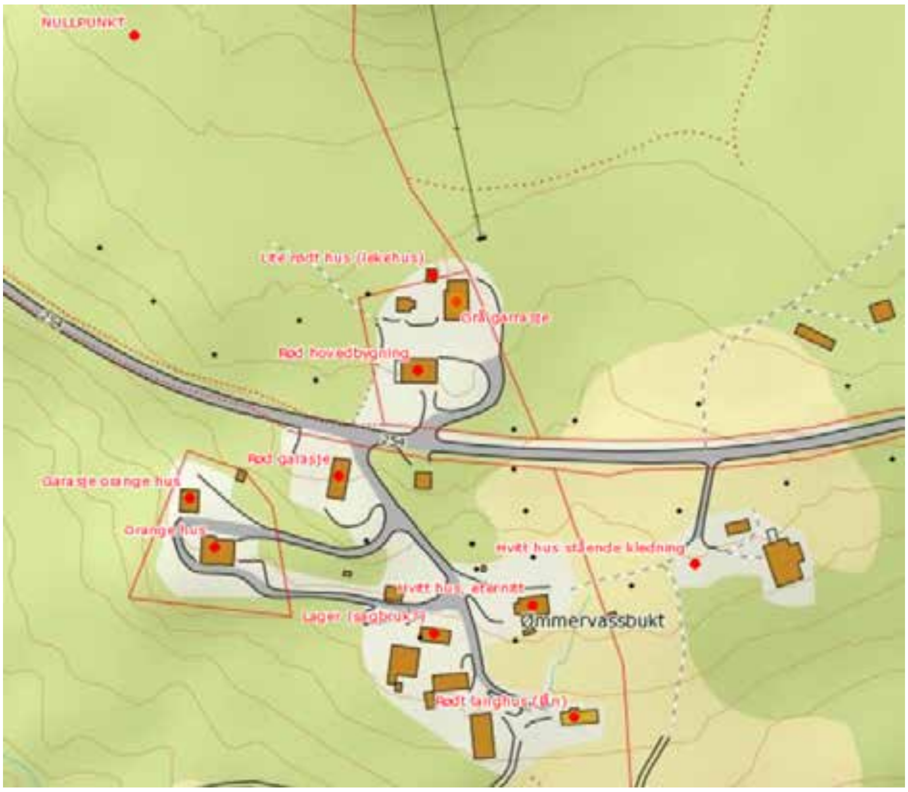
3

4 Referanser – navn på utsatte objekter/hus:

Følgende navn i kart, røde punkter med navn, brukes som referanser i videre analyse:



Vestre område.



Sørøstre område.

4

5 Utsatte objekter – plassering og skadebeskrivelse

Beskrivelse av objekter og skader. Husnavn, se oversiktsbilder forrige side.

OBS, avstander er mål i kart og kan være +/- 1 – 2 meter. Vinkler er målt i utskrift av kart med linjal og graderskive og vil heller ikke være helt absolutt.

5.1 Grått hus

Vest for eksplosjonssted.
Kortvegg mot øst, avstand 412 m, refleksjonsvinkel ca 14 grader.
Langvegg mot sør, avstand 415 m, refleksjonsvinkel ca 76 grader.

Moderne hus. To "husmorsvindu" på kortvegg, tre større vinduer og et par mindre på langvegg. Ingen skader verken på kortvegg eller langvegg.

Bilde tatt fra litt sør for ES. Grått hus oppe på brink. (Gult ned til venstre)

Grått hus. Hjørne mot ES.

5.2 Gult hus (hovedreferanser for grovanalyse)
Vest-sørvest for eksplosjonssted.
Kortvegg mot øst, avstand 202 m, refleksjonsvinkel ca 14 grader.
Langvegg mot sør, avstand 210 m, refleksjonsvinkel ca 76 grader.

”70-tallshus”.
Kun dør på kortvegg. Blåst inn.
Langvegg: Tre av tre store vinduer knust. Halvparten av ”husmorsvindu” i 1.etg knust. Vindu i 2.etg skjøvet inn.

Kortvegg mot øst og ES. Dør blåst inn.

Langside mot sør. Vinduer knust. Vinduer skjøvet inn.

Langside mot sør, vestre del, 2. etg.

6

Langside sør.

Langside nord. Ingen skader. ES opp til venstre.

7

5.3 Lite rødt hus (lekestue)

Sørøst for eksplosjonssted.
Nordvegg, avstand 167 m, refleksjonsvinkel ca 52 grader.
Vestvegg, avstand 167 m, refleksjonsvinkel ca 38 grader.

Bilde fra sør. ES opp til venstre.

Bilde fra vest. Ett av to vindu knust. (Skjermet av typografi/vegetasjon?)

Vegg mot nord.

Bakside. Begge vindu hele.

8

5.4 Grå garasje
Sørøst for eksplosjonssted.
Kortvegg mot nord, avstand 179 m, refleksjonsvinkel ca 52 grader.
Langvegg mot vest, avstand 181 m, refleksjonsvinkel ca 38 grader.

Langvegg mot vest. Fire av fire vindu knust. Takrenne henger.

Bakvegg mot øst. Ett vindu knust (blåst eller sugd ut).

Blikkskur/påbygg på nordside.

9

5.5 Rød hovedbygning
Sørøst for eksplosjonssted.
Langvegg mot nord, avstand 190 m, refleksjonsvinkel ca 40 grader.
Kortvegg mot vest, avstand 190 m, refleksjonsvinkel ca 50 grader.

Bilde. Retning fra nedenfor ES, mot husets nord og vestside.

Nordside. Vindu skjøvet inn. Kun vindu i dør som er knust.

Vestside. Dør presset inn.

5.6 Rød garasje

Kortvegg mot nord, avstand 209 m, refleksjonsvinkel ca 32 grader.

Vegg mot nord. Port trykket inn.

Sidevegg mot vest

Sidevegg mot øst med vindu. Ingen knust.

11

5.7 Oransje hus

Fasade mot nord, avstand 226 m, refleksjonsvinkel ca 9 grader.
Fasade mot vest, avstand 229 m, refleksjonsvinkel ca 81 grader.

Fasade mot nord. Ingen knuste vinduer, men skjøvet inn + strukturelle skader inne.

Fasade mot vest.

12

5.8 Garasje - oransje hus

Fasade mot nord, avstand 202 m, refleksjonsvinkel ca 8 grader.

Fasade mot nord.

Fasade mot øst. Dør 2. etg vippet frem.

Fasade mot vest. Vegg buler.

Fasade mot sør (bakside)

13

5.9 Lager (sagbruk)

Langvegg mot nord, avstand 296 m, refleksjonsvinkel ca 30 grader.

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5.10 Hvitt hus, eternitt (se også 8.1.1)
Langvegg mot nord, avstand 304 m, refleksjonsvinkel ca 28 grader.
Kortvegg mot vest, avstand 305 m, refleksjonsvinkel ca 62 grader.

Nordside. De fire store vindu knust, de to små hele.

Vestvegg. Alle vinduer hele.

Østvegg. Ett av to vindu knust. (Blåst ut?)

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5.10.1 Hvitt hus, stående kledning

Bygning i sørøst.
OBS plassert annerledes enn i kart. Se flyfoto.
Fasade mot nord, avstand ca 337 m, refleksjonsvinkel ca 45 grader.

Fasade mot nord. Ingen skader.

5.11 Rødt langhus (lån)

Bygning lengst i sør-sørvest
Langvegg mot nord, avstand 357 m, refleksjonsvinkel ca 30 grader.

Fasade mot nord. Ingen vindu knust (nå).

16

6 Grovanalyse
Grunnet mange usikkerheter må det vurderes hvor detaljert og omfattende en analyse skal være for å dekke formålet. En grovanalyse uten for mange detaljer kan gi en indikasjon på mengder omsatt.

6.1 Hypotese
Vindusskadene på gult hus representerer et (side)trykk på 5 kPa. (Reflektert 10 kPa .)

6.2 Grovanalyse
Avstanden fra nullpunkt (SVV koordinater) til gult hus er 202 meter. Midt på langvegg er avstanden + ca 8 meter; ca 210 meter.

Dette trykket og denne avstanden gir ved hjelp av ConWep eller BastCalk en mengde TNT på **732 kg**.

Legges det til at skadene er resultat av et ikke ubetydelig bidrag fra reflektert trykk, og at sidetrykket har vært noe lavere blir TNT mengden lavere.

Grovt anslag, eksplosjonen har hatt effekt av mellom 500 og 1000 kg TNT.

6.3 Sårbarhet i analysen
Relativt små endringer i verdiene lagt inn i grovanalysen påvirker resultatet i vesentlig grad.

- Trykket ved gult hus: Dersom gult hus har vært utsatt for et høyere trykk så blir også beregnet mengde TNT høyere. Var sidetrykket 6 kPa ville mengden TNT kunne beregnes til 1.127 kg. Var sidetrykket 7 kPa ville TNT kunne beregnes til 1.631 kg.
- Regnes sidetrykket å ha vært lavere for eksempel 4 kPa ville mengden TNT reduseres til 441 kg.
- Refleksjonstrykk er i dette ikke medregnet (kommenteres i pkt. 8.1).
- Analysen er også sårbar for hvilke avstander som legges til grunn.

7 Alternativ vurdering.
En alternativ vurdering av de mengder stoff som dekomponerte og forårsaket luftsjokk er å se på eksplosivforskriftens formler for minimums sikkerhetsavstand, jf også tabellene i veiledningen.

Som grunnlag for våre sikkerhetsavstander etter tabeller for oppbevaring av eksplosive varer legger vi til grunn formelen:

$$D = k \times Q^n$$

D - avstanden (sikkerhetsavstand fra potensielt eksplosjonssted til utsatt objekt)
n - 1/3 for faregruppe 1.1

Altså for eksplosive varer i faregruppe 1.1 skal sikkerhetsavstanden være minimum konstanten (k), som er avhengig av type utsatt objekt, multiplisert med tredje roten av mengden.

For bolighus er k = 22,2. Denne skal være satt for å gi en sikkerhetsavstand som gir en 5 kPa trykkpåvirkning ”side on” fra en eksplosjon.

Med mengden Q som ukjent, blir formelen

$$Q = (D/k)^3$$

Ut fra overnevnte grovanalyse, observasjoner og hypotese hvor det antas å ha vært ett trykk på 5 kPa på ca 210m blir mengden ut fra denne formelen **846 kg TNT**.

Hadde avstanden hvor trykket var 5 kPa vært vurdert til 190 m (altså at trykket på 210 m har vært lavere) blir beregnet mengden etter formelen 627 kg TNT.

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Hadde avstanden vært vurdert til 230 m (altså at trykket på 210 m har vært høyere) blir beregnet mengde 1.112 kg TNT.

(OBS, stemmer antakelsene om et sidetrykk på 5 kPa ved gult hus så er det gule huset et bilde det raseringsnivå man kan få på hus som ligger på minimumsavstand.)

8 En mer omfattende analyse.

Grovanalysen kan i seg selv gi en indikasjon, men det kan og bør generelt legges inn noen flere vurderinger. I denne saken er det imidlertid så mange usikkerheter at kost/nytt vurdering av for mye analyse kan være dårlig, jf pkt 6.3.

I det etterfølgende utvider jeg analysen, men skal man komme helt ned i materien må det måles størrelser på vinduene, tykkelser, antall lag og kvaliteter.

En helt naturlig første øvelse blir, ut fra de data vi har, å vurdere skader også på andre bygninger.

8.1 Vurdering av andre bygninger

8.1.1 Hvitt hus, eternitt.

Fasade mot ES. Refleksjonsvinkel ca 28 grader og da utsatt for refleksjonstrykk ca 2 ganger sidetrykk (se pkt 8.2). Fire litt større vinduer er gått, to mindre ikke knust. Om dette borger for et trykk på 5 kPa, så var sidetrykket på ca 2,5 kPa.

2,5 kPa sidetrykk på 304 meter gir en beregnet TNT ladning på 495 kg.

Legger man på til 6 kPa reflektert trykk (3 kPa sidetrykk) da vinduene kan ha tålt noe høyere trykk blir beregnet ladning 726 kg, en størrelsesorden vi kjenner igjen fra grovanalyse gult hus.

Legger man på til 7 kPa reflektert trykk (3,5 kPa sidetrykk) blir beregnet ladning 1.000 kg.

Kortvegg. Refleksjonsvinkel ca 62 grader og da utsatt for refleksjonstrykk ca 2 ganger sidetrykk, men er da opp mot den vinkelen der man får et forsterket reflektert trykk over en faktor på 2 (se pkt 8.2). Dette kan gi holdepunkter for at ladningen ikke kan ha vært over 1.000 kg TNT.

8.2 Vurdering av refleksjonstrykk

Man kan vurdere bygningens orientering mot trykkbølgens utberedelse for også å vurdere graden av reflekterte trykk.

Trykket på vegg vendt mot eksplosjonssted blir høyere grunnet reflektert trykk. Når vinkelen er 0^o på trykkbelgefronten (vegg vendt rett mot eksplosjonssted) blir det reflekterte trykket, grovt og forenklet vurdert, størst. Ved en avstand og mengde som i Drevje hvor sidetrykket som har truffet bygningene er nede i 5-10 kPa kan man da grovt anta at reflektert trykk er 2 ganger sidetrykk. Enten nærmere eksplosjonssted (eller på samme sted med langt større dekomponert mengde) vil faktoren øke med avtagende avstand (eller med betydelig økt mengde); faktoren øker med økende trykk.

Med økende vinkel avtar reflektert trykk til vinkelen er 90 grader og man har en sidevegg ut refleksjon av trykkbølge; kun sidetrykk. For lave trykk kan en regne faktoren P_r / P_s som 2 til over 40 grader før den får en lokal økning over 2 som så avtar til 1 og rent sidetrykk på 90^o .

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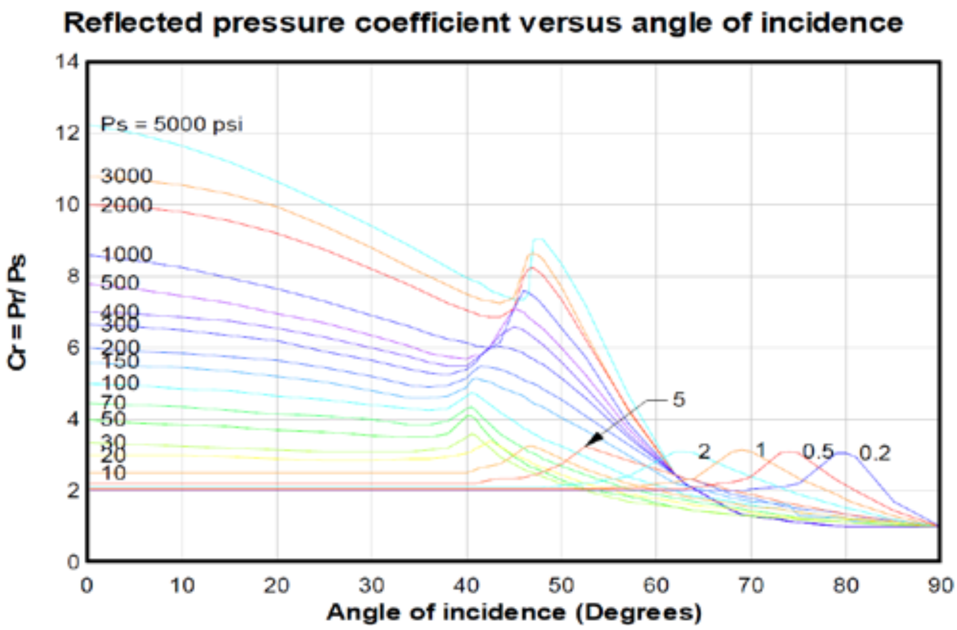

Figur: Plott mottatt fra Forsvarsbygg.

Gult hus, fasade sør, har en refleksjonsvinkel på ca 76 grader.
Jf grovanalyse: Ladning på 732 kg, 210 meter gir et sidetrykk på 5 kPa (0,73 PSI).
I figuren over er det et plott for 1 PSI og en for 0,5 PSI. Peaken for 0,73 vil da ligge mellom disse.
Da vinkelen på langveggen er i den vinkelsektoren som gir forsterkninger i reflekterte trykk kan dette ha gitt en refleksjonsfaktor på mellom 2,5 og 3 (beregnet 2,74) på langveggen og P_r på 13,7 kPa. Dette er en betydelig økning i faktisk trykk lagt til grunn i grovanalysen. **Dette taler for et sidetrykk kan ha vært lavere med tilsvarende mindre beregnet ladning.**

8.3 Størrelser og kvalitet på vinduer

Dette er ikke annet enn grovanalysert.

8.3.1 Vindusarealer

Dette kan gjøre helt konkret ved å måle vindusflatene i Drevja (er ikke gjort) eller bruke ulike PI kurver for små, middels og store vinduer.

8.3.2 Vindustykkelse og antall lag.

3, 4 eller 5 mm…
Ett lags, to lags, tre lags.
Slik registrering er ikke gjort.

8.3.3 Andre vurderinger av vinduskvalitet.

Innfesting, alder …
Generelt var vinduskvaliteten dårlig. Gamle vinduer.

8.4 Vurdering av impulsen

For å beskrive en trykkbølges energi så må man i tillegg til trykket vurdere varigheten av trykket som gir et integrert areal under plottet av bølgen; impulsen. Impulsen på ett gitt trykknivå avhenger av mengde omsatt sprengstoff. Større mengde gir større impuls på samme trykknivå, man da lenger fra eksplosjonssted.

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732 kg TNT, ref grovanalyse, gir en kalkulert impuls (side) på 22 kPa/ms.

Man må beregne impulser for å bruke PI kurver.

8.5 PI kurver

Trykkbølger kan være svært komplekse. Vurdering av impulsen er også grunnleggende for å beskrive en trykkbølge og dens raserende egenskaper. En enkelt tilnærming med å anslå ett visst trykk som har gitt de observerte skader har tidligere vist seg for enkelt (ref Forsvarsbyggs analyser av hendelsen i regjeringskvartalet). Det er utarbeidet PI kurver (trykk- impulskurver) for ulike vindusstørrelser og kvaliteter.

8.5.1 Vurdering av gult hus:

Jf punkt 6.2 som estimerer en ladning på 732 kg.
Jf punkt 8.2 om at ladningen har vært mindre.

Forsvarsbygg (Ståle Skudal) har hjulpet meg med noen beregninger og plott i et par PI kurver, ett for mellomstore vinduer 1,2 m x 0,8 m og ett for halve størrelsen. Beregninger for 250, 500, 650, 750, 1000 og 1600 kg TNT er lagt inn.
(650 kg ble tatt med da den viser deg å treffe 90 % knusningskurven for det største vinduet. 1.600 kg ble tatt med for å komme noe høyer for det mindre vinduet som tåler mer).

Resultat av beregninger gult hus 210 meter, vinkel 76^{o}:

TNT (kg)	P_r (kPa)	I_r (kPa*ms)
250 kg	8,5	74
500 kg	11,5	118
650 kg	12,5	140
750 kg	13	154
1.000 kg	14	186
1.600 kg	15,5	254

Resultat plottet for vindu 1,2 m x 0,8 m, 4 mm vanlig glass:

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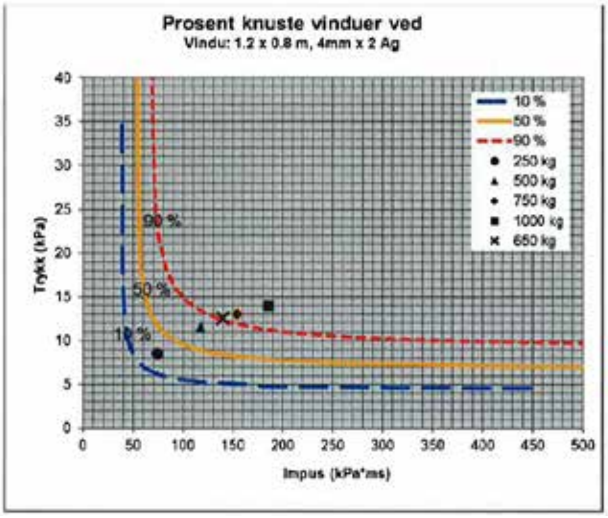
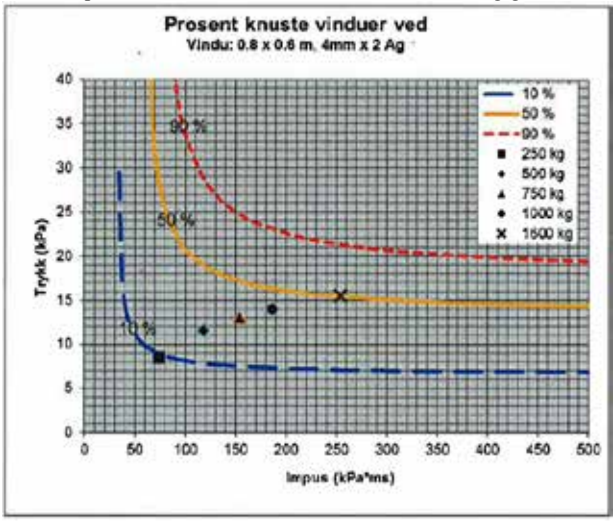


Resultat plottet for vindu 0,8 m x 0,6 m, 4 mm vanlig glass:



Statistisk grunnlag for % andel knuste glass er dårlig, men det at tre av tre store vinduer knuste støtter at ladningen var på mer ca 700 kg TNT. Det ser imidlertid ut til at vinduene er noe større enn 1,2 x 0,8 m. Dette gir noe lavere motstandevne og lavere minimumsmengde for å knuse.

Ca 50 % knusing av de minste vinduene gir indikasjoner på at om de var på 0,8 x 0,6 meter så var mengden ca. 1.600 kg. Imidlertid ser også disse ut til å være noe større. Vurderes 50% knusning i 1,2 x 0,8 m PI-kurven, så indikerer det mellom 250 og 500 kg TNT.

Igjen, dette gir indikasjoner. Viten om målene på vinduene kunne styrket presisjonen i beregningene som synes å vise i retning av **mellom 400 og 1000 kg TNT**.

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8.5.2 Vurdering av hvitt hus, eternitt:
Jf punkt 8.1.1 som estimerer en ladning på 495 kg. Eller 1.000 kg om trykket var på 7 kPa.

Beregning av 1.000 kg TNT og 304 meter gir et trykk på 3,5 kPa side. På denne vinkel er reflektert trykk det dobbelte; 7 kPa. Impuls side blir 103 kPa*ms. Reflektert impuls blir 185 kPa*ms.

I plott for vindu 1,2 x 0,8 m gir dette bare ca 50 % knusing. Fire av de fire største vinduene ble knust. Her kan det være at vinduet i huset var bredere enn 80 cm og kvaliteten er ukjent, mulig dårlig, som begge ville øke % knuste vinduer. Denne gir imidlertid en indikasjon på at ladningen kan ha vært på **opp mot 1.000 kg TNT**.

8.5.3 Vurdering av rødt langhus (lån):
Beregning av 1.000 kg TNT og 357 meter gir et trykk på 2,8 kPa side. På denne vinkel er reflektert trykk det dobbelte; **5,6 kPa**. Impuls side blir 88 kPa*ms. Reflektert blir denne **149 kPa*ms**.

I plott for vindu 1,2 x 0,8 m gir dette ca 10 % knusing. Igjen er det vanskelig å vurdere vinduenes mål, men de fremstår som gamle og potensielt svake. Denne gir en indikasjon på at ladningen må ha vært **mindre enn 1.000 kg TNT**.

8.5.4 Vurdering av rød hovedbygning
Beregning av 1.000 kg TNT og 190 meter gir et trykk på 6,5 kPa side. På denne vinkel er reflektert trykk det dobbelte; **13,3 kPa**. Impuls side blir 166 kPa*ms. Reflektert blir denne **302 kPa*ms** på 40^o.

I plott for vindu 1,2 x 0,8 m gir godt over 90 % knusing. Igjen er det vanskelig å vurdere vinduenes mål, men med ingen knuste vindu støtter dette at ladningen må ha vært betydelig **mindre enn 1.000 kg TNT**.

Beregning av 500 kg TNT og 190 meter gir et trykk på 4,8 kPa side. På denne vinkel 40^o er reflektert trykk det dobbelte like før kurven stiger; **9,8 kPa**. Impuls side blir 105 kPa*ms. Reflektert blir denne **189 kPa*ms**.

I plott for vindu 1,2 x 0,8 m gir da mellom 50 % og 90 % knusing. Igjen er det vanskelig å vurdere vinduenes mål. Det er kun vinduet i døra som ble knust, men de øvrige er skjøvet inn så det kan ikke utelates at ladningen var større enn 500 kg TNT. Det er også ukjent om vegetasjonen og typografien for dette huset har gitt noe skjerming.

8.6 Typografi og andre stedlige forhold.
Typografi og vær kan også legges inn. Hvordan får gassen utvidet seg. Ideellt i 180 graders halvkule eller er det andre forhold som påvirker utbredelsen. Er lendet på noen måte kanaliserende eller på annen måte slik at man kan få variasjoner i trykkutberedelsen?

Mot sørvest er det en del vegetasjon. Denne kan ha påvirket trykkbølgen i den retningen noe. **Beregninger på hus i denne retning kan med det gi en noe for lav TNT mengde.**

9 Avsluttende kommentarer:
Spørsmål som gjenstår er hvordan trykkbølgen i dette tilfellet har vært, kanskje med en primærreaksjon/effekt og en sekundær. En deflagrasjon til detonasjon og kanskje med en avsluttende deflagrasjon i deler av massen. Dette kan være sentralt i vurderingene er hvilke TNT ekvivalenter man skal legge til grunn.

10 Alternativ tilnærming

Ladningsberegningen er ment som en hjelp til å kunne analysere hva som skjedde.
Hvilke stoff (tank) gikk til detonasjon?

MEMUen bestod av to tanker med

- Fremre tank: ANPP (UN Nr 1942) – 4.600 kg
- Bakre tank: Matrise (UN Nr 3375) – 7.400 kg

Med en TNT ekvivalent på 0,2 ville dette tilsvare hhv 920 kg og 1.480 kg TNT.
Gitt at hele den ene eller hele den andre mengden detonerte så ville dett gitt et sidetrykk på 210 meter (gult hus) på hhv 5,5 kPa (AN) og 6,7 kPa (ANE).
Hele mengden samlet (2.400 kg TNT) ville gitt et trykk på 8,2 kPa.

TNT ekvivalenten til emulsjonen kan forvente å ligge høyere enn 0,2, kanskje helt opp mot 0,7 (Forenklet: ANFO har 0,8. Fratrukket ca 10 % vann i matrisen). Settes ekvivalenten til 0,7 skulle man forvente et sidetrykk på 210 meter på **11,4 kPa**. (Jf. pkt. 8.2; med ett reflektert trykk på over 32 kPa). Settes ekvivalenten til 0,6 skulle man forvente et trykk på 9,9 kPa. (Reflektert 27 kPa). Raseringsnivået på gult hus vurderes å ikke være etter så høye trykk. **Gitt at det er enten det ene eller det andre tankinnholdet som gikk til detonasjon så gir dette en indikasjon på at det var ANPP beholdningen som gikk til detonasjon.**

I denne vurderingen er det ikke trukket fra stoff som kan ha dekomponert i brannen før detonasjon. Det er heller ikke vurdert om det kun er deler av matrisebeholdningen som detonerte.

Odd Arne Grøvo EKS/DSB

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VEDLEGG 3: TEKNISK NOTAT – EKVIVALENT DETONERENDE LADNING ESTIMERT UT FRA MÅLTE VIBRASJONER

Teknisk notat

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0806 Oslo

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Til:	Direktoratet for samfunnssikkerhet og beredskap
v/:	Gry Haugsnes
Kopi til:	
Dato:	18. september 2014
Rev. nr./ Rev. dato:	1/6. november 2014
Dokumentnr.:	20140409-01-TN
Prosjekt:	Eksplosjon Drevja
Utarbeidet av:	Christian Madshus
Prosjektleder:	Christian Madshus
Kontrollert av:	Finn Løvholt

DSB – Eksplosjon i ladetruck ved Drevja 17. desember 2013, kl. 15:26. Ekvivalent detonerende ladning estimert ut fra målte vibrasjoner

Innhold

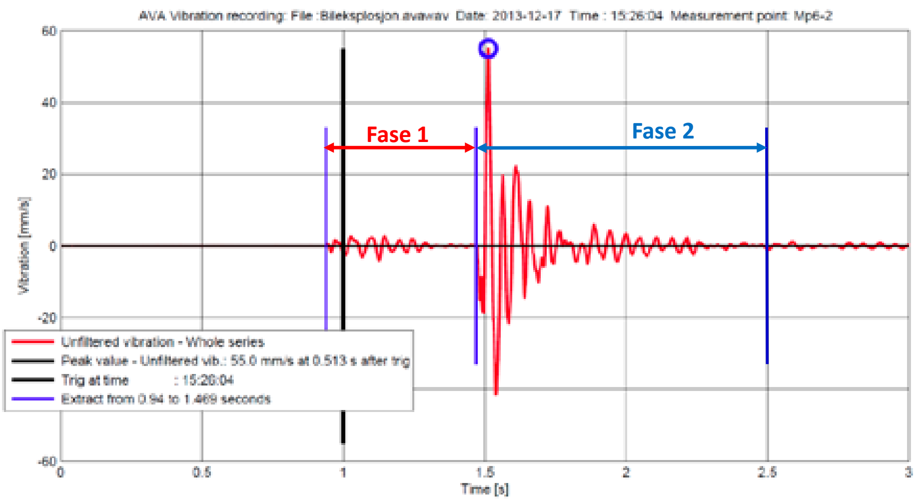
Dokumentnr.: 20140409-01-TN
Dato: 2014-09-18
Rev. nr.: 0
Side: 2

1 Bakgrunn

I forbindelse med oppgradering av Fv. 78 Holand – Leirosen i Vefsn, med arm til Ømmervatn, parsell mellom Ømmervatn og Drevjamoen, er det etablert et brudd for uttak av sprengstein. I forbindelse med lading av salve nr. 50, 17. desember 2013, tok det fyr i ladetrucken for bulksprengstoff. Det lyktes ikke å slukke brannen og etter ca. 2 ½ time, kl. 17:26 inntrådte en kraftig eksplosjon.

På nærliggende gårdsbruk er det montert en måler for å overvåke vibrasjoner fra sprengningene i steinbruddet. Måleren er montert på grunnmur på grisefjøs, med målepunktbetegnelse MP6-2. Måleren registrerer vibrasjoner i vertikal retning. Instrumentet er av typen AVA, er installert og driftes av Multiconsult og lagrer vibrasjonsforløp hver gang en forhåndsinstallert triggeverdi blir overskredet. Instrumentet registrerte vibrasjonene fra eksplosjonen 17. desember.

Figur 1 viser vibrasjonsforløpet fra eksplosjonen, slik det er registrert av sensoren på grunnmuren i PM6-2.



Figur 1 Registrert vibrasjonsforløp fra eksplosjon ved Dervja 17. desember 2013

Direktoratet for samfunnssikkerhet og beredskap (DSB) har gitt NGI i oppdrag å benytte vår kunnskap til å tolke vibrasjonsopptaket og gi et best mulig estimat på hvilken mengde sprengstoff, i TNT-ekvivalent som gikk av under eksplosjonen.

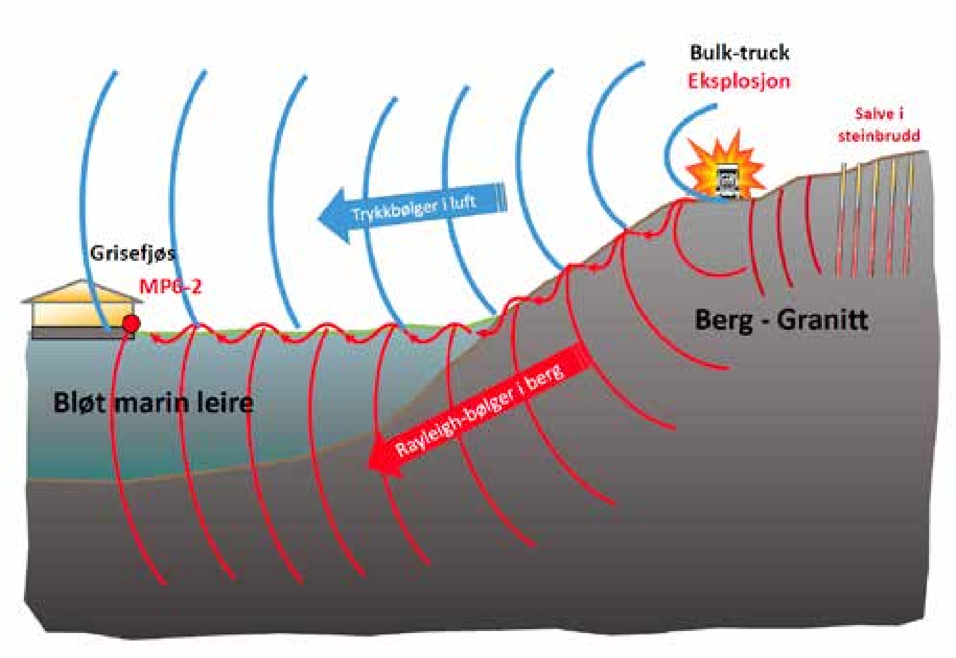
Vi har i oppdraget trukket på vår kompetanse om vibrasjoner i jord og berg, om utbredelse av trykkstøt i luft og om kobling mellom trykkstøt og vibrasjoner i bakke og bygninger. Dette er kompetanse vi i stor grad har bygget opp i samarbeid med Forsvarsbygg, Forsvarets forskningsinstitutt, SINTEF og flere utenlandske institusjoner.

2 Tolkning av vibrasjonsforløpet

Vibrasjonsforløpet fra eksplosjonen i Figur 1, viser tydelig to separate faser, gitt som Fase 1 og Fase 2 i figuren.

Vår tolkning er at Fase 1 er vibrasjoner som er overført som mekaniske bølger fra eksplosjonen gjennom bakken, mens Fase 2 er bevegelser som er indusert i bakken omkring grunnmuren og direkte i grunnmuren, i det lufttrykkbølgen fra eksplosjonen passerer. Dokumentasjon som underbygger denne tolkningen er gitt i det etterfølgende.

Figur 2 illustrerer situasjonen skjematisk: Der trucken eksploderte var det bart berg. Berget i området er oppgitt til å bestå av fast granitt med noe glimmerskifer. Der grisefjøset ligger er grunnen oppgitt til å bestå av bløt leire. Ut fra oppgitte koordinater er korteste avstand fra sprengstofftrucken til målepunktet på grisefjøset $\boldsymbol{D_{exp}}$ **= 226 m**.



Figur 2 Situasjon - Skjematisk

Vi vil i dette tekniske notatet benytte vibrasjonsregistreringene i Fase 1 og Fase 2 til to gi to uavhengige estimater på ekvivalent ladningsmengde som gikk av i eksplosjonen.

3 Bølgetyper og ankomsttider

3.1 Egenskaper ved Fase 1

Uten å vite mer om bergets egenskaper enn det vi har fått oppgitt og kan finne på NGUs kart, vil vi ut fra erfaringer anta at det har en p-bølgehastighet, C_{p_berg} nær 5500 m/s. (Ref.: bla. Fortifikasjonshåndboken tabell 4.2) Med C_{p_berg} = 5500 m/s og dynamisk Poisson ratio, $\nu_{d\_berg} = 0.20$, gir dette en skjærbølgehastighet i berget på ca. C_{s_berg} = 3400 m/s. Er dessuten berget ganske homogent mot dybden vil det med disse dataene ha en overflatebølgehastighet (Rayleighbølgehastighet) på ca. C_{R_berg} = 3100 m/s.

Eksplosjonen i trucken må ha gitt en nært vertikal impulslast på bergoverflaten. Ved en slik belastning vi det meste av vibrasjonsenergien gå over til overflatebølger (Rayleighbølger). Siden slike bølger dempes mindre med økende avstand enn volumbølger (p- og s-bølger) fordi energispredningen er mindre, er det å forvente at rystelsene som kom frem til MP6-2 var fullstendig dominert av Rayleighbølger. Eventuell ikkelinearitet i berget nær eksplosjonen vil være minimal når det gjelder virkning på bølgehastigheten.

Frekvensanalyse av vibrasjonene i Fase 1 viser dominerende frekvens på ca. $f_1 = 21$ Hz. Det vil si at bølgelengden for Rayleighbølgene er ca.; $\lambda_R = V_R/f_1 = 150$ m. Slike Rayleighbølger penetrerer ca. 1 – 1.5 ganger bølgelengden ned i berget, dvs. ca. 150 til 200 m og er således styrt av bakkens egenskaper ned til denne dybden.

Vi vet ikke mer om grunnen under grisefjøset enn at den består av bløt leire. Fjøset ligger på høyde ca. 75 moh. Marin grense i området er mellom 100 og 150 moh. Det er derfor overveiende sannsynlig at leira er marin. Det har vi også fått bekreftet av en person med god kjennskap til stedet. Vår erfaring fra denne typen leirer i tilsvarende avsetninger, og fra målinger i nærliggende Finneidfjord, tilsier at leira har skjærbølgehastighet på ca.: C_{s_leire} = 100 m/s. (I Finneidfjord er det målt s-bølge hastighet i leira ned til 80m/s). Leira kan antas vannmettet. Da vil den ha en kompresjonsbølgehastighet nær C_{p_leire} = 1500 m/s, tilsvarende et dynamisk Poissons tall på $\nu_{d\_leir} = 0.498$. Massetettheten for denne typen leire vil være ca.: $\rho_{leire} = 1800$ kg/m^3. Overflatebølgehastigheten i leira vil da være ca. C_{R_leire} = 96 m/s. Tykkelsen på leirlaget der grisefjøset ligger har vi ikke informasjon om. Vi antar at den er moderat, typisk ikke mer enn 30 m.

Siden bølgelengden for Rayleighbølgene i berget er lang i forhold til tykkelsen på leirlaget og utbredelseshastigheten for disse bølgene i berget er langt høyere enn i leira, vil vibrasjonene i Fase 1 ankomme til MP6-2 med nær samme hastighet som de har i berget.

Vi kan anta at vibrasjonene som ankommer måleren i MP6-2 som Fase 1 er overflatebølger som går i bakken og har bredt seg ut fra eksplosjonen med en hastighet på ca. C_{R_berg} = 3100 m/s.

Av Figur 1 er første ankomst av bakkevibrasjonene vist med vertikal blå strek på $t_{vib\_målt}$ = 0.935s i tidsskalaen i figuren. Tidsaksen i vibrasjonsregistreringen fra instrumentet i MP6-2, som er vist i Figur 1, er ikke relatert til eksplosjonsøyeblikket men til når instrumentet trigget på vibrasjonene. Triggetidspunktet er satt til 1.000 s. Ankomsttiden i figuren sier derfor ikke noe om hvor lang tid bølgen har brukt fra eksplosjonsstedet og målepunktet. Det eneste vi kan lese fra figuren er forskjellen mellom ankomsttiden for bølgen i bakken – Fase 1 og lufttrykkstøtet – Fase 2.

Rayleighbølgene vil i noen grad være dispersive (utbredelseshastigheten avhenger av frekvensen) på grunn at bakkens / bergets stivhet nok øker noe med dybden. Bølgepakken vil derfor trekkes noe ut i tid etter som den brer seg utover. Det er derfor ikke mulig å plukke ut et helt eksakt ankomsttidspunkt for bølgene som kommer gjennom bakken.

Ankomsttid relatert til eksplosjonsøyeblikket kan nå estimeres fra antatt bølgehastighet og målt avstand:

Vi vet fra innmåling et avstanden fra der ladetrucken eksploderte til målepunktet på grisefjøset er D_{exp}=226 m. Med en antatt bølgehastighet på C_{R_berg} = 3100 m/s tilsier dette at bølgen ankommer målepunktet, ca. t_{vib_exp} = 226m / 3100m/s = 0.073 s etter eksplosjonen.

3.2 Egenskaper ved Fase 2

Vi antar at starten på Fase 2 er bakkens og grunnmurens respons på ankomsten av fronten på lufttrykkstøtet fra eksplosjonen. Lufttemperaturen i tidsrommet for eksplosjonen er oppgitt til +4°C. Dette tilsvarer en lydhastighet i luft på ca. C_{lyd} = 334 m/s. Imidlertid vil fronthastigheten ved MP6-2 være noe høyere på grunn av overtrykkets størrelse. Basert på gjentatte omganger med beregninger har vi kommet til at toppverdien av overtrykket fra eksplosjonen ved MP6-2 har vært i størrelsesorden $p_{6\text{-}2\_5}$ = 5kPa. Vi benytter her denne verdien i den videre analysen av ankomsttidene. Med dette trykket vil fronthastigheten til lufttrykkstøtet ved vibrasjonsmålepunktet (MP6-2) være omtrent $C_{front\_5} = 1.02 \cdot C_{lyd}$ = 341 m/s. I siste kapittel er det tatt med en diskusjon om usikkerhet i estimatene. Fronthastigheten på lufttrykkstøtet er følgelig vesentlig høyere enn overflatebølgehastigheten i leire. Basert på et stort antall målinger vi og andre har utført for forsvaret, og fra teoretiske modeller (Ref: bla. Madshus et al.), vil bakken (og grunnmuren) under slike forhold få en nær umiddelbar respons i det fronten på lufttrykkstøtet ankommer.

Starten på Fase 2 kan altså antas å være nær eksakt ankomsten av fronten på lufttrykkstøtet.

Denne ankomsten er angitt med den andre vertikale blå streken i Figur 1, ved $t_{trykk\_målt}$ = 1.464 s i figurens tidsakse.

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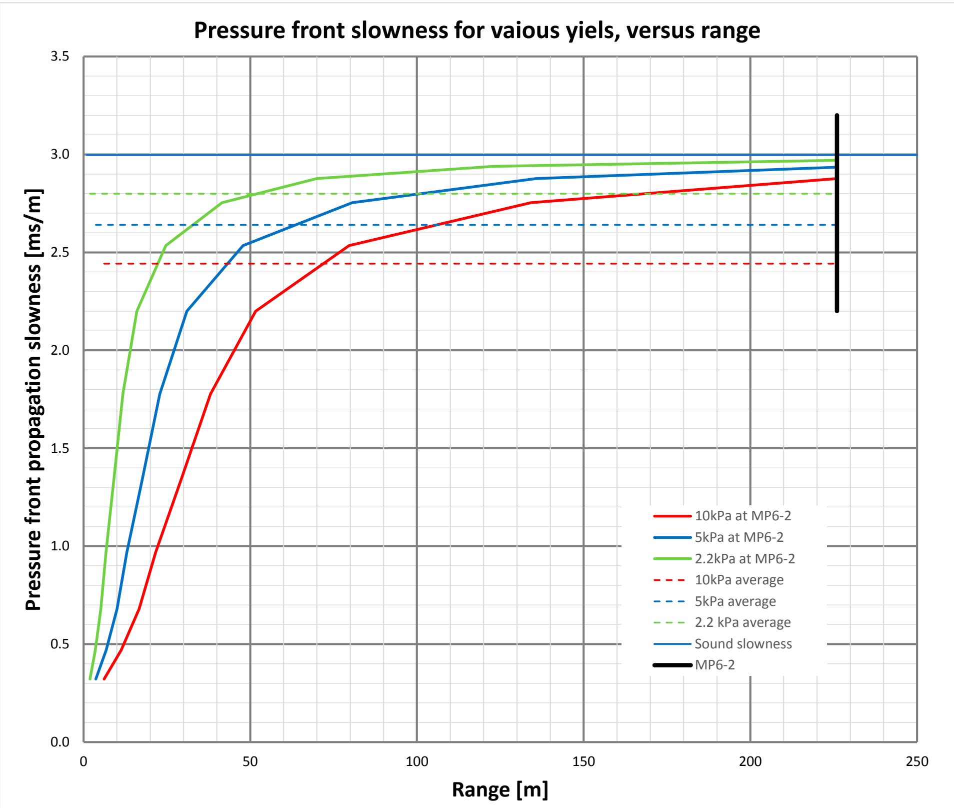
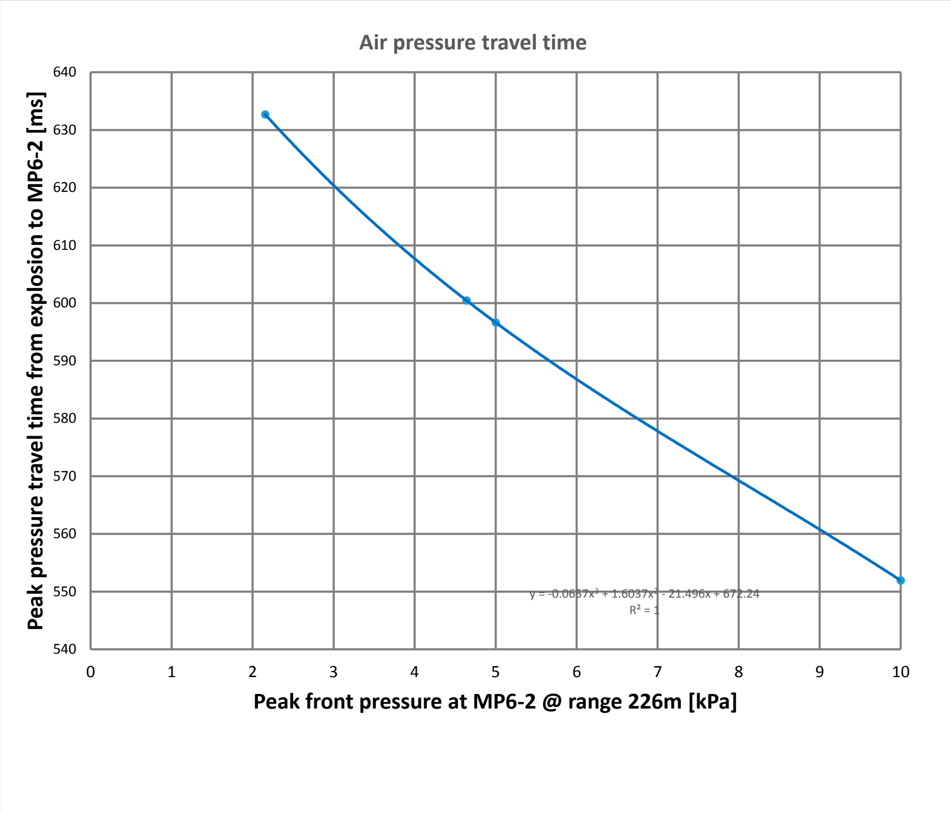
Siden fronttrykket har vært svært mye høyere nær eksplosjonen og har avtatt utover, vil også fronthatigheten ha vært mye høyere nær eksplosjonen og blitt lavere med økende avstand ut til vibrasjonsmålepunktet. Figur 3 plotter hvordan hastigheten, uttrykt som slowness [ms/m] varierer fra nær nullpunktet for eksplosjonen til vibrasjonsmålepunktet. Det er plottet trykkhastighetsprofiler for henholdsvis toppverdi-trykk 10kPa, 5kPa og 2.2kPa ved MP6-2. Kurvene er basert på Fig 11 i ANSI standarden og ligningene 3.1 – 3.4 i Fortifikasjonshåndboken. Plott av slowness [ms/m] i stedet for hastighet har den fordelen at gangtiden er lik arealet under kurvene så det er lettere å se hvordan den siste delen av utbredelsesveien bidrar mest til gangtiden.



Figur 3

Figur 4 plotter forventet gangtid fra eksplosjonsstedet til vibrasjonsmålepunktet som funksjon av trykk toppverdien ved målepunkt MP6-2. Antar vi igjen at dette trykket var omtrent 5kPa vil forventet gangtid etter beregningen ha vært t_{trykk_exp} = 0.597s. **Dette tilsvarer en differanse mellom estimert ankomsttid for lufttrykkbølgen og bakkevibrasjonsbølgen på $t_{diff\_exp} = (t_{trykk\_exp} - t_{vib\_exp})$ = (0.597s – 0.073s) = 0.524s.**



Figur 4

Fra plotten i Figur 1 kan vi lese av følgende målte differanse i ankomsttid til: $t_{diff\_målt} = (t_{trykk\_målt} - t_{vib\_målt}) = (1.464s - 0.935s) = 0.\underline{529s}$. Dette stemmer svært godt med den beregnede forventede forskjellen i ankomsttider. Det gir på denne måten en strek indikasjon på at vår tolkning av det registrerte vibrasjonsforløpet, at den første fasen – Fase 1 er mekaniske bølger, overført direkte gjennom bakken som Rayleighbølger, og at den andre fasen – Fase 2 er en umiddelbar respons av leire og grunnmur på ankomsten av lufttrykkstøtet fra eksplosjonen.

Det faktum at beregningene gir så god overensstemmelse mellom beregnet og målt forskjell i ankomsttider er en indikasjon på at toppverdien av trykket ved vibrasjonsmåleren har vært omtrent 5kPa. Et vesentlig annet trykk ville gitt et betydelig større avvik.

4 Ekvivalent eksploderende ladningsmengde estimert fra direkteoverførte vibrasjoner – Fase 1

Som vi har verifisert kan vi anta at den første fasen – Fase 1 av det registrerte vibrasjonsforløpet fra eksplosjonen er vibrasjoner som er overført direkte gjennom grunnen som overflatebølger.

Det finnes en del empiriske relasjoner for sammenheng mellom ladningsstørrelse, avstand, bergkvalitet / grunnforhold og resulterende vibrasjon for sprengninger i berg. Erfaring viser imidlertid at det er betydelige forskjell i vibrasjonsoverføringsegenskapene fra sted til sted, selv der bergforholdene tilsynelatende er like. Det er derfor ikke mulig å benytte slike generelle sammenhenger for å få et brukbart estimat på ekvivalent ladningsstørrelse i eksplosjonen ved Drevja.

Det har imidlertid fortsatt foregått sprengninger i steinbruddet ved Drevja også etter eksplosjonsulykken. Vibrasjonene fra disse sprengningene er blitt registrert med den samme vibrasjonsmåleren på grunnmuren til grisefjøset MP6-2. Vi har benyttet data fra disse sprengningene til å finne en stedsspesifikk utbredelsesmodell for vibrasjoner fra området der trucken eksploderte frem til målepunktet på grisefjøset - MP6-2.

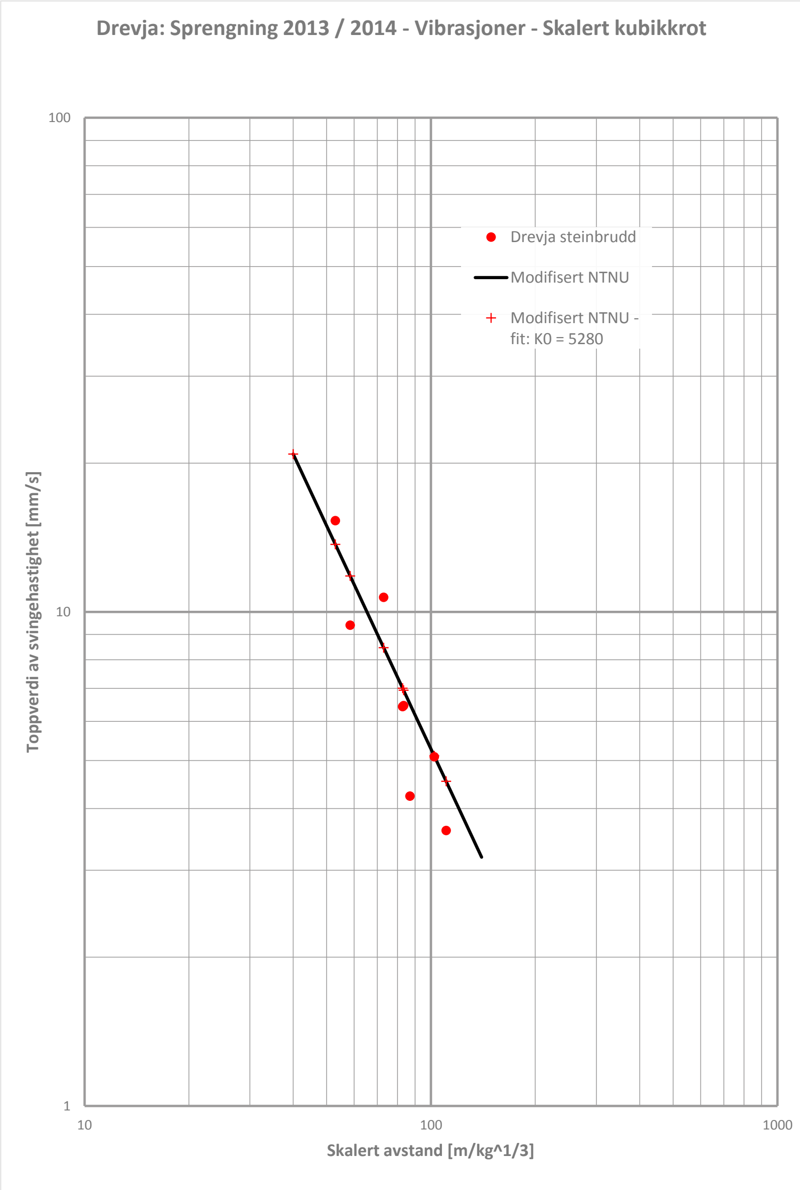
Vi har fått tilgang til salvedata og vibrasjonsopptak fra i alt 10 salver. Salvens plassering og derved avstanden til målepunktet er dels tatt ut fra kart og befaring i terrenget. Tre av savlene er imidlertid innmålte med GPS. Fra de 10 salvene har vi plukket ut 8 som vi vurderer å inneholde de beste dataene. Dataene er tilpasset følgene modell for utbredelse av vibrasjoner fra sprengning.

$$V = K_0 \cdot \left(\frac{D}{Q^{1/3}} \right)^{-1.5}$$

Størrelsen $d = \left(\frac{D}{Q^{1/3}} \right)$ betegnes som den skalerte avstanden.

Her er V toppverdien av målt vibrasjonshastighet fra salven [mm/s], D er avstanden [m] og Q er største ladning per tennerintervall i salven. K_0 er en bergfaktor som avhenger av bergkvalitet og andre stedsavhengige egenskaper. Denne modellen kommer opprinnelig fra NTNU, men er modifisert under forarbeidet til NS8141 – (Ref.: Gjengedal.) Vi velger her en kubikkrotskalering som passer best for disse dataene som ikke er frekvensveid, slik det nå er foreskrevet i nye NS8141. For frekvensveide vibrasjoner passer en kvadratrotskalering best.

I Figur 5 er vibrasjons-toppverdien fra de 8 salvende plottet mot skalert avstand, bestemt ut fra største delladning og avstand for de enkelte salvene. Den heltrukne grå linjen og de røde kryssene representere en miste kvadraters tilpasning av modellen til datapunktene. Den beste tilpasningen gir en stedegen bergfaktor; K_{0_Drevja} **= 5280**. Dette er en ganske høy bergfaktor og indikerer at berget på Drevja er kompakt og gir en god overføring av vibrasjoner med lite tap.



Figur 5

Modellen er utviklet for ordinær bergsprengning, det vil si for ladninger som er innspent i borehull i berget som for steinbrudd- og tunnelsalver. Også fra slike salver vil imidlertid vibrasjonene stort sett bre seg ut til større avstander som overflatebølger. Kun i en indre sone omtrent ut til en avstand lik dybden fra overflaten ned til salven vil volumbølger dominere. Med en avstand mellom 140m til 300m fra steinbruddsalvene til vibrasjonsmålepunktet MP6-2 vil derfor vibrasjonene fra steinbruddsalvene bre seg ut som overflatebølger over det alt vesentlige av avstanden, på samme måte som vibrasjonene fra eksplosjonen.

Imidlertid skjedde eksplosjonen av sprengstoffet på ladetrucken som en kontakteksplosjon mot bergoverflaten eller også muligens noe frakoblet i en liten avstand over bergoverflaten, dersom deler av trucken fortsatt var intakt da eksplosjonen inntraff. Denne ladningen hadde derfor en helt annen vibrasjonsmessig kobling til berget enn steinbruddsalvene.

For å kunne sammenholde data fra steinbruddsalvene med vibrasjonene fra eksplosjonen benytter vi oss av en grunnsjokk-koblingsfaktor beskrevet av ARA. Den gjelder for diverse grunnsjokkparametere, blant annet toppverdi av svingehastighet *V*.

$$f_k = \frac{V_{nær\_overflaten}}{V_{innspent}}$$

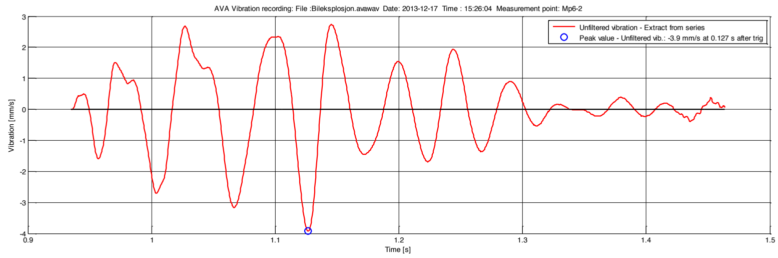
I vårt tilfelle vil vi måtte sette inn for $V_{innspent}$ i beregningsmodellen, mens vi har målt $V_{nær\_overflaten}$ fra eksplosjonen:

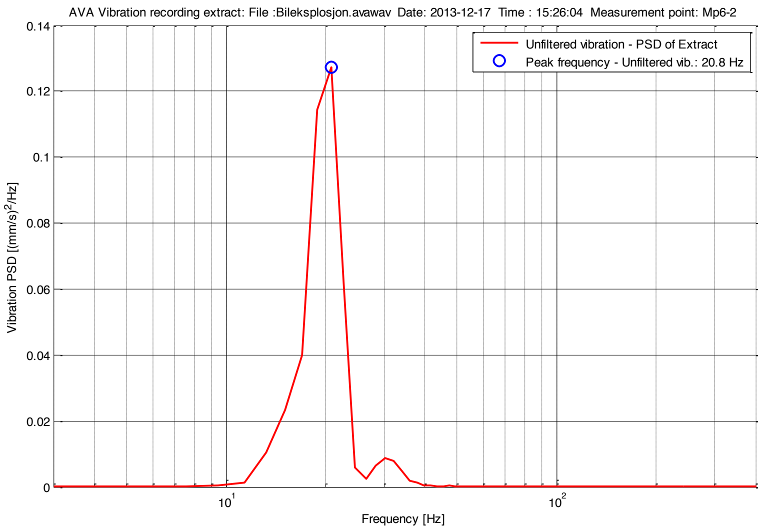
$$V_{innspent} = \frac{V_{nær\_overflaten} = V_{målt\_Fase1}}{f_k}$$

Innsatt i utbredelsesmodellen og løst for ladningen får vi følgende uttrykk for den estimerte ekvivalente ladningsstørrelsen:

$$Q_{est\_Fase1} = \left(\frac{V_{målt\_Fase1}}{f_k \cdot K_{0\_Drevja}} \right)^2 \cdot D_{\exp}{}^3$$

Figur 6 viser et utsnitt av det registrert vibrasjonsforløpet med Fase 1 isolert. Figuren viser at den største toppverdien av vibrasjonen er: $\boldsymbol{V_{målt\_Fase1}}$ **= 3.9 mm/s.**





Figur 6

I følge ARA er koblingsfaktoren for grunnsjokk, f_k = ***0.14*** for en kontaktdetonasjon mot bakkeoverflaten. Dersom detonasjonen har skjedd noe over fjelloverflaten vil koblingsfaktoren bli lavere, typisk, f_k = ***0.10.***

Innsatt for den målte toppverdien av vibrasjon, den stedsspesifikke bergfaktoren, koblingsfaktoren og avstanden fra eksplosjonsstedet til målepunktet D_{exp}=226 m, gir denne analysen av de direkteoverførte vibrasjonene følgende verdier for den estimerte ekvivalente ladningen.

Detonasjon	i kontakt med bergoverflaten	noe over bergoverflaten
Koblingsfaktor - f_k	0.14	0.10
Estimert ekvivalent ladningsmengde	320 kg	**630 kg**

Vi anser den høyeste verdien som det beste estimatet.

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5 Ekvivalent eksploderende ladningsmengde estimert fra vibrasjoner indusert av lufttrykkstøt – Fase 2

Vi har vist at utbredelseshastigheten til lufttrykkstøtet er vesentlig større enn overflatebølgehastigheten i leira ved grisefjøset. I en slik situasjon vil lufttrykket virke som en super-seismisk last på bakkeoverflaten. Bakken vil da reagere med en nær umiddelbar respons på trykket.

Ut fra et stort antall målinger NGI og andre har utført for Forsvaret har vi funnet ut at det er en ganske entydig sammenheng mellom toppverdi av lufttrykkstøtet, toppverdi av den resulterende bakkevibrasjonen og av bakkens spesifikke overflatebølgeimpedans. Dette forutsetter at trykket ikke er høyere enn at lineær akustikk tilnærmet gjelder. For trykk i størrelsesorden 5kPa er denne betingelsen i tilstrekkelig grad oppfylt.

Den spesifikke impedansen for overflatebølger for leirmaterialet i grunnen omkring grisefjøset kan antas å være:

$$Z_{g\_leire} = \rho_{leire} \cdot C_{R\_leire} = ca.180\ Pa \Big/ \frac{mm}{s}$$

Forsøksresultatene viser at forholdet mellom toppverdien av lufttrykket og toppverdien av den resulterende bakkevibrasjonen kan uttrykkes:

$$\frac{P_{\exp}}{V_{målt\_Fase2}} = Z_{ag\_leire} = f_{ag} \cdot Z_{g\_leire}$$

Her er f_{ag} en koblingsfaktor som er omkring 0.5.

Løst for det ukjente lufttrykket fra sprengingen gir dette:

$$P_{\exp} = f_{ag} \cdot Z_{g\_leire} \cdot V_{målt\_Fase2}$$

Figur 6 viser et utsnitt av hele vibrasjonsforløpet fra eksplosjonen, med fokus på Fase 2. Som det fremgår er toppverdien av denne delen av vibrasjonsforløpet $V_{målt\_Fase2}$ = 55 mm/s.

Innsatt målt vibrasjon $V_{målt\_Fase2}$ i ligningen med $f_{ag} = 0.5$, blir forventet toppverdi av lufttrykkstøtet fra eksplosjonen med vibrasjonsmålepunktet MP6-2:

$$P_{\exp} = 0.5 \cdot 180\, Pa/mm/s \cdot 55mm/s = 4.9kPa \approx 5kPa$$

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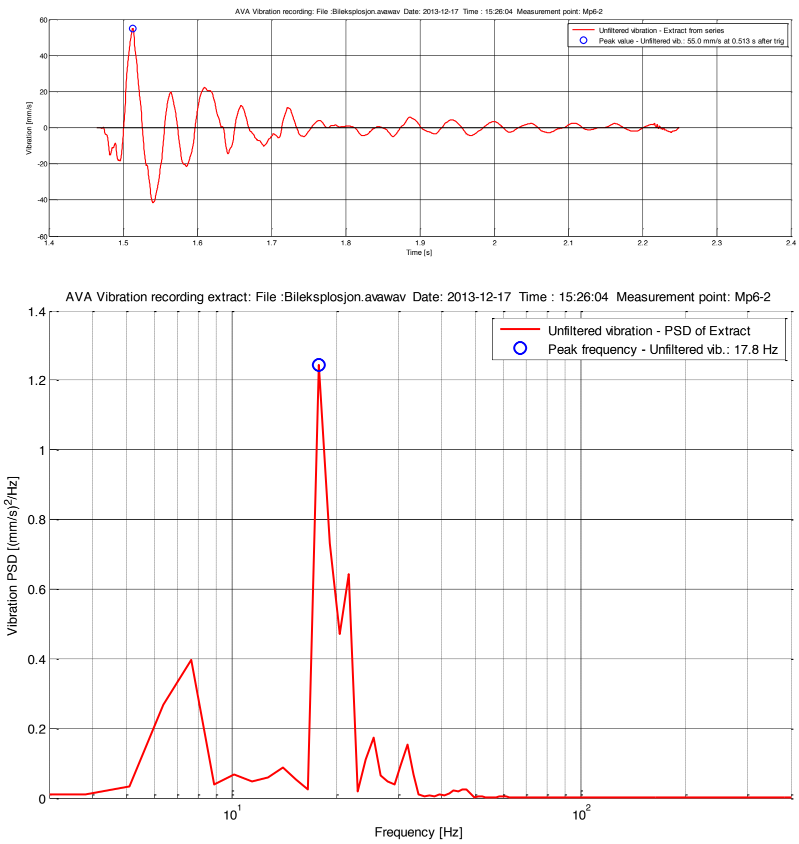


Figur 7

Figur 11 i ANSI gir sammenhengen mellom skalert avstand og trykk antatt en fri overflateeksplosjon. Trykk på ca. 5kPa tilsvarer en skalert avstand på, d_{trykk_Fase2} = 24.6 m/kg$^{1/3}$. Da får vi:

$$Q_{\exp\_Fase2} = \left(\frac{D_{\exp}}{d_{trykk\_Fase2}} \right)^3$$

Innsatt gir dette følgende estimerte ekvivalente ladning som gikk av i eksplosjonen:

Koblingsfaktor – f_{ag}	0.5	0.75
Estimert ekvivalent ladningsmengde	**775 kg**	1700kg

Vi anser den laveste verdien som det beste estimatet.

Analyse av den delen av det registrerte vibrasjonsforløpet som er indusert av lufttrykkstøtet fra eksplosjonen gir altså et noe høyere estimat på ekvivalent ladning enn det analyse av de direkteoverførte vibrasjonene gir, men begge metodene gir estimert ladning i samme størrelsesorden.

Fra Figur 6 kan man se at frekvensen på de lufttrykkinduserte vibrasjonene, og derved også frekvensen på lufttrykkstøtet, siden bakken oppfører seg super-seismisk, er ca. f_{trykk_Fase2} = 18Hz.

Det vil si at typisk bølgelengde på lufttrykkstøtet er

$$\lambda_{trykk\_Fase2} = \frac{C_{front\_Fase2}}{f_{trykk\_Fase2}}$$

Innsatt frekvensen og C_{front_5} = 341m/s blir bølgelengden ca. 19m. Dette er lengre enn to ganger bredden på fjøsbygningen. Det vil si at stivheten av bunnplaten / grunnmuren til grisefjøset i liten grad påvirker koblingen mellom lufttrykket og vibrasjonen. Grunnmuren og bakken vil få de samme vibrasjonsbevegelsene. Trykkstøtet gir også noe virkning på veggene i bygningen, men bygningen tilfører også ekstra masse som trekker i motsatt retning. Dette vil kunne modelleres mer detaljert, men det er en stor oppgave som neppe forbedrer estimatet av ladningsstørrelsen vesentlig. Vi mener at betraktningen ovenfor, med koblingsfaktor f_{ag} = 0.5 gir et rimelig godt estimat.

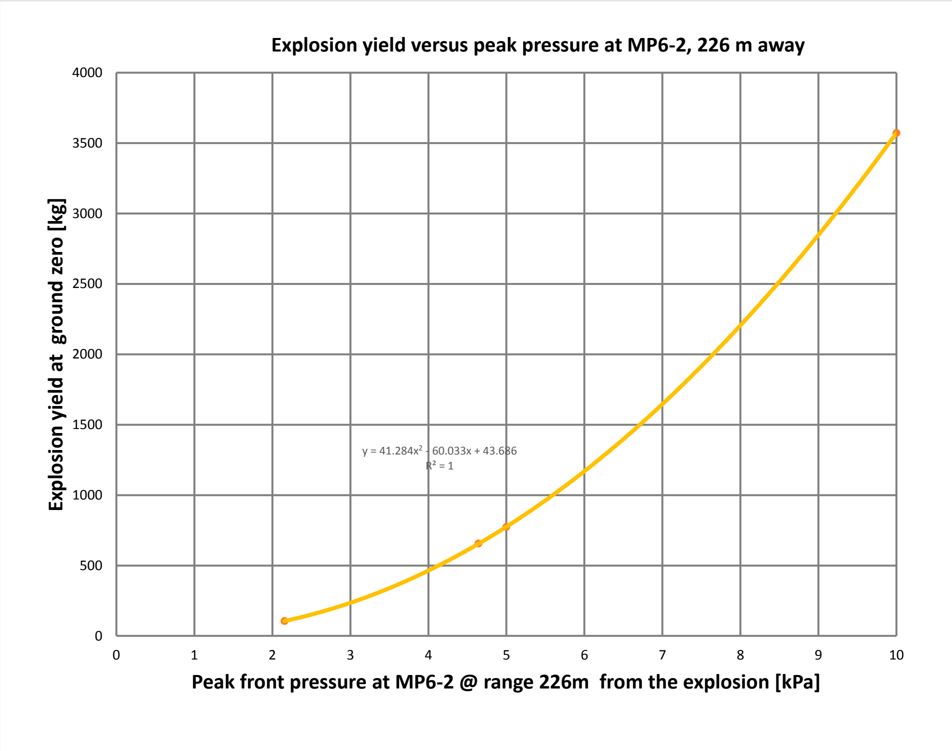
6 Ekvivalent eksploderende ladningsmengde estimert fra knuste vinduer

På de fotografiene vi har fått tilsendt ser det ut til at samtlige vinduer i grisefjøset er blitt knust under eksplosjonen. Dette gjelder i alle fall de vinduene som vender mot eksplosjonsstedet og de som ellers vises på fotografiene.

Vi har ikke direkte fått i oppdrag å analysere virkningen av lufttrykkstøtet på vinduene. Vi gjør likevel en enkel vurdering ut fra det vi ser av bildene.

ANSI omhandler i kapittel 6.3.2 knusing av vindusglass som følge av lufttrykkstøt. Figur 25 i standarden viser data og modell som gir sammenhengen mellom sannsynlighet for at vindusglass knuses og toppverdi av innkommende lufttrykkstøt. Figuren viser at for en sannsynlighet for knusning nær 1.0, dvs. at nær alle ruter som utsettes for trykket blir knust, så må trykket være et sted mellom 5kPa og 10kPa.

Vi har tidligere vist at ca. 5kPa trykkstøt ved grisfjøset tilsvarer at en ekvivalent ladning på ca.775 kg eksploderer på 226m avstand. Sammenhengen mellom trykkstøt på denne avstanden og ladning som eksploderer er svært ikke-lineær og at en økning i trykket gir en sterk økning i tilsvarende ladning på eksplosjonsstedet. Figur 8 viser denne sammenhengen, basert på figur 11 i ANSI og tilsvarende andre modeller / data.



Figur 8

Av figuren ser vi blant annet at det må til en ladning på ca. 3570 kg for å oppnå et trykkstøt på 10kPa, 226m unna.

En enkel analyse av knuste vindusglass kan på denne måten indikere at ekvivalent ladning som eksploderte var i størrelsesorden 800 kg, men kan også ha vært større.

7 Konklusjon og diskusjon

Vi har i teksten ovenfor presentert analyse av vibrasjonsforløp fra eksplosjonsulykken ved Drevja 17. desember 2013 slik det ble registrert i målepunkt MP6-2 på grunnmur på grisfjøs 226 m fra eksplosjonsstedet.

Den delen av vibrasjonsforløpet som skyldes vibrasjoner overført direkte gjennom bakken og den delen som skyldes vibrasjoner som er indusert av lufttrykkstøtet fra eksplosjonen, er analysert hver for seg. Vi har supplert disse to analysene med en enklere analyse av ankomsttidene for de to delene av vibrasjonsforløpet og av det vi kan se av knuste vindusruter på de fotografiene vi har fått tilsendt.

Ut fra en helhetsvurdering av disse analysene vil vi konkludere med at vårt beste estimat på den ekvivalente sprengstoffmengden som gikk av i eksplosjonen var ca. 750 kg.

Metoden vi har benyttet for analyse av de direkteoverførte vibrasjonene har sin styrke i at den er basert på en stedsspesifikk utbredelsesmodell for vibrasjoner i bakken som vi har etablert på grunnlag av vibrasjonsdata og salvedata fra sprengninger i steinbruddet, omkring eksplosjonsstedet. Svakteten ved metoden er at den avhenger av en koblingsfaktor for å kunne ekvivalere vibrasjoner fra innspente ladninger med en kontakteksplosjon. Variasjon i graden av kontakt og derved størrelsen på koblingsfaktoren kan gi en variasjon i estimert ladning på omkring en faktor to. Denne metoden gir estimert ladning i den nedre sjiktet.

Metoden som baserer seg på trykkstøtindusert vibrasjon går via først å estimere toppverdien av trykkstøtet ved grisfjøset, for så å regne tilbake til hvilken ladning som vil gi et slikt trykkstøt på den aktuelle avstanden. Koblingen mellom trykkstøt og vibrasjon er ganske komplisert og er basert på forenklinger og empiriske data. Også her inngår en koblingsfaktor som nok kan endre det estimerte trykket i alle fall med en faktor på 1.5. Betraktningen av de knuste vinduene gir også et estimat på toppverdien av trykkstøtet ved grisfjøset. Det som gir størst variabilitet i ladningsestimatet med disse metodene er tilbakeregningen fra trykkstøt ved grisehuset til ladning på eksplosjonsstedet. Denne sammenhengen er ikke-lineær på en slik måte at små variasjoner i estimert trykk gir en mye større variasjon i estimert ladning på den høye siden.

Estimatet av ladningsstørrelsen ut fra ankomsttidene for de to fasene av vibrasjonsforløpet går også via estimat av trykkstøtet ved grisefjøset. Det virker som denne metoden gir et ganske skarp indikasjon av trykket og derved av ladningsstørrelsen.

Estimatene fra de enkelte metodene er summert opp i tabellen nedenfor:

		Metode			
Parameter	**Estimat**	**Direkte vibrasjon**	**Trykkindusert vibrasjon**	**Ankomsttider**	**Knuste vinduer**
Trykkstøt	Beste estimat	-	4.9 kPa	5.0 kPa	5 kPa
	Yttergrense	-	7.4 kPa	-	10 kPa
Ladningsstørrelse	**Beste estimat**	**630 kg**	**775 kg**	**775 kg**	**775 kg**
	Yttergrense	321 kg	1700 kg	-	3570 kg

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Vibrasjoner fra sprengning og annen anleggsvirksomhet – Veiledning til NS8141

[6] Sondre Gjengedal (2012 / 2013)
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Institutt for geologi og bergteknikk, Trondheim

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VEDLEGG 4: NOTAT FRA FFI – SPREGNINGSULYKKE I DREVJA 17. DES 2013

FFI Forsvarets forskningsinstitutt

Dato:	Vår referanse:	Deres referanse:
11. september 2014	14/01697-2/FFI	

Direktoratet for samfunnssikkerhet og beredskap
v/ Gry Haugsnes
Rambergveien 9
3115 Tønsberg

Sprengningsulykken i Drevja 17. des 2013

Dette notatet inneholder FFI sine vurderinger av hendelsesforløpet i forbindelse med at en bil lastet med utgangsstoffer til ammoniumnitratbasert sprengstoff eksploderte i Drevja 17. desember 2013 som følge av en brann som oppstod i bilens motorrom.

To personer fra FFI deltok i en befaring av ulykkesstedet 3. og 4. juni 2014, sammen med representanter fra DSB, Statens Vegvesen, Sivilforsvaret og det spanske firmaet Maxam, som eide bilen. Under denne befaringen ble det funnet et stort antall vrakrester som var spredt rundt i et område på flere hundre meter omkring eksplosjonsstedet.

Av de forhold som FFI i ettertid har sett ganske nøye på er følgende:

- Fordelingen av vrakrester i forhold til bilens plassering ved eksplosjonen
- Simulering av motorblokkens utkast ut fra dens funnsted
- Analyse av video-opptak av selve eksplosjonen
- Analyse av utkast av små aluminiumsfragmenter fra tankene.

Av de forhold som er av betydning for FFI sin vurdering er følgende:

- Bilen inneholdt to tanker for sprengstoffproduksjon; en fremre tank som inneholdt prillet ammoniumnitrat; og en bakre tank som inneholdt en oljekontinuerlig emulsjon bestående av en vandig løsning av ammoniumnitrat, diesel og emulgator. Ved fylling av

Vedlegg: 0

Saksbehandler: Ove Dullum	Postboks 25, 2027 Kjeller Besøksadresse: Instituttveien 20, 2007 Kjeller	Sentralbord: Dir: Faks:	63 80 70 00 63 80 76 59 63 80 71 15	Mil retn nr: Org.nr: e-post:	0505 NO 970 963 340 MVA ffi@ffi.no

www.ffi.no

borehull, blandes innhold fra begge disse tankene med bl a natriumnitritt og eddiksyre. Blandingsprosessen forgår i et eget blandeverk bakerst på bilen.
- I eksplosjonsøyeblikket stod bilen plassert på noenlunde bart fjell som heller ned mot svinefarmen. Dette stedet er nå sprengt bort på grunn av veiarbeidet i området.

Egenskaper til ammoniumnitrat

Ammoniumnitrat (AN) er mye omtalt i litteraturen, men det er stor uklarhet omkring de fysiske egenskapene, og ikke minst de detonasjonsmessige egenskapene til dette stoffet. Spesielt gjelder dette TNT-ekvivalenten, som både er vanskelig å definere og vanskelig å måle, fordi den avhenger av en lang rekke parametre. En rapport om hendelsen[1] som et spansk universitet har gjort på oppdrag fra Maxam, inneholder en fyldig litteraturstudie av detonasjonsegenskapene. Rapporten viser at TNT-ekvivalenten for AN er angitt med verdier fra 0,05 til 0,82. Dette stemmer også med våre egne studier. Imidlertid anser rapporten en verdi mellom 0,39 og 0,50 som den mest sannsynlige verdien. En annen rapport av Kersten et al.[2] konkluderer imidlertid med at en TNT-ekvivalent på 0,1 – 0,2 er det mest sannsynlige.

Den egenskapen som er mest interessant i denne studien er den såkalte Gurney-hastigheten som karakteriserer utgangshastigheten for metallfragmenter som eventuelt omslutter det aktuelle sprengstoffet. Dette er en størrelse som avhenger av sprengstoffets detonasjonshastighet, energiinnhold, tetthet m m. Noe forenklet kan man si at Gurney-hastigheten angir en hastighet som i praksis er maksimal utgangshastighet for fragmenter. En utgangshastighet som er større enn Gurney-hastigheten kan ikke utelukkes, men det må da være svært god kontakt mellom metall og sprengstoff, samt at metallet ikke må være for tykt, for at dette skal skje. For militær ammunisjon vil man sjelden se fragmenter med utgangshastigheter over 80% av Gurney-hastigheten.

I boka til Klapötke[3] anbefaler man å bruke en verdi for Gurney-hastigheten som er 32,5% av detonasjonshastigheten. For TNT ligger Gurney-hastigheten på ca 2400 m/s. For AN er detonasjonshastigheten i de fleste kilder oppgitt til ca 2800 m/s, hvilket skulle tilsi en Gurney-hastighet på ca 900 m/s. I det omfattende arbeidet til Hurley[4] antyder man Gurney-hastigheter for AN på 500 – 1300 m/s. Når AN smelter går imidlertid detonasjonshastigheten ned[6]. Det samme vil skje med Gurney-hastigheten.

I vårt tilfelle kan man, på grunnlag av det som er beskrevet ovenfor, kunne utelukke utgangshastigheter på over 1100 m/s.

Av øvrige egenskaper for ammoniumnitrat oppgis et smeltepunkt på 170 °C, samt at det dekomponerer ved ca 210 °C. Produktene av dekomponering er i første rekke dinitrogenoksid og vanndamp. Ved høyere temperaturer blir også andre gasser dannet.

Til tross for at sprengstoffets termiske ledningsevne er svært lav, og dets varmekapasitet er ganske høy, er det høyst sannsynlig at sprengstoffet var smeltet ved detonasjon. Det kan ikke utelukkes at detonasjonsegenskapene kan ha blitt endret i stor grad. Rapporten til King viser at smeltet ammoniumnitrat som ligger over dekomponeringstemperaturen får øket sin sensitivitet. Eksempelvis trenger AN en ladning på ca 0,5 kg TNT for

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[1] Sanchidrián J A, A Santos, L M Lopez, P Segarra, R Castedo; Explosion of a Mobile Explosive Manufacturing Unit in Drevja, Norway, December 2013. Determination of the Explosion Yield, Universidad Politéchnica de Madrid, March 2014
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[4] Hurley, Christoph; Development of ammonium nitrate based explosives to optimize explosive properties end explosive welding parameters used during explosion cladding; Colorado School of Mines, 2013

å detonere, men ved 250 °C kan den detoneres med en ordinær fenghette[5]. Teoretisk sett vil imidlertid en oppvarming til smeltepunktet tilsvare 10 – 30% økning i energiinnholdet i sprengstoffet.

Trykkbølgen i luft fra en detonasjon blir i noen grad redusert ved at sprengstoffet er innesluttet i metall eller annet materiale. Den kritiske faktoren er her forholdet mellom massen av metallet og sprengstoffmassen uttrykt i TNT-ekvivalenter. I det aktuelle tilfellet var dette forholdet i størrelsesorden 0,2, hvilket tilsier en trykkreduksjon på ca 15%.

Analyse av filmopptak

Filmopptaket ble gjort av en anleggsarbeider som holdt til i en brakkerigg som var plassert inne på Drevjamoen leir, bak velferdsbygget i leiren. (UTM E422800, N7320580). Dette er ca 3020 m fra nullpunktet. Denne riggen er nå fjernet. Filmopptaket var gjort med en moderne iPhone 5 smarttelefon. Dette opptaket har vært tilgjengelig i uredigert stand. Ut fra kjennskapet til oppløsningen og bildevinkelen i dette opptaket kan man si en del om omfanget av utkast m m.

En slik telefon har en synsvinkel på ca 31 x 55 grader og tar 24 bilder per sekund med en oppløsning på 320 x 568 piksler. Det skal visstnok være mulig, i noen grad, å zoome et video-opptak på en slik telefon, men ifølge brukeren var en slik funksjon ikke brukt. Dette kan også verifiseres ut fra en vurdering av størrelsen på huset til høyre i opptaket, hvis bortre ende må ha befunnet seg 30 – 35 m unna.

Fotografen må berømmes for en svært stødig kameraføring, inntil han blir skremt av trykkbølgen.

Lysglimtet fra detonasjonen finner sted 2,6 sekunder ute i opptaket.

Etter at det verste lysblaffet har lagt seg etter ca 1,6 sekunder, er det mulig å observere enkelte glødende gjenstander som slynges ut av eksplosjonen. De som er synlige, og når høyest, er bergenet til å ha et toppunkt som ligger 430 m over detonasjonspunktet. Toppunktet nås etter ca 5 sekunder, men det er vanskelig å fastslå dette nøyaktig. Et legeme som kastes rett opp uten luftmotstand vil nå denne topphøyden etter 9,9 sekunder når utgangshastigheten er 92 m/s. Fragmenter som når denne topphøyden etter ca 5 sekunder må derfor ha blitt kastet ut med høyere hastighet og samtidig blitt kraftig bremset av luftmotstanden. Etter at toppunktet er nådd, daler fragmentene ned med tilsynelatende lav hastighet, men i opptaket blir denne fasen avbrutt av trykkbølgens ankomst.

I analysen har vi lagt til grunn at splintene har en luftmotstandskoeffisient lik den som gjelder for naturlig dannede splinter fra granater. Splinter som dannes av aluminiumstanken har imidlertid en fasong, i form av flak, som kan tyde på en noe høyere luftmotstand.

En analyse av dette viser at et aluminiumsfragment ikke ville kun nå opp i denne høyden med mindre det veier minst 1,5 kg, hvilket tilsvarer en størrelse på ca 40 x 40 cm når man antar at tykkelsen på flaket er ca 3 mm. Med denne vekten måtte utgangshastigheten ha vært ca 1270 m/s. Dette virker urealistisk, gitt den lave Gurney-hastigheten. Luftmotstanden til aluminiumsdelene kan også, som nevnt ovenfor, være noe undervurdert, hvilket forsterker konklusjonen om at de fragmentene vi ser ikke kan være aluminium.

[5] King Allan W; Threshold Shock Initiation Parameters of Liquid Phase Ammonium Nitrate. International Society of Explosive Engineers, 2008

		
Frame 61. Venstre del av bilder flammer opp pga interlacing	Frame 62. Første og kraftigste lysglimt	Frame 78. 0.7 s etter første glimt
		
Frame 102 Første observasjon av fragmenter	Frame 133 Fragmenter høyest oppe	Frame 280 Siste bilde før fotografen skvetter til

Figur 1 Utvalgte bilder fra videoopptaket.

Det er derfor mest sannsynlig at det dreier seg om stålfragmenter på noen hundre gram. Et fragment på 300 gram kan nå denne høyden dersom utgangshastigheten er ca 700 m/s. Det vil nå toppunktet etter ca 6,5 sekunders flukt. Det kan utelukkes at det dreier seg om lettere ikke-metalliske fragmenter eventuelt biter av et materiale med pyrotekniske egenskaper, som f eks bildekk eller store klumper av tankenes innhold. Disse vil ikke ha stor nok tetthet til at de kan nå den aktuelle høyden.

Den relativt høye utgangshastigheten som kreves for å nå denne høyden, sammenlignet med Gurney-hastigheten, tilsier at disse fragmentene må ha ligget nær sprengstoffet, og mest trolig i kontakt med det.

Opptaket viser også at ca 6,9 sekunder (rundt frame 165) etter detonasjon er det fremdeles et stort fragment ca 290 m over bakken. Dette må være et tyngre fragment enn det som ble nevnt ovenfor. Opptaket viser tydelig at fragmentene kastes ut med ulike hastigheter, hvilket er forenlig med at bitene hadde ulik nærhet til sprengstoff ved detonasjon.

Fragmentenes tilsynelatende lave fallhastighet er forenlig med det som er beskrevet ovenfor. Slike gjenstander vil ha en naturlig fallhastighet på 35 – 55 m/s avhengig av størrelse og materiale.

Det er også verdt å merke seg at utkastet tilsynelatende er ganske symmetrisk, sett fra observatøren. Her må man huske på at bilen var orientert 50 – 60 grader i forhold til synsretningen og med front til høyre mot observatøren.

Det kraftige og til dels vedvarende lyset skyldes at de gassene som er dannet vil brenne og avgi lysstråling i en viss tid.

Trykkbølgen treffer huset 9,0 sekunder etter lysglimtet. Dette stemmer bra med en lydhastighet som på den angjeldende dag må ha vært ca 331 m/s, gitt en lufttemperatur på ca 0 C.

En delkonklusjon er her at de glødende partiklene som kan ses på opptaket ikke kan være annet enn stålbiter som veier minst 300 gram og som har blitt kastet ut med en hastighet på inntil 700 m/s. Man observer også partikler som kastes ut med lavere hastighet, hvilket kan være tyngre fragmenter.

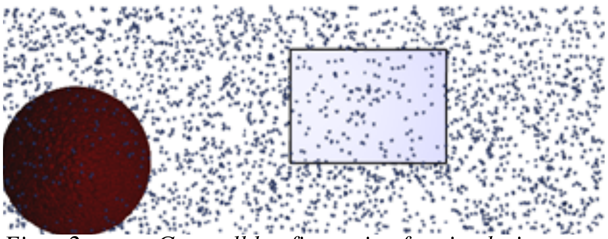
Simulering av utkast av motorblokk

Motorblokken ble funnet ca 200 m fra nullpunktet og på et punkt som ligger ca 35 m lavere. Dette gir et godt holdepunkt for å bedømme hvilken hastighet blokken har blitt kastet ut med og i noen grad også i hvilken vinkel utkastet har skjedd. Dette indikerer hvor den kraften som har forårsaket utkastet kommer fra.

Avstanden mellom nullpunktet og funnstedet for motorblokken, tilsier at den har blir kastet ut med en hastighet på minimum 40 m/s. Dette kan fastsettes ved en enkel ballistisk beregning uten å ta hensyn til luftmotstand. For et slikt legeme vil luftmotstand ha svært liten påvirkning.

Analysen av motorblokkens utkast er gjort ved hjelp av programkoden IMPETUS AFEA som er til utprøving ved FFI. Dette er et finite element program som er velegnet ved studier av hvordan legemer påvirkes av kraftige belastninger i form at kollisjoner med andre legemer eller fra trykkbølger og utkast som fra en detonasjon.

Generelt var oppsettet for simuleringene som vist i figur 2. Motoren ble modellert som en stiv og homogen blokk, 1,1 m lang, 0,8 m høy og 0,5 m tykk og med en vekt på 900 kg. Nedsiden av blokken befinner seg 0,5 m over bakken. Sprengstoffet ble modellert som en blokk med TNT, fordi egenskapene for AN ikke er tilgjengelig i programmet. Sprengstoffets masse ble variert fra 300 – 900 kg og det hadde fasong som en rettvinklet boks, en kule, en halvkule, eller en kjegle. Høyden over bakken og horisontal avstand til sprengstoffet ble også variert for sprengstoffet. I noen tilfeller ble sprengstoffet liggende delvis under motorblokken.

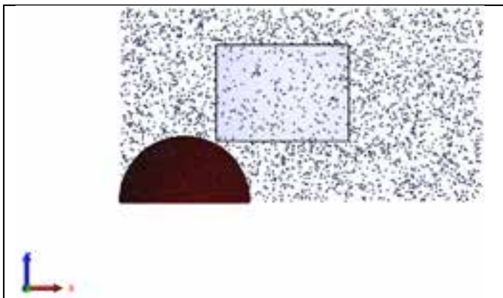
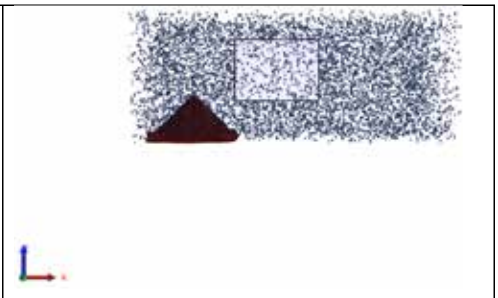
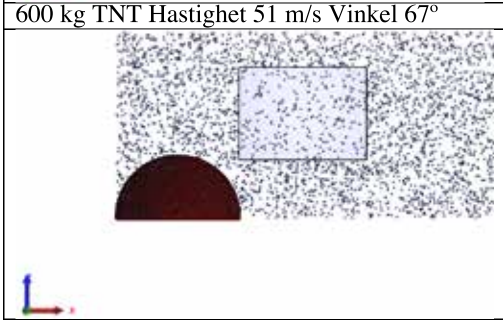
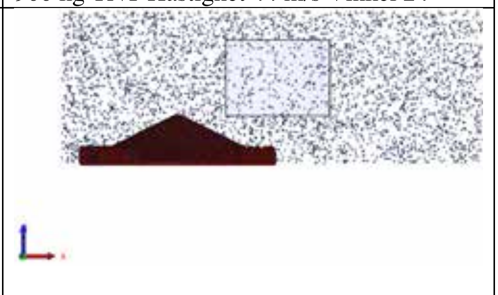


Figur 2 *Generell konfigurasjon for simuleringene med ladning til venstre og motorblokk til høyre for midten*

Antall partikler som sprengstoffet deles opp i var satt til 200 000. Det ble også gjort en simulering med 2 000 000 partikler, men dette påvirket ikke resultatet i noen stor grad.

Ettersom man ikke har noen indikasjon på hvor en detonasjon startet, har vi antatt at detonasjonen finner sted samtidig i hele sprengstoffet. Denne forenkling vil i mindre grad påvirke resultatet.

Figur 3 viser fire konfigurasjoner hvor resultatet, i form av sprengstoffmasse, utkasthastighet og utkastvinkel, blir slik at motorblokken ville ha landet på funnstedet.

	
600 kg TNT Hastighet 51 m/s Vinkel 67°	900 kg TNT Hastighet 44 m/s Vinkel 24°
	
900 kg TNT Hastighet 44 m/s Vinkel 25°	750 kg TNT Hastighet 48 m/s Vinkel 68°

Figur 3 *Fire mulige konfigurasjoner som gir mulig løsning for motorblokkens utkast.*

Til sammen ble det gjort 37 simuleringer, med ulike konfigurasjoner av sprengstoffets form, mass og dets posisjon i forhold til motorblokken.

Det vil i praksis finnes et utall andre konfigurasjoner som ville ha gitt riktig resultat i form av vinkel og hastighet. Resultatene sannsynliggjør følgende delkonklusjoner:

- Ladning som ligger 0,5-1,0 m fra motor må ha mer enn 900 kg TNT for at motor skal ha nødvendig utgangshastighet.
- Dersom avstanden er kortere vil det være tilstrekkelig med 600 kg TNT.
- Beregningene antyder at posisjonen til ladningen må ha vært svært nær eller delvis under motor.
- Motoren får i simuleringene maksimal hastighet siden det ikke er modellert andre strukturer rundt som kan «stjele» noe av impulsen.

En usikker faktor ved denne analysen er at man ikke helt kan utelukke at motorblokken har blitt kastet ut vannrett, eller endog med negativ utgangsvinkel, og kommet til ro på funnstedet etter at den har truffet bakken én eller flere ganger. Underlaget av grov pukk eller fjell som preget mye av området mellom nullpunktet og funnstedet, ville kunne gi minimalt merke i bakken og således ikke blitt lagt merke til. En faktor som imidlertid taler i mot denne muligheten er at deler av gearboksen ble funnet 430 m fra nullpunktet og omtrent i bilens retning. Siden denne delen er plassert noe bakenfor motoren og ganske lavt er funnstedene forenlig med at begge delene ble kastet oppover. På grunn av at gearboksen er mindre, men likevel tung, vil den bli kastet lenger bort.

Utkastets fordeling

Under befaringen fikk man et klart inntrykk av at aluminiumrester, som ser ut til å være fra tankveggene, i svært stor grad ble funnet bak og til siden for bilen. De registrerte funnene viser også at de fleste av de små aluminiumsbitene er spredt til siden eller bakover.

Mangelen på aluminiumsbiter som spres framover kan skyldes at førerkabinen og motor har sperret for disse bitene. Det er også en indikasjon på at detonasjon kan ha startet ganske nær førerkabinen, fordi en detonasjon i en viss avstand fra kabinen ville trolig ha kastet den del splinter framover. Dette er forenelig med det man fant fra simuleringene av motorutkast, som viste at detonasjonen må ha skjedd nært og delvis innunder motoren.

Det er imidlertid verd å merke seg at små aluminumsbiter har blitt spredt rett bakover, men ikke rett framover. De som ble kastet ut rett bakover kan ha kommet fra toppen av fremre tank, men det er mer sannsynlig at de kommer fra bakre tank. I tillegg finner man ikke igjen store rester av noen av tankene. På den annen side er det man har funnet av aluminium bare en liten del av den mengden aluminium som var til stede i hovedtankene og andre deler. Dette peker i retning av følgende forhold:

- Detonasjonen startet nær bakken og lenger fram enn midten av fremre tank
- Detonasjon har også funnet sted inne i fremre tank
- Også bakre tank må ha detonert

De fragmentene som er synlige på video-opptaket, kan stamme fra bilens nedre strukturer og som kan ha befunnet seg i kontakt med sprengstoffet, eller i nærheten av det. Dette kan dog ikke fastslås med sikkerhet.

Funn av små aluminiumsflak, men typisk vekt på 50 gram, ble funnet inntil ca 200 m fra nullpunktet. Disse flakene hadde en tykkelse på 5 eller 3 mm og må således stamme fra selve aluminiumstankene. Størrelsen av disse var ned mot 10 cm^2. Tabellen nedenfor viser rekkevidden av slike fragmenter med forskjellige vekter og utgangshastigheter.

Masse (kg)	Utgangshastighet (m/s)	Rekkevidde (m)

0,005	400	95
	1000	108
0,05	400	185
	1000	220
0,5	400	345
	1000	403

Som man ser er det vekten av fragmentet som i første rekke bestemmer hvor langt det kan gå. Dette betyr at det er vanskelig å si hvilken utgangshastighet fragmentene kan ha hatt ettersom vi ikke kjenner i hvilken vinkel de er blitt kastet ut. Det som imidlertid er klart, både ut fra størrelse og rekkevidde, er at bitene må ha vært i kontakt med sprengstoffet ved detonasjonen.

Følsomhet av oppvarmet ammoniumnitrat

I forsøk på å forstå hva som kan ha skjedd, og spesielt hva som kan ha startet detonasjonen, har vi funnet fram til en del litteratur som kan kaste lys over problemet. Fremfor alt er det rapporter som omhandler detonasjon i oppvarmet eller smeltet ammoniumnitrat som er av interesse.

Et amerikansk MSDS-dokument[6] slår fast at AN vil detonere hvis det varmes opp i lukket rom eller utsettes for sjokk, og at AN i seg selv ikke er brennbart, men vil bidra til å øke brennbarheten av tilstøtende materialer.

En rapport fra det amerikanske innenriksdepartementet[7] er også sentral. Når AN varmes opp og smelter går den kritiske diameteren ned slik at det skal mindre til før man får en reaksjon. Imidlertid skal det svært mye til for at AN som ligger åpent skal detonere. Ren AN vil heller ikke underholde en brann. Imidlertid kan et slag mot stoffet gi en detonasjon. I tillegg kan tilsats av brennbare materiale skape en deflagrasjon i materialet som etter hvert kan gå over i en detonasjon. I den foreliggende situasjon har begge former for initiering vært mulig. Man kan se for seg at det har oppstått et mekanisk sammenbrudd i bærende strukturer slik at f eks fremre tank har falt ned på en masse med AN som har rent ut av tanken, og dermed gitt en lokal trykkoppbygning i massen. Man kan også se for seg at en blanding av smeltet og prillet AN har rent ut og blitt overøst med brennende diesel, eddiksyre eller natriumnitritt som kan ha gjort AN mer sensitiv.

I en rapport fra Naval Ordnance Lab[8] pekes det på at et porøst sprengstoff lettere gir overgang fra deflagrasjon til detonasjon fordi porene leder de varme gassene innover i stoffet. Det er usikkert om dette er relevant i vårt tilfelle, men det er trolig at selv om den fremre tanken hadde vært utsatt for varme i over en time, er lite trolig at all massen ville ha smeltet. Dersom tanken så kollapser eller åpner seg vil derfor en blanding av smelte og priller strømme ut.

Selv om massen av priller ikke var fullstendig smeltet, må deler av den ha hatt en svært høy temperatur og dermed vært svært følsom.

I en amerikansk rapport[9] om en eksplosjonsulykke i en gjødselfabrikk i Iowa, pekes det på følgende forhold som gjør AN mer følsom:

- Høy konsentrasjon

[6] Material Safety Data Sheet – Ammonium Nitrate; CF Industries Sales LLC, Deerfield, IL, 2013
[7] Van Dolah R W, C M Mason, FJP Perzak, J E Hay, D R Forshey; Explosion Hazards of Ammonium Nitrate under Fire Exposure; U S Dept of the Interior, Bureau of Mines, 1966.
[8] Bernecker Richard R, Donna Price; Transition from Deflagration to Detonation in Granular Explosives; NOLTR 72-202, Naval Ordnance Laboratory, Silver Spring, NJ, 1972
[9] Thomas Mark J, Alan Cummings, Mariano Gomez; Chemical Accident Investigation Report – Terra Industries Inc. Nitrogen Fertilizer Facility, Port Neal Iowa; United States Environmental Protection Agency, 1995

- Lang lagringstid
- Høy temperatur
- Forurensning med uorganiske stoffer eller metaller
- Innkapsling, innpakking (gir høyere trykk ved oppvarming)
- Områder i sprengstoffet med lav tetthet (f eks bobler)

Det siste punktet tilsier at kontakt med kokende væsker eller at det på andre måter danner bobler i den smeltede AN kan gi opphav til detonasjon.

Konklusjon

FFI sine vurderinger peker klart i retning av at det har funnet sted en detonasjon i prillene og at dette har skjedd etter at det smeltede prillene helt eller delvis hadde rent ut av tanken. Det fremste indisiet er lokalisering av motorblokk og gearboks. Simuleringer antyder at 600 – 900 kg TNT-ekvivalenter har bidratt til utkast av motorblokk. Funn av smeltet aluminium gjør det ganske åpenbart at det må ha gått hull i minst én aluminiumstank som følge av brannen. Brennende diesel kan ha medvirket til intens varmepåvirkning, og dermed smelting av aluminium, i nedre del av tankene.

Det virker sannsynlig at en detonasjon i den fremre tanken med priller har ført til en antenning av emulsjonen i bakre tank. Mangel på funn av større deler fra tankene indikerer at det har foregått en detonasjon i begge. Dersom bakre tank ikke hadde detonert, ville man forvente å finne store rester av den.

Det faktum at en slik detonasjon har funnet sted, reiser spørsmålet om det er hensiktsmessig å transportere sprengstoff i to-komponent form, dersom en av komponentene har en følsomhet som kan sammenlignes med den ferdige blandingen.

Fullskalatest

Den aktuelle ulykken i Drevja, samt flere rapporter om lignende ulykker tidligere, slår fast at AN kan detonere dersom det utsettes for en brann. Det som er spørsmålet er hvilken mekanisme som utløste detonasjonen.

Konklusjonen reiser en del spørsmål som det er vanskelig å besvare ad teoretisk vei. Blant disse er:

- Hva utløste detonasjonen? (temperatur, slag, smeltet metall, kjemisk prosess, eller en overgang fra deflagrasjon til detonasjon)
- Hvor fort vil tanken smelte?
- Hvordan flyter smeltet AN?
- Hvor fort vil AN dekomponere i en brann?
- Hvordan vil følsomheten øke med økende temperatur?

Det har blitt gjort branntester av emulsjonen. Disse har vist at til tross for at en tank med slik emulsjon står i en heftig brann, og det går hull på tanken, og emulsjonen renner ut, blir det ingen detonasjon. Vi kjenner ikke til at tilsvarende tester er gjort med prillet AN. I så fall er det en mangel i det empiriske grunnlaget for å tillate bruk og transport av slikt materiale.

Under en fullskala test av en slik tank må man sørge for å få monitorert eksperimentet i form av video, temperaturmålere, trykkmålere, osv.

En slik test kan være kostnadskrevende og man må være klar over at ikke man er garantert noen klar konklusjon etter et slikt eksperiment.

Ove Dullum

forsker

VEDLEGG 5: BILDEANALYSE FRA DSB

Bildeanalyse av bilder tatt ved brann i MEMU på Drevja 17.12.2013

DSB har mottatt bilder av brannforløpet fra ulike kilder som politi, brannvesen, anleggsarbeidere, privatpersoner og media. Bildene er stort sett tatt fra en avstand på over 500m i forhold til brannen i F-114. Brannforløpet er vanskelig å beskrive ut ifra bilder, da tolkning av bilder er forbundet med stor usikkerhet. På grunn av dette, vil bildene og beskrivelsene som følger her hovedsakelig fungere som supplement til andre observasjoner og analyser.

Tidspkt	Bilde	Analyse
kl 13:07 Brannen oppdages ca kl 13:04 og har her vart i ca 3 minutter.	Bilde 1: 	• Viser brannens arnested. • Flammer på høyre side av F-114 under frontruten og i tillegg er det to mindre flammer lengre ned på denne siden, ved grillen. • Rundt midten av fronten er det en tydelig avsetning av sot på oversiden av grillen. • Lyskasteren til høyre for bilen ble ikke slått av før evakuering.
kl 13:26 Brannen har vart i ca. 22 min.	Bilde 2: 	• Førerhuset er i full brann. • Ingen flammer på lasteplanet, deksel ses tydelig. • Ser ut til å brenne på bakken foran bilen. • Sort røyk kan tyde på forbrenning av plast, gummi, diesel og olje. • Lyskasteren ses til høyre for brannen.

kl 14:06 Brannen har vart i 1t 2 min	Bilde 3: 	Røyken er nå mindre sort og mer grå. Det kan tyde på at det er vanndamp i røyken. Vanndamp vil kunne gi hvit røyk, men sammen med sort røyk fra forbrenning av hydrokarboner kan røyken se mer grå ut.
Kl 14:23 Brannen har vart i ca. 1t 19 min	Bilde 4: 	Røyken ser mer grå og hvit ut enn på bilde tatt kl 14:06. Som nevnt tidligere kan hvit røyk tyde på at det er vanndamp i røyken. Vanndampen kan stamme fra både vanntanken på lasteplanet men også fra dekomponering av ammoniumnitrat.
Kl 14:30 Brannen har vart i ca. 1t 26 min	Bilde 5:  Bilde 5 zoomet: 	Ser ut som brannen ikke har nådd enden av lasteplanet, men at de bakerste bildekkene brenner. Ser ut som det brenner på bakken foran og ved siden av bilen. Kan være diesel, olje, smeltet plast og bildekk. Kan også tenkes å komme fra kjemikalier fra tankene om bord som har rent ut og brenner enten alene eller i kombinasjon med de tidligere nevnte materialer.

Kl 15:15 Brannen har vart i 2t 7 min	Bilde 6A:  Bilde 6B: 	• Ser ut til at førerhytta er utbrent. • Produksjonsenheten på lasteplanet er omsluttet av brann. • Ser ut til at horisontal skrue har falt litt ned når man sammenligner bilde 6A og 6B. Tyder på svikt i bæreegenskapene til aluminiumstankene.
Kl 15:21 Brannen har vart i 2t 17 min	Bilde 7: 	Intensivering av brannen.

Kl 15:26 Brannen har vart i 2t 22 min	Bilde 8: 	Intensivering av brannen.
Kl 15:26 Eksplosjonen	Bilde 9: 	Brennende/glødende nedfall.

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