Accident Investigation Board Norway

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REPORT ON FIRE IN TANK TRAILER IN THE SKATESTRAUM TUNNEL IN SOGN OG FJORDANE ON 15 JULY 2015

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Photos: AIBN

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REPORT ON SERIOUS TRAFFIC ACCIDENT

Date and time:	15 July 2015 at 10:27
Scene of the accident:	The Skatestraum tunnel in Bremanger Municipality in Sogn og Fjordane County
Road no, main section (hp), km:	Fv 616 HP2, km 5.791
Type of accident:	Fire in tank trailer
Vehicle type and combination:	Truck and drawbar trailer approved for tank transport of flammable liquids
Transport firm:	Måløy Havneservice AS
Type of transport:	Tank transport of 35,500 litres of petrol

NOTIFICATION OF THE TRAFFIC ACCIDENT

On 15 July 2015, the Accident Investigation Board Norway (AIBN) was informed through the media of a fire in a trailer inside the Skatestraum tunnel on the Fv 616 road in Sogn og Fjordane County. Upon contacting the police, the AIBN was informed that a trailer carrying 16,500 litres of petrol had broken loose from the truck and run into the tunnel wall. One of the tank chambers had started to leak, and the petrol had been ignited. Because of the extensive build-up of smoke and heat, it was not possible to enter the tunnel until Tuesday 21 July, when two accident inspectors from the AIBN visited the scene of the accident.

SUMMARY

On the morning of Wednesday 15 July 2015, a heavy goods vehicle set out from Måløy Havneservice AS's facility in Måløy. The vehicle consisted of a truck and trailer, loaded with 19,000 and 16,500 litres of petrol respectively, for delivery in Florø.

Approximately 10 minutes after crossing the Oldeide ferry landing, the vehicle entered the Skatestraum tunnel, a subsea tunnel falling/rising at a gradient of 10%. About 450 metres after starting the uphill drive from the lowest point of the tunnel, the trailer broke loose from the truck and the front right-hand corner hit the tunnel wall. The impact made a hole in the front tank chamber and the petrol it contained ran out.

Because of the steep gradient of the tunnel, the petrol quickly ran towards the lowest point. All the petrol was eventually ignited and the fire spread from the lowest point of the tunnel to the eastern portal, over a distance of approximately 900 metres.

When the incident occurred, there were 17 people inside the tunnel in total. They all managed to evacuate without sustaining any serious injuries.

The result of the investigation shows that the trailer drawbar broke due to an advanced state of internal corrosion in the drawbar rods. This corrosion was first detected during an inspection in 2011. The rust damage was repaired by welding sheets of metal onto the rusted parts of the trailer drawbar. The metal sheet was welded onto the outside of the corroded areas, without removal of any rust in that connection and without any further assessment of the scope of the internal corrosion damage to the drawbar rods. The repairs were not in accordance with the trailer manufacturer's

specifications, which state that welding is not permitted and that damaged drawbars must be replaced.

From the time that the repairs were carried out until the trailer drawbar broke, the trailer had undergone eight official inspections without the defective repairs having been detected.

The investigation found that the tunnel’s surface water system was not designed to handle the amount of petrol that ran out. Furthermore, a leakage in the surface water pipes caused some of the petrol to run into the ground. This meant that both the petrol running on top of the roadway and the petrol that ran into the surface water system was on fire.

The SP Technical Research Institute of Sweden has studied possible sources of ignition and the spread of fire in the tunnel. It concluded that the petrol vapour was most probably ignited by a vehicle following behind the trailer that had broken loose. The report also concluded that the falling/rising gradient of the tunnel had a significant bearing on the spread of the fire, and that this was exacerbated by the inadequate capacity of and a fault in the tunnel’s wastewater and drainage system.

According to SP’s calculations, the maximum heat release rate exceeded 400 MW during the period when both the running petrol and the tank trailer were on fire, and the temperature above the burning trailer was approximately 1,350 °C. The greatest air flow rate generated by the fire inside the tunnel was around 100 km/h. Furthermore, the report concludes that any persons caught in the smoke downstream or upstream of the fire would have found it very difficult to evacuate and would most probably have lost consciousness and subsequently died.

The investigation also found that risk analyses have been conducted that, among other things, describe a fire/explosion in a heavy goods vehicle and accidents involving dangerous goods, but that no descriptions have been provided for how such scenarios are to be handled when it comes to extinguishing the fire, evacuation, self-rescue and assisted rescue.

After the fire, Sogn og Fjordane county administration has not implemented or considered implementing compensatory measures to limit the consequences of any similar incidents.

The AIBN submits four safety recommendations as a result of this investigation.

1. FACTUAL INFORMATION

1.1 Sequence of events

On the morning of Wednesday15 July 2015, a heavy goods vehicle set out from Måløy Havneservice AS’s facility in Måløy. The road tanker consisted of a tank truck and a tank trailer, loaded with 19,000 and 16,500 litres of petrol, respectively, for delivery in Florø.

When the driver had driven the road tanker ashore at Oldeide, he stopped to allow the cars that came off the ferry behind him to pass. He did so to avoid having a tail of cars behind him along the road to Florø, which was narrow and winding. Nor did he want to have cars behind him through the Skatestraum tunnel, which reaches its lowest point 80 metres below the surface of the sea and falls/rises at a gradient of 10%; see Figure 3.

Approximately 10 minutes after leaving Oldeide ferry landing and heading towards Florø, the road tanker entered the Skatestraum tunnel on the Fv 616 county road. To prevent the brakes from overheating while driving to the lowest point of the tunnel, the driver only used the truck’s retarder and engine brake.

About 450 metres after starting to drive uphill from the bottom of the tunnel, the driver heard a bang and noted that the truck was going faster although he had not stepped on the accelerator. When he checked the mirror, he saw that the trailer had broken loose from the truck and that it was standing with its front right-hand corner up against the tunnel wall some way behind the truck. He stopped the truck and went out, and observed that some parts of the trailer drawbar were still attached to the truck. The trailer drawbar had broken just in front of where it was attached to the trailer; see Figure 2.

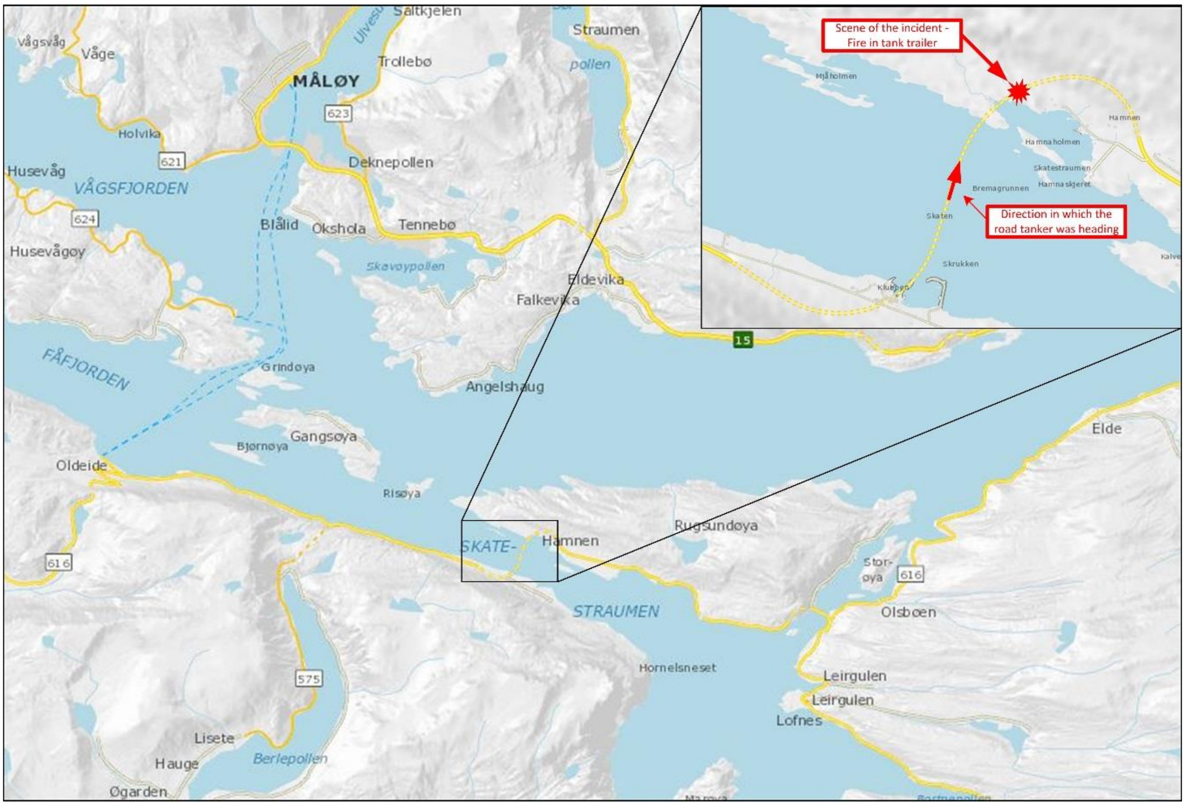


Figure 1: The scene of the accident and the direction in which the road tanker was heading Map: Road map, NPRA

When he looked towards the trailer, he observed that petrol was leaking out of the trailer's front tank chamber. The driver immediately notified the Traffic Control Centre (VTS) of the incident using the tunnel's emergency telephone, enabling them to close the tunnel. At the same time, he warned an oncoming passenger car, so that it was able to turn around and leave the tunnel.

Figure 2: Remains of the trailer drawbar attached to the truck after it had broken at the point where it was attached to the trailer. Photo: The police

Just over two minutes after discovering that the trailer had broken loose from the truck, the driver heard another bang and observed that fire had broken out at the rear end of the tank trailer. The tunnel ventilation system was sending the smoke from the fire in the direction of the tank truck, and the driver therefore chose to drive the truck out of the tunnel. The build-up of smoke from the fire increased, and the tank truck was surrounded by dense smoke through the final section of tunnel before reaching the exit. The driver parked the truck a good distance away from the tunnel portal, but subsequently had to move it further way because of the intense smoke and heat generation.

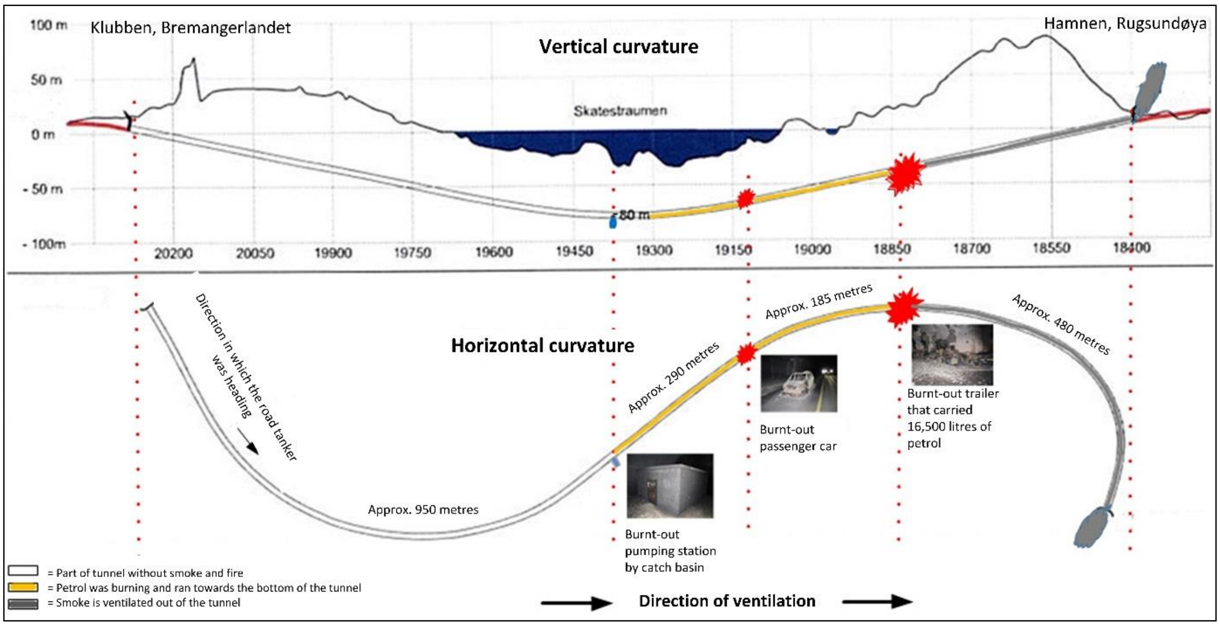


Figure 3: The tunnel's vertical and horizontal curvatures and overview of the fire incident. Illustration: AIBN/NPRA

Four passenger cars and one camper van had followed the road tanker into the tunnel. Three of the passenger cars and the camper van were able to turn around and leave the tunnel, while one passenger car was evacuated and left standing 150 m behind the tank trailer. The driver and passenger in the passenger car that was left behind were eventually evacuated in the camper van, which was one of the last two vehicles to leave the tunnel. A detailed description of the road users' experience of the incident is given in section 1.3.2.

Figure 4: The remains of the tank trailer as left behind when it had broken loose from the truck. Photo: AIBN

The fire in the tank trailer and tunnel developed quickly, and much of the petrol in the trailer's front tank chamber leaked out and ran towards the bottom of the tunnel. All the petrol was eventually ignited and the fire spread from the bottom of the tunnel up to the eastern portal, over a distance of approximately 900 metres. The tank trailer and the evacuated passenger car were completely consumed by fire, and the damage to the tunnel and tunnel infrastructure was extensive.

Figure 4 shows damage to the tank trailer and the tunnel.

1.2 Personal injuries

Five of the 17 people who were in the tunnel when the trailer caught fire suffered minor smoke injuries.

1.3 Survival aspects

1.3.1 The rescue work

The VTS first became aware of the incident when it received a call from the Skatestraum tunnel's emergency phone at 10:25. The call was made by the driver of the road tanker, who conveyed the message that petrol was leaking from the trailer. The VTS immediately closed the tunnel.

The emergency communication centre (ALSF) in Sogn og Fjordane received the message from the driver that a trailer was on fire in the Skatestraum tunnel at 10:27. They immediately issued a triple alert and notified the police and the Emergency Medical Communication Centre (AMK) in Sogn og Fjordane. Response personnel from all the rescue services were immediately deployed to the scene of the accident.

By chance, a police officer was already present in the vicinity of the tunnel portal at Hamnen (Rugsundøy side). He arrived at 10:48 and assumed the role of incident commander.

At 10:48, the first ambulance arrived at Hamnen and at 11:04, the air ambulance and a Sea King rescue helicopter arrived at Hamnen and Klubben (Bremanger side), respectively.

At 11:01, the information was received that 13 people had exited the tunnel at Klubben.

At 11:12, smoke divers were sent into the tunnel from Klubben. At 11:20, the information was received that a total of 17 people had been evacuated towards Klubben and that one person had been evacuated towards Hamnen. These people were attended to by rescue service personnel.

At 11:28, the smoke divers came back out of the tunnel. They communicated that there were no people present in the area between the burning trailer and the tunnel exit.

1.3.2 The road users' description of the incident

When the trailer broke loose from the tanker truck, there were four passenger cars and one camper van inside the tunnel.

The first vehicle (a passenger car) caught up with the road tanker just after passing the bottom of the tunnel and was driving behind it until the trailer broke loose from the truck. The driver of the passenger car observed that the trailer had started to sway violently over a distance of 50–100 metres before it broke loose and hit the tunnel wall. When the driver of the passenger car saw that liquid was leaking out of the tank trailer, he chose to turn his car around and exit the tunnel from where he had entered it. While driving back through the tunnel, he was able to warn the first oncoming car, but three other vehicles continued driving towards the leaking tank trailer.

Just after starting the ascent out of the tunnel, the driver and passenger of the camper van noticed that liquid was running down the side of their lane. Continuing uphill, they passed a passenger car at a standstill in their lane before arriving at the trailer that had run into the tunnel wall.

When they were 5–10 metres from the tank trailer, the people in the camper van heard a bang and a fire broke out around the trailer. The pressure wave from the fire pushed the bonnet of the camper van upwards and dislodged the headlights. The driver immediate started reversing towards the bottom of the tunnel. The two people in the van stated that the fire spread rapidly in the petrol that was running down the roadway. As they reversed downhill, the flames from the petrol stream were leaping up along the side of the camper van.

As the van approached the bottom of the tunnel they caught up with two people who were running downhill. The two people were eventually able to get into the camper van, and they proved to be the driver and passenger of the passenger car they had overtaken on their way uphill towards the road tanker. The two people said that they had stopped because of a puncture, and that they had left the car and run downhill when they heard the bang and saw that the trailer was on fire. As they left their car, they had stepped right into the petrol that was running down the roadway.

The camper van continued reversing to the bottom of the tunnel and some way up towards the Bremanger side. When it felt safe, the driver turned the camper van around and drove out of the tunnel.

Figure 5 shows where the vehicles were positioned in the tunnel at the time when the fire broke out in the trailer.

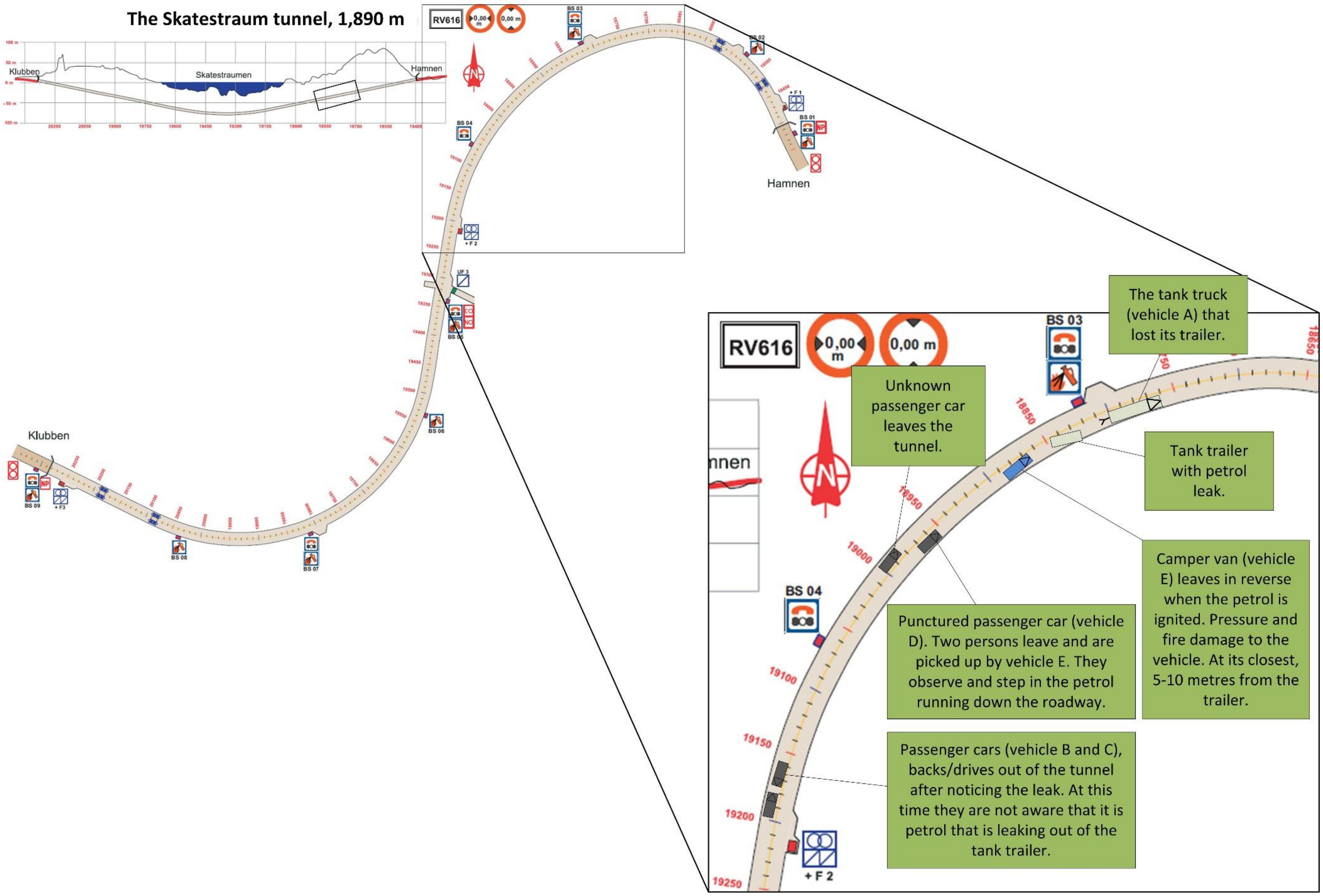


Figure 5: The positions of the vehicles in the tunnel at the time when the fire broke out in the trailer. Illustration: AIBN

1.4 Damage to vehicles and cargo

1.4.1 Damage to the tank trailer

The trailer that broke loose from the tank truck was completely destroyed in the fire that started when the trailer's cargo of 16,500 litres caught fire. Only burnt-out remnants of the trailer's front and rear axles remained when the fire had been extinguished; see Figure 6.

Figure 6: The remains of the tank trailer where it ended up inside the tunnel. Photo: AIBN

Damage and defects in the trailer drawbar are described in section 1.8.2.2

1.4.2 Damage to the passenger car

One of the passenger cars that followed the road tanker into the tunnel was left approximately 150 metres behind the tank trailer, because it could not be driven. The passenger car that was left behind was completely burnt out; see Figure 7.

Figure 7: The passenger car that was left approx. 150 metres behind the tank trailer was completely burnt out. Photo: AIBN

1.4.3 Damage to the camper van

The camper van was 5–10 metres from the tank trailer when the petrol was ignited. The van sustained pressure damage in the engine compartment, bonnet and bonnet hinges, in addition to heat damage and melting damage to the surfaces on the right-hand side and damage to the headlights.

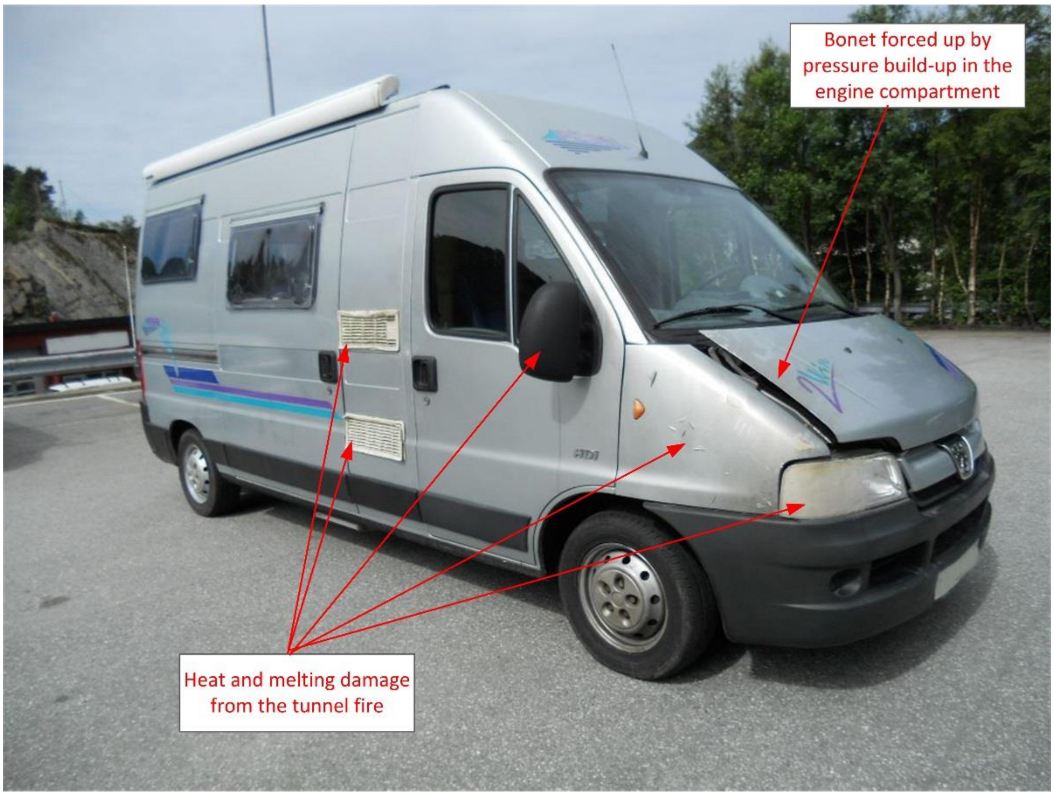


Figure 8: Damage to the camper van. Photo: Gjensidige

1.5 Damage to tunnel and infrastructure

The fire that broke out in the leaking petrol rapidly generated intense heat and thick smoke. In the area of the tank trailer, much of the sprayed concrete lining on the tunnel walls and ceiling broke and fell into the roadway. This caused the fire to spread to the insulation material (PE foam) that was installed behind the sprayed concrete lining.

The section of tunnel between the tank trailer and the exit at Hamnen (Rugsundøy side) sustained extensive smoke and heat damage. Hardest hit were the ventilation fans and electrical installations.

In the section of tunnel between the tank trailer and the bottom of the tunnel, there was damage to the drainage system, electrical installations and pumping system located by the catch basin at the lowest point of the tunnel.

Damage to the tunnel in the area around the tank trailer is shown in Figure 9, while an overview of damage to the section of tunnel between the tank trailer and the bottom of the tunnel is shown in Annex A.

Figure 9: Shows damage to the tunnel bore in the area of the tank trailer, viewed in the direction towards which the smoke was ventilated. Photo: AIBN

1.6 Incident site

The incident site extended over a distance of approximately 900 metres. It extended from the lowest point of the tunnel at 80 metres below sea level to the western portal at Hamnen on Rugsundøya island; see Figure 3.

The tank trailer stopped with the front right hand corner up against the tunnel wall on a right-hand bend with a radius of 400 metres, at a distance of 475 metres from the lowest point of the tunnel and 425 metres from the tunnel portal at Hamnen. At this point the roadway has a longitudinal downhill slope of approximately 10% and a one-sided cross slope to the right, viewed in the direction in which the road tanker was heading. The tunnel was coated with PE foam and fibre-reinforced sprayed concrete. On the left-hand side of the roadway in the direction in which the road tankers was heading, close to where the tank trailer broke loose, there is an SOS telephone and an emergency lay-by.

Drainage for jetting water is alongside the kerb on the right-hand side of the roadway, where the kerb has integrated side-entry gullies with sand traps. The main tunnel drainage system is located below this; see section 1.10.2. Both drainage systems feed the water to a catch basin at the bottom of the tunnel.

1.7 Road users

The driver of the road tanker was a Norwegian national, who was 52 years old at the time of the accident. He had been employed by Måløy Havneservice AS for several years, and he had extensive experience of driving road tankers. He was responsible for follow-up and maintenance of the firm’s vehicle fleet, and he was among the key personnel involved in the purchase of vehicles and equipment.

A print-out of the activity log for the driver's driving and rest periods showed that he had had the prescribed weekly rest period the weekend before the incident. From the time of the weekly rest period up until the time of the incident, his working hours had been in accordance with regulatory working, driving and rest period provisions.

There were 16 other road users in the tunnel when the incident occurred. They were distributed between five vehicles (four passenger cars and one camper van).

1.8 Vehicle and load

The vehicle combination consisted of a triple-axle tank truck and a triple-axle tank trailer. It was carrying 35,500 litres of petrol for delivery in Florø. The petrol was distributed between the tank chambers as shown in Figure 10.

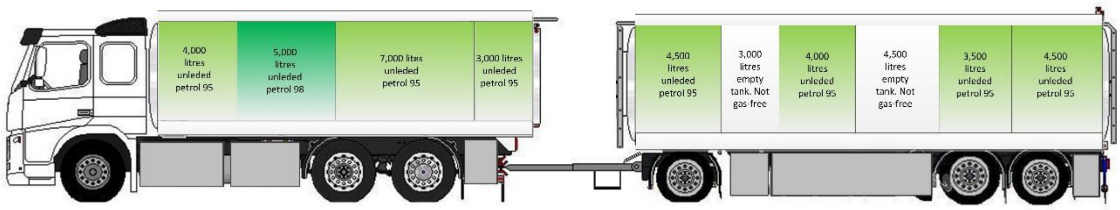


Figure 10: Distribution of the load on the road tanker involved in the incident in the Skatestraum tunnel on 15 July 2015. Illustration: AIBN

1.8.1 Tank truck

The tank truck was a 2011 model MAN 26.540, type 6x2-2 LL/LLS. It had been registered to the present owner (Måløy Havneservice AS, Måløy) on 23 September 2011, and had a built-on tank of the type HNK Bilcon, with four separate tank chambers; see Figure 10. The truck had passed its most recent periodic roadworthiness test on 21 August 2014.

The truck was approved for the carriage of liquids having a flashpoint of no more than 60 °C (FL + AT vehicle). The truck had first been issued with an ADR approval certificate on 30 September 2011, which had been renewed most recently on 24 September 2014 and was valid until 2 October 2015.

1.8.2 The tank trailer (drawbar trailer)

1.8.2.1 *In general*

The tank trailer was a 1997 model Eurotank type ET trailer. The tank was made of aluminium and it was self-supporting. It had six separate tank chambers; see Figure 10. The tank trailer had first been registered on 23 July 1997. The previous owner had bought it in 1999 and owned it until Måløy Havneservice AS bought it on 19 January 2012. The tank trailer was owned by Måløy Havneservice AS at the time of the incident.

The tank trailer was approved for the carriage of liquids having a flashpoint of no more than 60 °C (FL + AT vehicle). The tank trailer had first been issued with a certificate of ADR approval on 23 July 1997, which had been renewed most recently on 30 April 2015 and was valid until 30 April 2016.

When the trailer drawbar was delivered from the trailer manufacturer, it had welded-on steps on each of the two drawbar rods, and a welded-on expanded metal grate on top. These parts had not been welded on by VBG, the drawbar manufacturer.

Figure 11: Tank trailer of the same make and type as the one that caught fire in the Skatestraum tunnel. Photo: AIBN

1.8.2.2 *The drawbar breakage*

Examination of the drawbar by the AIBN and the Norwegian Defence Laboratories (NDLO), chemistry and material technology showed extensive interior rust damage in both drawbar rods. As a result of the rust damage, the drawbar rods had been overloaded, which caused them to break as the road tanker was driving through the tunnel.

More detailed information about the condition of the drawbar can be found in the NDLO report mentioned in section 1.12.1 and Annex C.

1.8.3 The tank trailer's inspection, repair and approval history

The AIBN has obtained information about the relevant tank trailer's inspection, repair and approval history from documentation received and in meetings with the Norwegian Public Roads Administration's (NPRA), the Directorate of Public Roads.

From first-time registration in 1997 and up until 2011, the tank trailer underwent annual periodic roadworthiness tests and ADR inspections. Based on these inspections, a certificate of approval for the carriage of flammable liquids having a flashpoint of no more than 60 °C was issued/renewed annually. No serious faults or defects that required repairs were detected in any of these inspections.

1.8.3.1 *ADR inspection in May 2011*

The tank trailer was once again inspected by the NPRA in May 2011 for renewal of the ADR approval. Several defects were discovered during this inspection that needed to be repaired before the ADR certificate could be renewed. Some of the defects were so serious that the tank trailer was permitted to drive no further than to a workshop for repair. The following defects were found during the inspection:

- Drawbar rust damage. See Figure 12 and detailed photos in Figure 13 and Figure 14.
- Uneven brakes and weak brakes.
- Cracks and extensive rust damage in the front axle mounting brackets.
- Cracks in the spring suspension for the second axle.
- Broken spring in the third axle.
- Various light faults.
- Faulty earthing points and strain relief fittings/bushings for various cables.
- Various cracks in tank/chambers.

According to the NPRA, inspection sheets and photos are both filed in the agency's archive system and are available to the agency's inspectors if a vehicle needs to be inspected subsequently.

Figure 12: Rust damage to the drawbar found in the NPRA's inspection of the trailer in May 2011. Photo: NPRA

Figure 13: Rust damage in left drawbar rod. Photo: NPRA

Figure 14: Rust damage in right drawbar rod. Photo: NPRA

1.8.3.2 *Repairs and periodic roadworthiness tests*

Based on the defects that were found, the tank trailer was repaired at an approved garage, which was also owned by the vehicle owner at the time (see section 1.14.5).

Before starting these repairs, the same garage also carried out a periodic roadworthiness test of the trailer, which it was approved to undertake. The defects found during this test were identical to the defects that were noted during the NPRA's ADR inspection in May 2011. Under point 6.13 – Towbar/fifth wheel – on the inspection sheet, the rust damage to the trailer drawbar was checked with the number 2. This indicates that the trailer would not be approved until the defect was repaired.

The rust damage was repaired by welding sheets of metal onto the rusted parts of the trailer drawbar. The sheet metal was welded onto the outside of the corroded areas, without removing any of the rust and without any further assessment of the extent of the internal corrosion damage to the drawbar rods. The sheet metal was joined to the drawbar by welded seams along the drawbar rods. No seams were welded at the front or rear ends of the two pieces of sheet metal. The two pieces of sheet metal that were welded to the drawbar rods are shown in Figure 15 and Figure 16.

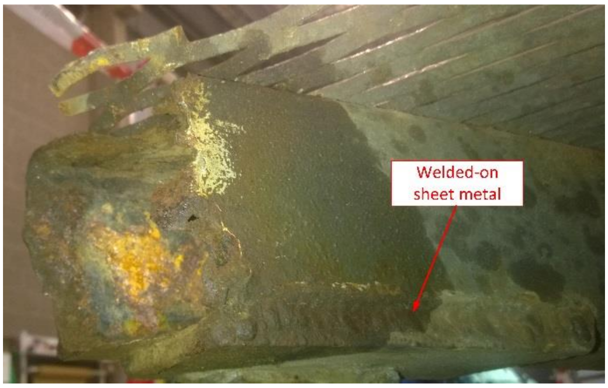


Figure 15: Sheet metal welded onto the left drawbar rod during repair work. Photo: AIBN

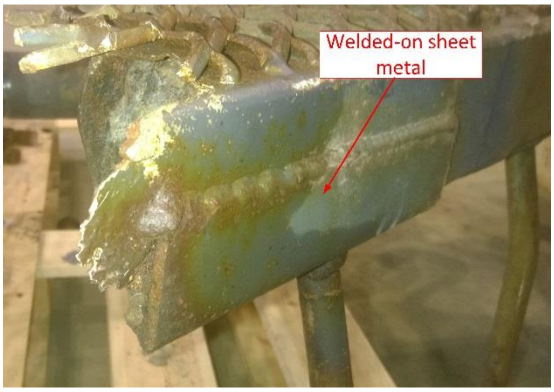


Figure 16: Sheet metal welded onto the right drawbar rod during repair work. Photo: AIBN

Once the repairs had been completed, the tank trailer passed the periodic roadworthiness test. The checkpoint for the drawbar was checked with the number '0' to indicate that it had been inspected and found to be in order. Both the initial inspection and the follow-up inspection of the repaired defects were carried out by the same inspection body.

1.8.3.3 *Follow-up inspection after ADR inspection in July 2011*

When the repair and periodic roadworthiness test had been completed, the trailer was presented to the NPRA for follow-up inspection of the previous administrative inspection and renewal of the ADR approval. The trailer was taken to a different Driver and Vehicle Licensing Office from the one that conducted the previous ADR inspection. This time round, the points that had been checked as defective on the relevant inspection sheets issued by the NPRA were approved. The faults in the vehicle's technical condition (lights, brakes, wheel suspension, trailer drawbar etc.) were largely signed off on the basis that the vehicle had passed its periodic roadworthiness test, while the points checked as defective in the tank and tank equipment were signed off on the basis of the follow-up inspection performed by the NPRA.

The NPRA has informed the AIBN that the inspectors who carried out the ADR inspection did so in accordance with established procedures, under which no new technical inspection is required of vehicles that have passed a periodic roadworthiness test during the past month, as the documentation from that test is seen as confirmation of the vehicle's technical condition. According to the NPRA, a technical administrative inspection shall otherwise be carried out on vehicles that have passed their roadworthiness test more than one month ago. This inspection is intended to ensure that the vehicle is satisfactory in terms of road safety and that it meets the applicable provisions of the Norwegian Motor Vehicle Regulations. The technical administrative inspection is based on the same checkpoints as the periodic roadworthiness test.

1.8.3.4 *Inspections during the period 2012–2015*

From the time when the present owner bought the tank trailer in 2012 up until the fire in the Skatestraum tunnel on 15 July 2015, the tank trailer has undergone a total of eight official inspections (periodic roadworthiness tests and ADR inspections). Three of these were periodic roadworthiness tests carried out by inspection bodies other than the one that approved the tank trailer after it was repaired in 2012, while five of these inspections were carried out by the NPRA as part of the renewal process for the ADR approval. Two of the five ADR inspections relied on the results of the periodic roadworthiness tests and concluded that the tank trailer was in satisfactory technical condition, while a technical administrative inspection was carried out by NPRA personnel in the other three instances. No faults or defects in the trailer drawbar were noted in any of these eight inspections.

A detailed overview of roadworthiness tests and ADR inspections carried out during the period 2011–2015 is provided in Annex B.

1.8.4 The manufacturer's instructions for repair and maintenance of the trailer drawbar

The drawbar manufacturer VBG Group Truck Equipment AB in Sweden (VBG) has issued instructions for installation, repair and maintenance of the drawbar in question.

VBG's installation instructions of 9 December 1999 include the following statement:

> *6. Installation of hoses and cables*
>
> *VBG does not permit any welding or drilling in the drawbar rods for the mounting of clamps/fixings. VBG recommends that hoses and cables be clipped onto the outside of the steel sections.*

The AIBN has been informed by VBG that this text was also included in previous editions of the installation instructions for this type of drawbar.

The chapter 'Inspection and service requirements' in edition 38-233900c of VBG's 'Driver's manual' includes the following instructions:

> *DRAWBARS, GABLES AND DRAWBAR RODS*
>
> ***Note:*** *All welding and any form of remaking are prohibited.*
>
> *Check:*
>
> *1. That no deformations, cracks or other damage have occurred.*
>
> *2. That all threaded connections are intact and that they are not out of torque.*
>
> *For applicable torques, see the installation instructions for the product.*
>
> *3. That wear and slack in the automatic drawbar do not exceed the specified values.*

1.9 Weather and driving conditions

There was a natural draught through the tunnel bore in the direction that the road tanker was heading and visibility was good. The roadway inside the tunnel was clear and dry.

1.10 The Skatestraum tunnel

1.10.1 Design, traffic and safety installations

The Skatestraum tunnel is a subsea single bore tunnel on the Fv 616 road between Hamnen on Rugsundøya island and Klubben at Bremangerlandet in Bremanger Municipality. The tunnel is 1,902 metres long and has an annual average daily traffic[1] (AADT) of approximately 300[2] vehicles. It was designed in accordance with the NPRA's

[1] Annual average daily traffic (AADT) = average daily traffic through the year, total for both directions.
[2] Data from the NPRA's National Road Database (NVDB).

Manual 021 – Road tunnels. According to the NPRA, heavy goods vehicles represent approximately 10% of the traffic. The tunnel has a 6-metre wide roadway with a 1-metre wide concrete shoulder on either side. It has an overhead clearance of 4.5 metres. The speed limit in the tunnel is 80 km/h. The tunnel rises at a gradient of 10% on either side of the lowest point, which is approximately 80 metres below sea level. It was opened for traffic on 12 July 2002.

According to the emergency response plan dated 1 December 2013, the tunnel's safety installations at the time of the incident met the requirements for tunnel class B[3]. These installations are listed in Table 1 below.

Table 1: The tunnel's safety installations according to the emergency response plan. Source: The NPRA

Installation ● Required ○Discretionary		Built/installed in accordance with current requirements
Emergency lay-bys/turning bays	●	1 emergency lay-by/turning bay for heavy goods vehicles at the lowest point of the tunnel. 2 emergency lay-bys when driving uphill towards Hamnen and 1 when driving uphill towards Klubben. These are big enough to allow passenger cars and vans to turn around without difficulties.
Lighting	●	Yes
Ventilation	●	Yes
Uninterruptible power supply (UPS)	●	Yes
SOS telephone	●	4 SOS telephones
Fire-extinguishing equipment	●	9 fire extinguishers – 6 kg
Water-based fire suppression system	●	No
Flashing red stop signals	●	Yes
Remote-controlled barriers for closing the tunnel	●	No
Variable signs	○	Yes
Communication and broadcasting system	●	Yes
Mobile phone coverage inside the tunnel	○	No
Over-height barrier (indicator)	●	Yes

[3] Tunnels in Norway are classified on the basis of traffic load and tunnel length.

1.10.2 Drainage

1.10.2.1 *In general*

The Skatestraum tunnel has two drainage systems: one for collecting and handling liquid and jetting water/surface water from the roadway, and one for draining ground water. Both drainage systems are located below roadway level in the area behind the kerb with side-entry gullies/sand traps and inspection manholes every 80 metres.

At the bottom of the tunnel is a catch basin for collecting all the drained water (both jetting/surface and ground water) before it is pumped out with the aid of automatic pumps. The pumping station with sludge sump, oil separator and catch basin is described in section 1.10.2.3.

Figure 17 is a section of the construction drawings showing pipes for surface/jetting water, drainage pipes and discharge pipes in red, green and black, respectively. The surface water pipe is sealed (not perforated), as it is designed to carry surface water/jetting water/oil spills to the oil separator. The drainage pipe is perforated as it is designed to collect and carry ground water to the sludge basin. The discharge pipe is also sealed as it is designed to carry the water discharged by the pumps out of the tunnel.

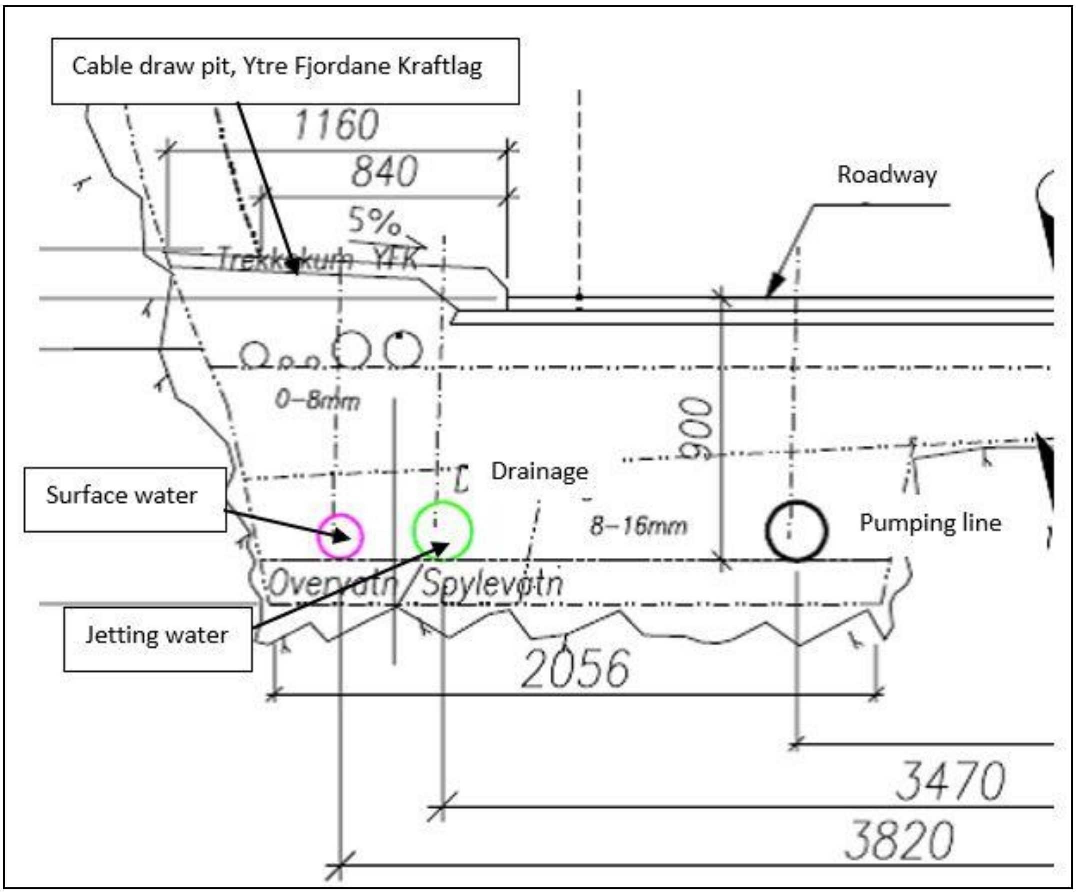


Figure 17: Section of the construction drawings showing the road's drainage system in cross section. Source: the NPRA

Figure 18 shows a sand trap and side-entry gully, and marks left by the petrol which ran on top of the asphalt along the kerb. This sump is part of the jetting/surface water system and is designed to drain away surface water/oil spills from the roadway in the event of oil leaks from vehicles or during tunnel cleaning operations. It is evident from Figure 18 that the system did not have sufficient capacity to receive the petrol, which continued to run along the kerb.

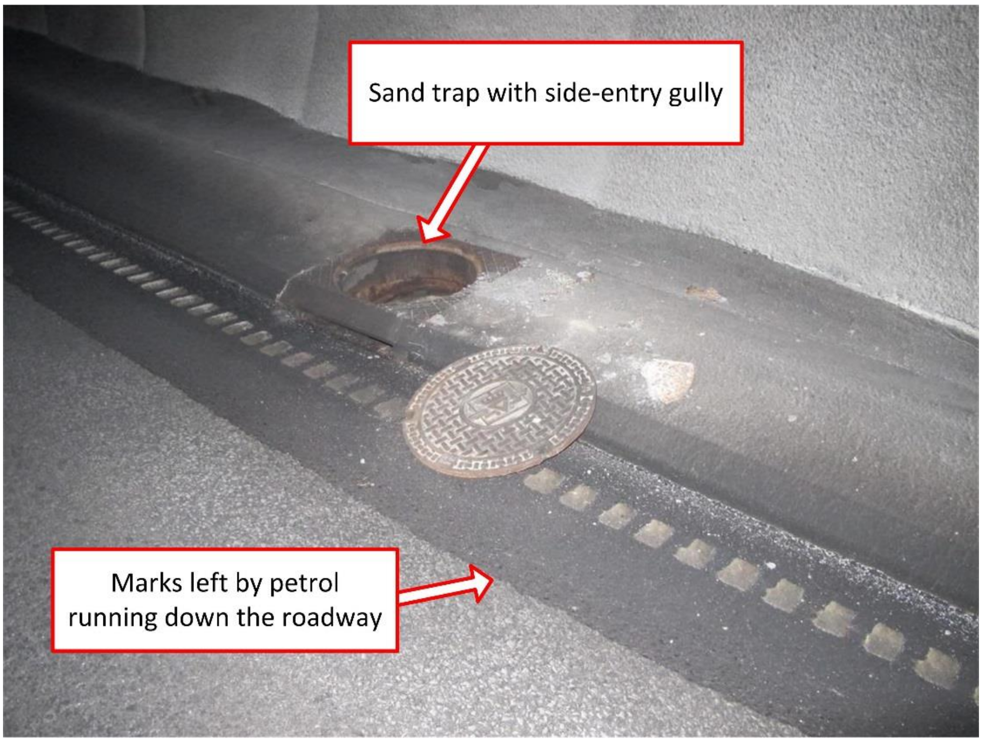


Figure 18: Sand trap with side-entry gully where the petrol ran past. Photo: AIBN

1.10.2.2 *Leaks in the drainage system*

When repair work was performed after the fire, it was found that there had been leaks in the jetting water system. The wrong type of gasket had been used between the drainage pipes and sand trap inlets/outlets, so that water leaked into the ground; see Figure 19. This meant that the petrol entering the sand traps through the gullies leaked into the ground below the sand traps and ran into the ground water drainage system. No petrol was found in the oil separator down by the pumping station that was connected to the jetting water system; see section 1.10.2.3.

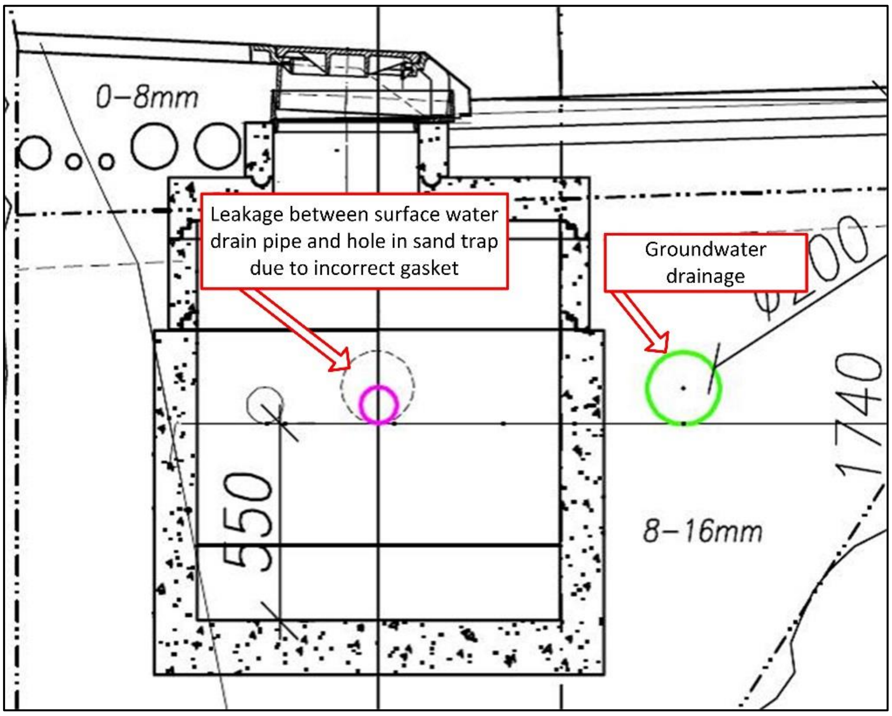


Figure 19: Section of the construction drawings showing the sand trap. In reality, the drainage pipe (green) is most probably located at a lower level than the jetting water pipe. Source: NPRA ('As built' drawing)

The sand trap outlets were not fitted with submerged pipes that prevent/reduce the possibility of hazardous liquids spreading through the surface water system. This was not a requirement when the tunnel was put into operation in 2002. The requirement for submerged outlet pipes was first introduced in NPRA Manual 021 – Road tunnels when it was revised in 2010.

1.10.2.3 *The pumping station*

The two drainage systems described in section 1.10.2 feed the jetting water and ground water to the bottom of the tunnel where it is collected in a catch basin before being pumped out of the tunnel. Figure 20 is a simplified schematic drawing, showing the pumping station, catch basin and a smaller sludge sump. The drawing also shows an oil separator connected to the jetting/surface water system. Clean water from the oil separator runs via a split tank on the surface water line before it runs into the sludge basin. Detectors in the oil separator automatically transmit signals to the VTS when an oil film forms in the oil separator.

The catch basin has platform grating on top, which can be used to access the area below the pumping station. The platform grating can be reached via some stairs behind the pumping station.

The outlet for surface water and ground water is located above the sludge basin. The sludge basin and catch basin are separated by a concrete overflow section.

The examination of the pumping station showed that the pumping station, structures below and the surrounding rock had suffered heat and soot damage. The surface water in the sludge basin was black and looked contaminated, while the surface water in the catch basin was without significant contamination.

Heat damage was found in one of the pipe ends below the pumping station – a surface and groundwater outlet.

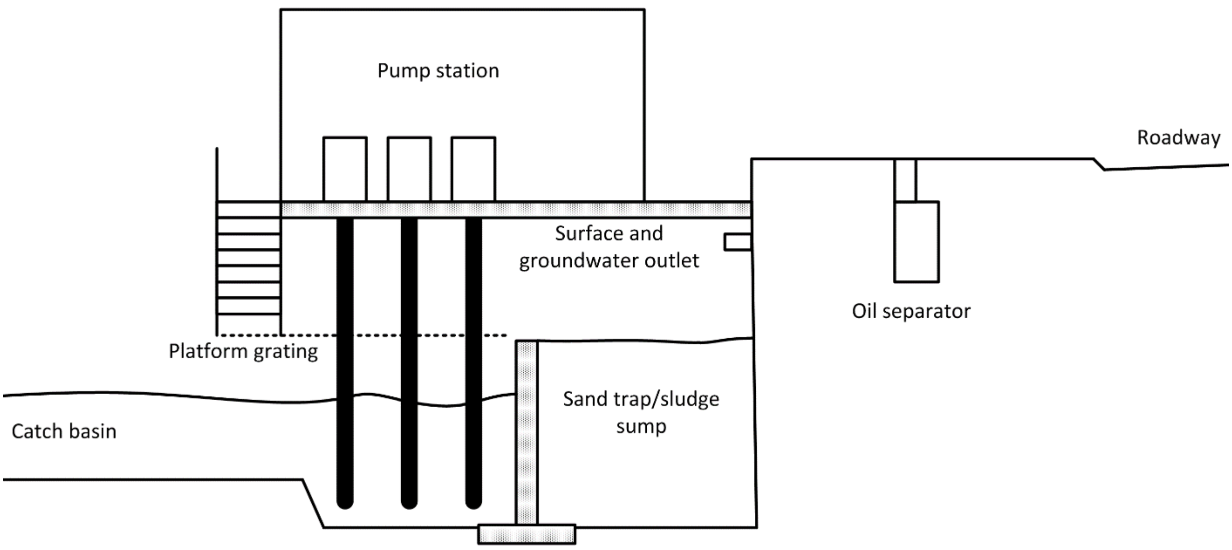


Figure 20: Principle drawing of the pumping station at the bottom of the tunnel. The drawing is not to scale. Illustration: AIBN

1.10.3 Ventilation

1.10.3.1 *Technical description*

The tunnel has longitudinal ventilation with air inlet and discharge through the portals. Four fans are installed at each end of the tunnel. The fans are controlled automatically based on CO and NO concentrations measured inside the tunnel. The system can be controlled manually from the VTS centres in Lærdal and Bergen, or overridden from the emergency control panel outside the tunnel.

1.10.3.2 *Use of the ventilation in the event of fire*

In the event of fire, the ventilation system is normally controlled by the VTS in accordance with procedures drawn up in collaboration with the fire service. The fire service can also control the ventilation from the emergency panel outside the tunnel.

The fire ventilation is pre-set to blow from Klubben towards Hamnen. This direction of fire ventilation was decided in consultation with the local fire service. It is possible to manually override and change the direction of ventilation.

In fire mode, the ventilation system provides a stable flow rate of approximately 2 m/sec. The power supply is without redundancy, so that the system will stop working in the event of a power cut.

1.10.4 Lighting

Tunnel lighting fixtures with 55W QL lamps are installed throughout the tunnel with 18 metre distances between centres. They are rated as satisfying IP 66. Extra lighting fixtures have been installed at the portals.

1.10.5 Communication and communication lines

There is radio coverage, but not mobile phone coverage in the tunnel. The VTS has the ability to issue radio alerts to road users. The Norwegian Public Safety Network for communication between the emergency services is also installed in the tunnel.

When the fire broke out in the tunnel, the radio alert system did not work, however. The VTS was not aware of this. The following is stated in the NPRA's own evaluation report *Brann i Skatestraumtunnelen. Evalueringsrapport* ('Fire in the Skatestraum tunnel. Evaluation report') from 2016:

> *The VTS was concentrating on using a radio alert and informed the 110 emergency communication centre about this option. The logs do not show how the 110 emergency communication centre responded to this request. The VTS operator who was handling the incident was not aware that the radio alert system was inoperative at the time.*
>
> *This had been reported to the VTS, but the message had not been forwarded. The related procedure is being evaluated and followed up by the VTS.*

1.10.6 Emergency response plan

The emergency response plan for the Skatestraum tunnel applicable at the time of the incident was dated 1 December 2013. The emergency response plan had been prepared by the NPRA Western Region's Road Department in Sogn og Fjordane County and was signed by the head of department and fire safety manager.

The emergency response plan describes general matters that are common to all tunnels in the Western Region and has a separate part describing matters relating specifically to the Skatestraum tunnel. The emergency response plan is divided into two parts: S1 *'Information about the tunnel'* and S2 '*Risk analysis'.* Much of the content of S1 is reproduced in section 1.10.1 of this report, while some of the content in S2 is reproduced in section 1.10.7.

1.10.7 Risk analyses

1.10.7.1 *Completed risk analyses*

The risk analysis prepared and presented in S2 in the emergency response plan is based on a total of 18 scenarios. Frequency calculations have been carried out for one of these scenarios: 'Traffic accident without personal injury'. No frequency calculations have been carried out for the other scenarios on the grounds that the volume of traffic through the tunnel is low[4].

The following scenarios mentioned in the risk analysis are considered relevant in relation to the present fire:

- Scenario 4: Fire in heavy goods vehicle
- Scenario 13: Dangerous goods
- Scenario 14: Hazardous liquid – running into the drainage system
- Scenario 15: Explosions

The risk analysis mentions that these scenarios have been assessed, but, with the exception of the following, includes very little about what risk-reducing/compensatory measures should be implemented for each of the scenarios:

> *In statistical terms, fires represent approximately 1% of all incidents in a tunnel. The most common causes of fires in vehicles inside tunnels are:*
>
> *- Overheated brakes*
>
> *- Electrical faults in a vehicle*
>
> *- Collisions*
>
> *The fire frequency is based on the traffic volume (traffic operation). Because the probability of fire is so closely linked to the traffic volume, the most effective way of reducing the risk is to regulate the traffic, for example by means of:*
>
> *- Speed-reduction measures*
>
> *- Restrictions on the carriage of dangerous goods*
>
> *Based on the calculations that have been carried out concerning the probability of fire in the tunnel, the NPRA has not found it appropriate to introduce such measures.*

[4]An annual average daily traffic AADT of 150 vehicles/day (in 2012) is used in the risk analysis.

1.10.7.2 *The NPRA's guidelines for conducting risk analyses*

The NPRA's Manual V721 – *Risikovurdering i vegtrafikken* ('Risk analyses of road traffic) describes recommended methods of conducting risk analyses.

Chapter 2 of the Manual – 'General model for risk assessment', contains an example of a risk matrix that can be used for carrying out risk assessments; see Figure 21.

Risikomatrise

Frekvens / Konsekvens	Lettere skadd	Hardt skadd	Drept	Flere drepte
Svært ofte (minst 1gang pr år)	Uh 2			
Ofte (1 gang hvert 2.-10. år)	Uh 1	Uh 2		
Sjelden (1 gang hvert 10-30. år)	Uh 3	Uh 1	Uh 2	
Svært sjelden (sjeldnere enn hvert 30. år)		Uh 3	Uh 1	

Uønsket hendelse nr 1 (Uh 1) kan være møteulykke på en bestemt strekning, Uh 2 kan være utforkjøring og Uh 3 kan være påkjøring av gående og syklende

Fargekodene angir en vurderingsskala for risiko og kan tolkes slik:

Tiltak ikke nødvendig

Tiltak skal vurderes

Tiltak bør vurderes

Tiltak nødvendig

Below is the AIBN's translation of the risk matrix:

Risk matrix

Frequensy/Consequense	Minor injury	Serious injury	Death	Several deaths
Very often (at least 1 time each year)	UI 2			
Often (1 time every 2-10 year)	UI 1	UI 2		
Rearly (1 time every 10-30 year)	UI 3	UI 1	UI 2	
Very rearly (less than every 30 year)		UI 3	UI 1	

Unwanted incident no 1 (UI 1) can be a meeting accident on a defined route, UI 2 can be driving of the road and UI 3 can be running into a pedestrian or a cyclist.

The colors shows a scale for assesment of risk, and can be read as follows:

Measures not necessary

Measures shall be considered

Measures should be considered

Measures are necessary

Figure 21: Risk matrix taken from the NPRA's Manual V721. Source: the NPRA

For incidents where the consequences can be 'several deaths' or are defined as 'disastrous', the manual states that 'Measures shall be considered' or 'Measures are necessary' regardless of the frequency of the incident.

1.11 Technical registration systems

A printout from the road tanker's tachograph showed that it was holding a recorded speed of 74 km/h just before it entered the Skatestraum tunnel. The speed increased towards the bottom of the tunnel and was 89 km/h when it started the ascent from that point. When the trailer broke loose from the truck, the recorded speed had dropped to approximately 45 km/h.

1.12 Tests and research

The AIBN has carried out three separate studies in connection with the fire in the Skatestraum tunnel. The Norwegian Defence Laboratories has carried out metallurgical examinations of the trailer drawbar, while the SP Technical Research Institute of Sweden[5] (SP) has looked into possible causes of ignition and the development of the fire in the tunnel. Summaries of their reports are discussed in the following subsections. All the reports are enclosed with this report.

1.12.1 Metallurgical examinations of the trailer drawbar

The examinations carried out by the AIBN found extensive interior rust damage in the two drawbar rods that broke. The original wall thickness of 4 mm was significantly reduced in a number of places due to a very advanced state of corrosion.

In order to document the damage, corrosive action and strength of the remaining parts of the trailer drawbar, the Norwegian Defence Laboratories (NDLO/ADK) was commissioned to carry out metallurgical examinations of these parts. During these examinations, the drawbar rods were cut into several pieces. Photos of cut-through drawbar rod sections, showing rust damage and welded-on pieces of sheet metal, are shown in Figure 22.

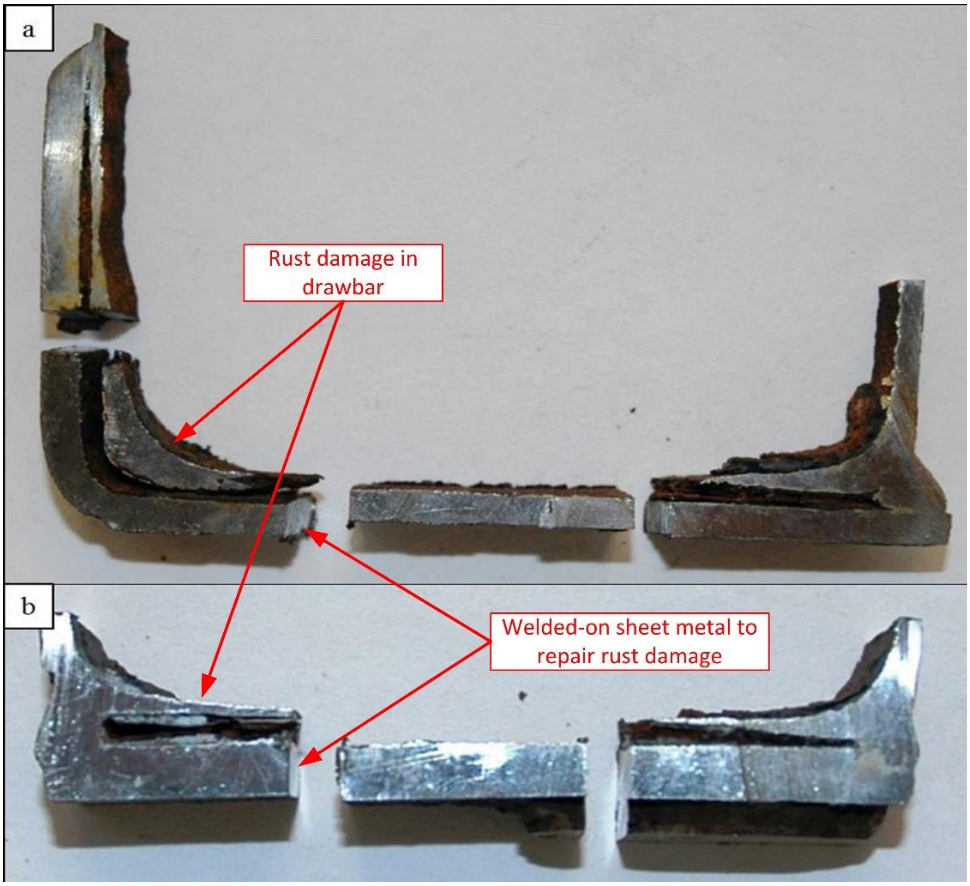


Figure 22: Cut-through section of the right (a) and left (b) drawbar rods in the area where pieces of sheet metal had been welded on during rust repairs. Photo: The Norwegian Defence Laboratories

[5] https://www.sp.se/en/Sidor/default.aspx

The following was the conclusion of the report from the Norwegian Defence Laboratories:

- *The failure of the investigated trailer tongue is due to excessive corrosion that has removed large parts of the steel profile material.*
- *The corrosion damages on the inside of the steel profiles are most likely due to exposure to moisture containing chlorine entering the profile inside from the spacing at the tongue insert. The corrosion seems to have been accelerated due to the steel plates welded to the bottom part of the profiles thus resulting in crevice corrosion.*
- *The observed sand particles observed within the corrosion products between the added steel plates and the original profile wall indicates lack of corrosion removal prior to the welding.*
- *Weld defects such as lack of fusion and undercut are observed, but has in our opinion not contributed to the development of the failure.*
- *As the plates welded to the steel profiles were not welded to the trailer tongue end brace no forces were collected through the steel plates, in our opinion the stiffening of a corroded area as observed in this case will contribute to a higher susceptibility to corrosion fatigue. This point can be confirmed by stress analysis.*
- *Attempts were made to retrieve samples in order to perform standard tensile testing of the steel profile base material, due to corrosion through the whole wall thickness this was not possible, and the plate thickness was measured to vary from 0-2,9 mm.*
- *Fractography could only confirm overload damages in one corner of the right profile and it seems likely that most of the failure occurred prior to the accident due to corrosion and/or corrosion fatigue.*
- *The trailer tongue has most likely been supported by the wire mesh welded on top of the steel profiles and on to the end brace. Based on tensile testing the spot welds could have resisted loadings up to 10 tons, but the strength will however vary largely by the direction of the load.*

The full report from the Norwegian Defence Laboratories is enclosed in Annex C.

1.12.2 Study of possible ignition sources after the petrol leakage in the Skatestraum tunnel

SP's study of the origin of the fire and ignition sources is based on information obtained by the AIBN during its investigation. SP has studied documentation and descriptions of the scene of the fire, damage to the tunnel and its drainage system, damage to the vehicles involved and descriptions and statements by witnesses after the incident.

Based on available information, SP has considered the following hypotheses on how the petrol was ignited:

Table 2: Assessment of possible ignition sources. Source: Investigation into the origin of the fire in the Skatestraum tunnel on July 15, 2015 – Part 1, SP Technical Research Institute of Sweden

Possible cause of ignition	**Probability**
Sparks from collision	Improbable
Electricity in tank trailer	Improbable
Electrical installations in the tunnel	Improbable
Spark formation as a consequence of the tank trailer moving and scraping against the wall	Improbable
Spark formation as a consequence of static electricity when the petrol ran out of the tank and onto the roadway	Improbable
Hot surfaces on the tank trailer such as hot brake discs or other hot surfaces	Low
The driver of vehicle B observed ‘smoke’ between the tank trailer and the tunnel wall	Improbable
A vehicle (behind the tank trailer) initiated the fire	High

The study of possible ignition sources concluded that it was highly probable that the fire was initiated by one of the vehicles that was following the road tanker, particularly the camper van (vehicle E) as that vehicle had sustained pressure damage indicating that there may have been an explosion in the engine compartment.

Figure 23: Close-up photo of the bonnet of the camper van that was driving behind the road tanker and stopped behind the trailer. The photo shows that the bonnet has been lifted up, probably as a result of a pressure change in the engine compartment. Photo: Gjensidige

The people who were inside the van also observed that the petrol was ignited and that there were flames around the van before it started to reverse down the slope. The fact that the van's bonnet had been forced up, indicates that the fire started as a consequence of a pressure change in the engine compartment.

The full report from SP – *Utredning om brandens uppkomst i Skatestraumtunnelen 15 juli 2015 – del 1* ('Investigation into the origin of the fire in the Skatestraum tunnel on July 15, 2015 – Part 1') is enclosed in Annex D.

1.12.3 Study of the development of the fire in the Skatestraum tunnel.

SP has studied and analysed the development of the fire in the tunnel in terms of the spread of heat, smoke and gases. The purpose of this study has been to describe and assess the possibility of survival for road users in the tunnel from a time perspective.

The study was carried out based on documentation about the tunnel's design, material damage, the amount of petrol involved and the leakage, witness statements and the AIBN's own photos and description of the scene of the accident. As part of the study, SP was also asked to conduct simulations and subsequently produce animations to describe and enable visualisation of the development of the fire.

The full report from SP – *Utredning om brandens utveckling i Skatestraumtunnelen 15 juli 2015 – del 2* ('Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2') is enclosed in Annex E.

1.12.3.1 *Timeline of the fire*

Table 3 shows the timeline for the incident before and after the fire broke out. The times in the second column were estimated on the basis of witness statements, documented facts and findings at the scene of the accident after the incident. There may be some uncertainty attached to these times. The positions of the vehicles and of fire cabinet F2 are shown in Figure 5, and sand trap 5 is shown in Annex A.

Table 3: Timeline of the incident before and after the fire broke out. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

Logged time	Time in min:sec from the start of the fire	Event
	-2:40	The accident occurs, the tank trailer breaks loose and collides with the tunnel wall – vehicle A
	-2:40	Vehicle B has stopped 10 m further down and witnesses the accident
10:24:51	-01:41	The door to BS03 is opened by the driver
	-01:30	Petrol front 150 m downhill from the tank trailer
10:25:36	-00:54	The tunnel is closed
10:25:38	-00:52	Tunnel closure is confirmed
	-00:30	Vehicles B and C meet vehicles E (the camper van) and D at F2 (see Figure 5), 367 m downhill from the tank trailer
	-00:20	Petrol front at F2
	00:00	Vehicle B has reached the lowest point of the tunnel
	00:00	The fire starts. At this point in time, the camper van is located 10–20 metres from the tank trailer
	00:00	Vehicle D stops (the road users step out into the petrol that is flowing past)
	00:05	Vehicle A drives towards Hamnen (immediately after the fire started)
	00:25	Vehicle E is by sand trap 5 (103 metres from the tank trailer)
	00:25	The petrol reaches the pumping station (463 metres from the tank trailer)
	00:25	The flames have reached sand trap 5 (103 metres from the tank trailer)
10:27:50	01:20	Short-circuit in the night light cable between the tank trailer and the portal at Hamnen

Logged time	Time in min:sec from the start of the fire	Event
	01:30	Vehicle A drives out of the tunnel at Hamnen in dense smoke
10:28:01	01:31	The first of fans V01-V08 starts up
10:28:16	01:46	All fans V01-V08 in operation
10:28:20	01:50	Critically high CO level at F1
	01:50	Vehicle E has reached the pumping station and picks up two road users from vehicle C. Talking is difficult due to noise from the fans
	02:00	The flame front reaches the pumping station

1.12.3.2 *The survival aspect as the fire developed*

The fire development can be divided into three scenarios: the spillage fire along the roadway (from the petrol that ran out), the fire in the tank trailer and the fire down by the pumping station at the bottom of the tunnel. In the following sub-sections, we have summarised SP's assessment of the possibility of survival in each of the three fire scenarios.

<u>The spillage fire</u>

When the tank trailer hit the tunnel wall, the front tank chamber ruptured and the petrol started to leak out. Based on traces of petrol registered along the roadway, the road's cross slope and longitudinal slope, the average leakage rate was calculated at around 1,000–1,200 litres per minute (17-20 l/s). The petrol was estimated to have run down the roadway at a speed of 2.6 m/s and to have reached the bottom of the tunnel (100 metres from the pumping station at sand trap no 1 – see Annex A) after about 3 minutes. Assuming that the diameter of the rupture was approximately 100 mm, the front tank chamber would have emptied in the course of four minutes.

The petrol was ignited approximately 2 minutes and 40 seconds after the tank trailer hit the tunnel wall and the petrol started to leak out, most probably by the camper van that was following close behind, see section 1.12.2. The flame front moved down the tunnel at a speed of approximately 3.9 m/s. Figure 24 shows the estimated fire effect of the spillage fire as a function of time. As shown in the figure, on its own, the burning petrol along the roadway generated an effect of more than 200 MW.

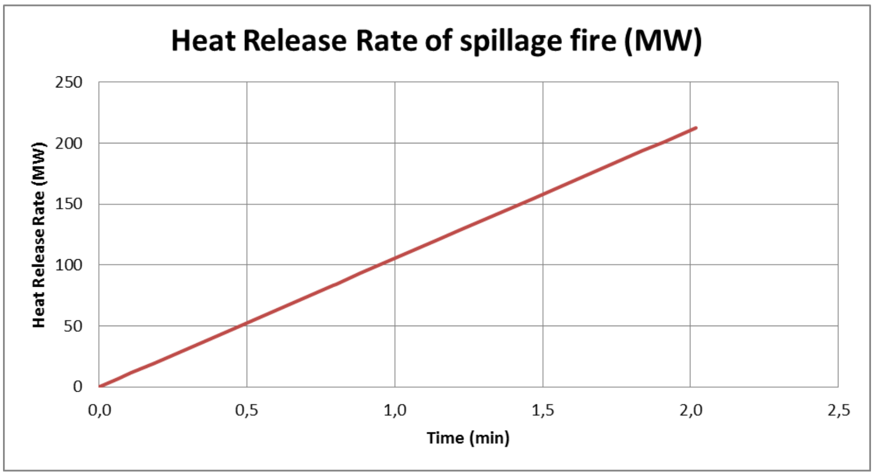


Figure 24. Estimated fire effect of the spillage fire as a function of time from ignition. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

From a survival perspective, once the flame front reached the bottom of the tunnel, the spillage fire would have been life-threatening for any people in the area between the pumping station and the tank trailer. The calculations show that, as a result of the ventilation, the air temperature below the tank trailer was not in itself very high, but heavy smoke emission and heat radiation exceeding the critical value for survival occurred after approximately two minutes; see Figure 25.

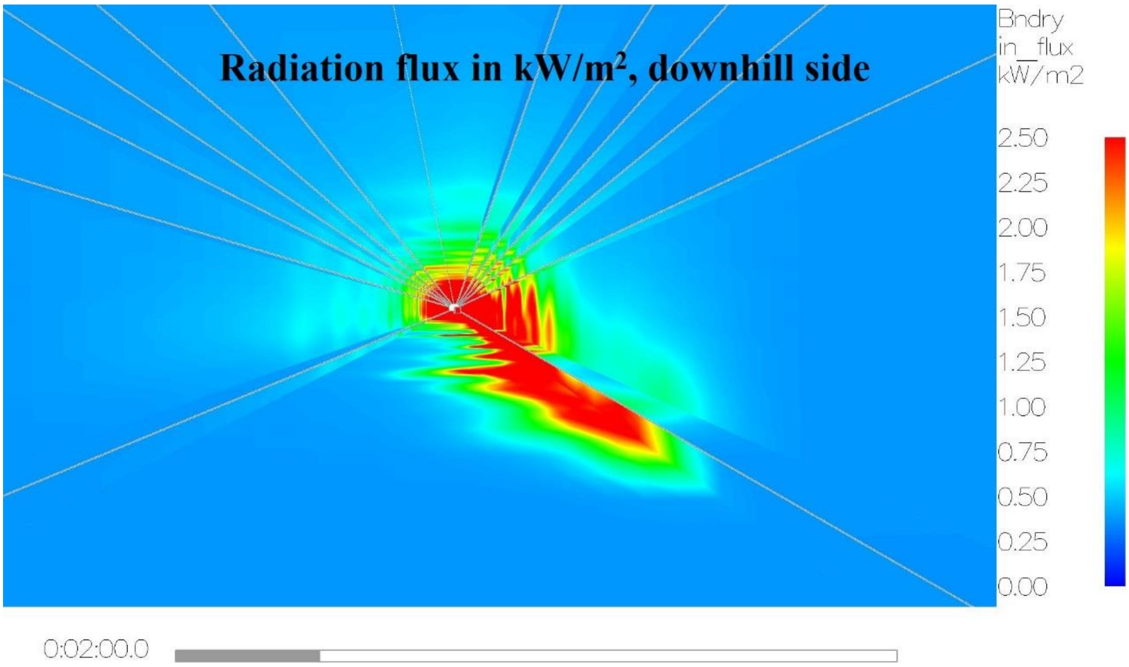


Figure 25. Estimated heat radiation 100 metres from the flame front below the tank trailer, after 120 seconds. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

The calculations show that all the petrol that leaked from the tank trailer, burnt up in the course of seven minutes. The fire first died down near the tank trailer after about five minutes, and then died down by sand trap no 1 (100 metres from the pumping station) after about seven minutes.

<u>The fire in the tank trailer</u>

The fire in the tank trailer is best described as a pool fire. It first ate into the top of the aluminium tank, while the cooling effect of the petrol inside kept the lower part of the tank more or less intact. The remaining structure took the form of a pot in which the petrol soon started to boil, producing an intense fire with an estimated fire effect of 227 MW (12.9 MW/m^2). The temperature above the tank trailer soon rose to almost 1350 °C and the smoke emission was intense.

Figure 26 shows the estimated total fire effect of the spillage fire and the fire in the tank trailer. The steeply rising fire effect during the first seven minutes can be explained by the petrol that was on fire along a large surface of the roadway. When this fire died out, the pool fire in the tank trailer remained and the fire effect was stabilised. After just over 40 minutes, this fire also died down.

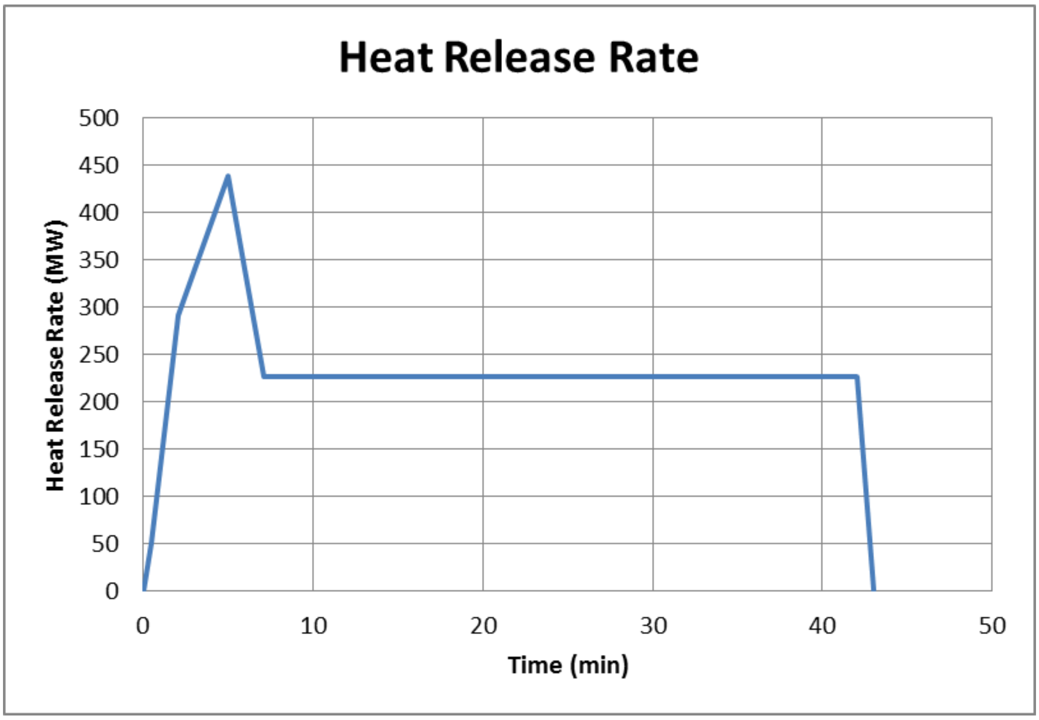


Figure 26: Total fire effect as a function of time. The graph includes both the spillage fire and the fire in the tank trailer. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

In the area above the tank trailer towards the tunnel portal at Hamnen, there would have been no possibility of survival. The intense smoke emission developed rapidly and the smoke caught up with the tank truck as it drove out of the tunnel at Hamnen one and a half minutes after the petrol was ignited. Calculations show extensive and deadly heat radiation throughout the tunnel from the scene of the fire to outside the portal at Hamnen; see Figure 27.

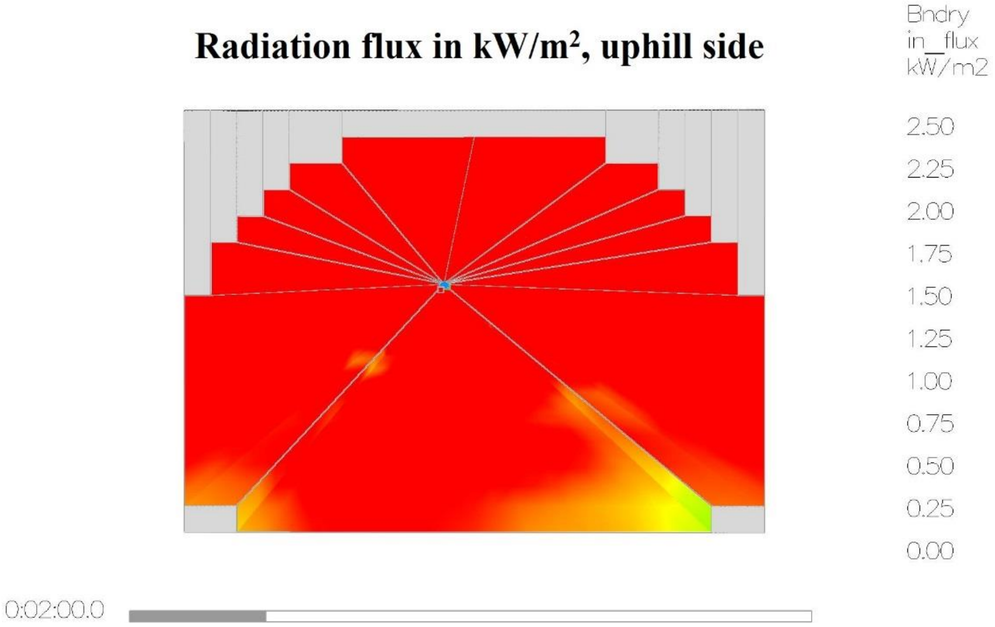


Figure 27: Estimated heat radiation at the tunnel portal above the scene of the fire after 120 seconds. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

Estimated smoke temperatures on the upper side of the fire are shown in Figure 28. The calculations show temperatures of between 170 °C and 200 °C at the tunnel portal at Hamnen, declining relatively steeply in the longitudinal direction. The graph below is consistent with the damage that was found in the tunnel and infrastructure after the incident; see Figure 29.

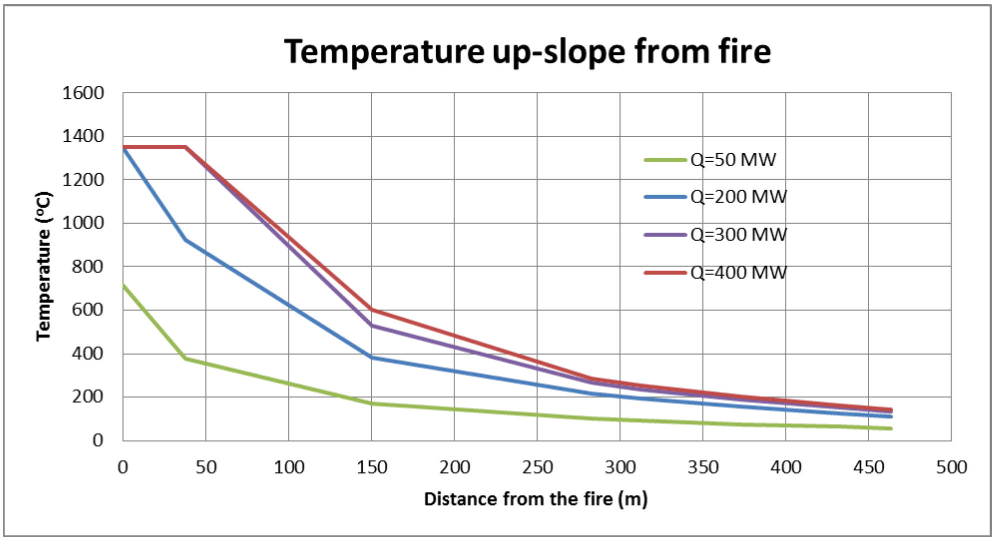


Figure 28: Estimated temperatures along the tunnel (above the scene of the fire) for different fire effects. Source: Investigation into the development of the fire in the Skatestraum tunnel on July 15, 2015 – Part 2, SP Technical Research Institute of Sweden

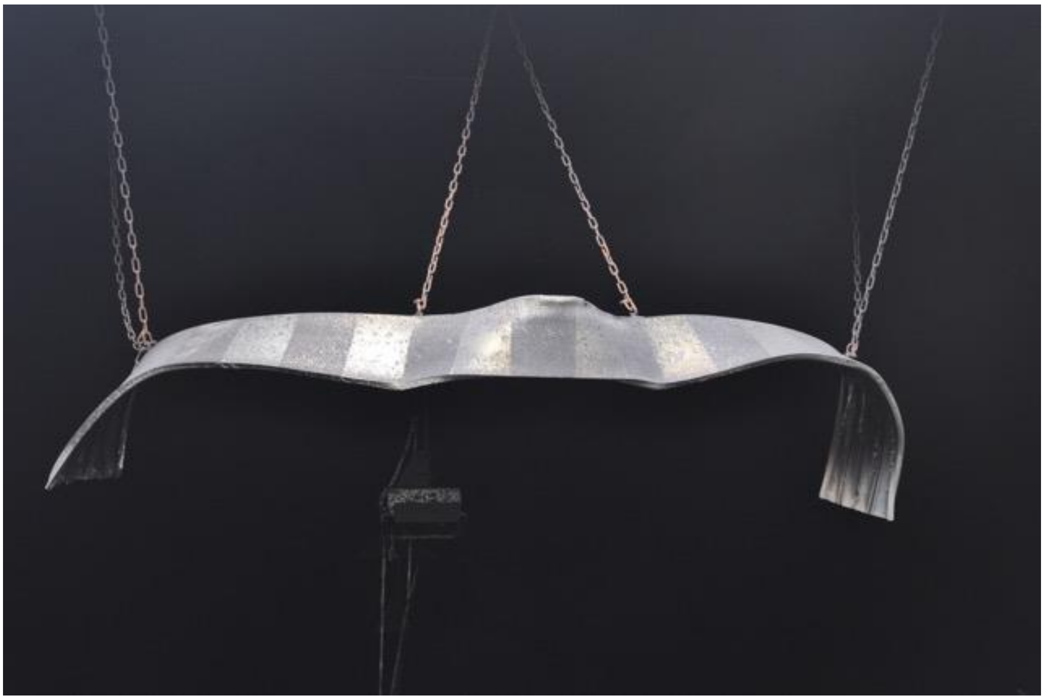


Figure 29: Aluminium over-height barrier at the tunnel portal at Hamnen, clearly deformed by the heat. Photo: NPRA

Calculations by SP also show that the fire generated powerful air streams with flow rates approaching 27 m/s ≈ 100 km/h above the scene of the fire. Below the fire, the air flow rate was estimated to be nearly 9 m/s ≈ 32 km/t.

<u>The fire down by the pumping station</u>

There are two systems for water drainage in the Skatestraum tunnel (see section 1.10.2): one for surface water drainage and one for ground water drainage. Both systems feed the water to the bottom of the tunnel where it is collected in a catch basin before being discharged from the tunnel by pumps. The drainage system for surface water runs via a series of sand traps located every 80 metres. When the petrol started to leak from the tank trailer, it rapidly filled up this system and the volume of petrol exceeded the capacity of the gullies and drainage pipe system. As a consequence of this, the petrol was left in the roadway and continued to run down the roadway, bypassing the gullies along the kerb; see Figure 30.

Figure 30: Sand trap with gully approximately 270 metres below the scene of the fire. The photo shows dark marks caused by petrol running past the gully. Photo: AIBN

Both the petrol that ran into the surface water drainage system and the petrol that leaked into the groundwater system ended up in the catch basis under the pumping station. This petrol was ignited and created a surface fire in the sludge basin under the pump house. The following is stated in the report from SP:

> *The events at the pumping station were quite complex, yet relatively simple to explain in fire engineering terms. The fire in the sludge basin burned in the form of an open pool fire that generated a great deal of smoke and heat. Due to the relatively high air flow in the tunnel, an excess of pressure was created in the sludge basin relative to that of the tunnel, and so the smoke and heat from the former were sucked into the latter. This is the explanation for the smoke and soot damage that were observed in the area around the pumping station. Local damage to outlets and drains can be explained by a rich supply of oxygen. Petrol vapours were transported to the areas that were rich in oxygen, starting fires in all of the openings that led to the basin. This kind of fire tends to last a relatively long time, as evaporation is a slow process, and continues as long as there is liquid petrol left.*
>
> *In conclusion, it can be said that the events that occurred near to the pumping station did not have any discernible effect on the main fire event in the tunnel; rather, they simply constituted an obstacle to the fire and rescue service operation and caused damage*

There was external and internal soot and fire damage to infrastructure such as cabling, electrical components and surfaces, but these are deemed to be relatively small compared with the damage to the tunnel further up at the Hamnen end.

Figure 31: The pumping station at the bottom of the tunnel with fire and soot damage to the surfaces. Photo: AIBN

1.12.3.3 *The conclusion reached in the report*

The report concluded that nobody died in the fire, because the road users acted rapidly and correctly. The report also concludes that it took about two minutes for the ignited petrol to reach the bottom of the tunnel, after which there would have been no possibility of survival for any road users in the area between the pumping station and the tunnel portal at Hamnen, a distance of approximately 950 metres. The possibility of survival was first and foremost precluded by smoke emission and heat radiation from the burning petrol. The fire is estimated to have had a maximum fire effect of around 440 MW with a maximum temperature of 1350 °C by the tank trailer.

In summary, the reports concludes the following:

- The tunnel’s falling/rising gradient of 10% played a decisive role in the spread and development of the fire.

- The rates at which the initial smoke and heat spread to the areas above and below the scene of the fire are determined by the gradient of the tunnel.

- The drainage system that should have drained away the liquid from the roadway surface was not effective enough to avoid a surface fire with an effect exceeding 200 MW within two minutes of ignition.

- Because of the air streams generated by the fire, the ventilation system had no effect on the sequence of events or the environment in the tunnel.

- Fatalities were prevented by rapid and correct action on the part of those involved.

- In the area below the fire, radiation heat would have caused certain death had it not been possible to evacuate before being enveloped in smoke.

- Any persons caught in the smoke downstream or upstream of the fire would have found it very difficult to evacuate and would most probably have lost consciousness and subsequently died.

- The powerful thermal current generated by the fire gave rise to an air flow rate of 27 m/s (100 km/h) upstream of the fire (hot) and 9 m/s (30 km/h) downstream of the fire (cold).

- The initial fire caused by the petrol leakage had an effect of 212 MW. The fire peaked at 440 MW for a brief period when both the petrol in the roadway and the remaining petrol in the tank were on fire at the same time.

- The estimated maximum temperature was 1350 °C under the roof 10–20 m uphill from the tank trailer.

- Going uphill from the fire, the temperature dropped from around 600 °C about 150–200 m from the tank trailer to just under 200 °C at the tunnel portal (460 m from the tank trailer).

- The smoke quickly exceeded the critical values and was followed by high temperatures and finally radiation heat.

1.13 Acts and regulations

Use, operation, inspection and control in the road sector are largely regulated by the Act of 18 June 1965 No 4 relating to road traffic (the Road Traffic Act) and its regulations, and by the Act of 21 June 1963 No 23 relating to roads (the Road Act). Transport of dangerous goods is regulated by the Act of 14 June 2002 No 20 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (the Fire and Explosion Act).

1.13.1 Requirements of the driver

The Road Traffic Act and pertaining traffic rules specify the driver’s responsibilities with regard to vehicle use.

1.13.2 Technical requirements for vehicles

The Regulations of 4 October 1994 No 918 relating to technical requirements for and approval of vehicles, parts and equipment (the Motor Vehicle Regulations) define technical requirements for motor vehicles and tank trailers registered for the first time after 1 January 1995. In addition to the technical requirements, there are specific requirements for use of vehicles, both in general, and under specific conditions and for specific types of transport.

1.13.3 Regulations relating to overland transport of dangerous goods

The purpose of the Regulations of 1 April 2009 on overland transport of dangerous goods (the ADR Regulations) is to protect human life and health, the environment and material assets against misadventures, accidents and undesirable intentional incidents in connection with overland transport of dangerous goods.

The regulations are administered by the Norwegian Directorate for Civil Protection and Emergency Planning (DSB), and define specific technical requirements for vehicles that are to carry dangerous goods. These requirements come in addition to the requirements laid down in the Motor Vehicle Regulations. The regulations also confer powers to introduce restrictions on overland transport of dangerous goods.

1.13.4 Regulations relating to periodic vehicle inspections

The Regulations of 13 May 2009 relating to periodic vehicle inspections lay down requirements for those who carry out periodic roadworthiness tests of vehicles. The regulations concern periodic roadworthiness tests of Norwegian-registered vehicles and requirements imposed on inspection bodies that are to carry out such tests.

1.13.5 Regulations relating to vehicle repair shops

The Regulations of 13 May 2009 on vehicle repair shops lay down requirements for workshops that intend to carry out repair work, maintenance, alteration work, installation work and bodywork on vehicles. It applies to everybody who intends to carry out such work. The regulations include requirements for premises, technical equipment and the technical manager etc.

1.13.6 Acts, regulations, standards and guidelines for the construction, operation and maintenance of roads

The following regulations, standards and guidelines are relevant in connection with this investigation:

- The Regulations of 26 June 2002 No 847 relating to fire prevention measures and inspection (the Fire Prevention Regulations).
- NPRA Manual 021 – Road Tunnels (1992) and NPRA Manual 021 – Road Tunnels (2002). The manual has the status of a standard and was adopted in pursuance of the Road Act.
- NPRA Manual 163 – Water and frost protection in tunnels (1995). This manual has the status of a guideline.
- The NPRA's Manual R511– Safety Management of Road Tunnels (2014). This manual has the status of a guideline.
- NPRA Manual V721 – Risk assessment in road traffic (formerly Manual 271).

1.14 Authorities, organisations and leadership

1.14.1 Sogn og Fjordane County Authority

Sogn og Fjordane County Authority owns the county road network and is responsible for overall transportation planning in Sogn og Fjordane County. Included in the ownership are around 140 tunnels that are part of the county road network. Some of these roads/tunnels, including the Skatestraum tunnel, were transferred from the NPRA to the county authority during the administrative reform in 2010. In addition to being responsible for safety and overall planning, the county authority is also responsible for prioritising investment measures and major maintenance operations on the county road network.

Sogn og Fjordane County authority has nobody on its staff with special expertise in planning and implementing operational and maintenance tasks on the road network. These tasks are accomplished through 'joint' road administration. Joint road administration means that the State and the county authority are served by a joint administration for carrying out county road tasks at the regional level. The NPRA Western Region, represented by the road department in Sogn og Fjordane County, serves as the joint road administration for the county authority. The joint road administration is regulated by a five-year agreement between the county authority and the NPRA, in addition to annual delivery agreements. Among other things, these agreements describe how authority is to be delegated by the county authority to the NPRA. It is clear from the overall guidelines that responsibility may not be delegated, which means that it is Sogn og Fjordane County authority that has overall responsibility for the county road network. In the present case, this applies to responsibility for the Skatestraum tunnel.

The NPRA manuals are used as the basis for the planning, construction, operation and maintenance of the road network in Sogn og Fjordane County.

1.14.2 The Norwegian Public Roads Administration (NPRA)

The NPRA is an administrative agency that reports to the Ministry of Transport and Communications. The agency is organised into two administrative levels: the Directorate of Public Roads and five regional offices. The NPRA is responsible for the planning, construction, operation and maintenance of national roads, and for approval and supervisory activities relating to vehicles and road users. The NPRA also prepares provisions and guidelines for road design, operation and maintenance, road traffic, road user training and vehicles.

The NPRA is also assigned the task of offering joint road administration for the county roads at the regional level.

1.14.2.1 *The Directorate of Public Roads' Department for Road Users and Vehicles*

The Directorate of Public Roads' Department for Road Users and Vehicles is charged with administering regulations relating to driving licences, driving tests, technical vehicle approval and provisions on vehicle use. The department is also assigned specialist tasks at the national level for matters relating to traffic users and vehicles.

The department's area of responsibility includes the approval and supervision of workshops that carry out vehicle repairs and of inspection bodies that carry out periodic roadworthiness tests, roadside vehicle inspections and inspections of use of protective equipment in vehicles. The department is furthermore responsible for the approval and supervision of driving schools and the procedures for driving tests.

The NPRA has signed a collaboration agreement with DSB on monitoring vehicles that carry dangerous goods. This is one of the department's specialist tasks relating to road users and vehicles at the national level. For more information about the collaboration agreement between the NPRA and DSB, see section 1.14.4.

Responsibility for implementation of the tasks of the Department for Road Users and Vehicles has been delegated to the Regional Road Director in each of the five regions.

1.14.2.2 *The NPRA Western Region*

The NPRA Western Region is headed by a Regional Road Director. The Regional Road Director reports to the county authority on matters relating to county roads, and the

Directorate of Public Roads on matters relating to national roads and other central government tasks; see Section 10 of the Road Act.

Among other things, the Regional Road Director is charged with the following tasks:

- Ensuring an effective joint road administration for the county authority in matters relating to county roads.
- In the capacity of joint road administration, on the county authority's initiative, assisting the county authority in its role as regional developer, including with analyses and assessments of various measures in the transport area.
- Seeing to the development, operation, maintenance and administration of national and county road networks and follow-up of their use by road users.
- Seeing to the inspection and approval of various undertakings such as driving schools, vehicle repair shops and inspection bodies, as well as the supervision and approval of vehicles and vehicle drivers.

1.14.2.3 *Approval of vehicle repair shops*

The NPRA is the competent authority for the approval of repair shops that are to carry out repair work, maintenance, alteration work, installation work and bodywork on vehicles. An approved workshop may carry out repairs on vehicles in the category for which it has been approved.

The Vehicle Repair Shop Regulations, which regulate the approval of vehicle repair shops, grant exemption from the requirement for approval for owners who carry out repair and maintenance work on their own vehicles or on vehicles at their disposal.

1.14.2.4 *Approval of inspection bodies*

The NPRA is also the competent authority for the approval of inspection bodies that carry out periodic roadworthiness tests. An approved inspection body may carry out periodic roadworthiness tests of vehicles in the category for which it is approved. The approval does not lay down any restrictions regarding the inspection of vehicles belonging to the inspection body, the owner of the inspection body or the inspector himself.

The AIBN has asked the NPRA what guidelines apply to periodic roadworthiness tests of vehicles owned by the inspection body or the inspector himself. To this, the NPRA gave the following reply:

> *The present wording of the Regulations on Periodic Vehicle Inspections contains no direct requirement precluding vehicle owners from carrying out roadworthiness tests on their own vehicles. Among other things, there is a historical aspect to this in that the bus companies used to have a 'self-inspection scheme' which was continued when periodic roadworthiness tests were introduced, allowing them to carry out self-inspections, and subsequently roadworthiness tests, on their own vehicle fleet. This also applies to major transport companies that have their own approved workshops and control bodies. This can also be extended to mean that the inspectors may test their own vehicles. However, it is difficult to reconcile this with the requirements regarding the quality management system (see Sections 13 and 14 of the Regulations on Periodic Vehicle Inspections), and in view of this, the great majority of inspection bodies have drawn up procedures to prevent such a practice.*

The NPRA informs the AIBN that work has begun on revising the powers conferred by the Road Traffic Act relating to the approval and supervision of vehicle repair shops and inspection bodies. This work includes consideration of the requirement for impartiality, among other things. A draft amendment of Section 19 of the Road Traffic Act has been distributed for consultation with the deadline for submissions set to 1 October 2016.

1.14.2.5 *Approval of road tanker repair shops that carry out tank inspections in accordance with the ADR Regulations*

Atmospheric[6] tank vehicles and demountable tanks, as defined in Chapter 1.2 of ADR, that are used for transporting petroleum products, shall be subject to periodic tank inspections. The Norwegian Directorate for Civil Protection and Emergency Planning (DSB) is the competent authority for the approval of repair shops that intend to carry out such inspections.

DSB has approved a total of eight such repair shops for carrying out such periodic inspections. The owners of two of these repair shops also run transport firms that transport petroleum products by road tanker.

In its approval of these workshops, DSB has not laid down any restrictions on the inspection of vehicles owned by the repair shop owner directly or through other undertakings.

1.14.3 Måløy Havneservice AS

Måløy Havneservice AS was formed in Måløy in 1945 as a tank facility for fuel and oil products sold on commission for Shell.

The present owner took over the company in 1995. The main business consists of the sale and distribution of fuel and lube oils in addition to bunker oil for ships. In addition to the tank facilities in Måløy, they have facilities in Ålesund and Fosnavåg. They also own some self-service petrol stations for the sale of vehicle fuels.

Måløy Havneservice AS owns two tank trucks and one tank trailer for transporting flammable liquids.

Måløy Havneservice AS's own drivers are responsible for monitoring the condition of the firm's vehicles. During the intervals between the periodic roadworthiness tests/ADR inspections, essential repairs are carried out by or on the orders of the drivers.

1.14.4 Directorate for Civil Protection and Emergency Planning (DSB)

The Directorate for Civil Protection and Emergency Planning (DSB) is an administrative government agency that reports to the Ministry of Justice and Public Security. DSB's responsibility in the public security area includes responsibility for national, regional and local civil protection and emergency planning, fire and electrical safety, protection of business and industry, hazardous substances and product and consumer safety. DSB is also responsible for civil protection.

[6] Atmospheric tanks are understood to be tanks for transporting liquids with vapour pressure (absolute pressure) not exceeding 110 kPa (1.1 bar) at 50 °C, which are designed in accordance with 6.8.2.1.14 (a) ADR and equipped with an aeration system in accordance with 6.8.2.2.6 ADR. (Tank code LGBF).

Together, the DSB and the NPRA have prepared *Retningslinjer for saksbehandling og ivaretakelse av brann- og elsikkerhet i vegtunneler* (‘Guidelines for fire and electrical safety in road tunnels’). The guidelines are primarily aimed at those who plan, build and operate road tunnels, those who supervise fire safety in road tunnels and those charged with responding to fires and accidents in road tunnels.

DSB is the competent national technical and supervisory authority for all handling of flammable, reactive, pressurised and explosive substances, and for the transport of dangerous goods by road and rail (ADR/RID transport).

In order to ensure optimum use of resources for monitoring the transport of dangerous goods by road, DSB and the NPRA have entered into a collaboration agreement. This collaboration agreement concerns the following items:

- Examination system and issuance of ADR competence certificates.
- Control of inspection halls and approval of vehicles, including annual inspections for the carriage of dangerous goods, to be carried out by the NPRA.
- Establishing and announcing local restrictions on the carriage of dangerous goods by road.
- Work on roadside inspections.

Concerning vehicle inspections, DSB has introduced the following conditions relating to how they should be conducted:

- The NPRA inspects and approves vehicles through periodic roadworthiness tests and other inspections in accordance with the technical vehicle requirements set out in Part 9 of ADR.

- DSB is responsible for verifying that the test/inspection guidelines are in accordance with the applicable regulatory framework.

- Tanks on tank vehicles shall be approved on the basis of reports from undertakings that have been accepted by DSB for carrying out tank inspections; see the list at www.dsb.no.

1.14.5 The company that owned the trailer in 2011 (at the time when rust damage in the trailer drawbar was found during an inspection by the NPRA)

The company that owned the tank trailer at the time when rust damage was found in the drawbar (2011) was a subsidiary of a bigger transport undertaking, which, in turn, was a subsidiary of the holding company Gran Taralrud Holding AS. The repair shop that repaired the tank trailer after rust damage was found in the trailer drawbar was also a subsidiary of the same transport undertaking. The company structure is shown in Figure 32.

The transport firm that owned the tank trailer did not receive its assignments directly from relevant transport buyers. It drove for the parent company, which signed the contract with the buyers.

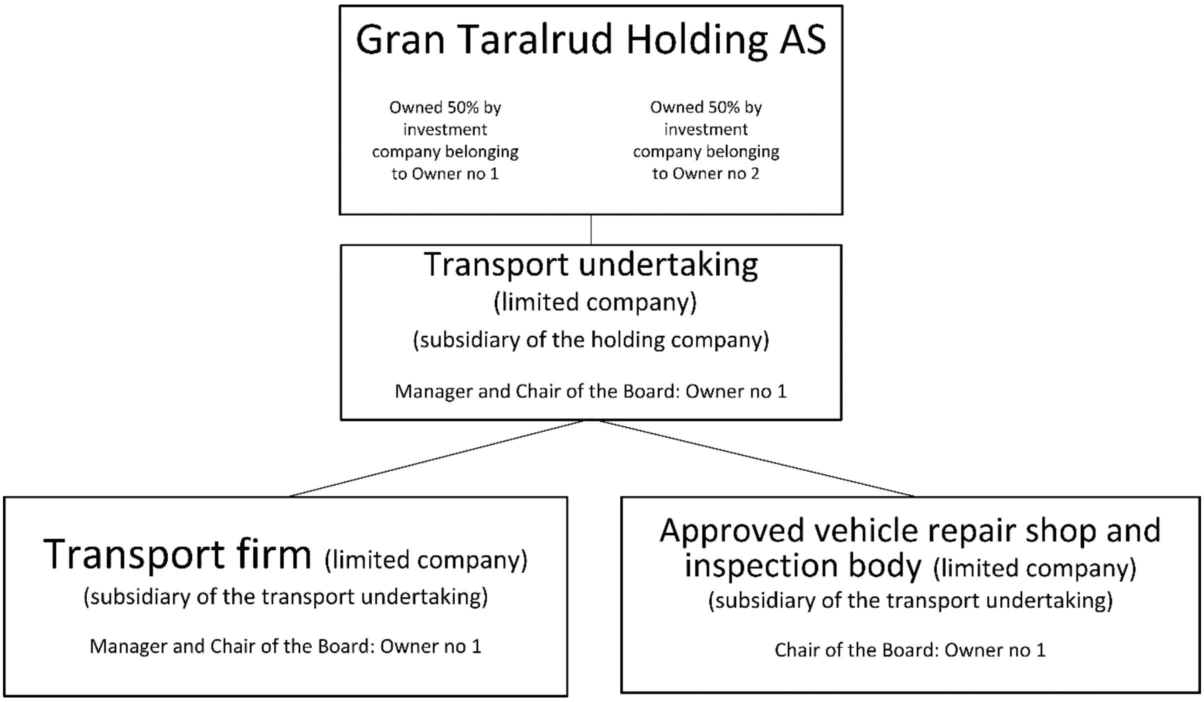


Figure 32: Overview of the structure in which the transport firm and repair shop were subsidiaries, as applicable at the time when the tank trailer was repaired. Illustration: AIBN

1.14.5.1 *The transport undertaking's quality system*

The transport undertaking's quality system, which also applied to the transport firm, included daily and monthly checklists with guidelines on what should be checked. The daily check comprised 21 checkpoints, covering both personal and technical matters. The monthly check comprised 75 checkpoints, all relating to the technical condition of the vehicle.

These checks were to be carried out by the driver of the vehicle/vehicle combination. The completed daily and monthly checklists were to be handed in to the firm at specified times.

1.14.5.2 *Repair and maintenance of the transport firm's vehicles*

At the time of the incident, the transport firm owned about 100 vehicles/vehicle combinations and employed 300 people. For the greater part of the vehicle fleet, service agreements had been entered into with relevant dealer repair shops. The tank trailers that formed part of individual vehicle combinations were also covered by these service agreements. The repair shop owned by the transport undertaking was also used for repairs and official inspections of the firm's vehicles.

1.14.5.3 *The vehicle repair shop*

The vehicle repair shop was officially approved for carrying out repairs on all types of vehicles. It was also an approved inspection body for carrying out periodic roadworthiness tests. The repair shop was approved by DSB for conducting periodic inspections of tanks in accordance with the ADR Regulations.

The repair shop has informed the AIBN that the procedures have been changed after the incident, so that instead of repairing damage to trailer drawbars, they now replace them with new parts. Trailer drawbars are also the subject of special focus during periodic roadworthiness tests.

1.15 Other information

1.15.1 Fires in other tunnels

Tunnel fires previously investigated by the AIBN include: vehicle fire in the Oslofjord tunnel on 23 June 2011 (AIBN Road report 2013/05), fire in a heavy goods vehicle in the Gudvanga tunnel on 5 August 2013 (AIBN Road report 2015/02) and fire in a coach in the Gudvanga tunnel on 11 August 2015 (AIBN Road report 2016/03).

These fires did not involve the carriage of dangerous goods and the sequence of events was therefore unlike the one in the Skatestraum tunnel, which involved a vehicle carrying 16,500 litres of petrol. The reports do show the damage potential of fires in long tunnels, however.

1.16 Implemented measures

1.16.1 NPRA

Following the incident discussed in this report, the NPRA has sent a letter of information to HGV repair shops and inspection bodies. The letter stresses the importance of thorough inspections of trailer drawbars and drawbar components. It points out that trailer drawbar manufacturers are very restrictive concerning repairs to/modification of trailer drawbars, and that the repair shops must comply with the manufacturer's instructions concerning the repair of wear and other damage, weaknesses, rust and fractured/broken drawbars. It is stressed that this is becoming increasingly important because of the growing influence of developments in material technology and design on the design of trailer drawbars and drawbar components.

The letter reminds the inspection bodies that drawbars are to be inspected as described in the instructions for the periodic roadworthiness tests. A rust hammer/pickaxe should be used where rust damage is suspected, and reference is made to the rust damage guidelines that can be downloaded from the NPRA's website[7]. The NPRA's letter of information is enclosed in Annex F.

The NPRA, Directorate of Public Roads has informed the AIBN that the same clarifications have been communicated to NPRA inspection personnel who carry out roadside and administrative vehicle inspections, and to personnel who supervise and approve inspection bodies and vehicle repair shops.

NPRA Western Region has also evaluated the fire in the Skatestraum tunnel and submitted several proposals for improvement relating to the VTS centre's handling of the incident.

1.16.2 Sogn og Fjordane County Authority

When the Skatestraum tunnel was renovated after the fire, the standard and equipment/installations in the tunnel were upgraded as follows:

- 10 new emergency telephones and 19 new fire extinguishers have been installed.

[7] www.vegvesen.no/Kjoretoy/Eie+og+vedlikeholde/EU-kontroll/for-kontrollorganene

- The tunnel roof and wall has been sectionally covered with PE foam in the part of tunnel that was damaged by fire.

- Alarms have been installed in all technical rooms to warn any personnel that are present in these rooms when the tunnel is closed.

- A new daylight lighting system has been installed at the tunnel portal on the side of the tunnel that was damaged (the Hamnen side).

- Evacuation lights have been installed throughout the tunnel.

- Remote-controlled barriers have been installed at the tunnel entrances.

- The fans that were damaged have been replaced by fans with a greater diameter.

- The emergency response plan was revised after the renovation work was completed.

- Night-time lighting has been installed along just over half the length of the tunnel.

- The emergency telephone booths have been moved to the outside of the tunnel and further away from the tunnel portals on both sides.

The incorrectly installed gaskets in the surface-water sand traps have been replaced in the part of the drainage system that was damaged (from the scene of the fire to the bottom of the tunnel). There are plans to replace the rest of these gaskets at a later date.

The revised emergency response plan is dated 9 May 2016. The risk analysis that forms part of the revised emergency response plan describes the same scenarios as those described in the emergency response plan dated 1 December 2013. The emergency response plan of 2016 also fails to describe what risk-reducing/compensatory measures should be implemented for each of the assessed scenarios.

2. ANALYSIS

2.1 Introduction

The AIBN has investigated the sequence of events, the factors that contributed to and the consequences of the fire in the Skatestraum tunnel. A tank trailer carrying 16,500 litres of petrol was completely burnt out in the incident and there was extensive material damage to the tunnel. Five people suffered minor smoke injuries.

The analysis start with an assessment of the sequence of events. The AIBN first assesses why the tank trailer broke loose from the truck and ran into the tunnel wall, rupturing the front tank chamber. It goes on to assess the road users' actions and self-rescue efforts in a situation in which petrol was running down the roadway and there was a fire in the tunnel. The response efforts of the VTS and rescue services during the incident were also assessed.

The investigation has also focussed on how and why a tank trailer with advanced rust damage was allowed to carry dangerous goods on the road network, and on where the inspection and repair procedures for the tank trailer had failed. This is discussed in section 2.3. The discussion also addresses why the trailer drawbar was not satisfactorily repaired after the inspection in 2011. The AIBN also discusses why the unsatisfactory repair work was not discovered in the subsequent inspections of the tank trailer that took place up until the incident itself in July 2015.

The procedures allowing inspection bodies and inspectors to carry out periodic roadworthiness tests of vehicles they themselves own or have at their disposal are also examined.

The investigation has also focused on the dramatic consequences of the tank trailer breaking loose in the tunnel. The AIBN has therefore analysed the leakage, ignition and fire development after the front tank chamber ruptured. In that connection, SP's report on possible ignition sources and the development of the fire has been essential in enabling an understanding of what happened. How the petrol was ignited is discussed in section 2.5, the development of the fire is discussed in section 2.6 and the drainage systems are discussed in section 2.7.

Finally, the AIBN examines subsequent follow-up work regarding safety in tunnels. This examination looks at risk assessments, the possible introduction of restrictions on the carriage of dangerous goods, and Sogn og Fjordane County Authority's responsibility for following up on safety in the Skatestraum tunnel.

2.2 Assessment of the sequence of events

2.2.1 <u>The triggering event and the spread of fire</u>

The investigation has shown that the tank trailer broke loose from the tank truck because the trailer drawbar was overloaded. The material strength of the drawbar rods was significantly reduced due to an advanced state of internal corrosion.

When the tank trailer broke loose, it hit the tunnel wall approximately 475 from where the road tanker started the ascent from the bottom of the tunnel. One of the tanks on the tank trailer ruptured, and the petrol that ran out was ignited. This caused the fire to spread to the bottom of the tunnel, both along the roadway and through the tunnel's drainage system. As the fire developed, it burnt holes in all the tank compartments on the tank trailer.

In the AIBN's opinion, the reason why the trailer drawbar broke was because the strength of the drawbar rods had been reduced due a very advanced state of corrosion. The petrol that ran out was then most probably ignited by heat/sparks from a van that had stopped behind the tank trailer. The AIBN believes that the rapid spread of fire to the bottom of the tunnel was due to the steeply falling/rising gradient of the tunnel (10%).

The corrosion damage to the trailer drawbar, the ignition of the petrol and the spread of the fire is discussed in more detail in sections 2.3, 2.5 and 2.6.

2.2.2 The road users' actions

In the AIBN's opinion, the driver acted in accordance with what should be expected of drivers of vehicles carrying dangerous goods. He acted responsibly, both during the journey prior to the incident and in the situation after the tank trailer had broken loose from the truck. He stopped to let other cars pass before he left the ferry landing at Oldeide and he mindfully engaged the truck's retarder and engine brake to curtail the speed as he drove towards the bottom of the tunnel. When the tank trailer broke loose, he immediately notified the VTS centre, stopped oncoming vehicles and evacuated the tunnel in a responsible manner.

The five vehicles that entered the tunnel behind the road tanker acted quickly when they saw that the tank trailer had hit the tunnel wall. Four of these vehicles turned around immediately, while the driver and passenger in the fifth car evacuated on foot as they believed their car could not be driven. They were subsequently picked up and taken out of the tunnel by the camper van that had turned around.

The AIBN believes that the situation would have been critical for the road users in the road tanker and the five vehicles, had they not reacted as quickly as they did.

2.2.3 The VTS centre's response

No radio alert was issued in connection with the incident and the road users did not receive any warning. According to the NPRA, the VTS operator was concentrating on warning the road users and notifying other parties of the possibility of issuing a radio alert without receiving any response. The VTS operator was not aware that the radio alert system was not working in the Skatestraum tunnel, however, although the VTS centre had previously been notified of this. The AIBN does not know why this information had not been received by the VTS operator.

In previous reports, the AIBN has highlighted the need to immediately instruct road users located in a tunnel to evacuate during a fire. This issue was addressed in Safety recommendation ROAD No 2013/08T after the Oslofjord tunnel fire in 2011 and Safety recommendation ROAD No 2015/03T after the Gudvanga tunnel fire in 2013. In the AIBN's opinion, fast and informative notification is a key element to improving road users' chances of self-rescue before a tunnel is filled with smoke.

The NPRA's own evaluation of the fire in the Skatestraum tunnel mentions the inoperative radio alert system and defined this as one of several learning points after the fire. The AIBN takes a positive view of the fact that the NPRA has identified the problem and recommended measures to ensure that radio alerts are issued in consultation with the local fire service.

2.2.4 The response of the fire and rescue services

The fire in the Skatestraum tunnel was very intense and produced a great deal of smoke. On being notified of the incident, the VTS centre notified the emergency communication centre in Sogn og Fjordane, which immediately proceeded to issue a triple alert. The fire and rescue services responded and arrived at the tunnel within a relatively short period of time, considering the distance.

The fire crew focused on searching for and rescuing any road users that might still be inside the tunnel. They then withdrew until the fire died out by itself. The AIBN considers the response of the fire and rescue services to have been satisfactory, in relation to the intensity of the fire and the limited possibility of searching the tunnel once the fire had escalated.

2.3 The trailer's repair and inspection history

In the following sub-sections, the AIBN discusses the repairs that were carried out after the ADR inspection in 2011, and the official inspections that took place between 2011 and the Skatestraum tunnel incident in 2015. A systematic overview of inspections that took place during this period is shown in Annex B.

2.3.1 The NPRA's ADR inspection in May 2011 when the rust damage was found

A technical inspection of the tank trailer was carried out by the NPRA as part of the renewal process for the ADR approval in May 2011. During this inspection, an extensive list of technical defects were found in the tank trailer, including extensive rust damage in the trailer drawbar. The defects in the tank trailer were documented by photographs and an inspection sheet on which all the defects were noted. During the inspection, a prohibition was issued on use of the tank trailer until the defects were repaired.

The AIBN is of the opinion that the NPRA's documentation of the defects that were found during the inspection in May 2011 was satisfactory. It is also a good thing that all the documentation, including the photographic material, from the inspection was filed, so that the NPRA could use this information in its process of approving the tank trailer once the defects were repaired.

2.3.2 Repairs and periodic roadworthiness tests of the tank trailer

The periodic roadworthiness tests and repairs to the tank trailer were carried out by the same repair shop, which held NPRA approval both as a vehicle repair shop and as an inspection body.

Before starting the repair work, the repair shop carried out a roadworthiness test of the tank trailer as it was due for such a test at the time. The same type of defects were noted in this test as in the NPRA inspection in May 2011, including rust damage in the trailer drawbar.

The rust damage in the trailer drawbar was repaired by welding two sheets of steel over the two visible rust holes on the underside of the drawbar. No preparation work or examination to ascertain the total extent of the rust damage was carried out before welding the steel sheets to the drawbar rods.

The repairs to the trailer drawbar were not in accordance with the trailer drawbar manufacturer's instructions. The manufacturer's instructions include the following wording: 'all welding and any form of reworking are prohibited'.

The AIBN takes a critical view of the fact that an approved repair shop makes repairs to a vehicle that are in contravention of the manufacturer's instructions for the products it has designed and produced. In the AIBN's opinion, the trailer drawbar should have been replaced, not repaired.

The case under consideration concerned repairs to the drawbar for a tank trailer that would be transporting dangerous goods. The trailer drawbar is a very important component in terms of safety, as it is the main connection between the truck and the tank trailer. There are no instructions for extra securing of this connection, so for safety reasons, it is therefore important that such components are monitored and repaired as specified.

Based on the rust and fracture propagation shown in Figures 13 and 14, the AIBN is of the opinion that the repair shop should have examined the trailer drawbar more thoroughly. The result of such examinations should have been assessed in relation to the manufacturer's guidelines for the repair and restoration of its trailer drawbars.

After completing the repairs, the repair shop carried out a follow-up inspection of the defects noted during the periodic roadworthiness test, and the tank trailer was approved without remarks.

The AIBN finds that the repair shop neither repaired the trailer drawbar in a professional manner, nor carried out a satisfactory inspection of the defects noted during the periodic roadworthiness test. The AIBN finds that this was particularly unfortunate in that the repairs were made without ascertaining the extent of the rust damage, and that the manner in which the welding work was done did not contribute to increasing the strength of the structure.

2.3.3 Follow-up inspection after the ADR inspection in May 2011

When the tank trailer had been repaired and approved in a periodic roadworthiness test in July 2011, it was once again presented to the NPRA for follow-up inspection of the defects found in the ADR inspection in May 2011.

The points checked as defective when the tank was inspected, were approved when the repairs were inspected. The technical condition of the tank trailer was then approved solely on the basis that it had passed the periodic roadworthiness test and on a visual inspection of the defects previously noted on the inspection sheet issued by the NPRA in May 2011.

In the AIBN's opinion, the NPRA should have discovered the defective and unworkmanlike repairs to the trailer drawbar in this inspection. Even if the NPRA's procedures indicate that, in ADR inspections, the technical condition of vehicles can be approved on the basis that they have passed approved periodic roadworthiness tests, the AIBN is of the opinion that the Driver and Vehicle Licensing Office in question should have conducted a more comprehensive follow-up inspection of the defects on the tank trailer. This should have been done on the basis of the points that were checked as defective on the inspection sheet from May 2011, which were signed off. Furthermore, the NPRA had filed all the documents and photos from the first ADR inspection. A review of that documentation and a visual inspection of the repaired trailer drawbar should have given cause to find the repairs inadequate.

2.3.4 No rust damage was detected during periodic roadworthiness tests and ADR inspections between 2012 and 2015

During the period 2012–2015, there were eight official inspections of the tank trailer, five of which were ADR inspections conducted by the NPRA.

The AIBN notes that no remarks were made concerning the ‘repaired’ trailer drawbar in any of the eight official inspections of the tank trailer that were carried out during this period. The AIBN therefore questions the quality of these inspections and whether these inspections are capable of detecting serious faults in vehicles.

2.3.5 The AIBN’s overall assessment

Based on the above, the AIBN finds that there were system failures and lack of know-how on the part of the vehicle repair shop that repaired the tank trailer, the inspection bodies that carried out the periodic roadworthiness tests as well as the NPRA in its ADR inspections during the relevant period. These failures help to explain why the rust damage in the trailer drawbar was allowed to develop so that the strength of the trailer drawbar was significantly weakened. It caused the trailer drawbar to break loose from the truck.

Point by point, this can be summed up as follows:

- The AIBN is of the opinion that the NPRA’s inspection in May 2011, when the rust damage in the trailer drawbar was detected, was carried out in a satisfactory manner.
- The AIBN finds that the periodic roadworthiness tests carried out by the repair shop in June/July 2011 were not satisfactory and not in accordance with the manufacturer’s instructions.
- The follow-up inspection of points checked as defective during the roadworthiness test, which was carried out by the same repair shop, did not discover the ineffective repairs to the trailer drawbar.
- When the tank trailer was presented for follow-up inspection by the NPRA in July 2011, it was approved by the Driver and Vehicle Licensing Office on the basis of the roadworthiness test, without a more comprehensive follow-up inspection.
- Between January 2012 and July 2015, eight official inspections were carried out of the tank trailer, without any remarks concerning the incorrect repairs to the trailer drawbars being noted.

After the accident, the NPRA, Directorate of Public Roads has sent out information/guidelines on following up repairs and damage to trailer drawbars to repair shops, inspection bodies, organisations, users and the NPRA’s Driver and Vehicle Licensing Offices. The information includes details as to how they should proceed with regard to inspections, follow-up inspections and repairs to these components. The AIBN is of the opinion that the written information provides good guidelines on how to follow up repairs and will therefore not submit any further safety recommendation in connection with this report. However, the AIBN expects the NPRA, Directorate of Public Roads to check that this information is incorporated into the training and procedures of repair shops, inspection bodies and the NPRA's Driver and Vehicle Licensing Offices.

2.4 Impartiality in connection with periodic roadworthiness tests of own vehicles and ADR tanks

The AIBN believes that inadequate procedures and knowledge on the part of the repair shop that both repaired and inspected the vehicle help to explain why the tank trailer was approved with a drawbar that was extensively damaged by rust, had reduced strength and had not been repaired in accordance with the manufacturer's instructions.

The AIBN questions the practice of allowing inspection bodies that are approved to carry out periodic roadworthiness tests of vehicles and tanks, to also inspect vehicles they themselves own or have at their disposal. In addition to the safety aspect, there is also a financial aspect to such inspections. The defects that are noted can in some cases oblige the vehicle owners or users to carry out costly repairs. Although the AIBN has no documentation showing that this is the case, it is not difficult to imagine that faults can be 'overlooked' by inspection bodies inspecting their own vehicles, in order to save on costs. The tank trailer referred to in this report was first repaired and then approved in a periodic vehicle inspection by one and the same repair shop. This repair shop was owned by the same transport undertaking that owned the transport firm that owned the tank trailer. In this instance, the AIBN has no indication that the ownership had any impact on the repairs that were carried out and the subsequent follow-up inspection. The repair shop in question had been carrying out this type of repair on trailer drawbars for a long time, regardless of who had been the owner or user of the tank trailer.

Nonetheless, the AIBN finds this type of link between a vehicle owner and the inspection body for periodic roadworthiness tests of the vehicles to be unfortunate. For safety reasons, the AIBN is of the opinion that both the NPRA and DSB should give some consideration to impartiality in connection with official vehicle inspections.

The AIBN takes a positive view of the fact that the NPRA has initiated work to revise the regulatory framework for the approval and supervision of repair shops and inspection bodies for periodic roadworthiness tests, in connection with which the requirement for impartiality is being assessed. In the AIBN's opinion, DSB should similarly consider this issue with regard to the approval of tanks to be used for the carriage of dangerous goods.

2.5 Sources of ignition of the petrol

Alternative sources of ignition were considered by the SP based on information about the tunnel's technical installations, the sequence of events and witness statements.

SP considered the camper van, which was located approximately 10 metres from the tank trailer when the fire started, to have been the most probably source of ignition. SP considered that there was little probability that hot surfaces on the tank trailer had been the source of ignition, but did not exclude the possibility. On the other hand, it was considered unlikely that the petrol vapour was ignited by static electricity, sparks from electrical installations in the tunnel, sparks from the collision with the tunnel wall or electrical faults/cables in the tank trailer.

The AIBN supports SP's conclusion that the petrol vapour may have been ignited by hot surfaces or sparks from the electrical systems in the camper van's engine compartment. It was in this area (behind the tank trailer) that both the driver and passenger in the camper van and the driver of the road tanker observed that the fire started. Damage to the camper van also shows that the bonnet was pushed upwards. Furthermore, according to the driver of the camper van, the camper van's headlights were dislodged. The AIBN believes that this may have been a consequence of pressure building up as petrol vapour was drawn into the engine compartment by the van’s cooling fans and was ignited there.

2.6 The development of the fire in the Skatestraum tunnel

SP conducted an analysis of the development of the fire in the Skatestraum tunnel. The analysis was based on witness statements, logged data and technical findings in the tunnel, among other things. SP concluded that the fire developed very rapidly and that, within two minutes of the fire having broken out, there was little or no possibility of survival over a distance of approximately 950 metres, from the pumping station up to the tunnel portal at Hamnen.

The AIBN understands that three factors stand out as special and had the combined effect of making this incident dramatic and potentially life-threatening for road users. These three factors are:

- The tunnel’s gradient and drainage system.
- The rapid spread of petrol along the road surface.
- The extreme fire effect, smoke emission, temperatures and radiation heat produced by the fire.

The Skatestraum tunnel has a gradient of 10%, which caused the leakage from the tank trailer to spread over a wide area. The situation was worsened by the fact that the side entry gullies, which are intended to remove surface water and jetting water from the tunnel, did not have the capacity to handle the amount of petrol that was running down the roadway. The petrol ran along the kerb of the tunnel and reached the bottom of the tunnel approximately three minutes after it started to leak out.

When the petrol near the tank trailer was ignited approximately 2 minutes and 40 seconds after the tank trailer collided with the tunnel wall, an intense surface fire spread along the roadway. The flame front moved down the tunnel and reached the bottom of the tunnel after approximately two minutes. On its own, this fire in the roadway generated a fire effect of 200 MW in addition to heavy smoke emission and intense radiation heat, and it would have been deadly had the road users not managed to evacuate.

Above the scene of the fire, the smoke front reached the tunnel portal at Hamnen in the course of 66 seconds. The AIBN considers that, had anybody been caught in the smoke, they would soon have died as a consequence of the high temperature, the smoke and the heat radiation.

In the AIBN’s opinion, there is a clear relationship between the high rate at which the fire spread and developed in intensity and the steep gradient of the tunnel. The gradient of 10% inside the tunnel, combined with the fact that the drainage system was unable to drain away the liquid from the roadway surface, caused the petrol that leaked out to quickly spread over a wide surface area, which in turn generated a lot of smoke and heat, and explains the intensity of the fire.

2.7 The drainage systems in the tunnel

Little petrol was found in the drainage system for surface water/jetting water after the fire. Nor was any fire damage found in this system. This suggests that very little petrol was drained from the roadway surface during the fire. Because of the gradient of the tunnel, the petrol ran down the slope at high speed and the side entry gullies did not have the capacity or were not designed to drain away the petrol from the roadway surface.

The inability of the drainage system to drain away the petrol contributed significantly to the spread and intensity of the fire. In the AIBN's opinion, tunnels with steep gradients should have a drainage system for surface water with gullies that are designed to drain away more liquid so as to reduce to a minimum the consequences of a fire in flammable liquids or of other dangerous liquids leaking out inside such tunnels. This would help to increase the road users’ time window for evacuation.

The sand traps did not have submerged outlet pipes as this was not a requirement at the time when the tunnel was put into operation. The absence of submerged outlet pipes can increase the danger of any flammable liquids that run into the sand traps spreading to other parts of the drainage system. The absence of submerged outlet pipes can also cause surface impurities to run straight into the pipe system and clog it up over time. The investigation has not been able to ascertain whether this happened in this particular incident, however.

Because the gaskets around the inlet and outlet pipes to/from the sand traps did not provide a seal, the petrol ran into the ground and spread to the groundwater drainage system. As a result, the petrol ran into the sludge basin, where it burnt quite intensely. The AIBN believes that the inadequate seal between the sand traps and the inlet/outlet pipes contributed to causing the fire in the sludge basin at the bottom of the tunnel.

In the AIBN’s opinion this is not just a problem in single bore tunnels, but also in twin bore tunnels with steep gradients. The experience to be gained from this fire is that the fire spread quickly, and that road users had a very short space of time in which to take in the situation and evacuate the tunnel.

In addition to necessary repairs after the fire in 2015, some additional work was done in the tunnel in order to improve safety (see section 1.16.2). This included sealing the joints between the sand traps and inlet/outlet pipes in the part of the system that was damaged by fire. It is with some concern that the AIBN notes that these joints have only been sealed in this part of the system. A similar leakage somewhere else in the tunnel will still cause hazardous liquids to run into the ground. This situation will persist until the rest of the drainage system is repaired.

The AIBN believes that, in the event of a similar leakage in the Skatestraum tunnel, large volumes of liquid will still run down the roadway towards the bottom of the tunnel, as no changes have been made to the side entry gullies. The surface water system will not have the capacity to handle a corresponding amount of running liquid. A similar leakage and subsequent fire could therefore make the evacuation significantly more difficult than was the case in the fire discussed in this report.

In the AIBN’s view, one measure to prevent the spread of dangerous spills from vehicles would be to change/increase the tunnel's surface water drainage system so that large spills of hazardous liquids can be drained away and stopped at an early stage. This is one way of reducing the size of the incident site.

The AIBN submits one safety recommendation on the basis of this investigation, with a view to increasing the time window available to road users for evacuation: that measures be implemented to prevent leakages from vehicle cargo and fuel tanks from spreading over large areas.

2.8 Follow-up work on safety in the Skatestraum tunnel

2.8.1 Risk assessments

A fire in a vehicle carrying dangerous goods is a serious incident with a high potential for injury. When such an incident occurs inside a tunnel, the injury/damage potential is even higher. Tunnel experts in Norway and the rest of the world, consider such incidents to be among the worst things that can happen on the road network.

Seen against the backdrop of tunnel fires in the last decade – including the fire in the Oslofjord tunnel in 2011 and the Gudvanga tunnel in 2013, which occurred before the emergency response plan for the Skatestraum tunnel was revised, the AIBN believes that Sogn og Fjordane County Authority and the NPRA should be well aware of the injury/damage potential of a tunnel fire. It appears that this was not addressed, however, in the risk analysis that accompanied the emergency response plan. The risk analysis says very little about what risk-reducing/compensatory measures should be implemented for each of the scenarios. Nor is there any description of how these scenarios should be dealt with in terms of fire-fighting, evacuation, search and rescue.

The two tunnel fires in 2015 (in the Gudvanga and Skatestraum tunnels), of which the tunnel fire in the Skatestraum tunnel could potentially have been disastrous, have reinforced the need for such risk assessments. The AIBN takes a critical view of the fact that the injury/damage potential does not appear to have been acknowledged even in the revised edition of the emergency response plan (dated 9 May 2016).

The incident described in this report shows that the Skatestraum tunnel did not have the design and safety equipment required to deal with an incident involving leakage of dangerous goods. Nor have measures been implemented that might reduce the consequences should such an incident occur. A leakage from a vehicle carrying flammable liquids is particularly difficult to deal with in a tunnel with a falling/rising gradient of 10%.

The AIBN has seen similarly inadequate risk analyses in its previous investigations of the fires in the Oslofjord and Gudvanga tunnel. In the AIBN's opinion, the risk analyses must take account of the specific risks associated with and the characteristics of each individual tunnel. It is also important to take into account new knowledge about tunnel design, self-rescue by road users, fire-fighting and search and rescue work, and the injury/damage potential that has been demonstrated through the AIBN's investigations over the last decade. In the AIBN's opinion, the challenges associated with incidents in this type of tunnel are not only encountered in the Skatestraum tunnel, but in all similar tunnels on the network of national, county and municipal roads in Norway.

The AIBN believes that tunnel owners must take responsibility for ensuring that realistic risk analyses are conducted, in which measures to deal with identified scenarios/incidents are also described and assessed. In that connection, reference is made to NPRA Manual V721 – *Risikovurdering i vegtrafikken*, which prescribes that measures must be assessed or implemented for the most serious scenarios/incidents, regardless of the probability that they will occur. A safety recommendation is submitted on this issue.

2.8.2 Restrictions on the carriage of dangerous goods in tunnels

This investigation showed that road users had a very short time window in which to evacuate the tunnel when the tank trailer broke loose from the truck. The road users responded rapidly and correctly when the incident occurred, but a minor change in the circumstances could have had dramatic consequences. The AIBN considers that several alternative measures could be implemented to reduce the number of misadventures and accidents with vehicles carrying dangerous goods and the consequences of any such incidents should they occur.

One measure that could reduce the number of road users that are put at risk would be to regulate other traffic while vehicles carrying dangerous goods are driving through a tunnel. This could be done, for example, by closing the tunnel while it is being used by vehicles carrying dangerous goods. With the traffic volumes that pass through the Skatestraum tunnel, such regulation would be of little consequence to other road users as the tunnel would only be closed for a few minutes at the time. Another measure would be to impose restrictions on vehicles carrying certain types of dangerous goods in specific tunnels to be defined, for example deep subsea tunnels with steep rising/falling gradients.

The Regulations relating to overland transport of dangerous goods provide for the possibility of introducing restrictions relating to the transport of dangerous goods through road tunnels. Based on the fire in the Skatestraum tunnel, the AIBN is of the opinion that DSB, as administrator of these regulations, together with the tunnel owners, should consider whether such restrictions should be imposed. This should be considered with a view to improving safety in connection with the transport of dangerous goods in specific tunnels defined as having a high accident risk.

The AIBN submits one safety recommendation on this issue.

2.8.3 Sogn og Fjordane County Authority's responsibility for following up on safety in the Skatestraum tunnel

Sogn og Fjordane County Authority owns the Skatestraum tunnel and is responsible for its operation, maintenance and safety. Together with large parts of the rest of the national road network in Sogn og Fjordane County, the tunnel was transferred to Sogn og Fjordane County Authority as part of the administrative reform in 2010. Hence, Sogn og Fjordane County Authority had no influence on the tunnel design, its safety equipment and safety level up until that point in time.

However, the AIBN is of the opinion that Sogn og Fjordane County Authority, once it had taken over responsibility for the Skatestraum tunnel, should have done more to ensure that assessments and tasks of importance to safety were carried out in the tunnel. Neither the risk analysis from 2013 nor the new analysis from 2016 include adequate assessments of scenarios and measures. Furthermore, the restoration of the tunnel after the fire has not increased the capacity of the surface water system to prevent liquid from spreading over wide areas as it did in the present incident. The defective seals around the sand trap inlet/outlet pipes have only been repaired along the section that was damaged by fire. After the fire, Sogn og Fjordane County Authority has not implemented or considered implementing compensatory measures to limit the consequences of any similar incidents.

Based on the investigation, it is the AIBN’s opinion that Sogn og Fjordane County Authority has not adequately discharged its responsibility for ensuring a satisfactory safety level in the Skatestraum tunnel. The AIBN considers that Sogn og Fjordane County Authority must review and improve its follow-up of safety in the Skatestraum tunnel and other tunnels in the county, so that essential measures are implemented to reduce the risk of serious incidents.

The AIBN submits one safety recommendation on this issue.

3. CONCLUSION

3.1 Important results of the investigation with a bearing on safety

a) The rust damage that was detected in an ADR inspection of the tank trailer in 2011 was repaired in contravention of the manufacturer's instructions, by welding sheet steel on top of the rust holes. Rather than increasing the strength of the structure, the repairs contributed to increasing the risk of corrosion fatigue. The corrosion was allowed to develop, until the trailer drawbar finally broke in 2015.

b) There were system failures and lack of know-how on the part of the vehicle repair shop that repaired the tank trailer, the inspection bodies that carried out the periodic roadworthiness tests as well as the NPRA inspectors who conducted the ADR inspections during the period 2011-2015, when the inadequate repair work was not discovered in the subsequent inspections.

c) The gradient of 10% inside the tunnel, combined with the fact that the drainage system was unable to drain away the liquid from the roadway surface, caused the petrol that leaked out to quickly spread over a wide surface area, which in turn generated a lot of smoke and heat, and explains the intensity of the fire.

d) When the tank trailer broke loose, the road users had a very short time window (approximately 2 minutes) in which to evacuate the tunnel before the smoke and the heat caught up with them. The road users responded rapidly and correctly when the incident occurred, but a minor change in the circumstances could have had dramatic consequences.

e) The risk analyses for the Skatestraum tunnel from 2013 and from 2016 after the fire, are both inadequate in terms of assessing scenarios and measures. The damage/injury potential associated with the carriage of dangerous goods and fires has not been adequately assessed in relation to the tunnel’s special characteristics.

f) There is no restriction on the transport of dangerous goods through the tunnel. The Regulations relating to overland transport of dangerous goods provide for the possibility of introducing restrictions relating to the transport of dangerous goods through road tunnels.

g) Sogn og Fjordane County Authority’s follow-up of safety in the Skatestraum tunnel has not been satisfactory. Neither has the capacity of the tunnel’s surface water system been increased after the fire, nor have any measures been implemented to reduce the consequences of any similar future incidents.

3.2 Investigation results

3.2.1 The sequence of events

a) The tank trailer broke loose from the tank truck because the trailer drawbar was overloaded. The material strength of the drawbar rods was significantly reduced due to an advanced state of internal corrosion.

b) The front tank chamber on the tank trailer ruptured, and large volumes of petrol ran onto the roadway and continued down towards the bottom of the tunnel.

c) The petrol vapour was probably ignited by hot surfaces or sparks from the electrical systems in the camper van's engine compartment.

d) The driver of the road tanker acted in accordance with what should be expected of drivers of vehicles carrying dangerous goods. He stopped to let other vehicles pass, he mindfully engaged the truck's retarder and engine brake to curtail the speed, called the VTS centre immediately, stopped oncoming vehicles and evacuated the tunnel in a responsible manner.

e) The five vehicles that entered the tunnel behind the road tanker acted quickly when they saw that the tank trailer had hit the tunnel wall.

f) The response of the fire and rescue services was satisfactory in relation to the intensity of the fire and the limited possibility of searching the tunnel once the fire had escalated.

3.2.2 The tank trailer's repair and inspection history

a) When the tank trailer was inspected in 2011, extensive rust damage was found in the trailer drawbar, in addition to a number of other defects. During the inspection, a prohibition was issued on using the tank trailer, other than driving it to a repair shop.

b) The rust damage in the trailer drawbar was repaired by welding steel sheet on top of the rust holes.

c) The repair shop failed to examine the extent of the rust damage before carrying out the repairs.

d) The rust damage was repaired in contravention of the trailer manufacturer's instructions, which state that welding is forbidden on trailer drawbars.

e) The repair shop that carried out the repair work was also an approved inspection body for conducting periodic roadworthiness tests. Once it had repaired the trailer drawbar and other defects noted on the inspection sheet, this repair shop also approved the tank trailer in a roadworthiness test (in July 2011).

f) During the period 2012–2015, there were eight official inspections of the tank trailer (three periodic roadworthiness tests and five ADR inspections). Nothing was noted concerning the 'repaired' trailer drawbar in any of these inspections.

g) After the incident in the Skatestraum tunnel, the NPRA, Directorate of Public Roads has sent out information/guidelines on following up on repairs and damage to trailer drawbars to repair shops, inspection bodies, organisations, users and the NPRA's Driver and Vehicle Licensing Offices.

h) The repair shop has subsequently changed its procedures, so that instead of repairing damage to trailer drawbars, they now replace them with new parts. Trailer drawbars are also the subject of special focus during periodic roadworthiness tests.

3.2.3 Tunnel and infrastructure

a) The 10% gradient of the Skatestraum tunnel caused the leakage from the tank trailer to spread over a wide area.

b) The side entry gullies in the sand traps that are supposed to drain away surface water and liquid spills from the tunnel, were not capable of collecting/handling the petrol that ran down the roadway. The petrol ran along the kerb and reached the bottom of the tunnel approximately three minutes after it started to leak out.

c) Much of the petrol that collected in the sand traps ran into the ground and spread to the groundwater drainage system, as the gaskets between the sand traps and the inlet/outlet pipes did not provide a seal.

d) When the tunnel was restored after the fire, the capacity of the drainage system was not increased to prevent the spread of liquid over large areas. The defective seals around the sand trap inlet/outlet pipes have only been repaired along the section that was damaged by fire.

3.2.4 Ignition and development of the fire

a) The AIBN supports SP’s conclusion that the petrol vapour was ignited by hot surfaces or sparks from electrical systems in the camper van’s engine compartment.

b) The fire developed very rapidly and, within two minutes of the fire having broken out, there was little or no possibility of survival over a distance of approximately 950 metres from the pumping station up to the tunnel portal at Hamnen.

c) Approximately 2 minutes and 40 seconds after the tank trailer collided with the tunnel wall, an intense surface fire spread along the roadway. The flame front moved down the tunnel and reached the bottom of the tunnel after approximately two minutes.

d) On its own, the fire in the roadway generated a fire effect of 200 MW in addition to heavy smoke emission and intense radiation heat, and it would have been deadly had the road users not managed to evacuate.

e) Above the scene of the fire, the smoke front reached the tunnel portal at Hamnen in the course of 66 seconds. The AIBN considers that, had anybody been caught in the smoke, they would soon have died as a consequence of the high temperature, the smoke and the heat radiation.

f) There is a clear relationship between the high rate at which the fire spread and developed in intensity and the steep gradient of the tunnel.

g) The inadequate sealing of the joints between the pipes and the sand traps caused the fire to spread to the groundwater drainage system and into the sludge basin and pumping station at the bottom of the tunnel.

3.2.5 Follow-up of safety in the Skatestraum tunnel

a) The risk analysis and emergency response plan for the Skatestraum tunnel, as revised in 2013, describes scenarios involving fire/explosion in a heavy goods vehicle and misadventures involving dangerous goods. There is no description of how these scenarios should be dealt with in terms of fire-fighting, evacuation, and search and rescue.

b) Sogn og Fjordane County Authority has also failed to describe how scenarios involving fire/explosion in a heavy goods vehicle should be dealt with in terms of fire-fighting, evacuation, and search and rescue in its revision of the emergency response plan in 2016.

c) After the fire, Sogn og Fjordane County Authority has not implemented or considered implementing compensatory measures to limit the consequences of any similar incidents.

3.2.6 Other investigation results

a) The repair shop, which carried out periodic roadworthiness tests and repairs to the tank trailer, and the transport firm that owned the tank trailer were both owned by the same transport undertaking. In this instance, there is nothing to suggest that the ownership structure had any impact on how the repairs and subsequent roadworthiness test of the tank trailer were carried out. Nonetheless, the AIBN finds it questionable that inspection bodies are allowed to inspect vehicles they themselves own or have at their disposal as this can give rise to conflicts between financial and safety objectives.

b) No radio alert message was issued during the course of the incident. Although this was of no consequence for the road users' chances of self-rescue, the AIBN finds it questionable that a system that is potentially a vital element in ensuring the road users' chances of self-rescue was inoperative.

4. SAFETY RECOMMENDATIONS

The investigation of this accident has identified several areas in which the AIBN deems it necessary to submit safety recommendations for the purpose of improving road safety.[8]

In addition to the submitted safety recommendations, this investigation report provides a detailed description of what caused the trailer's drawbar to break as a result of an advanced stage of internal corrosion in the drawbar rods.

After the accident, the Directorate of Public Roads on behalf of the Norwegian Public Roads Administration (NPRA) has sent out information/guidelines on following up repairs and damage to trailer drawbars. The AIBN is of the opinion that the written information provides good guidelines on how to follow up repairs and will therefore not submit any safety recommendation on this topic. However, the AIBN expects the NPRA to follow up that this information is incorporated into the training and procedures of garages, inspection bodies and the NPRA's Driver and Vehicle Licensing Offices.

Safety recommendation ROAD No 2016/13T

Like most other tunnels in Norway, the Skatestraum tunnel has a drainage system designed in accordance with the NPRA's manual on road tunnels. The gradient of 10% inside the tunnel combined with the fact that the drainage system was unable to drain away the liquid from the roadway surface, caused the petrol that leaked out to quickly cover a wide area, which in turn generated strong heat and a lot of smoke and explains the intensity of the fire on 15 July 2015. In order to prevent the spread of dangerous spills from vehicles and limit the size of the accident site, the tunnels' wastewater drainage systems should be designed with a greater capacity for draining away large spills of dangerous liquids and prevent them from spreading at an early stage.

The AIBN recommends that the NPRA revise its requirements for tunnel drainage systems, so that they are designed to handle large spills of dangerous liquids carried by vehicles.

Safety recommendation ROAD No 2016/14T

The risk analyses for the Skatestraum tunnel carried out both before and after the fire on 15 July 2015 were not in accordance with the recommended guidelines in Manual V721 – Risk analyses related to road traffic, which require consideration or implementation of measures related to the most serious scenarios/incidents, regardless of the probability that they will occur. The AIBN is of the opinion that the risk analyses were inadequate with respect to the consideration of scenarios and risk-reducing measures. Inadequate risk analyses can entail that the damage potential and the unique features of each tunnel are inadequately assessed and addressed.

The AIBN recommends that Sogn og Fjordane county administration and the NPRA, when conducting risk analyses, describe and follow up measures related to the described scenarios/incidents.

Safety recommendation ROAD No 2016/15T

The investigation of the fire in the Skatestraum tunnel on 15 July 2015 showed that road users had a very short time window for evacuating the tunnel when the tank trailer broke loose from the truck. Road users responded rapidly and correctly when the incident occurred, but a minor change in circumstances could have had dramatic consequences. Because of the short time window and the extensive effect of a fire, the AIBN is of the opinion that consideration must be given to restricting the transportation of dangerous goods through the Skatestraum tunnel and similar tunnels.

[8] The investigation report is submitted to the Ministry of Transport and Communications, which will take necessary steps to ensure that due consideration is given to the safety recommendations, cf. Section 14 of the Regulations of 30 June 2005 on Public Investigation and Notification of Traffic Accidents etc.

The AIBN recommends that the relevant road authority together with the Directorate for Civil Protection and Emergency Planning introduce restrictions on the transportation of dangerous goods through tunnels, based on a risk assessment of each individual tunnel.

Safety recommendation ROAD No 2016/16T

The investigation of the fire in the Skatestraum tunnel on 15 July 2015 shows that the safety of this tunnel has not been adequately followed up by Sogn og Fjordane county administration. The risk analyses of the Skatestraum tunnel carried out both before and after the fire did not adequately address scenarios and measures. When the tunnel was restored after the fire, the capacity of the drainage system was not increased to prevent the spread of liquid over large areas. Nor have measures been considered or implemented to reduce potential consequences or restrict the transportation of dangerous goods.

The AIBN recommends that Sogn og Fjordane county administration review and strengthen its follow-up of safety in the Skatestraum tunnel and other similar tunnels on the county roads.

Accident Investigation Board Norway

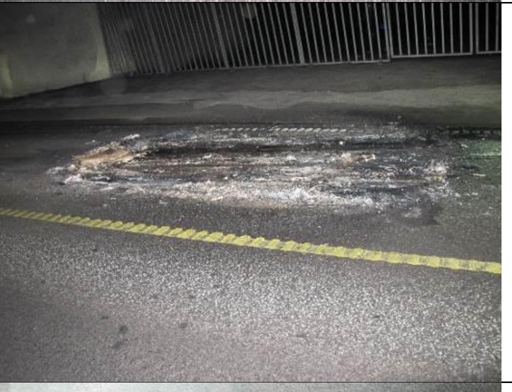
Lillestrøm, 11 November 2016

ANNEXES

ANNEX A: Drainage sand traps and vehicle wreck positions in the Skatestraum tunnel, registered on Tuesday 21 July 2015

The registration was carried out jointly with the police. The registration started from the midpoint of the pumping station at the bottom of the Skatestraum tunnel. The measurements were carried out using a measuring wheel.

Element	Metres from midpoint of pumping station	Photo
Sand trap with drainage (sand trap no 1)	41.9	
Sand trap with drainage (sand trap no 2)	128.5	
Damage to kerb	186.7	
Sand trap with drainage (sand trap no 3)	204.4	

Sand trap with drainage (sand trap no 4)	284.9	
Passenger car (rear end)	286.7	
Sand trap with drainage (Opened manhole) (sand trap no 5)	369.1	
Sand trap with drainage (sand trap no 6)	447.4	
Rear end of tank	467.0	

Front end of tank	475.5	

ANNEX B:

Overview of inspections of tank trailer HV 6927 carried out between 2011 and 2015.

Date	Periodic roadworthiness test		Administrative inspection – technical (NPRA*)		ADR inspection** (NPRA)		ADR approval certificate
	Inspection result	Defect found	Inspection result	Defect found	Inspection result	Defect found	Valid until:
							28 May 2011
10 May 2011			Not approved	Brakes, wheel suspension, springs, lights, fractures in frame, rust in trailer drawbar	Not approved, prohibition issued on carriage of dangerous goods	Fracture formation in tank, tubing, electrical cables, earthing points	
5 July 2011	Not approved	Brakes, wheel suspension, springs, lights, fractures in frame, rust in trailer drawbar					
5 July 2011	Approved in follow-up inspection of defects noted on inspection sheet of 5 July 2011						
6 July 2011			Approved in follow-up inspection of defects noted on inspection sheet of 10 May 2011		Approved in follow-up inspection of defects noted on inspection sheet of 10 May 2011		Certificate renewed 6 July 2011 and valid until 30 April 2012
25 April 2012					Approved		30 April 2013
17 September 2012	Approved						
25 September 2012					Approved		25 September 2013
24 September 2013	Not approved	Brakes, springs					

Date	Periodic roadworthiness test		Administrative inspection – technical (NPRA*)		ADR inspection** (NPRA)		ADR approval certificate
	Inspection result	Defect found	Inspection result	Defect found	Inspection result	Defect found	Valid until:
25 September 2013	Approved in follow-up inspection of defects noted on inspection sheet of 24 September 2013						
2 October 2013					Approved Roadworthiness test of 25 September 2013 forms the basis for approval of the technical condition		2 October 2014
20 August 2014	Not approved	ABS connection, springs					
27 August 2014	Approved in follow-up inspection of defects noted on inspection sheet of 20 August 2014						
24 September 2014					Approved Roadworthiness test of 27 August 2014 forms the basis for approval of the technical condition		30 April 2015
30 April 2015					Approved		30 April 2016

*= the Norwegian Public Roads Administration

**= Where a periodic roadworthiness test has not been carried out less than 30 days previously or an administrative inspection is carried out, a technical inspection shall be carried out at the time of the ADR inspection to ensure that the vehicle's condition is safe and in accordance with regulatory requirements.

FLO/VEDL/FOLAT
Norwegian Defence Laboratories
Chemistry - Materials

Client	Technical Report
AIBN	Client's ref: English version of report no.: 150925-03
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Title

Failure analysis of broken trailer tongue

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1 Introduction

The Norwegian Defence Laboratories was requested to assist in the failure analysis of a broken trailer tongue, Figure 1. The client wanted an evaluation of possible causes and to what extend the observed repair welds had contributed to the failure.

The investigation involves visual inspection, fractography in light microscope/SEM and metallography.

Figure 1 Overview image of failed trailer tongue.

2 Results

2.1 Initial investigation and visual inspections

Initial investigation of the trailer tongue was performed at AIBN 10/9-15, prior to transportation to RTV (Norwegian Defence Maintenance Division, Romerike Technical Workshop) where further inspections and sampling were performed.
Observations were documented by photo.
Overview images of the trailer tongue steel section fractures are shown in Figure 2. From the images it is evident that both steel profiles show extensive corrosion and that steel plates have been welded to the bottom part of the profiles, the steel profiles is corroded through the whole wall thickness in the these areas.

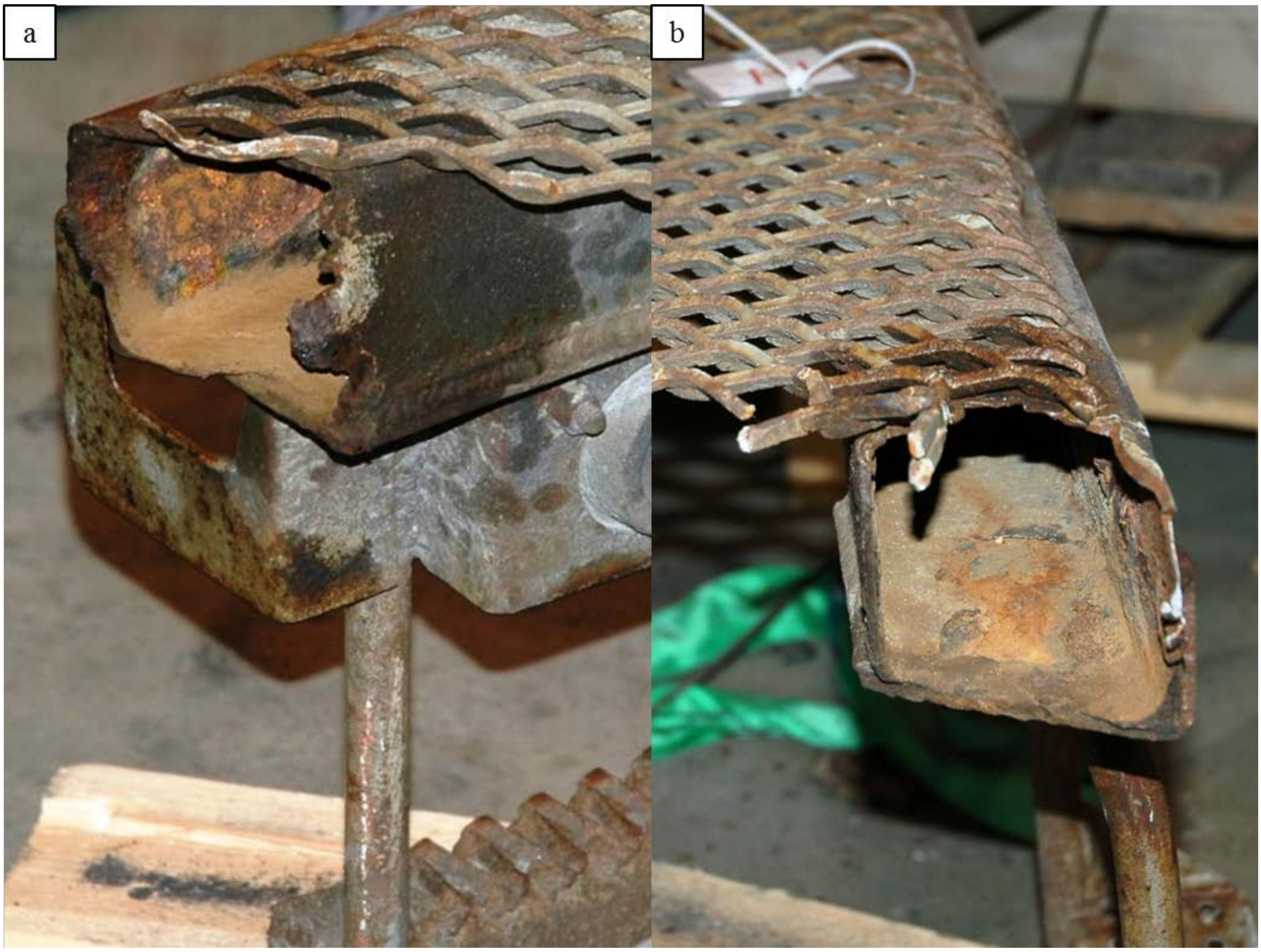

Figure 2a: Image of fracture marked «left side» (V). b: Image of fracture marked «right side» (H).

The corrosion was not limited to the steel profile ends and a layer of corrosion products were readily observed on the inside.
Further, it was observed that the profiles had spacing at the weld connection at the trailer tongue insert, and that it is evident that the inside of the profiles continuously would be exposed to moisture, Figure 3.
Attempts were made to measure the steel profile wall thickness with no success due to the thick layer of corrosion products on the inside.

A wire mesh had been welded to the steel profiles including the end brace that had been exposed to fire, and traces of spot welds and remains of the wire mesh were readily observed, Figure 4. The indications are that the wire mesh has contributed to the integrity of the trailer tongue.

Figure 3 Image of the steel profile welds at the tongue insert showing spacing resulting in moisture entering the inside of steel profile.

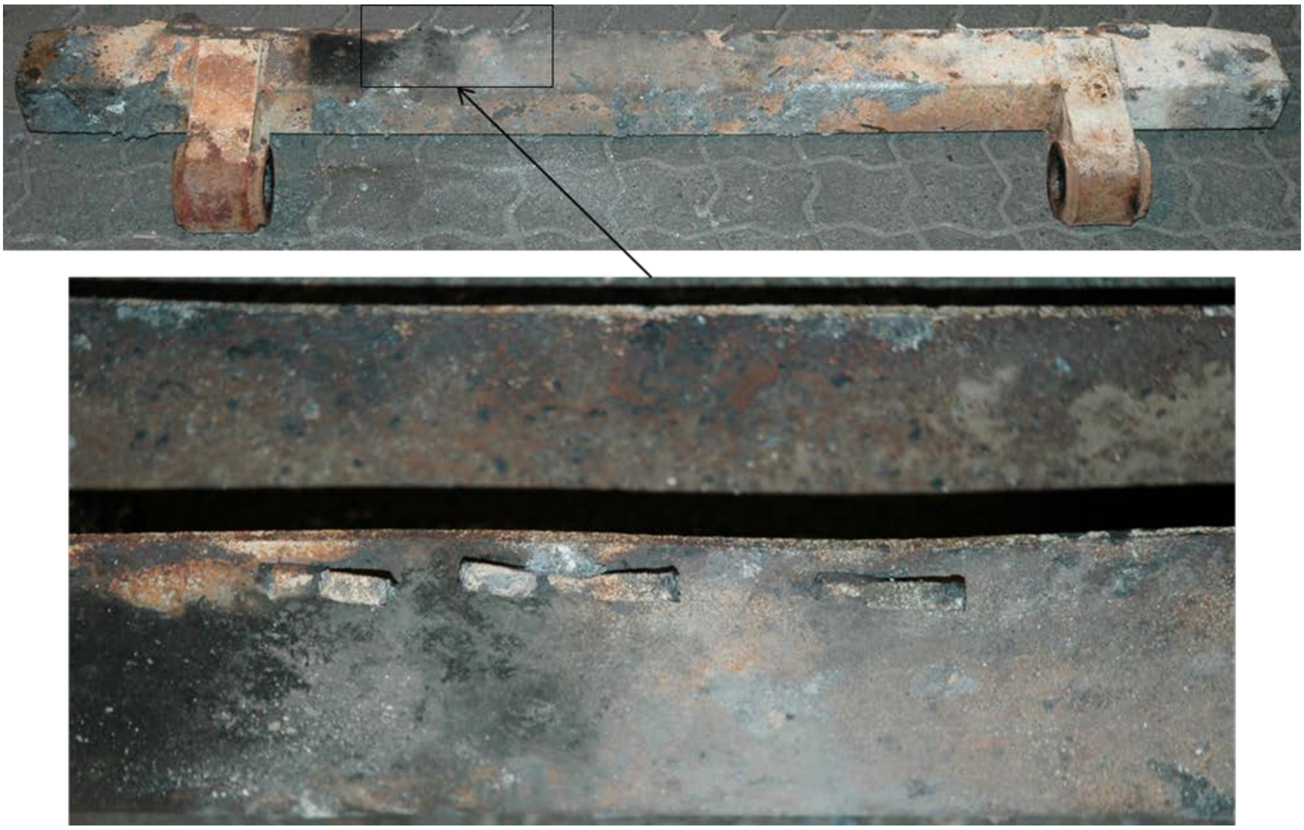

Figure 4 Image of trailer tongue end brace having spot welds and remains of wire mesh.

2.2 Failure analysis of trailer tongue steel profiles

The sampling is shown in Figure 5a-d. The sections of the steel profiles confirm excessive corrosion at the inside and corrosion through the wall thickness at the areas having additional steel plates welded, see Figure 6ab.

The corrosion layer were removed from the areas cut out from the steel profile on the left and right side respectively, and the wall thickness were measured using caliper and micrometer. On the right side (H) the wall thickness varied from 1,3 to 2,8 mm and on the left side (V) from 1,9 to 2,9 mm.

To obtain an impression of the extend of corrosion on other parts of the steel profiles a sample was cut out at the spacing shown in Figure 3. A more precise description of the specimen area is shown in Figure 7a. The painting and corrosion products were removed and a wall thickness varying from 3mm to 0mm was observed, Figure 7bc.

Attempts were made to machine standard tensile test specimens, however, due to corrosion pits this turned out not to be possible.

Figure 5 Images of the steel profile sampling as received from RTV. a-c: Right side (H). c-d: Left side (V).

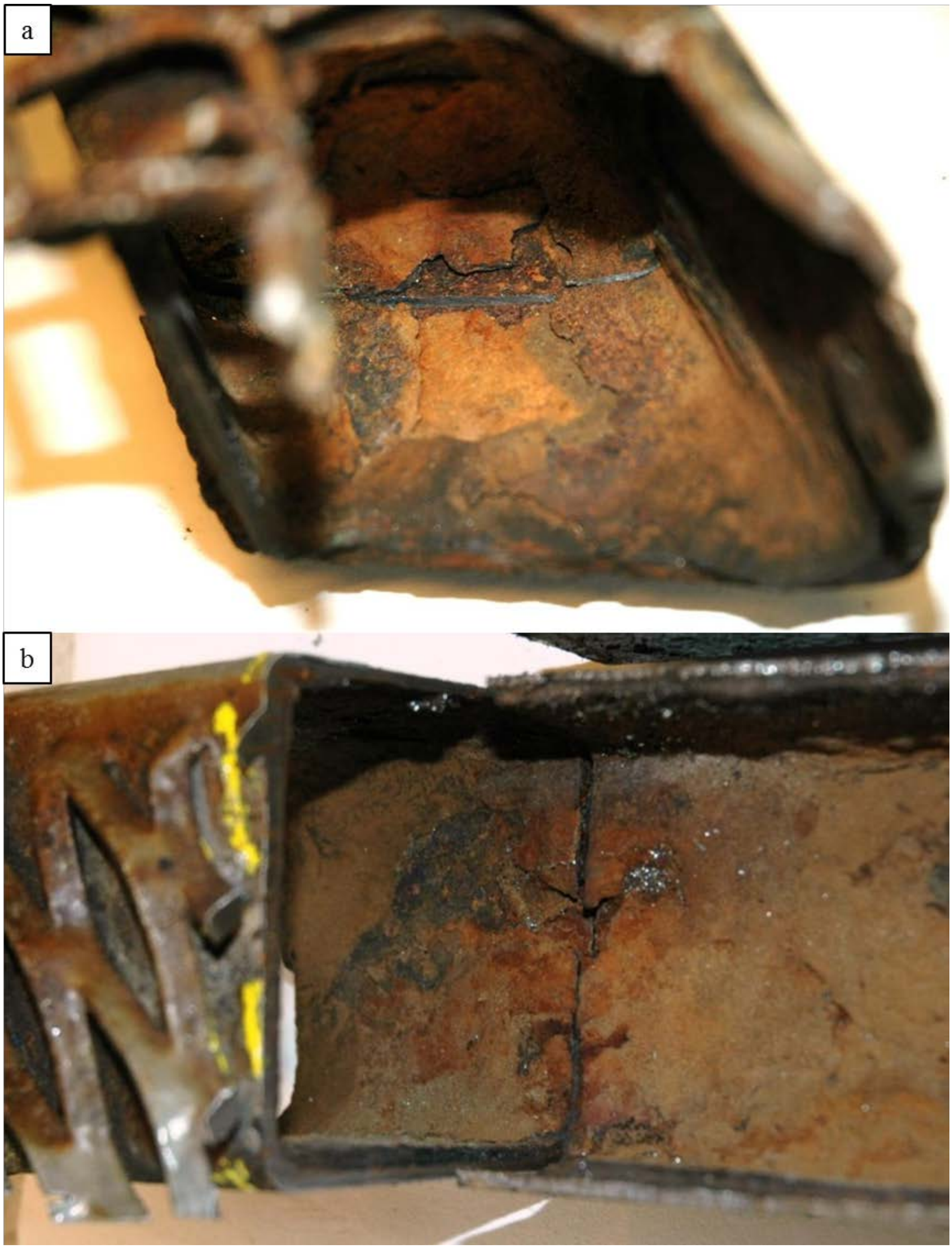

Figure 6 a: Image of through wall thickness corrosion at right side (H), b: Image of through wall thickness corrosion at left side (V).

Figure 7a: Image showing area selected for characterization of the general corrosion. b: Image of the outside following paint removal. c: Image of inside following removal of corrosion products.

2.2.1 Metallography

In order to document the extent of corrosion at the lower failed areas of the steel profiles, metallographic cross sections were cut as shown in Figure 8.
The specimens were mounted in epoxy, grinded and polished. Images of the polished samples as observed in stereo light microscope are shown in Figure 9a-d. It is evident from the images that the original bottom wall of the steel profile are corroded from both sides, further image *b* reveals lack of weld fusion and image *c* reveals weld undercut.
The microstructure of the steel profiles consists of ferrite and perlite and is compatible with a construction steel quality, Figure 10ab. The chemical analysis show a carbon content of 0,17 wt% for both profiles, see Table 1 and Table 2. Further analysis in SEM equipped with EDS confirms manganese steel base material and corrosion products containing chlorine (Cl), see Figure 11 and Figure 12. Further, mineral particles was observed within the corrosion products most likely originating from sand.

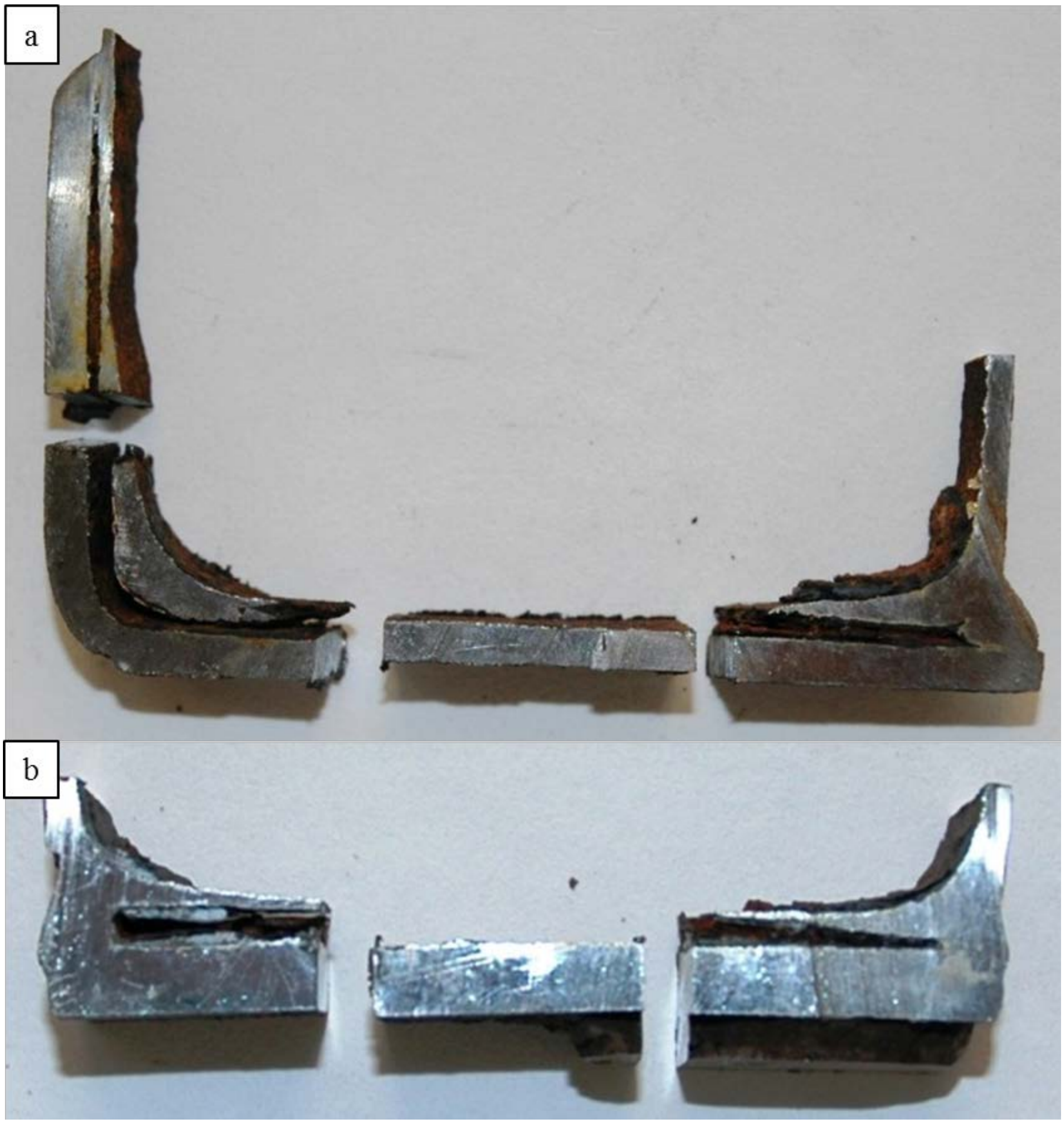

Figure 8 Specimens obtained from a: right side (H) and b: left side (V).

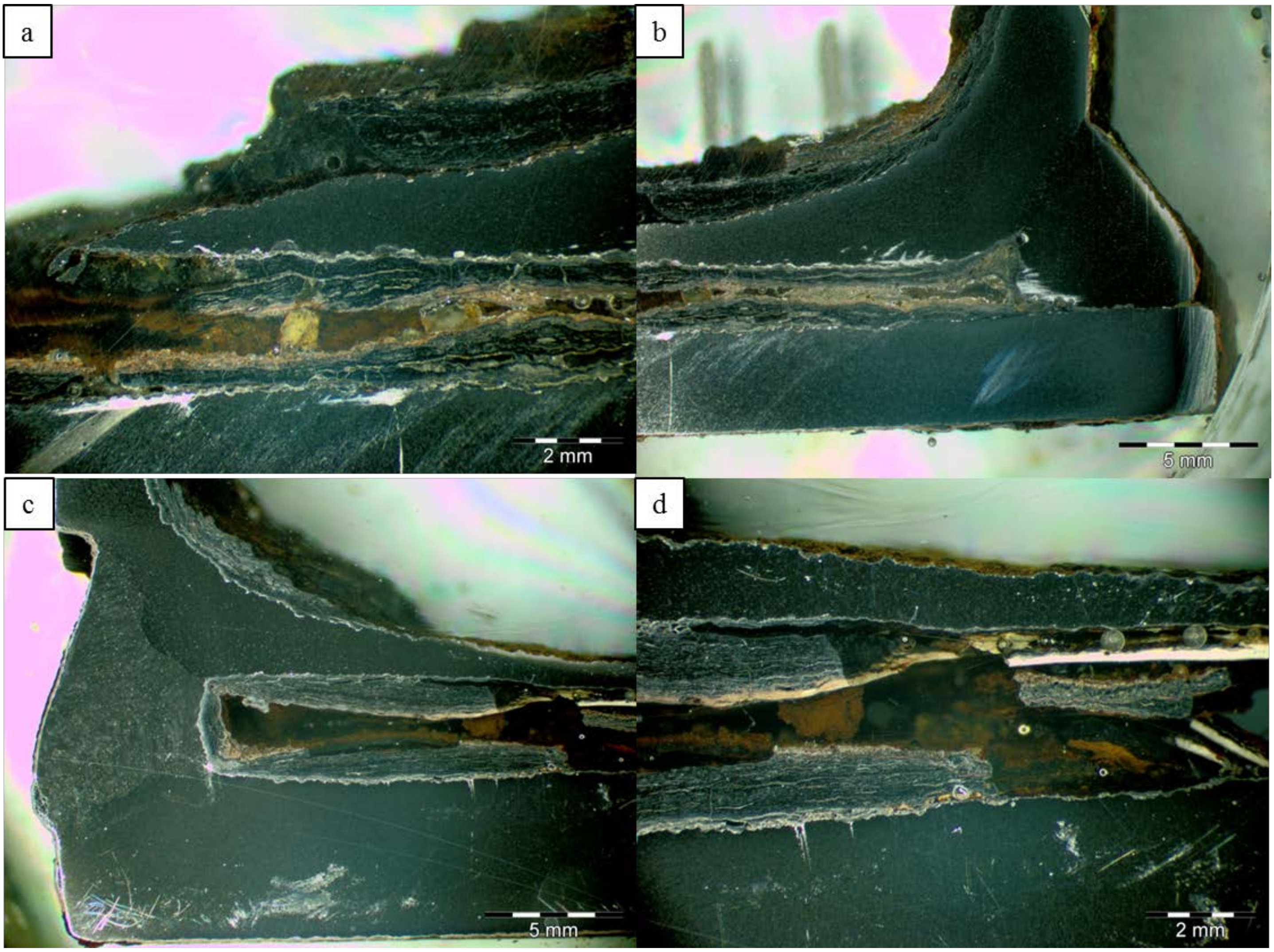

Figure 9 Images of metallographic cross sections through steel profile towards the welded steel plates. A-b: Right isde (H), c-d: Left side (V).

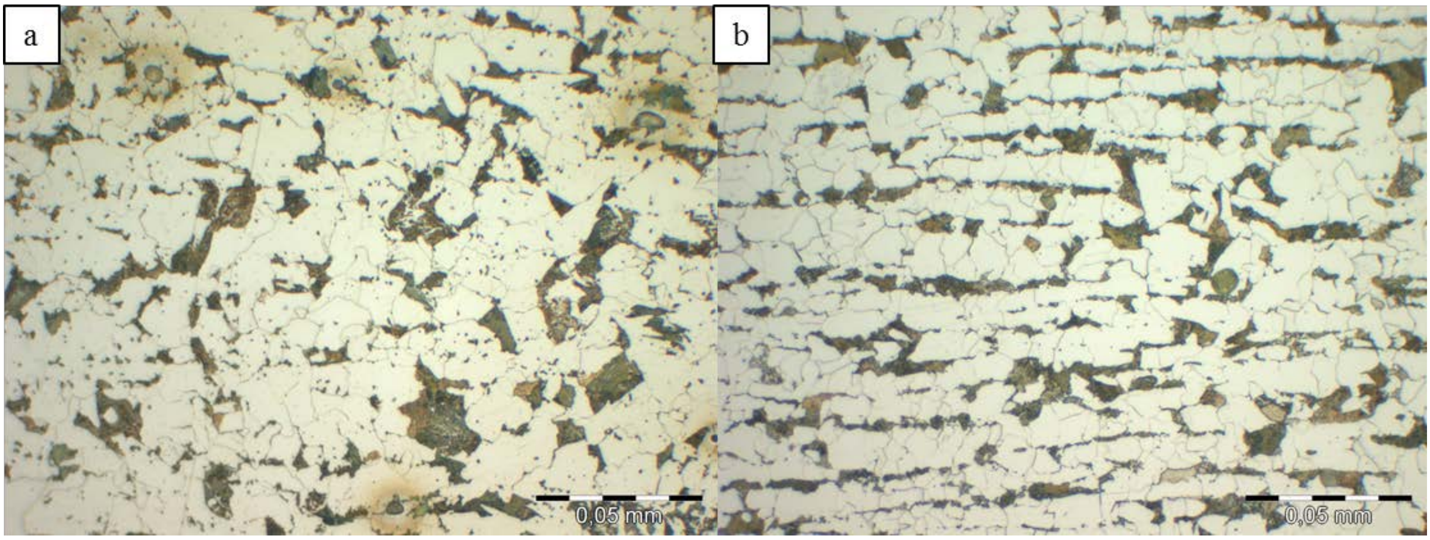

Figure 10 Microstructure images from a: Left side (V-profile) and b: Right side (H-profile), showing ferrite and perlite. Specimens etched in Nital.

Table 1 Chemical composition for steel profile on right side (H) obtained by mass spectrometry*.

C* %	**Si*** %	**Mn*** %	**P*** %	**S*** %	**Cr*** %	**Ni*** %
0.168 ± 0.005	0.185 ± 0.003	1.10 ± 0.012	0.015 ± 0.001	0.012 ± 0.001	0.024	0.025 ± 0.001
Mo* %	**Al*** %	**Cu** %	**Co** %	**Ti** %	**Nb** %	**V** %
< 0.001	0.046 ± 0.003	0.014	< 0.001	0.001	0.029 ± 0.002	0.002
W %	**Pb** %	**B** %	**Sn** %	**As** %	**N** %	**Fe** %
0.007 ± 0.002	< 0.001	0.0002 ± 0.0001	0.004	0.005 ± 0.003	0.007 ± 0.001	98.2 ± 0.017

* TI report 63406-24-022205.

Table 2 Chemical composition for steel profile on left side (V) obtained by mass spectrometry*.

C* %	**Si*** %	**Mn*** %	**P*** %	**S*** %	**Cr*** %	**Ni*** %
0.174 ± 0.005	0.187 ± 0.002	1.10 ± 0.010	0.018	0.013 ± 0.001	0.025 ± 0.001	0.027 ± 0.002
Mo* %	**Al*** %	**Cu** %	**Co** %	**Ti** %	**Nb** %	**V** %
< 0.001	0.046 ± 0.002	0.015	< 0.001	0.001	0.030 ± 0.002	0.002
W %	**Pb** %	**B** %	**Sn** %	**As** %	**N** %	**Fe** %
0.005 ± 0.003	< 0.001	0.0003 ± 0.0002	0.004	0.006 ± 0.003	0.008 ± 0.001	98.1 ± 0.017

* TI report 63406-24-022205.

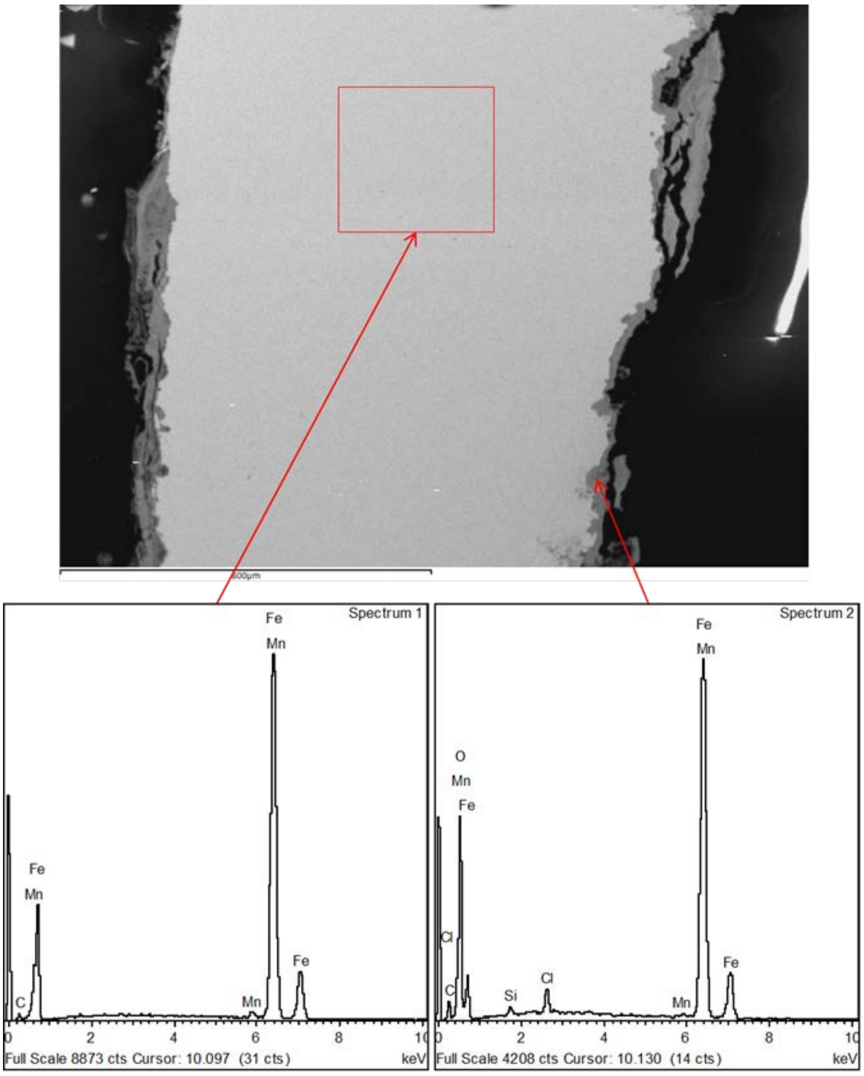

Figure 11 SEM image of a cross section through profile on right side (H). The image shows corrosion on both sides of the profile. The attached EDS spectrums identify a manganese steel base material and corrosion products containing chlorine (Cl).

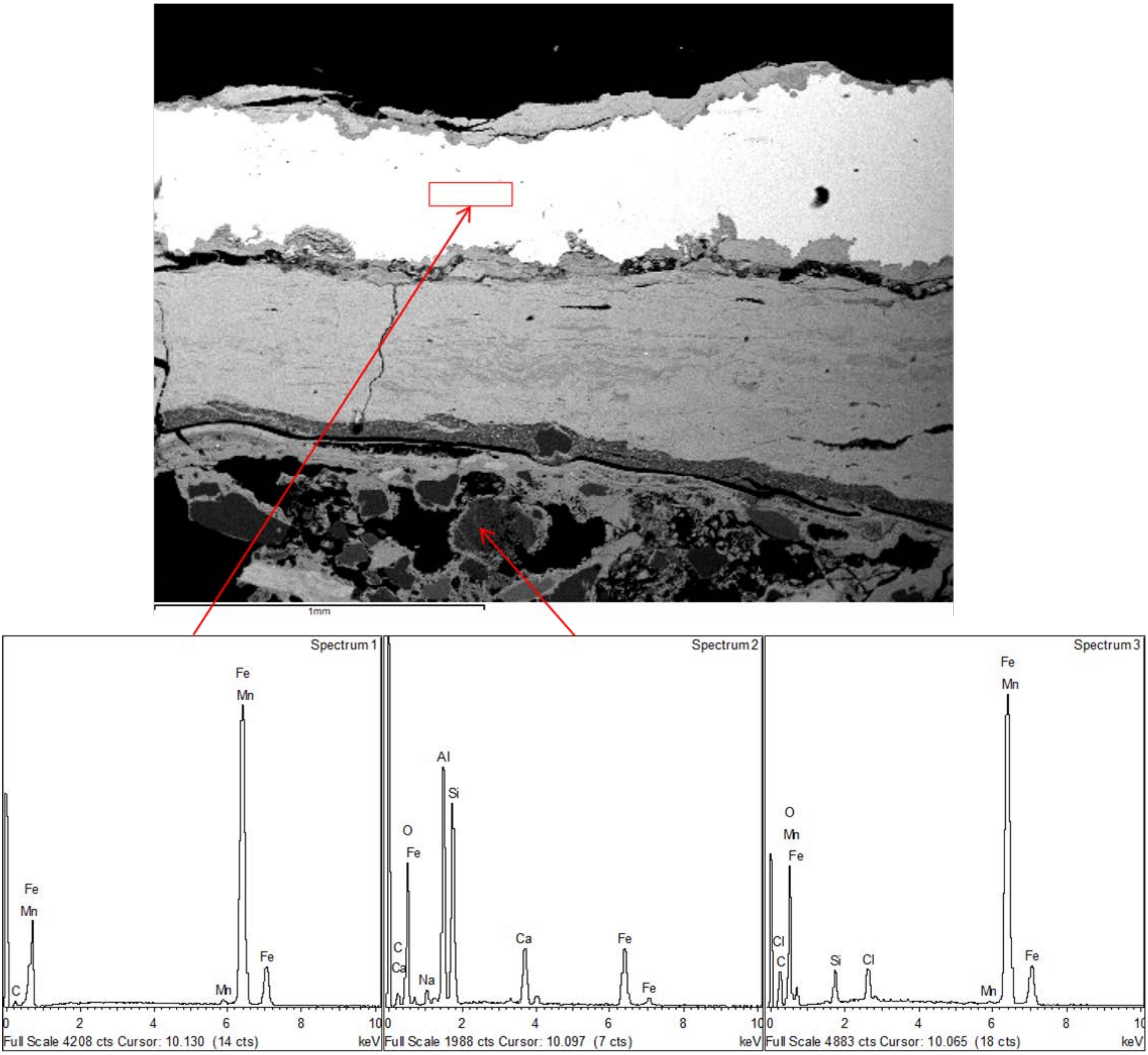

Figure 12 SEM image of a cross section through profile on left side (V). The image shows corrosion on both sides of the profile. The attached EDS spectrums identify a manganese steel base material and corrosion products containing mineral particles (sand) and chlorine (Cl).

2.2.2 Fractography

The fracture surfaces were studied in stereo light microscope to reveal areas with possible overload.

A summary of the observations are illustrated in Figure 13 and Figure 14 for the left (V) and right (H) profile respectively. In general for the bottom part of the profiles no steel base material could be observed and the material were completely corrode in the whole through thickness. The fracture surfaces observed appeared to be old with contact damages and corrosion. The investigation revealed however a small part at the upper right area on the right (H) profile, see Figure 14d, that showed signs of overload.

This area was cut out for further analysis in SEM.

The fractography images in SEM shown in Figure 15a-d reveals a dimpled surface consistent with ductile overload. Consequently, the area failed due to overload and was intact prior to the accident.

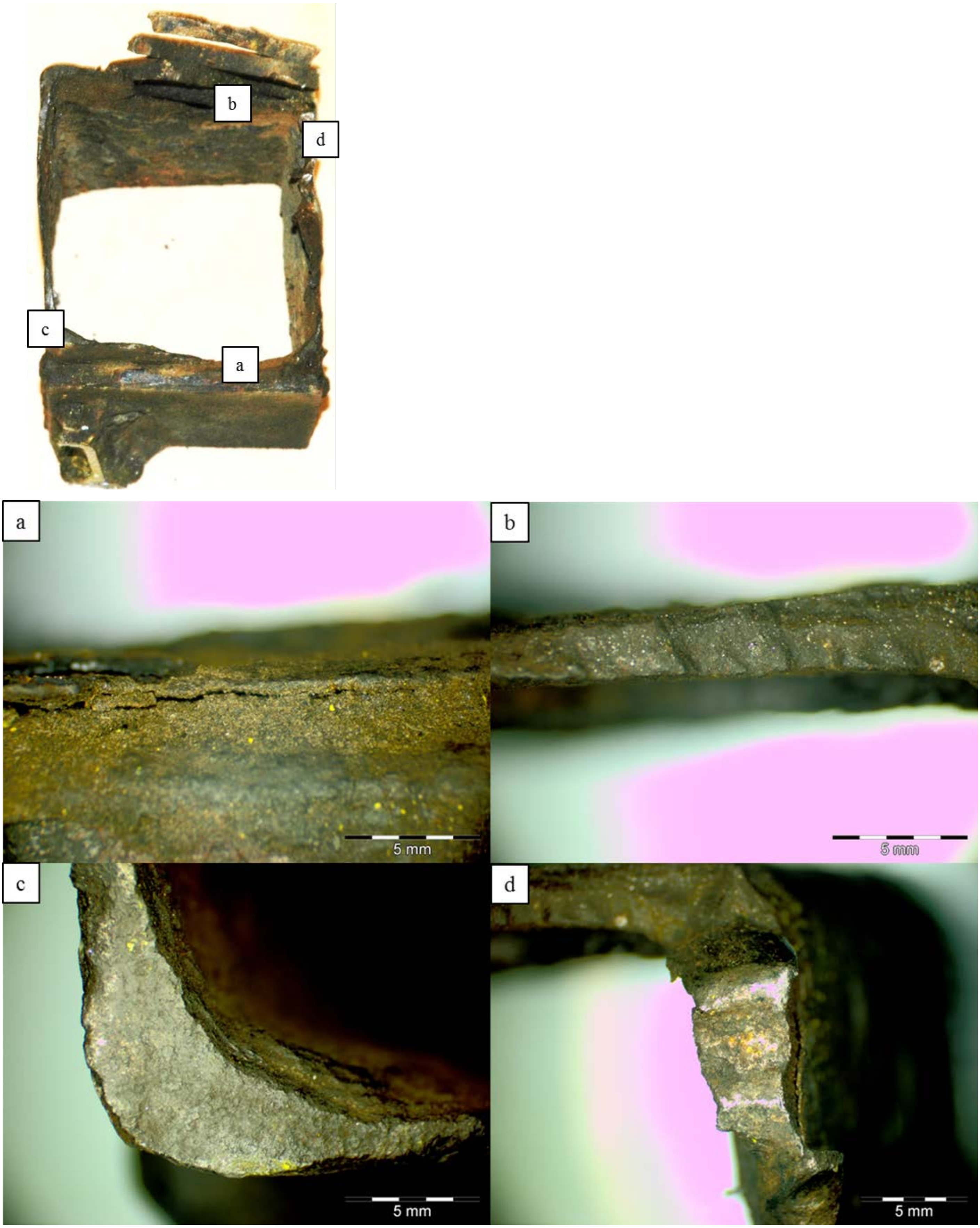

Figure 13 Overview image of failure at left side (V) identifying the location for the images obtained in stereo light microscope a-d.

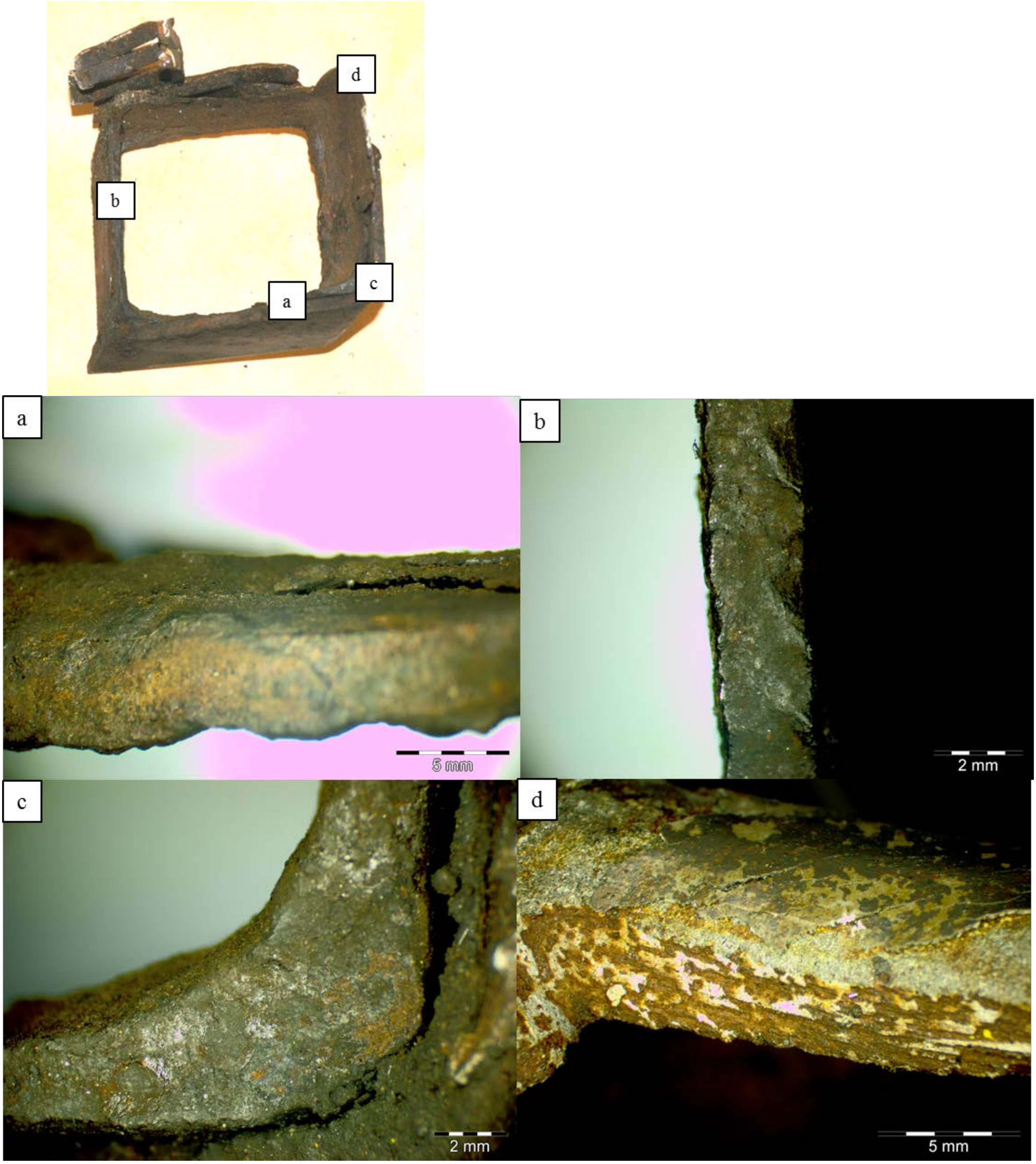

Figure 14 Overview image of failure at right side (H) identifying the location for the images obtained in stereo light microscope a-d.

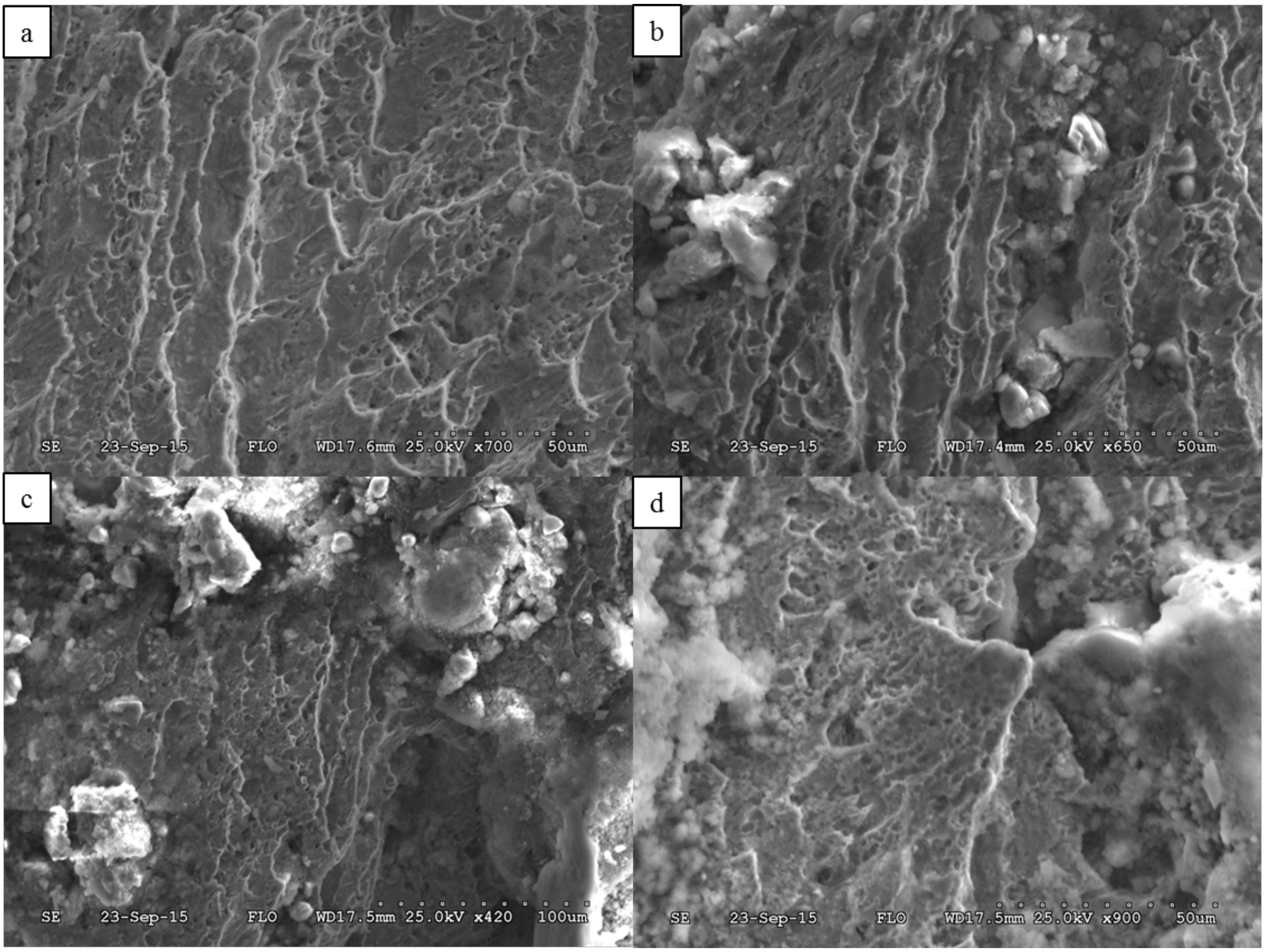

Figure 15a-d: Fractography images in SEM of the area shown in Figure 14d. The images show a dimpled fracture surface and initiation of corrosion occurred post failure.

2.3 Failure analysis of wire mesh

As shown in the overview images in Figure 1 and Figure 4 the trailer tongue had a wire mesh welded to the structure. Based on the appearance of the steel profiles it was decided to make a further analysis of the strength contribution from the wire mesh.

When holding the wire mesh up against the trailer tongue end brace, a good correlation between residual wires and spot welds were obtained, Figure 16. A total of about 20 spot welds where observed across the trailer tongue end brace.

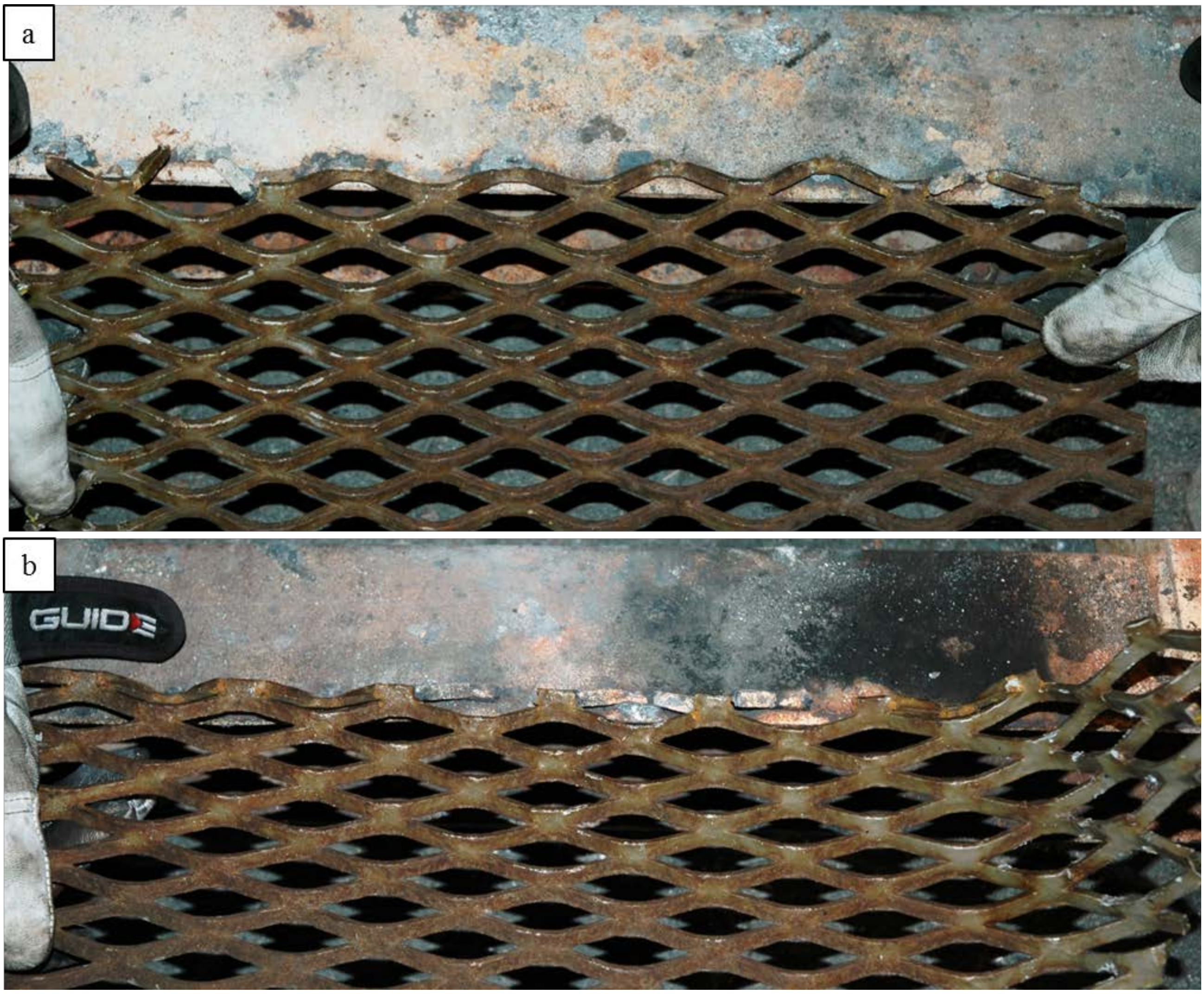

Figure 16ab images of wire mesh held up against the trailer tongue end brace.

The wire mesh fracture surfaces showed typical evidence of overloading with area reduction and shear lips at the failures adjacent to the spot welds, see Figure 17ab.
A filed spot weld was investigated further in SEM and overload was confirmed based on a dimpled fracture surface as shown in Figure 18ab.

Figure 17 Image of a: failed wire in wire mesh and b: failed spot weld.

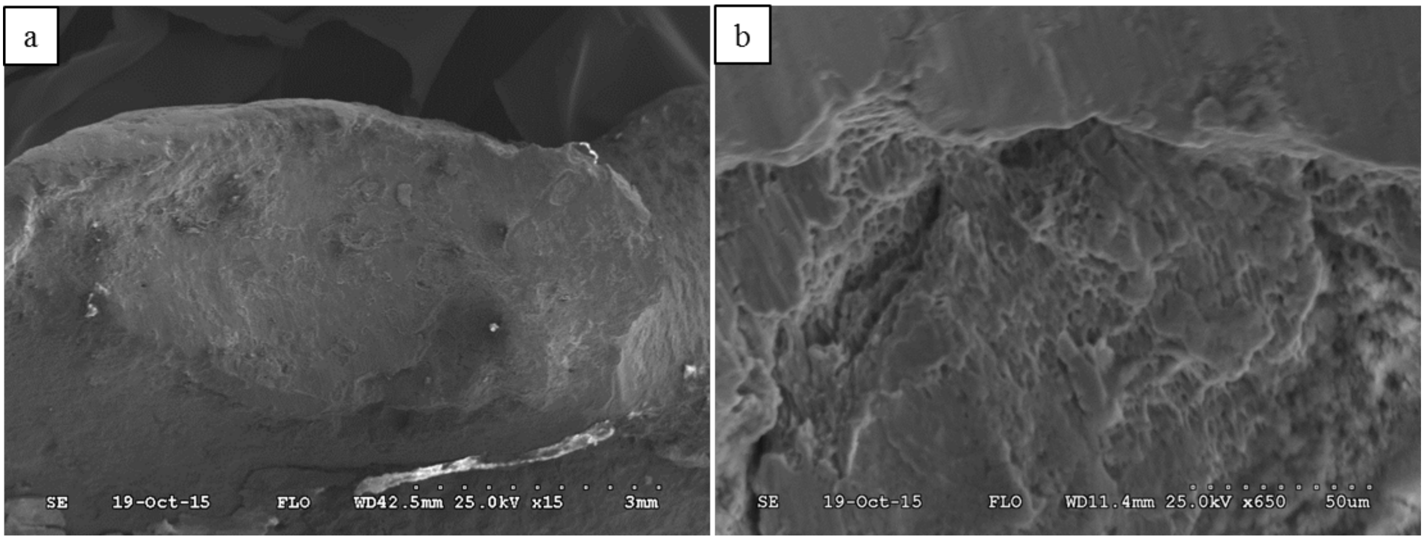

Figure 18a Image in SEM of failed spot weld. b: SEM images showing dimpled fracture surface consistent with overload.

In order to obtain an impression of the wire mesh strength a metallographic cross section through a spot weld was made, see Figure 19a. The micro structure consisted of a hardened structure at the spot weld and ferrite and perlite within the wire see Figure 19bc respectively.
The micro structure observations were confirmed by micro hardness measurements showing a hardness of 200 $HV_{1,0}$ at the weld and 150 $HV_{1,0}$ within the wire.

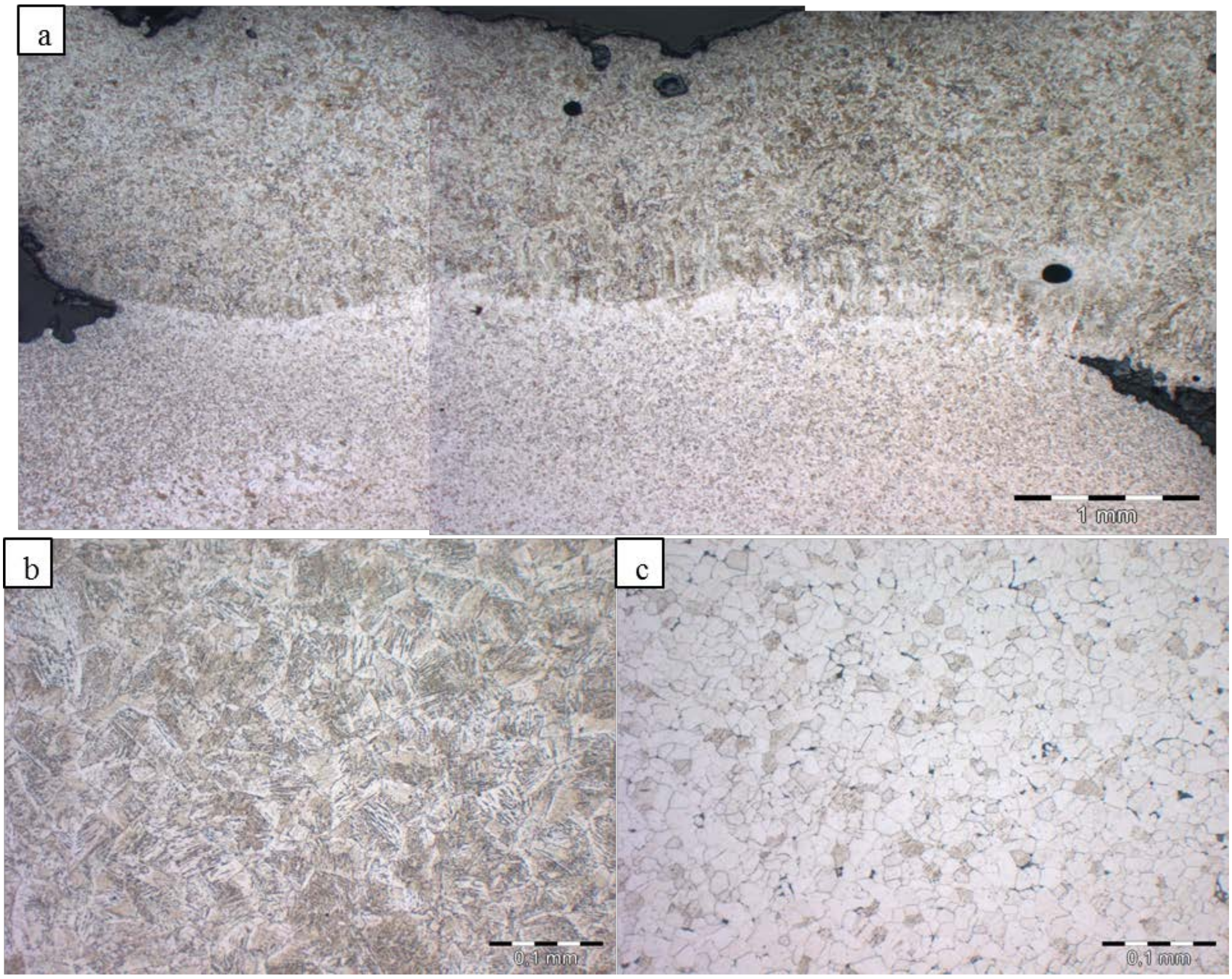

Figure 19 Microstructure images as observed in light microscope of spot weld cross section a: Overview image, b: hardened microstructure at spot weld, c: ferrite perlite structure within wire. Specimen etched in Nital.

In order to measure the actual strength of the wire mesh a test specimen was cut out in order to test a single weld point. Overview images of the test sequence are shown in Figure 20a-d.
The wire mesh failed at the wires adjacent to the weld point confirming the microstructure observations. The load at failure was measured to 500 kg.

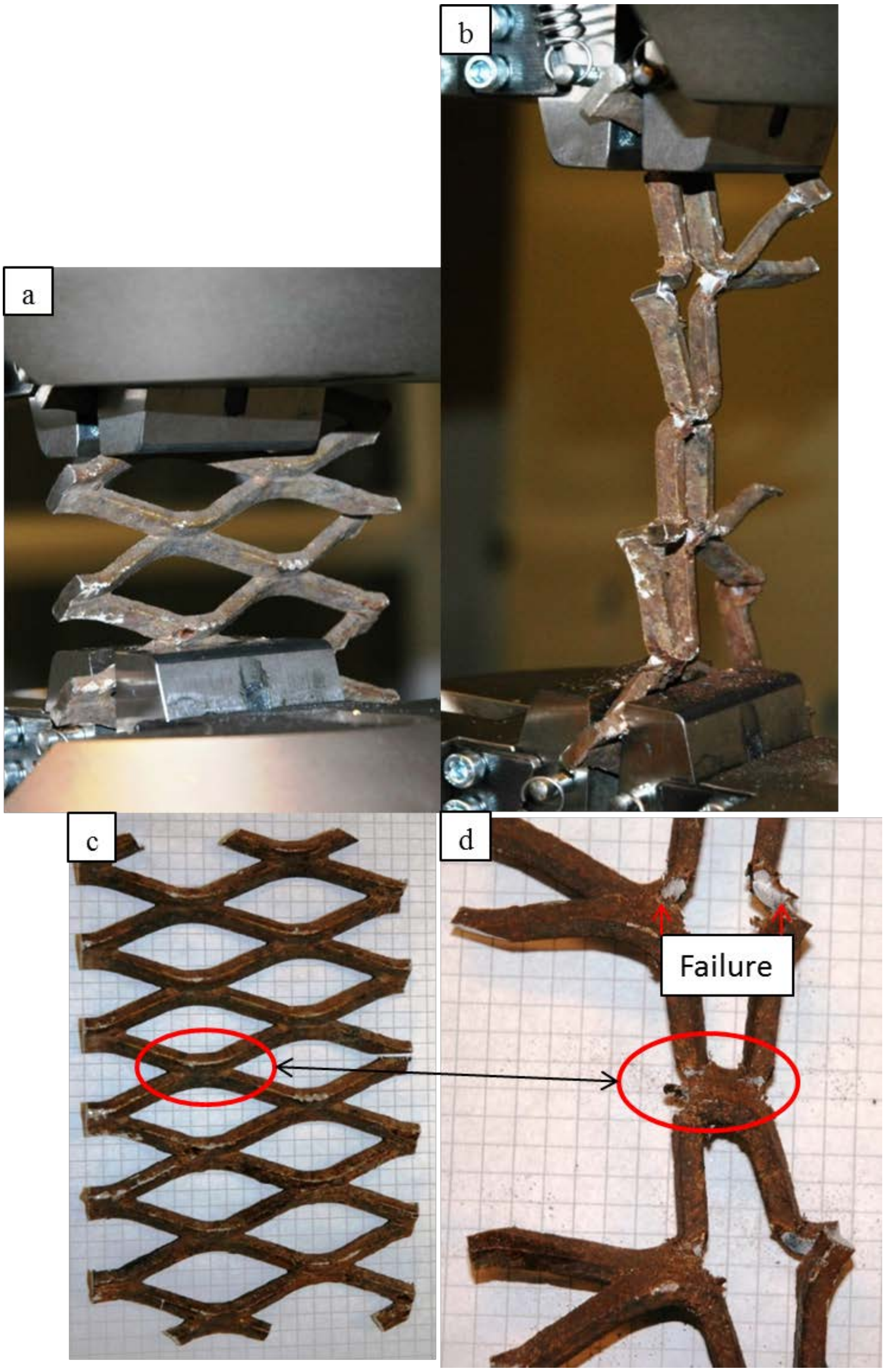

Figure 20a: Image of wire mesh specimen mounted in tensile testing machine. b: Image of wire mesh specimen mounted in tensile testing machine after testing. c: Overview image of wire mesh sample identifying the single weld tested. d: Image of wire mesh sample after testing with identification of the location for final fracture.

3 Conclusion

The failure of the investigated trailer tongue is due to excessive corrosion that has removed large parts of the steel profile material.

Fractography could only confirm overload damages in one corner of the right profile and it seems likely that most of the failure occurred prior to the accident due to corrosion and/or corrosion fatigue.

The corrosion damages on the inside of the steel profiles are most likely due to exposure to moisture containing chlorine entering the profile inside from the spacing at the tongue insert. The corrosion seems to have been accelerated due to the steel plates welded to the bottom part of the profiles thus resulting in crevice corrosion.

The observed sand particles observed within the corrosion products between the added steel plates and the original profile wall indicates lack of corrosion removal prior to the welding.

Weld defects such as lack of fusion and undercut are observed, but has in our opinion not contributed to the development of the failure.

Attempts were made to retrieve samples in order to perform standard tensile testing of the steel profile base material, due to corrosion through the whole wall thickness this was not possible, and the plate thickness was measured to vary from 0-2,9 mm.

As the plates welded to the steel profiles were not welded to the trailer tongue end brace no forces were collected through the steel plates, in our opinion the stiffening of a corroded area as observed in this case will contribute to a higher susceptibility to corrosion fatigue. This point can be confirmed by stress analysis.

The trailer tongue has most likely been supported by the wire mesh welded on top of the steel profiles and on to the end brace. Based on tensile testing the spot welds could have resisted loadings up to 10 tons, but the strength will however vary largely by the direction of the load.

If strength calculations for the corroded trailer tongue are to be performed the strength contribution from the spot welded wire mesh must be taken into account.

REPORT

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Investigation into the origin of the fire in the Skatestraum Tunnel on July 15, 2015 – part 1

SP Fire Research was commissioned by the Accident Investigation Board Norway (AIBN)[1] to investigate the origin of the fire that occurred in the Skatestraum Tunnel on July 15, 2015.

The background to and description of the incident is given in the report produced by the AIBN that this text is an appendix to. An analysis of the spread of the fire is given in a separate SP Report – Part 2 [1].

Initial course of events

A trailer containing 16,500 litres of petrol became detached from the truck that was pulling it and, as it collided with the tunnel wall approximately 460 m from the low point of the tunnel, at the level of the pumping station, one or more holes or slits were created in the forward tank section (compartment). There is no possible way to determine exactly how large the holes/slits became, but it is possible to come to an approximation by estimating the flow of the petrol on the surface of the road downstream of the tank and towards the pumping station at the bottom of the tunnel. The amount of petrol that flowed onto the surface of the road in the initial stages of the spill is important with regard to analysing the ignition process.

By analysing witness statements relating to the ignition itself, immediately prior to and after, a probable cause of the fire can be determined. Multiple hypotheses or possibilities for ignition are presented and evaluated in this report.

Facts regarding the trailer

When the truck lost contact with the trailer, the trailer's brakes were automatically activated. This resulted in the trailer beginning to slow down before it hit the tunnel wall; however, this braking was not sufficient to prevent a collision. According to the AIBN, the velocity of the truck was approximately 45 km/h at the moment of the incident. The position of the front wheels of the trailer show that they in all probability must have come into contact with the edge of the pavement before the trailer collided with the tunnel wall. With what force and orientation the trailer impacted the tunnel wall may be of significance with regard to the origin of the fire.

According to information received by the AIBN, there is no battery-powered backup in the type of trailer involved (see Figure 1). This means that all conceivable sources of electrical

[1] Assignment reference 15/546.

current were disconnected when the contact with the truck was lost.

The trailer was divided into six compartments, each of which held varying amounts of petrol; Figure 1 details how the petrol was distributed (see the printed values at the top of the tank). The compartment closest to the point of collision contained 4,500 litres. The tank itself consisted of 5 to 6 mm-thick aluminium sheets [2], which were mounted on a steel beam system that held the tank in place.

Figure 1: A photograph of a trailer of the same type as that involved in the incident.

In Figure 2, it is possible to see that the trailer's front-right wheel is located relatively close to the tunnel wall. The fact that the trailer appears not to have moved following the collision indicates that the automatic brakes activated. A comparison of Figures 1 and 2 shows that the right corner of the trailer must have been severely caved in, as the front-right wheel is turned and close to the tunnel wall. It can thus be assumed that large amounts of petrol were flowing out at the moment of collision. How much petrol flowed onto the surface of the road in the initial outflow is difficult to ascertain, but in Part 2 [1] of this report an average flow of 1000-1200 litres per minute (17-20 l/s) is estimated. As the outflow was a dynamic process (greater at the beginning and decreasing over time), it is difficult to estimate with any degree of precision how long it took for the first compartment to be emptied. Additionally, it is not certain that the compartment was entirely emptied in the initial outflow. It was, however, established that the large outflow of petrol onto the pavement coalesced over time into a 0.4-0.7 m-wide streak of petrol that flowed onto the surface of the road and then down, along the edge of the pavement, due to the transverse slope of the tunnel. It is this streak of petrol on the road surface that witnesses describe seeing on the surface of the road leading up from the pumping station to the trailer. A drainage system was intended to ensure that any spillage that ran along the edge of the pavement was collected in surface water drains with openings of the type shown in Figure 3 (the openings face the road surface). These surface water drains are placed every 80 m along the Skatestraum tunnel. How much petrol ran into them, however, is difficult to ascertain, and is discussed in more detail in Part 2 [1].

Figure 2: The position of the trailer after the fire. Note that the front wheels are directed towards, and in close proximity to, the wall.

Ignition of petrol vapours

As the petrol began to flow out of the trailer, petrol vapours immediately began to form and rapidly mix with the surrounding air. The density of pure petrol vapour is roughly four times that of air, meaning that they spread close to the surface of the road, both radially and down-slope due to the pull of gravity (the tunnel inclines 10% in the direction of traffic). It has been concluded that the air flow in the tunnel was not particularly high at the moment of the incident, meaning that the vapours were not diluted or transported away to any great extent.

Petrol vapours can be ignited in several different ways. These include spontaneous ignition above hot surfaces, static electricity, and sparks created by friction between hard materials. The lower and upper flammability (explosive) limits for petrol vapours in air are 1.7% (lean mixture) and 7.6% (rich mixture), respectively, at ambient temperatures. Petrol has a low flashpoint (>40°C), meaning that it is a highly volatile liquid at ambient temperatures. The temperature in the tunnel at the moment of the incident was estimated as being between 10 and 15°C. Thus, it is likely that the petrol vapours were relatively concentrated in the vicinity of the trailer when the ignition occurred.

It is, from a practical perspective, difficult to ignite petrol vapours using a hot surface and, if this occurs, the surface temperature must be relatively high. For spontaneous ignition of petrol vapours to occur in this way, a surface temperature of 760°C with zero air flow is required. Higher air flows require a higher surface temperature [3].

Figure 3: A surface water drain with an opening of 60 by 5 cm that faces the road surface. The black streak (roughly 0.7 m wide in Figure 3) on the road surface is where the greatest portion of the petrol flowed and was ignited (hence the marks). This surface water drain was 187 m down-slope from the trailer.

It is well-established that the energy levels required to ignite flammable petrol vapours are very low. The lowest energy that is necessary for ignition is roughly 0.2 mJ, and the highest to make entirely sure that it occurs is around 10 mJ [4]. This naturally varies with the concentration of the gas (which is lowest in stoichiometric conditions and highest near to the flammable limits). If liquid petrol flows over a hot surface, the corresponding surface temperature requirements for spontaneous ignition are roughly similar to those for igniting pure petrol vapours [3].

A spark may be considered to be a discharge between two objects of differing electric potential. Static electricity can be created by, for example, liquid flowing through a non-conductive (e.g. plastic) pipe or hose, a free-falling stream of liquid, or a person walking across a floor, leaving a chair, removing clothing, handling plastic objects, or standing next to electrically charged objects. Static electricity can also be created through induction (wire). In order to avoid creating static electricity, some form of earthing/equipotential bonding is required [5, 6]. The energy of a spark depends on which materials are involved in its creation, the difference in electrical potential energy, and how the energy is discharged. Energy levels during a static electricity discharge may range between 0.01 and 10 mJ [5], which entirely encompass the range of values that are required to ignite flammable petrol vapours. It is, for example, well-established that a fire can occur during an ordinary fuelling process at a petrol station due to the formation of sparks; when a person fills their tank, they are earthed by the handle of the petrol pump, but they become unearthed when they let go. As they are likely wearing isolating shoes and thus unable to gradually discharge the accumulated static electricity, they may abruptly discharge this energy, in the form of a spark, when they touch the pump handle again. In a particularly unfortunate series of events, this spark starts a fire in the petrol vapours that flow out of the filler pipe of the tank.

Witness statements

When the driver stopped the truck (Vehicle A) and stepped out of it, he saw that the trailer had become detached from the truck and collided with the tunnel wall. When he looked down-slope, towards the trailer, he discovered that petrol was flowing out from the front-right of the trailer (i.e. the forward tank compartment) in the direction of travel. Roughly two minutes after the driver discovered that the trailer had come loose, he heard a bang and saw that a fire had started at the back of the trailer. He let go of the phone that he was using to call the emergency services and ran to the truck to drive it out of the tunnel, as the smoke was moving in his direction.

Four vehicles followed the truck and trailer up the slope. The driver of the first, which was a car (Vehicle B), was a witness to the incident. He stopped roughly 10 m down-slope from the trailer that had collided with the tunnel wall. He saw that petrol had begun to flow towards his vehicle, noted that there was “smoke” between the trailer and the tunnel wall, and became stressed and began to reverse towards the pumping station with his hazard warning lights on to warn others. He stated that the petrol flowed “a great deal” and at the same pace as his vehicle was reversing. This witness did not mention anything about passing a fire on his way down to the pumping station, but stated that he met a car (Vehicle C) containing a driver, their mother-in-law, and two children, and that he alerted them of the danger. Vehicle C also began to reverse; the driver turned on the car’s hazard warning lights and sounded the horn to warn others. When both vehicles had reversed almost to the bottom of the slope and were about to turn around, their occupants noted that other vehicles were passing without reducing their speed to any great extent (they saw brake lights, however, which indicated that these vehicles had slowed down).

These vehicles are interesting with regard to what occurred during the ignition. One (Vehicle D) stopped at the top of the slope, 150 m from the trailer, as they had suffered a puncture. According to the driver of Vehicle D, they began braking when they sensed that something was amiss. They could not see what was burning, but observed a wall of yellow flames higher up (this section of the tunnel is fairly winding). One of the passengers of Vehicle D exited it via a door on the right, and in so doing stepped into a “river” of flowing petrol as she left the area. She smelled petrol, and both she and the driver ran down the tunnel. The other vehicle was a 2002 Peugeot Boxer HDI campervan (Vehicle E), shown in Figure 4, which drove all the way up to the trailer.

Shortly after Vehicles D and E passed the pumping station, the witness in Vehicle B heard a bang. He saw an intense “flash of light”, but could not see the trailer (due to the winding tunnel). The witness described the bang as being sharp and distinct. The witness in Vehicle C, which was at the bottom of the slope in the turning space, also stated that he heard a bang and that the car shook. The witness inspected his car afterwards and smelled petrol.

There are two witness statements from the passengers in the campervan (Vehicle E). The witness who was in the passenger seat described how they met two vehicles that were reversing with their hazard warning lights on and sounding their horns. They were about to begin driving up from the bottom of the tunnel when the witness noticed that something was flowing on the surface of the road, which they thought was water. They drove past a car (Vehicle D) that was parked in the road. A short while later, they saw the trailer that had collided with the tunnel wall. They considered whether they would be able to pass it, which appeared to be possible at the time. The witness did not have time to consider further, however, as there was a bang and flames sprang up around the campervan. The witness stated that they were roughly 5-10 m from the trailer when the bang occurred, that the bonnet of the campervan was slightly displaced, and that its headlights were loosened in their housing. The driver managed to put the campervan in reverse and immediately began to reverse down-slope. They stated that the liquid that they had observed acted in the manner of a wick as the fire spread. When the witness was asked if they could see any flames when they arrived they said no, but that the interval between the moment they saw the trailer and the explosion was a matter of seconds.

The statement of the other witness – the driver – consists of a similar description of the journey up to the trailer. They saw a vehicle parked on the road near to the trailer, and liquid running along the edge of the pavement at the right side of the tunnel. When they reached the trailer, they considered attempting to pass it. When they saw the trailer, they noted that a “river” of liquid was flowing down from the trailer and towards the right side of the road. They did not notice any fire at that time. The driver estimated that he was roughly 20 m from the trailer when he put the car in reverse and began to back up, and that it was at that moment that the trailer began to burn. The fire spread towards the edge of the pavement and onto the road surface between the campervan and the edge of the pavement. . The fire spread quickly past the campervan, and the driver attempted to reverse fast enough to keep the flames in front of the vehicle. When the vehicle was halfway between the trailer and the bottom of the tunnel, an explosion occurred.

The witness states that the bonnet of the car was displaced, and that its headlights fell out of their housing. They did not notice any more explosions. The witness described damage to the engine compartment of the campervan that they considered to be of a potentially severe nature.

Possible hypotheses

There are many possible explanations for why the fire started. It is likely that petrol poured out of the trailer for over two and a half minutes before it was ignited. The most probable ignition sources are sparks and hot surfaces. Table 1 presents a list of the possible sources of ignition, analysing how likely to have caused ignition each was.

Table 1: Analysis of hypotheses as to the possible causes of the fire.

Possible cause	Mechanism	Analysis	Probability to have caused ignition
Sparks caused by the collision.	When the trailer collided with the tunnel wall, sparks of sufficiently high energy to ignite the petrol vapours may have been formed.	At least two and a half minutes elapsed before a fire was observed. The area between the trailer and the tunnel wall was cooled by leaking petrol.	Non-existent
An electrical source in the trailer.	An amount of electrical current remained in the trailer after it disconnected from the truck.	There was no battery-powered backup in the trailer, and thus the electrical supply disappeared when the trailer became detached. In addition, the fire started a relatively long time after the collision occurred.	Non-existent
Electrical equipment in the tunnel.	Electrical equipment was present in the tunnel ceiling, e.g. lighting. The formation of sparks may have caused a fire.	The electrical engineering equipment used in tunnels has a high IP rating. The equipment used in the Skatestraum Tunnel was rated to IP 66. In addition, petrol vapours do not rise, and so did not move towards fixed electrical installations in the ceiling, but remained at the level of the surface of the road.	Non-existent

Possible cause	Mechanism	Analysis	Probability to have caused ignition
Sparks were formed by the scraping of the trailer against the tunnel wall.	When the petrol flowed around and under the tires these became slippery, and thus the trailer began to move due to the inclination, scraping against the wall and forming sparks that later ignited the petrol.	There is no evidence that the trailer moved after the collision. The distance and velocity required for sparks to form are likely quite extensive.	Non-existent
Sparks were created by static electricity when the petrol flowed out from the tank and onto the surface of the road.	It is well-known that free-falling streams of liquid, given a sufficient fall height, can generate static electricity.	The tank was made of aluminium and thus conductive; additionally, any contact with the tunnel wall will have earthed the system. The petrol in the trailer likely contained a conductive additive, and so its flowing onto the ground will have meant that the road surface became linked to the 'electrical system' of the tanker truck. Thus, the entire system became equipotentially bonded, preventing the possibility of a discharge.	Non-existent

Possible cause	Mechanism	Analysis	Probability to have caused ignition
Hot surfaces, such as brake discs, on the trailer.	It is well-established that hot surfaces can start fires through spontaneous ignition.	The temperature of the brake discs were likely not 760°C when the leak occurred. If this had been the case, the fire would have started immediately. It is difficult to conceive of other, sufficiently hot, parts on the trailer that may have caused the ignition.	Low
The driver of Vehicle B saw “smoke” between the trailer and the tunnel wall.	He was 10 m from the trailer when petrol began to flow, and states that he saw “smoke”.	It has, however, been established that the fire did not start while Vehicle B was in the vicinity, which means that the witness cannot have seen fire smoke; there is no ‘middle way’ with open petrol fires, and they are either non-existent, or extremely obvious. It is most likely that what the witness saw was something along the lines of some kind of condensation of the petrol vapours.	Non-existent

Possible cause	Mechanism	Analysis	Probability to have caused ignition
The fire was ignited by a vehicle.	When Vehicle E was 5-20 m down-slope from the trailer, something suddenly happened, according to both of the witnesses in the vehicle. Prior to this, there was no fire. One witness stated that they heard a bang and that the bonnet of the car was displaced, and that flames then appeared in front of and beside the vehicle.	Vehicle E drove towards the trailer, and became surrounded by petrol vapours that were sucked into the engine compartment. These were most likely ignited somewhere within the vehicle, likely in the engine compartment or directly beneath it, causing the bonnet of the car to be displaced. Such a bang may be experienced as distinct and sharp.	High

The probable cause of the fire

Based on the summary provided in Table 1, there are very few plausible explanations for why the fire started, the exception being the last one presented. Consequently, that hypothesis will be expanded upon here.

As the petrol began to flow out of the trailer, petrol vapours began to flow down-slope due to gravity. The velocity at which this took place or how concentrated the vapours were are as-yet unknown. Any air flow in the tunnel, however small, will have diluted the vapours and slowed the speed at which they flowed down-slope. The liquid petrol flowed down-slope (gravitational flow) at roughly 2-3 m/s (2). The vapours were apparently not sufficiently concentrated at the location of Vehicle D, which was 150 m down-slope from the trailer, to start the fire, even though its right side was entirely surrounded by flowing petrol.

When Vehicle E approached the trailer it drove through the petrol vapours, which were sucked into the engine compartment. When it stopped, roughly 5-20 m from the trailer, an explosion occurred, displacing the bonnet of the car. Simultaneously, witnesses observed flames in front of and beside the vehicle. It is highly probable that Vehicle E ignited the fire due to an accumulation of a mixture of flammable gases and air in its engine compartment. The former likely entered the engine compartment due to a combination of air resistance in the tunnel and the vehicle's cooling fan. When the vehicle slowed down and stopped, the concentration of the gas mixture in the engine compartment became within the ideal range for rapid combustion (1.7-7.6%). The rapid expansion of the gas mixture pushed the bonnet of the car upwards while itself simultaneously expanding downwards, such that the flame front ignited the petrol on the surface of the road.

[2] Calculations performed using the classic Manning formula yield 2.6 m/s (9 km/h) for a 10% inclination – see Part 2 [1]

There were a number of components in the vehicle's diesel engine compartment that were capable of igniting the mixture of gases that was created; sparks can be formed by, for example, electrical devices such as the carbon brushes of generators or motors with a DC commutator, which may consist of fan or pump motors. The vehicle's engine compartment also contained hot surfaces; a catalytic converter, a turbocharger, and particulate filter, all of which, among other objects in the engine compartment, can reach temperatures exceeding 700°C. Which of these components is most likely to have caused the ignition cannot be determined without conducting a more extensive investigation and accompanying tests.

Another hypothesis is that the combustion engine of the vehicle may have received a richer than usual fuel mixture, as its normal supply of diesel was supplemented with petrol vapours from the air intake, which may have caused combustion to take place in such a way that uncombusted hydrocarbons were ignited in the exhaust system, which then 'shot' out flames.

However, the most likely explanation is the former, i.e. that a mixture of gases accumulated in the engine compartment and was ignited, creating an excess of pressure that displaced the bonnet of the car and started the fire. Whether the fire started due to electrical ignition/a hot surface or the exhaust system backfiring may be possible to investigate, provided photographs of the engine compartment are available.

The witness in Vehicle E described damage to the engine compartment of the campervan that they considered to be of a potentially severe nature, which would support the former hypothesis. The second explosion that the witnesses reported took place when Vehicle E reversed down the slope with the flame front directly in front of it, halfway between the top of the slope and the pumping station, and was caused by the ignition of flammable gases in the surface water drainage system. This explosion was unrelated to Vehicle E; in all probability, the flammable gases in the surface water drainage system were ignited by the flame front. Vehicle E and its passengers escaped as a result of their quick reaction to the danger.

In Figure 4 it is possible to see the displaced bonnet of the car and how the radiation flux affected the side of the vehicle.

Example of a similar sequence of events leading to an ignition

Several other incidents have involved a vehicle entering a cloud of petrol vapours and, in doing so, igniting the gas mixture. As is discussed above, a vehicle with a combustion engine presents many possible ignition sources in such a situation. Below is a sequence of video stills from an incident in which a tanker truck was in the process of filling up two petrol storage tanks at a petrol station. The sequence consists of a number of screenshots from a video [7]. For an unknown reason, the petrol vapour recovery system did not work and the petrol vapours spread radially to cover most of the area around the pumps.

Thanks to a surveillance camera, it is possible to watch a vehicle drive into the vapour cloud, which is ignited (Figures 5 and 6). It is clear from the screenshots that the cloud is not particularly thick – perhaps a few decimetres – due to the difference in density between air and petrol vapour. Figure 8 shows the large area covered by the petrol vapour cloud, and how quickly the fire spread. The fire was eventually extinguished, and its sources traced to the openings of the two petrol storage tanks.

Figure 4: Vehicle E, which was closest to the trailer when the fire started. It can be seen clearly that the bonnet was slightly displaced, and how the radiation flux affected the side of the vehicle that was exposed to the flames.

Figure 5: Screenshots from a surveillance camera video at a petrol station, at which a tanker truck was filling up petrol storage tanks. Hoses are connected to two tanks. At the extreme bottom-right in both screenshots a vehicle can be seen arriving; by comparing its location relative to the lines of the parking space it is possible to see how the vehicle has moved between the two screenshots.

Figure 6: The left screenshot shows the petrol cloud being ignited and spreading both radially and towards one of the storage tank filling points, where it becomes an open flame.

Figure 7: The flame pulls back from the vehicle and moves on to the next storage tank filling point.

Figure 8: The radial spreading of the fire, through the petrol vapour cloud and towards the next storage tank filling point, is clearly visible.

Conclusions

The most probable cause of the ignition of the trailer in the Skatestraum Tunnel on July 15, 2015 is a vehicle ('Vehicle E' in the investigation), which entered and then ignited a flammable cloud consisting of a mixture of petrol vapours. Both witness statements and technical data support this explanation.

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References

1. Ingason, H. and Y.Z. Li, *Investigation into the development of the fire in the Skatestraum Tunnel on July 15, 2015 – Part 2*. 2016, SP Fire Research Project no. 6P03116.
2. Torstensson, H., *Säkerhetsbrister och skador vid tanktransport av farligt gods på väg, in P21-290199*. 1999, R&D report by the Swedish Rescue Services Agency.
3. *Ignition Risk of Hydrocarbon Liquids and Vapors by Hot Surfaces in the Open Air - API RECOMMENDED PRACTICE 2216*. 2003, American Petroleum Institute.
4. Clark, J.S., *Tändenergi*. 1960.
5. Egardt, E., *Statisk elektricitet och potentialutjämning*. The Swedish Civil Contingencies Agency (MSB).
6. Mulligan, J.C., *Handling Flammable Liquids, in Cepmagazine*. July 2003. https://www.youtube.com/watch?v=OSICMPvs220.

REPORT

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Investigation into the development of the fire in the Skatestraum Tunnel on July 15, 2015 – Part 2

SP Fire Research was commissioned by the Accident Investigation Board Norway (AIBN)[1] to investigate the development of the fire involving a tanker trailer in the Skatestraum Tunnel. The investigation focuses on the initial development of the fire and its consequences. The commission also includes laying the groundwork for the creation of an animated video of the initial development of the fire (<10 min).

The background to the incident and a description of it are given in the report produced by the AIBN that this text is an appendix to. The cause and sequence of events up until the moment that the fire started are not presented here, but in a separate SP Report – Part 1 [1].

Background to the commission

The AIBN commissioned SP Fire Research to undertake the following tasks:

1. Establish a timeline for the initial flowing of liquid and development of the fire.
2. Chart temperature and smoke development for the entire duration of the fire.
3. Calculate the heat release rate for the entire duration of the fire.
4. Describe the conditions throughout the tunnel in relation to the ability of its occupants to survive.
5. Evaluate the extent of the damage to the tunnel, relating this to the type and size of the fire.
6. Create a three-dimensional animated video of the initial development of the fire (<10 min).

In order to establish a timeline, an analysis of witness statements and technical data logged by the Norwegian Public Roads Administration (NPRA) has been undertaken. SP Fire Research was given access to photographs taken by the AIBN, an evaluation report written by the NPRA [2], witness statements from those involved in the accident, and technical information regarding the tunnel. Based on the data and simple one-dimensional models presented in [3], the heat release rate and temperature, gas, and smoke development were calculated as a function of time. In addition, radiation flux and flame length were calculated in order to evaluate the impact of the fire on the structure of the tunnel. Relatively simple calculations for temperature, gas, radiation flux, and smoke were performed solely to evaluate the situation up-

[1] Assignment reference 15/546.

slope from the fire. In order to assess the situation down-slope from the fire, a three-dimensional calculation was performed using the Fire Dynamics Simulator (FDS) software package [4]. These three-dimensional calculations also formed the basis for the animated video that depicts the initial development of the fire. Using these calculations it is possible to describe the conditions throughout the tunnel in relation to the ability of its occupants to survive.

The fire did not result in any fatalities, primarily due to fortunate circumstances and the quick and correct reactions of those involved. The causes of the extensive damage to the tunnel structure are only considered in relation to an assessment of the heat load that the structure was exposed to.

A timeline for the initial flowing of liquid and development of the fire

In order to be able to establish a timeline, the development of the fire was analysed and related to the positions of the various vehicles and what witnesses saw or experienced in connection with the incident. Focus was placed on the aftermath, particularly the flowing of petrol out of the tank and onto and along the surface of the road. In the following, events are analysed with reference to when they occurred, based on the witness statements and logged data that has been made available.

Table 1 presents a timeline based on estimated times for what occurred, and may have occurred; these were arrived at using logged and calculated points in time. The first column gives the exact time, and the second the calculated time in minutes and seconds (min:sec) after the point at which it is assumed that the fire started. A minus sign means that the event took place prior to the estimated ignition of the fire. The accuracy of the calculated times is related to a great extent to the accuracy with which the various speeds of vehicles, flowing of fuel, and spreading of flames were estimated. The designations (Vehicles A-E) are explained in the text.

The first witness was the driver of the tanker (Vehicle A). On its journey through the tunnel (undertaken at a speed of 45 km/h, according to the AIBN), the driver noticed that its speed increased without him further depressing the accelerator. He looked in the rear-view mirror and saw that the trailer had become detached from the truck, and had come to rest with its front-right corner against the tunnel wall down-slope. He stopped the truck and exited it to find that the trailer hitch had broken off. When he looked towards the trailer, he noted that a large amount of petrol was running from the forward tank section. The driver called the Traffic Control Centre (TCC) by going to emergency station BS03, requesting that they close the tunnel. He also warned vehicles that came towards him from the Hamnen portal (the east end of the tunnel) and instructed them to turn around. Roughly two minutes after the driver discovered that the trailer had become detached, he heard a bang and saw that a fire had started at the back end of the trailer. As the smoke spread towards him he decided to drive the truck out of the tunnel. The smoke from the fire increased, and the last part of his journey was undertaken through thick smoke. The driver parked a “good” distance from the tunnel portal, but later had to move the vehicle due to the high amount of smoke and heat. This information provides an idea of the situation at the Hamnen portal when Vehicle A left the tunnel, one and a half minutes after the start of the fire.

As the trailer, which contained 16,500 litres of petrol, impacted the tunnel wall approximately 460 m from the low point of the tunnel, at the level of the pumping station, one or more holes or slits were created in the forward tank section (compartment). There is no way of determining how large the holes/slits became, but it is possible to come to an approximation by estimating the flow of the petrol on the surface of the road downstream of the tank and towards the pumping station at the bottom of the tunnel.

According to the schematics provided in the report by the AIBN, the inclination of the tunnel across the direction of the traffic is 3.5%. The width of the flow of petrol that ran from the trailer to the pumping station varied between roughly 0.4 and 0.7 m. Figure 1 shows part of this flow. An average width for the flow of 0.5 m has been used in the calculations. By using equations for flows driven by gravity (the Manning formula) in an open channel, which was created as a result of the 3.5% inclination across the direction of traffic and the edge of the pavement (see Figure 2), it is possible to estimate the velocity of the flow. The distance to the pumping station was 472 m, and the inclination in the direction of traffic was 10%. According to the calculations, the speed of the flowing petrol was 2.6 m/s (~10 km/h), and it took 3 minutes for it to reach the bottom of the slope. By estimating the area of the cross section of the flowing petrol and factoring in its density (790 kg/m^3), it is possible to calculate the average flow rate from the trailer; 1000-1200 l/min (17-20 l/s). This flow rate will have varied, however, over the course of the flow, particularly at its beginning and end. If an opening with a diameter of 100 mm at the bottom of a 4.5 m^3 tank and a petrol level of 1.2 m are assumed, the flow was 38 l/s at the beginning, decreasing to zero over the course of just under 4 minutes. This shows that the average flow of 1000-1200 l/min, calculated based on the conditions on the surface of the road, is reasonable.

Figure 1: A photograph showing how petrol flowed on the surface of the road, from the trailer and down-slope towards the pumping station at the bottom of the tunnel. The dark section of the road surface shows where the petrol flowed and subsequently burned. The drain cover had a diameter of 0.609 m.

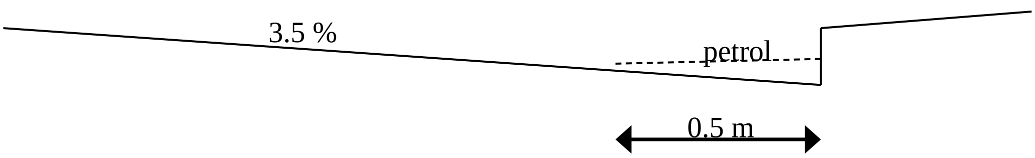

Figure 2: An illustration showing how the petrol flowed along the edge of the pavement due to the inclination across the direction of traffic.

The distance between the front of the trailer after the collision and emergency station BS03 was 34 m. The truck probably stopped some tens of metres up-slope from the trailer. The time it took the driver of Vehicle A to exit the vehicle, look down towards the trailer, and proceed to emergency station BS03 was likely between 30 and 60 seconds. Normal walking speed on a horizontal surface is 1.3 m/s [5] but, as the tunnel had an inclination of 10%, the speed was likely slightly lower, and was roughly estimated as being 1 m/s. Thus, the driver probably walked a distance of 34-68 m in the given time interval. The door to BS03 was opened by the driver at **10:24:51**, meaning that the collision occurred at some point between 10:23:51 and 10:24:21. **10:23:51 was selected** as a conservative estimate **for the starting point**, meaning that a minute passed between the collision and the driver opening the door of the emergency station at BS03. According to the driver's statement, he heard a bang while using the phone in the emergency station. The driver also stated that the interval between the trailer colliding with the tunnel wall and the fire starting was approximately two minutes.

Table 1: A timeline of the events of the incident, including before and after the start of the fire. Note that the estimated times are based on calculations that involved inherent uncertainties in the assumptions of the speeds of vehicles. See Figure 3 and Table 2 for more detailed information regarding their positions and distances from important points relating to the incident.

Logged time (h:min:sec)	Time in min:sec from the start of the fire	Event
	-02:40	The incident occurs; the trailer becomes detached from the truck (Vehicle A) and collides with the tunnel wall
	-02:40	**Vehicle B comes to a halt 10 m down-slope and witnesses the incident**
10:24:51	-01:41	The door to emergency station BS03 is opened by the driver of the truck
	-01:30	**The petrol front reaches a point 150 m down-slope from the trailer**
10:25:36	-01:36	The tunnel begins to close
10:25:38	-01:38	The tunnel is entirely closed
	-00:30	**Vehicles B and C meet Vehicles D and E near to point F2, 367 m down-slope from the trailer**
	-00:20	**The petrol front reaches point F2 in Figure 3**
	00:00	**Vehicle B arrives at the bottom of the slope**

Logged time (h:min:sec)	Time in min:sec from the start of the fire	Event
	00:00	**Vehicle E reaches the trailer and begins to reverse**
	00:00	*Estimated time of ignition of the fire*
	00:00	**Vehicle D stops (the passenger steps out into the flowing petrol)**
	00:05	**Vehicle A leaves for the Hamnen portal (just after the fire is ignited)**
	00:25	**Vehicle E arrives at Drain 5, 103 m down-slope from the trailer**
	00:25	**The fuel flow reaches the pumping station, 463 m down-slope from the trailer**
	00:25	**The flame front arrives at Drain 5, 103 m down-slope from the trailer**
	00:25	**An explosion occurs in the surface water drainage system at Drains 4 and 5**
10:27:50	01:20	One of the cables of the tunnel's lighting system, located between the incident site and the Hamnen portal, is short-circuited
	01:30	**Vehicle A leaves the tunnel at the Hamnen portal amid thick smoke**
10:28:01	01:31	The first of a series of fans (consisting of V01-V08) is activated
10:28:16	01:46	All of the fans (V01-V08) have been activated
10:28:20	01:50	Critically high CO levels at F1
	01:50	**Vehicle E picks up two women from Vehicle C, near to the pumping station; verbal communication is difficult due to the fans running**
	02:00	**The flame front arrives at the pumping station**

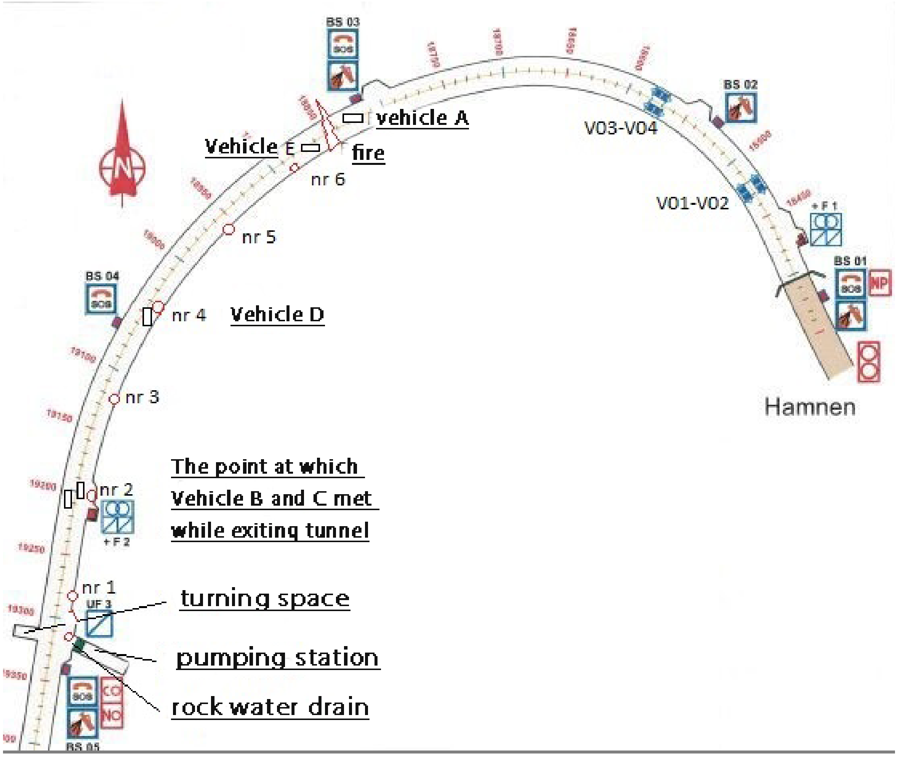

Figure 3: A diagram showing the positions of vehicles, emergency stations, drains, the fire, the turning space, and the pumping station.

Table 2: The specific locations of positions inside the tunnel.

Position according to Figure 3 (m)	Distance from the Hamnen portal (m)	Distance from the fire (m)	Distance from the pumping station (m)	Object/description
18390	0	463	923	The Hamnen portal
18420	-30	433	893	F1
18480	-90	373	833	Fans V01 and V02
18540	-150	313	773	Emergency station BS02 – measures CO/NO levels
18570	-180	283	743	Fans V03 and V04
18815	-425	38	498	Emergency station BS03
18849	-459	4	464	Front of the trailer (collision point)
18853	-463	0	460	Centre of the trailer (fire location)
18858	-468	-5	455	Back of the trailer
18878	-488	-25	435	Drain 6
18897	-507	-44	416	Lights in the ceiling that were unaffected by/functional after the fire
18956	-566	-103	357	Drain 5 (drain cover found 1 m away)

Position according to Figure 3 (m)	Distance from the Hamnen portal (m)	Distance from the fire (m)	Distance from the pumping station (m)	Object/description
19038	-648	-185	275	Vehicle B (burnt-out car)
19040	-650	-187	273	Drain 4 (drain cover partially dislodged)
19060	-670	-207	253	Emergency station BS04
19121	-731	-268	192	Drain 3
19138	-748	-285	175	Damage to the surface of the pavement
19196	-806	-343	117	Drain 2
19220	-830	-367	93	Point F1
19283	-893	-430	30	Drain 1
19300	-910	-447	13	Point UF3
19310	-920	-457	3	Drain in which a fire developed, near to the pumping station
19313	-923	-460	0	Pumping station and turning space
19340	-950	-487	-27	Emergency station BS05 – measures CO/NO levels (at the bottom of the slope)

At least four vehicles drove up the slope after Vehicle A. The statements of the witnesses in these are of interest with regard to determining how far the petrol may have flowed before it was ignited. The driver of the first vehicle (Vehicle B), which was a car, witnessed the accident first-hand. He stopped roughly 10 m down-slope from the trailer that had collided with the tunnel wall. Thus, Vehicle B stopped at the same time as the incident occurred, i.e. 10:23:51. The driver of Vehicle B saw that petrol had begun to leak from the trailer and flow towards his vehicle. He became stressed and reversed back towards the pumping station with his hazard warning lights on to warn others. The driver of Vehicle B stated that the petrol flowed at the same pace as his vehicle was reversing (~10 km/h), and that he met a car (Vehicle C) containing a driver, their mother-in-law, and two children, and that he alerted them of the danger. Vehicle C also began to reverse with its hazard warning lights on and sounding its horn to warn others. The drivers of both Vehicles B and C noted that, when both had reversed almost to the bottom of the slope (roughly to F2, 367 m down-slope from the trailer) and were about to turn around, two other vehicles passed them. This was 30 seconds prior to the start of the fire if we assume a reversing speed of 10 km/h for Vehicle B. Vehicle B is calculated to have reached the lowest point of the tunnel, and was intending to turn around just prior to the start of the fire.

One of the vehicles (D) that met Vehicles B and C stopped part-way up the slope, 150 m down-slope from the trailer, due to a punctured tyre (see position in Figure 3). This was **immediately prior to the start of the fire**. A speed of 30 km/h has been assumed, as the driver likely proceeded uphill relatively slowly. They state that they saw a fire from where they were, 150 m down-slope from the trailer. They did not see what was burning, but observed a wall of yellow flames higher up (this section of the tunnel has relatively sharply curves). The passenger of the car stated that she exited it via a door on the right, and in so doing stepped into a “river” of flowing petrol as she left the area. Calculations show that the petrol front passed this location 20 seconds prior to the start of the fire, i.e. shortly before Vehicle D stopped. It has been estimated that the petrol front advanced at 10 km/h. Both the driver and the passenger ran down-slope, towards the pumping station. They attempted to stop a car that was reversing, and when they looked up the slope they saw that the flame front moved down-slope, along the “river”. They also heard an explosion at the same time, which is likely when the covers of surface water Drains 4 and 5 were dislodged (see Figure 3). The explosion itself is further discussed in the section of this report that deals with the surface water drainage system.

The other vehicle that passed Vehicles B and C was a campervan (Vehicle E). It drove all the way up to the trailer, arriving there at 10:26:30, at the same moment that it is assumed that the fire started. A speed of 40 km/h has been assumed for Vehicle E, which is slightly higher than that of Vehicle D. These assumptions are uncertain, but in the context of the course of events not improbable.

The witness in Vehicle E, who was in its passenger seat, described how they met two vehicles that were reversing with their hazard warning lights on and sounding their horns. Vehicle E met Vehicles B and C roughly 30 seconds before the start of the fire. They were about to begin driving up from the bottom of the tunnel when the witness noticed that something was flowing on the surface of the road, which they thought was water. According to the calculations, the petrol front reached the point where the cars met 20 seconds before the start of the fire, which is corroborated by the statement of one of the witnesses. If a speed of 40 km/h is assumed, they reached the trailer at 10:26:30, at the same moment that it is assumed that the fire started. The driver immediately began to reverse. The fire spread quickly past the campervan, and the driver attempted to reverse fast enough to keep the fire in front of the vehicle. Calculations show that the fire front maintained a speed of 3.9 m/s, or 14 km/h. When the vehicle was halfway between the trailer and the bottom of the tunnel, an explosion occurred. If the speed of the reversing vehicle is assumed to be 15 km/h, Vehicle E passed the drain covers that were explosively dislodged 25 seconds after the start of the fire.

At this point in time, Vehicles B and C were at the turning space at the bottom of the slope (see Figure 3). The witness in Vehicle B heard a bang shortly after Vehicles D and E passed (it took 40 seconds for Vehicle E to drive up to the trailer). The witness from Vehicle B saw an intense “flash of light”, but could not see the trailer (winding tunnel). The witness in Vehicle C, which was at the bottom of the slope in the turning space, also stated that he heard a bang and that the car shook. The witness inspected his car afterwards and smelled petrol, suggesting that diluted petrol vapours had reached the bottom of the slope. This was calculated to have happened at roughly the same time as the fire started. Based on the investigation that has been presented in Part 1, the fire likely started when Vehicle E reached the trailer [1]. The petrol front reached Drain 1 (at the lowest point of the slope) 25 seconds after the start of the fire and 3 minutes and 5 seconds after the trailer became detached. The flame front is calculated to have reached the bottom of the slope two minutes after the start of the fire. At that point in time, the speed of the air flow had increased from a few decimetres/s to 8 m/s (very high), which likely affected the situation at the bottom of the slope. The flames were pushed down, the smoke was pushed back, and the temperature down-slope from the fire was probably strongly affected (this aspect is discussed in more detail in the next chapter).

At this point in time the petrol had almost certainly reached Drain 1, which was furthest down the slope. This can be clearly seen in Figure 4, in that the soot stain can be seen to disappear when it reaches the drain, and does not appear down-slope (to the right) of it. Some of the petrol was siphoned into the surface water drainage system (Drains 1 to 6) on its way to the bottom of the slope. The evidence suggests that the petrol reached the pumping station and the basins located under it; the ‘The fire at the pumping station’ section contains a more in-depth discussion of this.

Figure 4: Photograph showing Drain 1, which was furthest down the slope, and which is also visible in Figure 3. Here, the evidence suggests that petrol flowed into, rather than past, the drain. This petrol is calculated to have reached the drain roughly 25 seconds after the start of the fire (3 minutes after the incident occurred); the flame front did so roughly 2 minutes after the start of the fire.

According to the information presented in the ‘Brann i Skatestraumstunnelen’ (’Fire in the Skatestraum Tunnel’) report [2], a a lighting cable that was located between the incident site and the Hamnen portal was short-circuited at 10:27:50 (01:20); at 10:28:20 (01:50) an alarm for high CO levels was triggered at F1, which was 433 m from the centre of the trailer. This indicates relatively high temperatures and rapid transportation of fire gases up-slope towards the Hamnen portal. Calculations show that the smoke had passed F1 one minute after ignition, and reached the Hamnen portal after one minute and six seconds. The fans were started at a point between 10:28:01 and 10:28:16.

Vehicle E reached the pumping station at 10:28:20 (01:50), and picked up two women from Vehicle C. They had difficulty communicating with one another because the fans were running. This shows that the timeline established for the vehicles agrees well with the statements made by witnesses. Ten seconds later, the flame front reached Drain 1 at the bottom of the slope; by that point, all of the vehicles had left the area and driven towards the Klubben portal (the west end of the tunnel).

Criteria for survival

There are several different criteria with which to calculate the likelihood of survival in a fire scenario in a tunnel. Often, the values that are available in the literature for these calculations vary significantly. When performing a comprehensive analysis, metrics such as ‘Fractional Incapacitation’ (FI) and ‘Fractional Effective Dose’ (FED) are used, which include the combined effects of the various parameters that impact humans’ ability to survive during a fire [6]. Another approach is to provide individual, critical values for different parameters. The critical values for the parameters used in the present analysis were assigned in accordance with [7]:

Visibility: ≥10m

Temperature: ≤60°C

Radiation flux: ≤2 kW/m

Toxic gases (Purser model): FI_{tot} <1 (or FED)

The values stated for CO alone are 6000-8000 ppm for a five-minute exposure.

The effect of the initial spillage fire on those who evacuated down-slope from the trailer

In Figure 5, a heat release rate curve for the initial spillage that formed down-slope from the trailer is shown. Tests performed by SP show that a spillage of the depth in question has a heat releaser rate per square metre of roughly 0.9 MW/m^2 [8]. As the spill is assumed to have had an average width of 0.5 m, the heat release rate was calculated based on the position of the flame front as a function of the time that had elapsed following ignition. After all of the petrol had flowed out of the first compartment it burned up and, finally, extinguished.

At the point in time at which the fire started, the petrol had flowed roughly 100 m down-slope from the trailer. The spillage reached the last drain, 430 m down-slope from the trailer, just over three minutes after the trailer became detached. In Figure 5, the calculated heat release rate for the spillage fire that spread down the tunnel over the course of the two minutes immediately proceeding ignition is shown.

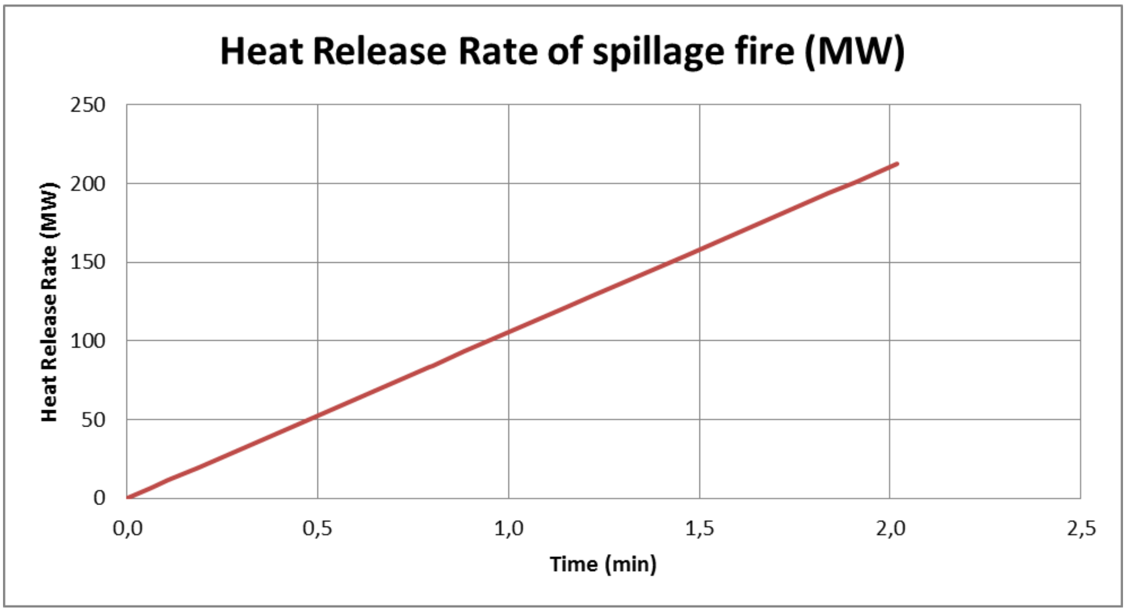

Figure 5: Calculated heat release rate for the spillage fire down-slope from the trailer as a function of time after ignition.

The air velocity during the incident was likely very low due to the small difference in elevation between the Hamnen and Klubben portals. Unless there was a strong wind or large difference in temperature between the external environment and interior of the tunnel, the air velocity was likely to have been low as no fans were running at the moment of the accident.

When the petrol spillage was ignited, a buoyancy force is created that rapidly increased the air velocity since the fire occurred on a slope with a 10% inclination. This meant that the initial air flow was determined by the fire. The air velocity in the tunnel began to increase rapidly; after approximately 10 seconds it was 1.8 m/s; after 1 minute, almost 5 m/s. It further increased as the fire developed. When the fans started, 1.6 minutes after ignition, the air speed increased by a further 2 m/s, to almost 7 m/s (see Figure 6). When the flames reached the Drain 1, 2 minutes after ignition, the air velocity was 8 m/s.

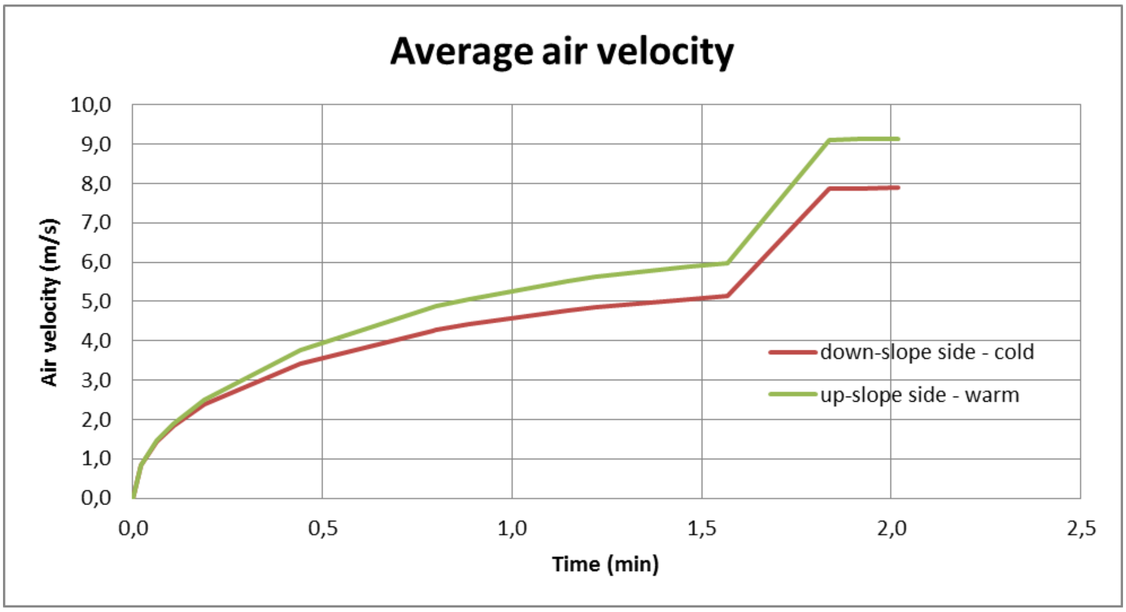

Figure 6: Calculated air velocity, based on the spillage fire down-slope from the trailer. After 1.6 minutes the fans started.

The three-dimensional (3D) calculations, performed using the FDS software package, indicate that the temperature was not particularly high down-slope from the fire. The temperature at the ceiling was between 70 and 200°C (see Figure 7). As the fire was a ‘line fire’ (long and thin in shape), the fire gases were cooled down relatively effectively. In addition, the ventilation system was turned on relatively quickly due to the thermals, which further cooled the surrounding air. This explains why there were no signs of damage down-slope from the fire. Inspections following the incident did not find that the technical systems in that area had been damaged.

The entire cross-section of the tunnel filled with smoke after a few minutes, which would have lowered the possibility of survival of anyone who had remained in the area. Visibility in the smoke was somewhere between 0 and 1 m, but the CO level was not very high during the initial period; below 75 ppm 2 minutes after ignition (see Figure 8). Up-slope from the fire, the CO level was around 150 ppm. It was also at this point in time that the alarm at F1 was triggered by high CO levels (a lower limit of 300 ppm); considering the various uncertainties in the calculations that were performed, this shows that the calculations correspond relatively well with reality.

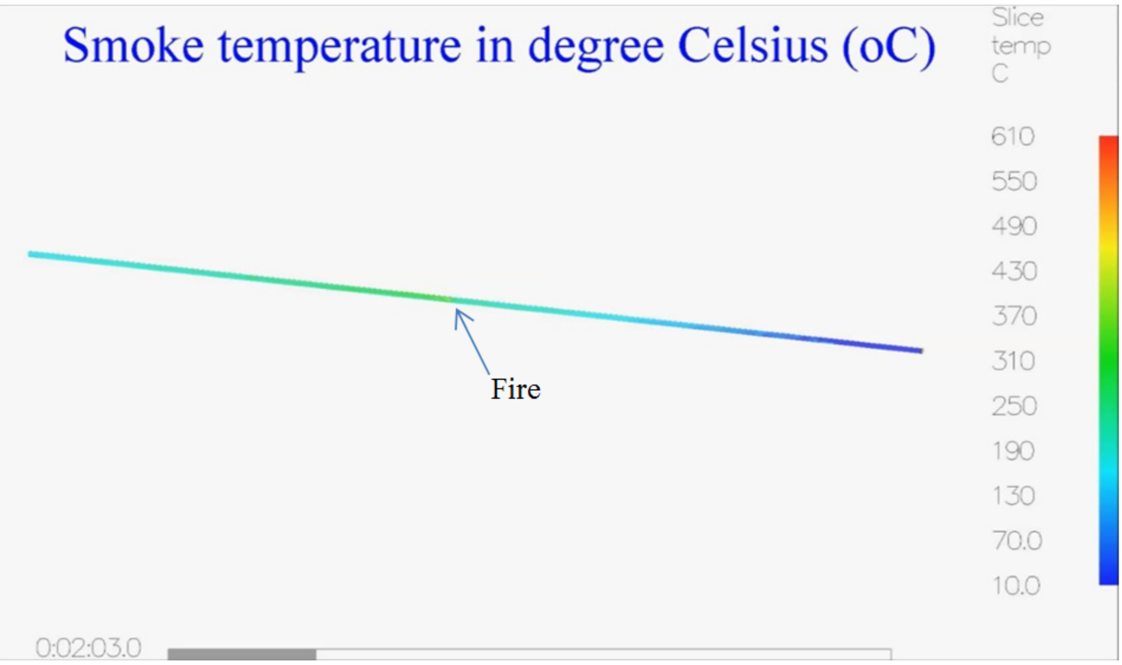

Figure 7: An overview of the 3D calculations (FDS), showing the temperature inside the tunnel two minutes after the start of the fire.

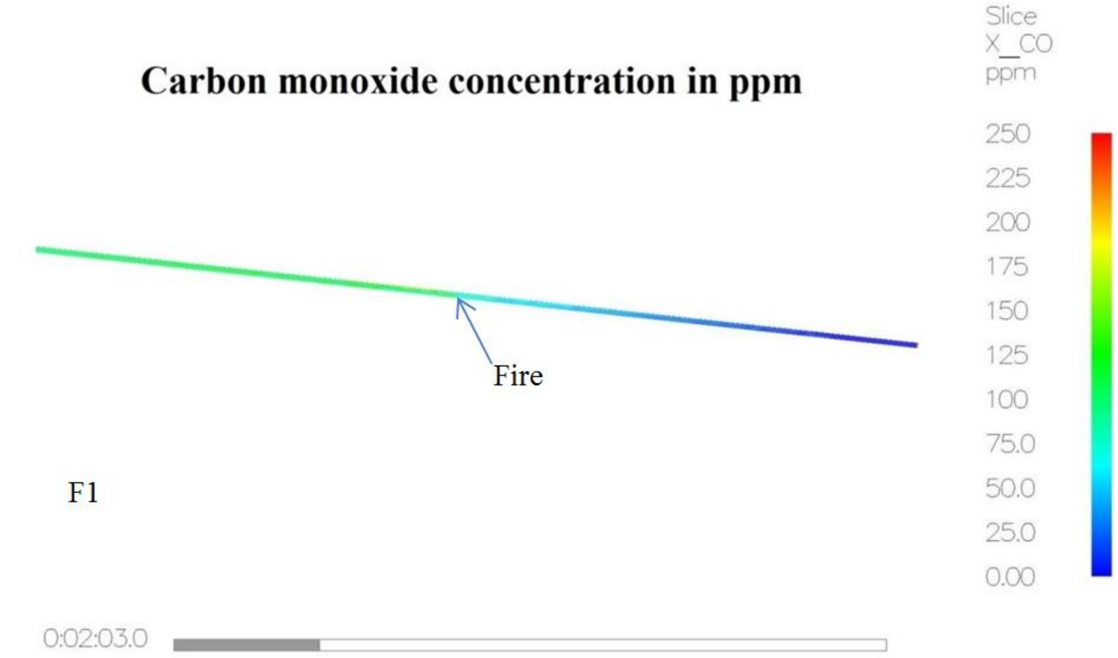

Figure 8: The calculated CO level in the tunnel two minutes after the start of the fire.

The calculated radiation flux exceeded critical levels (2.0 kW/m^2) in all parts of the tunnel down-slope from the fire, except for the 100 metres nearest to the pumping station (see Figure 9). Anyone who had remained up-slope from point F2 (93 m up-slope from the pumping station) would have perished due to the radiation flux from the flames by the side of the road.

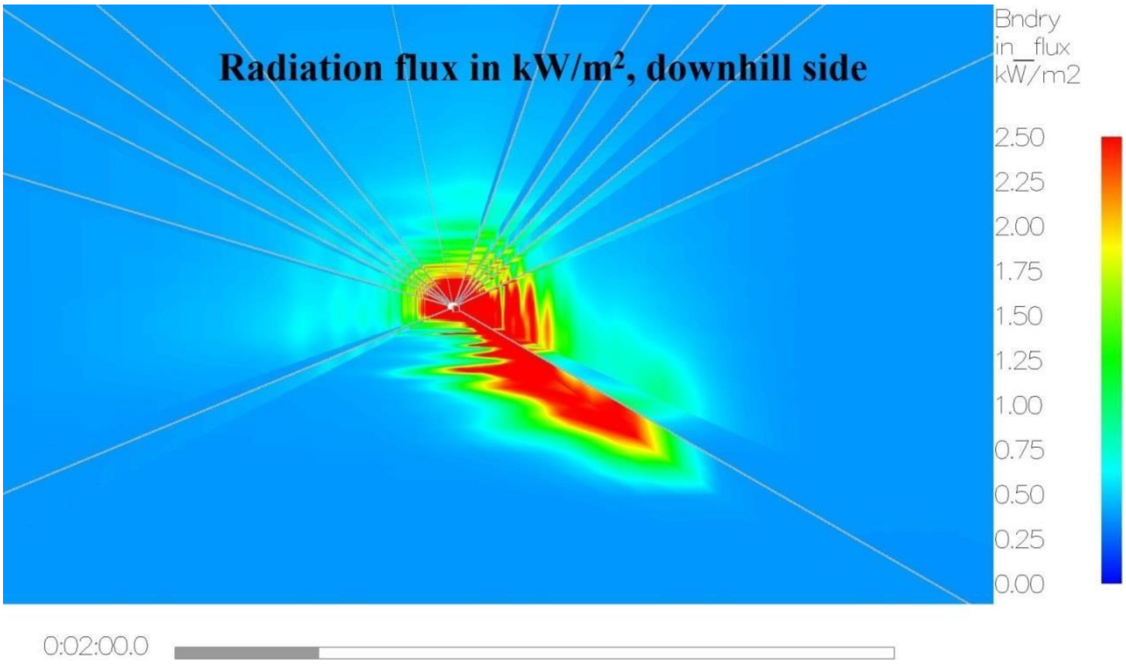

Figure 9: The calculated radiation flux down-slope (downhill) from the fire, two minutes after the start of the fire.

Due to the remarkably rapid and correct reactions of all involved in the accident, there were no fatalities. As everyone involved quickly reached the bottom of the slope and turned their vehicles around (except for Vehicle E, which reversed all the way), they were all able to safely exit the tunnel at the Klubben portal. The increase in air velocity generated by the fire diverted smoke and heat away from the pumping station. Later, another fire raged for an extended period of time in one of the basins, which explains the soot and localised damage found on technical equipment near to the pumping station. This damage does not have any direct connection with the initial spillage event.

It is likely that much of the petrol flowed into Drains 1-6 on the way down the slope (see Figure 3), but exactly how much is difficult to estimate. The explosion that occurred in Drains 4 and 5 was related to the presence of flammable petrol vapours in the surface water drainage system when the flame front passed. In other areas of the tunnel the concentration of the gas mixture was either higher or lower than the flammability limits (1.7-7.6 %) when the flame front passed.

Calculations show that, after 7 minutes, all of the petrol that had flowed onto the surface of the road had been burned up. The first area to be depleted of petrol, and thus go out, was that near to the trailer, after roughly 5 minutes; the last was that near to Drain 1.

The fire environment up-slope from the trailer

The entire tank of the trailer was continually heated by the surrounding flames. The sections of the remaining aluminium compartments still contained petrol in liquid and vapourised form. According to the AIBN, the majority of the compartments were 80-90% full with petrol, the rest being vapours. The upper parts of the tank compartments that were filled with petrol vapours began to collapse and melt due to the heat of the flames. In the parts of the tank compartments where liquid petrol lay adjacent to the 5-6 mm thick aluminium sheet, it efficiently cooled it. The liquid petrol was 10-15°C at the moment of ignition. In other words, the parts of the tank that were not in contact with liquid petrol melted and flowed away rapidly. The rigidity of aluminium decreases sharply at 175-250°C [9]; at 660°C, it melts. This eventually created a pool of fire in the upper tank compartments with a heat release rate of 2-2.5 MW/m^2 [3]. At the same time as the petrol began to burn in the upper tank compartments in which there was still petrol, the rest of the petrol was heated by the surrounding flames.

These five compartments contained roughly 12,000 litres of petrol. As the petrol on the surface of the road and the tires and other combustible elements of the truck burned, the liquid petrol in the remaining tank compartments was rapidly heated. Tests performed by SP Fire Research using a small-scale tank clearly show how this may have happened [10]. When the temperature of the petrol reached >40°C, all of the petrol in each tank compartment began to boil. This meant that the burning rate was much higher than that of a petrol fire in an open vessel or a tub. Ultimately, the intensity with which the liquid petrol of the trailer boiled was determined by the mass loss rate of the liquid. Thus, petrol vapours equal to roughly 0.3 $kg/s/m^2$ were created, corresponding to 12.9 MW/m^2 [10]. An assumed petrol surface area of 17.5 m^2 gives a heat release rate of 227 MW at the point in time at which the entire trailer (all of the remaining tank compartments that were filled with petrol) burned. This fire continued as long as there was petrol left in the trailer. Towards the end of the conflagration it is likely that the trailer collapsed and petrol suddenly poured out, but the effect of this was negligible as compared to what had occurred prior to this.

Figure 10 shows the calculated total heat release rate for the entire duration of the fire. This includes both the spillage fire and the burning of the remaining petrol in the trailer. At the beginning, the heat release rate increased in a linear fashion; this was the point in time at which the fire spread down-slope from the trailer (see Figure 5). When the uppermost sections of aluminium of the remaining tank compartments had melted and flowed away, the petrol vapours inside them began to burn. This took place over the course of 30 seconds, which explains the sharp increase in heat release rate as compared to Figure 5. Eventually, the entirety of the liquid petrol began to burn, and after roughly 5 minutes the fires in the spillage down-slope from the trailer and the boiling tank compartments had developed fully. The total heat release rate reached 440 MW for a short period of time, at the point at which the spillage fire down-slope from the trailer began to burn itself out. The heat release rate thus decreased to 227 MW, as only the compartments in the trailer were burning. The fire consumed a total of 16,500 litres of petrol, corresponding to 560 GJ of energy; the area of the curve roughly corresponds to this figure.

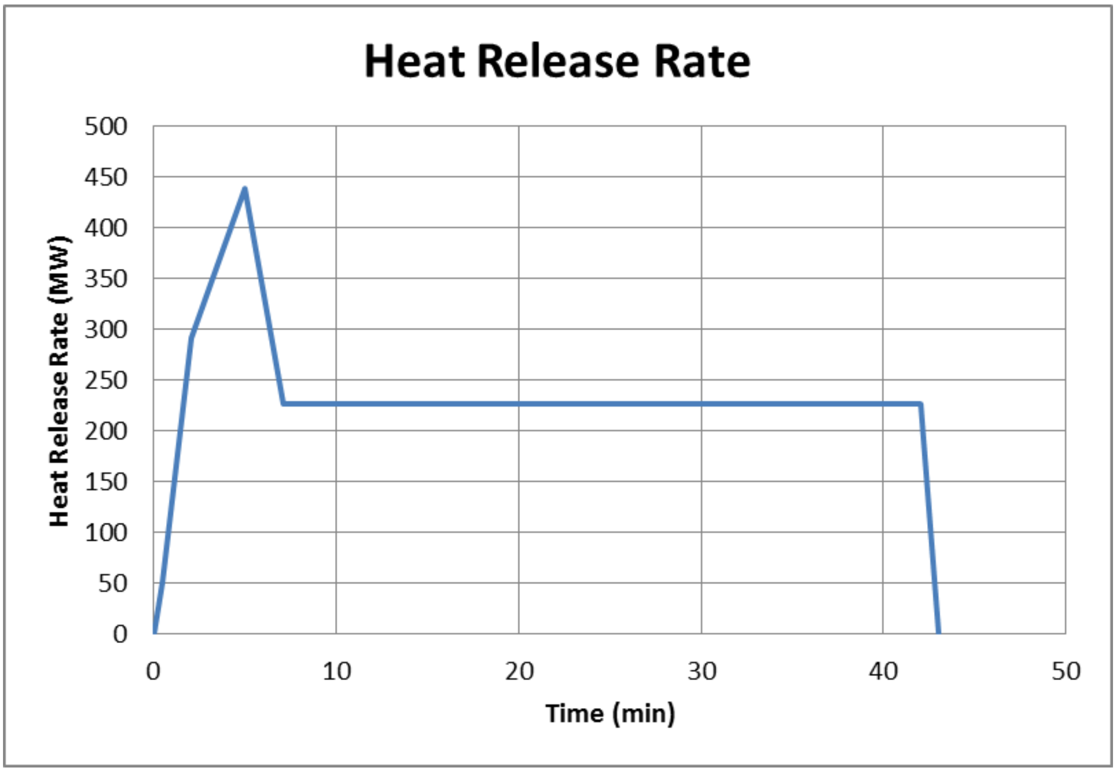

Figure 10: The total heat release rate. This includes both the initial outflow of petrol and the burning of the trailer.

Figure 11 shows the calculated average air velocity for the entire duration of the fire, both up-slope and down-slope from the fire. The highest calculated value was roughly 27 m/s, corresponding to the outflow of a jet fan in a tunnel. These are very high velocities, and explain why the driver of the tanker had to move the vehicle, as is discussed above.
When a fire becomes as intense as the one that occurred in the Skatestraum Tunnel, the question of ventilation-controlled fires is raised; i.e. whether there was sufficient oxygen to supply the fire for its entire duration. By calculating the oxygen concentration up-slope from the fire it is possible to estimate if this was the case; this is shown in Figure 12. For the fire to be considered to have been ventilation-controlled, the values should be close to 0. That they are at 15-17%, however, suggests that the fire had an ample supply of oxygen throughout.

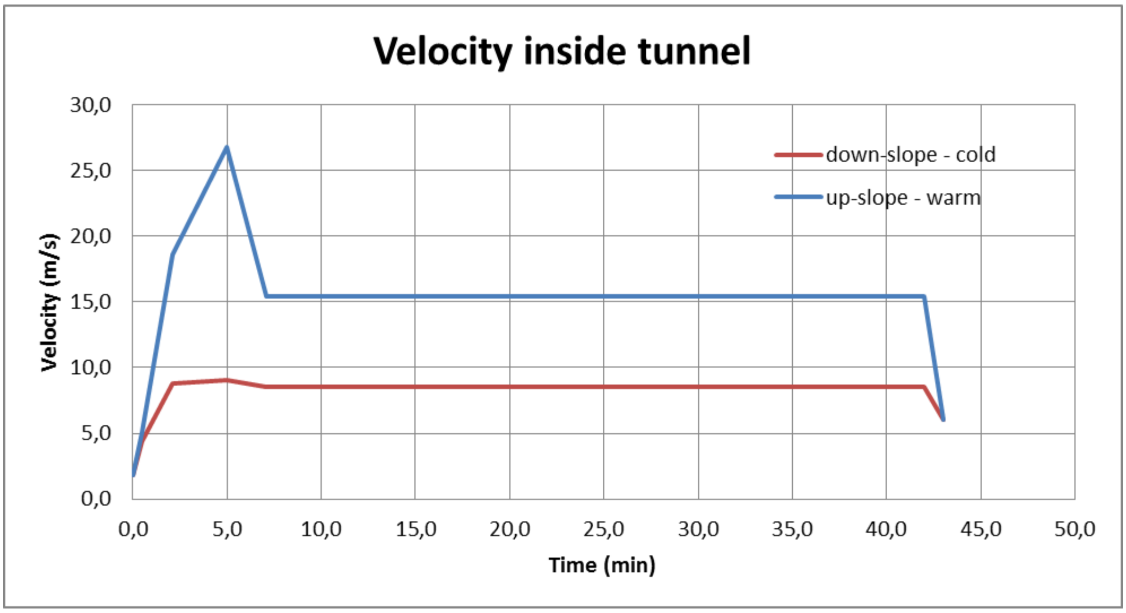

Figure 11: Calculated air velocity up-slope and down-slope from the fire.

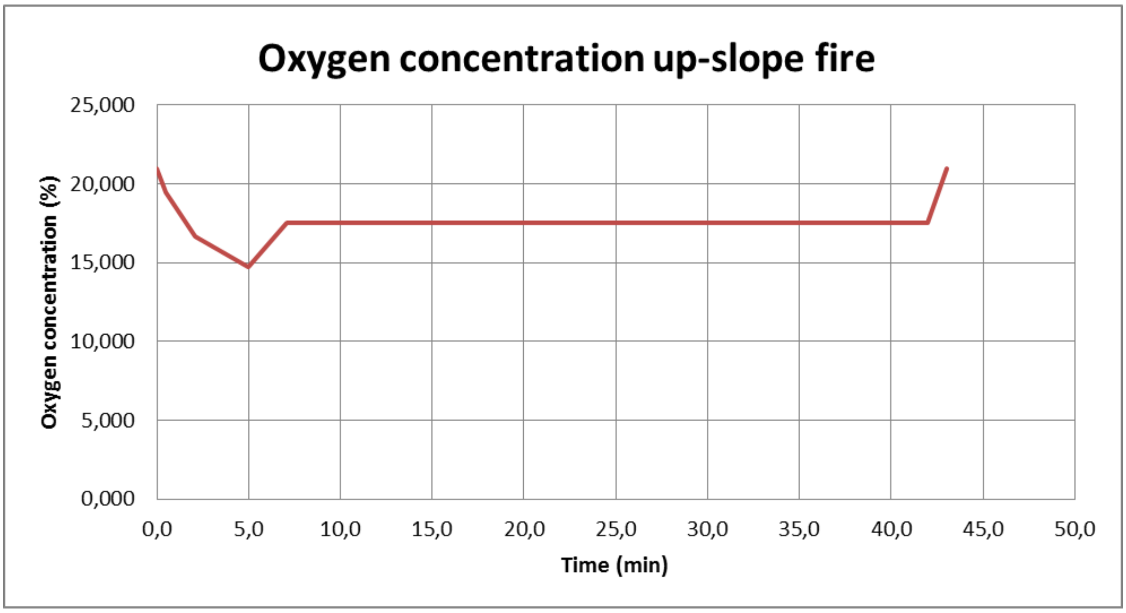

Figure 12: Calculated oxygen concentration (%) up-slope from the fire.

The fire was very intense, producing very high temperatures and air flows. Visibility in the smoke up-slope from the fire has been calculated as being 0.3-0.4 m, which would have made it difficult for anyone in that area to maintain their bearings. CO levels were not particularly high, however, due to the ample oxygen supply, efficient combustion, and strong diluting influence of the air supply. The calculations thus show that CO levels were far below critical, but that the temperatures and radiation flux up-slope from the fire were lethal. Figure 13 shows that the radiation flux values exceeded critical levels only two minutes after the start of the fire.

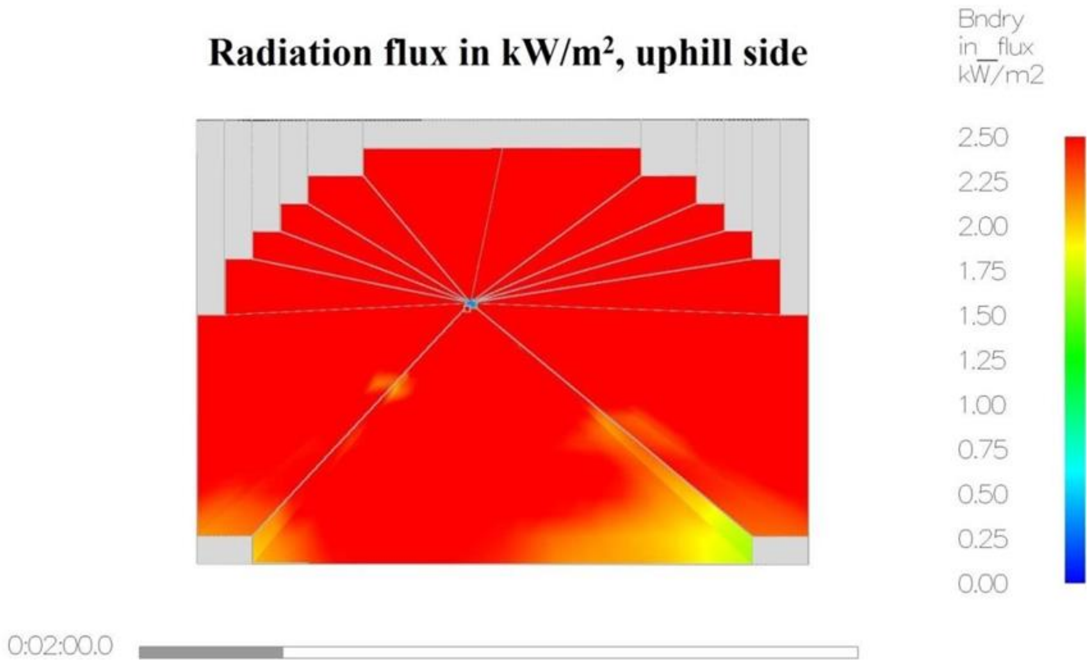

Figure 13: A 3D simulation, created using the FDS software package, showing that critical radiation flux levels were reached throughout the area up-slope from the fire after two minutes.

Calculated temperatures up-slope from the fire

In Figure 14, the calculated gas temperatures for the ceiling near to the trailer are shown. These show that the gas temperature rapidly became very high, reaching 1350°C, the highest temperature that is theoretically possible in a tunnel fire [11], after only a few minutes. This corresponds to the temperature levels of a RWS time-temperature curve [12]. The temperature up-slope from the fire decreased rapidly with distance. The damage done to the shotcrete is easy to explain based on the temperatures to which it was exposed, and the duration of this exposure. The shotcrete was 60 mm thick, reinforced with steel fibres, and insulated from the rock with PE insulation.

Figure 15 shows how the average temperature for the entire cross-section varied throughout the area of the tunnel up-slope from the fire. These values were achieved using four different heat release rates; 50, 200, 300, and 400 MW. As plastics melt at different temperatures, 170°C is generally considered to be an 'average' value, above which the majority of plastics have begun to melt. The graph thus provides an explanation of the damage that occurred in the tunnel up-slope from the fire. Near to the V03 and V04 fans, which were 283 m from the fire, the average temperature was 304°C; near to V01 and V02, which were 373 m from the fire, it was 212°C. These temperatures explain why the fans stopped working only 14 minutes after the start of the fire.

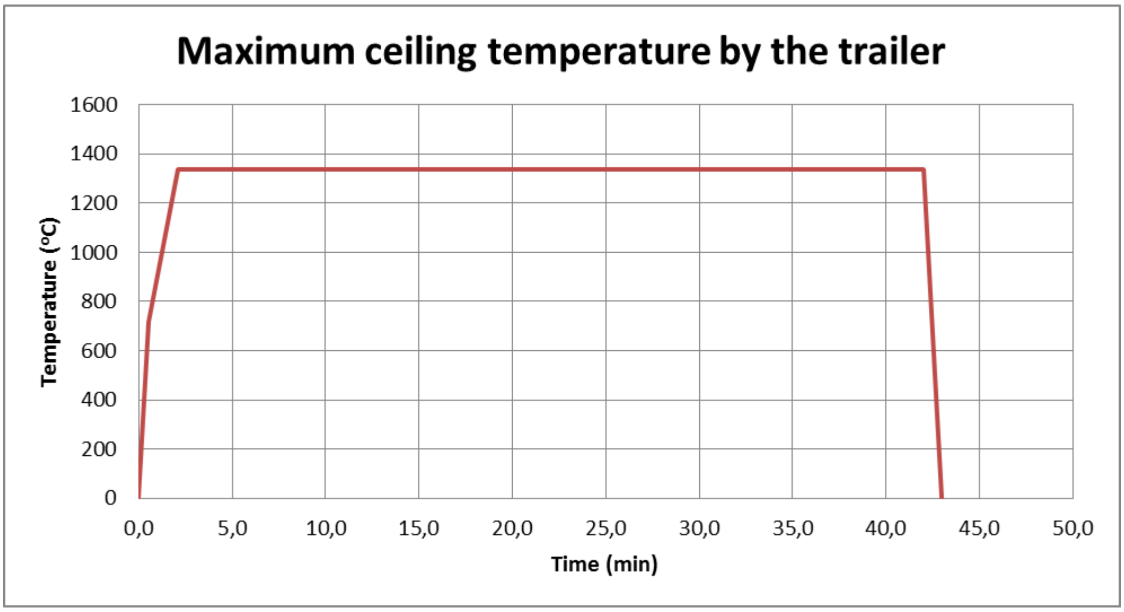

Figure 14: Calculated highest temperature at the primary site of the fire (the trailer).

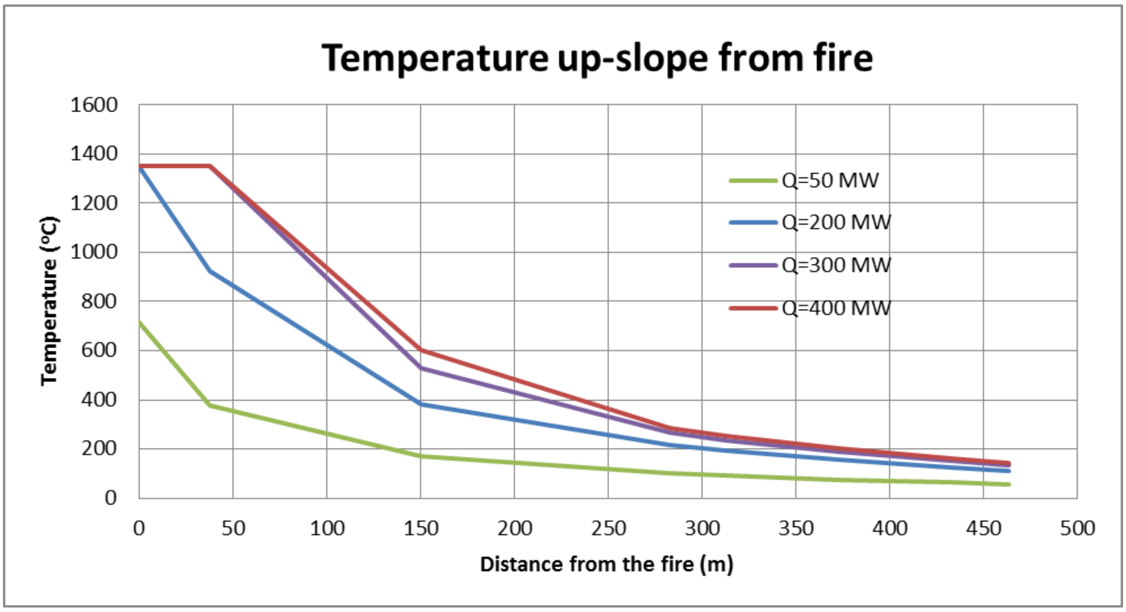

Figure 15: Calculated temperatures along the tunnel (up-slope from the fire) for different heat release rates.

The temperature at the Hamnen portal was just under 200°C, according to Figure 15, and Figure 16 is a photograph of the height limit sign at this exit, showing how it was affected by the fire. The rigidity of aluminium decreases significantly between 175 and 250°C [9], which may explain why the sign was deformed by its own weight.

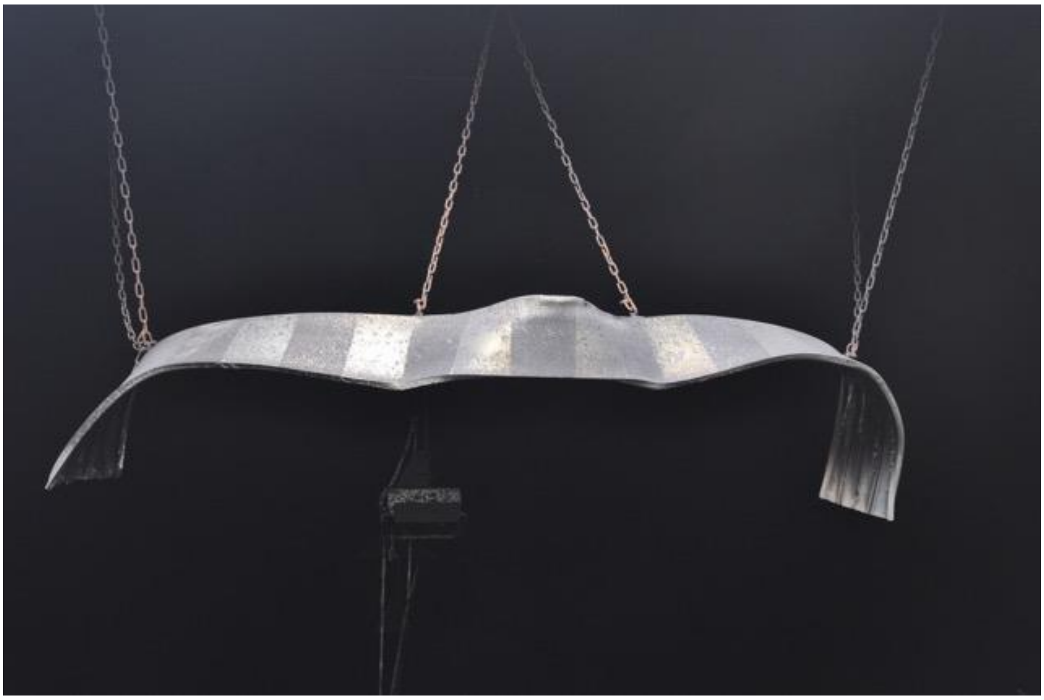

Figure 16: A photograph taken after the fire of the height limit sign at the Hamnen portal (source: NPRA).

Table 3 clearly shows that many of the technical systems located up-slope from the fire were damaged to the extent that they ceased to function during the period between 10:28:35 and 10:40:00 (between 2 and 14 minutes after the start of the fire). The cables of emergency station BS03, which was 38 m from the fire, were damaged after 3 minutes and 30 seconds. Shortly after this, a handheld fire extinguisher was apparently removed from its position in BS03 but, as no one was in there, the fire must have caused this. In BS02, which was 313 m from the fire, the same phenomenon occurred at approximately 13 minutes, and a minute later, the ceiling fans broke.

It is obvious that the damage and events that occurred up-slope from the fire correspond well to the calculations presented here. Most of this occurred 10-15 minutes after the start of the fire. This is due to the fact that cables cannot normally function in temperatures above 170°C, as they begin to cease to function as their plastic covers melt. What fire safety requirements were placed on the materials that were in use in the tunnel has not been determined, but materials should always continue to function at relatively high temperatures, even above 200°C.

Table 3: Logged events and times, after the flame front reached the pumping station.

Logged time (h:min:sec)	Time after ignition (min:sec)	Event
10:28:35	**02:05**	**System confirms that the door of BS03 is open**
10:29:39	**03:09**	**Critically high CO levels at F1**
10:30:00	**03:30**	**Cables in BS03 short-circuit due to high temperature; cabinet destroyed by fire**
10:30:06	**03:36**	**Emergency ventilation system in full operation**
10:30:06	**03:36**	**Hand-held fire extinguisher is removed in BS03 (cable likely severed due to fire damage)**
10:31:20	**04:50**	**System confirms that a hand-held fire extinguisher has been removed** **(cable likely affected by fire, likely in BS03)**
10:33:50	**07:20**	**Phone handle lifted (likely due to fire damage)**
10:39:20	**12:50**	**Short-circuit in BS02 (hand-held fire extinguisher removed, but no one was present), 250 m from BS03**
10:39:32	**13:02**	**System confirms that a door is open in BS02, but no one was present (probably error message)**
10:40:00	**13:30**	**Fans cease to function at F1 due to melted fan blades; CO meter ceases to function**

The damage to the tunnel structure and technical equipment up-slope from the fire

The damage to the shotcrete up-slope from the fire (see Figure 17) is simply explained by the rapid increase in gas temperature. The shotcrete closest to the trailer was exposed to incident radiation flux of up to 400 kW/m^2 (see Figure 18), which is the highest level of radiation flux that is considered to be possible to occur during tunnel fires. In the Runehamar tests in 2003, [13] a roughly equal level of radiation flux was measured. This radiation flux corresponds to that obtained during furnace testing, during which the temperature is controlled according to an RWS curve.

An indication of the extent of the damage on the shotcrete is given by the flame length; in Figure 19, this is shown as a function of time. Although the flame length up-slope from the fire varied greatly, it is calculated to have been 150 m at its longest, which would have meant that the shotcrete was more badly damaged in this area. The plastic insulation that was located behind the shotcrete may have been either burned or melted. This initially occurred closest to the fire and then further away, for as long as the back of the shotcrete received a supply of air.

The extent of the damage that occurred further away from the fire is unknown, but that done to the tunnel structure is likely fairly obvious in the area between the incident site and 80-150 m up-slope. Further up-slope, the damage that occurred was most likely limited to technical systems.

Figure 17: Damage to the shotcrete just up-slope from the trailer.

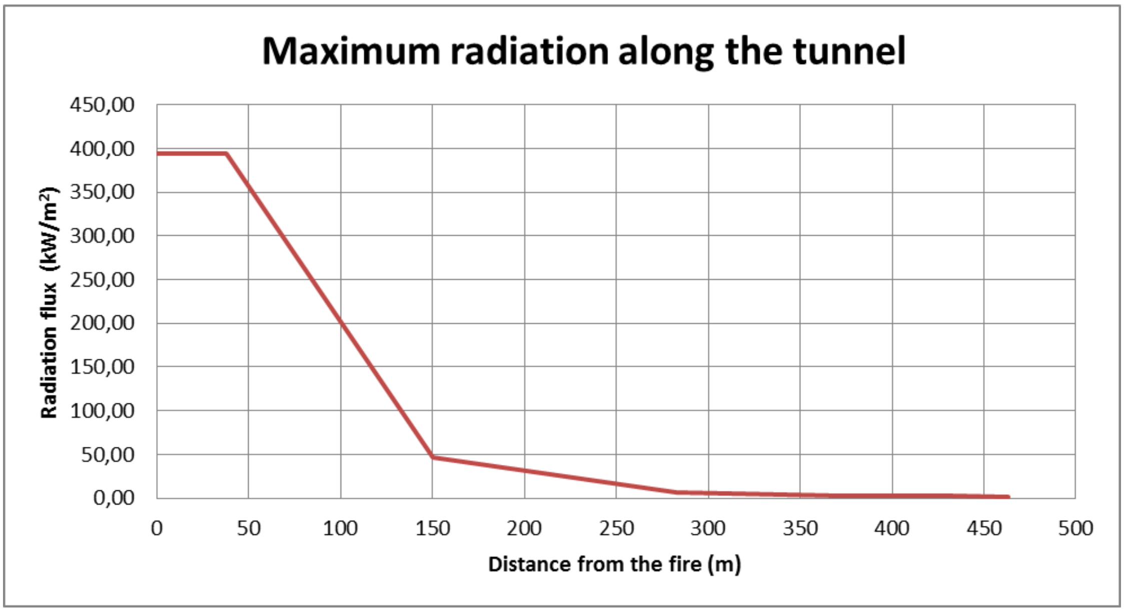

Figure 18: Calculated incident radiation flux towards the tunnel structure as a function of distance from the fire.

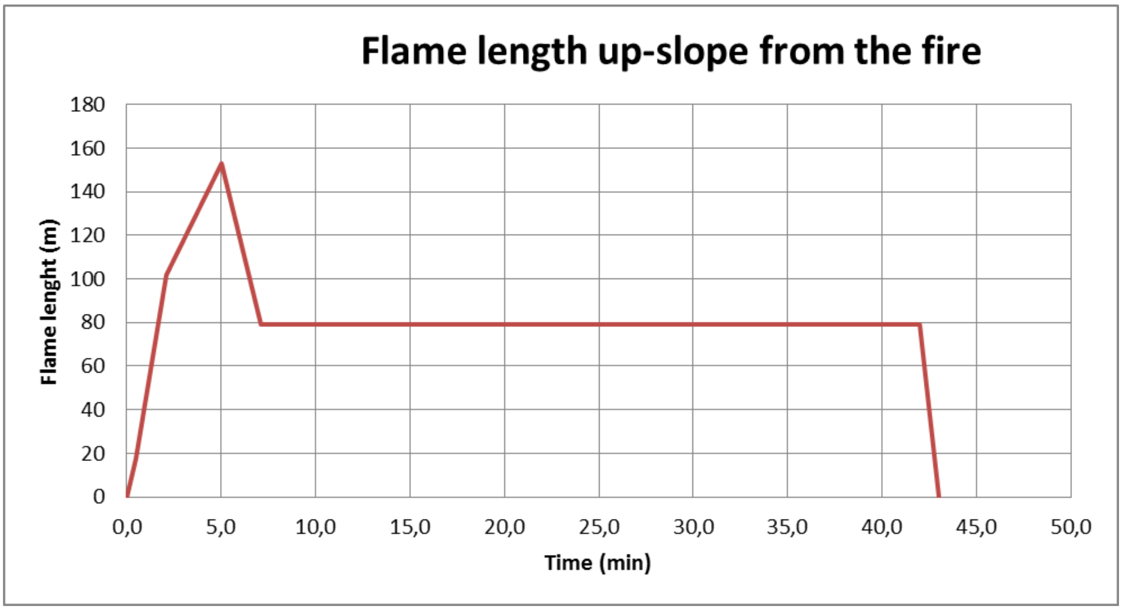

Figure 19: Calculated flame length up-slope from the fire.

The fire at the pumping station

There are two systems for transporting water and hazardous liquids in the Skatestraum Tunnel. One deals with the water that leaks into the tunnel behind the shotcrete (from the rock/groundwater; referred to in this text as ‘rock water drainage system’), the other with liquids that originate within the tunnel, such as water used for cleaning or liquids that leak from vehicles (referred to in this text as the ‘surface water drainage system’). The drains, which are placed every 80 m at the edge of the pavement, have openings of 0.6 x 0.05 m, and are intended to divert liquids that flow along the surface of the road. The rock water drainage system should be separate from the surface water drainage system.

When the petrol flowed out of the trailer, it flowed along the edge of the pavement and passed Drains 6-1 (which together constitute the surface water drainage system for this part of the tunnel); in the process, some of it ran into the drains. These were connected to one another with 110 mm plastic pipes, such that if one became full it would continue to be drained. There was also an oil separator, located near to the pumping station, that was connected to the surface water drainage system. It has been found that the surface water drainage system was not watertight (sealant was missing), and so petrol leaked into the bedrock. Thus, petrol flowed all the way down to a drain that was placed outside the pumping station, marked as ‘rock water drain’ in Figure 3, and into the sludge basin beneath the pumping station [2].

Beneath the pumping station there were two basins; a sludge basin and a water basin. These were separated by a wall with an opening at the top. Pipes led from both the oil separator and the rock water drain to the ceiling of the sludge basin below the pumping station. A fire burned for a relatively long time in the opening of the pipe that was connected to the rock water drain, as did one in the sludge basin. These fires were evidenced by the soot, melted cables, and clear signs of local fire damage. When the petrol entered the sludge basin, it floated on top of the water already in there due to the difference in density, and as the fire spread to it, a pool fire occurred. As there were grates above the sludge and water basins, smoke and heat spread throughout the part of the tunnel near to the pumping station. This fire did not, however, affect the events of the first hour following the incident.

The events at the pumping station were quite complex, yet relatively simple to explain in fire engineering terms. The fire in the sludge basin burned in the form of an open pool fire that generated a great deal of smoke and heat. Due to the relatively high air flow in the tunnel, an excess of pressure was created in the sludge basin relative to that of the tunnel, and so the smoke and heat from the former were sucked into the latter. This is the explanation for the smoke and soot damage that were observed in the area around the pumping station. Local damage to outlets and drains can be explained by a rich supply of oxygen. Petrol vapours were transported to the areas that were rich in oxygen, starting fires in all of the openings that led to the basin. This kind of fire tends to last a relatively long time, as evaporation is a slow process, and continues as long as there is liquid petrol left.

In conclusion, it can be said that the events that occurred near to the pumping station did not have any discernible effect on the main fire event in the tunnel; rather, they simply constituted an obstacle to the fire and rescue service operation and caused damage.

Special observations that require explanation

Among the material that SP has had access to are a number of events that have proven difficult to explain. None of these are of any great significance to the development of the tunnel fire, but all are interesting from a fire engineering perspective. In Figure 20, it can be seen that petrol appears to have flowed out of Drain 3. The only conceivable explanation for this is that the drain overflowed due to a blockage in a pipe. When this may have happened cannot be determined.

Figure 20: A photograph of Drain 3, showing the discrepant marks that suggest that petrol flowed out of the drain and along the surface of the road.

Figure 21 clearly shows the damage done to the door of the pumping station. This can be explained by the fire that occurred in the sludge basin. Due to the high air velocity in the tunnel, it can be assumed that large and turbulent flames swept past the door. High local radiation flux would thus explain the damage. It can also be observed that the soot on the pumping station was burned away, which indicates high gas temperatures. Due to the high air flow and turbulence, the temperatures in the other parts of the area near to the pumping station may not have been very high, however. In order to better understand the course of events, more information regarding and photographs of the damage are required.

Figure 21: Very marked fire damage on the door of the pumping station, located directly above the sludge basin. Just past the pumping station was a grated floor, which was above the sludge and water basins. There were clear signs of a fire having occurred in the sludge basin.

In Figure 22, heavy spalling damage can be observed above the cover of an inspection hatch belonging to the rock water drainage system 175 m from the pumping station. This damage was likely caused by a fire that came from underneath, via cracks or slits in or around the lid, and is best explained by the occurrence of a fire in the rock water drainage system. Such a fire would likely create flames with high flame speed and radiation flux values. It is uncertain why this occurred, but the damage was not caused by the fire on the road surface; it is far too localised to be explained by a fire that radiated heat and caused damage from above.

Figure 22: An inspection hatch, located 175 m from the pumping station and belonging to the rock water drainage system.

In Figure 23, the severe fire damage done to the rock water drain outside the pumping station can be seen, which can be explained by the fire that occurred in the rock water drainage system. The severe damage at the top of the pipe branch indicates that the fire was more intense higher up (towards the surface of the road), where there was more oxygen. It has been established that the fire travelled the entire length of the section of the rock water drainage system that was connected to this drain, all the way to the trailer. The pipe branches that were connected to it were severely damaged.

Figure 23: Parts of the rock water drain that was located outside the pumping station. The signs of an intense fire are quite clear.

Discussion and summary

The incident discussed above is unique in several ways. A tanker truck fire in a tunnel has happened before, for example in 1982 in the Caldecott Tunnel in the USA [14]. What is unique about the incident in the Skatestraum Tunnel, and of significance to the course of events, is the steep (10%) inclination of the tunnel. This affected how rapidly both the petrol flowed down-slope and the smoke and heat spread within the tunnel. The surface water drainage system that was supposed to divert liquid from the surface of the road did not do so efficiently enough to prevent a surface fire that reached just over 200 MW within two minutes of ignition. The air flow generated by the fire negatively impacted the effect of the ventilation system, such that it had little influence on the course of events and the environment inside the tunnel.

There were no fatalities in this fire due to the rapid and correct reactions of all of those involved. If the exit of one of the people in the tunnel had been blocked by an obstacle, or someone had made a different decision, they likely would not have survived, considering the rapid development of the fire. Anyone in the area down-slope from the fire would not have survived due to radiation flux if they had not managed to evacuate before the smoke travelled down the slope. In the same way, any road users up-slope from the fire would have perished as they would not have been able to exit rapidly enough due to reduced visibility, and thus would have died due to the high temperature and radiation flux. Through their quick thinking and decision-making, the people inside the tunnel saved themselves. None of the technical safety systems that existed in the tunnel played any significant role in the outcome. The sequence of events that led to the outflow of petrol made it impossible to influence the outcome.

The surface water drainage system installed in the tunnel did not function properly, as a large portion of the petrol flowed all the way down to the bottom of the slope. Due to the steep inclination, the speeds at which the petrol flowed and the vehicles travelled in reverse were roughly the same. A solution to the problem of stopping such a flow of petrol is a challenge for the future. A new design for the surface water drainage system is necessary.

In order to investigate how people might best survive the initial stages of such a fire, it is best to start by examining the situation down-slope from the fire and then consider the situation up-slope from it. The smoke that spread in the immediate aftermath of ignition limited visibility to a level far below the determined critical distance of 10 m. The smoke front reached the lowest point of the tunnel two minutes after ignition. Anyone caught in the smoke would have had significantly reduced visibility, to possibly a few decimetres. The smoke filled the entire cross-section of the tunnel, from the trailer to the lowest point of the petrol fire, 430 m from the trailer. The calculations performed show that the gas temperature, aside from at 50 m from the lowest point, exceeded 60°C. At a distance of 100 m from the lowest point, the radiation flux exceeded the critical value for survival. In general, it can be said that anyone standing beside the flowing petrol when it was ignited would have found it difficult to proceed further down the tunnel if they had been caught in the smoke. Anyone located more than 50 m from the lowest point of the tunnel would have experienced difficulty breathing, and anyone more than 100 m from the bottom would have had a very slim chance of survival. Thus, the calculations indicate that anyone in the area between the trailer and 330 m down the slope from the trailer would have been at risk of losing consciousness and subsequently dying. In summary, the sequence of events of the fire down-slope, towards the bottom of the tunnel, was: the smoke reached critical levels, as did the gas temperature shortly after, followed by the radiation flux. The toxicity of the atmosphere in the tunnel was not, however, alarmingly high down-slope from the trailer. In order for a person to lose consciousness within 5 minutes due to exposure to CO, levels of between 6000 and 8000 ppm are required [7].

Up-slope from the fire, the smoke front reached the Hamnen portal 1 minute and 6 seconds after ignition, according to calculations, giving a speed of 25 km/h. Visibility in the smoke rapidly became very limited; calculations suggest 0.4 m or less. The gas temperature at the Hamnen portal reached 60°C 1 minute and 30 seconds after the start of the fire. The critical radiation flux level was reached 2 minutes after the start of the fire. The same sequence of events occurred up-slope from the fire; first, the smoke reached critical levels, then temperature, then radiation flux. The levels of toxicity were not critical within this time interval. The uncertainties in the calculations of CO levels are relatively large, but they provide a clear indication of the fact that heat and smoke were critical factors in this incident. Petrol burns relatively purely (i.e. low production of CO) in good ventilation conditions as compared to many other fuels. The fire was never ventilation-controlled, which means that there was a rich supply of oxygen throughout the fire. The length of the flames up-slope from the trailer was 80-150 m during the majority of the duration of the fire. This, together with the fact that the fire was not ventilation-controlled, indicates that no flames should have reached the Hamnen portal. If contradictory witness statements exist, they may be explained by airborne objects or fire in the insulation material. If fire in the insulation material behind the shotcrete occurred, its intensity was influenced entirely by the supply of oxygen.

Anyone caught in the fire would have had great difficulty leaving the area. The delay caused by the reduction in visibility would likely have resulted in loss of consciousness due to heat, and then death. This would have been true for anyone caught in the fire up-slope from F2 and all the way to the Hamnen portal, i.e. almost the entire northern section of the tunnel.

According to calculations, the strong buoyancy generated by the fire resulted in an air velocity of over 27 m/s up-slope from the fire (warm air) and 9 m/s down-slope (cool air). The initial heat release rate of the fire, the result of outflowing petrol, was estimated as being 212 MW, rising to a maximum of 440 MW during a short period when both the outflowing petrol was burning and the remaining petrol in the trailer had ignited. At the point in time at which only the fire in the trailer remained, the heat release rate was calculated as being 227 MW. The highest calculated temperature was 1350°C at the ceiling, 10-20 m up-slope from the centre of the trailer. The temperature up-slope from the fire decreased rapidly; 150-200 m up-slope it was 600°C, and at the Hamnen portal (460 m) it was just below 200°C.

The damage done to the shotcrete can be explained based on the analysis and calculations that have been presented in this report. The radiation flux of 400 kW/m^2 in the vicinity of the trailer is the highest that is considered to be possible to occur during tunnel fires. The extensive damage done to both the shotcrete and the plastic insulation behind it can be explained by the temperatures and flame lengths that were calculated. Estimated flame lengths of 150 m demonstrate the enormity of the fire. The remaining five tank compartments in the trailer were likely intact for a considerable part of the duration of the fire. Following the initial spill of petrol, no substantial outflow occurred. The most intense period of the fire, which was when the petrol from the tanker burned, likely did not last for more than 40-45 minutes.

The fire near to the pumping station, which had a longer duration, was related to the petrol that flowed into the surface water drainage system and then found its way into basins and a rock water drain at the bottom of the slope. This fire did not have any significant effect on the ultimate outcome of this incident.

Conclusions

- The fact that the tunnel has a 10% inclination significantly influenced the course of events.
- The rapid initial spreading of the smoke and heat up- and down-slope from the fire was the result of this inclination.
- The surface water drainage system that was supposed to divert liquid from the surface of the road did not do so efficiently enough to prevent a surface fire that reached just over 200 MW within two minutes of ignition.
- The air flow generated by the fire negatively impacted the effect of the ventilation system, such that it had little influence on the course of events and the environment inside the tunnel.
- That no one was killed in this fire can be ascribed to the rapid and correct reactions of all involved in the accident.
- Anyone in the area down-slope from the fire would have died from radiation flux.
- Anyone caught in the smoke, whether up- or down-slope of the fire, would have had great difficulty leaving. The delay caused by the reduction in visibility would likely have resulted in loss of consciousness due to heat, and then death.
- None of the technical safety systems that existed in the tunnel played any significant role in the outcome.
- According to calculations, the strong buoyancy generated by the fire resulted in an air velocity of over 27 m/s up-slope from the fire (warm air) and 9 m/s down-slope (cool air).
- The initial heat release rate of the fire, the result of outflowing petrol, was estimated as being 212 MW, rising to a maximum of 440 MW during a short period when both the outflowing petrol was burning and the remaining petrol in the trailer had ignited.

- The highest calculated gas temperature was 1350°C at the ceiling, 10-20 m up-slope from the centre of the trailer.
- The gas temperature up-slope from the fire decreased rapidly with distance; 150-200 m up it was 600°C, and at the Hamnen portal (460 m) it was just below 200°C.
- The smoke exceeded critical levels first, followed by the gas temperature, and finally the radiation flux.

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References

1. Ingason, H., *Investigation into the development of the fire in the Skatestraum Tunnel on July 15, 2015 – Part 1*. 2016, SP Fire Research 6P03116.
2. *Brann i Skatestraumstunnelen 15. Juli 2015 - Evalueringsrapport*. Januari 2016, Region Vest Vegavdelning Sogn og Fjordane - Statens Vegvesen.
3. Ingason, H., Y.Z. Li, and A. Lönnermark, *Tunnel Fire Dynamics*. 2015: Springer.
4. McGrattan, K., S. Hostikka, J. Floyd, and R. McDermott, *Fire Dynamics Simulator (Version 5), Technical Reference Guide: Volume 3: Validation*. 2010, National Institute of Standards and Technology.
5. Ingason, H., A. Bergqvist, A. Lönnermark, H. Frantzich, and K. Hasselrot, *Räddningsinsatser i vägtunnlar*. 2005, Räddningsverket.
6. Purser, D.A., *Assessment of Hazards to Occupants from Smoke, Toxic Gases, and Heat*. The SFPE Handbook of Fire Protection Engineering, 4th ed. ed, ed. P. DiNenno. 2008: Quincy: National Fire Protection Association.
7. Ingason, H., ed. *TG2.2 - Target criteria*. 2005, UPTUN Report WP2 - task Group 2.
8. Ingason, H., G. Appel, and U. Lundström, *Water spray interaction with liquid spill in a road tunnel*. 2015, SP Report 2015:19 SP Swedish Technical Research Institute.
9. van Haaren, L., *Deformation of Aluminium Sheet at Elevated Temperatures - Experiments and Modelling*, in *Department of Mechanical Engineering* 2002, University of Twente Enschede, The Netherlands.
10. Ingason, H. *Small Scale Test of a Road Tanker Fire*. in *International Conference on Fires in Tunnels*. 1994. Borås, Sweden: SP Swedish National Testing and Research Institute.
11. Lönnermark, A. and H. Ingason, *Gas Temperatures in Heavy Goods Vehicle Fires in Tunnels.* Fire Safety Journal, 2005. 40: p. 506-527.
12. *Beproeving van het gedrag bij verhitting van twee isolatiematerialen ter bescherming van tunnels bij brand*. 1979, Instituut TNO voor Bouwmaterialen en Bouwconstructies: Delft, The Netherlands.
13. Ingason, H., A. Lönnermark, and Y.Z. Li, *Runehamar Tunnel Fire Tests*. 2011, SP Technical Research Institute: SP Report 2011:55.
14. *Caldecott Tunnel Near Oakland California, April 7, 1982*, in *Highway Accident Report Report No. 3665A.* Highway Accident Report Report No. 3665A., National Transportation Safety Board Washington D. C.

To all heavy vehicle workshops and testing centres

Repair and inspection of drawbars

The Norwegian Public Roads Administration has been made aware that a number of cases of severe corrosion and deterioration of drawbars for trailers have been discovered of late. This has been noted in connection with various inspections.

Purely in terms of road safety, faults or defects in drawbars are extremely serious as there is such huge potential for harm in the event of failure or breakage of the drawbar. A trailer weighing 20-30,000 kg may cause enormous damage to other road users if it loses its connection to the vehicle towing it while in motion.

Therefore, Trafikant- og kjøretøyavdelingen [the Road Users and Vehicles Department] would like to ask workshops and testing centres to focus more closely on drawbars when repairing drawbars and in connection with periodic vehicle inspection. We will be focusing more closely on this inspection point in conjunction with our technical roadside inspections and administration inspections.

Repair of drawbars
Most manufacturers of drawbars impose severe restrictions on the repair/welding/modification of drawbars. Many of them have clear instructions regarding maintenance of the various components associated with drawbars (drawbeams, couplings, eyes, bushes, etc.), but also regarding replacement of wear parts and of the drawbar itself.

Workshops must consider the repair instructions prescribed by the vehicle manufacturer – and, in this case, the manufacturer of drawbars – in respect of wear, damage, deterioration, corrosion and breakage of the drawbar itself and associated components. This is becoming increasingly important as developments in the fields of material technology and design influence the design of drawbars and associated components.

Inspection of drawbars
It is also important for testing centres to undertake thorough inspection of drawbars and associated components. This inspection is described in greater detail in the inspection instruction for periodic vehicle inspection as specified in section 6.1.6. In particular, we ask inspection bodies to review this inspection point with their inspectors to ensure that this is inspected thoroughly.

Furthermore, we wish to request use of a corrosion hammer/corrosion pick in instances where corrosion damage, etc. is suspected. In this respect, please see the corrosion damage guide, which states the following:

"The load-bearing structures must initially be inspected visually. If any corrosion damage is discovered, a corrosion hammer should be used to establish the extent of the corrosion damage. The corrosion hammer should be used with caution, and only to the extent necessary in order to determine the assessment."

The inspection instruction describes the fact that assessment of corrosion damage must be undertaken in line with this guide. The corrosion damage guide can be downloaded from the following link: http://www.vegvesen.no/Kjoretoy/Eie+og+vedlikeholde/EU-kontroll/for-kontrollorganene

We also draw your attention to the fact that if any improper repair or modification is discovered, this is a defect which must be evaluated with a level 2 or 3 fault.

Finally, we would again like to point out the importance of you working in your capacity as a testing centre or workshop to inspect drawbars and associated components in line with the inspection