Accident
Investigation Board
Norway

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REPORT ON FIRE IN HEAVY GOODS VEHICLE IN THE OSLOFJORD TUNNEL ON NATIONAL ROAD 23 ON 5 MAY 2017

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Photos: AIBN

TABLE OF CONTENTS

REPORT ON ROAD TRAFFIC ACCIDENT

Date and time:	5 May 2017, at 17:50
Scene of the accident:	The Oslofjord tunnel, Frogn municipality, Akershus county
Road no, main section (hp), km:	National road 23, hp 1, km 8.240
Type of accident:	Vehicle fire in a tunnel
Vehicle type and combination:	MAN 18.440 tractor unit with Kogel semitrailer
Type of transport operation:	Goods transport subject to a licence requirement

NOTIFICATION OF THE ACCIDENT

At 17:55 on Friday 5 May 2017, the Traffic Control Centre (VTS) Region East notified the Accident Investigation Board Norway (AIBN) of a fire in a heavy goods vehicle on national road (Rv) 23 in the Oslofjord tunnel. The incident occurred at 17:50. VTS was alerted by the automatic incident detection (AID) system that a vehicle had stopped in the tunnel, and a CCTV camera in the tunnel ceiling captured the development of the vehicle fire. On the basis of an overall assessment of the situation and the damage potential that a fire in a heavily trafficked undersea tunnel represents, the AIBN chose to respond that evening and arrived at the scene of the incident at 23:00.

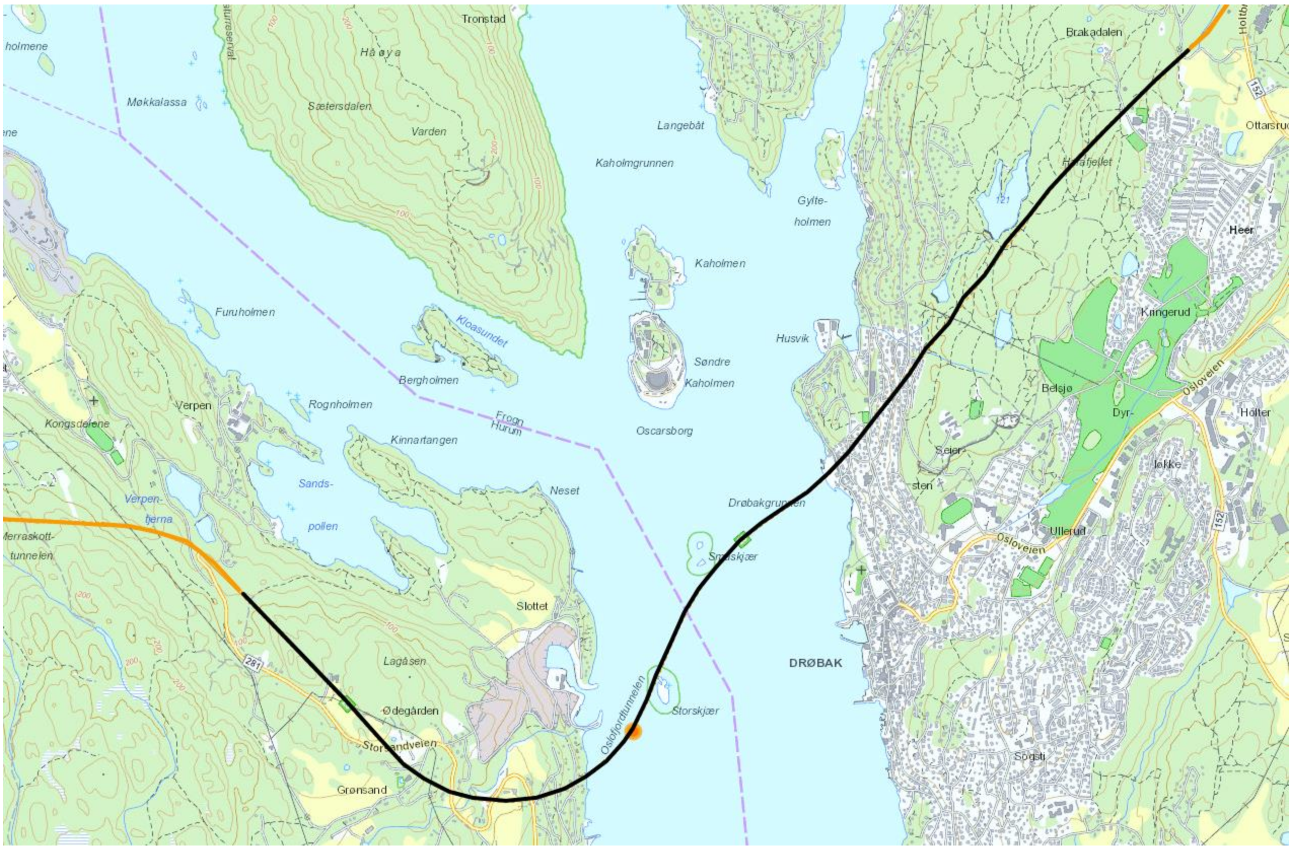

Figure 1: The Oslofjord tunnel (in black) is part of the national road 23 road (in orange), and connects Måna in Frogn municipality in Akershus county with Verpen in Hurum municipality in Buskerud county. Map: Kystinfo.no. Illustration: AIBN

SUMMARY

On Friday 5 May 2017 at 17:50, a fire broke out in a Latvian-registered heavy goods vehicle inside the Oslofjord tunnel. The heavy goods vehicle was on its way up a slope towards Drøbak and was approximately 2.3 km from the tunnel exit. At this point, it had driven approximately 5 km from the tunnel entrance at the Hurum end. The driver initiated extinguishing, but did not manage to stop the fire. He then evacuated the tunnel as a passenger in a car that happened to be passing, and was not injured during the incident.

The Traffic Control Centre (VTS) closed the Oslofjord tunnel at 17:51, approximately one minute after VTS received an incident detection notification of a fire in a vehicle via the tunnel's AID system. Seven vehicles drove into the tunnel after the closure was initiated despite activated red stop signals. Among these were two heavy goods vehicles that continued all the way to the scene of the fire before stopping. It was later discovered that the Oslofjord tunnel had been closed via the tunnel's back-up control system because of a technical fault. This meant that it took longer than normal for the barriers at the tunnel entrances to go down. It has also been revealed that the radio notification system in the tunnel was not working during the incident, and that the road users were thereby not notified of the fire by radio.

The tunnel's ventilation system stopped automatically when the tunnel was closed. Attempts were made to activate the fire ventilation system six minutes later, but it was not possible to activate via the signal plan 'Brannstengt' ('Fire closure'). For this reason, a traffic operator from VTS had to activate the fire ventilation manually in the control system. Approximately 12 minutes after the tunnel had been closed, response and rescue personnel drove into the tunnel from the Drøbak end. They requested full fire ventilation, which is predefined in the direction towards Hurum, when they were met by a smoke plug around 250 metres before the scene of the fire. This meant that smoke and ventilation air were carried 5 km towards the tunnel exit at the Hurum end. The tunnel was filled with smoke with an airspeed of 5-6 m/s.

The drivers of the two heavy goods vehicles that had driven all the way to the scene of the fire before stopping entered the nearest emergency shelter in the tunnel when they understood that the situation was serious. As a result of this, VTS was notified of activity in the 'P' emergency shelter, located 210 metres from the burning vehicle, and two persons were observed in the emergency shelter via CCTV monitoring. The fire service then entered the tunnel with smoke divers, and both road users were evacuated from the tunnel about one hour after the fire had started. Both drivers received minor burns in the incident.

The heavy goods vehicle, including its load, was completely burnt out. There were also incipient fires in the two heavy goods vehicles that stopped behind the burning vehicle, and both vehicles received significant smoke and heat damage, including on parts of their loads. The fire service's good and coordinated extinguishing effort was decisive to the fire being extinguished and limited to only one vehicle in this situation.

The fire in the heavy goods vehicle started as the result of an engine breakdown. A connecting rod and a piston pin from the accident vehicle's engine were found on the road just before the scene of the fire. Technical investigations later revealed a large hole in the engine block's left side from where these parts had fallen out. This was also captured by one of the tunnel's video cameras, which showed that the parts were red-hot when they hit the road. The investigation has revealed that the heat development in these essential parts was due to the flow of oil being reduced or stopped

after a bearing had moved out of position. Damage to a fuel pipe has also been revealed in connection with these parts being ejected through the engine block. The Accident Investigation Board Norway (AIBN) believes that the fire started when fuel or oil was ignited by the heat that had been generated in the engine.

The AIBN has seen several similarities with the vehicles that caught fire in the Oslofjord tunnel in 2017 and 2011. Both tractor units came from the same manufacturer and the engine type was almost identical, and there are a number of similarities in the damage to the engine parts. The investigation has not been able to establish for certain that this is due to weaknesses in construction, since both vehicles had driven a great number of kilometres and there are indications of inadequate maintenance.

No safety recommendations have been issued in this regard, but the investigation points out the importance of vehicles transporting goods through long subsea tunnels with demanding geometric conditions being correctly equipped and adequately maintained.

The AIBN has examined the safety follow-up of the Oslofjord tunnel, and mapped and assessed the systematic activities that the Norwegian Public Roads Administration has established to address safety in the tunnel. Through this investigation, the AIBN has revealed five important safety problems that the AIBN believes can affect the safety in the Oslofjord tunnel:

a) There were several major and minor technical faults in the tunnel's safety equipment. There is no comprehensive nonconformity system where faults and nonconformities in the tunnel's safety equipment can be reported and technical operational statuses can be monitored and followed up.

b) Several faults and deviations in the tunnel's safety equipment were not revealed at periodic inspections.

c) It has not been the Norwegian Public Roads Administration's practice to follow the internal guidelines in manual R511 for safety approval of tunnels in operation. The change has not been evaluated or in other ways risk assessed by the Norwegian Public Roads Administration.

d) The Norwegian Public Roads Administration as the tunnel manager has not kept the emergency response plan for the Oslofjord tunnel up to date in accordance with the requirements of the Tunnel Safety Regulations. The last risk analysis for the tunnel has not been attached to or implemented in the emergency response plan, and the plan does not cover corrective measures in the event of failure of technical equipment.

e) The Norwegian Public Roads Administration as the tunnel manager has not organised regular exercises in the Oslofjord tunnel in accordance with the requirements of the Tunnel Safety Regulations. Nor has a fire inspection of the tunnel as a special fire object been carried out since 2013.

On the basis of the findings made in this investigation and current practice for the safety follow-up of the Oslofjord tunnel, the AIBN believes that the Norwegian Public Roads Administration has room for improvement in terms of its follow-up of tunnel safety.

The AIBN issues four safety recommendations on the basis of this investigation.

1. FACTUAL INFORMATION

1.1 Sequence of events

The AIBN has compiled this description of the sequence of events on the basis of obtained information, interviews with involved people and response personnel and surveillance footage from the Norwegian Public Roads Administration's Traffic Control Centre (VTS).

1.1.1 Triggering event

On 5 may 2017, after having unloaded goods at Langhus, Vestby and Vinterbro in the morning, the driver of a Latvian-registered heavy goods vehicle proceeded to Drammen to load toilet paper from Vajda-Papir Scandinavia AS. The cargo was bound for Västerås in Sweden.

The driver chose a route from Drammen to Västerås that took him through the Oslofjord tunnel. At 17:45, the heavy goods vehicle entered the 7,305-metre-long Oslofjord tunnel from the west. According to the driver, the vehicle travelled at a steady speed of around 70 km/h down to the lowest point of the tunnel, a distance of approximately 2,450 metres.

The driver stated that he used the tractor unit's exhaust brake to slow down the vehicle while driving down the 7% slope in the tunnel. The exhaust brake gradually became less effective during the descent, which the driver described as the system turning itself off and on. At that point, the driver started applying the vehicle's service brakes by pressing the brake pedal.

After the heavy goods vehicle had started to ascend from the bottom of the tunnel, the driver heard mechanical scraping noises followed by an explosion coming from the underside of the tractor unit. He stopped the vehicle immediately and applied the handbrake before turning off the tractor's engine and lights. The heavy goods vehicle stopped in the right-hand lane approximately 2,250 metres from the tunnel exit on the Drøbak side at approximately 17:50.

Figure 2: Triggering event with incipient fire under the heavy goods vehicle. Photo: CCTV image from the tunnel – NPRA

At 17:51, the driver left the tractor unit to see what had happened, and found that there was a fire in the engine compartment with liquid leaking out below it. The liquid that was running onto the road surface was also on fire. He fetched the fire extinguisher from the tractor unit to try to put out the fire. There was now a great deal of smoke, and the smoke was moving towards the Drammen side of the tunnel. The driver was unable to extinguish the fire, which escalated quickly.

At 17:52, a passenger car stopped in an emergency lay-by approximately 40 metres in front of the burning heavy goods vehicle, and the passenger car's driver called VTS from an emergency phone inside the tunnel to notify them of the burning vehicle. VTS instructed the passenger car’s driver to take the driver of the heavy goods vehicle with him and evacuate the tunnel. The two drivers evacuated at 18:04 by driving up the tunnel in the direction of Drøbak.

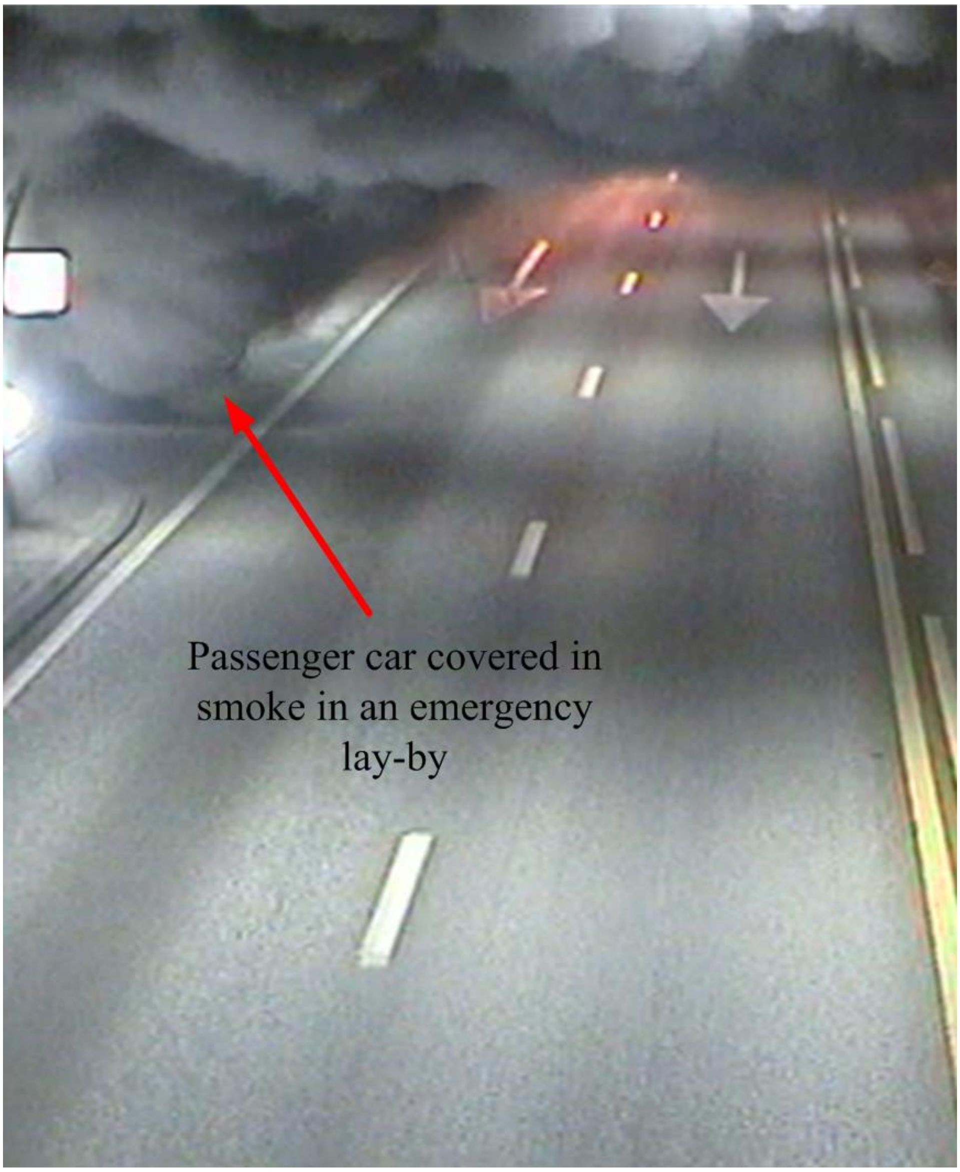

Figure 3: Smoke in the tunnel with the passenger car in an emergency lay-by in front of the heavy goods vehicle. Photo: CCTV image from the tunnel – NPRA

Several vehicles travelling in both directions passed close by the burning heavy goods vehicle on their way towards the tunnel exits, both before and after the attempt to extinguish the fire. At 17:53, the upper part of the tunnel in the direction of Drammen was partially filled with smoke, but several vehicles nonetheless continued to drive down the tunnel towards the burning vehicle. At this time, the fire in the heavy goods vehicle was developing rapidly, resulting in heavy smoke in the tunnel.

1.1.2 Notification, tunnel closure and initial evacuation

1.1.2.1 *Notification*

VTS was alerted to the incident of a vehicle stopping and the subsequent fire at 17:50[1] via the automatic incident detection (AID[2]) function in the tunnel's CCTV system. At about the same time, at 17:51, Follo fire service IKS (intermunicipal company) was

[1] The cited times are logged times as reported in VTS's incident report about the vehicle fire.
[2] AID = Automatic Incident Detection.

notified by a passing driver calling the emergency telephone number 110. VTS notified the emergency services at 17:54. VTS and the fire service's emergency communication centre east (ABØ) kept the line open throughout the incident.

The driver of the heavy goods vehicle contacted his employer on his mobile phone when the incident occurred. He did not use an emergency phone in the tunnel or his mobile phone to contact the emergency services or VTS.

1.1.2.2 *Tunnel closure*

VTS closed the Oslofjord tunnel at 17:51, approximately one minute after it had been alerted to the incident by the AID system. The closure was carried out in accordance with the signal plan 'Brannstengt' ('Fire closure'), the pre-defined control plan for the tunnel.

Fire closure entailed closing the tunnel in both direction with flashing red stop signals and lowering the barriers at both tunnel portals. After the incident, it came to light that the Oslofjord tunnel was closed using the tunnel's backup control system, and that this system was faulty. The fault meant that it took approximately 55 seconds to lower the barriers at the tunnel portals, and not 20 seconds as would have been the case based on normal procedure.

As the tunnel was in the process of closing due to fire, five passenger cars and two heavy goods vehicles entered the tunnel despite the flashing red stop signals being activated and signs bearing the text 'Tunnel stengt/Closed' at the tunnel entrances. Three passenger cars later turned around inside the tunnel, while two heavy goods vehicles and two passenger cars continued into the tunnel. One of the passenger cars turned back when it encountered smoke, while the second one, a van pulling a trailer, turned around inside the actual smoke plug. The van exited the tunnel on the Drammen side at 18:03. The two heavy goods vehicles continued all the way to the scene of the fire before stopping.

When the fire closure of the Oslofjord tunnel was initiated, there were a total of 127 vehicles inside the tunnel. Of these vehicles, 63 passed the burning heavy goods vehicle despite heavy smoke emission from the vehicle and the fire's rapid development.

Closure due to fire meant that other tunnels nearby[3] were also closed by means of barriers. This presented a challenge for the emergency services responding to the incident, as queues formed at the approaches to the tunnels. No direct contact between VTS and the emergency services had been established at the time and, according to the response personnel, this complicated communication with VTS to have barriers opened.

[3] The Frogn and Vassum tunnels at the Måna side of the Oslofjord tunnel, and the Stampleinsås and Merraskott tunnels on the Hurum side.

Figure 4: Vehicles continued to drive into the tunnel despite warning lights at the tunnel entrance. The two heavy goods vehicles that were caught in the smoke can be seen driving towards the entrance. Photo: CCTV image from outside the tunnel – NPRA

Figure 5: Vehicles that continued to drive towards the tunnel by continuing past the barrier as it was being lowered. Photo: CCTV image from outside the tunnel – NPRA

Figure 6: Two heavy goods vehicles driving towards the fire encounter smoke about 400 metres before reaching the burning heavy goods vehicle. A passenger car is turning in the background. Photo: CCTV image from the tunnel – NPRA

Figure 7: Van pulling a trailer on its way out of the tunnel after having turned around in the smoke. Photo: CCTV image from the tunnel – NPRA

1.2 Firefighting and rescue work

1.2.1 The driver's extinguishing effort

About two minutes after the fire started, the driver of the heavy goods vehicle attempted to extinguish the fire using the fire extinguisher from his vehicle. The footage from CCTV cameras inside the tunnel shows that the fire receded somewhat, but quickly flared up again once the fire extinguisher was empty.

The driver then decided to discontinue his extinguishing efforts. The wall-mounted fire extinguishers in the tunnel had not been used.

1.2.2 How the fire service's efforts were organised

The length of the Oslofjord tunnel means that three fire services are involved, namely Røyken fire and rescue service, Hurum fire service and Follo fire service IKS ('FBV').

FBV has its response location by the eastern tunnel portal at Drøbak, Hurum fire service by the escape tunnel at Storsand and Røyken fire and rescue service by the escape tunnel at Storsand and the western tunnel portal on the Hurum side of the Oslofjord. Assistance is sought from nearby fire services on both sides of the Oslofjord if necessary.

According to the emergency response plan for the tunnel, FBV's on-scene fire commander[4] is to lead the fire services' response in the Oslofjord tunnel in connection with incidents and accidents. Efforts directly targeting the scene of the accident/fire is therefore to be carried out from the Drøbak side under FBV's command, FBV being the fire service with the most response and firefighting resources. Røyken fire and rescue service and Hurum fire service are responsible for rescue and evacuation efforts from the Hurum side in connection with incidents in the tunnel.

1.2.3 The fire service's incident notification and response

At 17:51, ABØ was notified of the vehicle fire in the Oslofjord tunnel by a call to the 110 emergency communication centre by a motorist who passed the burning heavy goods vehicle. FBV was notified immediately, and then Røyken fire and rescue service and Hurum fire service via Vestviken 110 emergency communication centre.

At 17:53, FBV dispatched an on-scene fire commander, three crew vehicles, two tankers and one ATV[5] to the Oslofjord tunnel. The first FBV vehicle reached the tunnel ten minutes later. The joint on-scene commander for Røyken fire and rescue service and Hurum fire service arrived at the tunnel at 18:04. The first response vehicle from Røyken fire and rescue service arrived at 18:07, and Hurum fire service's first vehicle arrived at 18:26.

1.2.4 Firefighting and resources

On arriving at the Oslofjord tunnel, FBV immediately entered the tunnel with one crew vehicle and one tanker, and encountered the smoke layer after approximately two kilometres, 250 metres before reaching the scene of the fire. The response team leader

[4] The Norwegian title was 'Fagleder Brann', and has since been changed to 'Innsatsleder Brann'.
[5] All-Terrain Vehicle with four or six wheels and one driver's seat.

requested full fire ventilation in the tunnel and continued towards the fire. At that time, FBV had not received information about the number of vehicles and people in the tunnel.

When notified of the fire in the Oslofjord tunnel, FBV responded with a new purpose-built tanker, acquired at the turn of the year 2016/2017. The purpose-built tanker can carry 11,000 litres of water and 500 litres of CAF.[6] The tanker has two deluge guns, one on the roof of the vehicle and one mounted on the front bumper. The deluge gun mounted on the bumper is specially intended for use in tunnels. Both deluge guns are operated from the tanker's cabin. The tanker is also equipped with a thermal imaging camera at the front, with a monitor and joystick inside the cabin.

Figure 8: View from the cabin of FBV's purpose-built tanker used during the extinguishing efforts in the Oslofjord tunnel on 5 May 2017. Photo: Follo fire service IKS

[6] Compressed Air Foam System.

Firefighting was initiated from the tanker while preparations were made for extinguishing efforts from the crew vehicle. Moss intermunicipal fire and rescue service also assisted the extinguishing effort with two tankers. Around 100,000 litres of water were used to fight the fire. The water was carried to the scene of the fire by tankers and taken from the tunnel's storm water drainage pit. The CAFS was also used.

At 18:50, FBV reported that the vehicle fire was under control, and the extinguishing effort was concluded at 20:13.

While the extinguishing effort was in progress inside the tunnel, Hurum fire service and Røyken fire and rescue service followed the procedure set out in the emergency response plan for the Oslofjord tunnel, and started searching the tunnel when FBV's response team leader had confirmed that they could enter.

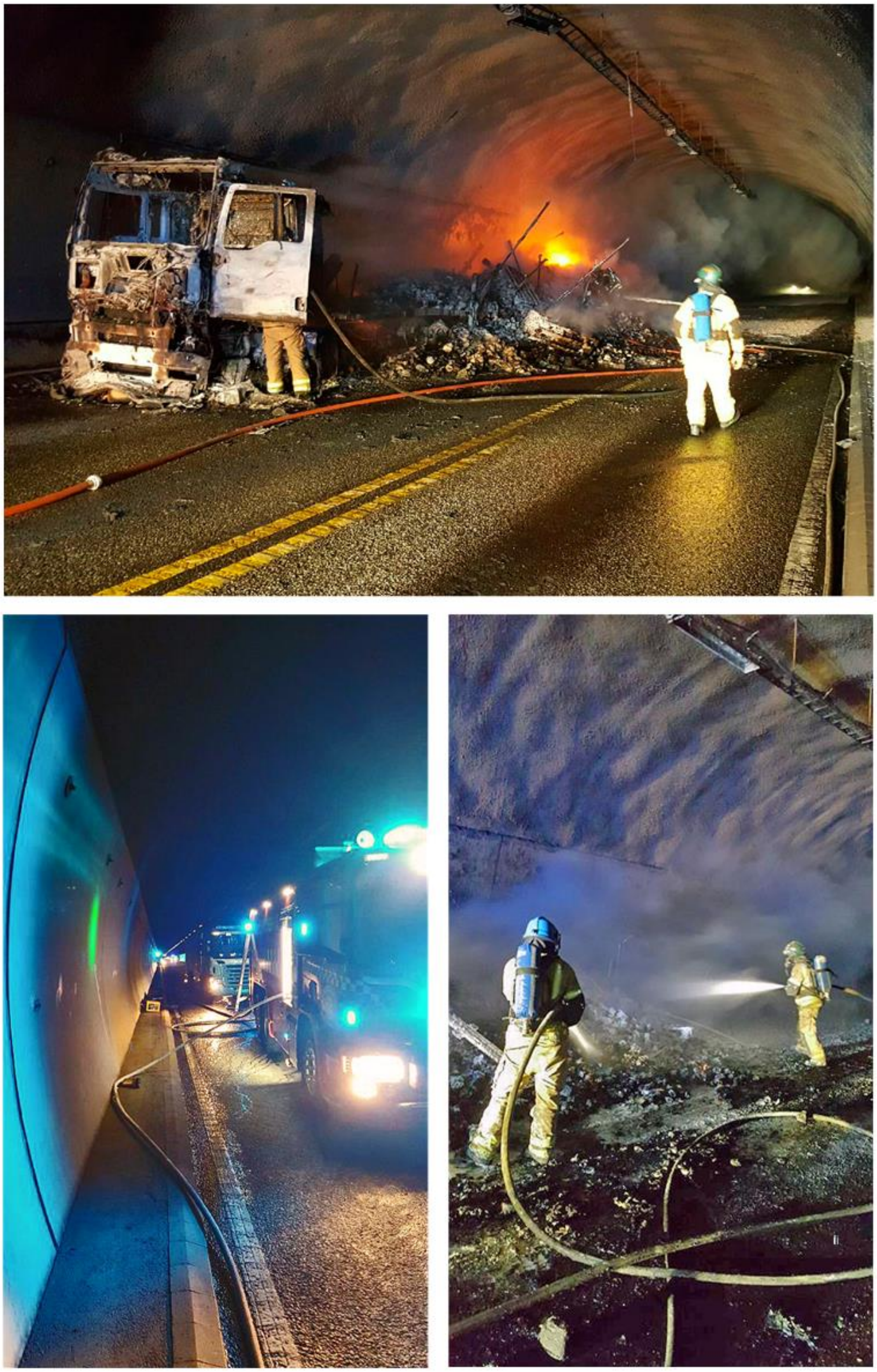

Figure 9: The top photo shows the effect of the fire ventilation on FBV’s working conditions when the smoke plug was ventilated away from the fire in the direction of Drammen. The bottom left photo shows the fire service's tankers, which drove back and forth to fill up FBV’s tanker. As a result, FBV did not run out of water during the extinguishing effort. The bottom right photo was taken when FBV had managed to suppress most of the flames in the vehicle. Photo: Moss intermunicipal fire and rescue service

1.2.5 The efforts of the police and health service

The Oslofjord tunnel falls under East Police District, which will provide the on-scene commander function and have overall responsibility for all emergency response to incidents in the Oslofjord tunnel. The police's response to incidents in the tunnel is led from the Drøbak side. The incident command post (ICP) for the police, health and fire services is set up at the toll booth office outside the tunnel entrance.

The police on both sides of the Oslofjord tunnel was notified of the incident at 17:54. Personnel from East Police District arrived at the Drøbak side of the tunnel nine minutes later and set up ICP outside the tunnel. Lier police station placed an on-scene commander at the tunnel entrance on the Hurum side and one by the escape tunnel at Storsand.

At 18:12, ambulances arrived at the Oslofjord tunnel. Ambulances were deployed from Oslo and Akershus ambulance service, the rescue helicopter service and Søndre Buskerud ambulance service. In an early phase, the health service's on-scene commander also ordered a CBRN[7] vehicle and two health express buses to be sent to the Oslofjord tunnel to assist in the event of a high number of casualties. The medical resources received confirmation that there were no major injuries at an early stage, and the health express buses and the CBRN vehicle were dismissed.

1.2.6 Overview of the emergency services' resources

When notified of a vehicle fire in the Oslofjord tunnel, the emergency services mobilised a great deal of resources. Table 1 lists the police, fire service and health service resources dispatched to the Oslofjord tunnel for the firefighting, search and rescue work during the incident.

Figure 10: The resources at the fire service's disposal in connection with the fire in the Oslofjord tunnel on 5 May 2017 included an ATV. Photo: Hans O Torgersen/Aftenposten

[7] Chemical, biological, radiological and nuclear substances.

Table 1: Resources from each of the emergency services that responded to the fire in the Oslofjord tunnel.

Emergency service	Resources
Police	
Follo Police District	On-scene commander, three patrol cars
Lier police station	Unknown
Fire service	
Follo fire service IKS	3 crew vehicles, 2 tankers, 3 ATVs, 1 on-scene commander + 1 support staff
Hurum fire service	1 crew vehicle, 1 tanker, 1 UTV, 1 smaller vehicle
Røyken fire and rescue service	1 crew vehicle, 1 tanker, 2 smaller vehicles, 1 ATV
Moss intermunicipal fire and rescue service	2 tankers
Health service	
Oslo and Akershus ambulance service	13 ambulances
Søndre Buskerud ambulance service	3 ambulances
The rescue helicopter service	3 helicopters
Other	1 CBRN vehicle, 2 health express buses

1.2.7 Use of ventilation during the incident

The ventilation shuts down automatically when the Oslofjord tunnel is closed due to fire. This is a pre-set action. The emergency response plan for the Oslofjord tunnel describes this as follows:

In the event of a fire in the tunnel, the signal plan 'Brannstengt' ('Fire closure') shall be implemented. This means that if the tunnel's ventilation system is running, it will shut down. The VTS operators shall spend the first few minutes, up to a maximum of seven minutes after a fire or smoke development has been detected, assessing the situation in the tunnel.

This entails observing whether there are many vehicles/persons inside the tunnel, the location of the fire in the tunnel, the type of vehicle that is on fire, which direction the burning vehicle is facing, whether dangerous goods are involved etc. In order to ensure that fire crews have good visibility and working conditions when they arrive at the scene, the operators will consult with the 110 emergency *communication centre or directly with the on-scene fire commander to decide if and when to start fire ventilation.*

This procedure was followed, and the ventilation system was shut down at 17:51. Telephone contact was established between VTS and ABØ at 17:54, and it was decided to keep the fire ventilation switched off. At that time, there were road users inside the tunnel as well as vehicles passing the burning heavy goods vehicle.

At 17:57, VTS attempted to activate the fire ventilation in consultation with ABØ. Fire ventilation, which represents 50% of the system's capacity, proved impossible to activate via the signal plan 'Brannstengt' ('Fire closure'), however, and had to be activated individually via the control system by a VTS operator.

The response personnel entered the tunnel at 18:03 and encountered the smoke plug around 250 metres before reaching the scene of the fire. The fire service then requested full ventilation from ABØ. VTS, which was on a direct line with ABØ, heard the request and initiated full ventilation at 18:04. According to the fire service, this caused the smoke to move towards the Hurum side, and the response personnel were able to follow the smoke plug towards the fire. It is estimated that this delayed the fire service by two minutes.

After fire ventilation was initiated, the smoke and ventilation air from the fire were led 5 km towards the tunnel opening on the Hurum side, and the tunnel filled with smoke at a rate of 5–6 m/sec. The smoke from the fire reached the Hurum side of the tunnel at 18:24, and at 18:30, Røyken fire and rescue service reported large amounts of smoke coming from the tunnel.

Figure 11: Smoke from the fire coming out of the tunnel portal on the Hurum side of the Oslofjord tunnel. Photo: Edgar Dehli

1.2.8 Search and rescue efforts

Røyken fire and rescue service assembled at the tunnel portal on the Hurum side in accordance with the pre-defined response plan. Hurum fire service entered the escape tunnel at Storsand to observe the development of the smoke in the tunnel and check whether anybody was evacuating through the tunnel. When the smoke had cleared, Hurum fire service started their search using a UTV (Utility Task Vehicle) at 18:48.

Hurum fire service met FBV in the tunnel, and they agreed on how to divide the search of the tunnel and emergency shelters between them. As the search progressed towards the Hurum side of the tunnel, they encountered Røyken fire and rescue service, which had started from the tunnel opening on the Hurum side. There were no road users in the escape tunnel, and nobody evacuated the tunnel on foot on the Hurum side of the tunnel. At 19:18, the fire service confirmed that no vehicles or persons were left inside the road tunnel.

VTS checked the cameras in the emergency shelters during the incident, but could not confirm that there were no more people in the tunnel. The fire service therefore conducted a full search of the tunnel, including all the emergency shelters and behind the tunnel lining. The search of the emergency shelters was completed at 19:35, and confirmation that the tunnel had been cleared was given three minutes later.

Røyken fire and rescue service and Hurum fire service did not enter the tunnel until they received the go-ahead from ICP.

Figure 12: Smoke from the Oslofjord tunnel during the fire on 5 May 2017. Photo: Edgar Dehli

1.2.9 Evacuation of road users

The driver of the burning heavy goods vehicle stayed by the vehicle for about six minutes before being picked up by a passing passenger car. As shown by the tunnel’s CCTV system, the scene of the incident was completely covered in smoke at 17:56, and the passenger car left the scene immediately afterwards. The passenger car exited the tunnel on the Drøbak side at 18:04.

At 18:04, VTS received an alarm (door alarm and AID) from emergency shelter ‘P’, located 210 metres from the burning heavy goods vehicle, and saw on the CCTV system that there were two persons inside the shelter. They were the drivers of the two heavy goods vehicles that had driven through the red light to enter the tunnel and stopped at distances of 123 and 156 metres, respectively, behind the burning vehicle in the direction towards Drøbak. At 18:11, ICP was notified by VTS that there were two persons inside the emergency shelter, and this information was communicated to the fire service.

FBV started its ATV search of the tunnel at 18:25, and two smoke divers arrived at emergency shelter ‘P’ four minutes later. The two drivers had then spent about 25 minutes in the shelter. The smoke divers communicated to them that the fire was under control and that it was safe to stay in the shelter.

The two drivers were not evacuated from the tunnel immediately, however. According to FBV, this course of action was chosen because of the fire service’s capacity and lines of evacuation, and because of the high temperature in the tunnel caused by the vehicle fire. It was decided to delay the evacuation until the temperature in the tunnel decreased.

Figure 13: Firefighters have arrived in the emergency shelter. The smoke in the shaft between the emergency shelter and the tunnel is visible in the photo. The road users used the first aid kit in the emergency shelter to drink water and treat burns they had suffered to their hands.
Photo: CCTV image from inside emergency shelter ‘P’ – NPRA

At 18:37, the first of the two drivers who had taken refuge in the emergency shelter was evacuated by ATV using a buddy mask attached to the firefighter’s breathing apparatus, followed by the second driver at 18:46. Since only one buddy mask was in working order during the evacuation, the drivers had to be evacuated one at a time. At the time of the evacuation, the two drivers had spent about 32 and 42 minutes, respectively, in the emergency shelter.

At 18:52, both drivers had been evacuated from the tunnel and were attended to by health personnel on site. They were evacuated from the tunnel on the Drøbak side, where the majority of the healthcare resources were based. One of them was taken to Akershus University Hospital by ambulance, while the other received medical attention on site.

Figure 14: Firefighters preparing to evacuate the two road users. Photo: CCTV image from inside emergency shelter 'P' – NPRA

1.2.10 Coordination and communication between the emergency services and VTS

1.2.10.1 *Coordination between emergency services*

The ICP command post was set up by the toll booth office outside the tunnel portal on the Drøbak side in accordance with the emergency response plan for the tunnel. A BAPS[8] channel for coordination between the emergency services was established. Several communication channels were used during the work inside the tunnel, and monitoring of all channels was organised to improve coordination between the emergency services.

Because of problems communicating via the digital multi-agency public safety network Nødnett in the road tunnel and escape tunnel, FBV and Hurum fire service were at times unable to receive messages from or transmit messages to other emergency services during the incident. The firefighters used mobile phones to compensate for these problems.

[8]BAPS - *Brann Akuttmedisin Politi Samvirke* (Fire, emergency medicine, police cooperation) – the emergency services' system for sharing information with each other. *Samvirke* is a shared talk group that other parties may also be granted access to.

1.2.10.2 *Coordination between the emergency services and VTS*

ICP established direct contact with VTS, and a representative of the fire service's on-scene command was responsible for this communication throughout the incident.

The alarm was received at watch handover time at ABØ and VTS, which meant that they had more resources than normal available, and this made it possible to maintain direct contact between ABØ and VTS throughout the incident.

During the work in the tunnel, a talk group was established that allowed VTS to be in direct contact with ICP. During the initial phase of the incident, VTS did not have access to a shared talk group with the emergency services.

The fire closure of the Oslofjord tunnel meant that nearby tunnels were also closed with barriers. This created some challenges for the emergency services responding to the incident, and queues formed at the approaches to the tunnels.

1.3 Personal injuries

The driver of the heavy goods vehicle that caught fire was not injured in the incident. The two drivers who were evacuated from the emergency shelter both sustained minor burns.

They burnt their hands when they touched the emergency shelter door handle, which was made of metal and was very hot because of the intense heat from the fire.

No road users suffered serious smoke inhalation injuries as a result of the incident.

1.4 Damage to vehicles

The heavy goods vehicle, including its cargo, was completely burnt out. Non-metal components on and around the heavy goods vehicle were charred, and steel components were partly deformed as a result of the intense heat.

Figure 15: The heavy goods vehicle after the fire had been extinguished, with burnt-out tractor unit and semi-trailer. Photo: The police

1.4.1 Engine part findings at the scene of the incident

Engine parts from the heavy goods vehicle were found scattered on the road at distances of between 51.2 and 79.3 metres behind the burnt-out vehicle, see Figure 16.

Figure 16: Engine parts from the heavy goods vehicle scattered on the road. Photo: The police

One of the connecting rods from the engine was found in the roadway 67.6 metres behind the burnt-out heavy goods vehicle. Other parts of the engine block and a piston were also found in the roadway behind the vehicle.

Figure 17: One of the connecting rods from the engine, located in the roadway, 67.6 metres behind the burnt-out heavy goods vehicle. Photo: The police

It was soon determined that the engine parts came from the tractor unit's engine. The engine parts had cooled down to the ambient temperature when they were found, but subsequent observations from CCTV footage from the tunnel showed that some of these parts were red-hot when they fell onto the road.

Figure 18: A piston pin and a red-hot connecting rod lying in the roadway inside the tunnel after the engine breakdown. Photo: CCTV image from the tunnel – NPRA

1.4.2 Technical examination of the engine carried out in Redningsverket AS's premises in Råde

The heavy goods vehicle was examined on 12 May 2017. No findings were made that suggested that the vehicle fire could be linked to faults in the electrical system.

The examination revealed a big hole in the lower left side of the engine block. The hole was circular in shape with a diameter of approximately 14 centimetres at its widest, and a fuel pipe outside the hole had been severed.

Signs of short-circuiting caused by the engine breakdown were found near the hole in the engine block. These findings indicate that the fire originated in the engine compartment.

Figure 19: Hole in the lower left side of the engine block. The fuel line on the outside of the engine block had been severed. Photo: The police

1.4.3 Technical examinations of the engine and components in the AIBN's premises

Following the technical examination in Redningsverket AS's premises in Råde, the engine was taken to the AIBN's premises at Lillestrøm, where mechanics from MAN took the engine apart on 1 and 2 November 2017.

Figure 20 shows an exploded view drawing of the crankshaft system with pistons.

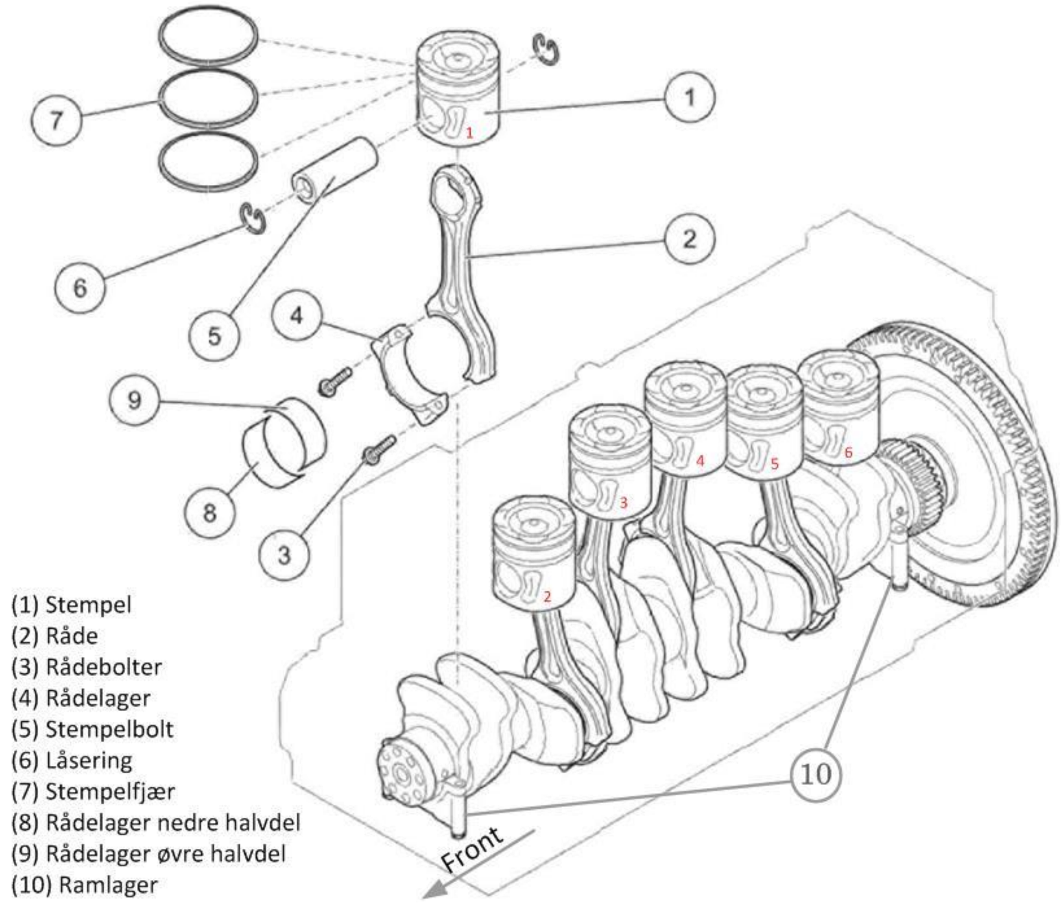

Figure 20: Exploded view drawing of the crankshaft system with pistons. 1. Piston. 2. Connecting rod. 3. Connecting rod bearing bolt. 4. Connecting rod bearing cap. 5. Piston pin. 6. Locking ring. 7. Piston ring. 8. Bottom connecting rod bearing shell. 9. Top connecting rod bearing shell. 10. Crankshaft bearing cover. Illustration: MAN/AIBN

Parts of the connecting rod and the piston from cylinder 4 were also found when the engine was disassembled, see Figure 21. These parts matched those found on the road inside the tunnel.

Figure 21: Parts from cylinder number 4, including the piston, piston pin and connecting rod. Photo: The police

1.4.3.1 *Examination of the engine to determine the cause of the fire*

The examination of the damaged engine showed damage to the engine block and crankpin's bearing surfaces where the connecting rod for cylinder number 4 was attached. Disassembly of crankshaft bearing number 4 showed that the bearing halves had come loose and rotated with the crankpin. The rotation of the bearing halves had reduced/blocked the oil supply to big-end bearing number 4. At the same time, it also reduced/blocked the oil supply to crankshaft bearing number 4.

Figure 22 is a photo of the disassembled crankshaft bearing number 4, where the bearing halves had rotated. The normal position of the bearing halves is for the split to be parallel with the split in the bearing block for the crankshaft bearings. Extensive damage was also found in the bearing halves of crankshaft bearing number 4, see Figure 23.

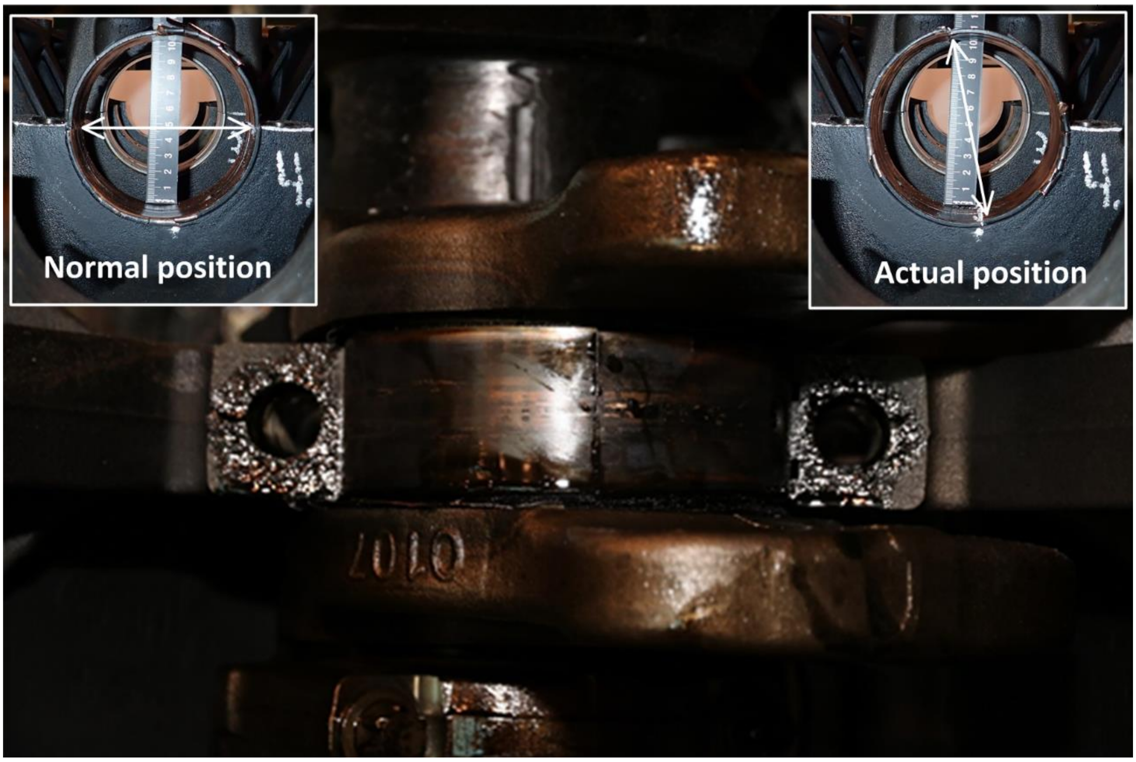

Figure 22: Close-up of the crankpin where the bearing halves of crankshaft bearing number 4 have rotated almost 90°. Photo: The police/AIBN. Illustration: AIBN

Figure 23: Bearing halves from crankshaft bearing number 4 on the left and from crankshaft bearing number 3 on the right. Photo: The police

The bearing halves of crankshaft bearing number 4 are clearly deformed and discoloured, and the damage is consistent with the bearing halves having rotated and been exposed to high temperatures. Figure 23 shows that the bearing halves of crankshaft bearing number 3 are virtually undamaged.

1.4.3.2 *Crankshaft bearing halves*

A visual inspection of the bearing halves for the crankshaft bearings showed that the bearings were from different number series. The manufacturer has informed the AIBN that when an engine is assembled at the factory, the same number series is used for all the crankshaft bearing halves.

The thickness of the crankshaft bearing halves was measured using a micrometer, and all the bearing halves that could be measured were within the manufacturer's stated tolerance limits. The radial slack and diameter of the crankshaft were also measured. The radial slack was somewhat smaller than recommended by the manufacturer, while the crankpin diameter was bigger than the normal dimension, but smaller than the stated dimension for a new crankshaft.

1.4.4 Damage to other vehicles

Two heavy goods vehicles stood 123 and 156 metres, respectively, behind the burning vehicle. These two vehicles were unable to turn around inside the tunnel and could not evacuate when the tunnel filled with smoke.

During the incident, there were also incipient fires in these heavy goods vehicles, and the tractor units and some of the cargo sustained heat, melting and smoke damage as a result of the fire. Plastic components on the exterior of the vehicles were partly melted (bumpers, tarpaulins, mud flaps and mirrors). Neither of the two heavy goods vehicles were in a drivable condition after the fire.

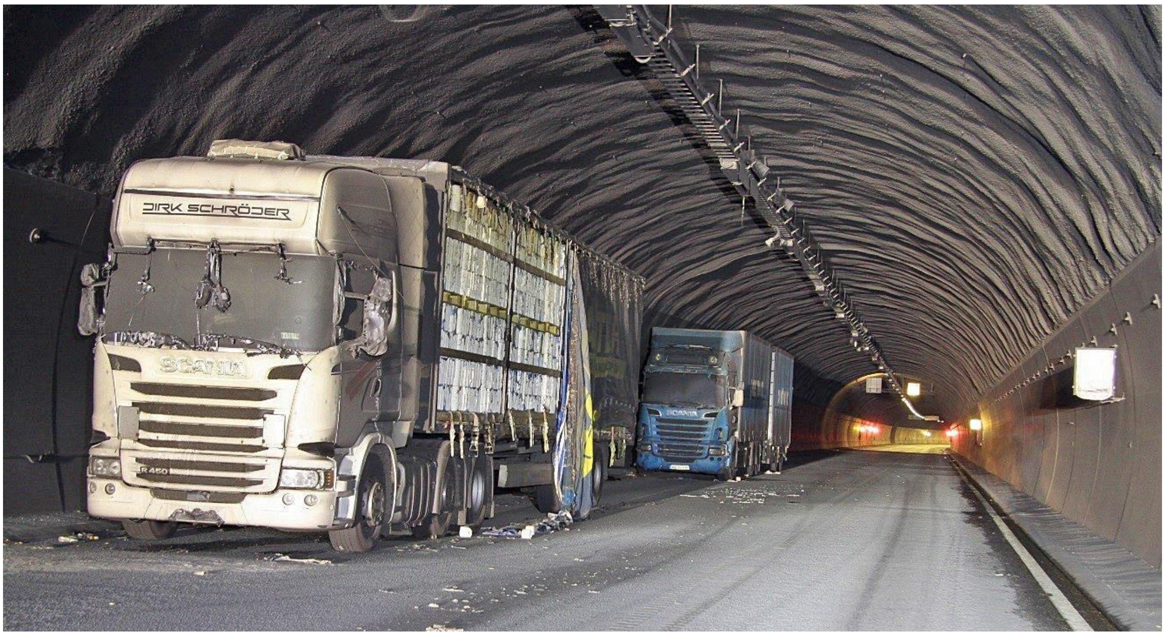

Figure 24: The heavy goods vehicles located 123 and 156 metres, respectively, behind the burning heavy goods vehicle in the tunnel. Both tractor units had visible heat, melting and smoke damage. Photo: The police

Figure 25: Heat, melting and smoke damage on the tractor unit of the heavy goods vehicle located 123 metres behind the burning vehicle inside the tunnel. Photo: AIBN

1.5 Other damage and consequences of the fire

1.5.1 Damage to the tunnel structure and repairs

Based on information from the consultancy company Aas-Jakobsen AS, which has inspected and registered damage to the tunnel lining on assignment from the Norwegian Public Roads Administration (NPRA), spalling was found to have occurred, with a maximum depth of approximately 6–8 cm found on wall lining elements on the right-hand side of the tunnel at the scene of the fire (in the direction in which the heavy goods vehicle was travelling). Cracks had occurred on the rock side of these elements as a result of the heat they had been exposed to during the fire.

The damage also included burning/melting of the sealing compound used in the joints between wall elements on both sides of the tunnel, extending approximately 100 metres from the scene of the fire towards the Hurum side of the tunnel. Visible damage to the cable ladder in the tunnel ceiling and its fastening bolts was also found in the same area.

The sprayed concrete tunnel vault was found to be light grey in colour in the area of the fire, which indicates that soot from the fire was burnt off. This occurs at temperatures exceeding 750 °C, with a probable maximum temperature of as much as 1200 °C. On inspection, localised melting/evaporation of PE foam behind the PE vault in the area of the fire was observed on the opposite side of the scene of the fire. This was caused by heat radiating through the wall joints where the sealing compound between the concrete wall elements had melted or burnt away.

As a result of the fire, six wall elements had to be replaced, and the cable ladders, including lighting fixtures and electrical wiring in the tunnel, had to be replaced over a distance of approximately 400 metres. Equipment and labour costs associated with the repair of electrotechnical systems after the fire amounted to approximately NOK 4.5 million. The total costs resulting from the fire are estimated at about NOK 9.5 million.

Figure 26: Spalling damage to wall elements inside the tunnel. Photo: Aas-Jakobsen/NPRA

1.5.2 Consequences for traffic

Following the fire, the Oslofjord tunnel remained closed for traffic for 24 days until it was reopened at 18:00 on 29 May.

When the tunnel reopened, a temporary ban was introduced on vehicles longer than 12 metres driving through the tunnel on weekdays from 07:00 to 09:00 and from 15:00 to 18:00. The NPRA's report[9] on the incident describes the ban as being based on a wish to reassure others driving through the tunnel during rush hour by keeping long vehicles away.

The ban was lifted on 11 October 2017, when a maximum weight of 32 tonnes was introduced on weekdays from 07:00 to 09:00 and from 15:00 to 18:00.

1.6 Incident site

The heavy goods vehicle stopped in the right lane, approximately 2,250 metres from the tunnel exit on the Drøbak side. The distance from the incident site to the tunnel exit on the Hurum side was 5,000 metres, and to the escape tunnel 3,320 metres.

Based on CCTV footage from the Oslofjord tunnel, the fire started only a few metres before the heavy goods vehicles came to a stop in the tunnel.

The distance from the incident site to emergency shelter 'P', to which the two heavy goods vehicle drivers evacuated, was 210 metres. The distance from the first and second heavy goods vehicles behind the vehicle on fire and emergency shelter 'P' was 87 and 54 metres, respectively.

[9] Norwegian Public Roads Administration. (2017). Rv. 23 Oslofjord tunnel fire on 5 May 2017 – incident report. NPRA Eastern Region, road department for Akershus.

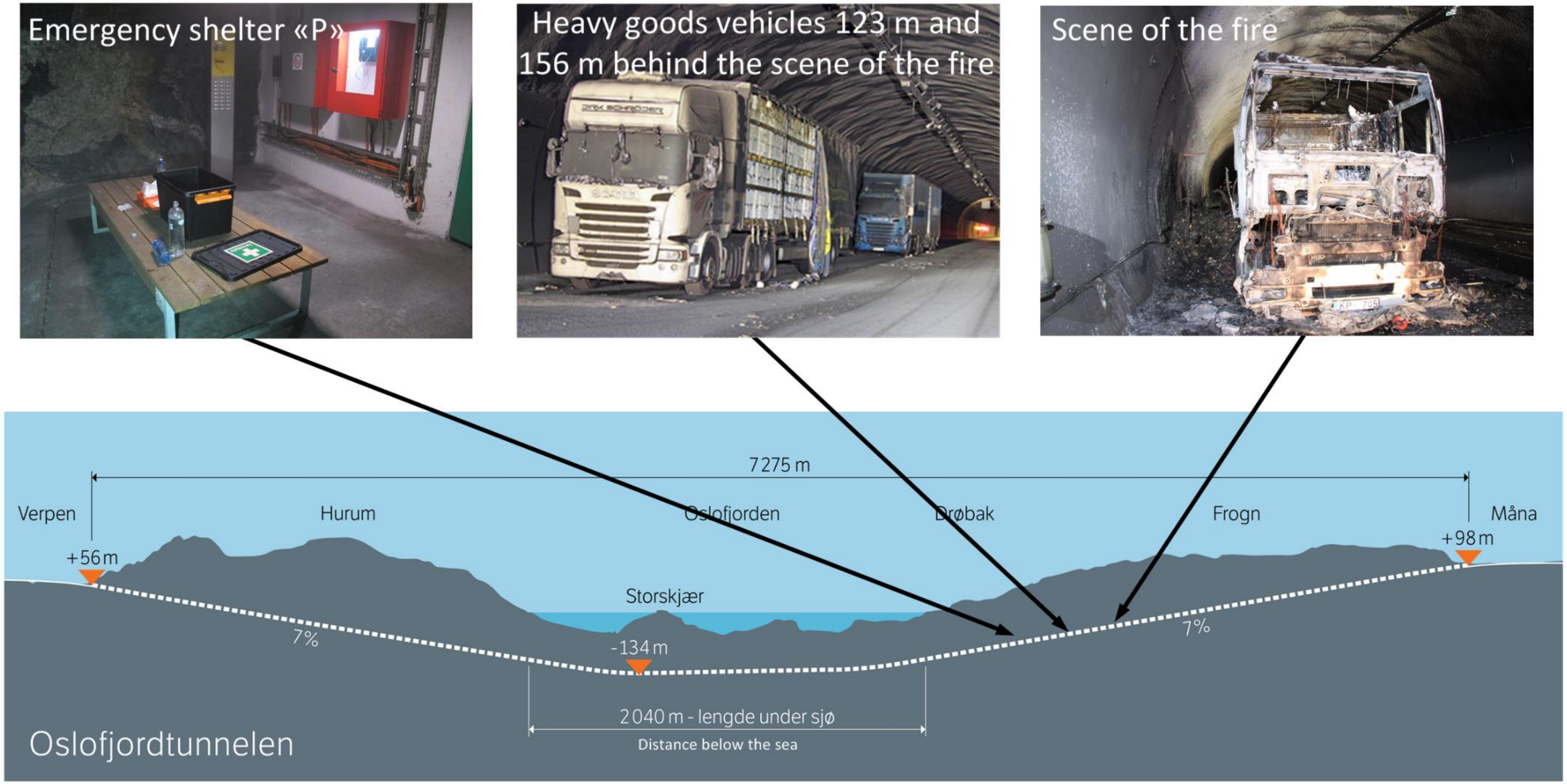

Figure 27: Overview of the Oslofjord tunnel with important locations from the incident. Illustration and photos: NPRA/AIBN

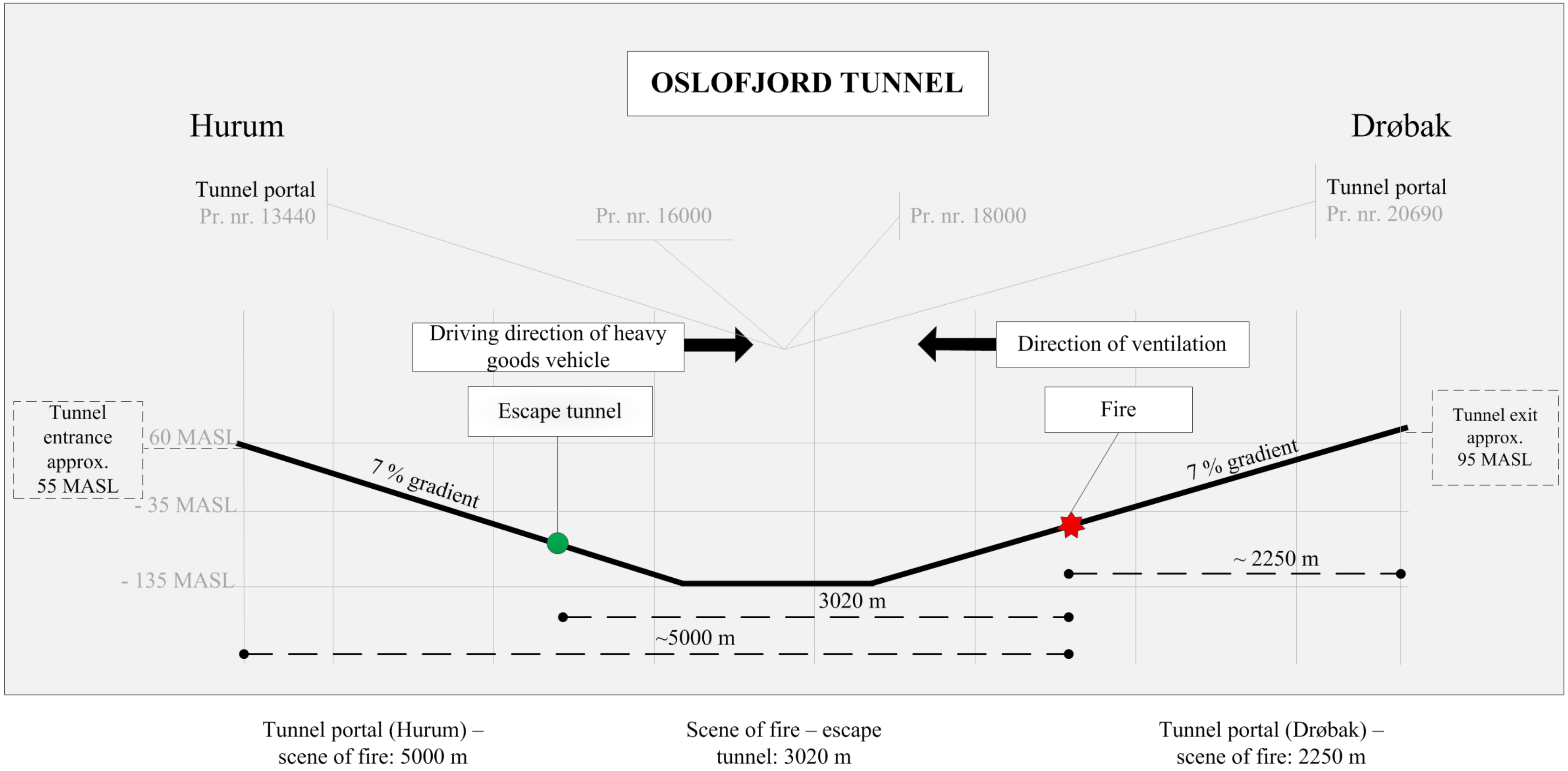

Figure 28: Schematic drawing of the Oslofjord tunnel. The incident site is marked with a red star. Illustration: AIBN

1.7 Road users

1.7.1 The driver of the heavy goods vehicle that caught fire

The driver was male, a foreign national and 37 years old at the time of the accident. He had driven category CE heavy goods vehicles for approximately 6 months, and smaller lorries in category C1 before that. In total, he had about two years' experience of driving lorries.

The driver was employed by a Latvian company. The incident happened during his first trip to Norway, and it was the first time he drove through the Oslofjord tunnel. After driving from Latvia to Sweden on 1 May 2017, the driver had driven the vehicle in question on transport assignments in Sweden and Norway for four days before the incident occurred.

1.7.2 Other road users

The driver of the first heavy goods vehicle, located 123 metres behind the burning vehicle, was male, a foreign national and 56 years old at the time of the accident.

The driver of the second heavy goods vehicle, located 156 metres behind the burning vehicle, was male, a foreign national and 33 years old at the time of the accident.

1.8 Vehicle

1.8.1 The heavy goods vehicle

1.8.1.1 *General information about the heavy goods vehicle*

The heavy goods vehicle consisted of a 2007 model, Latvian-registered MAN 18.440 tractor unit, first registered in Germany, and a Kogel semitrailer. The tractor unit was owned by Sia Aavtrans, the semitrailer by Swedbank Leasing.

Information about the weight of the heavy goods vehicle has not been available to the AIBN, but information from the NPRA and technical data for corresponding vehicles indicate that it had an unladen weight of around 13.5–14 tonnes. The vehicle carried a cargo of toilet paper with a total weight of 10.2 tonnes. It is therefore assumed that the heavy goods vehicle weighed a total of 24–25 tonnes.

1.8.1.2 *Maintenance and inspection history*

The driver of the heavy goods vehicle has stated that he had limited knowledge of the tractor unit that caught fire, as he had only driven it for a short period before the incident. This included information about the tractor unit's maintenance and inspection history. The driver had not received any information from the client or owner of the vehicle about special precautions or problems with the tractor unit.

The driver had received no fault messages on the tractor unit's dashboard before the incident, but there had been an orange exclamation mark on the dashboard before he took over the tractor. The owner of the tractor unit had told the driver that the fault had been repaired, but that the warning light would not go off.

The AIBN has not been able to obtain information about the vehicle's maintenance history or any technical inspections carried out before the incident. Information from MAN shows that the last time the tractor unit was registered as having been serviced by a MAN workshop was on 16 June 2010 in Germany. The tractor unit's odometer reading at the time was 343,708 km.

1.8.1.3 *The tractor unit's engine and exhaust brake system*

The tractor unit had a MAN engine of the type D2066 LF31. It was a six-cylinder, 440 hp engine with a piston displacement of 10,518 cm^3. The Euro 4 emission standard applied to the tractor unit at the time of its registration. The vehicle had a 16-gear manual gearbox.

The tractor unit was equipped with a MAN exhaust brake system (EVB[10]). According to the manufacturer, this system generates more braking power than conventional exhaust brakes. In conventional exhaust brakes, a valve cuts off or restricts the exhaust flow in the exhaust manifold or exhaust pipe. The Bosch Automotive Handbook states that a conventional exhaust brake will provide a braking power of 140–200 kW for the tractor unit in question. The manufacturer’s documentation shows that the vehicle's exhaust brakes generate a braking power of up to 250 kW. This is sufficient to fulfil the requirements for auxiliary brakes for vehicles carrying dangerous goods (ADR vehicles).

Information provided to the AIBN by the manufacturer shows that the maximum exhaust brake effect is achieved at a rotational speed of 2,400 rpm. Figure 29 shows the tachometer of the tractor unit in question. Different rpm ranges are indicated, where the green range (1,200–2,000 rpm) indicates maximum torque and minimum consumption. The red range starts at 2,800 rpm, and represents critical rotational speeds that could cause engine damage. According to the manufacturer, the driver will be warned if the rotational speed exceeds 2,800 rpm (red range).

Figure 29: Tachometer showing different rotational speed ranges in rpm. Source: MAN. Illustration: AIBN

The engine’s rotational speed can exceed the maximum 2,800 rpm during long downhill drives and where the gear is used for braking. The manufacturer states that, at worst, this

[10] Exhaust Valve Brake.

could damage the engine. The AIBN has been informed by the manufacturer that the exhaust brake will not be deactivated if the rotational speed exceeds 2,400 rpm.

The tractor unit in question was not equipped with other forms of auxiliary brakes, for example a retarder.[11]

1.8.1.4 *Disabled engine systems*

Upon examination, the tractor unit’s exhaust system was found to have been manipulated. The engine’s exhaust gas recirculation (EGR) valve, which is intended to help to reduce emissions of pollutants, had been blocked using a steel plate, see Figure 30. The investigation also found that the particulate filter had been disabled by making a big hole in the filter, see Figure 31.

[11] Retarder – auxiliary brakes that create resistance in the driveline.

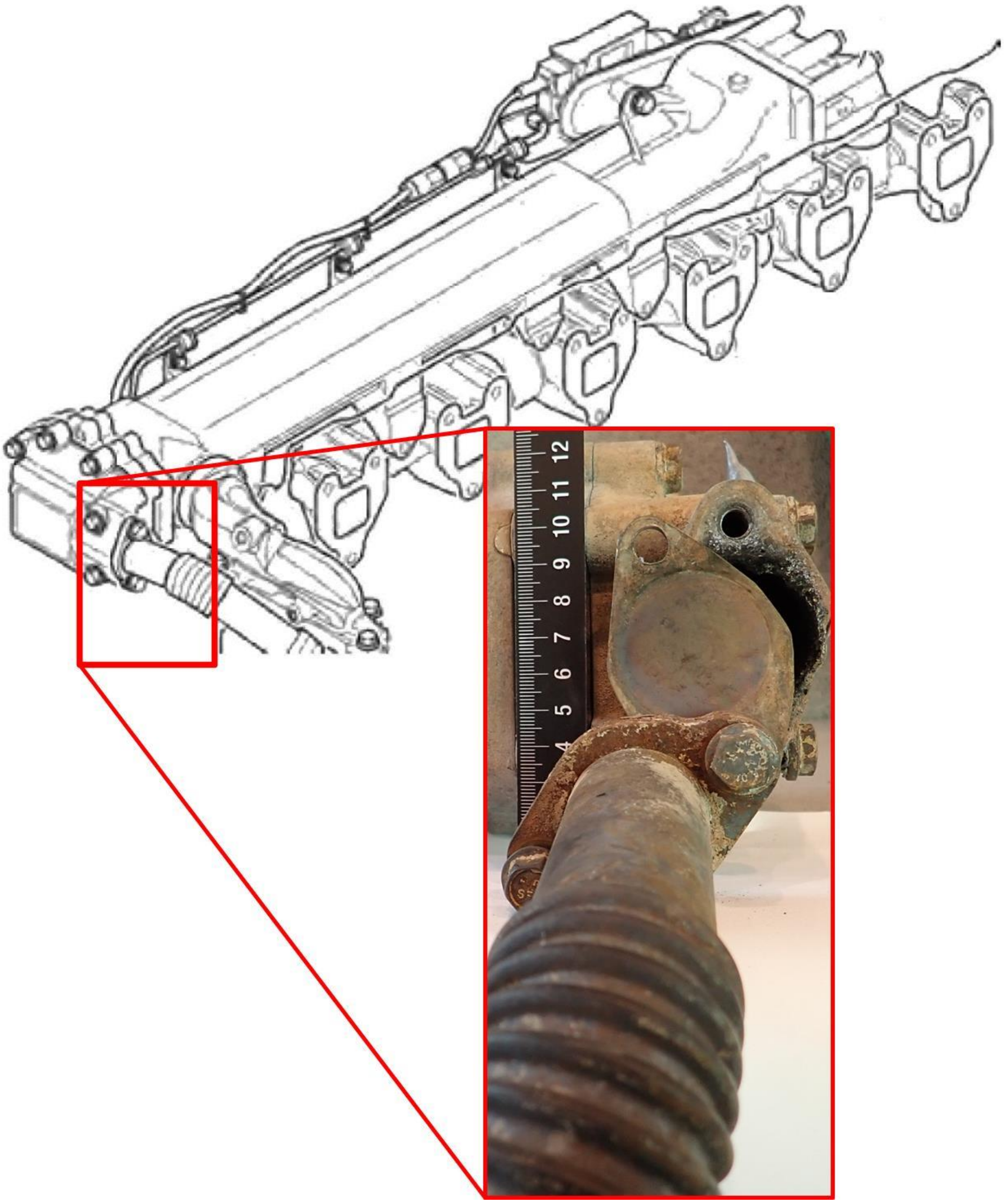

Figure 30: The EGR system had been disabled by inserting a steel plate in the exhaust channel. Illustration: MAN. Photo: AIBN

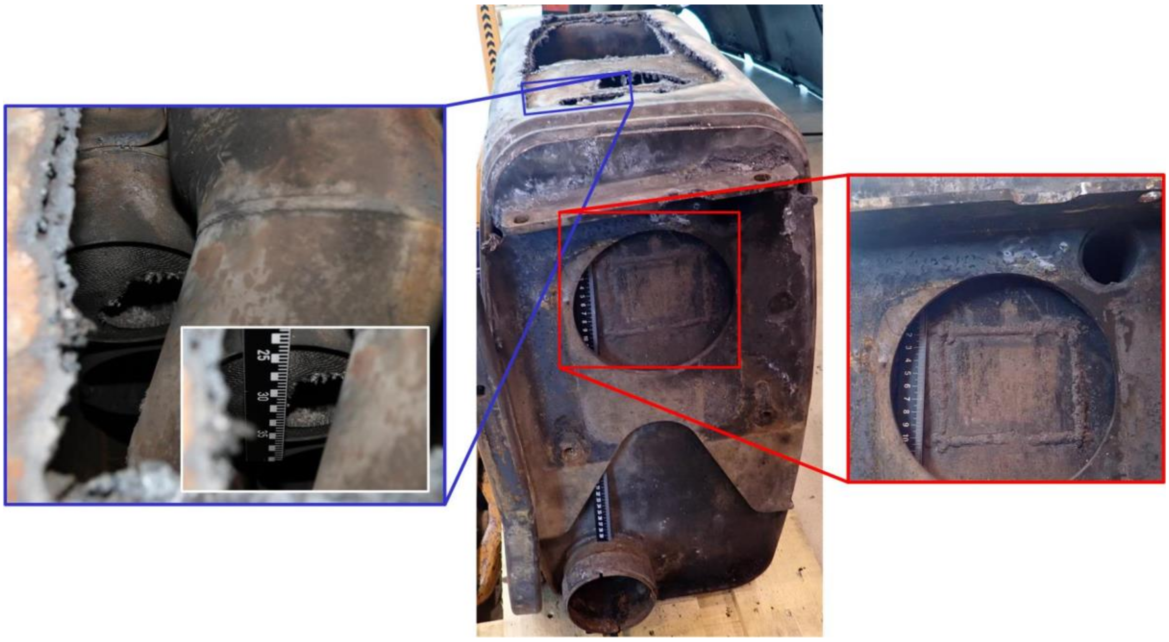

Figure 31: Hole in the particulate filter and hole closed by welding. Photo: The police/AIBN

1.8.1.5 *The speed of the heavy goods vehicle in the tunnel*

According to the driver, the heavy goods vehicle was travelling downhill at a speed of about 70 km/h inside the tunnel. The driver had set the speed in advance so that the vehicle could not go faster than 70 km/h. At the tunnel entrance and at the lowest point of the tunnel, the speed was somewhat less because queues were forming in the tunnel.

Based on the driver’s statement, the AIBN has reviewed CCTV footage from cameras in the Oslofjord tunnel to calculate the vehicle’s speed. The calculations are presented in Figure 32 and show the estimated average speed between the tunnel’s CCTV cameras (marked with red lines). The calculations provide a good indication of the speed the driver chose in the tunnel, but must be interpreted with caution as there is some uncertainty associated with both times and registration points.

No information has emerged about what gears the driver used while driving in the tunnel.

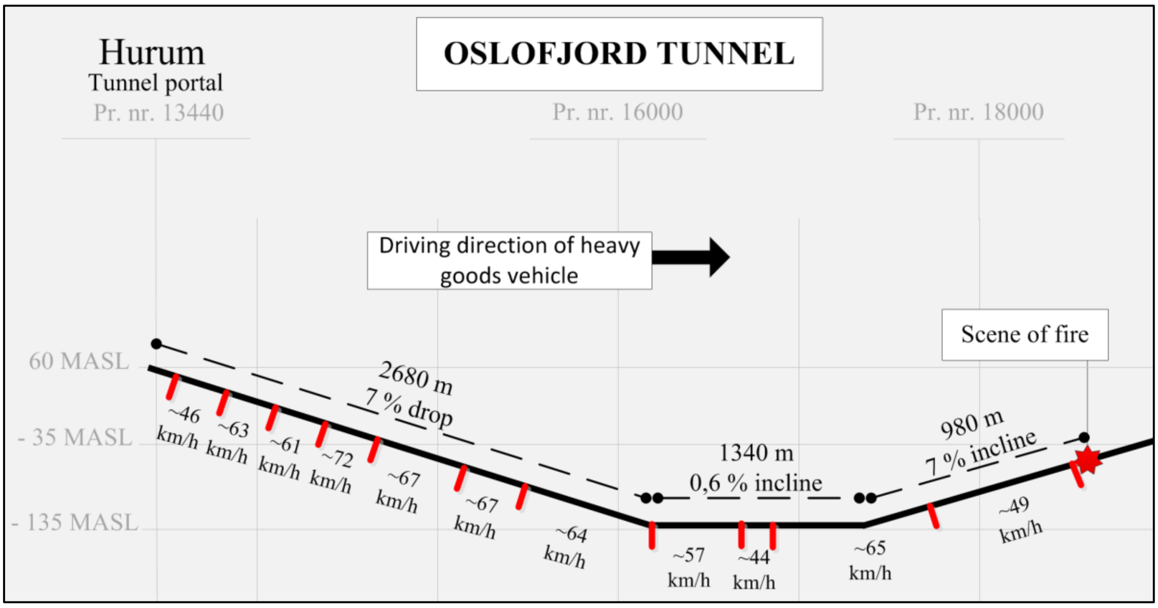

Figure 32: Calculated speed of the heavy goods vehicle. Illustration: AIBN

1.8.1.6 *Speed and braking force diagram with EVB engine brake*

The AIBN has also obtained information from the vehicle manufacturer, which describes the theoretical braking force of MAN's engine brake (EBV) for the heavy goods vehicle in question. Figure 33 shows braking force delivered by the exhaust brake in different gears as a function of speed. The 16 black lines show the braking force (kN) in each gear.

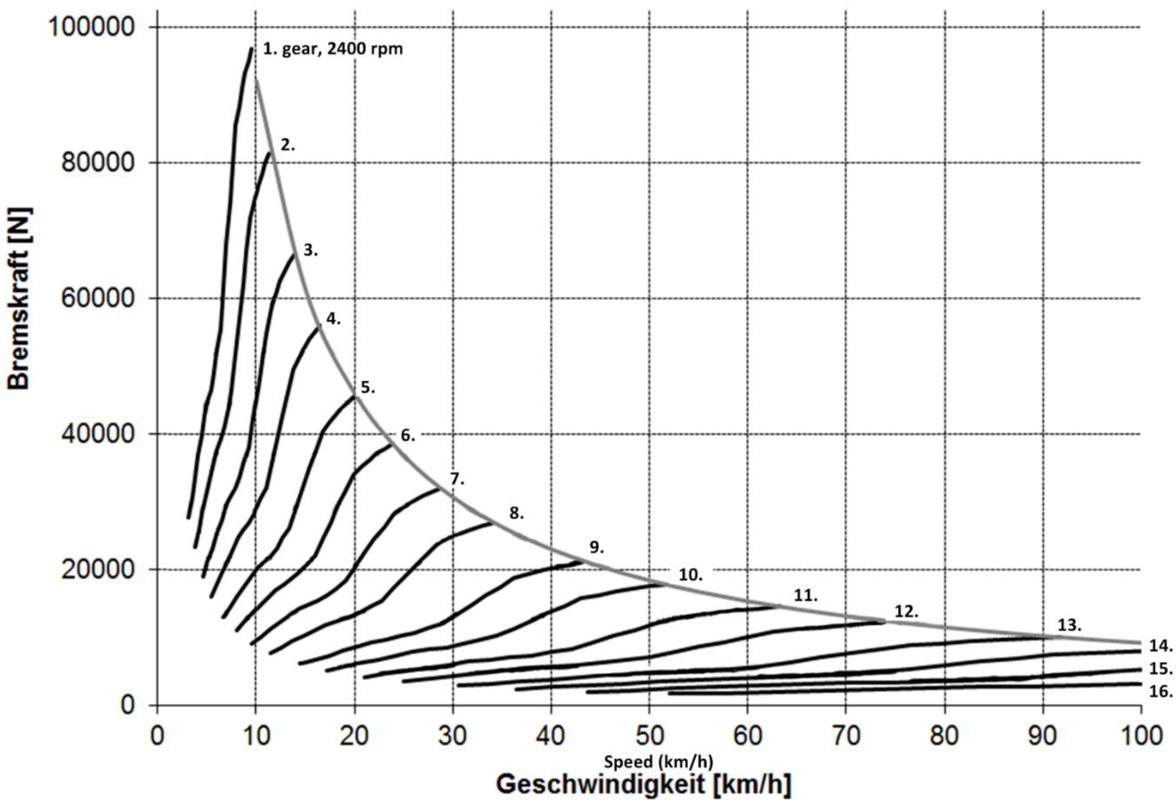

Figure 33: The link between braking force (N), choice of gear, speed and gradient. The graph applies to a vehicle with EVB engine brake. Source: MAN. Illustration: AIBN

The grey curve represents the limit value for maximum engine braking force at a rotational speed of 2,400 rpm.

1.8.2 Other vehicles

The first heavy goods vehicle located behind the burning vehicle inside the tunnel was a Swedish-registered Scania R450 tractor unit pulling a German-registered semitrailer. The second heavy goods vehicle was a Scania R506 tractor unit with a semitrailer, both Norwegian-registered.

1.9 The self-rescue principle

The principle of self-rescue is the fundamental principle for road tunnel evacuation in the event of fire. The NPRA's Manual N500 *Vegtunneler* ('Road Tunnels') defines self-rescue as follows:

> *Evacuation of tunnels in the event of fire or other incidents is based on the principle of self-rescue. This means that road users make their own way out of the tunnel, either on foot or by means of a vehicle.*

However, the fire service is expected to assist when appropriate considering the safety aspect and on the basis of agreed emergency response arrangements adapted to each individual tunnel. The principle of self-rescue does not only apply to road tunnels, but is generally applicable in connection with evacuation from an object that is on fire.

The following is quoted from the NPRA's report *Etatsprogrammet Moderne vegtunneler 2008 – 2011: strategi trafikantsikkerhet og brannsikkerhet i vegtunneler* ('Agency programme modern road tunnels 2008–2011: Strategy for road user safety and fire safety in road tunnels'), chapter 3.2 on the self-rescue principle:

> *The principle of self-rescue is generally accepted throughout society, and does, in principle, apply to all types of structures.*
>
> *…*
>
> *Self-rescue is the overriding principle in all Norwegian road tunnels. Only in rare cases can external rescue personnel come to people's aid in connection with incidents inside a tunnel. Road users must also be aware of this, and a particular responsibility for ensuring that this condition is known rests with the owner.*
>
> *…*
>
> *The main prerequisite for self-rescue to be practicable is that the tunnel must be designed for and equipped with technical installations that will work in an emergency. All external rescue efforts shall be planned and implemented in accordance with an approved emergency response plan. In the initial phase of an incident, however, the self-rescue principle will always apply and thus have a bearing on the extent of the incident.*

1.10 The Oslofjord tunnel – design, traffic and safety equipment

The Oslofjord tunnel is a undersea single bore tunnel on national road 23 between Måna on the Drøbak side, located in Frogn municipality in Akershus county, and Verpen on the Hurum side, located in Hurum municipality in Buskerud county. The tunnel is part of the

Trans-European Transport Network (TEN-T) and was opened for traffic on 29 June 2000. The tunnel is classified as a special fire object in category A5.

1.10.1 Tunnel design

The Oslofjord tunnel is 7,306 metres long and built in accordance with guidelines set out in Manual 021 – Road Tunnels published in 1992. The tunnel has a T11 profile with a cross-section of 11 metres, tarmacked roadway and a permitted overhead clearance of 4.5 metres. The gradient is 7% over a distance of approximately 3 km at each end of the tunnel. The speed limit in the tunnel is 70 km/h.

The Oslofjord tunnel is classified as a category C tunnel as defined in Manual 021 from 1992. The expected annual average daily traffic[12] (AADT) for a category C tunnel 20 years after its opening has been estimated at 4,000–8,000 vehicles.

The walls of the Oslofjord tunnel are lined with 15-cm thick concrete elements, and the tunnel ceiling is covered in PE foam which, in turn, is covered with a 6-cm layer of sprayed concrete. There are heat-insulating PE foam mats behind the concrete elements and sprayed concrete.

1.10.2 Traffic volume and composition

Manual 021 (1992) states that the expected AADT twenty years after opening shall be used for tunnels. The AADT figures for the Oslofjord tunnel in the planned opening year (1999) was estimated at 4,200 vehicles, with a heavy vehicles percentage of 16%. The tunnel's traffic forecasts were based on a traffic growth of 1.3% per year.

[12] Annual average daily traffic (AADT) is the average daily traffic through the year, total for both directions.

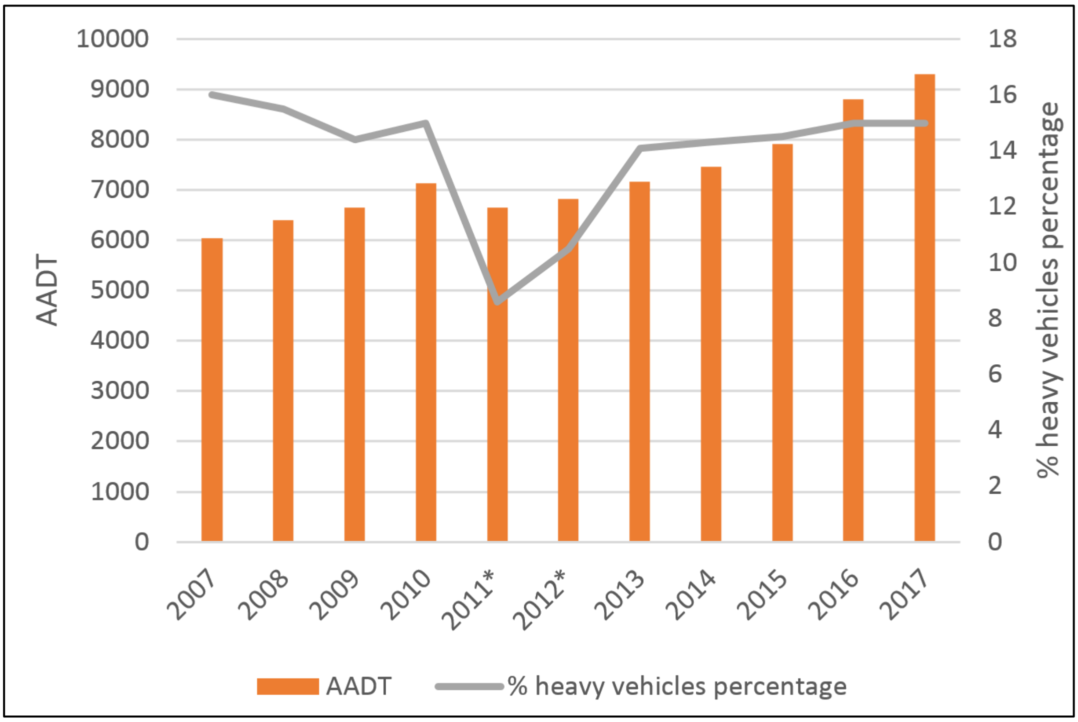

*Figure 34: AADT figures for national road 23, the Oslofjord tunnel, for the period 2007–2017. *The tunnel was closed for heavy vehicles during parts of 2011 and 2012. Source: Norwegian Public Roads Administration. Illustration: AIBN*

Based on the traffic figures from the opening year and the estimated annual growth, the AADT for the Oslofjord tunnel twenty years after its opening can be estimated at 5,500 vehicles. Traffic figures for 2017, i.e. 17 years after the tunnel opened, show that the Oslofjord tunnel had an AADT of approximately 9,300[13] vehicles per day with a heavy vehicles percentage of approximately 15%, see Figure 34. The Oslofjord tunnel is designed for an AADT of up to 7,500 vehicles per day (Safetec, 2011).[14]

1.10.3 Safety equipment

1.10.3.1 *Signage, light signals and road barriers*

The approaches to the Oslofjord tunnel have signs showing a speed limit of 40 km/h in addition to two speed bumps. ‘Steep hill’ warning signs with yellow flashing lights and a sign below giving the gradient in percent, the distance and the text ‘Low gear’ are placed on both sides of the road. The flashing lights are automatically activated by tall vehicles. There are also information signs with information about radio channels, variable message signs, flashing red stop signals and barriers outside the entrance to the tunnel. When the barriers are lowered, the sign ‘STOPP ved rødt blink’ (‘STOP when red light is flashing’) is activated together with flashing red stop signals at the tunnel entrances.

Inside the tunnel, there are digital speed signs for use in connection with incidents inside the tunnel, and ‘snu og kjør ut’ (‘turn and exit’) signs in the ceiling by the turning bays (located at intervals of approximately 1.5 kilometres inside the tunnel) that are activated

[13] According to National Roads Database.
[14] Safetec. (2011). The Norwegian Public Roads Administration – *Risikoanalyse av Oslofjordtunnelen med omkjøringsveger*. (‘Risk assessment of the Oslofjord tunnel and alternative routes’) Main report, ST-04121-4.

by VTS. 'Low Gear' is also written on the roadway inside the tunnel, and the speed limit is 70 km/h.

There are barriers at the roundabouts on the Drøbak side (before the toll booth) and on the Hurum side of the Oslofjord tunnel.

Figure 35: Lowered barrier with warning lights and signage outside the Oslofjord tunnel. Smoke from the vehicle fire inside the tunnel is also visible in the photo. Photo: Joakim Fjeldli/DRM 24

1.10.3.2 *Escape routes and evacuation lights*

The Oslofjord tunnel has three escape routes, namely the two tunnel portals and one escape tunnel that can also be used as a response route for emergency vehicles.

The tunnel is fitted with dynamic emergency lighting, 'tunnel stripes', with integrated LED lighting in the form of a continuous dynamic guiding line on the tunnel wall. The tunnel stripe is green and installed horizontally at a height of 60 cm above the verge along the whole length of the tunnel. Tunnel stripes have also been installed around the doors to the emergency shelters.

In the event of an incident in the tunnel requiring evacuation, the tunnel stripe will be activated automatically when the signal plan 'Brannstengt' ('Fire closure') is implemented. The horizontal tunnel stripe will then pulsate to show the way to the tunnel portals, the escape tunnel or the closest emergency shelter. In addition, white tunnel stripes on the walls in the shape of arrows show the way to the emergency shelter doors. If road users enter an emergency shelter, orange LED lights will be activated and flash outside the door to notify the fire service that there are people inside.

Figure 36: Dynamic green lights guide road users towards the emergency shelters. Arrows on the tunnel walls point the way to the doors of the emergency shelters. Photo: AIBN

1.10.3.3 *Emergency shelters*

There are 25 emergency shelters approximately 250 metres apart throughout the tunnel (see Figure 37). The emergency shelters are built in niches blasted into the side of the tunnel where future access tunnels will be located. One wall is made from concrete, the other walls and the ceiling are bare rock. The shelters are lettered A–Y, with photoluminescent signs, from Drammen towards Drøbak. The emergency shelters range in size from 3x3 to 8x8 meters, and each shelter can accommodate 30–50[15] people.

The emergency shelters are under continuous CCTV surveillance by VTS, and have two-way emergency telephones[16] for communication with VTS. They are also covered by the AID system and have a door alarm. Each emergency shelter contains a first aid kit, thermal blankets, and water for drinking and rinsing. Air cylinders are installed in twenty of the shelters and can provide up to three hours of fresh air. Shelters with a volume of more than 180 m^3 do not have air cylinders, and it has been calculated that no additional air will be required. Information signs have been installed in the shelters, that among other provide information in Norwegian and English about the emergency equipment and communication with VTS.

The emergency shelters are designed to withstand fires of up to 200 MW for up to three hours. When a fire occurs in the tunnel, the VTS operators must assess whether there is a need to eliminate shelters near the scene of the fire (i.e. turn off the tunnel stripe around the door), depending on the extent of the fire.

[15] Figures from the emergency response plan for the Oslofjord tunnel based on the area and volume of each emergency shelter.
[16] Two-way emergency telephones mean that the public/road users can call VTS, but the VTS operator can also contact the emergency shelters.

During the incident, VTS was alerted by door alarms from eight emergency shelters and notified ABØ. After the incident, it was discovered that VTS had received incorrect alarm messages from seven emergency shelters, and that only one shelter in the tunnel had been used.

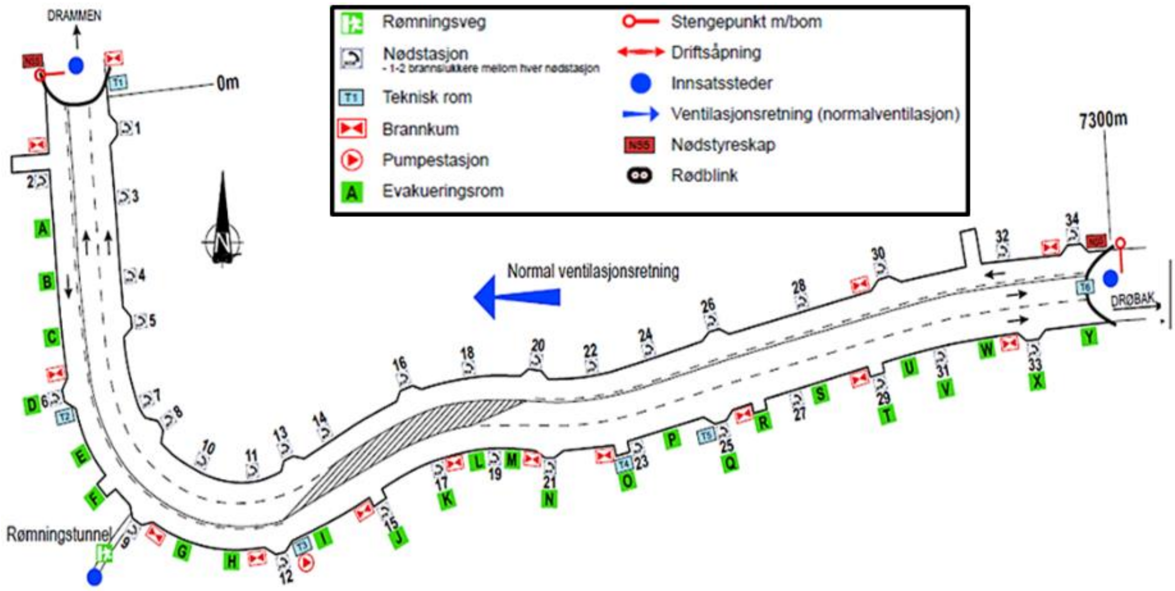

Figure 37: Schematic diagram of the Oslofjord tunnel showing the direction of ventilation (blue arrow) and the emergency shelters (green squares). Illustration: NPRA

1.10.3.4 *Ventilation*

The Oslofjord tunnel has longitudinal ventilation with intake and discharge of air through the tunnel portals. The difference in height between the tunnel openings means that there is natural draught towards the Drøbak side, but the tunnel's pre-defined direction of ventilation is towards Drammen, regardless of where in the tunnel the accident/fire is located. This direction of ventilation has been decided based on the fact that efforts directly targeting the scene of the accident/fire will be carried out from the Drøbak side under the auspices of FBV, which has the greatest response and firefighting resources.

The tunnel ventilation system comprises 34 1250N fans with four different settings. The full ventilation power is 1515 kW, with a design air velocity of 5–6 m/s. The fire ventilation power is half of this, with a design air velocity of 2–3 m/s. The direction of ventilation can be reversed, and the fans will provide 70% of the full ventilation power in reverse mode.

In accordance with the fire procedures for the Oslofjord tunnel, VTS will implement measures in the tunnel on the instructions of the police's on-scene commander, or the on-scene fire commander, where the latter has overriding responsibility for use of the ventilation system. In accordance with the emergency response plan, the fans in the tunnel are dimensioned for fires of up to 50 MW, and fans exposed to a fire should be capable of functioning for 60 minutes at 125 °C.

If one pair of fans is destroyed by fire, the emergency response plan states that the remaining fans in the tunnel will have sufficient capacity to deal with a 45 MW fire. According to the NPRA's report, there were six fans that did not function as intended during the fire on 5 May 2017, which means that 17.6% of the fans in the Oslofjord tunnel were inoperative at the time of the accident.

1.10.3.5 *Communication and communication lines*

Communication in the tunnel includes the digital multi-agency public safety network Nødnett and VHF,[17] and Nødnett is used for communication between the emergency services in connection with incidents in the tunnel. This is described in section 7.3.4 of the emergency response plan for the Oslofjord tunnel:

> *7.3.4 Radio and communication*
>
> *Nødnett has been installed in the tunnel and shall be used for communication between the emergency services. To communicate with VTS during an incident, the emergency services will have to use mobile phones or use the emergency service's own communication centre as an intermediary.*

The NPRA informs the AIBN that it is possible for VTS operators to listen in on the police districts' *samvirke-2* channels.

The Nødnett network is wholly owned and operated by the Norwegian Directorate for Civil Protection. This is described in more detail in section 1.13.2.

There is limited mobile phone coverage inside the tunnel, and none in the emergency shelters. There are emergency telephones in all the emergency shelters and the escape tunnel. VTS operators can call the emergency telephones in the shelters.

In the event of an incident in the Oslofjord tunnel, VTS can inform road users inside or outside the tunnel by interrupting the ordinary radio broadcast with what is known as radio alert messages. Radio alerts to road users inside the tunnel can also be transmitted from the emergency control cabinet outside the tunnel. Signs inside the tunnel with flashing yellow lights will be activated to notify road users when the radio alert message function is in use.

The tunnel also has 34 SOS telephones on alternate sides of the tunnel at intervals of approximately 250 metres. An alarm will notify VTS when an SOS telephone is used, and direct contact is established with the VTS operator. The number of the SOS telephone that is being used will indicate where in the tunnel the caller is located.

1.10.3.6 *Cameras*

The Oslofjord tunnel has full CCTV[18] coverage with AID. The CCTV system also covers the areas outside the tunnel at Måna and Verpen, as well as the Måna roundabout. There is also full CCTV camera coverage with AID in all emergency shelters, which are continuously monitored.

Ninety-nine cameras with AID are installed in the tunnel with sequential transfer of footage from the tunnel to VTS. The AID system detects vehicles that stop, dropped

[17] Very High Frequency – electromagnetic radiation in the 30–300 MHz range.
[18] CCTV: closed-circuit television – camera/video surveillance.

cargo, and persons and animals in the roadway. The system can also detect smoke. VTS receives an alarm and video images from the camera in question when an incident occurs.

1.11 Nonconformities in the safety equipment in the Oslofjord tunnel

1.11.1 Nonconformities identified before the fire on 5 May 2017

A four-monthly test of the safety equipment in the Oslofjord tunnel was carried out on 8 and 9 March 2017. The test identified several electrotechnical nonconformities in the tunnel. Many of these faults had not been repaired when the vehicle fire occurred in the tunnel on 5 May 2017, two months after the four-monthly test. Table 2 shows some of the electrotechnical nonconformities in the Oslofjord tunnel identified during the four-monthly test on 8 and 9 March 2017.

Table 2: Electrotechnical nonconformities in the Oslofjord tunnel identified during four-monthly test on 8 and 9 March 2017. Source: NPRA

Fault – documented during four-monthly test on 8 and 9 March 2017	**Status as of 5 May 2017 (date of the fire)**	**Progress schedule**
4 fans with faults – motor protectors triggered.	Not repaired.	New ones ordered on 23 March, expected installation date 7 or 8 Sept. 2017.
Two flashing red lights in the tunnel were not working.	Not repaired.	Repaired before the tunnel opened on 29 May 2017.
Six ‘radiomelding’ (‘radio alert’) signs were not working.	Not repaired.	Expected to be replaced by new signs in connection with the transition to DAB, 7 or 8 Sept.
Two mechanical variable ‘turn and exit’ signs were not working.	Not repaired.	Repaired before the tunnel opened on 29 May 2017.
Ten emergency stations with low sound in communication with VTS.	Not repaired.	Supplier contacted to explore the possibility of amplifying the sound. Expected repair date September 2017.
Faulty radio alert message for fire. No message.	Radio messages were breaking up.	Radio transmitter upgraded before the tunnel opened on 29 May 2017.
Radio interruption from the emergency control cabinet was not working.	Unknown whether this fault was repaired before or after the fire.	Faulty fibre optic cable, the cable has been replaced.
Faulty guiding lighting.	Continuous maintenance.	Continuous maintenance.

1.11.2 Nonconformities identified during the fire on 5 May 2017

During the fire on 5 May 2017, several nonconformities in the safety equipment in the Oslofjord tunnel that were not known in advance were identified. These nonconformities and their repair status are shown in Table 3.

Table 3: Unknown nonconformities in the safety equipment in the Oslofjord tunnel identified during the fire on 5 May 2017. Source: NPRA

Nonconformity	Repaired
Unknown electrotechnical nonconformities	
One ‘turn and exit’ sign inside the tunnel in the direction towards Drammen did not work during the fire.	Before the tunnel opened for traffic on 29 May 2017.
Activation of fire ventilation in the signal plan ‘Brannstengt’ (‘Fire closure’) did not work during the fire.	Before the tunnel opened for traffic on 29 May 2017.
Fault in the tunnel’s backup control system (backup server) during the fire.	Tested and verified to be in order on 26 May 2017.
The radio alert message function did not work in the tunnel during the fire.	Tested and verified to be in order on 24 May 2017.
In addition to the four non-functioning fans, two more fans did not work during the fire.	Unknown.
Incorrect phone number for emergency shelter 'P' registered at VTS.	Checked on 21 May 2017.
False alarm on seven emergency shelters and two emergency shelter antechambers during the fire.	Unknown.
Unknown technical nonconformities	
High temperature of emergency shelter door handles during the fire.	The door handles have not been changed since the fire.
Other unknown nonconformities	
The Nødnett network functioned very poorly in the tunnel during the fire.	Verified to be in order on 24 May 2017.

As described in the NPRA's report, these nonconformities placed additional strain on VTS during the incident. The report reads as follows:

> *When the fire had been detected by AID, several faults that were not known in advance were uncovered in connection with the fire/emergency closure of the tunnel. Many of these faults placed strain on the VTS operators who, in addition to dealing with the incident, had to perform several time-consuming manual tasks because of the nonconformities.*

As mentioned in the table above, the Nødnett network functioned poorly during the incident. Tests carried out after the fire showed good signal strength and no obvious faults in the system. The operating contractor performed extensive tests of the Nødnett network on 22 May 2017. It was found that installed components not in use interfered with the system, which was the reason for the sporadic network problems encountered during the fire. The fault was repaired on 23 May 2017, and the network was tested in the early hours of 24 May 2017.

1.12 Follow-up of safety in the Oslofjord tunnel

Tunnels are an element in the road network that is subject to extensive and special requirements, and more stringent safety management requirements apply to tunnels than to the rest of the Norwegian road network.[19]

The Directorate of Public Roads is responsible for ensuring that all aspects of tunnel safety are addressed and for taking necessary steps to ensure compliance with the provisions of Regulations No 517 of 15 May 2007 on minimum safety requirements for certain road tunnels (the Tunnel Safety Regulations). Its area of responsibility includes following up Manual R511 – *Sikkerhetsforvaltning av vegtunneler* ('Safety Management of Road Tunnels') and ensuring that the minimum requirements stipulated in Manual N500 – *Vegtunneler* ('Road Tunnels') are complied with.

NPRA Eastern Region, represented by the road department for Akershus, has full responsibility for the Oslofjord tunnel, including operation, maintenance and incident management.

1.12.1 Periodic inspections of tunnels

The Tunnel Safety Regulations Section 9 reads as follows:

> *The Directorate of Public Roads shall conduct regular inspections to ensure that all tunnels that fall under the scope of these regulations comply with the requirements stipulated here. The interval between two inspections of a tunnel must not exceed six years.*
>
> *If the Directorate of Public Roads finds that a tunnel does not fulfil the regulatory requirements, it must inform the tunnel manager and tunnel safety inspector that steps must be taken to improve tunnel safety.*

The AIBN has been informed that, in principle, two different types of inspections are carried out: one general inspection every five years that focuses on the physical tunnel elements based on Manual R610 – *Drift og Vedlikehold* ('Operation and maintenance'), and one inspection of the technical safety equipment every six years.

A report is prepared on the basis of these inspections and sent to the Directorate of Public Roads. When nonconformities with significant financial and/or safety consequences are identified, the Directorate shall procure funds to close these nonconformities. The Directorate of Public Roads may also consider closing a tunnel if the nonconformities are deemed to be serious.

The Oslofjord tunnel was most recently inspected following the fire in 2012, and another inspection is scheduled for autumn 2018.

[19] Norwegian Public Roads Administration. (2013). *Temaanalyse om dødsulykker i tunnel– UAG 2005-2012.* ('Thematic analysis of fatal tunnel accidents') NPRA reports, No 267.

1.12.2 Safety approval of tunnels

Manual R511 – *Sikkerhetsforvaltning av vegtunneler* ('Safety management of road tunnels'), which has directions status, requires all tunnels to be safety-approved. The following is reproduced from the manual:

> *All tunnels must undergo safety approval. This applies*
>
> *1. Before the construction of a new tunnel begins (safety approval of plans)*
>
> *2. Before a new tunnel can be opened for traffic*
>
> *3. At least once every six years during the tunnel's period of operation*
>
> *4. Before any safety equipment upgrades that could potentially change the safety situation in the tunnel (approval of the plans)*
>
> *5. After any upgrades as mentioned in 4.*

The tunnel manager, in this case NPRA Eastern Region, must apply to the Directorate of Public Roads for approval through inspection reports documenting nonconformities etc. The following guidelines for safety approval of tunnels open for traffic are described on page 18 of the manual:

> *The tunnel manager shall also ensure that an application for continued permission to keep the tunnel open for traffic is submitted at least once every six years. (Renewal of safety approval)*

According to the NPRA, however, the prevailing practice has been to not follow the guidelines set out in the manual for safety-approval of tunnels in operation. The NPRA states that Manual R511 is scheduled to be revised in the course of 2018, and that the requirement for renewal of safety approvals as described in the current manual will be removed.

The NPRA also states that no evaluation or risk assessment has been carried out of this practice.

1.12.2.1 *Safety approval of the Oslofjord tunnel*

According to the NPRA, the Oslofjord tunnel's most recent safety approval by the Directorate of Public Roads took place on 28 June 2012. The safety approval was based on measures implemented in the tunnel after the fires in 2011, with the condition that the emergency shelters in the tunnel are a temporary measure to be replaced by another permanent solution at a later date. The reason for this condition is that section 2.3.4 of Annex I to the Tunnel Safety Regulations does not permit emergency shelters without access to the open air.

The safety approval of the Oslofjord tunnel dated June 2012 was valid for five years, which means that the tunnel was safety-approved at the time of the fire. As a consequence of the practice described in section 1.12.2, the tunnel's safety approval has not been renewed in 2017.

1.12.3 Risk assessment of the Oslofjord tunnel

A risk assessment must be included in the safety documentation submitted to the Directorate of Public Roads when applying for safety approval of a tunnel. The most recent risk assessment[20] for the Oslofjord tunnel, prepared by Safetec on behalf of the NPRA, is dated 16 January 2017. The purpose of the assessment was to assess the effect of increased traffic as a result of the Oslofjord tunnel no longer being a toll road.

According to the risk assessment, traffic projections for the Oslofjord tunnel show that passenger car traffic will increase by 38% from 2016 to 2018, and by 83% from 2016 to 2026. The tunnel’s expected AADT is 11,600 vehicles per day in 2018, and 15,400 vehicles per day in 2026. A near-doubling in passenger car traffic can be expected, while the carriage of goods (heavy/long vehicles) is expected to increase by approximately 10%.

The risk assessment also deals with the principle of self-rescue, and the following is quoted from the report:

> *The main prerequisite for self-rescue to be practicable is that the tunnel must be designed and adapted with this in mind, and that it is equipped with technical installations that will work in an emergency. All external rescue efforts shall be planned and implemented in accordance with an approved emergency response plan, but in the initial phase of a sequence of events, the self-rescue principle will always apply. In turn, this will have a bearing on the severity of the incident.*

The risk assessment has not considered how the pre-defined direction of fire ventilation in combination with the tunnel's distinctive characteristics and the increased traffic load will influence the self-rescue principle. The risk assessment also describes how heavy goods vehicle fires in tunnels in Norway have only caused minor personal injuries.

The risk assessment goes on to conclude that an increase in traffic will increase the probability of undesirable incidents and that the number of vehicles exposed in the event of fire in a tunnel will increase as a result of the increase in AADT. The report also emphasises that the frequency of major fires in heavy vehicles in the tunnel is deemed to be low, and will remain low even if the traffic volume increases.

1.12.4 Exercises in the Oslofjord tunnel

According to the Tunnel Safety Regulations Annex 2 Section 5, the tunnel manager and rescue services must hold regular exercises. This is to be done in cooperation with the tunnel safety inspector. The Tunnel Safety Regulations require full-scale exercises under as realistic conditions as possible to be held at least every four years. Annual part-exercises and/or simulation exercises shall be held in the years between the full-scale exercises. The Tunnel Safety Regulations Annex 2 Section 5 continues:

> *The tunnel safety inspector and rescue services shall evaluate these exercises, prepare a report and present expedient proposals.*

[20] Skogvang, Ø., Musæus, S.U., Værnes, R. & Jenssen, G.D. (2017). The Norwegian Public Roads Administration – *Risikoanalyse av Oslofjordtunnelen*. (‘Risk assessment of the Oslofjord tunnel’) Safetec. Main report, ST-12127-5.

Exercises have not been held in the Oslofjord tunnel in accordance with the Tunnel Safety Regulations' requirement for a full-scale exercise at least once every four years. The most recent exercise in the tunnel took place on 22 October 2014, and it took the form of a tabletop exercise for the emergency services that will respond in the event of an incident in the Oslofjord tunnel. The last full-scale exercise in the Oslofjord tunnel was held on 31 May 2012.

1.12.5 Inspection of the Oslofjord tunnel as a special fire object

The Oslofjord tunnel is classified as a special fire object[21] in category A5. Pursuant to Act No 20 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (the Fire and Explosion Act), the tunnel owner has primary responsibility for documenting that the tunnel's construction, equipment and maintenance is in accordance with the applicable regulations in terms of fire safety. The fire service shall ensure by means of inspections that owners of special fire objects fulfil their responsibilities and meet the fire safety requirements.

FBV shall inspect the tunnels in its district. According to the NPRA, the most recent inspection of the Oslofjord tunnel alone took place in 2011. The Oslofjord tunnel was also included in a joint inspection of several tunnels in the Oslo area in 2013. The AIBN is not aware of any more recent inspections of the tunnel.

1.12.6 Emergency response plans for tunnels

The emergency response plan forms part of a tunnel's safety documentation, and the Tunnel Safety Regulations Annex 2 Section 2.1 requires the tunnel manager to draw up safety documentation for each tunnel and keep it up to date.

The emergency response plan must cover both technical response and response to traffic incidents, and shall be prepared in cooperation with the local rescue services. Manual N500 – *Vegtunneler* ('Road Tunnels') requires an emergency response plan to contain:

> - *A description of the tunnel, equipment in the tunnel, diversion possibilities and available emergency response equipment*
>
> - *A risk assessment, if required*
>
> - *Procedures for incidents and failure of technical equipment, including safety equipment, with corrective measures for possible incidents in the tunnel*
>
> - *A description of important scenarios and emergency response plans for each scenario with a clarification of the responsibilities of each of the emergency services*

It is also stated that:

> *The emergency plan shall be prepared during the planning of the tunnel, further developed during the construction phase and revised as necessary.*

In addition, Manual R511 sets out guidelines requiring a complete emergency response plan to deal with response in the event of incidents involving road users as well as failure

[21] Any building, structure, facility, storage facility, tunnel, business, area etc. where a fire can originate and represent a threat to life, health, the environment or material assets.

of technical equipment and structural elements, such as the lights, control and monitoring systems, and communication systems, that affects road users in connection with incidents in tunnels.

1.12.6.1 *Emergency response plan for the Oslofjord tunnel*

The emergency response plan in force for the Oslofjord tunnel at the time of the fire in May 2017 was dated 16 July 2012. The plan was based on the traffic load in 2010, and it does not appear to have been revised since 2012.

The plan's Chapter 2 *Hendelser og tiltak ('Incidents and actions')* describes different incidents that could occur in the tunnel and what action to take. The actions to be taken mostly concern closure of the tunnel, signage and notification. As regards corrective action in the event of failure of technical equipment that affects road users, the following is quoted from section chapter 2.2 *Driftsstans teknisk utstyr ('Failure of technical equipment'):*

> *In the event of a sudden failure of technical equipment, messages/alarms will automatically alert VTS, which must notify the chief superintendent engineer and request any necessary assistance from the relevant contractor.*

No risk assessment is enclosed with the emergency response plan, and it contains no reference to the risk assessment conducted in 2017.

1.13 Authorities, organisations and leadership

1.13.1 Norwegian Public Roads Administration

The NPRA is an administrative agency under the authority of 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 the national road and county road networks, and for approval and supervisory activities relating to vehicles and road users. The NPRA also prepares rules and guidelines for road design, operation and maintenance, road traffic, road user training and vehicles.

1.13.1.1 *The Directorate of Public Roads*

The Directorate of Public Roads is responsible for strategic and overriding planning, budgetary matters, follow-up and resource management for national roads, and has overriding responsibility for road users and vehicles. It is also responsible for international activities. The Directorate of Public Roads is organised in five departments with subordinate sections and three staff entities.

According to the Tunnel Safety Regulations Section 4, the Directorate of Public Roads is an administrative body with responsibility for and coordinating tasks relating to ensuring that all aspects of tunnel safety are addressed and taking necessary steps to ensure compliance with the content of the Regulations. The Directorate of Public Roads must give permission before tunnels may be used (safety approval).

The Directorate of Public Roads shall also ensure that the relevant body:

a) *regularly tests and inspects tunnels and draws up safety requirements related thereto,*

b) *implements organisational and operational arrangements, including plans for dealing with emergencies for training and equipping rescue services,*

c) *defines a procedure for immediate closure of the tunnel in the event of an emergency,*

d) *implements necessary risk-reducing measures.*

The Directorate of Public Roads shall also conduct regular inspections to ensure that all tunnels that fall under the scope of the Tunnel Safety Regulations comply with the requirements set out in the Regulations. If the Directorate of Public Roads finds that a tunnel does not fulfil the regulatory requirements, it must inform the tunnel manager and tunnel safety inspector that steps must be taken to improve tunnel safety. The Directorate of Public Roads stipulates conditions for the tunnel's continued use or reopening, or other restrictions or conditions that will apply until remedial measures have been implemented.

1.13.1.2 *The NPRA's regional offices*

As head of the NPRA's regional office, the regional road director is responsible for the administration of both national and county roads at the regional level. In matters concerning national roads and other central government functions, the regional road director is subordinate to the Directorate of Public Roads, and to the county authority in matters concerning county roads, cf. the Public Roads Act Section 10. The road department for each county is part of NPRA's regional office, and the head of department reports to the regional road director. The regional office is tunnel manager for the Oslofjord tunnel.

Geographically speaking, the Oslofjord tunnel is divided between NPRA's Eastern Region and Southern Region, but NPRA Eastern Region functions as tunnel manager. A tunnel manager is charged with ensuring that tunnel operations are in accordance with the applicable regulations and manuals.

According to Manual R511, the tunnel manager must ensure that a report is prepared and submitted for all significant incidents or accidents. By significant incident is meant fires in vehicles or tunnel structures, as well as fatal accidents and accidents that result in serious injury to persons. The report must be completed within one month of the incident and shall be submitted to the appropriate tunnel safety inspector, the Directorate of Public Roads represented by the road department, and the rescue services.

According to the Tunnel Safety Regulations Annex 2 Section 2.1, the tunnel manager shall draw up safety documentation for each tunnel and keep it up to date. In addition, the tunnel manager and rescue services shall, in cooperation with the tunnel safety inspector, regularly organise joint exercises for the tunnel staff and rescue services.

1.13.1.3 *The Traffic Control Centres (VTS)*

VTS is responsible for monitoring the road network, traffic control and for internal notification in its own region and notification to the Directorate of Public Roads. The VTS centres are subordinate to the five regional NPRA offices, and they are located in

Mosjøen, Trondheim, Bergen, Porsgrunn and Oslo. In addition to this, the Western Region has a VTS centre in Lærdal.

The NPRA, represented by VTS in the Eastern Region, which is located in Oslo, is responsible for monitoring and controlling traffic through the Oslofjord tunnel. The traffic control centre for the Eastern Region also has national operational responsibility for the traffic information service. The traffic information is reported to VTS by road users, contractors and ferry companies etc.

1.13.1.4 *Tunnel safety inspector*

According to Manual R511, the tunnel manager shall, subject to the Directorate of Public Roads' prior consent, appoint a tunnel safety inspector for each tunnel or group of tunnels. Organisationally, the tunnel safety inspector for the Oslofjord tunnel belongs to NPRA Eastern Region's strategy, road and transport department. In tunnel matters, the tunnel safety inspector is the formal link between the Directorate of Public Roads, NPRA Eastern Region and the region's five road departments.

The tunnel safety inspector is charged with coordinating all measures of a preventive nature and safety-related measures to safeguard road users and operating personnel. The tunnel safety inspector shall be independent of his or her employer in all tunnel safety matters. The inspector shall also receive and forward different reports relating to tunnel safety and participate in the evaluation of all significant incidents and accidents.

1.13.1.5 *Fire safety manager*

Regulations No 1710 of 17 December 2015 on Fire Prevention do not require a fire safety manager, but they do set out requirements concerning systematic safety work and documentation of the duties of owners and users. As part of their organisations' internal control, owners and users must define how to attend to their regulatory duties and responsibilities.

The NPRA has stated that the organisation has chosen to retain the position of fire safety manager. The fire safety manager is the tunnel owner's representative and manages tunnel safety in accordance with internal handbooks and guidelines. The position of fire safety manager for the national and county road tunnels in the counties of Akershus and Telemark is a full-time position, and also includes functioning as deputy representative for the tunnels in Oslo.

1.13.2 The Road Supervisory Authority

The Road Supervisory Authority is a central government supervisory body charged with supervising the owners of national roads, the Norwegian Public Roads Administration and the state-owned construction company Nye Veier AS (New Roads Corporation). The purpose of the supervisory authority is to ensure the safety on the national road network.

In 2017, the Road Supervisory Authority became an independent administrative body that reports directly to the Ministry of Transport and Communications. The Road Supervisory Authority conducts risk-based system supervision, which means that supervisory activities are based on an assessment of risk in relation to consequences for traffic safety.

The Road Supervisory Authority has carried out many supervisory activities, for example relating to the safety management of tunnels in the Norwegian national road network.

1.13.3 Directorate for Civil Protection and Emergency Planning

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 the Norwegian Civil Defence.

DSB is the government's expert body for emergency communication, the authority with system responsibility for and owner of critical infrastructure, and a service provider for the Nødnett communication network. DSB owns Nødnett and is responsible for establishing, managing and developing it in line with the needs of its users. DSB is charged with:

- *Ensuring good availability and stable, secure and cost-efficient running of the Nødnett network.*
- *Follow up that users' Nødnett equipment has stable and secure user support services.*
- *Follow up that end-user training ensures correct use of Nødnett.*
- *Facilitating the effective use of Nødnett in day-to-day situations as well as in emergencies.*

1.13.4 Fire and rescue services

In Norway, the fire and rescue services (the fire service) are under the control of the municipal authorities. DSB controls municipalities through the Fire and Explosion Act and pertaining regulations. The purpose of this Act is to protect life, health, the environment and material assets. The fire and rescue service are expected to carry out preventive work, including inspections, to put out fires and to provide technical rescue resources in connection with fires and other accidents.

1.13.4.1 *Follo fire service IKS*

Follo fire service IKS (FBV) has been assigned primary responsibility for the Oslofjord tunnel and cooperates with Røyken fire and rescue service and Hurum fire service in connection with emergency response and exercises.

FBV is an intermunicipal company owned by the municipalities of Enebakk, Frogn, Nesodden, Oppegård, Ski and Ås. These municipalities cover an area of 780 square kilometres and have a combined population of more than 120,000 people. FVB is responsible for fire prevention, chimney sweeping and fire and accident response.

It has a fire station at Korsegården in Ås, approximately 9 km from the Oslofjord tunnel, which is staffed 24/7. FVB also has fire stations in Ski, Oppegård, Nesodden and Enebakk, from where personnel can respond to incidents in the Oslofjord tunnel.

1.13.4.2 *Røyken fire and rescue service*

Røyken fire and rescue service is also staffed 24/7, and is based approximately 15 kilometres from the Oslofjord tunnel's portal on the Drammen side, which is their entrance point to the tunnel.

1.13.4.3 *Hurum fire service*

Hurum fire service is a part-time service with a fire station at Tofte, approximately 18 kilometres from the escape tunnel at Storsand, which is their entrance point to the Oslofjord tunnel.

1.14 Regulations and guidelines

1.14.1 Acts of law:

The framework for the use, operation, inspection, control of and fire preparedness in road tunnels is mainly defined by the following Norwegian laws:

- Act No 23 of 21 June 1963 relating to roads (the Road Act).
- Act No 4 of 18 June 1965 relating to road traffic (the Road Traffic Act).
- Act No 20 of 14 June 2002 relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire service (the Fire and Explosion Act).

Regulations, standards and guidelines have been adopted pursuant to these acts.

1.14.1.1 *The Road Act*

The Road Act is administered by the NPRA and provides the legal basis for regulations, standards and guidelines that form the basis for the design and construction of roads and their operation and maintenance.

1.14.1.2 *The Road Traffic Act*

The Road Traffic Act is administered by the NPRA and provides the legal basis for regulations, standards and guidelines concerning signage, road markings and other measures to regulate road traffic.

1.14.1.3 *The Fire and Explosion Act*

The Directorate for Civil Protection and Emergency Planning (DSB) is the central government administrative authority for the Fire and Explosion Act. Chapter 3 Section 11 of the Act defines the fire service's duties. Among other things, reference is made to the fire service being charged with conducting fire prevention inspections of tunnels.

1.14.2 Regulations, standards and guidelines

The following regulations, standards and guidelines are discussed in more detail in this report:

- Regulations No 517 of 15 May 2007 on minimum safety requirements for certain road tunnels (the Tunnel Safety Regulations).

- Regulations No 1710 of 17 December 2015 on fire prevention.

- The NPRA's Manual N500 – Road Tunnels (2016). The manual has the status of a standard and was adopted pursuant to the Road Act.

- The NPRA's Manual R511– *Sikkerhetsforvaltning av vegtunneler del 1* (‘Safety Management of Road Tunnels Part 1’) (2014). The manual has the status of directions.

1.14.2.1 *The Tunnel Safety Regulations*

The Tunnel Safety Regulations apply to road tunnels longer than 500 metres that are part of the national road network and the trans-European road network in Norway (the TEN-T network), and its purpose as described in Section 1 is to:

> *Ensure the lowest permitted level of safety for road users in tunnels by defining requirements for the prevention of critical incidents that could endanger human life, the natural environment or the tunnel and for ensuring protection in the event of accidents.*

The Regulations were adopted in connection with the implementation of EU Directive 2004/54 and regulates matters relating to:

- The areas of responsibility of the administrative body, tunnel manager and tunnel safety inspector.

- Requirements for risk assessment.

- Minimum safety requirements for tunnels.

- Requirements for inspections.

- Reporting procedures.

- Approval procedures for tunnels that have not been approved, tunnels that have been approved but not put into use, and tunnels already in use.

- Time of approval of tunnels.

1.14.2.2 *Regulations on fire prevention*

Section 1 of the Regulations on fire prevention reads as follows:

> *These Regulations are intended to help to reduce the probability of fire and limit the potential consequences of fires to life, health, the environment and material assets.*

Among other things, the Regulations contain provisions on:

- General requirements concerning the owner and activity/user of structures.
- Prevention duties of owners of structures.
- Prevention duties of users of structures.
- The fire prevention duties of the municipal authorities.

1.14.2.3 *Manual 021 – Road Tunnels (1992)*

The 1992 edition of NPRA's Manual 021 – Road Tunnels applied at the time of the Oslofjord tunnel's construction. The manual has since undergone four revisions in 2002, 2006, 2010 and 2016, and the most recent edition is entitled *Håndbok N500 Vegtunneler* ('Manual N500 – Road Tunnels').

1.14.2.4 *Manual R511 – Sikkerhetsforvaltning av vegtunneler del 1 ('Safety Management of Road Tunnels Part 1')*

This manual was prepared to provide guidelines to ensure that the safety of Norwegian road tunnels is in compliance with the requirements set out in the Tunnel Safety Regulations, the Fire and Explosion Act and internal instructions issued by the NPRA.

1.15 Implemented measures

1.15.1 Norwegian Public Roads Administration

1.15.1.1 *Internal investigation of the fire in the Oslofjord tunnel on 5 May 2017*

A report prepared by the NPRA's road department for Akershus after the fire on 5 May 2017 describes conditions in the Oslofjord tunnel before the fire, the emergency services' efforts during the incident, how VTS East and the road department for Akershus handled the incident, work done before the reopening and measures implemented in the tunnel after the fire, as well as what experience the NPRA can draw from the incident.

The report states that many faults were identified during the most recent four-monthly test of the Oslofjord tunnel carried out on 8 and 9 March 2017. It also states that several faults in the tunnel's technical systems that were previously unknown to the tunnel owner were detected in connection with the fire closure of the Oslofjord tunnel on 5 May 2017.

1.15.1.2 *Measures implemented in the Oslofjord tunnel after the fire*

The section below describes the measures that the NPRA implemented before the Oslofjord tunnel was reopened for traffic on 29 May 2017 as described in the NPRA's report on the incident. These measures can be divided into probability reduction, preventive and consequence reduction measures.

Probability reduction measures

- The ‘Low Gear’ markings inside the Oslofjord tunnel have been changed to ‘Keep distance’ before and ‘Low Gear’ after the rumble strips.

- Refreshing/maintenance of rumble strips at ‘Low Gear’ inside the Oslofjord tunnel.

Preventive measures

- Heavy vehicle checks have been introduced on the Drøbak side of the Oslofjord tunnel, and are carried out by the Roadside Vehicle Inspection Section of the NPRA's Road Users and Vehicles Department.

- A ban was introduced on vehicles longer than 12 metres driving through the Oslofjord tunnel on weekdays from 07:00 to 09:00 and from 15:00 to 18:00. On 11 October 2017, this was changed to a ban on vehicles weighing more than 32 tonnes during the same periods.

Consequence reduction measures

- Signs bearing the text ‘Hold avstand/Keep distance, min 100 m, gjelder ikke personbil’ have been installed outside the Oslofjord tunnel’s portals.

- Signs bearing the text ‘Snu og kjør ut’ have been changed to ‘Snu og kjør ut + Brann/Fire’.

- Yellow flashing lights on the barrier have been changed to red flashing lights when the Oslofjord tunnel is closed.

- Signs bearing the text ‘Stengt tunnel’ outside the tunnel portals have been changed to ‘Stengt tunnel + Brann/Fire’.

- The time interval from the red flashing stop signals are activated until the barriers outside the tunnel portals start to go down has been shortened.

- A heavy vehicle breakdown recovery truck was stationed on the Drøbak side of the Oslofjord tunnel on weekdays between 09:00 and 15:00. This was a trial project that was discontinued after three months when an assessment concluded that the measure was inexpedient in relation to the cost and desired effect.

- Signs bearing the text ‘Videoovervåking’ have been placed at both tunnel portals to inform road users that the Oslofjord tunnel is under camera surveillance.

1.15.2 Follo fire service IKS

FBV has implemented the following measures since the incident:

- Extra smoke diver equipment with long air supply lines has been purchased for the tanker that was used when fighting the fire in the Oslofjord tunnel. This equipment is intended to guarantee fresh air to the tanker's driver if necessary.

- New hearing protection with accessories/communication equipment for use e.g. in tunnels is being tested. The reason for testing and, if applicable, purchasing this equipment, is that, during an incident, there is typically a lot of noise inside a tunnel from fans, pumps, fire and explosions. The hearing protection with accessories will be tested in the Oslofjord tunnel by agreement with the tunnel owner.

- On 25 August 2017, a meeting was held between the road department for Akershus, Buskerud county authority, Akershus county authority, Hurum fire service, Røyken fire and rescue service and FBV. The topic of the meeting was emergency preparedness and the capacity of the fire services responding to incidents in the Oslofjord tunnel, as well as measures to ensure safe and predictable access to the tunnel. A political decision by Buskerud county to have a fire engine permanently stationed near national road 23 by the Oslofjord tunnel was also discussed at this meeting. The meeting will be followed up in a separate process.

- A procedure for resource use in connection with emergency response in the Oslofjord tunnel has been established, and specifies that three fire stations shall always respond to a confirmed fire in the tunnel.

FBV has also identified and emphasised a number of learning points and lessons to be drawn from the incident, including that searching the roadway must take priority over searching emergency shelters, that, in order to ensure good information flow, it is desirable for the fire services to communicate with only one 110 emergency communication centre during incidents in the Oslofjord tunnel, and the importance of on-scene support for the on-scene fire commander.

1.16 The 2011 fire in the Oslofjord tunnel

On 23 June 2011, a Polish-registered heavy goods vehicle caught fire inside the Oslofjord tunnel as a result of engine breakdown. The engine breakdown took place during the ascent towards Drøbak, approximately 1.7 km from the tunnel exit. The risk to road users in the Oslofjord tunnel during the incident was increased by the fact that the tunnel's safety equipment and emergency response solutions did not adequately facilitate self-rescue. Consequently, several road users were trapped in the smoke.

1.16.1 Important safety issues identified during the investigation

In the course of the investigation, the AIBN identified five important safety issues that contributed to reducing system safety relating to the Oslofjord tunnel, and which resulted in road users becoming trapped in the smoke during the incident:

a) *The Oslofjord tunnel's emergency preparedness solution and safety equipment did not provide for an adequate safety level in relation to the traffic growth and traffic composition.*

b) *The fire and rescue preparedness for the Oslofjord tunnel was not dimensioned, equipped or organised according to what can be expected as regards the location and size of any fires in the tunnel.*

c) *Sufficient documentation was not available for the use of longitudinal ventilation in tunnel fires and for how evacuation should be carried out when there is a build-up of smoke in the tunnel.*

d) *The preconditions for the self-rescue principle were not safeguarded by the Oslofjord tunnel's safety equipment and emergency preparedness solution.*

e) *The Norwegian Public Roads Administration's safety management of the Oslofjord tunnel had not identified the relevant risk situation, and the agency's risk-based approach to safety and preparedness was inadequate.*

1.16.2 The engine breakdown

The AIBN's examination of the engine after the fire in 2011 found that:

On examination of the heavy goods vehicle, a large hole was found in the lower left side of the engine block (...). One of the engine's connecting rods was found outside the engine – on top of the tractor unit's front axle. The bearing cap (lower part of the connecting rod), the two bolts that attached the bearing cap to the connecting rod and parts of the bearing halves mounted between the connecting rod and crankshaft were found in the engine's oil sump (...).

One of the fastening bolts had snapped, and the other one was bent. The threaded part of the bent bolt that had been screwed into the connecting rod was deformed. There was corresponding deformation of the female treads in the connecting rod. Parts of the snapped bolt were still attached to the part of the connecting rod that was found outside the engine.

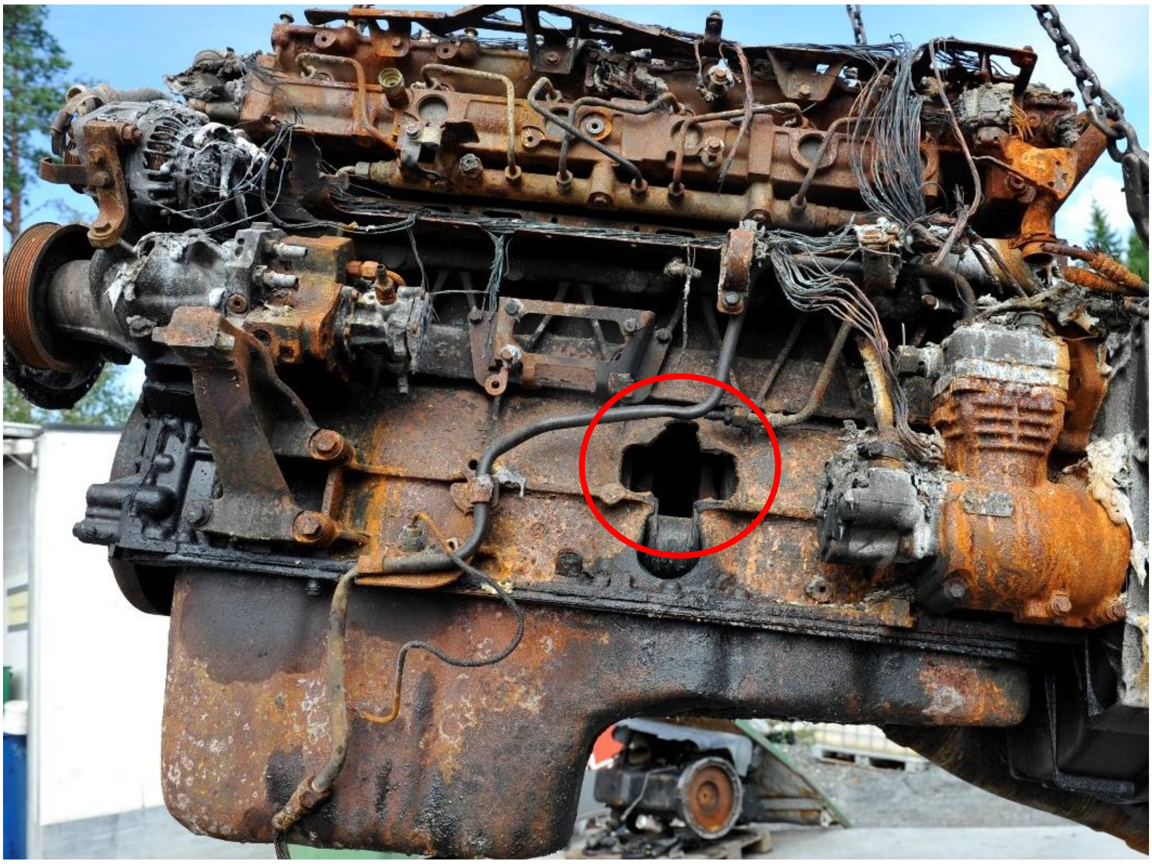

Figure 38: The engine from the tractor unit that caught fire in the Oslofjord tunnel on 23 June 2011. The red circle marks the hole in the engine block. Photo: AIBN

Figure 39: The big-end bearing of cylinder number 4 seen through the hole in the engine block of the tractor unit that caught fire in 2011. Photo: AIBN

In its report from the 2011 fire in the Oslofjord tunnel, the AIBN reached the following conclusion:

> *The AIBN is of the opinion that the reason for the engine breakdown that caused the fire was that one of the connecting rods in the engine became detached from the crankshaft (this probably gave rise to the metallic rumbling noise heard by the driver) and penetrated the engine block. The connecting rod then cut the supply of diesel to the diesel pump and damaged electrical cables running along the left side of the engine. The AIBN's assessment is that the fire in the engine started when oil fumes from the damaged engine or diesel from the damaged diesel line was ignited by hot engine components or by the electrical wire that the connecting rod hit.*
>
> *The investigation found that one of the connecting rod's bearing cap bolts had snapped and that the threads on the other bolt were deformed. In the AIBN's assessment, this damage indicates that the clearance between the crankshaft bearing and the crankpin was too great, which placed such strain on the bearing cap bolts that they snapped/were pulled from their sockets.*
>
> *The strain on the engine caused by speed regulation going downhill and the subsequent ascent up the tunnel may have hastened the engine breakdown. The AIBN also considers it a possibility that it may have been a coincidence that the heavy goods vehicle's engine broke down inside the tunnel.*

1.16.3 Similarities between the engine breakdowns in 2011 and 2017

The tractor unit that caught fire in 2011 was of the type MAN TGA 18.430, the same manufacturer and nearly the same type of engine that broke down in May 2017.

The engine breakdowns in the Oslofjord tunnel in 2011 and 2017 both occurred in cylinder number 4, which is located in the mid-section of the engine.

Figure 40 shows the connecting rods from the engine breakdowns in 2017 and 2011. The damage to the two connecting rods appears to be relatively similar with broken fastening bolts, deformation and discolouration caused by heat, see Figure 41.

Figure 40: The connecting rods from the fires in 2017 (left) and 2011 (right). Photo: AIBN

Figure 41: Bearing cap fastening from 2017 (left) and 2011 (right) with discoloration caused by heat. Photo: AIBN

1.17 Additional information

1.17.1 Supervision report, Case 2018-08

In August 2018, the NPRA published a supervision report, *Tilsynsrapport sak 2018-08*, that dealt with how safety in tunnels that have not been upgraded to comply with the Tunnel Safety Regulations is addressed through periodic inspections.

An important issue in the report was whether the NPRA has an adequate and efficient management system in place and uses it to plan, conduct and follow up periodic inspections to ensure that the minimum permitted safety level for the tunnel is maintained.

The report concluded as follows:

> *Overall, the supervision case found that the Directorate of Public Roads has no overriding national plan for periodic inspection of the tunnels that have not been upgraded, and that the periodic inspections are carried out in 87% of cases, but not followed up by the Directorate as required. Work has been carried out on the quality system processes, but central guidelines have yet to be drawn up.*
>
> *The Road Supervisory Authority found that the Directorate of Public Roads:*
>
> *• has not organised the execution of inspections in such a way as to ensure independent assessment*
>
> *• has not drawn up a national inspection plan and ensured that inspections take place within the six-year deadline*
>
> *• has not ensured that periodic inspections will determine whether the minimum requirements in the Tunnel Safety Regulations are complied with*
>
> *• is not following up periodic inspections*
>
> *• has not updated key guidelines*

The supervision report also refers to the Office of the Auditor General of Norway's report from 2016, which pointed out that the Directorate of Public Roads has failed to draw up or update key guidelines, guides and quality systems, and that the Directorate lacks adequate information to ensure that tunnels are managed in line with applicable laws and regulations.

The supervisory activity in relation to the NPRA identified a total of five nonconformities that will be followed up together with the Directorate of Public Roads.

2. ANALYSIS

2.1 Introduction

The AIBN initiated an investigation of the vehicle fire in the Oslofjord tunnel because of the considerable damage potential of such incidents and because there were several similarities with the big fire in the Oslofjord tunnel in 2011. The sequence of events, location of the fire and vehicle type were all very similar to the 2011 vehicle fire, and findings made during an inspection of the tunnel indicated that engine breakdown was also the likely cause of the most recent fire.

The vehicle fire and the circumstances surrounding the incident have been investigated and analysed in line with the AIBN's framework and analysis process for systematic safety investigations (the AIBN method). The sequence of events, from the time that the heavy goods vehicle entered the Oslofjord tunnel up until the time that everybody had been evacuated from the tunnel, has been mapped through sequential presentation in a STEP[22] diagram.

The fire in the Oslofjord tunnel was assessed in terms of events and actions that may have influenced the sequence of events and safety, either adversely (safety problems) or favourably (safety enhancers). These factors have been considered throughout the analysis.

The analysis of the triggering event, with the focus on driver behaviour, the tractor engine's braking power and the engine breakdown that triggered the incident, is presented in section 2.2. The AIBN has also conducted a thorough investigation and analysis of the following: barriers that can make it more difficult to extinguish fires in heavy vehicle engines, notification of the fire and closure of the Oslofjord tunnel, fire extinguishing, ventilation control during the fire, evacuation, search and rescue efforts, and VTS's work and coordination with the emergency services. These topics are discussed in sections 2.3, 2.4, 2.5, 2.6, 2.7 and 2.8, respectively.

Finally, the follow-up of safety in the Oslofjord tunnel is assessed, which had a bearing on the tunnel's safety level and the emergency response strategy in force at the time of the incident. Handling of nonconformities, maintenance intervals, periodic inspections, safety approvals and emergency response plans are discussed in this assessment, as well as exercises and technical fire inspections. Reflections on this are discussed in section 2.9.

2.2 Assessment of the triggering event

2.2.1 Driver behaviour before the engine breakdown

The driver's behaviour was analysed based on information from CCTV footage from inside the tunnel and the statement that the driver made to the police. The AIBN considers the driver's choice of speed and driving style to have been within the limits of what could be expected when driving through the Oslofjord tunnel. Information from the video footage indicates that the driver kept a steady speed below the speed limit while driving downhill in the tunnel.

[22] Sequentially Timed Events Plotting.

The driver periodically used both the tractor unit's exhaust brake and the heavy goods vehicle's ordinary service brakes during the drive downhill.

The driver has also stated that there was a fault indication light on the vehicle's dashboard in the form of an orange exclamation mark. At the beginning of the transport assignment, the driver had been told that the fault indicated by this warning light had been repaired. The investigation has not found any connection between this warning light and the engine breakdown.

2.2.2 The braking power of the tractor unit's exhaust brake

Based on the available information, the heavy goods vehicle that caught fire had an estimated weight of around 24–25 tonnes. Calculations[23] show that, given this weight and the gradient of 7%, a braking force of 14.5–15.1 kN would be required to keep the vehicle travelling at a steady speed. These calculations do not take account of air resistance.

The theoretical calculations show that to make optimum use of the exhaust brake, the maximum speed of the tractor vehicle travelling downhill in the tunnel should be just over 60 km/h when driving in eleventh gear. Calculations based on video footage show that the speed was over 60 km/h on several occasions, and in the AIBN's opinion this indicates that it is highly likely that the eleventh gear or a higher gear was used going down the tunnel.

In his statement to the police, the driver of the heavy goods vehicle that caught fire said that he experienced problems with the exhaust brakes some distance into the tunnel. The exhaust brake disengaged on several occasions, but the driver compensated for the loss of the exhaust brake by applying the heavy goods vehicle's service brakes. The investigation has not found the reason why the exhaust brake disengaged, but the AIBN's assessment is that when braking effect from the exhaust brake is lost, the engine's rpm will increase, as braking effect is provided by the engine alone until the service brakes are activated. The engine breakdown is analysed in more detail in section 2.2.3.1.

2.2.3 Assessment of the engine breakdown as initial cause of the fire

2.2.3.1 *Engine breakdown as triggering event*

Technical examination of the engine showed that the bearing halves for bearing number 4 had come loose and rotated with the crankpin. The rotation of the bearing halves reduced or blocked the oil supply to big-end bearing number 4, while also reducing or blocking the oil supply to crankshaft bearing number 4. Based on measurements and examination of the engine components, the AIBN is of the opinion that the bearing halves began to rotate as a result of thermal expansion in the crankshaft bearing cap, in addition to possibly being over-strained on account of excessive rpm in the engine.

Reduced lubrication of the big-end bearing and main bearing caused the temperature to rise as a result of the increased friction coefficient between the connecting rod and crankshaft. The AIBN believes that this build-up of heat caused beginning friction welding between the connecting rod and crankshaft, which in turn resulted in the connecting rod and piston pin being ejected from the engine and knocking a hole in the

[23] Braking force = $mg(\sin(\alpha) - f\cos(\alpha))[N]$; *where f = rolling resistance 0.008*

left side of the engine. This is consistent with observations from the tunnel’s CCTV system, which show that engine parts were red-hot when they hit the roadway.

As a consequence of the rotation of the bearing halves and the oil supply to the big-end bearing being severely restricted or cut off completely, the engine broke down on its way up the tunnel. How quickly heat built up in the engine depends on several factors, such as how restricted the oil supply was, how much the connecting rod was cooled down by the oily surroundings in which it moved and the strain put on the engine. Hence, the AIBN cannot determine with certainty when the bearing halves actually began to rotate, but it is considered likely that this happened in the lower part of the downhill slope in the tunnel.

The fire started immediately after the engine broke down. The technical examination of the engine showed damage to a fuel line on the left side of the engine block. The damage is consistent with parts of the connecting rod breaking free and being ejected from the engine block, as shown in the CCTV footage from the tunnel. The AIBN believes that the fire in the engine compartment started when fuel or oil came into contact with a hot surface.

2.2.3.2 *Similarities with the engine breakdown in the Oslofjord tunnel in 2011*

When investigating the scene of the 2017 fire, the AIBN found parts of a connecting rod and a piston pin from the broken-down engine in the roadway. The same type of components were found on top of the tractor unit's front axle after the vehicle fire in the Oslofjord tunnel on 23 June 2011.

The engine breakdowns in the Oslofjord tunnel in 2011 and 2017 both occurred in cylinder number 4. This cylinder is located in the engine's mid-section, which is usually the area exposed to the highest temperatures.

Engine parts from the tractor unit that caught fire in 2011 were studied more closely in connection with the examination of the tractor engine from the 2017 fire. Several similarities were found in the damage to these engine parts. In particular, there are similarities in the breakage of the bearing cap fastening bolts and the heat damage to the bearing caps. In the AIBN's opinion, it is therefore reasonable to assume that there was also a build-up of heat in the big-end bearings in the engine that broke down in 2011. Comprehensive examinations have not succeeded in determining the reason for this.

2.2.3.3 *Engine wear and condition*

The tractor unit in question was ten years old at the time of the fire. Based on the tractor unit's odometer reading of 343,708 km registered in 2010, the AIBN considers it probable that the tractor had run 1,000,000 km or more at the time of the incident.

Measurements of the crankshaft and crankshaft bearings carried out by the AIBN found the wear and tear on the components to be within the manufacturer's tolerance limits. The examination of the engine also showed that the crankshaft bearing halves were from different number series, which, according to the manufacturer, indicates that the engine had undergone repairs after its manufacture. The AIBN considers it probable that these bearing halves had been replaced at some point.

The technical examinations of the engine have also found that the clutch and flywheel between the engine and gear box had been replaced. The investigation has also uncovered that the tractor unit's exhaust system had been manipulated. However, no findings have been made to indicate that engine maintenance has been inadequate or that the manipulation of the exhaust system contributed to the engine breakdown.

2.3 Barriers that could reduce the probability of heavy vehicle engine fires

The AIBN has investigated several fires in tunnels that started in heavy vehicles. Common characteristics are that they started in the engine compartment and that they proved impossible to extinguish. This makes it important to focus on how such vehicle fires can be prevented.

The AIBN considers it important to check and identify circumstances that can help to prevent incidents such as brake failure/engine breakdown and subsequent fire in heavy vehicles.

However, previous investigations as well as the present one have shown that it would be very difficult to predict or detect an engine breakdown of the type that occurred in the Oslofjord tunnel on 5 May 2017 by means of heat scanners or other detection methods before the vehicle enters the tunnel. This makes it very challenging for tunnel owners and heavy goods vehicle drivers alike to avert such engine breakdowns and similar incidents.

The AIBN is of the opinion that consideration should be given to introducing further barriers to reduce the probability of fire in the engine compartment when driving in tunnels. This is particularly relevant in long undersea tunnels with steep downhill and uphill slopes. This investigation has shown that the heavy goods vehicle had no auxiliary brakes other than the exhaust brake. An auxiliary brake, for example a retarder, could have relieved the exhaust brake and service brakes in this situation, which might have helped to prevent the engine's rpm from increasing as the vehicle travelled downhill in the tunnel. The AIBN is also of the opinion that the vehicle's probable high mileage may have contributed to the engine breakdown.

In the AIBN's assessment, a retarder in addition to an engine brake could provide an extra safety margin for heavy goods vehicles driving through steep undersea tunnels. It would also be very beneficial if buyers of transport services were to demand documentation of satisfactory technical condition and level of maintenance for equipment used for demanding and risk-exposed transport routes such as steep undersea tunnels.

The AIBN will not submit any safety recommendations on this point, but the investigation does demonstrate a need for following up challenges relating to how vehicles are fitted out when driving through long and steep undersea tunnels.

2.4 Fire notification and closure of the Oslofjord tunnel

2.4.1 Notification of the emergency services

The driver of the heavy goods vehicle that caught fire did not notify the emergency services or VTS that the vehicle was on fire. A passing motorist notified VTS of the fire at the same time as VTS detected the incident through its CCTV system. In this way, notification was received quickly and the emergency services were able to rapidly respond. It is important that the driver should give notification, since information about the location of the incident, the number of road users involved and the type of cargo is crucial to enable the emergency services to respond as appropriately, safely and effectively as possible. As it happened, VTS had a relatively good overview of the incident in this particular case, but had the incident occurred in a tunnel without CCTV surveillance, the emergency services would not have had access to necessary information as quickly.

2.4.2 Closure of the Oslofjord tunnel

A fault in the control and regulation system for closing the Oslofjord tunnel caused the lowering of the barriers to be delayed by 35 seconds in relation to what would normally have been the case. The investigation has shown that the NPRA was not aware of this fault before the fire on 5 May 2017. The negative consequences of this fault were further exacerbated when several motorists ignored the flashing red stop lights and entered the tunnel after the fire in the heavy goods vehicle had started, but before the barriers were lowered.

The AIBN considers this to be a serious fault in the tunnel’s safety management system, and links it to inadequate tunnel safety management and follow-up. This will be analysed in more detail in section 2.9.

2.4.3 Motorists ignored flashing red stop signals

CCTV footage from the tunnel shows that several motorists ignored the flashing red stop signals. The AIBN's assessment is that by entering the closed tunnel, these motorists placed themselves at great risk and complicated VTS's work as well as the fire service's extinguishing efforts and search and rescue work.

Two heavy goods vehicles proceeded all the way to the scene of the fire, which meant that the fire had the potential to spread. Well executed firefighting efforts on the part of FBV prevented this from developing into a major fire with potentially lethal outcomes for those involved. The fire service’s efforts are discussed in sections 2.5 and 2.7.

The behaviour of motorists during the fire shows that flashing red stop signals alone are not enough to stop traffic, and that physical barriers constitute a very important safety barrier in connection with fires in tunnels. The lowering of tunnel barriers must therefore function in accordance with normal procedure at all times.

Furthermore, the AIBN is of the opinion that the motorists’ actions reflect a need to raise awareness and improve road users' knowledge about safe driving in road tunnels through information campaigns and driver education.

2.4.4 Notification of road users inside the tunnel

The NPRA's own investigations after the fire found that VTS operators could not verify whether the radio alert messaging system for the tunnel was working or not during the incident. However, documentation obtained by the NPRA indicates that the motorists involved did not receive radio messages during the fire. This means that these motorists were not notified of the fire in the tunnel.

In several previous reports, the AIBN has highlighted the need for immediate notification of road users located in a tunnel to evacuate in the event of fire. This issue was addressed in safety recommendation ROAD No 2013/08T after the Oslofjord tunnel fire in 2011, and in safety recommendation ROAD No 2015/03T after the Gudvanga tunnel fire in

2013, among others. In the AIBN’s opinion, quick and effective notification of road users is an important element in limiting the damage potential of tunnel fires and absolutely crucial to safeguarding possibilities for self-rescue.

The AIBN's assessment is that the fault in the radio alert system in the tunnel contributed to more vehicles continuing to drive into the tunnel during the fire. Since it is impossible for heavy goods vehicles to turn around inside a tunnel, it is particularly important that the notification system works and is used during a fire in order to stop such vehicles in time. The AIBN considers this a severe nonconformity and believes that it had negative consequences for road users during the fire.

2.4.5 Control and monitoring of traffic in the tunnel after the fire started

2.4.5.1 *Lack of barriers to stop vehicles*

Findings from this investigation show that there is a need to implement further safety measures in the tunnel to prevent motorists from driving all the way to the scene of the fire. The Tunnel Safety Regulations stipulate minimum requirements for safety equipment. The following is an excerpt from Annex I to the Regulations:

> *2.15 Equipment for closing tunnels*
>
> *2.15.1. All tunnels longer than 1,000 metres must have traffic lights installed in front of the tunnel entrances so that the tunnel can be closed in case of an emergency. Extra equipment, such as variable message signs and barriers, may be installed to ensure compliance with the instructions.*
>
> *2.15.2. It is recommended that equipment to stop vehicles in case of an emergency be installed at intervals not exceeding 1,000 metres in all tunnels longer than 3,000 metres that have a control centre and a traffic volume in excess of 2,000 vehicles per lane. The equipment shall consist of traffic lights and any additional equipment, such as loudspeakers, variable message signs and barriers.*

Based on the requirements set out in the Tunnel Safety Regulations and the findings made in the course of the investigation, the AIBN is of the opinion that the NPRA should look into the possibility of establishing further barriers inside the Oslofjord tunnel. This could prevent motorists who are already in the tunnel from driving on and placing themselves at great risk of being trapped in the smoke and heat.

2.4.5.2 *Traffic monitoring during the fire*

The Oslofjord tunnel does not have a vehicle counting system that gives VTS up-to-date information about the number of vehicles in the tunnel at all times. For this reason, the VTS operators had to rewind the CCTV footage from the tunnel during the fire on 5 May 2017 to obtain an overview of the number of vehicles in the tunnel when the fire started.

In the AIBN's assessment, the absence of real-time vehicle registration complicates both traffic monitoring during serious incidents in tunnels and the collection of information for use by the emergency services. When a fire breaks out in a long tunnel, the immediate implementation of traffic control measures can be crucial in order to prevent the damage potential from increasing as a result of the presence of other vehicles in the tunnel and the direction in which they are travelling. It is thus important that VTS has immediate access to information about and an overview of traffic in the tunnel.

In previous investigations, the AIBN has identified a need for real-time overview of vehicles in tunnels; see report ROAD No 2015/02 on the fire in the Gudvanga tunnel in 2013 and report ROAD No 2016/03 on the fire in the Gudvanga tunnel in 2015. This was also pointed out in safety recommendation 2016/5T, where the AIBN recommends that the NPRA review and improve equipment and procedures relating to tunnel fires. This includes developing real-time information technology.

2.5 Firefighting

2.5.1 Follo fire service IKS's on-scene command

Notification of the fire was received by the 110 emergency communication centres, ABØ and Vestviken 110 during watch handover, and the fire service therefore had more resources than normal at its disposal on the day of the incident. FBV's on-scene commander therefore had good support during the call-out, and this in turn resulted in good and continuous communication with VTS.

When notification of the fire in the Oslofjord tunnel was received, FBV's on-scene commander called out resources from FBV, Mosseregionen intermunicipal fire and rescue service (MIB), Hurum fire service and Røyken fire and rescue service.

Experience from previous tunnel fires show that working in tunnels is demanding for fire crews, and can require extensive resources. In the AIBN's opinion, the situation where plenty of resources were called out by the on-scene fire commander, as well as the early establishment of the police, health and fire services' incident command post (ICP) during the fire, were necessary to ensure good management and communication with VTS, the 110 emergency communication centres, the health service and the police.

2.5.2 Initial extinguishing effort and evacuation of the driver

During this incident, the driver used his own extinguishing equipment but did not succeed in putting out the fire.

The AIBN's previous investigations of tunnel fires have shown that it is demanding to put out fires in heavy vehicles, and that the fire extinguishers available in the vehicle or in the tunnel are not always sufficient to extinguish such fires at an early stage.

It has not been possible to examine all circumstances relating to this incident, but information that the AIBN has access to shows that the driver of the heavy goods vehicle did not make use of available equipment in the tunnel to try to extinguish the fire just after it started. The AIBN believes that it is important that drivers who find themselves in such situations act in an expedient and effectively manner and that they are both trained and prepared to do their best to put out the fire in an early phase. It cannot be concluded with any certainty, however, that the driver could have prevented the fire from developing had the wall-mounted extinguishing equipment been used.

CCTV footage from the tunnel shows that the driver of the burning heavy goods vehicle was evacuated from the scene of the fire by a passing motorist approximately six minutes after the fire started. The footage shows significant build-up of smoke in the tunnel and that the smoke was about to reach the passing motorist, who had stopped in an emergency lay-by about 40 metres in front of the burning vehicle. The driver would probably have become trapped in the smoke had he not been evacuated by the passing motorist.

2.5.3 Firefighting by Follo fire service IKS

2.5.3.1 *Extinguishing effort and resources*

During the incident, FBV entered the tunnel with a purpose-built tanker with deluge guns on the roof and at the front, acquired at the turn of the year 2016/2017. The tanker made a crucial difference to the extinguishing efforts by cooling down the burning vehicle and surrounding areas of the tunnel, as well as preventing the fire from spreading to the other two heavy goods vehicles in the tunnel. Moss intermunicipal fire and rescue service also helped with the water supply during the incident, which meant that the firefighters never ran out of water during their extinguishing efforts.

The AIBN's assessment is therefore that the fire in the Oslofjord tunnel on 5 May 2017 would very probably have affected three heavy goods vehicles if FVB had not had sufficient resources and equipment to cool down the fire in the vehicle and the fire gases. The AIBN also finds that the fire service's coordinated efforts to extinguish the vehicle fire, with an emphasis on FBV’s extinguishing efforts and resources, was the main reason why the fire was limited to one vehicle.

2.6 Ventilation control during the fire

2.6.1 Decision concerning and activation of fire ventilation

The ventilation system was stopped when fire closure of the tunnel was activated. VTS had observed that there were still vehicles and people in the tunnel, and decided in consultation with ABØ to wait before starting fire ventilation. Based on previous investigations of tunnel fires, the AIBN's assessment is that activating fire ventilation at that time could have adversely affected the possibility of evacuating the vehicles and road users who were still inside the tunnel. The AIBN therefore considers that VTS and ABØ made the correct decision under the circumstances.

As a consequence of the delay in activating the fire ventilation, the smoke from the fire spread slowly towards the FBV’s response team. The tanker encountered dense smoke as it approached the burning vehicle, and FBV had to request that fire ventilation be started to reach the scene of the fire. However, the AIBN does not believe that this was a major obstacle to their work. The delay gave VTS valuable time to get an overview of the situation using the CCTV cameras before the fire ventilation was activated.

2.6.2 Fire ventilation control fault

When the decision was made to activate fire ventilation in connection with the fire on 5 May 2017, the fans failed to start in fire ventilation mode. VTS therefore activated normal ventilation at level 2, which corresponds to fire ventilation. Later, full ventilation was activated. The AIBN finds that this course of action shows that VTS understood the situation correctly and was solution-oriented during the incident.

Problems activating the fire ventilation created unnecessary challenges and increased the VTS operators’ workload during the fire, but this nonconformity had no significant negative consequences for the extinguishing efforts inside the tunnel.

2.6.3 Fan failure

A total of 18% of the tunnel fans, or six fans, did not work during the incident. The tunnel owner was aware that four fans in the tunnel were out of order, and another two fans were found to have failed during the incident on 5 May 2017.

The AIBN finds that it warrants criticism that the four defective fans, which were identified two months before the fire, had not been repaired before. The fans were scheduled to be replaced in September 2017, six months after the first nonconformities were detected.

Repairs of technical equipment in tunnels that is critical to safety and effective tunnel ventilation should be given higher priority. The AIBN is also of the opinion that further nonconformities relating to the fans in the Oslofjord tunnel should have been identified before the fire, and links this to inadequate tunnel inspections.

The NPRA's report concerning the fire emphasises that the fan capacity in the Oslofjord tunnel does not meet current requirements. The report's assessment is that ventilation capacity and maintenance needs must be included in connection with an assessment of shorter maintenance intervals for safety installations in the tunnel. The AIBN supports this assessment.

2.6.4 Pre-defined ventilation direction

The direction of the fire ventilation in the Oslofjord tunnel was predefined, and led to the smoke being ventilated away from the Drøbak side towards the Hurum side of the tunnel. More than 5 km of the tunnel filled with smoke, and two drivers had to use emergency shelter 'P' to escape the smoke. The smoke ventilation allowed FBV to reach the scene of the fire and start extinguishing it, but also prevented personnel from Hurum fire service and Røyken fire and rescue service on the Hurum side of the tunnel from starting early search and rescue efforts in the longest part of the tunnel, where vehicles had been observed after the tunnel was closed.

The AIBN notes that, except for the tunnel ventilation being stopped for a while, the fire ventilation direction and strategy for emergency response work in the Oslofjord tunnel remains the same as during the 2011 vehicle fire in the same tunnel, during which nine road users were trapped in the smoke and had to be evacuated by fire crews. The following was commented on in the AIBN's report on that fire:

> *It has been decided that firefighting efforts are to be carried out from the Drøbak side, where the fire service has more resources. In order to ensure that it is free of smoke, the direction of the ventilation, and of the smoke, will always be from Drøbak towards Hurum, regardless of where in the tunnel a fire occurs. The AIBN understands this reasoning up to a point, but also has reservations about the smoke generated being uncritically ventilated towards the Hurum side. The AIBN questions whether predictability for the fire service and which fire service has more resources available for firefighting efforts should always govern fire ventilation, regardless of the nature of the incident and considerations relating to the evacuation of other road users from the tunnel.*

The AIBN also notes that in connection with this fire, the predefined ventilation direction again resulted in road users and vehicles being exposed to heat and smoke, as well as to the smoke being ventilated the longest way out of the tunnel.

Based on the findings made in the present investigation and in the investigation of the 2011 vehicle fire in the Oslofjord tunnel, the AIBN believes that there is still reason to question the use of pre-determined strategies and a pre-defined fire ventilation direction regardless of the nature of the incident or where in the tunnel the fire is located.

2.7 Evacuation, search and rescue efforts

2.7.1 The road users' possibility of self-rescue

The drivers of the two heavy goods vehicles that had driven all the way to the scene of the fire took refuge in the nearest emergency shelter in the tunnel when they understood the severity of the situation. Considering the location of the heavy goods vehicles in relation to the fire and the heat they were exposed to, the AIBN's assessment is that in connection with this incident, the drivers were right to leave their vehicles and take refuge in an emergency shelter. However, the AIBN would like to point out that previous investigations of fires in tunnels have shown that people who remain inside their vehicles suffer less serious smoke inhalation injuries than people who leave their vehicles to evacuate on foot.

The self-rescue principle applies to road users in connection with tunnel fires and subsequent evacuation. The principle is based on road users making their own way out of the tunnel, either using their vehicle or on foot. During this incident, the road users evacuated into an emergency shelter from which it is not possible to evacuate to open air. The AIBN's assessment of the sequence of events is that it was not possible for these road users to evacuate from the tunnel on their own due to the predefined fire ventilation direction. In the AIBN's opinion, the preconditions for self-rescue were not met during this fire.

2.7.2 The fire service’s rescue work in the tunnel

FBV’s response personnel were informed that there were people in emergency shelter ‘P’ while they were working to put out the fire. The leader of the smoke diving team at the scene decided to prioritise extinguishing the fire over evacuating these drivers from the tunnel, as he considered that they were safe in the shelter. VTS was in telephone contact with both ICP and the persons in the emergency shelter throughout the incident, and smoke divers came into the shelter during the incident.

In the AIBN’s opinion, the fire service prioritised correctly during this incident, as the pre-defined ventilation direction resulted in the area around emergency shelter ‘P’ filling with smoke, and there were also incipient fires in the heavy goods vehicles behind the one that caught fire. The temperature in the tunnel was also relatively high in the vicinity of shelter ‘P’. However, the AIBN would like to point out that the direction of ventilation complicated search and rescue efforts on the Hurum side of the fire as long as the fire was burning with unrestricted intensity. This is dealt with in more detail in section 2.7.4.

2.7.3 The fire service's evacuation equipment

The road users in the emergency shelter were evacuated one by one, as FBV had only one functioning buddy mask. The evacuation from the emergency shelter through the tunnel to the open air took place by ATV.

The AIBN's assessment is that in connection with this incident, with only two people to evacuate, their safety was ensured during the evacuation even if one of the buddy masks was not working. However, the AIBN is of the opinion that the evacuation would have been more complicated and time-consuming had there been more people in the emergency shelter, and that a larger vehicle would in such case have been needed to transport them out of the tunnel in a safe and efficient manner.

2.7.4 Search of the tunnel

Hurum fire service and Røyken fire and rescue service are responsible for searching the Oslofjord tunnel in the event of a fire, while FBV is responsible for extinguishing the fire. This plan was followed during the incident. Hurum fire service entered the escape tunnel, while Røyken fire and rescue service assembled by the tunnel portal on the Hurum side.

Experience from the 2011 vehicle fire in the Oslofjord tunnel shows that it was highly demanding and risky for the firefighters to conduct searches when the smoke plug was approaching the tunnel portal. Several motorists evacuated from the smoke-filled tunnel in their vehicles, and the emergency response personnel were at risk of being hit by vehicles. This forced the fire service to interrupt its search efforts in the tunnel.

Based on this experience in combination with information received from VTS, ICP decided during the fire on 5 May 2017 that Hurum fire service and Røyken fire and rescue service would not start searching the tunnel until FBV had the fire under control. As a result of this, Røyken fire and rescue service did not perform searches in the tunnel until the smoke plug reached the Hurum side. Footage from the tunnel's CCTV system shows that it took approximately 20 minutes from the first personnel from Røyken fire and rescue service arrived at the tunnel until the smoke from the fire had been expelled from the tunnel on the Hurum side.

The AIBN's assessment is that it would have been possible to search parts of the tunnel using appropriate equipment during the 20-minute period from the firefighters' arrival at the tunnel until the smoke plug reached the tunnel exit. Even though VTS had a certain overview of the traffic situation before the smoke covered the CCTV cameras, it was still uncertain whether there were more people in the tunnel in addition to the two drivers in emergency shelter 'P'.

When FBV managed to bring the vehicle fire under control, approximately one hour after it was detected, the search for road users started in the smoke-filled part of the tunnel. There were indications that several emergency shelters were in use, and both Hurum fire service and Røyken fire and rescue service carried out extensive searches of the tunnel. In the evaluation following the fire, FBV commented that searching the tunnel itself must take priority over searching the emergency shelters. The AIBN supports this assessment.

2.7.5 Use of the Nødnett network during the incident

The communication between ICP, ABØ and VTS worked well during the incident. However, there were major problems with the emergency communication network inside the tunnel. The communication problems were at times so severe that they affected the fire service's work. In addition, the fans in the tunnel made so much noise that the response personnel had to sit inside their vehicles to communicate with each other and/or with ICP outside the tunnel. There was also no Nødnett coverage in the emergency shelters.

Similar problems with the Nødnett network had been identified during previous call-outs to the Oslofjord tunnel, but the network was found to be in satisfactory condition when tested after a vehicle fire in the tunnel on 26 April 2017 and following an upgrade of the communication system in the fire service's response vehicles. It therefore came as a surprise to the response personnel involved that the network still functioned so poorly in the Oslofjord tunnel during the incident on 5 May 2017.

A well-functioning emergency communication network is an important precondition for good, effective and safe response to tunnel fires. Based on the facts uncovered in the course of this investigation, the AIBN is of the opinion that better procedures should be established for reporting faults and nonconformities in the Norwegian Directorate for Civil Protection's (DBS) public safety network Nødnett. In addition, DBS, as the body responsible for operating the digital public safety network, should do more to follow up and ensure that it is being operated, tested and maintained in a satisfactory manner. Control of the Nødnett network should also be included in the inspections and safety approval of tunnels, see sections 2.9.3 and 2.9.4.

2.7.6 Emergency shelters

According to the Tunnel Safety Regulations Annex I Section 2.3.4, no emergency shelters should be built without an evacuation route. However, based on experience from the vehicle fire in 2011, the NPRA nonetheless decided to build emergency shelters in the Oslofjord tunnel.

Emergency shelter 'P' was used by two persons during this fire, and the AIBN is of the opinion that the shelter protected them from being exposed to both smoke and heat. This means that the emergency shelter prevented serious and potentially life-threatening smoke inhalation injuries.

The AIBN also believes that the use of emergency shelters in tunnels must be seen in conjunction with the pre-defined ventilation strategy, whereby search and rescue efforts are not initiated on the side of the fire that the smoke is ventilated to until the fire is under control. During this fire, the search for people in the tunnel was not completed until one and a half hours after the fire started.

2.8 VTS's efforts and cooperation with the emergency services

In the AIBN's assessment, VTS did a good job during the fire in the Oslofjord tunnel. The fire was detected at an early stage, ventilation was first stopped to give road users time to evacuate, and then activated manually when fire ventilation was requested by FBV and failed to start as expected. The AIBN would particularly like to draw attention to the way in which VTS dealt with the drivers in the emergency shelter while the firefighting was going on in the tunnel. VTS communicated status information between the rescue personnel and the drivers, which reassured the drivers as well as providing important information to the response personnel that they used as a basis for making decisions concerning their further extinguishing and evacuation efforts.

After the fire closure of the Oslofjord tunnel, other tunnels nearby were also closed by VTS, which gave the emergency services greater scope of action. Closing other tunnels near the Oslofjord tunnel was a learning point from a vehicle fire in the tunnel in April 2017, and the AIBN takes a positive view of the fact that the VTS operators applied this learning point during the fire.

Closed access routes to the tunnel, on the other hand, did present some challenges for the emergency services when responding to the tunnel. The NPRA report emphasises that it is important to establish communication between VTS and the emergency services at an early stage to ensure rapid response and early exchange of information.

The fire started during watch handover at VTS and ABØ, which meant that more resources than normal were available during the incident. This resulted in good and continuous communication between the 110 emergency communication centre and VTS throughout the incident, both via the Nødnett shared talk group and by phone. The AIBN believes that this incident demonstrates how important it is to have experienced and well trained VTS operators.

2.9 Follow-up of safety in the Oslofjord tunnel

Risk-based safety management means that risk mapping and assessment are emphasised in the safety management system so that action is taken before a serious incident occurs. Based on this principle, the AIBN has, as part of its investigation, mapped safety follow-up in the Oslofjord tunnel, including systematic activities established by the NPRA to attend to safety in the tunnel. This entails compliance with requirements stipulated in the Tunnel Safety Regulations and guidelines set out in applicable manuals.

2.9.1 Handling of nonconformities

The investigation of the fire in the Oslofjord tunnel on 5 May 2017 identified several technical nonconformities in the tunnel’s safety equipment. Among other things, these nonconformities related to tunnel closure with barriers, activation of fire ventilation and available fan capacity, radio alert messages to road users, the Nødnett network and false emergency shelter alarms. The NPRA was aware of some of these nonconformities before the fire, while others were unknown and were only identified during the fire.

Many of the known faults were detected in connection with four-monthly testing of the tunnel systems on 8 and 9 march 2017, but had not been repaired before the fire. However, most of the nonconformities were repaired by the time the Oslofjord tunnel reopened for traffic after the fire on 29 May 2017, 24 days after the fire. Based on this time frame, the AIBN takes a critical view of why known nonconformities in the tunnel’s safety equipment detected during four-monthly testing had not been remedied at the time of the fire on 5 May 2017.

The AIBN takes a positive view of the fact that the NPRA as the tunnel owner tests the technical infrastructure in the Oslofjord tunnel every four months. However, there is no common registration system for faults and nonconformities relating to the tunnel’s safety equipment. Faults and nonconformities are registered in different systems, which include internal databases, minutes of meetings and email exchanges.

According to information received by the AIBN, it is demanding for the tunnel manager to obtain a good and comprehensive overview of registered faults and nonconformities, which systems are affected and the consequences for the overall safety situation in the tunnel. The AIBN sees a need for a comprehensive nonconformity system for the tunnel safety equipment where faults and nonconformities can be reported on a continuous basis, and where the tunnel manager can continuously monitor the technical operational safety status.

The AIBN submits one safety recommendation on this point.

2.9.2 Maintenance interval

The tunnel owner is responsible for control and, if relevant, for repairing faults and nonconformities in the technical systems in the tunnel. The tunnel's safety equipment should be checked regularly to prevent any faults or nonconformities that can contribute to increasing the extent of the damage if an incident occurs.

The AIBN is aware that the current maintenance intervals for the Oslofjord tunnel are based on tunnel category C, but that the tunnel would now have been classified as a category D tunnel. The age of the tunnel also requires short maintenance intervals. The AIBN takes a positive view of the fact that the NPRA has identified a need for shorter maintenance intervals for the Oslofjord tunnel since the incident.

2.9.3 Periodic inspections

In its capacity as the administrative body, the Directorate of Public Roads has a responsibility for following up safety in the tunnel. In the AIBN's opinion, periodic inspections are an important instrument in the administrative body's risk-based safety management of tunnels in operation.

In light of the findings made in the course of its investigation, which include several technical nonconformities in the tunnel's safety equipment and the absence of a comprehensive system for dealing with nonconformities, the AIBN takes a critical view of the fact that periodic inspections of safety equipment in the Oslofjord tunnel are only conducted every six years. The AIBN is of the opinion that the possibility of self-rescue is linked to the technical condition of the safety equipment in the tunnel, and this was also pointed out in the risk assessment from 2017. The AIBN is therefore of the opinion that the Directorate of Public Roads should increase the frequency of periodic inspections of the tunnel's safety equipment to ensure that the technical systems function as intended and comply with applicable requirements.

The AIBN has noted that the Road Supervisory Authority's supervision report dated August 2018 concludes that no national inspection plan has been drawn up to ensure that tunnels are inspected within the six-year deadline. Nor has the Directorate of Public Roads organised the inspections in such a way as to ensure independent assessment or followed up the periodic inspections. In addition, the supervision report concludes that the Directorate of Public Roads has not ensured that the periodic inspections will determine whether the minimum requirements in the Tunnel Safety Regulations are complied with.

The AIBN is of the opinion that the Road Supervisory Authority's supervision report supports the findings of this investigation as regards the Directorate of Public Roads' follow-up of safety in the Oslofjord tunnel.

2.9.4 Safety approval of the Oslofjord tunnel

The AIBN's report on the vehicle fire in the Oslofjord tunnel in 2011 questioned the tunnel's risk-based safety management. It also contained a recommendation addressing this issue. The following recommendation was issued:

> *The Accident Investigation Board Norway recommends that the Norwegian Public Roads Administration further develop its safety management system with respect to risk-based and proactive principles to ensure a satisfactory level of safety for the Oslofjord tunnel and similar road tunnels.*

At the time, the NPRA's internal manual requirements from 2007 concerning renewal of the Oslofjord tunnel's safety approval also applied. The guidelines in Manual R511 are still in force, which means that the safety approval of tunnels must be renewed by application to the Directorate of Public Roads every six years. However, the NPRA states that current practice is that the administrative body does not carry out such renewal of safety approvals for tunnels in operation. The argument for this practice is that the tunnels' equipment is continuously followed up through inspections and maintenance.

The AIBN has been informed that the manual guidelines are under revision, and understands that the new guidelines will not mention renewal of safety approvals for tunnels in operation. The requirements for approval following upgrades or modifications will remain in force, but the requirement for approval at six-year intervals will lapse.

The AIBN takes a critical view of this change, as it removes the possibility of conducting a comprehensive periodic inspection of the tunnel that is independent of incidents, upgrades and modifications. Renewal of safety approvals is an important and valuable aspect of the risk-based safety management of tunnels in operation, and, in connection with this, consideration should be given to introducing requirements for renewed risk assessments. In the AIBN's opinion, this is particularly important for older tunnels with an increasing traffic load and geometric peculiarities such as the Oslofjord tunnel.

According to the Directorate of Public Roads, it is desirable to establish a uniform practice for safety follow-up of tunnels in all NPRA regions. Upholding the manual requirement for renewal of safety approvals every six years would provide an opportunity for uniform safety follow-up throughout Norway. It would also provide the administrative body with documentation of the tunnel's approval status and condition. The transfer of large parts of the road network to the new and bigger counties after the regional reform will only increase the need for uniform and good practice relating to follow-up of tunnel safety.

Based on the findings made in this investigation and current practice, the AIBN sees reason to continue to question the NPRA's risk-based tunnel safety management.

The AIBN submits one safety recommendation on this point.

2.9.5 Emergency response plan for the Oslofjord tunnel

2.9.5.1 *Updating and implementation of risk assessments*

The emergency response plan is an important part of the tunnel's safety documentation and a contribution to ensuring good emergency preparedness. The Tunnel Safety Regulations require the documentation to be kept up to date.

The emergency response plan for the Oslofjord tunnel was most recently updated on 16 July 2012, and it referred to AADT figures from 2010. Traffic increased by around 30% from 2010 to the time of the fire in 2017. In the AIBN's opinion, the tunnel's risk situation is linked to the increasing traffic load, and the AIBN considers it unfortunate that the emergency response plan has not been revised or updated in step with the growth in traffic.

The investigation has shown that the NPRA as tunnel manager has not kept the emergency response plan for the Oslofjord tunnel up to date in accordance with the requirements of the Tunnel Safety Regulations.

Nor can the AIBN see that the most recent risk analysis of 16 January 2017 has been implemented in the emergency response plan. The NPRA's own manuals require risk assessments to be enclosed with emergency response plans. Even if the fire service was familiar with the risk assessment in this particular case, the AIBN considers it important that emergency response plans should refer to risk assessments and address any issues arising from such assessments.

The AIBN submits one safety recommendation on this point.

2.9.5.2 *Corrective action*

The investigation has shown that technical challenges and faults occurred during the fire and that operators had to resolve these issues while the incident was ongoing. In the current emergency response plan this is addressed as follows in section 2.2:

> *In the event of a sudden failure of technical equipment, messages/alarms will automatically alert VTS, which must notify the chief superintendent engineer and request any necessary assistance from the relevant contractor.*

The AIBN calls for the emergency response plan to contain a more detailed description of corrective actions and procedures in case of failure in the tunnel's safety equipment in order to safeguard road users' possibility of self-rescue in the event of an incident in the best possible way.

2.9.6 Exercises and inspection of the Oslofjord tunnel as a special fire object

The Tunnel Safety Regulations Annex 2 section 5 requires full-scale exercises under as realistic conditions as possible to be held at least every four years. The investigation has shown that this requirement has not been complied with.

Although the fire services responsible for the Oslofjord tunnel have reasonable experience of vehicle fires in the tunnel, the AIBN finds that the failure to comply with regulatory requirements warrants criticism. The AIBN is also of the opinion that FBV, in cooperation with the tunnel manager, should draw up a plan for holding realistic fire exercises in the Oslofjord tunnel.

The AIBN submits one safety recommendation in this connection.

Furthermore, the AIBN cannot see that fire inspection of the tunnel as a special fire object has been carried out since 2013. In light of the challenges identified during this incident, the AIBN sees a definite need for closer follow-up of the Oslofjord tunnel, including on the part of the fire service, in the form of regular inspections and supervisory activities in relation to the tunnel.

3. CONCLUSION

Like the 2011 fire in the Oslofjord tunnel, the fire in the heavy goods vehicle started as a result of engine breakdown. Although no one was seriously injured in the incident, the investigation has shown that the danger to road users was exacerbated by several technical nonconformities relating to the tunnel's safety equipment. The tunnel manager was aware of some of the nonconformities before the incident, but new and unknown nonconformities were also detected during the fire.

The investigation has found that the safety follow-up of the Oslofjord tunnel remains inadequate and that some of the requirements set out in the Tunnel Safety Regulations are not met.

3.1 Investigation results

3.1.1 Operational and technical factors

a) The bearing halves in crankshaft bearing number 4 moved from their correct position and blocked the oil flow to big-end bearing number 4. This resulted in a very high temperature that caused the big-end bearing to break down.

b) As a consequence of the bearing breakdown, the friction between the crankshaft and the connecting rod increased and it generated so much heat that the parts turned red-hot. The components' fastenings failed, and the connecting rod and piston pin were ejected through the engine block and landed in the roadway.

c) Flammable liquids such as engine oil and diesel were ignited by the red-hot engine parts. The fire spread rapidly in the engine compartment.

d) The driver of the heavy goods vehicle did not start his attempt to put out the fire until around two minutes after the engine breakdown, and was unable to bring the fire under control.

e) The driver did not make use of the extinguishing equipment in the tunnel, nor did he notify the emergency services of the vehicle fire.

f) The vehicle fire was soon detected by VTS via the CCTV system, and the emergency services were notified.

g) Tunnel closure was initiated using a backup control system. A fault in this system delayed the lowering of the tunnel barriers.

h) Seven vehicles, including two heavy goods vehicles, drove into the tunnel past the flashing red stop signals. The two heavy goods vehicles drove all the way to the burning heavy goods vehicle and were unable to turn round. The other five vehicles turned round inside the tunnel.

i) The ventilation system was stopped while VTS checked the CCTV system for any road users between the scene of the fire and the tunnel portal on the Hurum side.

j) FBV’s response personnel, who entered the tunnel from the Drøbak side, were stopped by smoke from the fire. Fire ventilation was activated, and the response personnel followed the smoke plug to the burning heavy goods vehicle.

k) The drivers of the two heavy goods vehicles that stopped behind the vehicle on fire were trapped in the smoke when the fire ventilation was activated, but managed to evacuate into an emergency shelter in the tunnel.

l) When the fire ventilation was activated, the smoke from the fire was ventilated out of the tunnel via the longest route.

m) Because of the smoke, Hurum fire service and Røyken fire and rescue service remained passive until the vehicle fire was under control before starting their rescue efforts.

3.1.2 Underlying factors

a) There was no satisfactory nonconformity system in place for dealing with nonconformities in the safety equipment in the Oslofjord tunnel.

b) The maintenance intervals for the Oslofjord tunnel were defined for a category C tunnel, but the annual traffic figures (AADT) would make it a category D tunnel.

c) The Directorate of Public Roads’ follow-up has not been sufficient to identify faults and nonconformities in the tunnel’s safety equipment.

d) The NPRA has changed its practice for renewal of safety approvals for tunnels in operation. The Oslofjord tunnel's safety approval from 2012 will not be renewed.

e) The tunnel manager had not kept the emergency response plan for the tunnel up to date as required by the Tunnel Safety Regulations and the NPRA’s own standards and guidelines.

f) A risk assessment had been conducted for the tunnel, but it had not been implemented in the emergency response plan.

g) The emergency response plan for the Oslofjord tunnel did not mention corrective actions and emergency preparedness to deal with technical equipment failure that would affect road users in the event of incidents in the tunnel.

h) The tunnel manager has not planned and conducted regular exercises in the Oslofjord tunnel in cooperation with the emergency services.

i) The fire service as supervisory authority for the tunnel has not conducted regular technical fire inspections of the Oslofjord tunnel as a special fire object.

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.[24]

The AIBN has previously investigated a fire in a heavy goods vehicle in the Oslofjord tunnel in 2011 (Report ROAD 2013/05). The AIBN proposed four safety recommendations as a result of the investigation. The safety recommendations proposed in this report offer further input on how to improve tunnel safety, including the Norwegian Public Roads Administration’s safety follow-up of the Oslofjord tunnel.

Safety recommendation ROAD No 2018/05T

The investigation of the fire in the Oslofjord tunnel on 5 May 2017 has revealed several technical deviations in the tunnel’s safety equipment. Several deviations were known to the Norwegian Public Roads Administration before the fire, and new unknown deviations were also revealed during the fire. The investigation has shown that there is no common internal nonconformity system for the tunnel’s safety equipment that gives the tunnel manager the possibility of monitoring the technical safety operational status on a running basis.

The AIBN recommends that the Norwegian Public Roads Administration establish a comprehensive nonconformity system for logging, handling and following up of faults and nonconformities relating to the Oslofjord tunnel’s safety equipment.

Safety recommendation ROAD No 2018/06T

The investigation of the fire in the Oslofjord tunnel on 5 May 2017 has revealed that periodic inspections have not been sufficient in revealing faults and deviations in the tunnel’s safety equipment. The Norwegian Public Roads Administration has also deviated from the requirements in its own manual as regards to renewed safety approval of tunnels in operation by changing practice without stating further grounds for this. The investigation of this incident has identified a need to follow up the safety level in the Oslofjord tunnel with regular inspections and approvals.

The AIBN recommends that the Norwegian Public Roads Administration comply with the requirement in its manual concerning safety approval of tunnels in operation through regular comprehensive inspections.

Safety recommendation ROAD No 2018/07T

The investigation of the fire in the Oslofjord tunnel on 5 May 2017 has revealed that the emergency response plan that applied at the time of the fire was dated 16 July 2012. This had been prepared with outdated traffic volume figures. The investigation has also revealed that there were several faults in the tunnel's technical safety equipment during the incident, and that the emergency response plan did not address corrective measures in the event of failures in technical equipment.

The AIBN recommends that the Norwegian Public Roads Administration bring the emergency response plan up to date in accordance with the requirements of the regulations, as well as requirements and guidelines in its manuals.

[24] 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.

Safety recommendation ROAD No 2018/08T

The investigation of the fire in the Oslofjord tunnel on 5 May 2017 has revealed that the Norwegian Public Roads Administration, as tunnel manager, has not organised regular drills in the Oslofjord tunnel in accordance with the requirements of the Tunnel Safety Regulations. The last full-scale drill in the tunnel was carried out on 31 May 2012, five years before the fire.

The AIBN recommends that the Norwegian Public Roads Administration, in cooperation with the emergency services, plan and execute regular drills in the Oslofjord tunnel under as realistic conditions as possible.

Accident Investigation Board Norway

Lillestrøm, 6 November 2018

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