Accident
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Norway

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REPORT Road 2018/03

REPORT ON TUNNEL ACCIDENT IN THE RAUNEKLEIV TUNNEL ON THE FV. 7 ROAD NEAR SAMNANGER IN HORDALAND COUNTY ON 11 JULY 2017

The Accident Investigation Board has compiled this report for the sole purpose of improving road transport safety. The object of any investigation is to identify faults or discrepancies which may endanger road transport safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for road transport safety shall be avoided.

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This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

Photos: AIBN

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REPORT ON ROAD TRAFFIC ACCIDENT

Date and time:	11 July 2017 at 10.45	
Scene of the accident:	The Raunekleiv tunnel on County Road Fv. 7 in Samnanger municipality, Hordaland county	
Road no, main section (hp), km:	Fv. 7 road, main section (hp) 19, km 8327 (in the middle of the tunnel)	
Type of accident:	Tunnel accident, hit by vehicle from behind, bicycle accident	
Vehicle type and combination:	**Bicycle:** TREK road bike, carbon (2013)	**Passenger car:** Suzuki Ignis, 2004
Type of transport operation:	Private, cycling holiday	Private

NOTIFICATION OF THE ACCIDENT

The Traffic Control Centre (VTS) notified the Accident Investigation Board Norway (AIBN) of the accident at 11.24 on 11 June 2017. The accident investigator on duty immediately initiated a preliminary investigation.

SUMMARY

On Tuesday 11 July 2017, at approximately 10.45, there was an accident in the Raunekleiv tunnel in which a cyclist died as a result of injuries sustained when he was hit by a passenger car. The cyclist was part of a group en route from Austevoll to Hardanger, but at the time of the accident, he was cycling some distance behind the rest of the group. The accident took place about halfway through the 250-metre-long tunnel when a passenger car travelling in the same direction caught up with the cyclist.

The Raunekleiv tunnel is a poorly lit tunnel with dark walls and is not adapted for cyclists and pedestrians. However, cycling in the tunnel is allowed, and no alternative route was signposted. The speed limit on the stretch of road in question was 80 km/h.

The Accident Investigation Board Norway (AIBN) concludes that the dark tunnel, the speed level and the lack of adaptation for cyclists were all contributing factors to the accident.

The AIBN proposes one safety recommendation based on this investigation.

1. FACTUAL INFORMATION

1.1 Sequence of events

Figure 1: The accident took place inside the Raunekleiv tunnel in Samnanger municipality. Map: Kystinfo.no, the Norwegian Coastal Administration

On Tuesday 11 July 2017, at approximately 10.45, a group of twelve Belgian cyclists cycled through the Raunekleiv tunnel on the Fv. 7 road on their way from Austevoll to Hardanger. The Raunekleiv tunnel is 250 metres long and is located between Trengereid and Norheimsund. Due to technical problems with one of the bicycles, two of the cyclists stopped shortly before reaching the Raunekleiv tunnel and ended up behind the rest of the group. The other ten continued, and nine of them cycled through the tunnel together as a group. The tenth cyclist also entered the Raunekleiv tunnel, but ended up a little behind the others.

A passenger car travelling in the same direction as the cyclists passed the two who had stopped outside the tunnel and drove on into the Raunekleiv tunnel. In a gentle curve to the left halfway through the tunnel, approximately 138 metres from the tunnel opening on the Samnanger side, the passenger car hit the cyclist from behind. According to the driver and witness who was driving behind the car involved in the accident, the cars were travelling at a speed of approx. 70 km/h at the time of the accident. The right-hand front corner of the passenger car hit the cyclist, seen in the direction of travel. The cyclist hit the bonnet, the windscreen and the roof, before he landed in his lane where he remained lying. The driver has stated that he did not see the cyclist, nor did he realise that he had hit a cyclist.

A witness driving in the opposite direction at the time of the accident has stated that he saw the bicycle going under the car behind him and stopped to help.

1.2 Rescue work and personal injuries

A person who witnessed the accident from a vehicle travelling in the opposite direction notified the Emergency Medical Communication Centre. The air ambulance arrived at the scene first, followed by the ambulance and doctor on duty. Witnesses immediately administered first aid, and the rescue personnel took over when they arrived at the scene.

The forensic port-mortem report concluded that the deceased died from the injuries sustained in the accident.

The driver of the passenger car wore his seat belt and did not suffer any physical injuries in the accident.

1.3 Damage to vehicles

The passenger car and the bicycle were examined. A reconstruction was carried out to recreate the possible point of impact between the bicycle and the car, see Figure 5.

1.3.1 Damage to the bicycle

The bicycle frame broke into several parts, and the wheels were deformed. The bicycle was equipped with a front light and tail light. According to witnesses, these lights were still turned on after the accident.

Figure 2: The bicycle frame broke into several parts, and the rear wheel was deformed. Photo: AIBN

Figure 3: The reconstructed bicycle. Photo: AIBN

1.3.2 Damage to the passenger car

The passenger car's windscreen broke on the right-hand side as a result of the impact with the cyclist. There was one dent in the bonnet and one in the roof, in addition to various marks and scratches on the right side of the front of the car and along the right side of the car, see Figure 4. The marks found are assumed to have been caused by the accident.

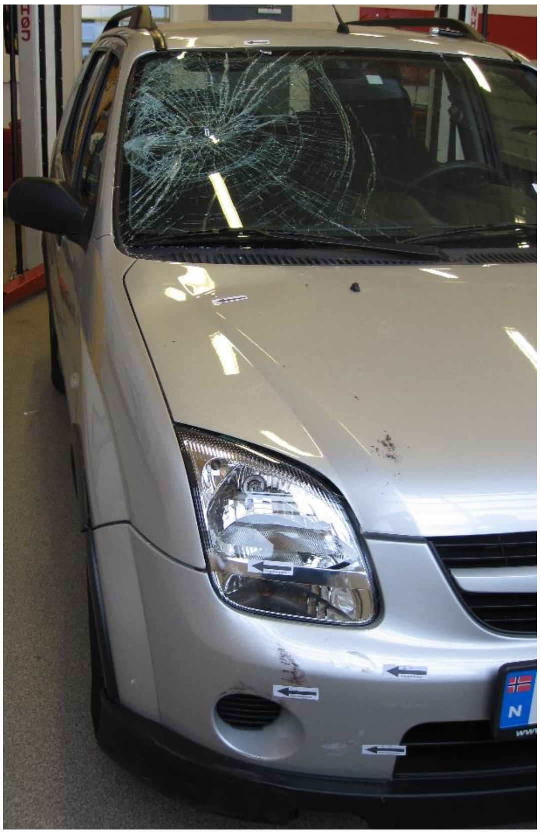

Figure 4: Damage to the right-hand side of the passenger car, with arrows marking the different dents/scratches/contact marks. Photo: AIBN

Figure 5: Assumed point of impact between the passenger car and the bicycle. Photo: AIBN

1.4 The scene of the accident

Trace marks and damage at the scene were documented by the police and the Norwegian Public Roads Administration (NPRA) on the day of the accident.

Figure 6: The photo was taken ten metres outside the tunnel opening. The light conditions when the photo was taken are very much like on the day of the accident. Photo: AIBN

The accident took place inside the Raunekleiv tunnel. The assumed accident site is about halfway through and at the darkest point of the tunnel, approx. 138 meters from the tunnel exit on the Samnanger side. The road was tarmacked and dry.

According to the police, the deceased person was found in the middle of the lane going towards Samnanger. Witness descriptions state that the bicycle came to rest in the middle of the opposite lane.

When the police arrived at the scene, the bicycle was lying in the right-hand ditch going towards Samnanger. The helmet, a pair of reading glasses, two pairs of sunglasses and a watch belonging to the deceased were also found in roughly the same place. The precise positions where these objects came to rest are nevertheless uncertain, as they may have been moved after the accident.

According to the NPRA, contact marks were found on a hazard marker sign on the right-hand side of the tunnel. The distance between the assumed point of impact and the final position of the accident victim is approx. 7.9 metres.

The passenger car had not left any brake marks. No material damage to the tunnel was found.

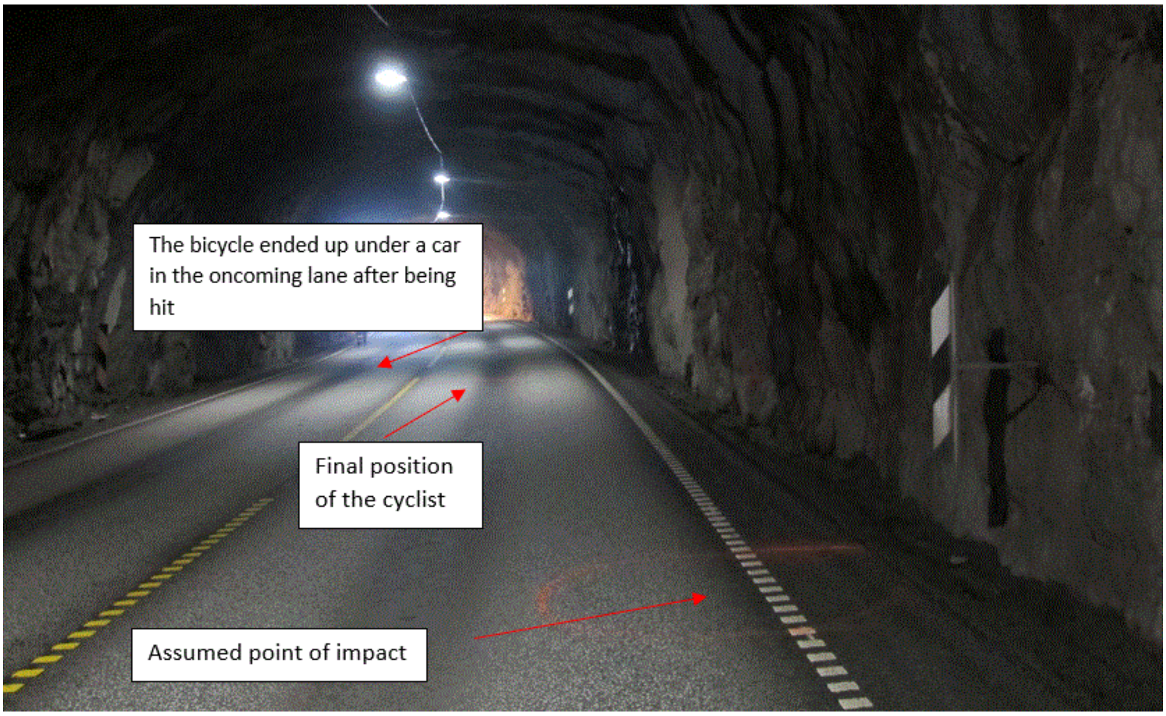

Figure 7: Based on findings made at the scene of the accident, the point of impact is assumed to have been approx. 138 metres from the tunnel exit on the Samnanger side. The cyclist's watch was found in the ditch in the area between the assumed point of impact and the cyclist's final position. Photo: AIBN

1.4.1 Inspection of the Raunekleiv tunnel

On 14 September, the AIBN inspected the tunnel and documented the road conditions, among other things. The AIBN carried out measurements on site and drove through the tunnel using “an actor” to represent the cyclist in order to visualise the cyclist's visibility. The cyclist’s clothing and the lights on the bicycle were similar to conditions on the day of the accident.

On 19 October, representatives of the University of South-Eastern Norway (formerly the University College of Southeast Norway) carried out tests of the lighting conditions in the tunnel. This is described in more detail in Chapter 1.9.

1.5 Road users

Blood samples were taken from both the driver of the passenger car and the cyclist. They both tested negative for alcohol and other drugs.

1.5.1 The driver of the passenger car

The driver was 86 years old at the time of the accident. He was issued a driving licence for class AMA1BEST on 6 September 1974, and since 2014 his right to drive motor vehicles has been renewed for one year at a time.

His licence was last renewed on 13 January 2017. He underwent a health check in connection with the renewal of his driving licence in January 2017. Based on an assessment of his cognitive functioning, general state of health and eyesight, supported by an optometrist’s certificate dated 16 October 2016, the driver's regular GP found that he met the health requirements stipulated in the Driving Licence Regulations.

The driver has stated that he has avoided driving in the dark for the past ten years, presumably because his night vision is reduced as a result of old age. He was wearing prescription glasses at the time of the accident.

1.5.2 The cyclist

The cyclist was a 58-year-old Belgian man. He was part of a group of twelve people from Belgium on a cycling holiday in Norway. The group consisted of experienced cyclists who had been on cycling holidays together several times. This was their first trip to Norway.

The cyclist was wearing a bicycle helmet, black cycling shorts and a red top, but had no reflective stickers etc. on his helmet or clothing.

A member of the group has told the AIBN that they found information about tunnels in Norway on a British website, http://www.cycletourer.co.uk/. The website contains a map that shows all tunnels in Norway.

According to one of the cyclists, they were aware that there was an alternative road around the tunnel. However, they chose to go through the tunnel based on information from the website indicating that the tunnel was safe for cyclists. The AIBN has been told that they cycled together in single file near the white edge line, but in the roadway. The cyclist who died was cycling a little behind the main group through the tunnel.

1.6 Vehicle and load

1.6.1 Bicycle

The cyclist who died rode a 2013-model Trek Madone 5.2 road bike with a carbon frame. The bicycle was equipped with a white front light and a red tail light. The pedals were clipless pedals and had no reflectors on the pedal or on the pedal arm.

1.6.2 Passenger car

The passenger car is a 2004 model Suzuki Ignis. The vehicle was most recently approved in a periodic roadworthiness test on 17 February 2016. The car was first registered in Norway on 20 January 2004, and is owned by the driver.

The NPRA carried out a technical inspection of the vehicle after the accident. Among other things, the lights were tested with specialist testing equipment. The left dipped beam was found to have minor non-conformities, and its light shone too far to the right. Following the inspection, it was concluded that the lights were in good condition despite the non-conformity. The car had summer tyres with adequate thread depth.

No technical faults or defects were found that could have contributed to the accident.

1.7 Weather and driving conditions

The accident took place inside the Raunekleiv tunnel, where the road was dry. The temperature at the time of the accident was approx. 15 ºC. According to the police, the weather conditions outside the tunnel were dry with normal daylight.

1.8 Road conditions

1.8.1 General information

The Raunekleiv tunnel is part of the Fv. 7 road in Samnanger municipality. This stretch of road was a national road until 2010, but is now part of Hordaland’s county road network.

The NPRA maintains the Fv. 7 road on behalf of the county authority through the joint road administration system. Part of the road, from Granvin to Steindalsfossen, is classified as a Norwegian Scenic Route, and is one of four stretches of road that make up Norwegian Scenic Route Hardanger.

The NPRA states that county road 7 in Hordaland county is popular among tourists. However, there is no overview of how many cyclists cycle this stretch of road each year.

The annual average daily traffic[1] (AADT) is 5,500 vehicles (2016), of which heavy vehicles make up approximately 10%.

[1] The total number of vehicles passing the section in the course of a year, divided by 365.

1.8.2 The Raunekleiv tunnel

Figure 8: The photograph was taken from the tunnel opening in the direction in which the passenger car was travelling. Photo: AIBN

The Raunekleiv tunnel is a single bore tunnel. It is 250 metres long and goes from main section (hp) 8201 to main section (hp) 8452. The speed limit in the tunnel is 80 km/h.

The Raunekleiv tunnel was completed in 1972. The tunnel has a ‘T8’ tunnel profile and was planned with a 'type C' cross-section in accordance with the guidelines applicable at the time when the tunnel was built. Cycling in the tunnel is permitted.

1.8.3 Road environment

The tunnel has a tarmacked road with two lanes and rumble strips on the edge marking and centreline. The roadway is approx. 6.3 metres wide, each lane is approx. 3.15 metres wide, and the hard shoulder is approx. 0.5 metres wide. The distance between the edge markers and the hazard marker signs on either side of the road is approximately one metre (see Figure 8 and Figure 9). The marker signs protrude approximately 50 centimetres from the tunnel wall, which consists of blasted raw rock.

The NPRA measures the condition of the road network approximately once a year. The tunnel was measured in 2017, and the measurements show that the roadway from Trengereid to Samnanger consists of a relatively straight stretch for the first 100 metres or so of the tunnel. Then it continues in a gentle curve to the left, which has a horizontal curve radius of approx. 420 metres at the accident site. The curve then becomes sharper, and approx. 200 metres into the tunnel it has a horizontal curve radius of approx. 330 metres. The curve in the tunnel makes it impossible to see through the tunnel from its openings, see Figure 8.

The gradient and camber measured at the accident site was 2.5° and 3.2°, respectively.

Figure 9: Road environment inside the Raunekleiv tunnel. Photo: AIBN

According to the NPRA, the lighting in the tunnel underwent maintenance in 2015, when 16 QL55w and 10 250w light fixtures were installed. A total of 26 new light fixtures were installed to replace 20 old ones (sox35w and 250w). No lighting calculations were conducted in connection with this maintenance work.

1.8.4 Surrounding environment

The Raunekleivvegen road, which is approximately one kilometre long, is an alternative route that makes it possible for cyclists and passenger cars alike to bypass the tunnel. This road is not signposted as an alternative route.

There is also a shared use path for cyclists and pedestrians along the road towards the tunnel in the direction of Samnanger. The shared use path stops just before the tunnel, and is not signposted further after the access road to the residential development.

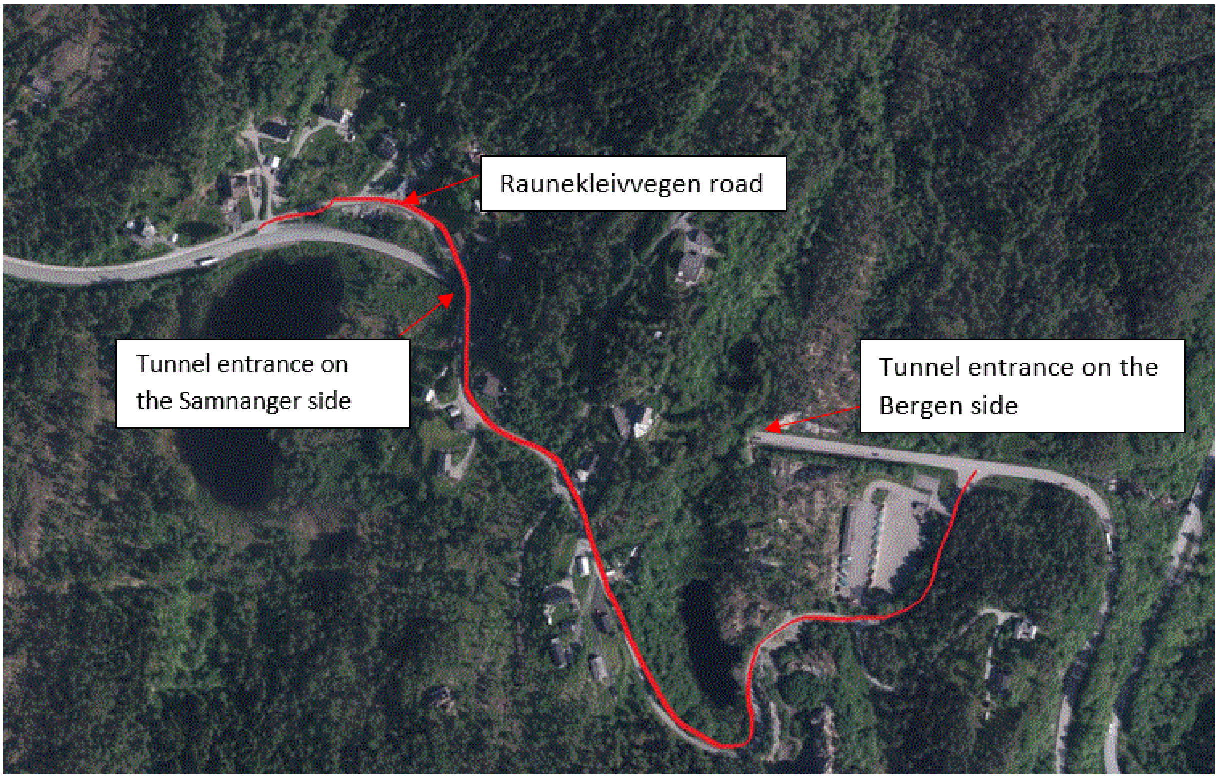

Figure 10: The map section shows the alternative route, Raunekleivvegen, marked in red over the tunnel. Source: Vegkart.no / AIBN

1.9 Special investigations

On assignment from AIBN, the University of South-Eastern Norway measured and analysed the lighting in the Raunekleiv tunnel. Systematic measurements were taken of lighting conditions throughout the tunnel, with the first measurement made 100 meters from the tunnel exit in the direction in which the car and cyclist were travelling.

1.9.1 Frame of reference for measurements

The current manual requirements for lighting (N500 Road Tunnels) were used as a frame of reference for the measurements.

The NPRA's handbooks are divided into three distinct levels: norms (N series) based on legislation, directions (R series) based on legislation or instructions from the Director General of NPRA, and guidelines (V series), which are supporting documents to the norms and directions.

The AIBN is aware that, because of the tunnel's age, the N500 Road Tunnels manual does not apply to the Raunekleiv tunnel. There were no lighting requirements at the time when the tunnel was built. The AIBN's choice to nevertheless use the current lighting requirements as a frame of reference for the measurements is based on the NPRA's own recommendations for lighting in tunnels used by pedestrians and cyclists.

In the V122 Bicycle Manual (2014), the NPRA recommended that all tunnels exceeding 100 metres in length and open to pedestrians and cyclists should have lighting and ventilation in accordance with the requirements set out in Manual N500 Road Tunnels. The Bicycle Manual (2014) recommends that lighting requirements should also apply to existing tunnels.

1.9.2 Results from the lighting analysis of the Raunekleiv tunnel

According to Manual V124, tunnels should have uniformity of luminance from the threshold zone to the exit zone, preferably with gradual reduction to give drivers better contrast sensitivity, visual acuity and better glare conditions.

The report concluded that the luminance of the road surface and walls do not meet the NPRA's recommendations.

Summary of the report:

> *The lighting in the Raunekleiv tunnel does not comply with the most important requirements put in place to ensure the safety and visual comfort of road users.*
>
> *The lighting level in the Raunekleiv tunnel is too low, and the distribution of lighting inside the tunnel is inadequate. This makes it more difficult for the visual system to adapt to the darkness inside the tunnel and increases the risk of accidents, since the existing lighting does not comply with the lighting parameters required for the permitted speed limit in the tunnel.*
>
> *The luminance level of the walls is low, causing reduced contrasts and a reduced ability to see cyclists/pedestrians.*
>
> *Both the overall uniformity of luminance and the longitudinal uniformity of luminance are below the requirements set out in the manuals. This increases visual discomfort and may have a tiring and distracting effect.*
>
> *The emergency lay-by lighting is inadequate.*
>
> *Also, there is a high risk of glare in the tunnel, and this could at worst disturb a driver's visual impressions.*

The report from the University of South-Eastern Norway is attached. (Annex A.)

1.10 Acts and regulations

1.10.1 The Road Traffic Act

The Act of 18 June 1965 relating to Road Traffic (the Road Traffic Act) and pertaining traffic rules stipulate requirements concerning the driver's responsibility with regard to vehicle use.[2]

1.10.2 Regulations on requirements for bicycles

Regulations No 119 of 19 February 1990 on requirements for bicycles (Regulations on requirements for bicycles) stipulate requirements for lights and reflectors on bicycles. These regulations apply to bicycles that are first put to use in Norway on 1 January 1971 or later.

[2] https://lovdata.no/dokument/NL/lov/1965-06-18-4?q=Vegtrafikkloven

1.10.3 The Public Roads Act

The Act of 21 June 1963 relating to Public Roads (the Public Roads Act) stipulates requirements for design and operation with pertaining regulations.[3]

1.10.3.1 *Requirements for the tunnel*

According to the NPRA, no manual norm existed for road tunnel building in 1972, and there were hardly any tunnel design requirements other than width and cross-section. Minimum requirements for lighting and ventilation in tunnels were not introduced until 1981.

Safe traffic in tunnels is regulated by a number of statutory and regulatory requirements. Regulations No 517 of 15 May 2007 on minimum safety requirements for certain road tunnels (the Tunnel Safety Regulations)[4] are important in this context. In 2015, the Tunnel Safety Regulations were also made applicable to tunnels in the county road network and the municipal road network in Oslo, see Regulations No 1566 of 12 October 2014 on minimum safety requirements for certain road tunnels in the county road network and the municipal road network in Oslo (the Tunnel Safety Regulations for County Roads etc.).[5]

The NPRA manual N500 Road Tunnels (2016) is fundamental to the design and requirements that apply to new tunnels, including adaptation for pedestrians and cyclists. The manual requires road tunnels that are longer than 100 metres to have lighting, and lighting calculations are to be conducted before lighting is installed. In addition, tunnels used by pedestrians and cyclists are required to have lighting installed if their length exceeds 25 metres. This requirement applies to all new tunnels and tunnels where lighting systems undergo rehabilitation.

1.11 Authorities, organisations and leadership

1.11.1 Hordaland County Authority

Hordaland County Authority owns the county road network and is responsible for the overall planning of transport in Hordaland county. This means that the county authority is responsible for about 2,900 kilometres of road and 16 of the 18 ferry services in the county. Ownership of some of the roads in the county was transferred from the NPRA to Hordaland County Authority in connection with the 2010 administrative reform. The county authority is also responsible for prioritising investments and major maintenance on the county road network.

The responsibility rests with the roads section of Hordaland County Authority's department of transport.

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[3] https://lovdata.no/dokument/NL/lov/1963-06-21-23?q=Vegloven

[4] https://lovdata.no/dokument/SF/forskrift/2007-05-15-517?q=Tunnelsikkerhetsforskriften

[5] https://lovdata.no/dokument/SF/forskrift/10/12/2014-1566?q=Tunnelsikkerhetsforskriften

1.11.2 The 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 national roads, and for approval and supervisory activities relating to vehicles and road users. The NPRA also prepares provisions and guidelines for road design, operation and maintenance, road traffic, road user training and vehicles.

The NPRA is also assigned the task of providing joint road administration for the county roads at the regional level. In this case, the relevant unit is the NPRA's Western Region, which is headed by a regional road director. The regional road director comes under the county authority in matters relating to county roads, but under the Directorate of Public Roads in matters concerning national roads and other central government functions, including Norwegian Scenic Routes – see the Public Roads Act Section 10. The NPRA is responsible for following up the operation and maintenance of Fv. 7 on behalf of the road's owner, Hordaland County Authority.

1.12 Additional information

1.12.1 Tunnel upgrades

As a consequence of requirements set out in the Tunnel Safety Regulations, tunnels longer than 500 metres will undergo extensive upgrading in the years ahead in the form of risk analyses and measures based on these analyses. This also applies to the tunnels owned by Hordaland County Authority.

The Raunekleiv tunnel is 250 metres long, which means that the Tunnel Safety Regulations' upgrading requirements do not apply. According to information provided by Hordaland County Authority and the NPRA, no traffic safety inspection (TS inspection) or risk assessment has been carried out of the Raunekleiv tunnel.

1.12.2 Report 'Sykling i tunnel' (2016)

The NPRA Western Region published the report 'Sykling i tunnel' ('Cycling in tunnels') in September 2016 (report number 257). The report was prepared following a problem memo from the NPRA's public roads unit for Sogn og Fjordane county concerning cycling through existing tunnels. The report lists short-term and long-term measures to keep cyclists safe in tunnels. The measures proposed included cyclist buttons/notification to alert motorists to the presence of cyclists in the tunnel, reducing speed limits to 60 km/h, establishing and signposting alternative routes, and improving lighting conditions inside the tunnel.

The report includes two documents for use in risk mapping: 'Risikovurdering for sykling i tunnel – rammeverk' ('Risk assessment for cycling in tunnels – framework') and 'Sjekkliste for vurdering av sykling i tunnel' ('Checklist for assessing cycling in tunnels'). The report states that the standard of the framework is in accordance with the applicable guidelines for risk management in the NPRA.

The report was prepared as a regional discipline memo and included in the NPRA's national management system's quality system under ROADS/tunnels. According to the

NPRA, the use of the framework is currently limited to the upgrade project to be carried out based on the requirements that follow from the Tunnel Safety Regulations. The risk assessment framework prepared will be used to assess tunnels that fall under the scope of the project in which cycling is allowed or where allowing cycling is under consideration. According to the NPRA, this also applies to tunnels in the county road network. It will be up to the relevant county authority to decide on any measures to be taken in these tunnels.

1.12.3 Demographic development and age-related weakening of driving skills

Information about demographic trends in Norway shows that the number of elderly drivers will increase in the coming years. In 1980, 20% of drivers over the age of 65 still held a driving licence. In 2014, this proportion had increased to 70%, and it will just keep growing (Scandinavian Insurance Quarterly 2/2014). According to the Institute of Transport Economics (TØI), elderly road users are at higher risk of being involved in and sustaining injuries in an accident. One possible explanation is that this could be related to age-related sensory and cognitive changes. The aging process leads to a deterioration of functions that are important for traffic safety with increasing age (Sagberg and Glad, 1999, in TØI 2003).

1.12.4 Normal vision changes with increasing age

Eyesight gradually changes with age. The lens of the eye stiffens, and the focal point moves further away. In addition, the lens gradually becomes less clear and lets less light pass. An unclear lens will also contribute to light scattering in the eye, resulting in increased sensitivity to glare and a reduced ability to see contrasts in the surroundings. These changes in the eye lens make driving in the dark much more difficult. Many people notice this from around the age of 50, and it worsens gradually with increasing age.

The changes in the lens and other parts of the eye as people grow older means that it takes longer to for the eye to adjust to darkness, or dark adaptation.[6] In cases where a person drives a car in normal daylight, the eyes have been exposed to plenty of light for a long time and will therefore take a while to adjust. The pupils will automatically contract or dilate depending on the light. This mechanism becomes slower with age (50 years +) and contributes to making the transition between light and darkness and vice versa more challenging. The general visual field sensitivity is also somewhat reduced with age, and some will also experience a loss of visual field.[7]

1.12.4.1 *Reference road user for tunnel lighting*

According to the report ‘Fremtidens tunnelbelysning’ (‘Tunnel lighting of the future’), prepared by Norconsult on assignment from the NPRA’s agency programme ‘Varige konstruksjoner 2012-2015’ (‘Lasting structures 2012–2015’), the current lighting requirements were defined on the basis of a 23-year-old with normal eyesight. (NPRA report number 562, 2016). The reason for this is the formula developed by the CIE[8], the international standardisation body for illumination, in its publication CIE 140 Road Lighting Calculations, where it uses a 23-year-old with normal vision as a point of

[6] https://sml.snl.no/syn

[7] http://www.overgang.no/tema/58/article/item/null/hva-skjer-med-oeye-og-syn-midt-i-livet

[8] Commision Internationale de l`Eclairage/International Commission on Illumination

reference in the formula used to calculate lighting requirements. It is up to the person using the formula to change the coefficient, if relevant, in order to correct for this fact.

The report specifies that how eyesight deteriorates varies between individuals, but estimates that, on average, a 40-year-old driver will need twice as much light to achieve the same visual performance as the 23-year-old for whom the lighting is dimensioned. At the age of 60, the average driver needs three times as much light. It is also emphasised that people become correspondingly more sensitive to glare, so it may not always be a good solution to simply intensify the lighting.

1.13 Implemented measures

1.13.1 The NPRA's assessment of the Raunekleiv tunnel

The AIBN has received information from the NPRA Western Region in which reference is made to the NPRA’s accident investigation group, which has prepared a list of points for review following the Raunekleiv tunnel accident.

The following points were considered:

- *Is the lighting adequate?*
- *Should the tunnel marker signs be removed?*
- *Should the tunnel be equipped with road marking to indicate no overtaking?*
- *Are road users sufficiently well warned that they are approaching a tunnel?*
- *Can the rumble strip markings deter cyclists?*
- *Should the tunnel have no cycling signs?*
- *Should the alternative route be signposted?*

According to the NPRA Western Region, they are also considering whether to conduct a risk analysis of the whole stretch of road.

1.13.2 Measures planned and measures implemented

Feedback that the AIBN has received from the Western Region indicates that no measurements have been carried out of the lighting, as the tunnel manager has deemed it to meet the required standard. Moreover, decisions have been made to remove the tunnel markers and whitewash the tunnel walls. Gravel is now to be placed in the ditch along the roadway to support areas along the side of the road. A ban on overtaking has not been considered.

Plans have also been made to erect tunnel ahead signs 100 metres earlier to facilitate the use of the alternative route.

As regards the rumble strip marking, the NPRA Western Region’s opinion is that it makes cycling more difficult. The Western Region has considered banning cycling in the tunnel, but chose instead to refer cyclists to a safe place for crossing over to the shared use path and the road around the tunnel, which will be signposted as an alternative route. Cyclist buttons have been considered, but there are several tunnels between Trengereid and Norheimsund, and the recommendation is that a uniform solution should be found for the whole stretch of road. One proposal is a system that detects cyclists and activates a warning sign with flashing orange lights in combination with dynamic speed limits.

2. ANALYSIS

2.1 Introduction

The cyclist who was hit by a car in the Raunekleiv tunnel was part of a group of tourists from Belgium on a cycling holiday in Norway. The accident took place inside a poorly lit tunnel that was open to cyclists and pedestrians. The tunnel is part of the stretch of road leading to Norwegian Scenic Route Hardanger, which contributes to increased tourism in the area. The AIBN is of the opinion that this places a special responsibility on the road's owner for ensuring the safety of road users. The severity of the accident and the fact that the deceased was a foreign tourist were also among the factors behind the AIBN's decision to investigate this accident.

The analysis begins with an assessment of the sequence of events, the cyclist's visibility and the driver's possibility of detecting the cyclist. It then goes on to discuss the tunnel's design, lighting and general level of safety for pedestrians and cyclists and, finally, the scope of the Regulations on requirements for bicycles.

2.2 Assessment of the sequence of events

The investigation has shown that the accident took place halfway through the tunnel, at a place where the lighting was at its poorest and at a distance from the tunnel entrance that would not yet have allowed a driver's eyes to adjust to the darkness after driving in daylight. In addition, the tunnel lighting was generally poor and the tunnel walls were dark. The bicycle was equipped with lights at the front and the rear at the time of the accident, but the cyclist was alone and had no form of reflective stickers etc. on his clothing, bicycle or helmet. The AIBN therefore finds that it was difficult to see the cyclist, and this assessment was confirmed during an inspection of the accident site.

Moreover, a curve in the tunnel caused the light conditions to change in that the background lighting changed from a dark tunnel wall at the entrance to an area of light from the opening at the other end in the final part of the tunnel. In the AIBN's assessment, this might have affected the possibility of spotting dark objects in the road. The speed limit at the accident site was 80 km/h, which leaves motorists little time to detect cyclists in the tunnel and thus very little scope of action to avoid accidents.

According to witnesses and the driver himself, the passenger car was travelling at a speed of 70 km/h. The driver has stated that he saw cyclists along the road when approaching the tunnel, but that this did not have any bearing on his driving inside the tunnel. He knew the area and was aware that the tunnel was dark with reduced visibility, but he neither saw nor perceived that there was a cyclist there.

He has stated that halfway through, he heard a bang and the right side of the windscreen was smashed. He assumed that a rock had hit the car. The damage to the car and bicycle, as well as the outcome of the accident, confirms the sequence of events even though it has not been possible to determine all movements in detail.

It is the AIBN's assessment that a complex set of circumstances was behind the sequence of events, and these factors are discussed in more detail in chapter 2.3, which deals with the driver's possibility of detecting cyclists in the tunnel, and chapter 2.4 on the tunnel's level of safety for cyclists.

2.3 The driver's possibility of detecting cyclists in the tunnel

Even though the driver in question had a valid driving licence and medical certificate, the AIBN is of the opinion that his vision, perception and reaction were naturally impaired by old age. The driver used prescription glasses. The AIBN’s assessment is that he represents a group of drivers who need both more light/impulses and more time to perceive hazardous traffic situations. The University of South-Eastern Norway describes the relevant lighting conditions in this case as being *‘far below the level required for the safety and comfort’* of all road users – including younger drivers with better night vision.

Demographic trends indicate that drivers whose driving skills have been weakened by old age will become more common in traffic in the years ahead. This investigation has shown that it was difficult to detect a cyclist under the prevailing lighting conditions.

2.4 The tunnel's level of safety for cyclists

This chapter describes the AIBN's understanding of the Raunekleiv tunnel as regards lighting and visibility, speed level, alternative route for cyclists, and the risk assessment of the tunnel.

2.4.1 Lighting and visibility

The AIBN examined the lighting conditions in the tunnel with assistance from the University of South-Eastern Norway. The weather and lighting conditions outside the tunnel on the day of this examination were similar to the situation on the day of the accident.

The most important conclusions are that the lighting is poorly distributed in relation to the transition from daylight, and that there is insufficient luminance and uniformity of luminance that reduce the possibility of perceiving contrasts. Also, there is no niche lighting and there is a risk of being dazzled in the short tunnel. See the attached report from the University of South-Eastern Norway for more information about the lighting conditions in the Raunekleiv tunnel.

The AIBN’s examination of the tunnel included using “an actor” in the cyclist’s role inside the tunnel, with and without a reflective vest, in order to assess how visible the cyclist was from the driver’s perspective. The lighting conditions were found to demand a lot from the driver's eyesight, and it was difficult to detect the actor representing the cyclist without a reflective vest.

The AIBN’s assessment is that if it is not possible to separate pedestrians and cyclists from motor vehicles inside the tunnel, the lighting should as a minimum meet the current manual requirements, even if this is not a requirement under the applicable legislation.

Manual N500 requires lighting calculations to be carried out in connection with the rehabilitation of lighting systems. The NPRA considered the replacement of light fixtures in 2015 maintenance, not rehabilitation, and therefore no such calculations were carried out. In the AIBN’s opinion, failure to carry out lighting calculations may have contributed to the lighting in the tunnel being inadequate at the time of the accident.

The investigation has also shown that, in terms of road users’ vision, lighting levels in tunnels are designed for a 23-year-old person with normal eyesight. Based on this accident, the AIBN is of the opinion that the dimensioning of lighting conditions should take account of the demographic development in Norway and the increased number of elderly drivers with impaired night vision. Lighting conditions should be adapted to the road users who will be using the tunnel rather than being designed for a driver with perfect night vision.

2.4.2 Speed level

The speed limit in the Raunekleiv tunnel was 80 km/h. This leaves motorists very little time to detect cyclists or pedestrian in the tunnel and take action to avoid them if they are in the motorist's lane. The combination of high speed, poor lighting and the limited possibility to cycle outside the roadway contributes to making it risky for pedestrians and cyclists to use the Raunekleiv tunnel.

In the AIBN's opinion, tunnel owners and the NPRA should consider the speed limits in this and other tunnels where cycling is permitted.

2.4.3 Alternative route around the Raunekleiv tunnel

There is an alternative road near the Raunekleiv tunnel that cyclists can use. It is called Raunekleivvegen and is an access road to the properties along the road. This alternative route was not signposted, nor were other measures taken to lead cyclists around the tunnel. The AIBN therefore finds that the cyclists had reason to assume that it was safe to cycle through the tunnel instead of going around.

2.4.4 Adaptation for cyclists

The stretch of road where the Raunekleiv tunnel is located leads to Norwegian Scenic Route Hardanger. This contributes to attracting tourists, including cyclists, to the area. The AIBN is of the opinion that this places a special responsibility to ensure the safety of road users on the road's owner.

According to the Norwegian Cyclists' Association, no official website exists to provide information to cyclists travelling along these stretches of road. This is also reflected in how the group of Belgian tourists had prepared for their cycling holiday in Norway. They had used a private British website[9] to find information to prepare them for cycling in tunnels in Norway. The website shows, based on feedback from other cyclists, which tunnels are open for cyclists and an assessment of whether or not the different tunnels are safe for cyclists. Tunnels that are deemed safe are marked in green on the website.

The Raunekleiv tunnel was open to cyclists and marked as safe (green). Therefore, the group of cyclists did not consider avoiding the tunnel, even if they saw on the map while preparing for the trip that there was an alternative route. The AIBN is of the opinion that Norwegian public road authorities should contribute to ensuring that information for tourists coming on cycling holidays is up to date, accessible and quality-assured.

[9] http://cycletourer.co.uk/maps/tunnelmap.shtml

2.4.5 Risk assessment

Cyclists had to share the roadway with cars in a poorly lit tunnel with dark walls. In combination with the speed limit and the traffic density, this increased the risk of cyclists being involved in an accident.

In 2016, the NPRA Western Region prepared a framework for risk assessment of tunnels in the region. This framework is described in the report ‘Sykling i tunnel’ (‘Cycling in tunnels’). If a risk assessment of the Raunekleiv tunnel had been carried out in accordance with this report, important risk factors could have been identified and compensatory measures implemented.

The Raunekleiv tunnel is under 500 metres long and does not fall within the scope of neither the Tunnel Safety Regulations nor other regulatory requirements in force that address the safety of cyclists in tunnels. In the AIBN's opinion, Hordaland County Authority as tunnel owner, possibly in consultation with the NPRA as road manager (joint road administration), should consider conducting risk assessments for safe traffic for cyclists in the Raunekleiv tunnel and similar tunnels. It should be possible to use the NPRA Western Region’s framework in this context.

The AIBN submits one safety recommendation in this connection.

2.5 The visibility of cyclists in tunnels

Regulations on requirements for bicycles set out requirements for lights and reflectors on bicycles, among other things. The regulations apply to bicycles that are first put to use in Norway on 1 January 1971 or later. This means that the regulations do not apply to bicycles that were first used outside Norway and are subsequently brought into Norway to be used here.

The examination has shown that it was difficult to see the cyclist inside the tunnel as he was not using reflectors. In the AIBN’s opinion, both the responsible authorities and special interest organisations should focus more on the visibility of all cyclists, particularly when cycling in tunnels.

3. CONCLUSION

The tunnel’s lighting and design, the cyclist’s inadequate visibility and the driver's difficulties in detecting the cyclist inside the tunnel were all contributory causes of the accident. Based on these findings, the AIBN is of the opinion that the safety of cyclists in tunnels should be improved.

3.1 The chain of events, operational and technical factors

a) No alternative route was signposted for cyclist to avoid the tunnel.

b) The cyclist who was hit used the roadway, as there was no pavement or cycle lane in the tunnel. Cycling in the roadway is not illegal.

c) The cyclist did not wear a reflective vest and was not easily visible despite the bicycle being equipped with a tail light.

d) The tunnel was poorly lit, and the accident took place in the darkest part of the tunnel, with dark tunnel walls and the possibility of being dazzled by light from the tunnel exit.

e) The driver's choice of speed left him little time to detect the cyclist and avoid hitting him.

f) The driver's age indicates that his night vision may be impaired.

3.2 Organisational and contextual factors

a) The road owner, Hordaland County Authority and the party responsible for road operation, the NPRA Western Region, had not carried out a risk assessment for cycling in the tunnel.

b) The Raunekleiv tunnel is shorter than 500 metres, and therefore it is not subject to the requirements for tunnel upgrading, cf. the Tunnel Safety Regulations.

c) The permitted speed in the tunnel is 80 km/h.

d) The Raunekleiv tunnel was completed in 1972. The tunnel lighting was replaced during standard maintenance work in 2015.

e) The alternative route was not signposted as a bicycle path, and no guidance was provided to cyclists to inform them that it might be a recommended alternative to cycling through the tunnel.

4. SAFETY RECOMMENDATIONS

The investigation of this road traffic accident has identified one area in which the Accident Investigation Board Norway deems it necessary to submit a safety recommendation for the purpose of improving road safety.[10]

Safety recommendation ROAD No 2018/04T

A cyclist died in the Raunekleiv tunnel on 11 July 2017 after being hit from behind by a passenger car inside the tunnel. The accident took place in the part of the tunnel that had the least light from the tunnel openings and the poorest ceiling lighting, in addition to the walls of the tunnel being dark in colour. The cyclist had to cycle in the roadway because there was no cycle lane. The Norwegian Public Roads Administration considered replacing the luminaires in 2015 as maintenance and non-rehabilitation, and no lighting calculations were made. The investigation has shown that older tunnels open to cyclists and not subject to current regulatory requirements should be mapped and followed up to ensure safety.

The Accident Investigation Board Norway recommends that Hordaland County Authority, in cooperation with the Norwegian Public Roads Administration, review

[10] 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.

relevant tunnels open to cyclists and implement measures to ensure safety also in tunnels that do not fall under the scope of regulatory requirements.

Accident Investigation Board Norway

Lillestrøm, 3 July 2018

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ANNEXES

Annex A: University of South-Eastern Norway (2018): Lighting analysis of the Raunekleiv tunnel (Samnanger municipality)

Lighting analysis of the Raunekleiv tunnel (Samnanger municipality)

**All calculations and measurements are based on luminance images taken on the day of the inspection, 19 October 2017.*

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The lighting analysis of the Raunekleiv tunnel was carried out in accordance with the requirements for road and tunnel lighting described in Manual V124 (the Norwegian Public Roads Administration) and Manual N500 (the Norwegian Public Roads Administration).

General information about tunnel lighting

In terms of lighting requirements, a tunnel can be divided into four different zones: the threshold zone (innkjøringssone), transition zone (overgangssone), interior zone (indre sone) and exit zone (utkjøringssone) (Figure 1). There is also an *access zone* before the tunnel opening that is equal to the *stopping distance* (SD) (100 metres in our situation). Stopping distance includes the perception, reaction and breaking times needed to stop a vehicle that is moving at a certain speed.

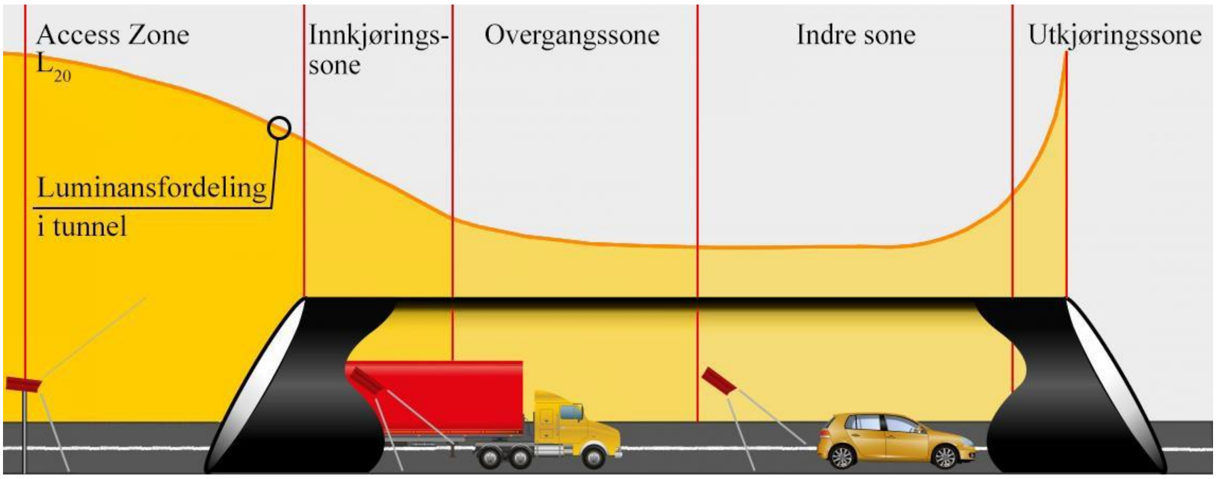

Figure 1. Tunnel zones, luminance distribution in the tunnel (luminansfordeling i tunnel)

The *access zone* is the area of road directly outside the tunnel entrance portal. This zone is important for recognising the tunnel opening and beginning the eye's adaptation to the lighting in front of the tunnel. The *threshold zone* is the first zone inside the tunnel where road users begin to adapt to the lower level of lighting. In order to provide the best possible visibility, the lighting in the threshold zone should be gradually reduced in accordance with the applicable requirements. The *transition zone* is the zone inside the tunnel where the eye continues to adapt to the lighting conditions. For this reason, the lighting level (luminance level) in the transition zone should be gradually reduced from the lowest level in the threshold zone to the luminance level of the interior zone. This lets road users arrive at the *interior zone* of the tunnel with their eyes adapted to the lighting level, and the lighting level in this zone should therefore be stable and in accordance with the applicable requirements.

Luminance is a measure of a surface's luminous intensity. It specifies the amount of light that passes through or is reflected by a particular surface within a given solid angle, and indicates how bright it will appear to the human eye when looking at the surface from a certain point. The unit of measurement for luminance in the SI system is candela per square metre (cd/m^2). Increased luminance will provide better contrast sensitivity, visual acuity and glare conditions if the driver's eyesight functions normally. Good luminance conditions require both a certain luminance level and that the level is relatively stable. Since luminance is a measure of how much light a surface reflects, the surface's colour and texture are important. Lighter surfaces reflect more light and can give a higher luminance level without using a more powerful lamp, which is also positive from an energy-saving perspective.

Glare may occur as a result of particularly high luminance or large luminance differences within the visual field. Glare is divided into two categories: uncomfortable glare and glare that impairs vision. Glare can also be a problem if the driver's eyes are affected by age or illness (e.g. unclear eye lenses) or if the windscreen is dirty. In a worst-case scenario, glare could prevent us from seeing the road ahead of us.

The luminance levels in the threshold zone and transition zone inside the tunnel depends on the adaptation luminance, which is measured in a visual field of 20 degrees from the driver's eye at a distance of 100 metres (in this situation) from the tunnel entrance (Figure 2).

Adaptation luminance can be defined as the average luminance value in the driver's visual field (for 20 degrees) that has an influence on the eye's adaptation to the existing lighting in the tunnel as the driver is approaching the tunnel but is still outside it.

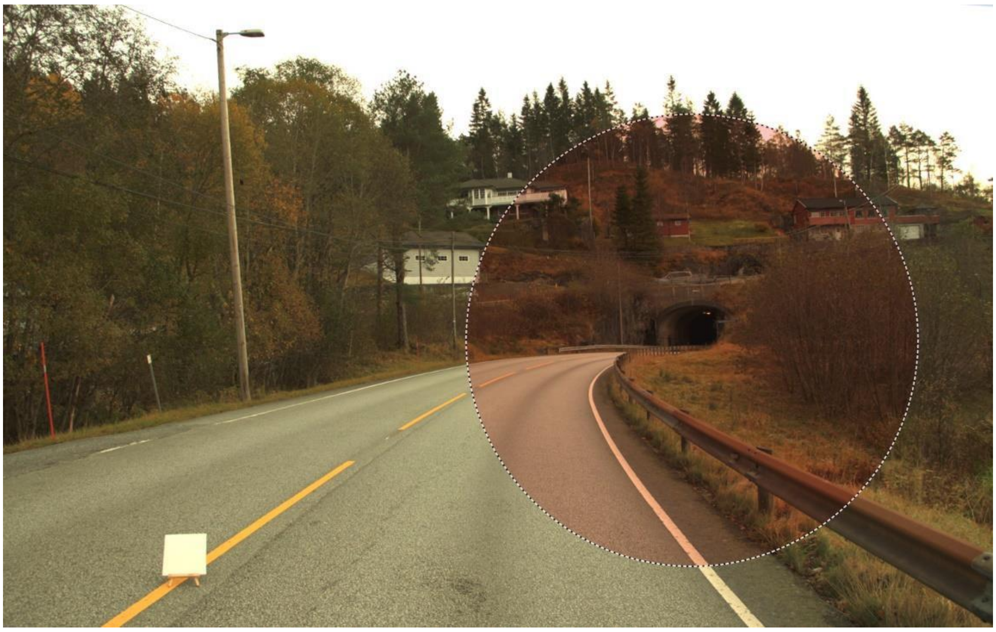

Figure 2. *Photograph taken on the day of the inspection at a distance of 100 metres from the tunnel opening with a 20-degree circle marked in red.*

The next important criterion for tunnel lighting is uniformity of luminance (U_0). Manual V124 gives the following definition of *uniformity of luminance*: 'U_o is the ratio of the road surface's minimum and average luminance values under dry road conditions or for the horizontal illuminance. Increased uniformity provides better conditions for vision.' According to Manual V124 and Manual N500: i) for the transition zone and interior zone, the overall uniformity of luminance shall be $U_0 = \geq 0.4$; ii) for the transition zone and interior zone, the longitudinal uniformity of luminance shall be $U_1 = \geq 0.6$. Manual V124 gives the following definition of *longitudinal uniformity of luminance*: 'Longitudinal uniformity of luminance (U_l) is the ratio of the minimum to the maximum luminance along a longitudinal line along the centre of a lane. It is calculated for each lane, and the lowest value must meet the requirement. Visual comfort improves with increasing longitudinal uniformity.'

The Raunekleiv tunnel

Table 1 shows the results from adaptation luminance calculations based on the light conditions on the day of the inspection. The table shows that there is a considerable difference between the adaptation luminance (L_{20}) on the day of the inspection and that calculated using the method recommended in Manual V124. This is to be expected, since daylight is dynamic and constantly changing. For this reason, state-of-the-art tunnel lighting systems have lighting control systems with an external photocell placed outside that helps to adjust lighting levels inside the tunnel based on the light level outside the tunnel. Other tunnel lighting planning is based on the requirements stipulated in Manuals V124 and N500.

We therefore recommend continuing with further analyses on the basis of adaptation luminance calculations carried out using the method described in Manual V124 (which requires higher luminance levels).

Table 1. *Results of the adaptation luminance calculations based on the light conditions on the day of the inspection (1) and the method described in Manual V124 (2).*

	Calculated values and explanation	*Existing values (measured on the day of the inspection)*
1. *Calculation of L_{20} based on light conditions on the day of the inspection:*	Adaptation luminance L_{20} measured on the luminance image taken on the day of the inspection (19 October 2017 at approx. 10:00) 100 metres from the tunnel opening (speed limit: 80 km/h) is 367.17 cd/m^2 (Figure 2). Based on the calculated L_{20} and according to Manual V124, the road surface's luminance level in the first half of the threshold zone (L_1) should be at least 5% of L_{20}, which is 18.36 cd/m^2. L_1 is defined as half of SD or the access zone, which in this context equals 50 metres. According to Manual V124, the luminance of the road surface towards the end of the threshold zone (100 metres into the tunnel) should be at least 40% of L_1, or 7.34 cd/m^2. Based on the tunnel lighting requirements set out in Manual V124, the road surface's luminance in the transition zone (which starts 100 metres into the tunnel) should be gradually reduced from 7.34 cd/m^2 to 6 cd/m^2 (during the day). In addition, the lower part of the tunnel wall from the ground and up to a height of 2 metres should have an average luminance corresponding to at least 60% of that of the nearest lane.	L_1 = 44.49 cd/m^2 The road surface at the end of the threshold zone had a luminance of 2.17 cd/m^2.
2. *Calculation of L_{20} in accordance with the method described in Manual V124:*	The adaptation luminance L_{20} calculated on the basis of the photo shown in Figure 2 and in accordance with the procedure described in Manual V124 (the Norwegian Public Roads Administration) is 5528.9 cd/m^2. Based on the calculated L_{20} and according to Manual V124, the road surface in the first half of the tunnel's threshold zone (L_1) must have a luminance of 276.45 cd/m^2 (5% of L_{20}). Towards the end of the threshold zone, the luminance of the road surface is 110.58 cd/m^2 (40% of L_1).	L_1 = 44.49 cd/m^2 The road surface at the end of the threshold zone had a luminance of 2.17 cd/m^2.

One of the factors that could cause problems in the threshold zone of the Raunekleiv tunnel is the absence of gradual reduction of the luminance of the road surface. In order to allow the eyes to adapt to the lighting inside the tunnel, the luminance level must be gradually reduced in this zone and into the transition zone so that the driver arrives at the interior zone with eyes completely adapted to the relatively low lighting inside the tunnel. If these recommendations are not complied with, the situation becomes more challenging for the visual system, and this could have serious consequences such as accidents.

In the first part of the Raunekleiv tunnel, lighting is reduced dramatically after a few metres (less than 50 metres) (see Figure 3, which shows the boundary between the high and low levels of luminance represented by the red oval in the middle of the picture). Luminance measurements on the day of the inspection show that the luminance of the road surface in the first half of the threshold zone before the transition between the relatively high and low luminance zones is 44.49 cd/m^2. At the same time, the road surface's luminance after this point (in the 'dark' section) is only 2.17 cd/m^2. First and foremost, there should be more light on the surface of the road in this zone (276.45 cd/m^2 instead of 44.49 cd/m^2). After the first 50 metres of the threshold zone, the road surface's luminance should be gradually reduced from 276.45 cd/m^2 to 110.58 cd/m^2.

However, the luminance is dramatically reduced from 44.49 cd/m^2 to 2.17 cd/m^2 at this point, which is not in accordance with the requirements set out in Manual V124. Generally speaking, the luminance of the road surface is far below requirements. This means that light conditions are poor for all road users, and the lighting is not adapted to drivers driving a vehicle at the permitted speed limit. This increases the risk of accidents.

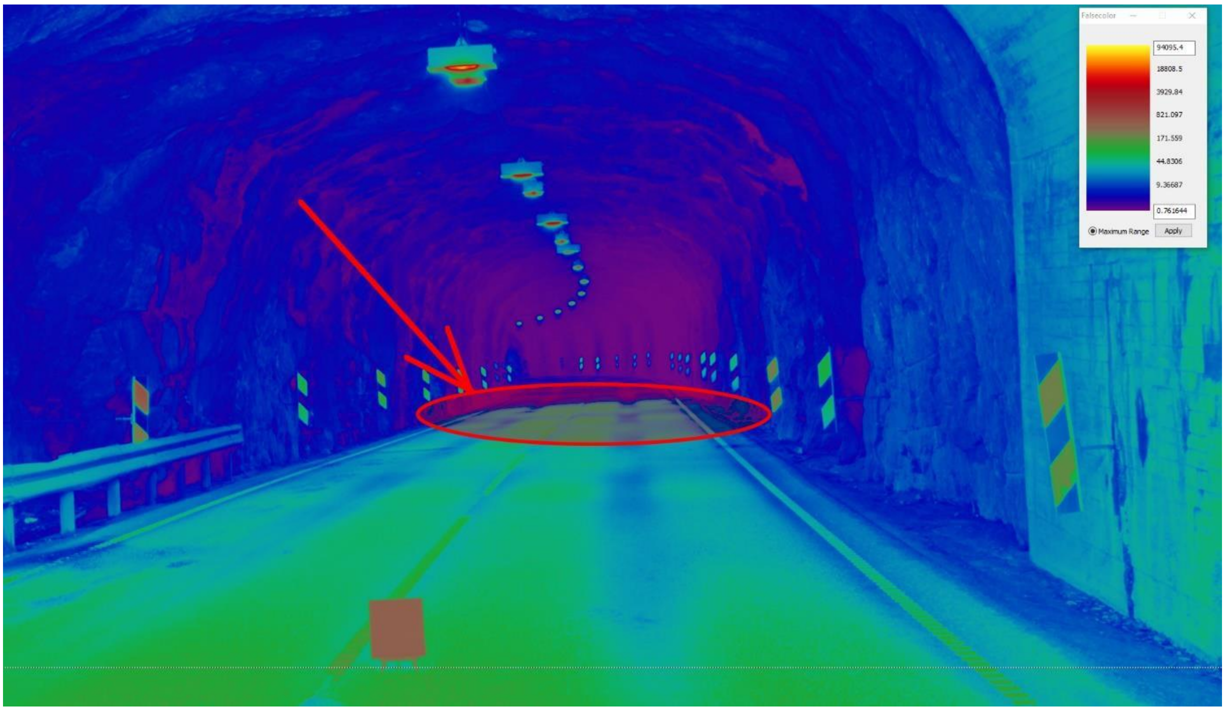

Figure 3. *The image shows the threshold zone of the Raunekleiv tunnel in false colours. The false colours are assigned to pixels with certain levels of luminance. The luminance scale is shown in the top right-hand corner of the image. The red oval marks the point where the lighting is dramatically reduced.*

In the transition zone (where the accident took place), the luminance of the road surface must be gradually reduced from 110.58 cd/m^2 to 6 cd/m^2. As shown in Figure 4, however, the road surface's luminance level is far too low at 0.58 cd/m^2, while manual V124 stipulates that it should be at least 6 cd/m^2 towards the end of the transition zone. This means that the luminance of the road surface in the transition zone of this tunnel is below the manual's requirements.

Manual V124 also requires the average luminance of the lower part of the tunnel walls (from the ground up to a height of 2 metres) to be at least 60% of that of the nearest lane. According to our measurements taken about 100 metres from the tunnel portal, the luminance of the road surface is 0.74 cd/m^2 and that of the nearest tunnel wall is 0.14 cd/m^2 (while it should be at least 0.44 cd/m^2). According to our measurements taken 20–25 metres from the tunnel portal, the luminance of the road surface is 20.3 cd/m^2, and that of the nearest tunnel wall is 2.81 cd/m^2 (while it should be at least 12.18 cd/m^2). According to measurements we made further into the tunnel, the luminance of the road surface is 2.27 cd/m^2 and that of the nearest tunnel wall is 1.17 cd/m2 (while it should be at least 1.362 cd/m^2). Based on the above, we can conclude that the luminance of the walls in the Raunekleiv tunnel should be higher. This can be corrected by increasing the level of lighting in the tunnel, using lamps with a wider beam angle that will illuminate the walls better, or painting the walls in lighter colours. The luminance level of the tunnel walls is far too low, reducing contrast and possibly making cyclists, pedestrians and animals etc. less visible.

Figure 4. *The image shows the transition zone in the Raunekleiv tunnel (approx. 100 metres from the tunnel portal) in false colours.*

The overall uniformity of luminance (U_0) in the transition zone calculated based on our measurements is 0.166. Manual N500 sets a minimum requirement of 0.4. This means that the overall uniformity of luminance in the Raunekleiv tunnel is lower than the lowest value specified in Manual V124. The longitudinal uniformity of luminance in the transition zone calculated based on our measurements is 0.296. Manual N500 sets a minimum requirement of 0.6. This means that the longitudinal uniformity of luminance in the Raunekleiv tunnel is only half of the minimum value required. Non-uniform distribution of luminance on the road surface reduces road users' visual comfort, weakens the general quality of the tunnel lighting, and could have undesirable consequences.

No quantitative analysis was carried out of glare that impaired vision. However, visual observation of the tunnel during the inspection and the luminance analysis presented in Figure 5 give grounds for concluding that the difference between the luminance of the light source and the average luminance of the tunnel ceiling and the road surface is sufficient to cause glare of road users.

The final factor that must be mentioned in this report is lighting in emergency lay-bys. According to Manuals V124 and N500, the illuminance in emergency lay-bys and turning bays should be 50% higher than in the road lanes. Figure 4 shows that this rule is not complied with in the Raunekleiv tunnel. The calculated average luminance of the road surface closest to the lay-by is 0.61 cd/m^2, while the calculated average luminance of the road surface in the lay-by is 0.09 cd/m^2. This means that the lay-by lighting is not in accordance with the requirements stipulated in the manuals, and that it should be better lit and have a higher lighting level than is currently the case.

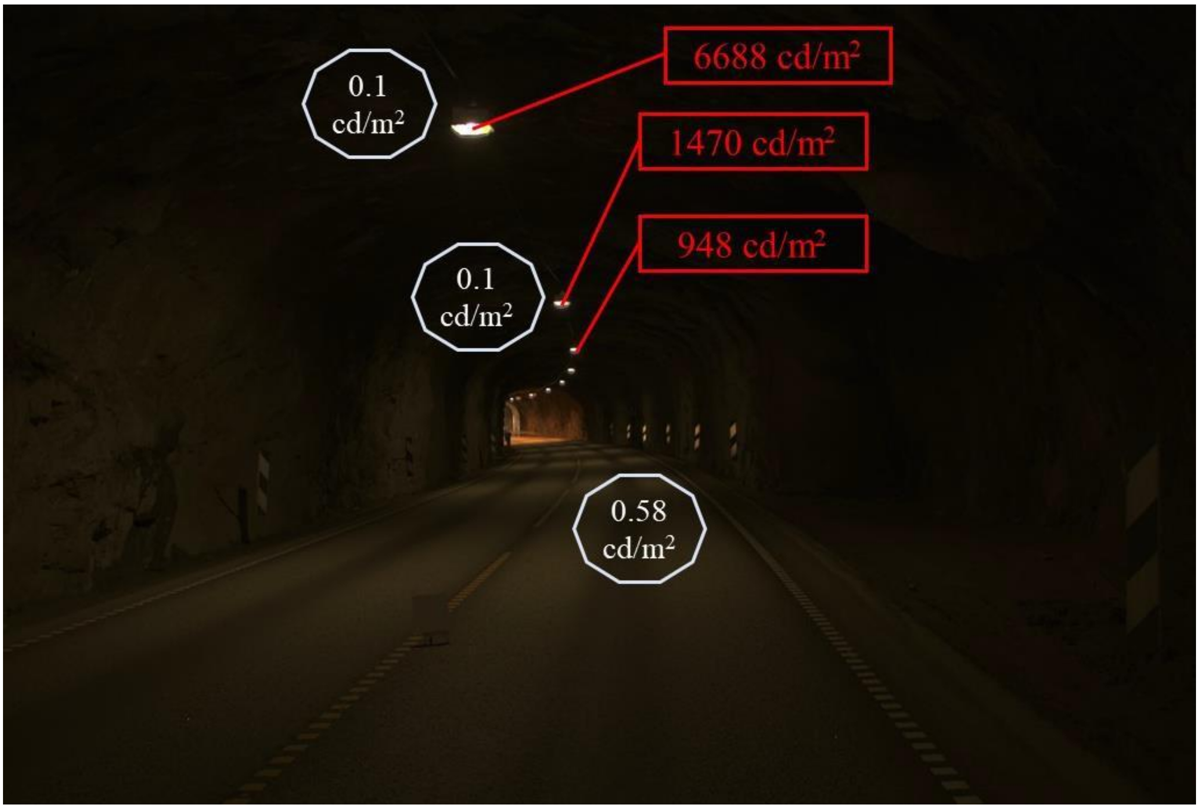

Figure 5. *The photo shows luminance values for light fixtures in the tunnel (in red) and average luminance values for the tunnel ceiling and the road surface (in white).*

Summary:

1. The lighting in the Raunekleiv tunnel does not comply with the most important requirements put in place to ensure the safety and visual comfort of road users.
2. The lighting level in the Raunekleiv tunnel is too low, and the distribution of lighting inside the tunnel is inadequate. This makes it more difficult for the visual system to adapt to the darkness inside the tunnel and increases the risk of accidents, since the existing lighting does not comply with the lighting parameters required for the permitted speed limit in the tunnel.
3. The luminance level of the walls is low, causing reduced contrasts and a reduced

ability to see cyclists/pedestrians.

4. Both the overall uniformity of luminance and the longitudinal uniformity of luminance are below the requirements set out in the manuals. This increases visual discomfort and may have a tiring and distracting effect.
5. The emergency lay-by lighting is inadequate.
6. Also, there is a high risk of glare in the tunnel, and this could at worst disturb a driver's visual impressions.