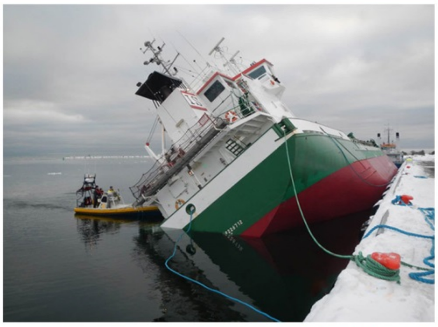
Statens haverikommission
Swedish Accident Investigation Authority



Final report RJ 2022:02e

Derailment involving a freight train between Kummelby and Häggvik, Stockholm County, on 11 February 2021

File no. J-05/21

2022-06-02

SHK investigates accidents and incidents from a safety perspective. Its investigations are aimed at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigations do not deal with issues of guilt, blame or liability for damages.

The report is also available on SHK´s web site: www.havkom.se

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This document is a translation of the original Swedish report. In case of discrepancies between this translation and the Swedish original text, the Swedish text shall prevail in the interpretation of the report.

Postadress/Postal address P.O. Box 6014 SE-102 31 Stockholm Sweden
Besöksadress/Visitors Sveavägen 151 Stockholm
Telefon/Phone +46 8 508 862 00
Fax/Facsimile +46 8 508 862 90
E-post/E-mail info@havkom.se
Internet www.havkom.se

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Content

1. SUMMARY

A freight train loaded with cars derailed on 11 February 2021 between Kummelby and Häggvik in Stockholm County. The train consisted of a locomotive and 19 wagons. After continuing 2,6 kilometres with four wagons derailed the train stopped at Häggvik station. No personal injuries occurred. However, the railway vehicles and the railway infrastructure were extensively damaged.

The derailment was caused by rail fatigue which, following a long loading period, propagated into a vertical crack and caused a broken rail. The crack formation had not been identified or dealt with as part of the infrastructure manager's system for preventive maintenance.

Safety recommendations

The Swedish Transport Administration is recommended to:

- Continue the development work it is doing to enable crack formation in rail to be identified at an earlier stage. (See section 4) *(RJ 2022:02 R1)*
- From a comprehensive perspective, review how current systems for preventing surface fatigue leading to broken rails can be improved. This review should include evaluating the intervals applied for non-destructive testing, follow-up of how defects are located, reported and marked out in practice and an analysis of the potential consequences of departing from the set interval for preventive machining. (See section 4) *(RJ 2022:02 R2)*

The Swedish Transport Agency is recommended to:

- Within the scope of its supervision, follow up the action taken by the Swedish Transport Administration as a result of recommendation RJ 2022:02 R1 and RJ 2022:02 R2. (See section 4) *(RJ 2022:02 R3)*

2. THE INVESTIGATION AND ITS CONTEXT

The scope and limitations of the investigation

The Swedish Accident Investigation Authority (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended to clarify, as far as possible, the sequence of events and their causes, as well as damages and other consequences. The results of an investigation shall provide the basis for decisions aiming at preventing a similar event from occurring in the future, or limiting the effects of such an event. The investigation shall also provide a basis for assessment of the performance of rescue services and, when appropriate, for improvements to these rescue services.

SHK accident investigations thus aim at answering three questions: *What happened? Why did it happen? How can a similar event be avoided in the future?*

SHK does not have any supervisory role and its investigations do not deal with issues of guilt, blame or liability for damages. Therefore, accidents and incidents are neither investigated nor described in the report from any such perspective. These issues are, when appropriate, dealt with by judicial authorities or e.g. by insurance companies.

The task of SHK also does not include investigating how persons affected by an accident or incident have been cared for by hospital services, once an emergency operation has been concluded. Measures in support of such individuals by the social services, for example in the form of post crisis management, also are not the subject of the investigation.

The decision and background to the initiation of an investigation

On 11 February 2021 at 10:22 hrs, SHK was informed that an accident had taken place at 02:16 hrs between Kummelby and Häggvik, Stockholm County. SHK began an examination of the accident site that same day.

On 25 February 2021, SHK decided to investigate the occurrence in light of the costs of the material damage being assessed to amount to at least EUR 2 million[1].

The investigation group

SHK has been represented by Jenny Ferm, Chairperson, Eva-Lotta Högberg, Investigator in Charge, and Mikael Hillbo, Operations Investigator.

[1] Criterion in the Accident Investigation Act (1990:712) indicating when rail accidents are to be investigated.

SHK has been assisted by Element Materials Technology AB through Gustaf Jonsson and David Hjertsén as experts in the investigation of fracture surfaces on metallic materials.

The investigation has been observed by the Swedish Transport Agency through Katarina Bjurman.

Investigation material

SHK has examined the accident site, infrastructure and railway vehicles. Pieces of a broken rail that was identified between Helenelund and Sollentuna commuter train stations were brought for a more detailed examination of the fracture surfaces and defects in the rail. The examination has included hardness testing, impact testing, chemical composition analysis, microstructure examination, examination of mechanical properties through tensile testing and fracture toughness testing.

SHK has studied recordings from vehicles, interlocking system and detectors, calls from and to the Swedish Transport Administration's traffic control centre, video material from the Public Transport Administration's platform cameras and weather data from SMHI.

SHK has interviewed:

- The driver of the train.
- Representatives of the Swedish Transport Administration within maintenance and technology.
- Representatives of Sperry Rail International Limited, which conducts ultrasound measurements on the section of track on behalf of the Swedish Transport Administration.
- Representatives of Infranord Mätenheten, which conducts manual inspections and verifications of indications from the ultrasound measurements on behalf of Sperry Rail International Limited.
- Technicians from Infranord Mätenheten who performed the most recent manual verifications of indications from ultrasound measurements on the section of track prior to the occurrence.
- Representatives of Omexom, which conducts safety inspections on the section of track and rectifies reported defect remarks identified by ultrasound scans.

Data from each interview has been worked into various sections of this report. SHK has studied documentation from the aforementioned organisations.

SHK has also obtained information from D-Rail AB, a company that, as part of a pilot project, had measuring equipment mounted on commuter trains that passed the section of track in question prior to the derailment.

A fact finding presentation meeting with the interested parties was held on 28 October 2021. At the meeting SHK presented the facts discovered during the investigation, available at that time.

3. DESCRIPTION OF THE OCCURRENCE

a) The occurrence and background information

Type of occurrence:	Derailment
Date and time:	11 February 2021, 02:15 hrs
Location, section of track:	Kummelby–Häggvik, track N2, Stockholm County, 12+719 km point in length measurement
Type of line:	Multitrack
Other transport operations or activities:	No
Railway company:	Green Cargo AB
Type of train, train no./operation:	Freight train 9400
Railway vehicle:	Locomotive Rd2, 91 74 000 1092-7, and 19 freight wagons[2]
Infrastructure manager:	Swedish Transport Administration
Contractor and subcontractor, ultrasound scans:	Sperry Rail International Limited and Infranord Mätenheten
Contractor, rectification of reported ultrasound remarks and performance of safety inspections:	Omexom
Speed at the time of the occurrence:	104 km/h[3]
Maximum permitted speed for the train: Maximum permitted speed for the track:	100 km/h 140 km/h
Weather:	Clear weather after the passage of a front with light snowfall, -11°C, light northerly wind.
Personal injuries:	None
Damage to railway vehicles:	Extensive
Damage to railway infrastructure	Extensive
Other damage:	Minor damage to cargo

[2] See Figure 13 for a list of wagon designations.
[3] See the section *Retrieval of data from the train event recorder* on p. 16.

Sequence of events

Green Cargo AB's train 9400 had departed from Malmö freight yard on 10 February with a final destination of Rosersberg. The wagons in the train were permanently coupled pairs of two-axle wagons, ten wagons of the type Hccmrrs, six wagons of the type Laaeilprs^{061} and three wagons of the type Laaeilprs^{983}. The train was 605 metres long and weighed 967 tonnes.

At midnight between the 10th and 11th of February, a change of drivers took place in Norrköping. The driver who was relieved reported that everything was working well to the new driver, who conducted the customary checks before the train departed from Norrköping. After departing from Norrköping, the driver conducted a retardation check[4] and noted that the braking system worked well despite the cold winter weather (-11°C). The driver had been a train driver since 1988 and was familiar with driving on the section of track.

When the train was approaching Kummelby, it was running on track N2, the second from the right of four tracks in the direction of travel. Normally, northbound trains run on tracks U1 and U2 but this train was running on track N2 as a result of planned maintenance. Track N2 is normally used by southbound commuter trains and freight trains, while N1 is used by southbound long-distance and regional trains. When necessary, the traffic controller can choose to run all types of trains on any of the tracks in either direction.

[4] A retardation check involves the driver, while the train is moving, checking that the set of vehicles' actual braking power is as calculated.

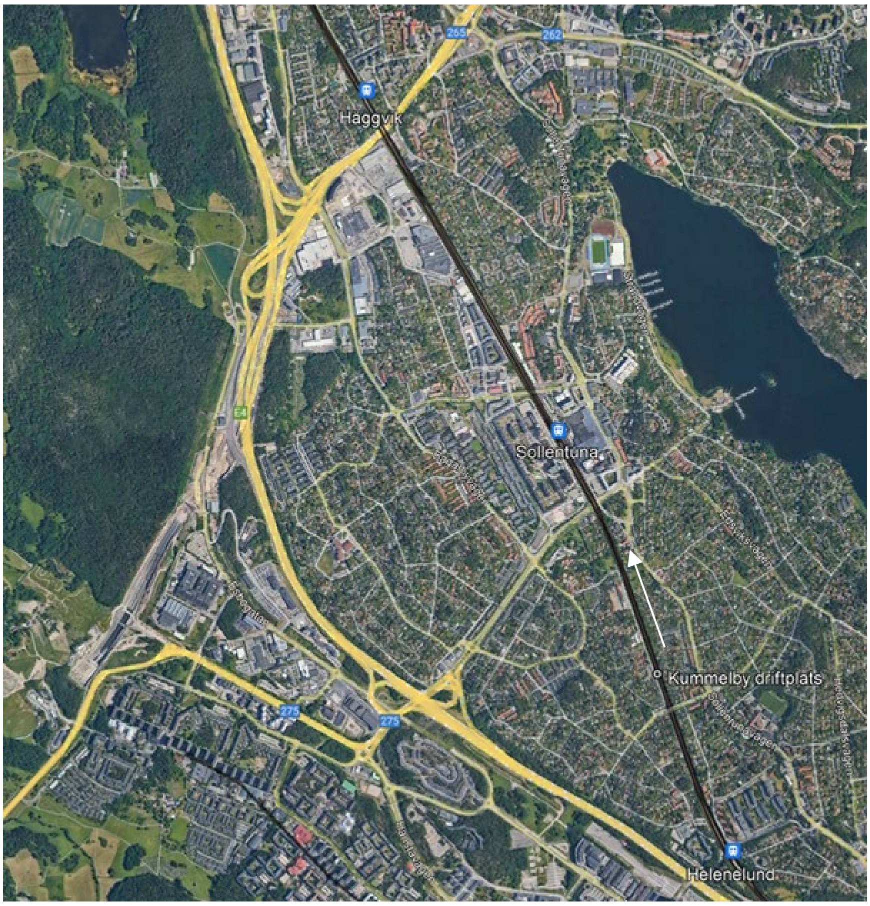

Figure 1. The derailment occurred between Kummelby and Häggvik in Stockholm County. The arrow indicates the train's direction of travel. Image from Google Earth, https://earth.google.com/web/@59.43062929,17.94464413,18.51909947a,6869.50520944d,35y,7.16089857h,6.73653929t,0.00079977r?utm_source=earth7&utm_campaign=vine&hl=sv. Arrow and the note 'Kummelby driftplats' added by SHK.

When the train arrived at Häggvik, the traffic controller at the Swedish Transport Administration's traffic control centre in Stockholm noticed that, on the track diagram, it looked as if 'several switches were out of control[5] behind the train'. The traffic controller contacted the driver at 02:16 hrs. In conjunction with this call, the driver noted that the brake pipe pressure fell and the train braked.

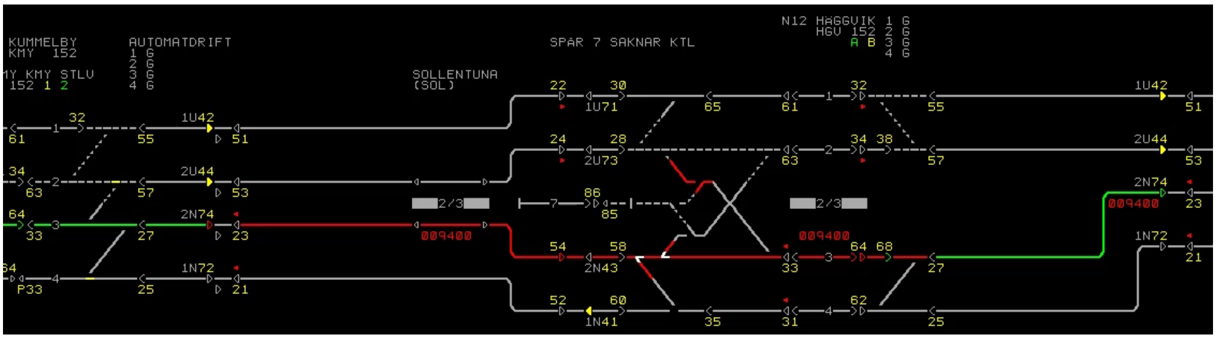

Figure 2. The traffic controller's control and monitoring system at 02:16:22 hrs. White markings indicate that control of the points is not confirmed (out of control). Source: Swedish Transport Administration.

The traffic controller blocked off the area and the driver turned on a blinking front light, placed a connector to short circuit the track line and went out to check

[5] Out of control means that the switches do not end up in the correct (confirmed) position.

the wagons. The driver found that a number of wagons further back along the train had derailed and informed the traffic control centre.

Two different parts of the train had derailed axles: the fifth and seventh pairs of permanently coupled wagons from the end and the two last pairs of permanently coupled wagons. The third and fourth pairs of permanently coupled wagons from the end were still on track. The last wagon was shifted sideways, with the rear portion in the adjacent track, N1 (see Figures 3 and 4). There were no other simultaneous train movements on track N1 at that time.

Figure 3. The train stationary following the derailment at Häggvik commuter station with the last wagon shifted sideways.

Figure 4. The last wagon came to a stop shifted sideways, with the rear portion in the adjacent track. The photographer is standing with their back facing in the train’s direction of travel.

The accident caused no personal injuries. However, major material damage occurred to the infrastructure along the 2,6 kilometre-long stretch of track affected by the derailment. Extensive damage also occurred to the derailed wagons. Minor damage occurred on the cargo consisting of passenger cars.

The accident site supervisor for the Swedish Transport Administration arrived at 02:59 hrs and coordinated the work at the accident site. During an inspection of the site, it was discovered that the last wagon had lost an axle. The accident site supervisor requested a traffic stoppage on all tracks passing Sollentuna and Häggvik on the basis of the risk that the axle could be on an adjacent track. The axle was found by the platform in Sollentuna and, after an inspection of the tracks, it was possible to lift the traffic stoppage for track U1. Damage to switches on track N2 prevented track U2 being used. During the inspection, it was also discovered that nine metres of rail were missing on track N2 between Helenelund and Sollentuna.

Rescue operation

The Swedish Transport Administration's traffic control contacted SOS Alarm at 02:35 hrs and informed them of what had happened. The log from the call indicates that they agreed that the Swedish Transport Administration would call back if there was a need to send any rescue resources. The Swedish Transport Administration has stated that no such need was identified.

b) Factual description of the events

Examination of the accident site

SHK examined the accident site the same day as the derailment occurred and the following day.

The aforementioned broken rail was identified between Helenelund and Sollentuna commuter stations (a few hundred metres north of Kummelby operations site). Nine metres of the rail on the right in the direction of travel were broken into over 20 larger and smaller pieces (see Figure 5). Some pieces of the rail were lying shifted sideways or several hundred metres behind the location.

Figure 5. Broken rail south of Sollentuna commuter station (the station is at the level of the tower block in the background).

SHK identified signs of preceding crack formation in the majority of the rail head at the fracture surface that comes first in the direction of travel (see Figure 6).

Figure 6. Signs of preceding crack formation in the rail head at the fracture surface that comes first in the direction of travel.

The pieces of rail that were found by the broken rail were brought by SHK for further analysis. White spray paint was identified on some of these pieces (see Figure 7). A marking on rail with the numbers 720 in yellow paint was also noted at the site (see Figures 8 and 16).

Figure 7. White spray paint on one of the pieces of broken rail.

Figure 8. Adjacent rail marked with 720 in yellow paint. Corresponding marking was also found on one of the broken pieces of rail (see Figure 16).

From the broken rail and forward of this there were signs of several axles derailing both directly to the right of the respective rail, with damage to the rail fastening, and at least one axle further to the right, past the edge of the sleepers. There were also several smaller breaks in the rail between the large break south of Sollentuna commuter station and Häggvik (see Figure 9).

Figure 9. Smaller break in the rail between the large break and Häggvik.

The final axle from the last freight wagon was found lying in the track alongside the edge of the platform at Sollentuna commuter station, 600 metres after the location where nine metres of rail was missing (see Figure 10).

Figure 10. The final axle from the last freight wagon was found lying alongside the edge of the platform at Sollentuna commuter station, 600 metres after the broken rail.

The last part of the wagon has then been dragged in the track for 2 km up to Häggvik, where the entire train came to a stop.

The train, including the lost axle, was inspected by SHK during the examination of the accident site. The inspection did not indicate any defects in bearing boxes, suspension, wheels or axles that could have contributed to the derailment.

Infrastructure

The section of track between the operations sites Kummelby and Häggvik is a part of the Swedish Transport Administration's infrastructure. Traffic control normally takes place by means of remote control from the traffic control centre in Stockholm in accordance with system H. This means that track clearance, tracks, switches and signals are controlled by an interlocking system.

The section of track is a multitrack system with four tracks. Train 9400 was running on track N2, which has a maximum permitted speed of

140 km/h. The track curves gently to the left. Track N1 has a maximum permitted speed of 200 km/h.

The Swedish Transport Administration's data from the (so called) route book includes details about the railway's operations sites, signals and road protection installations in the chosen direction of travel. The kilometre indications on the section of track between Kummelby and Häggvik are counted from Stockholm Central Station and begin at kilometre 0. For example, Kummelby operations site is at kilometre 11+950 metres (see Figure 11). Along the railway, there are overhead contact line posts that are numbered by kilometre and sequentially. For example, the post with the designation 12–13 is the 13th post at kilometre 12. According to the Swedish Transport Administration's track information system (BIS), post 12–13 is located at kilometre 12+716 metres.

D50 TC STOCKHOLM UNDERLAG TILL LINJEBOK TRAFIKVERKET
Cst → Avky

Km	Sth				Signaler, tpl m.m.
(Ulriksdal) – (Skavstaby) Flerspår. System H. ATC (Fjtkl Cst)					
	1U <1>	**2U** <2>	**2N** <3>	**1N** <4>	
	160/ 200	**130/** 140	**130/** 140	**160/** 200	
10+899	—	x	x	—	**Helenelund (Hel)** hp
11+030	—	x	x	—	Mblsi (So 2U4, 2N4)
11+195	—	140	140	—	Hatavla
11+491	200	—	—	200	Hatavla
11+629	x	x	x	x	Infsi (22, 24, 54, 52)
11+950	x	x	x	x	**Kummelby (Kmy)**
12+186	x	x	x	x	Ublsi (Kmy 1U42, 2U44, 2N74, 1N72)
12+296	x	x	x	x	Driftplatsgräns
13+200	—	x	x	—	**Sollentuna (Sol)** hp
13+336	—	x	x	—	Mblsi (Kmy 2U4, 2N4)

TRAFIKVERKET TC STOCKHOLM UNDERLAG TILL LINJEBOK D51
Cst → Avky

Km	Sth				Signaler, tpl m.m.
	1U <1>	**2U** <2>	**2N** <3>	**1N** <4>	
	200	140	140	200	
14+149	x	x	x	x	Infsi (22, 24, 54, 52)
14+590	—	—	—	—	Msi (86<7>)
14+678	x	x	x	x	**Häggvik (Hgv) ***
15+127	—	x	x	—	Häggvik plattform
15+258	x	—	—	x	Msi (32, 62)
15+260	—	x	x	—	Msi (34, 64)
15+639	x	—	—	x	Ublsi (Hgv 1U42, 1N72)
15+641	—	x	x	—	Ublsi (Hgv 2U44, 2N74)
15+763	x	x	x	x	Driftplatsgräns
16+110	x	—	—	x	Nedkopplingstavla
16+154	—	x	x	—	Nedkopplingstavla
17+050	—	x	x	—	**Norrviken (Nvk)** hp
17+151	—	x	x	—	Mblsi (Hgv 2U4, 2N4)

Figure 11. Excerpt from the Swedish Transport Administration's underlying data for the route book.

The train and its composition

Train 9400 consisted of locomotive Rd2 91 74 000 1092-7 and 19 wagons.

Detailed information about the length, weight, break percentage and the vehicles included is shown in the documents in Figures 12 and 13.

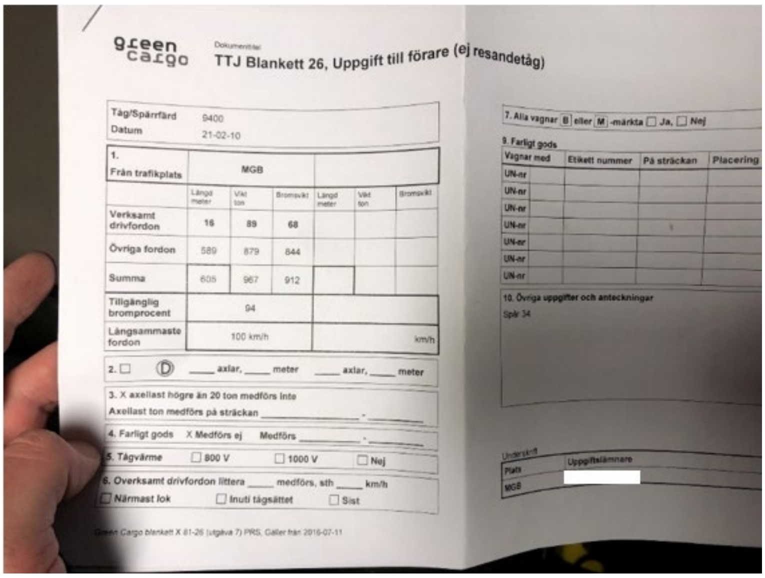

Figure 12. Form *Information for driver* regarding train 9400.

21/02/11 12:51 SIDA: 1

===== LISTA VAGNAR I TÅG =====

TÅG 9400 VID AVGÅNG MGB 210210

LN	VAGNSNR	D	AVST	BEST	S	AX	VKT	BRV	MOTTAGARE	UN/ST	ANTECKNINGAR
AKST = RS											
1	29080157		MFR	RSCO	L	4	44	40	AXESS		
2	43803261		MFR	RSCO	L	4	50	50	AXESS		
3	43803584		MFR	RSCO	L	4	50	50	AXESS		
4	43802669		MFR	RSCO	L	4	48	48	AXESS		
5	43803675		MFR	RSCO	L	4	50	50	AXESS		
6	29080314		MFR	RSCO	L 2	4	44	40	AXESS		
7	43800390		MFR	RSCO	L	4	48	48	AXESS		
8	29080298		MFR	RSCO	L	4	44	40	AXESS		
9	29080199		MFR	RSCO	L	4	44	40	AXESS		
10	29080405		MFR	RSCO	L	4	44	40	AXESS		
11	29080181		MFR	RSCO	L	4	44	40	AXESS		
12	43803501		MFR	RSCO	L T	4	50	50	AXESS		
13	43803022		MFR	RSCO	L	4	50	50	AXESS		
14	29080140		MFR	RSCO	L	4	44	40	AXESS		
15	29080413		MFR	RSCO	L	4	44	40	AXESS		
16	43800630		MFR	RSCO	L	4	48	48	AXESS		
17	29080132		MFR	RSCO	L	4	44	40	AXESS		
18	43803527		MFR	RSCO	L	4	50	50	AXESS		
19	29080389		MFR	RSCO	L	4	44	40	AXESS		

AVKOPPL RS 76 AX 879 TON 589 METER 844 BRVIKT 0 UBRK

VAGNAR TOTALT 76 AX 879 TON 589 METER 844 BRVIKT 0 UBRK

LOK1 RC2 1092 4 AX 88 TON 16 METER BRVIKT

Figure 13. Wagon list for train 9400.

According to Green Cargo AB, a departure inspection was performed in Malmö but the acknowledgement has not been saved. The departure inspection includes train wheel modules, suspension, brakes, wagon chassis and bogie frames, couplings, wagon bodies, cargo and unit loads.

Transwaggon was vehicle keeper and entity in charge of maintenance (ECM) for wagons 4, 7 and 16, of the type Laaeilprs^{983}. Autolink Group A/S (Axess Logistics Norway) was vehicle keeper and Rail-X AB was ECM for wagons 2, 3, 5, 12, 15 and 18, of the type Laaeilprs^{061}. Axess Logictics AB was vehicle keeper and Rail-X AB was ECM for wagons 1, 6, 8, 9, 10, 11, 13, 14, 17 and 19, of the type Hccmrrs.

SHK has studied maintenance records for the vehicles and has not identified any discrepancies that are deemed to be of relevance to the occurrence.

Recordings and observations about the section of track

<u>Retrieval of data from the train event recorder</u>

It is possible to establish from the data from the train event recorder that the train was being operated at a speed of no more than 105 km/h and that the driver adjusted the speed with a reduction in the train pipe pressure at 02:14:55–02:15:05 hrs (see Figure 14). The track slopes downhill from Kummelby to Sollentuna, which may explain why the speed of the train increased temporarily to 105 km/h.

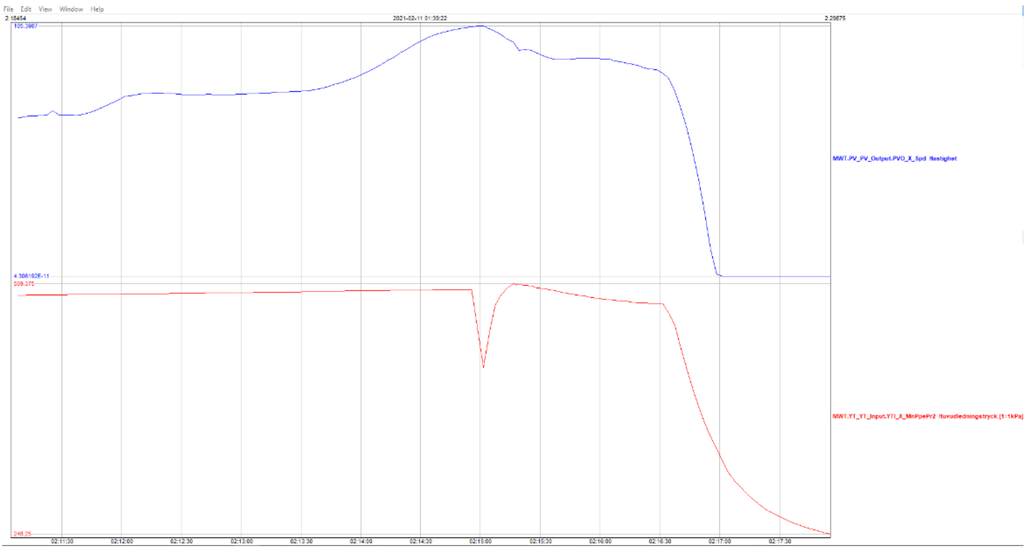

Figure 14. Excerpt from the train event recorder from 02:11 to 02:17 hrs. The blue line shows the speed and the red line shows the train pipe pressure. Source: Green Cargo AB

As shown in Figure 14, a short ‘notch’ in the speed curve coincides with the brake pipe pressure slowly beginning to fall. This is probably the effect of the derailment having begun, which is affecting the brake pipe pressure and the speedometer.

<u>Signalling and traffic control system</u>

The Swedish Transport Administration’s logs from the traffic control system indicate that the two preceding trains on track N2, commuter train 2285 southbound at 01:07 hrs and freight train 9804 northbound at 01:42 hrs, ran normally and without any indications of discrepancies. After this, train 9400 had ‘proceed’ at signal 2N74 from Kummelby and passed the signal at 02:14:35 hrs for track N2 in the direction of Häggvik. The locomotive passed the subsequent intermediate block signal 2N4 after the platform at Sollentuna at 02:15:14 hrs. The signal is located at kilometre 13+336 metres, which means that the last wagon in the train was 605 metres further back at that time, at kilometre 12+731 metres. The first derailed wagon, wagon 14, should have passed kilometre 12+719 metres and the site of the broken rail around eight seconds earlier, 02:15:06 hrs.

At 02:16:16, the locomotive was at Häggvik commuter station at the same time as the derailed wagons were passing the points south of the platform. In conjunction with the derailed wagons passing the points, these were indicated as being ‘out of control’ (see Figure 2).

At 02:18:35 hrs, the traffic controller had blocked off track N1 alongside the derailed train.

The rail that broke was the traction return rail, which is the rail through which the current that drives the train’s electric motors is returned. The insulated rail is the rail on which the track circuit’s insulated joints are placed. A break in the insulated rail, unlike a break in the traction return rail, can be seen through the track circuit being indicated as occupied and the signals show ‘stop’.

CCTV videos

SHK has studied videos from the Public Transport Administration’s security cameras at the platforms in Helenelund, Sollentuna and Häggvik.

On 11 February 2021 at 02:14:03 hrs, a freight train is seen passing Helenelund on track N2 in the northbound direction. Nothing abnormal appears in the video.

At 02:15:22 hrs, the freight train passes Sollentuna. A lot of snow is stirred up as it passes. The snow obscures the view of the train in such a way that it is not possible to determine whether the wagons are correctly positioned on the tracks as they pass.

At 02:16:46 hrs, the freight train arrives at Häggvik. Two wagons are abnormally far from the platform.

At 02:16:57 the freight train comes to a stop at the platform in Häggvik.

Detectors

Stationary detectors are located along the track in order to detect signs of hot axle boxes or wheel damage. The last hot axle box/hot wheel detector that detected the train was passed at 01:46 hrs on 11 February at Björnkulla, south of Flemingsberg. The last wheel damage detector that detected the train was passed at 18:23 hrs on 10 February at Dammstorp, between Malmö and Eslöv.[6] The data registered by the detectors that were passed show that the values for the train were within the specified tolerances.

[6] Because of planned track maintenance on the northbound tracks in the Stockholm area, the train was rerouted and passed on track N2 (southbound track), where there is no wheel damage detector.

Driver reports of discrepancies

The driver of the preceding train on the section of track did not note any discrepancies with the track. The Swedish Transport Administration has, on behalf of SHK, gone through calls received by the traffic control centre from 17:00 hrs on 10 February until the time of the occurrence. The Swedish Transport Administration has not found any report of any discrepancies with the track. Nor have any defect reports been received.

Measuring equipment on commuter trains

SHK has studied information from D-Rail AB, a company that, as part of a pilot project, had measuring equipment mounted on three commuter trains of the vehicle type X60 that run on the section of track in question. According to D-Rail AB, the purpose of the measuring equipment was to continually measure the infrastructure and convert the resulting data into maintenance data without affecting anything else in the rail network. D-Rail AB's equipment measures the movement of the axle through sensors mounted at a point as close to the centre of the wheel as possible on both the wheels on the axle. The sensors communicated wirelessly with a computer with GPS[7] located inside the vehicle.

An initial pilot project was implemented between 24 June and 30 November 2019 in cooperation with the Swedish Transport Administration, the Public Transport Administration and MTR Pendeltågen AB.

In a report[8] from the project in March 2020, the Swedish Transport Administration concluded that D-Rail AB's measurement system could detect difference in height between the rails, but that there were deviations from the measurements presented in certified standardized track position measurements (OPTRAM). The Swedish Transport Administration's report also states that the location of alarms received from D-Rail AB's sensors was rarely sufficiently precise.

Furthermore, the report states that D-Rail AB's measurement system was not useful for making maintenance decisions within the current regulatory framework. The authors suggested that a development or research project must be carried out before a measuring system such as D-Rail AB's is useful for making maintenance decisions within the current regulatory framework. The report states that for the Swedish Transport Administration, a development project such as this has a lower priority than processing the information that is already being gathered. This is because maintenance is not currently being performed optimally and could be improved using existing data.

A second project was implemented between 1 June 2020 and 31 December 2020. The Public Transport Administration, D-Rail AB and MTR Pendeltågen AB participated in this. According to D-Rail AB,

[7] Global Positioning System – satellite navigation system.
[8] "PILOT Fordonsbaserad mätning", authors Trafikverket, D-Rail AB och Sweco AB 2 March 2020.

the aim was to verify implemented changes, the need for which had emerged during the initial project and to further elucidate the benefits of the system.

Following the derailment, D-Rail AB has gone through its data from the equipment that was still on the commuter trains in February 2021. According to D-Rail AB, measurement data show a discrepancy in form of difference in height between the rails on the day before the derailment. The discrepancy is present for the first time on 10 February at 16:19 hrs and recurs on 11 February a 00:07 hrs, the second time with a higher amplitude. The position of the discrepancy is given by D-Rail AB initially at kilometre 12+808 metres. After having analysed its data further, D-Rail AB stated that the location should be moved minus 80 metres.

As far as SHK is aware, the registered discrepancy did not lead to any report to the Swedish Transport Administration or rectification prior to the occurrence.

Examination of railway vehicles

The railway vehicles were inspected after the occurrence by SweMaint AB on behalf of the railway undertaking Green Cargo AB. Wagons 1–13 in the train were transported to Rosersberg where, following a safety inspection by SweMaint AB, they were deemed to be operable and railworthy. During the recovery in Häggvik, two small dents on the outer edge of the wheel rim could be seen on wagon 13 (43803022). These were not deemed to have an impact on operability and railworthiness.

Wagons 14–19 in the train were recovered and moved to a siding in Rotebro. Following SweMaint AB's inspection on 9 April 2021, it was established that none of these wagons were able to be transported in a train in the condition they were in and that all the pairs of wheels needed to be replaced before they were transported to a workshop. A number of other instances of damage to footsteps, handles and gear to secure axle boxes and braking equipment under the wagons needed to be rectified before they were moved.

Examination of pieces of broken rail

The pieces of rail that were brought by SHK for examination are of the model UIC 60, which has a weight of 60 kg/m, is made of R260 grade steel, and was manufactured in 1993 in Luleå (see Figure 15).

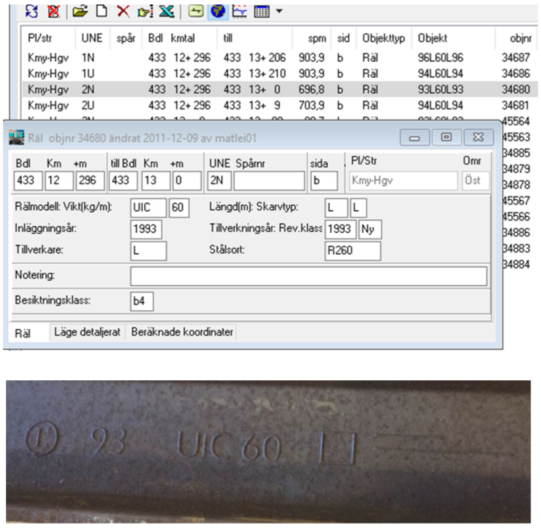

Figure 15. Register extract from the Swedish Transport Administration and marking on the rail shows that the rail is of the model UIC 60, R260 grade steel, manufactured in Luleå.

The Swedish Transport Administration's advice concerning requirement *TRVINFRA-00018 Banöverbyggnad, Spårkomponenter* specifies that what determines the choice of rail is the lifecycle cost with respect to technical and economic cost-effectiveness, as well as quality and safety requirements. The standard grade of steel used is R260. In curves where this is deemed technically and economically justifiable, R350LHT grade steel can be used instead. For tracks with a medium and high traffic density, the rail model UIC 60 is used.

Element Materials Technology AB has on behalf of SHK examined the rail pieces. The purpose of this examination was to document the fracture surfaces and defects on the fractured rail pieces and to establish the initial fracture and the fracture mechanism. The examination has included hardness test, an impact test, a fracture toughness test, a chemical composition analysis, a microstructure examination and a tensile test.

The 9 m rail has fractured in to several pieces (see figure 16). The fractured rail pieces do not show any global deformation. The fractured rail pieces show no or very little local deformation in the vicinity of the fracture surfaces. A small amount of the fractured rail is missing. The numbers 720 in yellow paint was identified on one of the rail pieces. White spray paint was identified on several of the pieces. The visual examination shows no welded joints or areas with repair welds on the rail pieces.

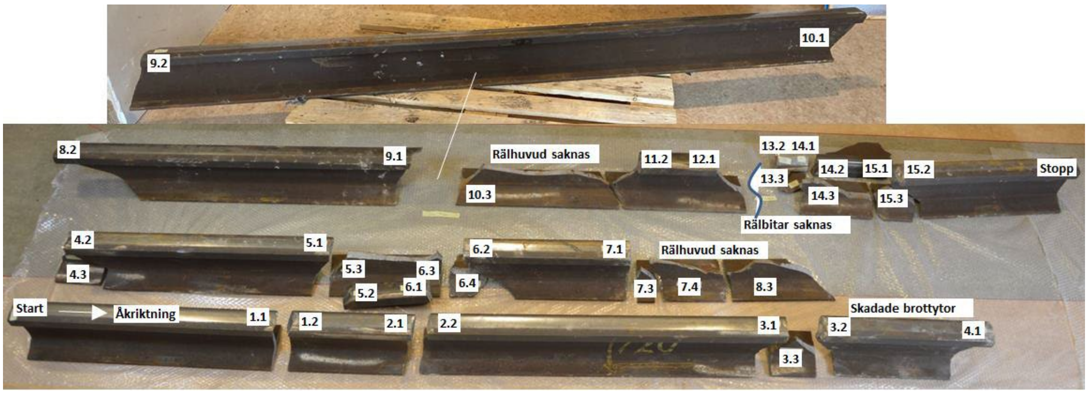

Figure 16. Sequential lineup of the fractured rail pieces. The fracture surfaces are numbered.

The first fracture, in relation to the direction of the freight train, is numbered 1.1/1.2 in Figure 16 and shows a fracture surface with an elliptical crack that has propagated vertically through almost the entire rail head. The visual examination shows that the vertical crack has its initiation at a crack, parallel to the rail head surface, a few millimeters below the surface. The parallel crack is actually a number of parallel cracks in different levels below the surface that originate from surface fatigue cracks.

Figure 17. Fracture surface 1.2 showing the surface fatigue cracks (a), spalling (b), parallel crack (c) and vertical crack (d).

Three more fracture surfaces shows distinct but smaller vertical fatigue cracks, 5.1, 10.1 and 11.2 in Figure 16. All the four fracture surfaces with fatigue cracks are positioned in between two sleepers.

The running surface on all examined rail pieces shows clear signs of surface fatigue. See example in Figure 18 were surface cracks have propagated parallel to the next surface crack resulting in spalling.

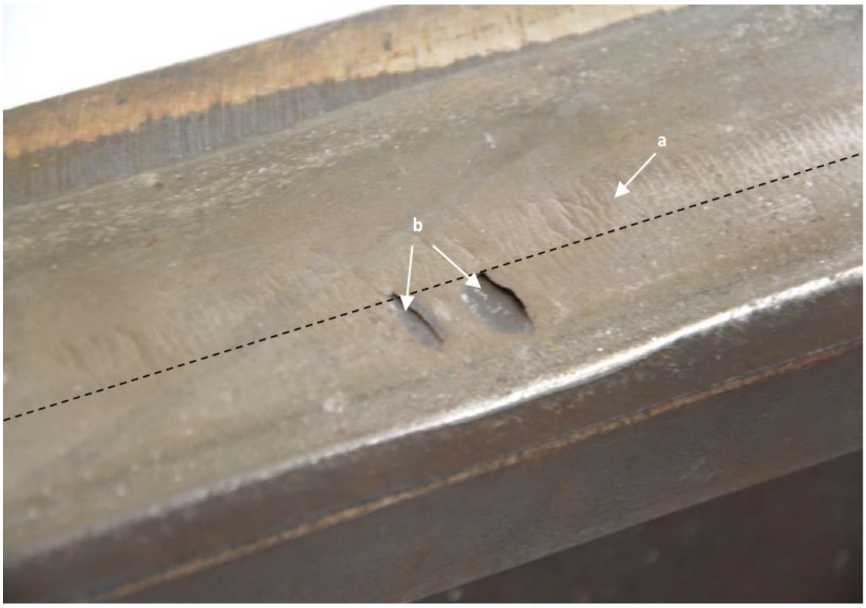

Figure 18. The running surface shows surface fatigue cracks (a) spalling (b) resulting from rolling contact fatigue. The position is located between fracture surface 11.2 and 12.1. The dashed line shows the position of the axial rail cut.

Figure 19 shows an axial cut along the rail head, between fracture surface 11.2 and 12.1, with surface fatigue cracks, spalls, parallel cracks and an early stage of a vertical crack.

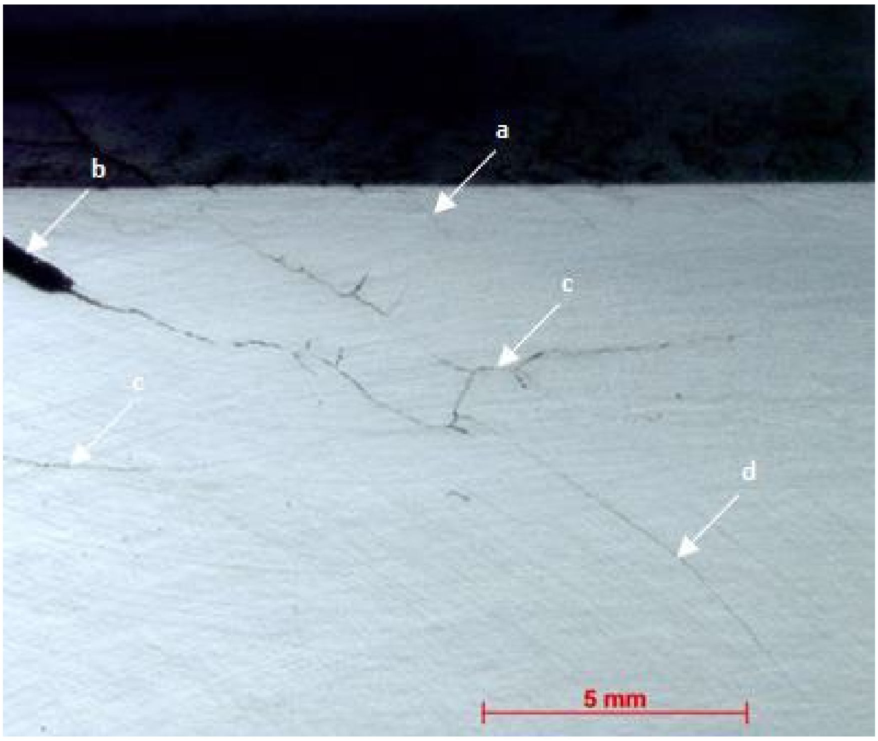

Figure 19. The image shows an axial cut along the rail head, between fracture surface 11.2 and 12.1, with surface fatigue cracks (a), spalls (b), parallel cracks (c) and an early stage of a vertical crack (d).

All remaining fracture surfaces show mainly overload fracture. The main part of the cracks also has parallel cracks a few millimeters below the running surface. A few of the cracks also show an early stage of a vertical crack.

Figure 20 shows dark spots on the running surface which indicate that parallel cracks have propagated below the surface. The dark spots are visible with some regularity but not on all rail running surfaces. There is no notable depression in the surface which would indicate friction or impact damage.

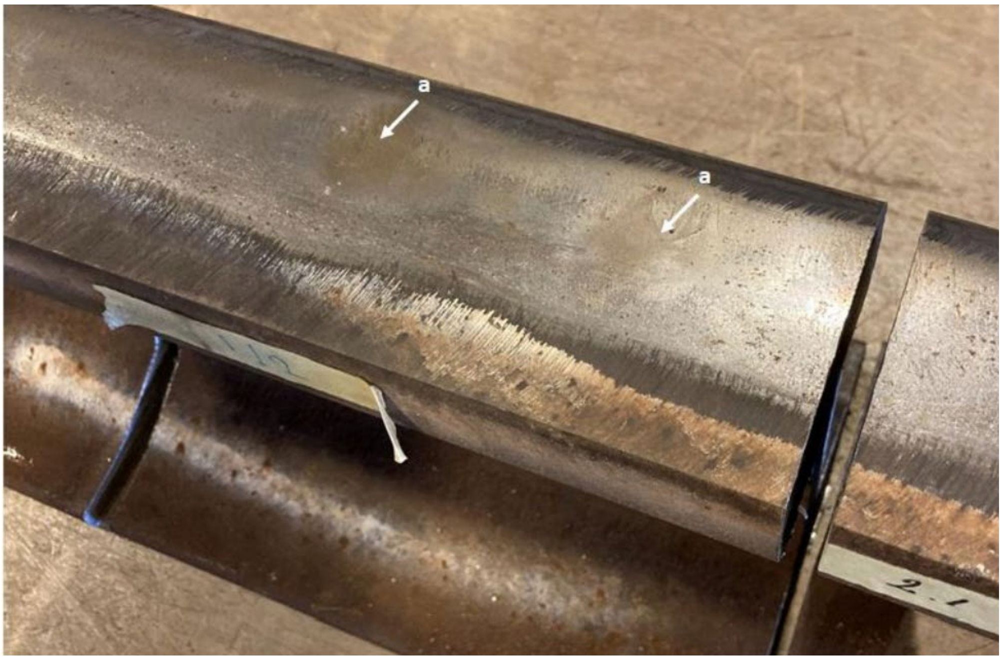

Figure 20. The running surface shows dark spots with surface cracking (a).

Figure 21 shows distinct mechanical damage on the edge of the running surface between crack surface 8.2 and 9.1. Further mechanical damage can be seen on the running surface between fracture surface 4.2 and 5.1 with axial and slightly angled indents

Figur 21. Mechanical damage between fracture surface 8.2 and 9.1.

Figure 22 shows the fracture surface 1.1 where the vertical crack has almost propagated through the entire rail head.

Figure 22. Fracture surface 1.1 with parallel crack (c), vertical crack (d) and overload zone (e) and the area investigated with scanning electron microscope (SEM).

Figure 14 shows the overload zone using a scanning electron microscope at 700x magnification. The overload zone shows a distinct brittle fracture character with transcrystalline cleavage fracture and river pattern.

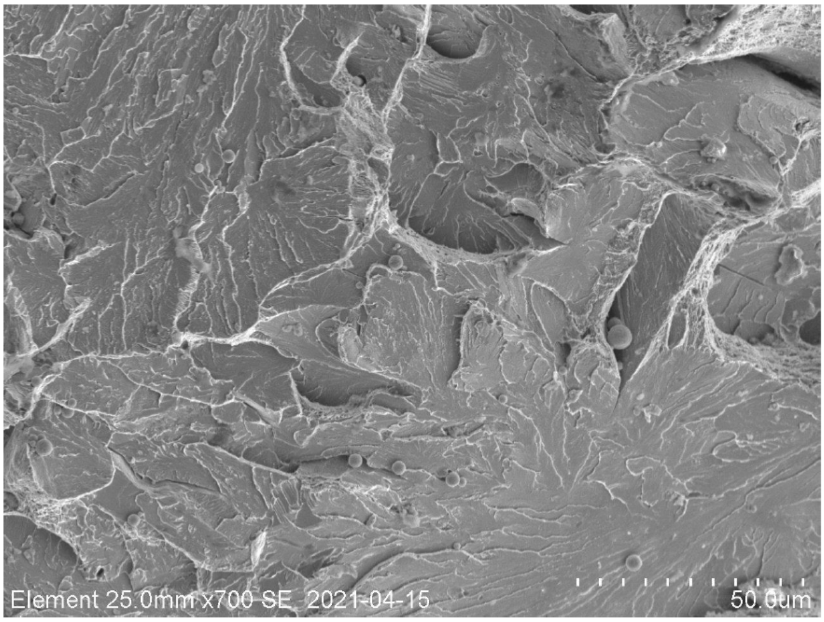

Figure 23. The fracture surface examined with a scanning electron microscope at 700x magnification. The overload zone shows a distinct brittle fracture character.

The material type is carbon manganese steel with a carbon content of 0.7wt%.

The examinations of hardness, fracture toughness, chemical composition and mechanical characteristic shows result within the acceptance criteria stated in *EN13674-1 Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above*. The European standard applies as a Swedish standard and is referred to in *Commission regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union.*

The impact toughness of the rail material is tested at 0°C, -20°C and -40°C. The absorbed impact energy, for all tested temperatures, is on a uniformly low level, below any transition temperature interval, where fracture occurs in a brittle manner. No acceptance criteria for impact toughness of material R260 is specified in EN13674-1.

A microstructural examination was performed on a polished and etched micro sample that was extracted close to the fracture surface 1.1. The examination shows a microstructure with relatively small grains, pearlite structure and ferrite in the grain boundaries, see Figure 24. The overall grain size is relatively small whit the grains in the core slightly larger than the grains close to the surface. The grains close to the running surface have a deformed elongated shape which indicates plastic deformation due to contact with the train wheel.

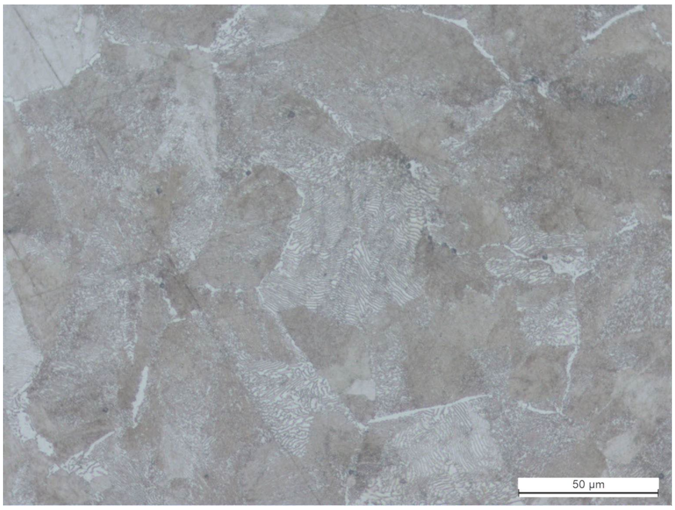

Figure 24. The rail head microstructure, below the running surface, at 500x magnification.

Conclusions from the rail examination

The reason of the rail break is fatigue. Surface cracks and parallel cracks below the running surface are present on all examined rail pieces. The surface cracks are visible on the running surface in a fish bone pattern and parallel cracks can be seen as dark spots on the running surface.

Fracture 1.1/1.2 (see Figure 16 och 17) is the primary fracture and the reason for the following failure of the rail. At the crack surface a number of parallel cracks has initiated the vertical crack that caused the first overload fracture. The critical crack length is 44 mm.

All overload fractures have brittle character. All fractures have likely occured in sequence during the passing of the freight train the night between the 10th and 11th of February 2021.

The propagating directions of the surface-, parallel-, and vertical cracks agree with derived loads between rail and train wheel.

Dark spots are visible on the right hand side rail before and after the fractured part of the rail. No dark spots are visible on the left hand side rail. This indicates that the right hand side rail is subjected to higher pressure- and friction loads.

The mechanical damage that is visible on the running surface is assessed not to have affected the rail break.

The examination concludes that the rail material R260 is sensitive to surface fatigue when exposed to high pressure- and friction loads. The extensive cracking inside the rail head indicates a long operating time where cracks have been allowed to propagate from surface cracks to parallel cracks and finally to vertical cracks.

The microstructure is normal for the steel type and carbon content.

Material with low absorbed impact energy is more brittle than material with higher absorbed impact energy. The material has a distinct low level of absorbed energy even for a material with high carbon content.

The brittle behavior of the fractured rail at high strain rates explains the large number of fracture surfaces and fractured pieces and that the pieces have spread out over a large area during the load impact that occurred at the passing of the freight train. The brittle behavior at high strain rates for this rail material is related to the character of steel with high carbon content and pearlite microstructure.

Measurements and inspections of the track infrastructure

The Swedish Transport Administration is the infrastructure manager for the railway and is responsible, among other things, for managing, maintaining and developing the rail network and its technical systems. In order to operate as the infrastructure manager, the organisation must, under Directive of the European Parliament and of the Council (EU) 2016/798 of 11 May 2016 on railway safety, be encompassed by a safety management system. A safety management system consists of the processes and procedures that have been introduced in an organisation in order to be in control of the risks resulting from its operations. The safety management system has to be documented and should be developed as the organisation changes and develops.

The Swedish Transport Administration's guideline *TDOK 2014:0162 Driftsäkerhet, säkerhet och underhåll av järnväg* is part of the Swedish Transport Administration's safety management system for railways and is the basis for governing maintenance within the Swedish Transport Administration. The guideline describes the overarching requirements that apply to reliability, safety and maintenance of the Swedish Transport Administration's rail network and that apply by virtue of the Swedish Transport Administration's operational and maintenance strategy.

The guideline defines maintenance as follows:

A combination of all technical and administrative measures and the actions of management during the life cycle of a unit that are intended to maintain it in, or return it to, a condition such that it can perform the required function. (Swedish standard, SS-EN 13306:2001, Maintenance-Terminology)

To guarantee that the decided safety level of the unit is maintained, the guideline specifies that a safety inspection shall be conducted at set intervals. The actual condition of the unit and discrepancies from the setpoint have to be reported in a consistently traceable and transparent way. It has to be possible to use this information in such a way that it can be combined with planned measures and facilitate decision-making at various levels of the organisation.

The Swedish Transport Administration's requirement document *TDOK 2014:0240 Säkerhetsbesiktning av fasta anläggningar* is included in the Swedish Transport Administration's safety management system for railways and describes the requirements the Swedish Transport Administration placed on safety inspection of railway installations in accordance with the guideline TDOK 2014:0162. [9]

The purpose of the safety inspections is to act as a control function of the railway installation in order to prevent the safety of the installation from deteriorating. The preparations prior to an inspection are to include obtaining the actual status from previous inspections. The inspection is done visually or through measurement. When conducting the inspection, the installation shall be assessed on the basis of two aspects: the actual condition and the risk of the installation not being able to fulfil the required function until the next safety inspection.

Inspection remarks are prioritised in accordance with four different options: A (emergency, necessary rectification shall be done immediately), V (rectified within two weeks of the inspection date), M (rectified within three months), B (rectified before the next inspection or in another way in accordance with the list of points in TDOK 2014:0240).

The inspection staff shall report the inspection in the Bessy[10] system as soon as possible after each inspection. Based on the chosen priority, a proposed deadline for rectification shall be specified.

The Swedish Transport Administration's requirement documents *TRVINFRA-00013 Banöverbyggnad Spårläge* and *TRVINFRA-00015 Banöverbyggnad, Oförstörande provning (OFP)* is included in the Swedish Transport Administration's infrastructure regulations. The purpose of the Swedish Transport Administration's infrastructure regulations is to describe the requirement placed on the properties and handling of the infrastructure installation. The documents are based on international standards and requirements in accordance with the EU's technical specifications for interoperability (TSI).

TRVINFRA-00013 includes requirements for track position, speed classes, limit values and tolerances as well as requirements for measures that must be met in order for train traffic to be allowed to run. The document includes requirements for which track position parameters are to be measured and evaluated according to the Infrastructure TSI, requirement level depending on speed class, limit values and tolerances,

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[9] SHK has noted two out-of-date references in TDOK 2014:0162 version 8.0 published on 01/01/2021. With regard to non-destructive testing, there is a reference to TDOK 2014:0084. However, TDOK 2014:0084 was replaced with TRVINFRA-00015 on 1 April 2020. TDOK 2014:0162 states that safety inspection of railway installations is done for the purpose of meeting the requirements of a high level of safety as part of the Swedish Transport Administration's work to comply with, among other things, BV-FS 1997:2. However, BV-FS 1997:2 was repealed by the Swedish Transport Agency in 2013.

[10] Bessy is an IT system for implementing safety, maintenance and takeover inspections of the Swedish Transport Administration's fixed railway installations.

measurement methods, reporting and documentation of measurement results.

TRVINFRA-00015 describes the intention of using Non-Destructive Testing (NDT) as being to detect defects and damage to rails, rail components, manganese crossings and welds at an early stage and thus avoid breaks. TRVINFRA-00015 specifies NDT methods and type of equipment to be used in the examination of rails, rail components and welds, periodicity for inspection and competence requirements for those who perform NDT inspection.

The Swedish Transport Administration has engaged Sperry Rail International Limited (Sperry Rail) to perform NDT of rails, points and rail components on the section of track in question. This contract includes automated inspection using a special measurement vehicle (the 'ultrasound train') and manual inspections of rail components, as well as verification of indications from the ultrasound train. The Swedish Transport Administration has engaged Omexom in order to rectify NDT defects that have been reported to Bessy. Omexom has also been engaged by the Swedish Transport Administration to perform safety inspections of the installation.

Sperry Rail, which operates in several European countries, has reported that the frequency of the ultrasound scans is different for different customers, with the most frequent interval applied being eight weeks. Other intervals that are applied are every three, six or twelve months. The frequency is determined by each infrastructure manager on the basis of local conditions.

The Swedish Transport Administration has reported that the inspection frequency of its track infrastructure is governed by which inspection class each section of the installation has. The inspection class is determined on the basis of speed and tonnage. The section in question belonged to inspection class four, which means that safety inspections have to be conducted three times per year (more details in *Safety inspections* on p. 39) and NDT once per year.

The Swedish Transport Administration's process for NDT is illustrated in Figure 25.

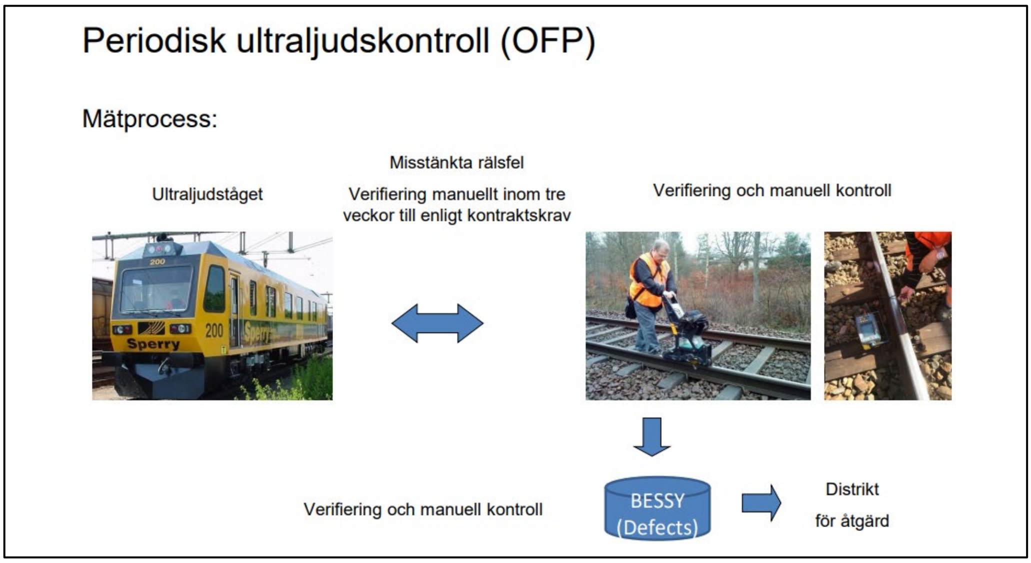

Figure 25. Visual representation of the Swedish Transport Administration's ultrasound scanning process. Source: Swedish Transport Administration.

The automated ultrasound scan is performed using a special measurement vehicle, the *ultrasound train*, which registers indications of defects in the rail. The indications from the train have to be verified and inspected manually by staff certified for this purpose within three weeks of the automated inspection.

Figure 26 shows Sperry Rail's flowchart for the ultrasound inspection.

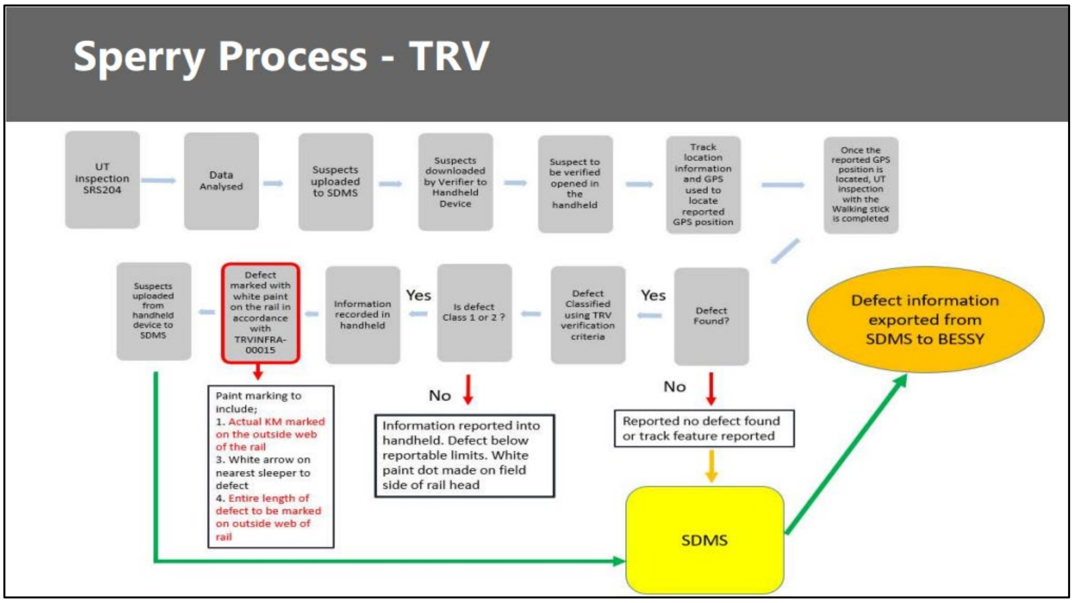

Figure 26. Sperry Rail's flowchart for ultrasound scans. Source: Sperry Rail.

The ultrasound train is equipped with 11 probes per rail that search for different types of defect: vertical, transverse and horizontal defects. Operators on the ultrasound train are Sperry Rail's own staff. Data from the train is analysed, processed and uploaded to Sperry Rail's data management system SDMS. Processed information is then downloaded to a handheld device by the person who is to inspect and verify the potential defects (Sperry Rail calls these 'suspects') identified by the train. Sperry Rail has engaged Infranord Mätenheten[11] to conduct the manual inspection and verification.

During the manual inspection, the equipment used to locate the defects registered by the ultrasound train are a handheld device, ultrasound instruments and a manual ultrasound wagon called a *walking stick*, which contains probes for detecting transverse, horizontal and diagonal defects in the rail. The manual inspection also includes a visual inspection. The outcome of the manual inspection and verification is registered in the handheld device.

Remarks that are verified are divided into group 1 and group 2 defects in accordance with the assessment criteria in *TRVINFRA-00015*. For group 1 defects, an assessment is made of whether the defect needs to be rectified as an emergency, within two weeks or within three months. Group 2 defects are defects that are allowed to remain in the installation. In accordance with *TRVINFRA-00015*, group 2 defects have to be inspected visually during all safety inspections performed on the installation in question. Group 2 defects also have to be examined using ultrasound during subsequent periodic NDT inspections of the installation in question. Group 1 and group 2 defects have to be reported to the Swedish Transport Administration's Bessy system. Remarks that are verified but do not meet the Swedish Transport Administration's criteria for being classified as group 1 or group 2 defects are saved in Sperry Rail's SDMS system.

Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår* describes how reportable defects that the ultrasound train has not registered can be detected visually during the manual inspection. In these cases, the defects detected are to be reported manually using Sperry Rail's handheld device.

Locating and reporting verified defects

Figure 27 shows the display that is shown when a user has started Sperry Rail's software on the handheld device in order to locate and verify defects.

[11] Infranord Mätenheten is an independent unit within Infranord AB that performs measurement services and non-destructive testing (NDT).

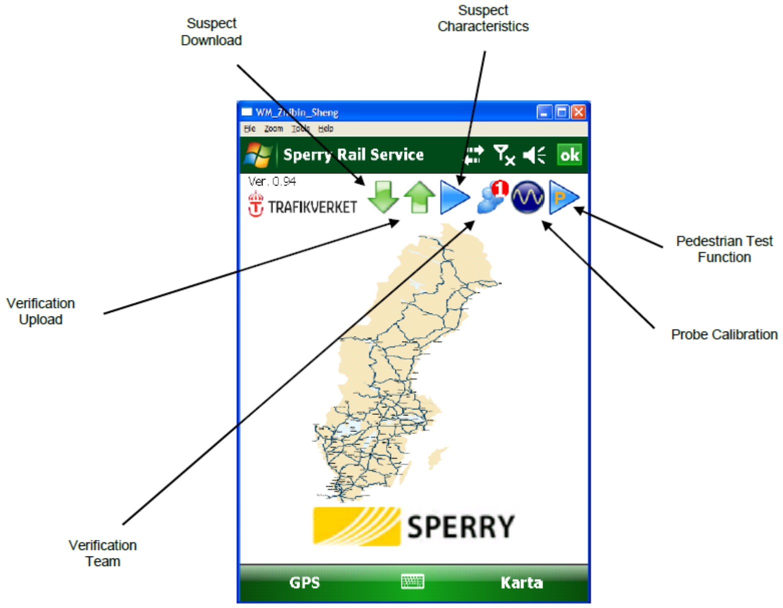

Figure 27. User interface for downloading, verifying and uploading defects. The images in Figures 27–31 are taken from Sperry Rail's user guide *WI7004 Use of Sperry Handheld Device – Swedish Transport Administration*

Figure 28 shows the handheld device's display as it appears when a user has downloaded information about suspected defects that are to be verified on a certain section of track. The display shows information about each defect such as identification number, priority, distance from defect, kilometre position and section of track. Pedestrian Test Function (triangular icon with a P) is used if the user has visually detected a defect that was not registered by the ultrasound train.

After the verification is complete for each day, the result has to be reported to Sperry Rail's SDMS system by the user pressing the 'green up arrow' on the handheld device.

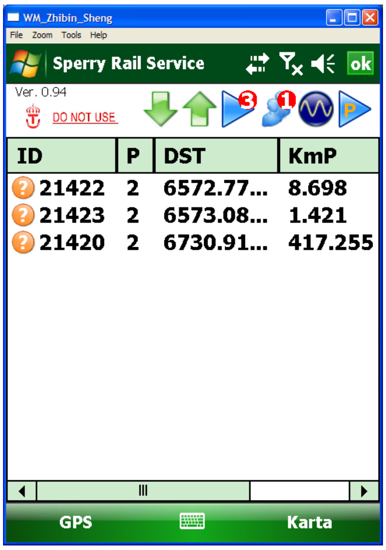

Figure 28. The display of the handheld device shows information about each suspected defect on the section of track that is to be verified. Source: Sperry Rail.

Figure 29 shows what the display on the handheld device looks like when the user has chosen a suspected defect. The display shows a countdown of the distance to the suspected defect. By clicking on the ‘defect’ button, the user moves forward and is able to register data about the suspected defect (see Figure 30).

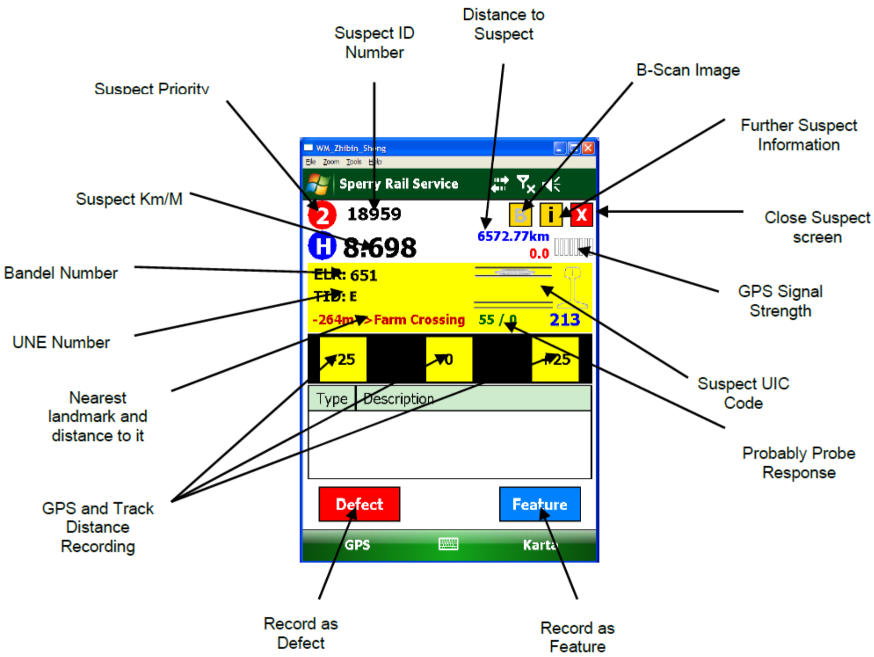

Figure 29. Display that shows information about the suspected defect. Source: Sperry Rail.

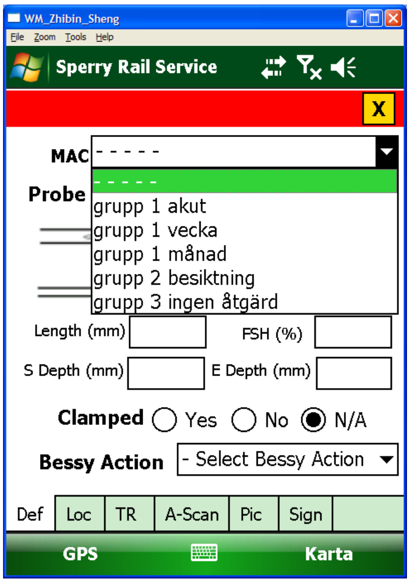

Figure 30. Variables such as severity are selected for each defect that is being verified. Source: Sperry Rail.

According to Sperry Rail, the user interface has been designed with the aim being for the user to confirm the geographic location of a defect. For example, if a defect has an incorrect kilometre indication, the user can correct this by entering the correct kilometre position. It is important that the user registers the GPS position of the defect. There is a function for doing this called 'Catch GPS' (see Figure 31). According to Sperry Rail, the person who checks and verifies a defect must register a GPS position or register 'no GPS available' before the verification of a defect can be completed.

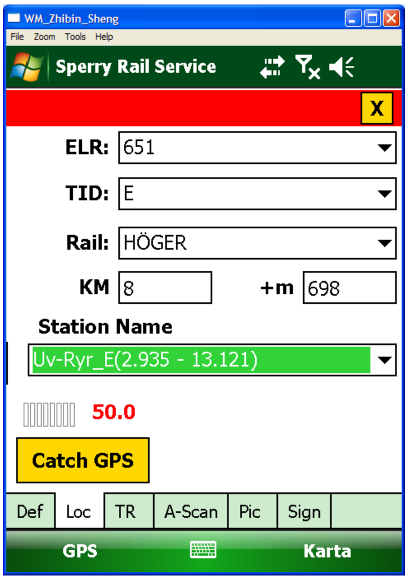

Figure 31. Display showing the 'Catch GPS' function. Source: Sperry Rail.

Uncertainty in position data

Sperry Rail has stated that there is some uncertainty in the kilometre data that is reported from the ultrasound train. The operator on the train sets the kilometre reading at the beginning of a run using information from the Swedish Transport Administration's representative who is present on the vehicle. When the vehicle is running, the kilometre indication will increase or decrease depending on the direction of travel. When the vehicle passes a kilometre point, the operator synchronises the kilometre reading. Because the vehicle runs at 40 km/h, the point at which the operator presses the 'synchronise button' will not be exactly in line with the kilometre post. For example, if the operator were to synchronise at kilometre 50+0 metres, it may actually be kilometre 50+3 metres. According to Sperry Rail, the fact that the kilometre indication can differ in this way is the reason why the person who is to perform verification uses the kilometre and track section information in order to find the approximate location of a suspected defect and then uses the GPS position from the train in order to locate the suspected defect.

Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår* states that, during a search for defects, the person who is performing verification is to work on the basis of the GPS point shown on the handheld device provided by Sperry Rail. The GPS point is described as being more accurate than the kilometre indication. In addition, it states that a post number or nearby signal always has to be filled in under notes. Relevant local information that pertains to the defect also has to be filled in. Examples listed include impacts from trains, a visually discernible crack, if a whole rail from weld to weld has to be replaced and several defects in a certain length. In addition, it states that if the given kilometre and metre indication is not consistent with the actual length measurement on the track, this has to be changed in the handheld device for each defect that is being reported.

<u>Marking defects</u>

TRVINFRA-00015 Banöverbyggnad, Oförstörande provning describes how verified defects from the ultrasound scan that belong to groups 1 and 2 shall be marked well visibly on the installation using either white permanent paint or white crayon. Poorly visible marking of group 2 defects that is detected during a safety inspection shall be made clearer by the inspector.

Defects that do not spread out along the length of the track are to be marked with a vertical line the full height of the rail at the exact point where the defect is located and with an arrow pointing to the defect.

Figure 32. Excerpt from Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår.* Example picture of how to mark a defect that do not spread out along the length of the track. Source: Infranord Mätenheten

Defects that are spread to a limited extent along the length of the track are to be marked with a 'U' around the location of the defect the full height of the rail and with an arrow pointing to the defect.

Defects that are spread out a lot (more than one metre) along the length of the track are to be marked with a vertical line the full height of the rail at either end of the defect, a dashed line on the foot of the rail between the vertical lines and arrows pointed at the defect closest to the vertical lines on either side of the location of the defect.

According to Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår* the kilometre number of the defect is also to be stated in crayon on the web of the rail and 'Gr2' is to be written on the web of the rail for group 2 defects. The Swedish Transport Administration's requirements *TRVINFRA-00015 Banöverbyggnad, Oförstörande provning* does not specify that the kilometre number of the defect has to be given but this is stated in the document that TRVINFRA-00015 replaced.

Figure 33. Excerpt from Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår* about how defects that are spread out a lot are to be marked on the installation. Source: Infranord Mätenheten

According to Sperry Rail's flowchart for ultrasound scans and Infranord Mätenheten's work instruction *Manuell OFP av räler och rälskomponenter i spår*, defects that are verified but which do not meet the criteria for group 1 or 2 are to be marked with a white dot on the outer edge of the rail head.

<u>Most recent inspections of the section of track in question prior to the occurrence</u>

According to data from Sperry Rail, the ultrasound train was run on track N2 between Kummelby and Häggvik most recently prior to the occurrence on 13 March 2020. In other words, eleven months before the derailment. On this occasion, the train registered twelve possible defects between kilometre 12+610 metres and 13+013 metres on track N2, track section 433, that were analysed and registered in Sperry Rail's SDMS system.

Analyzed ID	Run Date	UID	Priority	District	Elr	Track	KM Post	UIC	Suspect State	Verifier	Verified Date
85829	13-Mar-2020	64839	2	LDÖ	433	2N	12 km 610 m	221	Verified Defect		31-Mar-2020
85828	13-Mar-2020	64838	1	LDÖ	433	2N	12 km 685 m	211	Verified Defect		31-Mar-2020
85878	13-Mar-2020	64880	1	LDÖ	433	2N	12 km 687 m	221	Verified Defect		31-Mar-2020
85827	13-Mar-2020	64837	1	LDÖ	433	2N	12 km 691 m	221	Verified Defect		31-Mar-2020
85826	13-Mar-2020	64836	2	LDÖ	433	2N	12 km 755 m	221	Verified Defect		31-Mar-2020
85825	13-Mar-2020	64835	2	LDÖ	433	2N	12 km 841 m	221	Verified Defect		31-Mar-2020
85824	13-Mar-2020	64834	2	LDÖ	433	2N	12 km 894 m	221	Verified Defect		31-Mar-2020
85877	13-Mar-2020	64879	2	LDÖ	433	2N	12 km 912 m	221	Verified Defect		31-Mar-2020
85823	13-Mar-2020	64833	1	LDÖ	433	2N	12 km 920 m	221	Verified Defect		31-Mar-2020
85822	13-Mar-2020	64832	2	LDÖ	433	2N	12 km 935 m	221	Verified Defect		01-Apr-2020
85821	13-Mar-2020	64831	2	LDÖ	433	2N	12 km 939 m	221	Verified Defect		01-Apr-2020
85819	13-Mar-2020	64829	1	LDÖ	433	2N	13 km 13 m	221	Verified Defect		01-Apr-2020

Figure 34. Excerpt showing verified defects from the most recent ultrasound scan of the section of track. Source: Infranord Mätenheten.

The defects were subsequently inspected and verified on 31 March and 1 April by an NDT technician from Infranord Mätenheten. The NDT technician was certified in Ultrasound Level 2 Railway.

When interviewed, the NDT technician has stated that he found the defects with the help of the GPS function that ‘counts down’ on the handheld device. The NDT technician has stated that he is aware that the kilometre information from the ultrasound train is not always entirely accurate. Consequently, he filled in the number of the closest overhead contact line post in the comment field that is available for each defect on the handheld device when he was reporting so that this would make the defects easier to find by those who were to rectify them. He also ‘cached’ the GPS position in the handheld device when registering the defects. However, he did not change any of the kilometre information when reporting.

The NDT technician classified the defects from the train in accordance with the Swedish Transport Administration’s criteria. He then uploaded the information to Sperry Rail’s SMDS system. The defects classified as group 1 or 2 were transferred from Sperry Rail’s system to the Swedish Transport Administration’s Bessy system, which was eleven of the defects. One defect at km 12+755 was verified as a defect belonging to group 3. This is a defect that is so small no action is required. These defects are reported to Sperry Rail’s system but are not then reported to Bessy.

Bessy contains verified remarks registered on 31 March and 1 April 2020 on track N2 at the following kilometre numbers: km 12+610, 12+685, 12+687, 12+691, 12+841, 12+894, 12+912, 12+920, 12+935, 12+939 and 13+13. The remarks are registered as the defect type squat/227[12] (impression in the rail head).

[12] Defect type in accordance with UIC 712 R Rail defects.

Bessy also contains a number of remarks between kilometre 12 and kilometre 12+600 metres from 26 and 30 March 2020, of which the remark at kilometre 12+571 metres is registered as running surface defect/221. Other remarks are registered as squat/227. There is no remark at kilometre 12+719 metres where the nine metre-long broken rail occurred.

The NDT technician who performed the manual verification on 31 March and 1 April has stated that the white paint mark found on the track at the broken rail may have been made by him. He also states that, because the position data from the train is not always exact, the white marking could refer to the defects that he registered in Bessy with the inspection note ‘overhead contact line post 12–13’. According to the Swedish Transport Administration’s track information system BIS, post 12–13 is located at kilometre 12+716 metres. There are between 50 and 60 metres between each post. The NDT technician has stated that he previously had crayons that were not permanent and that may be the reason why no kilometre number is visible by the paint marking on the rail one year later. He has also suggested that the white paint could be from a remark in Bessy from a previous year that has not been rectified.

Three of the verified remarks in Bessy from 31 March have a note in free text that they should be by a overhead contact line post that has the designation 12–13. This is the post that is closest to the site of the broken rail. The following remarks are noted to be by post 12–13.

Km 12+685. Inspection note: Post 12–13 several defects Length: 5000 Depth: 0–15. Remark: Squat/227. Priority: M. Rectification date 16/06/2020. Rectification performed: Replacement.

Km 12+687. Inspection note: Post 12–13 several defects Length: 2000 Depth: 0–15. Remark: Squat/227. Priority: M. Rectification date 16/06/2020. Rectification performed: Replacement.

Km 12+691. Inspection note: Post 12–13 several defects Length: 3000 Depth: 0–15. Remark: Squat/227. Priority: M. Rectification date 16/06/2020. Rectification performed: Replacement.

Data from Sperry Rail indicates that the defect code from the ultrasound train for the remark at kilometre 12+685 metres is 211 (possible transverse defect away from rail end) and the defect code for the remarks at kilometre 12+687 metres and kilometre 12+691 metres is 221 (possible running surface defect away from rail end).

The remarks in Bessy are noted as rectified in June 2020. According to information from Omexom, which carried out remedial actions as a result of the remarks in Bessy, the rail has been replaced from kilometre 12+685 metres to kilometre 12+705 metres. Omexom has stated that they did not inspect locations other than those specified with kilometre numbers in Bessy and rectify the defects that were there. In order to locate the defects, Omexom uses the kilometre numbers specified in

Bessy and the paint markings with kilometre indications on the rail. The numbers of the overhead contact line posts can assist with navigation up to when they begin looking at the track. When interviewed, Omexom stated that GPS data is not provided via Bessy.

Omexom has stated that they had experienced an increased number of NDT remarks within their rectification area and that, for reasons including this, they had written to the Swedish Transport Administration to point this out prior to the occurrence.

After the occurrence, the Swedish Transport Administration and an independent surveyor inspected kilometre 12. The basis used during this inspection was the Bessy remarks from 2020. Notes from the inspection state that the rail has been replaced at kilometre 12+685 metres – kilometre 12+705 metres and at kilometre 12+735 metres – kilometre 12+743 metres.[13] There are remarks from 2020 in Bessy at kilometre 12+685 metres, kilometre 12+687 metres and kilometre 12+691 metres noted as rectified the same year. During the inspection, white markings on the installation were identified at kilometre 12+717 metres, kilometre 12+719 metres and kilometre 12+728 metres that had not remark from 2020 in Bessy. At kilometre 12+737 metres, kilometre 12+739 metres and kilometre 12+740 metres, it states that there is white marking on the installation but that the rail has been replaced. SHK has studied the Bessy remarks from 2018 and subsequently. Bessy contains an NDT remark from 2018 at kilometre 12+733 metres. The remark is classified as squat/227, with the following comment: *Post 12–13 several defects Length: 2500 Depth: 0–10*. The remark is registered as rectified through the replacement of the rail.

During the inspection, the Swedish Transport Administration noted that there were white markings at kilometres 12+886–12+888. In Bessy, there is a remark from 2020 on kilometre 12+894 about several defects on a distance of 20 meters noted as rectified through replacement of the rail. According to the inspection notes, however, the rail was only replaced from kilometre 12+894–12+903. Furthermore, it was noted during the inspection that there were remaining white markings at kilometres 12+923–12+931. In Bessy there is a remark from 2020 on kilometre 12+920 about several defects on a distance of 30 meters noted as rectified through the replacement of rail. According to the inspection notes, rails were only changed on kilometres 12+912–12+922. According to the Swedish Transport Administration, Omexom has stated that the defects have been rectified with partial replacement of rail, partial welding. Due to the above, the Swedish Transport Administration has requested an action plan for updated feedback routines that more clearly describes the contractor's actual performed measures in the facility.

Sperry Rail has at the request of SHK gone through indications of minor defects that are saved in Sperry Rail's system but which had not been

[13] The inspection documentation reports details for kilometre 12+130 metres – kilometre 13+030 metres. SHK has chosen to report the details closest to kilometre 12+719 metres.

reported to the Transport Administration. Sperry Rail's data contains measurement train indications of 'squat type' defects under the limit for reporting to the Swedish Transport Administration at kilometre 12+712 metres (see Figure 35). The indications showed a 30 mm longitudinal crack but no transverse crack. The limit for reporting to the Swedish Transport Administration was 100 mm longitudinal indications or indications with a depth of 10 mm.

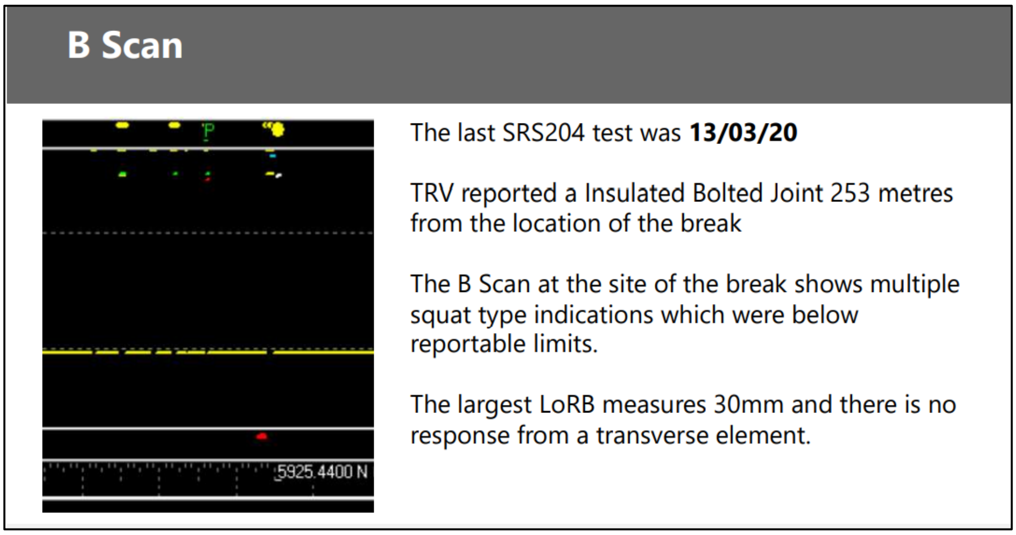

Figure 35. Sperry Rail's data shows that there were indications of minor defects that did not reach the limit for reporting to the Swedish Transport Administration at kilometre 12+712 metres. Source: Sperry Rail.

<u>Safety descriptions</u>

In addition to rectifying NDT defects, Omexom also conducts safety inspections of the track infrastructure on behalf of the Swedish Transport Administration. This assignment includes both inspections and rectification when necessary. The safety inspection is conducted through visual inspection of the installation. The inspection includes checks of the rails, sleepers, fencing and drainage. The section of track in question is subject to safety inspection three times per year. The most recent safety inspection prior to the occurrence took place on 26 October 2020.

Bessy contains no safety inspection remarks in respect of rails at kilometre 12 from 26 October 2020. There is one remark about 'head checks' (surface cracks in the running edge) at kilometre 13+40 metres to kilometre 13+70 metres. The remark is listed as rectified on 4 November 2020. From the previous safety inspection on 17 June 2020, there is a remark at kilometre 12+840 metres to kilometre 12+865 metres about 25 metres of worn-out rail that needs to be replaced between NDT defects. The remark is listed as rectified on 11 September 2020.

Omexom did not check the NDT remarks during the safety inspection. Omexom has stated that there was no requirement to check the NDT remarks during safety inspections. Consequently, Omexom has conducted safety inspection on the basis that NDT remarks are dealt with separately within the NDT process.

The Swedish Transport Administration has referred to the fact that TDOK 2014:0240 states, under the heading *Rail*, that a list of remaining rail defects (defect group 2) in accordance with the ultrasound report shall be included when conducting a visual inspection. TDOK 2014:0240 also states that a visual inspection should include checking that no circumstances that may lead to a broken rail or derailment can be observed. According to the interviewed project manager for maintenance at the Swedish Transport Administration, the latter text is broad and is possible to interpret as meaning that group 1 rail defects are a circumstance that could lead to broken rails and shall therefore be checked. Following the occurrence, the Swedish Transport Administration has drawn attention to the fact that the text allows for different interpretations.

After the occurrence, Omexom has made it a procedure to take an extract from Bessy showing NDT remarks along when conducting safety inspections. The purpose is to check that visual damage that is marked with paint is registered in Bessy and – if not – register these in Bessy with a comment that an unregistered defects was detected during a safety inspection. However, Omexom does not check paint markings without visible defects during the safety inspection. Omexom has stated that checking such paint markings is not included in the contract between Omexom and the Swedish Transport Administration.

Preventive machining (grinding) of rails

One of the maintenance activities that the Swedish Transport Administration conducts in order to prevent surface fatigue is grinding of rail. The interval for rail grinding is based on the type of steel, axle load, annual gross tonnage and curve radius.

The Swedish Transport Administration's Advice concerning requirement *TRVINFRA-00016 Banöverbyggnad Svetsning, bearbetning och smörjning*, which is part of the Transport Administration's infrastructure regulations, states that preventive grinding shall be conducted mechanically using a grinding train on newly laid lengths of rail of over 120 metres or new points so that points 1–3 are fulfilled:

1. takes place within one year of laying.
2. takes place before five million gross tonnes has passed after laying.
3. national contract for rail processing is being utilised.

TRVINFRA-00016 states that maintenance grinding shall be conducted mechanically using a grinding train on rails and switches at an interval such that either of points 1 or 2 is fulfilled:

1. takes place where the traffic is ≥ 5 MGT/year.
2. takes place where the Swedish Transport Administration has identified a need.

According to *TRVINFRA-00016*, corrective grinding shall be conducted mechanically using a grinding train on rails and points where damage or defects on the rail are more extensive than is possible to rectify using maintenance grinding.

According to the Swedish Transport Administration, the requirements regarding grinding have developed over the years. The Swedish Transport Administration has not found any information that the current requirements in TRVINFRA-00016 were developed as early as 1993, when the rails were laid on the relevant section. During the 1990s, rails were ground only against grooves and waves. The then Swedish Rail Administration introduced grinding against surface damage after a visit to the Transportation Technology Center (TTCI) in the USA in November 1995. After this meeting, regional guidelines for such grinding were introduced sometime in 1996, starting on the “Malmbanan”. After that, the grinding regarding surface damage/fatigue began as from 1997 onwards.

It is the Swedish Transport Administration’s assessment that it is likely that grinding regarding surface damage/fatigue began in 2002 or 2003 on the section of track in question. The first documented grind took place in 2006. After this the rail has been machined in 2006, 2014 and 2017. According to the Swedish Transport Administration, the grinding has not taken place entirely consistently with the intervals specified in *TRVINFRA-00016*. A grind was planned for 2019 but this did not take place. According to the Swedish Transport Administration, it is not documented why the grind did not take place but the likely cause given are that other maintenance actions were prioritised that year or there were logistical reasons that led to the measure being delayed.

4. ANALYSIS OF THE OCCURRENCE

This section is an overall analysis of roles and duties, rolling stock and technical installations, human factors and feedback and control mechanisms, including risk and safety management as well as monitoring processes[14].

Why did the train derail?

During the investigation, SHK has initially established that the signalling and traffic control system has functioned normally and that the train has been driven in a normal way. The log from the train's recording equipment shows that the driver has braked gently as a result of a descending gradient just before the derailment took place. No vehicle fault that could have caused the derailment has been identified.

It was identified during the examination of the accident site that nine metres of rail were missing from the rail on the right in the direction of travel between Helenelund and Sollentuna commuter train stations. The rail was broken apart into more than 20 larger and smaller pieces. Upon examination of these pieces, SHK identified signs of preceding crack formation in the majority of the rail head at the fracture surface that comes first in the direction of travel. The pieces of rail that were found by the broken rail were brought by SHK for further examination.

The result of the investigation has shown that the broken rail was caused by fatigue in the rail. Surface fatigue cracks and parallel cracks under the running surface have been identified along the whole of the examined rail. At the primary fracture surface, a large number of parallel cracks have initiated a vertical crack that led to the broken rail. The direction of propagation of surface, parallel and vertical cracks can be attributed to normal loads that arise between train and rail. Dark spots on the right but not the left rail in the freight train's direction of travel may indicate that the right rail is subjected to greater pressure and friction loads. The rail with dark spots is the outer rail in the curve and the majority of trains pass in the opposite direction while accelerating out of Sollentuna commuter station. All overload fractures have brittle character. All of the fractures have probably taken place during the passage of the freight train on the night of 10 and 11 February 2021.

SHK has obtained information from D-Rail AB, a company that, as part of a pilot project, had measuring equipment mounted on commuter trains that passed the section of track in question prior to the derailment. According to D-Rail AB, measurement data that they have studied following the derailment has shown a discrepancy in the form of difference in height between the rails on the day before the derailment. The position of the discrepancy is given by D-Rail AB as close to the site of the broken rail and was present for the first time on 10 February

[14] These points are included in the reporting structure that applies by virtue of Commission Implementing Regulation (EU) 2020/572 of 24 April 2020 on the reporting structure to be followed for railway accident and incident investigation reports. The composition of the headings here has been adapted to the type and extent of the accident.

at 16:19 hrs and then on 11 February at 00:07 hrs. Subject to uncertainties in, inter alia, the position data, the discrepancy could be an indication that a fracture in the rail was present earlier on the evening prior to the passage of the freight train. In which case, the fracture would have developed during the passage of the freight train.

The examination has shown that the values for the rail in respect of hardness, fracture toughness, chemical composition and mechanical properties are within specified intervals in accordance with the European standard *EN_13674-1 Railway applications - Track - Rail - Part 1: Vignole railway rails 46 kg/m and above*. The European standard applies as a Swedish standard and is referred to in *Commission Regulation (EU) No 1299/2014 of 18 November 2014 on the technical specifications for interoperability relating to the 'infrastructure' subsystem of the rail system in the European Union*. The examination has also shown that the rail material R260 is sensitive to surface fatigue when the rail is exposed to high pressure and friction loads. The extent of the cracks in the rail head suggest a long operating time during which the cracks have been allowed to propagate from surface cracks to parallel cracks and finally to the vertical crack. Since the fracture surfaces are worn and corroded, it has been difficult to quantify how long the operating time has been. It is considered reasonable to assume a period of several years where the crack has gone through the various phases from surface crack to vertical crack.

Why was the crack formation not detected?

Given the fact that the cracks suggest a long operating time, SHK has investigated what action has been taken by the infrastructure manager in order to prevent and detect crack formation in the rail. To prevent surface fatigue, the Swedish Transport Administration conducts preventive machining of the rail, non-destructive testing (NDT) using ultrasound scans and visual inspections of the rail.

<u>Preventive machining of rails</u>

One of the maintenance activities that the Swedish Transport Administration conducts in order to prevent surface fatigue is preventive machining of the rail. On the section of track in question, machining was conducted using grinding. The interval for machining was determined on the basis of a number of parameters including the gross tonnage run over a section of track. It emerged during the investigation that there had been departures from the interval that had been decided for the section of track in question. The rail should have been ground in 2019 but was last ground in 2017. Before this, the rail was ground in 2014 and 2006. According to the Swedish Transport Administration, it is not documented why there was a departure from the planned interval but probable reasons given are reprioritisation within the maintenance budget that year or that the grinding has been postponed for logistical reasons.

As a result of the lack of documentation of the Swedish Transport Administration's decision to depart from the planned interval for grinding, it is difficult to come to any conclusions about whether the decision was based on an assessment of whether this would have an impact on the growth of cracks in the rail and, by extension, on safety. The planned interval was based on how many gross tonne kilometres the Swedish Transport Administration deemed the rail may be exposed to before machining is appropriate. It is SHK's opinion that, for a departure from the planned interval to be permitted, an analysis of the consequences of this should first be conducted. Such an analysis should be a part of the infrastructure manager's risk management.

To be effective, machining needs to be done before cracks have grown. According to the Swedish Transport Administration, the rules and knowledge about machining have developed over the years. In this case, the rail was laid in 1993 and the first grinding regarding surface fatigue/surface damage was according to the Swedish Transport Administration probably done in 2002 or 2003. The first documented grind took place in 2006. The next grind was then put off until 2014 and subsequently in 2017. It appears that the long intervals between grinding have provided a potential growth period during which parallel cracks may have emerged.

As far as SHK has understood, the machining that did not take place has not been compensated for with any other action such as more frequent NDT inspections. The Swedish Transport Administration has stated that a review of the strategy for machining has been taking place since 2020 for reasons including the impact of multiple units on rails.

One consequence of a planned frequency not being adhered to is that it makes a full evaluation of the interval itself more difficult. Consequently, there may be grounds for the Swedish Transport Administration to analyse and document what consequences departures from a planned grinding interval may have on crack growth.

<u>Ultrasound scans to detect defects and damage</u>

The aim of NDT using ultrasound scans is to detect defects and damage in rails and components at an early stage and thus avoid fractures. Ultrasound scans using an ultrasound train were being performed at the time of the occurrence by Sperry Rail on behalf of the Swedish Transport Administration once per year on the section of track in question, most recently eleven months prior to the occurrence. The results from the ultrasound train were checked and verified by a certified NDT technician from Infranord Mätenheten. The technician then reported data to Sperry Rail, who analysed and processed them before they were reported to the Swedish Transport Administration's Bessy system. Omexom rectified verified NDT defects on behalf of the Swedish Transport Administration. Omexom retrieved information about which remarks needed to be rectified from Bessy.

The investigation has shown that there was no remark from the most recent NDT inspection, which was conducted in March 2020, registered in Bessy at the kilometre indication where the rail broke, kilometre 12+719 metres. Nor was there any remaining remark from previous NDT inspections at this kilometre indication. However, there were a large number of other remarks about NDT defects on other parts of track N2, kilometre 12.

At the same time, there was the paint markings on pieces from the broken rail at kilometre 12+719 metres of the type that, according to the Swedish Transport Administration, is only used when marking NDT defects in conjunction with verification of indications from the ultrasound train. However, there was no kilometre indication drawn on the rail, which, according to Infranord Mätenheten's work instruction, has to be written on the rail when marking verified NDT defects.

This raises questions of the type: Why was there no remark in Bessy when there was NDT paint on the rail? Had an NDT defect been identified at this location prior to the derailment that was marked out with paint on the rail but not registered in Bessy? Had an NDT defect been identified and marked out on the rail but registered at a different kilometre indication in Bessy? Or had the paint been added on another occasion?

At the request of SHK, Sperry Rail has reviewed their database, which contains all measurement data from the ultrasound train, i.e. more extensive data than the selection that is reported to the Swedish Transport Administration. During this review, Sperry Rail has found indications of a defect at kilometre 12+712 metres. However, these indications are well under the limit for what has to be reported to the Swedish Transport Administration. According to the Swedish Transport Administration, these limits, a crack depth of 10 mm or a 100 mm longitudinal crack, are based on technical reasons relating to measurements and rectification times. In terms of measurement, there are limitations in the potential to detect a small crack and in terms of rectification times, there is a desire to avoid including a large number of defects that require resources to inspect but which do not entail any risks from a traffic safety perspective.

In other words, it can be established that there was no indication from the train of a defect over the limit for reporting at kilometre 12+719 metres. It is possible for NDT technicians who are verifying indications from the ultrasound train to add a defect if they detect one in the infrastructure that is not included among the indications from the train. No such defect has been reported. The question remains of whether the paint markings on the rail might refer to another registered remark in Bessy?

The NDT technician who inspected and verified the indications from the ultrasound train in March 2020 has stated that the paint marking on the rail where the rail is broken could have been made by him and belong to one of the defects that he verified. He has stated that he filled in the number on the overhead contact line post that was closest to the defect he verified. He did this because the kilometre data from the ultrasound train is not exact. However, he did not change the kilometre number in his handheld device when reporting, which should be done according to Infranord Mätenheten's work instruction. According to the NDT technician, the paint marking could refer to the defect at kilometre 12+691 metres that he commented on with post 12–13. He has referred to the fact that the marking from the crayon he previously used to draw on kilometre numbers may have worn off since it was drawn on.

There are a large number of remarks registered in Bessy at kilometre 12 from the verification in March 2020. Three of the remarks have the comment *post 12–13 several defects*, the closest of which to the accident site has the kilometre indication 12+691 metres. The comment for this remark gives the length of the defect as three metres. As mentioned, the rail was replaced from kilometre 12+685 metres to kilometre 12+705 metres in June 2020. Omexom has stated that the replacement was conducted as a result of remarks in Bessy at kilometre 12+685 metres, kilometre 12+687 metres and kilometre 12+691 metres. The replacement of rail at these metres is also confirmed by the Swedish Transport Administration's inspection following the occurrence.

Omexom has stated that, if they identify a defect in Bessy out in the track infrastructure, they do not search for additional defect markings that are not in Bessy. Should they fail to find a defect at the position specified in Bessy, they do however look in the vicinity of the specified position.

Given that the kilometre indication from the ultrasound train may differ by a number of metres, SHK has also studied the GPS data that is registered for the verified defects. There are GPS positions saved in the ultrasound train's measurement data and GPS positions are also saved when the NDT technician verifies a defect. The GPS positions that are registered during the verification of defects are reported via Sperry Rail and then to Bessy.

In Figure 36, SHK has marked the location of the primary fracture (1) and the closest overhead line post (2), as well as other relevant positions based on GPS data. The figure shows the closest NDT remark according to Bessy, kilometre indication 12+691 metres, based, on the one hand, on the ultrasound train's GPS position (4) and, on the other, based on the GPS position (5) that the NDT technician verified. The figure also shows the position (3) of the indication that was in Sperry Rail's data about a defect that was below the limit for reporting.

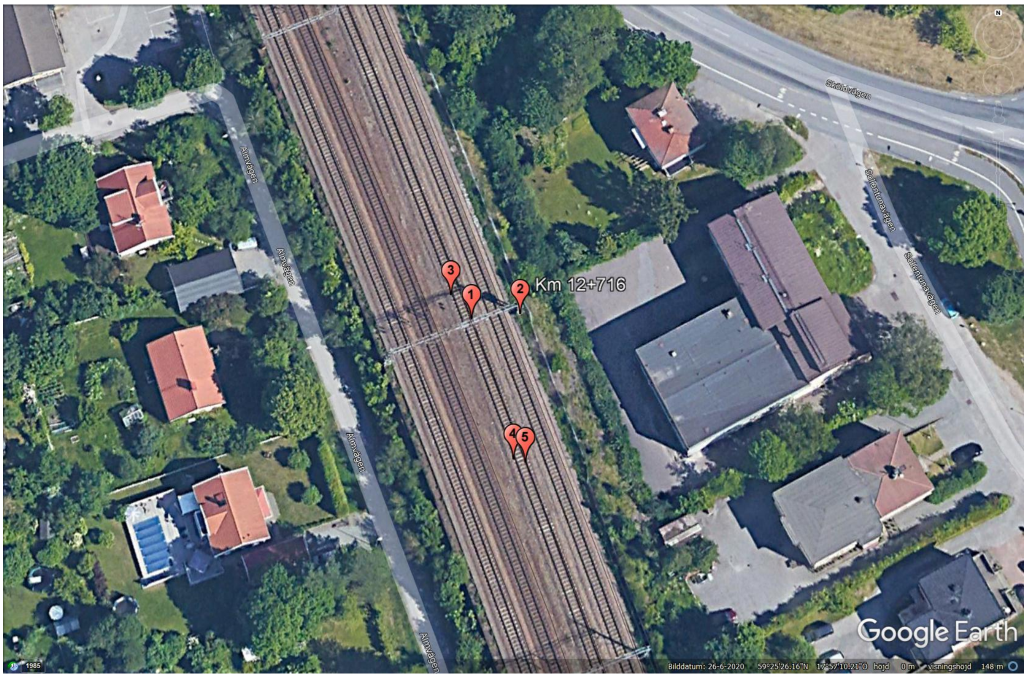

Figure 36. Positions of primary fractures (1), post 12–13 (2), remark that does not fulfil the criterion for remarks that have to be reported to Bessy (3), closest NDT remark from the ultrasound train that fulfils the reporting criterion (4), closest NDT remark according to verification/Bessy (5). Image from Google Earth, https://earth.google.com/web/@59.42396596,17.95280292,29.53804661a,143.61087405d,35y,0h,23.59401692t,360r?utm_source=earth7&utm_campaign=vine&hl=sv, with position markings added by SHK.

Based on the review of GPS data, it can be established that the GPS position verified by the NDT technician for kilometre 12+691 metres is consistent with the GPS position from the ultrasound train. It is also not unusual for positions to differ slightly from each other because the position indication is affected by where the NDT technician is when they register a defect as verified. It is SHK's assessment that the GPS data do not suggest that it is the site of the broken rail that was being referred to when verifying the defect that is listed in Bessy as having the position kilometre 12+691 metres.

One possible scenario is that the paint marking at kilometre 12+719 metres was intended as part of the remark at kilometre 12+691 metres with the designation *several defects.* However, the extent of the defects at kilometre 12+691 metres is specified as three metres in Bessy, while the paint marking at kilometre 12+719 metres was c. 30 metres further away.

Furthermore, the NDT technician has stated that the paint could come from a remark from a previous year that has not been rectified despite the remark being noted as rectified in Bessy.

SHK has studied excerpts from Bessy covering the period 2018–2020. There is an NDT remark in Bessy from 2018 with the note *several defects, 2.5 metres* at kilometre 12+733 metres. In other words, 14 metres from the primary fracture. The remark is registered as rectified through the replacement of the rail. An inspection report by an independent surveyor engaged by the Swedish Transport Administration following the derailment states that rail was replaced on kilometre 12+685–12+705 and kilometre 12+735–12+743. Furthermore, the inspection report states that paint marking is present, including at kilometre 12+728 metres that does not have a remark in Bessy from 2020. Only remarks from 2020 were used for comparison.

The inspection report also states that white paint was found, including at kilometre 12+737 metres, despite it having been established that the rail was replaced between kilometre 12+735 metres and 12+743 metres. The inspection report also lists a large number of other places at kilometre 12 where there are white paint markings but no remark in Bessy from 2020. During the inspection, the Swedish Transport Administration also found paint markings at kilometres 12+886–12+888 and kilometres 12+923–12+931 which according to the Swedish Transport Administration were among the remarks reported in Bessy which were rectified by replacement of rail. According to the Swedish Transport Administration, the contractor has stated that the faults have been rectified with partial rail replacement, partial welding. Due to the above, the Swedish Transport Administration has requested an action plan for updated feedback routines that more clearly describes the contractor's actual performed measures in the facility. At the time of the occurrence, the Swedish Transport Administration normally followed up rectification by checking in Bessy that the defects were noted as rectified. Following the occurrence, the Swedish Transport Administration has decided to follow up all rectification of NDT defects on site in the track infrastructure, not just via the system.

The list of indications from the ultrasound train that were verified by the NDT technician also included an indication of a defect at kilometre 12+755 metres. The defects is noted as a ‘3’, which Sperry Rail says means that it has not fulfilled the Swedish Transport Administration’s reporting requirements. The aforementioned inspection report contains a note about white paint at kilometre 12+760 metres that is not included in the Bessy remarks from 2020.

In summary, it can be established that, on its most recent run preceding the occurrence, the ultrasound train did not register at the site of the broken rail any defect that fulfil the criteria for a defect that has to be reported. However, smaller indications have been registered close to the site eleven months prior to the occurrence. Because the indications that the ultrasound train has registered on the rail at the site were not sufficiently large to be reported in the system for ultrasound scans, no action has been taken. SHK has not been able to determine why there was still OFP paint on pieces from the rail break. A possible explanation may be that the paint was added in connection with verification of other defects on the section but not reported in such a way that the colour-marked place became the subject of action.

Regardless of why the colour was added, it can be stated that the ultrasonic train did not register any indication of defect sufficiently large to be reported. The Swedish Transport Administration has stated that the Transport Administration, in cooperation with other infrastructure managers in Europe and operators that run ultrasound trains, is working to develop methods that allow defects to be detected at an earlier stage. One challenge presented by this work is finding a way to raise the alarm about the right defects without generating a large number of false alarms. Another challenge is that vertical cracks can be hidden under parallel cracks during ultrasound examination.

At the time of the occurrence, the ultrasound train was being run once a year on the section of track in question. Sperry Rail, which had the task of running the train, has stated that the interval applied differs between their different customers, with the highest frequency being eight weeks. According to the Swedish Transport Administration, it is primarily England that applied eight weeks because of specific problems they had with broken rails. According to the Swedish Transport Administration, the interval applied by the Transport Administration on this section of track is a common frequency in Europe. If the Swedish Transport Administration receives indications of problems on a section of track, e.g. an increased number of NDT remarks, a risk analysis can be initiated. Following the derailment in Häggvik, the Swedish Transport Administration conducted a risk analysis in which a number of risks associated with NDT remarks were analysed. This analysis resulted in the ultrasound train being run twice a year for a two-year period within the area in which the derailment occurred. It is the opinion of SHK that there may be reason for the Swedish Transport Administration to analyse whether there may also be other areas where a shorter interval may be justified.

Prior to the occurrence, Omexom wrote to the Swedish Transport Administration about an increased number of NDT remarks within their area of responsibility. At this stage, this did not lead to any risk analysis by the Swedish Transport Administration, as far as SHK is aware. The occurrence indicates that there may be grounds for the Swedish Transport Administration to revise how changes in the number of reported remarks are followed up. There may also be reason to investigate further why the number of NDT remarks has increased.

Location of defects

It is important to the location and rectification of defects that may lead to accidents that the position data are correct and processed in a consistent way. As has emerged, the NDT technician has stated that the kilometre information is rarely correct and he therefore filled in the number of the nearest contact overhead line post in the comment field in Bessy. However, he did not change the kilometre indication of the report despite this being technically possible. At the same time, Omexom has stated that they work on the basis of the kilometre number. They can use the kilometre post number for initial navigation to the site, but they then work on the basis of the kilometre indication. According to SHK, this presents an obvious risk of implicit information being lost; that what the NDT technician means to do by writing the number of the post is to replace the kilometre indication, is not obvious to the recipient of the information. The NDT technician has stated that Omexom usually gets in touch if there are any questions about reported information or difficulties locating defects but that they did not do so in this case. It has emerged during the investigation that the GPS data in Bessy were not used by Omexom to help them locate the defects during rectification. There appears to be a potential to develop a more consistent use of position data. There may be grounds here for the Swedish Transport Administration, together with its contractors, to review how position data are currently being reported and used in practice, to establish why any discrepancies occur and how it can be ensured that information is not lost along the way.

Safety inspection

One further occasion when damage to the rail can be detected is during the visual inspection that is performed as a safety inspection three times per year. Omexom, which also had this assignment, has stated that the inspection staff did not observe any discrepancy during the most recent safety inspection of kilometre 12, which took place in October 2020. Nor does Bessy contain any safety inspection remarks in respect of rails from the most recent safety inspection. From the previous safety inspection on 17 June 2020, there is a remark at kilometre 12+840 metres to kilometre 12+865 metres about 25 metres of worn-out rail that needs to be replaced between NDT defects. The remark is listed as rectified on 11 September 2020. It has been established that rail was replaced in several sections of kilometre 12.

The surface defects and dark spots identified on the rail after the derailment should have been visible at the visual inspection in October 2020. Omexom did not check the NDT remarks during the safety inspection. At the time of the safety inspections, Omexom did not check NDT remarks in conjunction with these. Omexom has stated that there was no requirement to check the NDT remarks during safety inspections. Consequently, Omexom has worked on the basis that NDT remarks are dealt with separately within the NDT process.

The Swedish Transport Administration has referred to the fact that the Transport Administration’s requirement document TDOK 2014:0240 states, under the heading *Rail*, that a list of remaining rail defects (defect group 2) in accordance with the ultrasound report shall be included when conducting a visual inspection. TDOK 2014:0240 also states that a visual inspection should include checking that no circumstances that may lead to a broken rail or derailment can be observed. Following the occurrence, the Swedish Transport Administration has drawn attention to the fact that the text allows for different interpretations.

After the occurrence, Omexom has made it a procedure to take an extract from Bessy showing NDT remarks along when conducting safety inspections. The purpose is to check that visual damage that is marked with paint is registered in Bessy and – if not – register these in

Bessy with a comment that an unregistered defect was detected during a safety inspection. However, Omexom does not check paint markings without visible defects during the safety inspection. Omexom has stated that checking such paint markings is not included in the contract between Omexom and the Swedish Transport Administration.

According to SHK, there may be grounds for the Swedish Transport Administration to clarify what inspections in respect of NDT remarks that shall and can be done during a safety inspection. Furthermore, there may be grounds for the Swedish Transport Administration, together with the contractors concerned, to review the consistency between the paint markings on the track and registrations in Bessy and, from a broader perspective, follow up how reporting and marking takes place in practice.

Previous occurrences of a similar nature

SHK has not previously investigated any similar occurrences.

5. CONCLUSIONS

a) Conclusions with regard to the causes of the occurrence

The derailment was caused by rail fatigue which, following a long loading period, propagated into a vertical crack and caused a broken rail.

Crack formation had not been identified or dealt with as part of the infrastructure manager's system for preventive maintenance.

b) Measures taken since the occurrence

- The Swedish Transport Administration has decided to follow up all rectification of NDT defects on site in the installation, not just via the system.
- The Swedish Transport Administration has requested action plans from the contractor concerned regarding improved feedback procedures and better documentation of rectification that takes place of the installation.
- The Swedish Transport Administration has reviewed how the safety inspection is conducted with the staff responsible for inspections at the contractors concerned.
- The Swedish Transport Administration has initiated a risk analysis of risks associated with NDT remarks.

- The Swedish Transport Administration has decided that NDT measurement shall take place twice per year in the area in question for the next two years.
- Omexom has made it standard procedure to also check visible NDT remarks when conducting safety inspections.
- Omexom has made it standard procedure to paint over white paint when a defect is rectified.

c) Other observations

None.

d) Findings

a) The driver had the requisite qualifications.
b) The train was driven normally.
c) The signalling and traffic control system has functioned normally.
d) No vehicle fault that could have caused the derailment has been identified.
e) It was identified during the examination of the accident site that nine metres of rail were missing from the rail on the right in the direction of travel on track N2 between Kummelby and Häggvik.
f) There were signs of preceding crack formation in the majority of the rail head at the fracture surface that comes first in the direction of travel.
g) The examination of materials has shown the broken rail was caused by fatigue in the rail.
h) The rail was last machined (ground) in 2017. Machining was planned for 2019 but this did not take place.
i) The results from the passage of the ultrasound train eleven months before the occurrence did not show any defect at the site of the primary fracture that reached the reporting limit.
j) The results from the ultrasound train eleven months before the occurrence showed several other defects at kilometre 12.
k) The results from the ultrasound train were checked and verified by a qualified NDT technician.
l) A large number of remarks at kilometre 12 were verified and rectified in June 2020.
m) The results from the ultrasound train eleven months before the occurrence showed an indication of a defect below the reporting limit at the site of the primary fracture.
n) Pieces of the broken rail were marked with paint of the same type that is normally used during NDT verification.
o) At the safety inspection 3.5 months before the derailment, the contractor who carried out the inspection assumed that NDT remarks were handled separately.

6. SAFETY RECOMMENDATIONS

The Swedish Transport Administration is recommended to:

- Continue the development work it is doing to enable crack formation in rail to be identified at an earlier stage. (See section 4) *(RJ 2022:02 R1)*

- From a comprehensive perspective, review how current systems for preventing surface fatigue leading to broken rails can be improved. This review should include evaluating the intervals applied for non-destructive testing, follow-up of how defects are located, reported and marked out in practice and an analysis of the potential consequences of departing from the set interval for preventive machining. (See section 4) *(RJ 2022:02 R2)*

The Swedish Transport Agency is recommended to:

- Within the scope of its supervision, follow up the action taken by the Swedish Transport Administration as a result of recommendation RJ 2022:02 R1 and RJ 2022:02 R2. (See section 4). *(RJ 2022:02 R3)*

The Swedish Accident Investigation Authority respectfully requests to receive, **by 5 September 2022 at the latest**, information regarding measures taken in response to the recommendations included in this report.

On behalf of the Swedish Accident Investigation Authority,

Jenny Ferm Eva-Lotta Högberg