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Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY REPORT
Rail Occurrence Investigation RO-2008-005
Final

Derailment of Train 5PS6
Bates, South Australia

19 April 2008

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Abstract

At approximately 0650 on 19 April 2008, freight train 5PS6, travelling from Perth to Sydney, derailed near Bates, SA. The derailment occurred about 13 track kilometres east of Bates. Thirteen wagons were derailed and about 800 m of track was damaged. There were no injuries.

The investigation concluded that an undetected crack at an unused bolt-hole increased in size until the rail completely fractured. The rail probably failed under the previous train (5MP5). As the wheels of train 5PS6 passed over the fracture, the impact forces caused the progressive failure of sleepers, a secondary rail fracture and the ejection of a small section of rail. Once a section of rail was missing, the impact forces on the rail increased significantly, causing the progressive failure of rail and sleepers until the freight wagons inevitably derailed.

The investigation acknowledged that new maintenance procedures were issued to reduce the risks related to bolt-hole cracks. However, the Australian Transport Safety Bureau has issued two safety advisory notices, concluding that there were further opportunities for improvement relating to:

- additional development of the ultrasonic testing process aimed at reducing operator dependence
- the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory Agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

Purpose of safety investigations

The object of a safety investigation is to enhance safety. To reduce safety-related risk, ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated.

It is not a function of the ATSB to apportion blame or determine liability. However, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

Developing safety action

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to proactively initiate safety action rather than release formal recommendations. However, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation, a recommendation may be issued either during or at the end of an investigation.

When safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation, the person, organisation or agency must provide a written response within 90 days. That response must indicate whether the person, organisation or agency accepts the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

Safety factor: an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (e.g. engine failure, signal passed at danger, grounding), individual actions (e.g. errors and violations), local conditions, risk controls and organisational influences.

Contributing safety factor: a safety factor that, if it had not occurred or existed at the relevant time, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

Other safety factor: a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report.

Other key finding: any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which 'saved the day' or played an important role in reducing the risk associated with an occurrence.

Safety issue: a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

Safety issues can broadly be classified in terms of their level of risk as follows:

- Critical safety issue: associated with an intolerable level of risk.
- Significant safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable.
- Minor safety issue: associated with a broadly acceptable level of risk.

EXECUTIVE SUMMARY

At approximately 0650[1] on 19 April 2008, freight train 5PS6, travelling from Perth to Sydney, derailed near Bates, SA. The track at the derailment site was owned and operated by the Australian Rail Track Corporation (ARTC) while the train was owned and operated by Pacific National (PN).

Train 5PS6 consisted of two locomotives (NR90 and NR51) hauling 44 wagons (15 of which were multiple-unit wagons). The train was 1770 m long and weighed a total of 3886 t. The posted track speed through the curve where train 5PS6 derailed was 80 km/h. There were no temporary speed restrictions in force at the time.

Freight train 5PS6 was about 13 km east of Bates, travelling at about 80 km/h, when the locomotive drivers recalled hearing 'crack, crack, crack' as though the locomotive wheels had passed over a broken rail. The driver eased off the throttle before noticing a reduction of brake pipe pressure, indicating that brake pipe air was exhausting to the atmosphere and the train brakes would begin to apply. Train 5PS6 came to a stop and upon further examination, the drivers discovered the train had derailed and a significant portion of track had been destroyed. The drivers contacted the ARTC train controller to advise that train 5PS6 had derailed and two derailed wagons were carrying dangerous goods (resin solution and various chemicals). Consequently, an exclusion zone was placed around the derailment site until an appropriate assessment could be conducted by hazardous materials assessors.

An investigation team from the Australian Transport Safety Bureau (ATSB) was dispatched to investigate the derailment. Initial observations indicated that the derailment may have been the result of a broken rail. The fractured section of rail contained a welded joint between two sets of three bolt-holes, originally drilled to allow joining of the rail using bolted fishplates[2]. The sections of rail containing the fractured surfaces were recovered for detailed examination.

The ATSB conducted a metallurgical examination of the rail samples and found three distinct regions in the fracture surface. It was evident that a crack, consistent with high cycle fatigue cracking, had existed in the web of the rail for some time. The crack was almost 20 mm in length, started at a bolt-hole and radiated out towards the welded rail joint. The second phase of cracking, which extended to the start of the weld, appeared to have occurred over a relatively short period of time and was consistent with a progressive overload or low cycle fatigue. The final fracture extended through the weld and the rail head to the outer surface of the rail.

Metallurgical examination also found that the microstructural transition between the weld heat affected zone and the original metal, coincided with the fatigue origin at the bolt-hole. This transition was likely to have acted as a localised stress concentrator at the bolt-hole. However, the ARTC Code of Practice, at the time, did not recognise the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding.

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1 The 24-hour clock is used in this report to describe the local time of day, Central Standard Time (CST), as particular events occurred

2 Fishplates are steel plates normally used in pairs for supporting and joining two rail ends together. The joint is commonly referred to as a mechanical joint.

To assist in identifying the fracture behaviour of rail, the ATSB engaged technical experts in fracture mechanics to conduct theoretical finite element, crack initiation and crack growth analysis. This analysis, supported by the findings of this investigation and similar incidents, concluded that any crack (at a bolt-hole in the web of a rail) is likely to increase in size until inevitable failure under cyclic loading typical of actual rail traffic. However, the ARTC Code of Practice did not categorise bolt-hole cracks as defects requiring action unless they exceeded 20 mm in length.

Continuous ultrasonic testing had been conducted in the area of the derailment three days before the derailment of train 5PS6. Examination of the data recorded by the ultrasonic test vehicle showed an echo pattern that was consistent with the initial fatigue crack at the bolt-hole. However, no suspected bolt-hole defects were reported by the test vehicle operator in the vicinity of the point where train 5PS6 derailed. The test vehicle operator did not recall seeing this particular echo pattern on the day, but advised that he would 'probably' have flagged it for closer examination had he noticed the pattern recorded by the test equipment. Had it been flagged for closer examination, it was still possible that the potential crack may not have been categorised as a defect since its measured size may have been assessed as below the 20 mm response threshold stipulated in the ARTC Code of Practice.

The investigation concluded that an undetected bolt-hole crack increased in size until the rail completely fractured, probably under the previous west-bound train 5MP5. As the wheels of east-bound train 5PS6 passed over the fracture, the impact forces caused the progressive failure of sleepers, a secondary rail fracture and the ejection of a small section of rail. Once a section of rail was missing, the impact forces on the rail increased significantly, causing the progressive failure of rail and sleepers until freight wagons inevitably derailed.

The investigation noted that the ARTC issued a new instruction in December 2008 specifying bolt-hole crack limits. Under this instruction, all bolt-hole cracks are recorded as defects and require removal, irrespective of the crack size. Similarly, Rail Technology International (RTI) has been actively conducting further development of their ultrasonic testing process to reduce the reliance on the operator to observe and react to specific data patterns.

The investigation acknowledged that new maintenance procedures were issued to reduce the risks related to bolt-hole cracks. However, the Australian Transport Safety Bureau has issued two safety advisory notices, concluding that there were further opportunities for improvement relating to:

- additional development of the ultrasonic testing process aimed at reducing operator dependence
- the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding.

1 FACTUAL INFORMATION

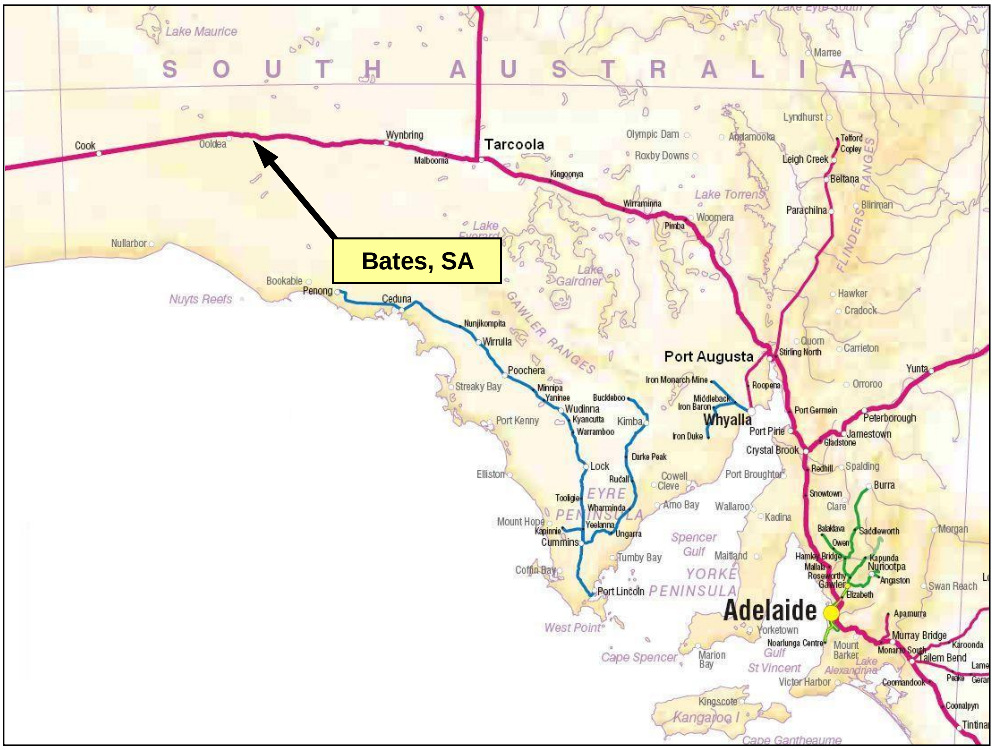
1.1 Overview

At approximately 0650[3] on 19 April 2008, freight train 5PS6, travelling from Perth to Sydney, derailed near Bates, SA. Fourteen wagons were derailed and about 800 m of track was damaged. There were no injuries.

Location

Bates railway yard is located at the 725.5 km mark[4], about 220 track kilometres west of Tarcoola on the Defined Interstate Rail Network (DIRN) between Adelaide and Perth (Figure 1). The derailment occurred on a curve about 13 track kilometres east of the Bates yard.

Figure 1: Location of Bates, SA



Map - Geoscience Australia. Crown Copyright ©.

1.1.2 Track information

The track at the derailment site was owned and operated by the Australian Rail Track Corporation (ARTC). Maintenance of the track, in accordance with the ARTC Code of Practice (CoP), had been contracted to Transfield Services.

3 The 24-hour clock is used in this report to describe the local time of day, Central Standard Time (CST), as particular events occurred

4 Distance in kilometres from a track reference point located at Coonamia in SA.

The track structure consisted of continuously welded 94 lb/yd (47 kg/m) rail secured to concrete sleepers by resilient fasteners and supported by a ballast bed having a minimum depth of 250 mm. The sleepers were spaced at approximately 666 mm centres.

The track in the area was mildly undulating with a number of curves as it passed through numerous sand dunes. Heading in an easterly direction, towards the point of derailment, the track was level before ascending a 1 in 100 gradient and entering an 800 m radius curve. The posted track speed through the curve where train 5PS6 derailed was 80 km/h. There were no temporary speed restrictions in force at the time.

The rail was manufactured in January 1970 by Australian Iron & Steel (Port Kembla). The applicable standard at the time of manufacture was the *Australian Standard Specifications for Railway Permanent Way Materials, AS E22- 1964 Steel Rails*. Figure 2 illustrates the level of wear that was present in the high rail (outer rail) of the curve. While there was some evidence of metal flow, the level of wear did not exceed the allowable rail wear limits documented in the ARTC Track and Civil Code of Practice (CoP) (refer to Table 1). In general, the track appeared to be well maintained and in good condition.

Figure 2: Rail profile

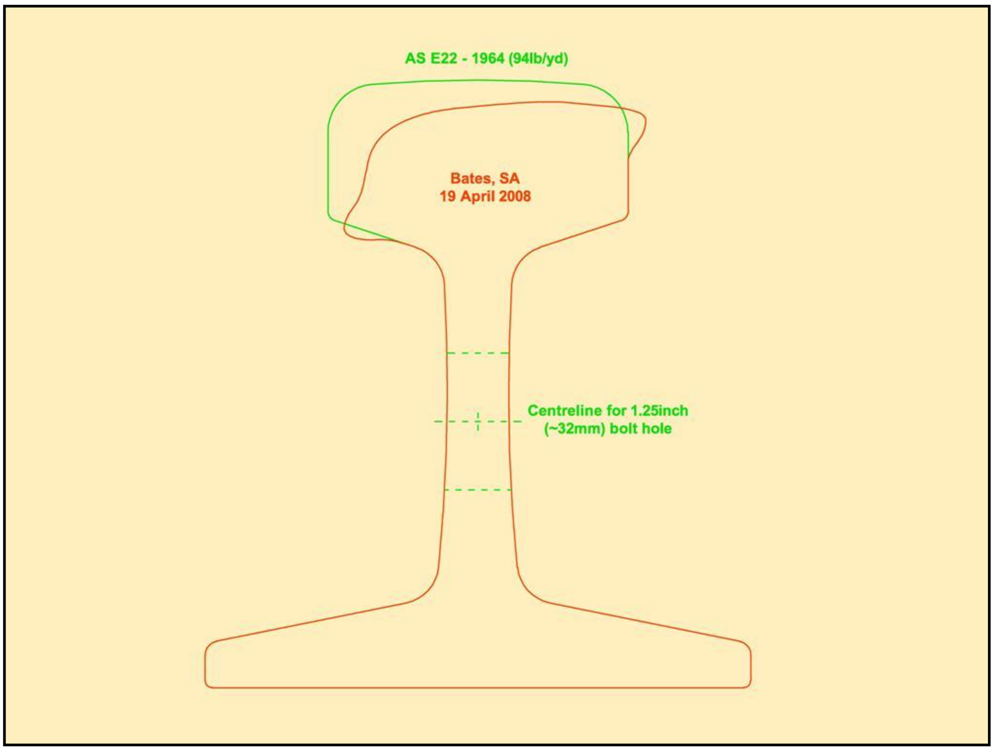


Table 1: Allowable rail wear limits for 94 lb/yd (47 kg/m) rail

	New rail profile	Limit	Actual rail profile
Rail Height	141 mm	128 mm	136 mm
Rail head area	2548 mm2	1528 mm2 (40% loss)	1985 mm2 (22% loss)

1.1.3 Train information

Freight train 5PS6 was owned and operated by Pacific National (PN). It consisted of two locomotives (NR90 and NR51) hauling 44 wagons (16 of which were multiple-unit wagons). The train was 1770 m long and weighed a total of 3886 t. A total of five wagons on train 5PS6 were carrying dangerous goods, consisting of resin solution, various chemicals, acids and environmentally hazardous substances. The maximum allowable speed for train 5PS6 was 100 km/h.

The driver at the time of the accident had about 15 years train driving experience. At the time of the derailment, both train drivers were appropriately qualified, assessed as competent and medically fit for duty.

1.2 The occurrence

Freight train 5PS6 was scheduled to depart Perth, WA at 2145 (Western Standard Time) on 17 April 2008. The train travelled to Cook, SA where a crew change occurred before departing at about 0300 (CST) on 19 April 2008 and continuing its journey towards Sydney. The drivers advised that the train was handling 'OK' and all appeared to be normal. About 13 km east of Bates, while travelling at about 80 km/h, the locomotive drivers recalled hearing a 'crack, crack, crack' sound from the locomotive wheels as they rounded a curve. The driver noted that the sound was similar to a previous experience where he had been driving a train that had passed over a broken rail.

The driver eased off the throttle before noticing a reduction of brake pipe pressure, indicating that brake pipe air was exhausting to the atmosphere and the train brakes would begin to apply. Train 5PS6 came to a stop and the driver contacted the ARTC train controller to advise that train 5PS6 had stopped due to a loss of brake pipe pressure.

The drivers walked back to investigate the cause of the brake application and discovered that the train had broken apart between the 28th and 29th wagon. Of the 28 wagons still coupled behind the locomotives, four were derailed. A significant portion of track behind this portion of train had been destroyed with nine derailed wagons laying at various angles to the track. Having checked the freight manifest, the drivers had noted that two of the derailed wagons were carrying dangerous goods. Consequently, they kept an appropriate distance from the damaged freight containers while conducting their inspection of train 5PS6.

The drivers contacted the ARTC train controller and advised that train 5PS6 had derailed, dangerous goods were involved and a significant portion of track had been destroyed.

Post occurrence

A total of five wagons on train 5PS6 were carrying dangerous goods. Only two wagons (carrying resin solution and various chemicals) were involved in the derailment and an exclusion zone was placed around the derailment site until an appropriate assessment could be conducted.

Hazardous materials assessor, investigators and recovery crews progressively arrived on site the following day (20 April 2008). The hazardous materials assessor inspected the freight, identified that only the containers of resin solution had ruptured, and revised the exclusion zone accordingly.

Investigators examined the site throughout the remainder of the day. After inspection, the front undamaged portion of the train was released so it could continue its journey to Sydney (departing the site at about 1300 on 20 April 2008) while the rear portion was hauled back to the Bates yard until the track could be repaired. Heavy lift cranes and hazardous materials recovery teams arrived on site later that day and began the recovery of derailed wagons so track repairs could be conducted.

The track was reopened for traffic at about 1517 on 24 April 2008 and the damaged rolling stock progressively recovered from the track side over the following weeks. A total of 14 wagons were damaged along with about 800 m of track.

2 ANALYSIS

An investigation team from the Australian Transport Safety Bureau (ATSB), representatives from the ARTC, Pacific National and a hazardous materials assessor, travelled to the derailment site on 20 April 2008.

Investigators examined and photographed the derailment site before releasing the site to permit recovery operations to begin. Evidence was sourced from the derailment site, various witnesses and the rail companies involved, including the ARTC, Transfield and Pacific National.

2.1 Sequence of events analysis

Initial observations indicated that the derailment may have been the result of rail that had broken some time before the passage of train 5PS6. Consequently, the following analysis also considers events that occurred before the passage of train 5PS6.

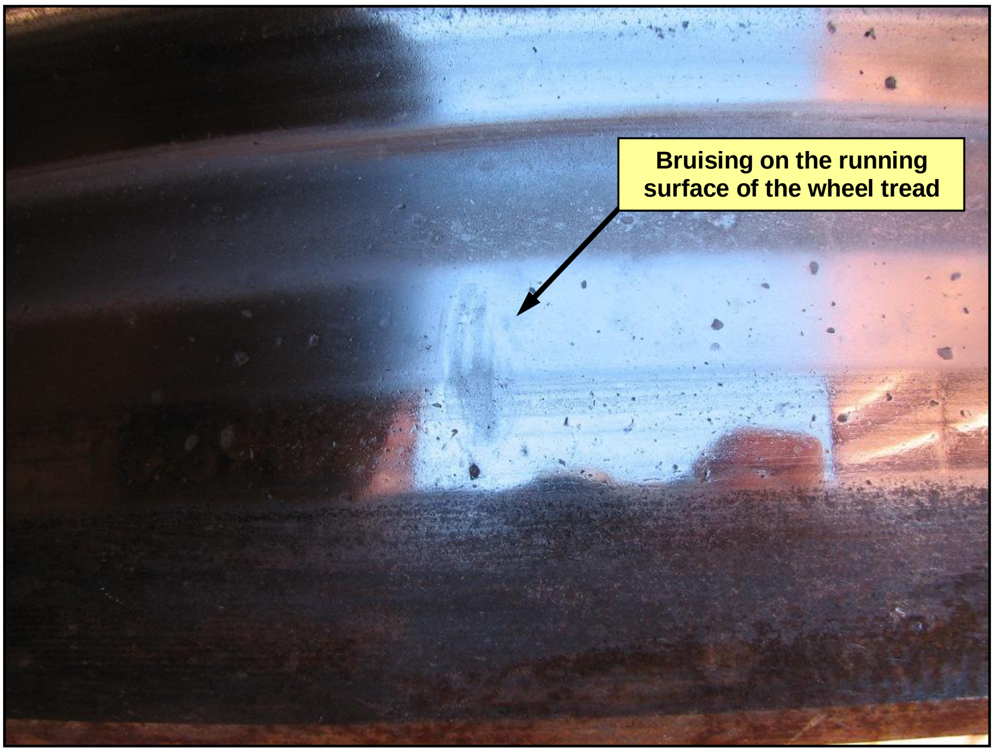
On 16 April 2008, 3 days before the derailment of train 5PS6, continuous ultrasonic testing was conducted through the Barton – Bates track section. The inspection did not note any rail defects near the derailment site.

On 19 April 2008, train 5PS6 was travelling from Perth towards Sydney and was routed onto the crossing loop at Ooldea (about 140 km east of Cook). Train 5PS6 remained at Ooldea while two trains (5MP9 and 5MP5) passed on the main line heading towards Perth. Those trains had already passed through Bates and had not reported any issues or problems with the track or train 5PS6.

Train 5PS6 continued its journey east and passed through Bates, about 50 km from Ooldea. It was about 13 km further east, while travelling at about 80 km/h, that the locomotive drivers recalled hearing the ‘crack, crack, crack’ sound from the left locomotive wheels as they rounded a curve. Noting that it sounded like a broken rail, the driver eased off the throttle before noticing a reduction of brake pipe pressure and the train brakes beginning to apply.

Evidence of wheel tread bruising was found on a number of left side wheels (referenced by the direction of travel) on wagons between the locomotives and the first derailed wagon (24th behind the locomotives). It should be noted that all wheels could not be examined in their entirety and evidence of bruising could only be sighted where the wheel tread surfaces were easily viewed. Figure 3 illustrates an example of the bruising, found on the first freight wagon behind the locomotives (Wagon RRGY07144Q).

Figure 3: Bruising on the wheel tread (Wagon RRGY07144Q)

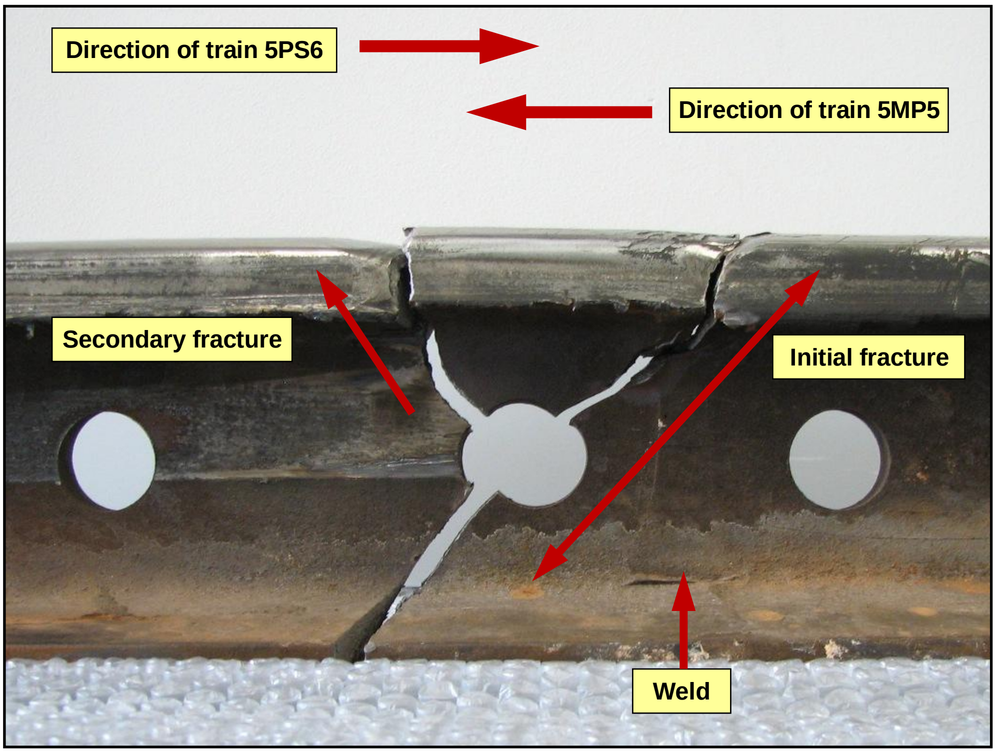


Examination of the track near the point of derailment found evidence of rail fracture. The pieces of rail were recovered and placed in their original configuration, allowing investigators to conduct an initial on-site examination of the fracture surfaces and determine a likely sequence of failure.

The fractured section of rail contained a welded joint between two sets of three bolt-holes, originally drilled to allow joining of the rail using bolted fishplates[5]. The rail fractured through the bolt-hole immediately adjacent to the weld. It was also evident that the fracture occurred immediately adjacent to a sleeper. The ATSB took possession of a short section of rail from either side of the fracture to allow metallurgical examination of fracture surfaces and steel properties. Examination of the track near the point of derailment found evidence of rail fracture. The pieces of rail were recovered and placed in their original configuration, allowing investigators to conduct an initial on-site examination of the fracture surfaces and determine a likely sequence of failure. illustrates the welded joint and the rail fractures (initial and secondary) after the rail was recovered and examined.

5 Fishplates are steel plates normally used in pairs for supporting and joining two rail ends together. The joint is commonly referred to as a mechanical joint.

Figure 4: Broken rail

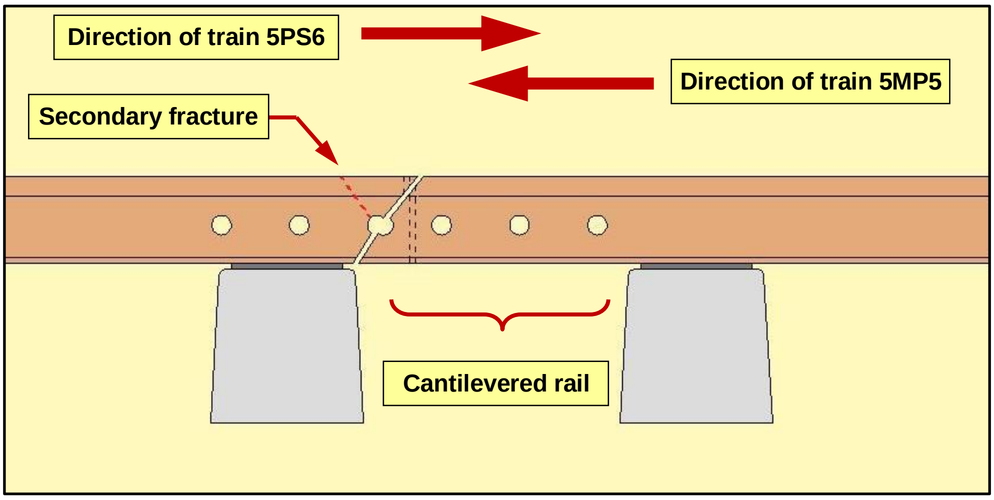


On-site evidence suggested the following as the most likely derailment sequence:

- A crack had developed in the web of the rail, radiating out from a bolt-hole. The crack was located in the outside (northern) rail of a curve.
- It is likely that the previously unidentified bolt hole crack rapidly propagated under the load of west bound train 5MP5 (1790 m, 4446 t). Examination of the track near the point of derailment found evidence of rail fracture. The pieces of rail were recovered and placed in their original configuration, allowing investigators to conduct an initial on-site examination of the fracture surfaces and determine a likely sequence of failure. illustrates the initial fracture.
- Rub marks on the fracture surfaces indicate that the rail separated slightly when it fractured, creating a gap (approximately 10 mm) between the two sections of rail.
- It is likely that the rail remained in this state until train 5PS6 approached from the west.
- The initial fracture occurred near the edge of a sleeper, leaving a cantilevered length of rail supported by one sleeper (Figure 5). This significantly increased the compressive force borne by that sleeper as train wheels passed over the fracture.
- As the wheels of train 5PS6 passed over the fracture and onto the cantilevered rail, the impact forces are likely to have caused the progressive failure of the concrete sleeper.
- Similarly, the load exerted on the trailing edge of the rail leading into the fracture is likely to have caused the secondary fracture and subsequent ejection of a small section of rail.

- Once a section of rail was missing, the impact forces on the rail would have increased significantly, causing the progressive failure of rail and sleepers until wagons inevitably derailed.

Figure 5: Fracture & sleeper configuration



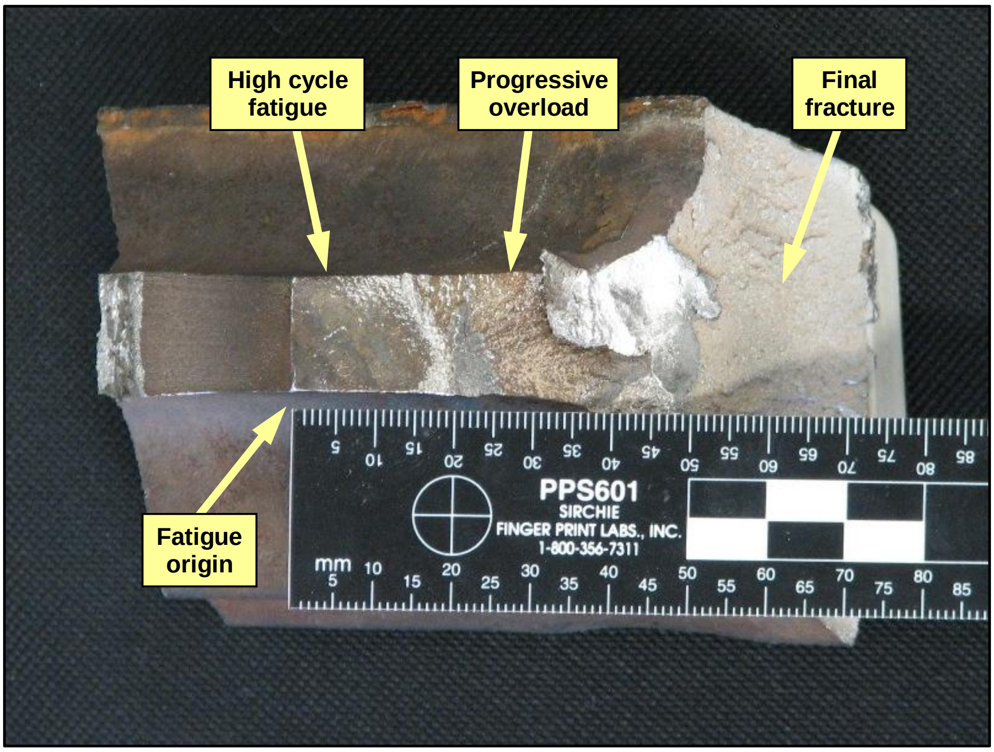
Considering it is likely the rail had broken before the passage of train 5PS6, it is unlikely that train handling contributed in any way to its subsequent derailment.

2.2 Metallurgical examination of fracture surface and steel properties

Examination of the fracture surface of the failed section of rail, found a substantial fatigue crack extending from the bolt-hole towards the weld. Three distinct regions were evident on the fracture surface (Figure 6):

- High cycle fatigue – The fracture surface adjacent to the bolt-hole exhibited beach (crack arrest) marks radiating from one corner (fatigue origin). The surface was relatively smooth and indicative of a high cycle fatigue crack. This region was almost 20 mm in length and was oxidised, indicating that the crack had existed for some time prior to the derailment.
- Progressive overload – As the crack progressed through the rail, the fracture surface became rougher and consistent with a progressive overload or low cycle fatigue. This region extended to the start of the weld, about 45 mm from the fatigue origin. The surface showed very low levels of oxidisation, indicating that this phase of cracking had developed over a relatively short period of time.
- Final fracture – The final fracture through the rail head and foot was matt grey/silver in appearance and occurred at or about the time of the derailment.

Figure 6: Fracture surface



A longitudinal cross section was taken through the fracture surface and etched in 2% Nital[6] solution. The etched surface showed transitions between the microstructures relating to the original rail condition, the weld between rails, and the weld heat affected zone (HAZ) between the two. It was found that the transition between the original metal and the HAZ coincided with the fatigue origin at the bolt-hole (Figure 7).

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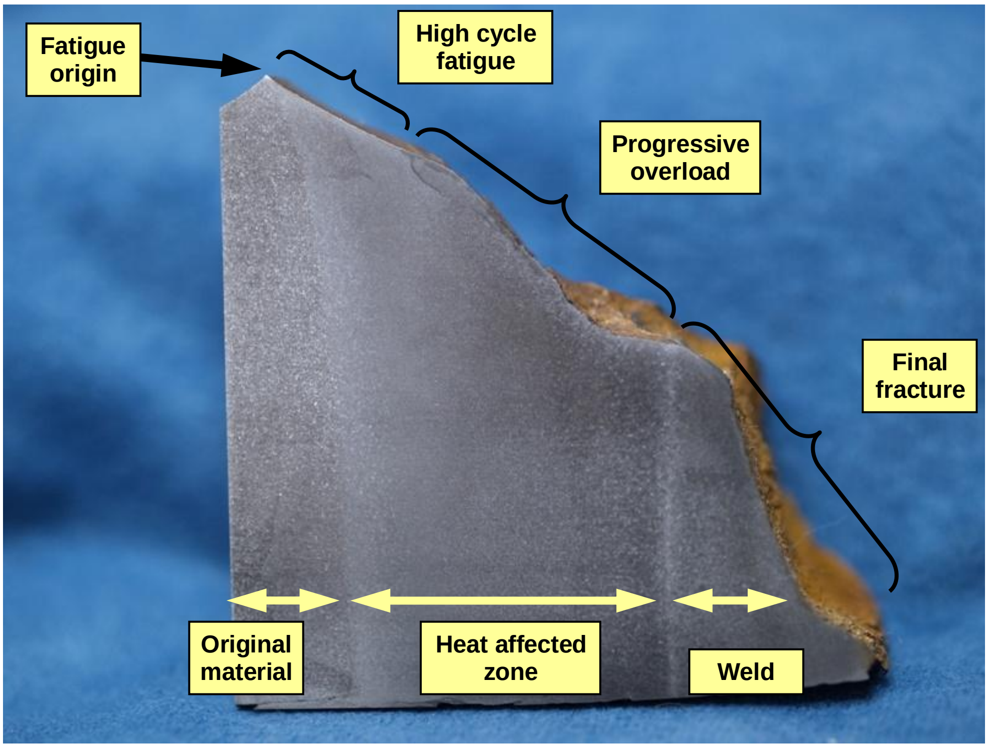
6 Nital is a solution of alcohol and nitric acid used for etching metals and revealing the microstructure of steels.

Figure 7: Longitudinal cross section through fracture surface



The rail was manufactured to *Australian Standard Specifications for Railway Permanent Way Materials - E22-1964 – Steel Rails*. This standard has since been superseded and the current standard is Australian Standard AS1085.1-2002 – *Railway track materials, Part 1-Steel rails.*

Chemical analysis was performed, on rail samples obtained from both sides of the welded joint, using optical emission spectroscopy[7]. The results showed that the samples conformed to the requirements of both standards (E22-1964 and AS1085).

The microstructure of the rail steel was examined in the area adjacent to the bolt-hole. The microstructure was predominantly pearlite[8] with small amounts of grain boundary ferrite[9] (white). While there were no microstructure requirements as part of standard E22-1964, the results did conform to the current standard AS1085.

2.3 Bolt-hole cracks

The most common reason for a hole to be drilled into the web of a rail is to join two lengths of rail using bolted fishplates. Cracking at a bolt-hole is usually caused by fatigue due to the repetitive cyclic loading applied by wheels as they pass over the joint. The cyclic loading induces shear stress in the web of the rail which is magnified by the stress concentration effect of the bolt-hole. Usually, additional stress concentrators exist in the form of scratches, corrosion pits or rough edges due

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7 Optical emission spectroscopy is a process for fast and accurate elemental analysis of metals.

8 Pearlite refers to the lamellar microstructure of ferrite and cementite, produced from austenite during the cooling of steel.

9 Ferrite is the term used for the crystal structure of iron, the major constituent of steel.

to poor drilling or the interaction between the bolt and the rail. The cracks usually propagate at an angle away from the hole.

It is generally recognised that loose or poorly supported joints can increase the risk of a bolt-hole crack. However, in this case, the joint was welded and the holes were unused. The surfaces of the bolt-holes were relatively clean, indicating that the rail had been welded when first installed and the holes may never have accommodated bolts. Apart from the physical condition of the bolt-hole, a number of factors can contribute to the development and propagation of cracks at unused bolt-holes.

Rolling stock

Some faults and defects in rolling stock can have a detrimental effect on rail and track condition. For example, wheel impacts due to tread flats can significantly increase the loading on rails and contribute to the development of rail cracks and ultimately, broken rails.

In this case, it was evident that the bolt-hole crack had existed for some time prior to the derailment. It was also likely that the rail had completely fractured shortly before train 5PS6 passed over the fault location. Consequently, potentially detrimental rolling stock conditions were considered in relation to both crack development and the eventual fracture of the rail.

The ARTC Wheel Impact and Load Detection (WILD) systems are used to identify undesirable rolling stock conditions such as tread flats. Data from the WILD system at Port Germein[10],SA has been available to operators since 2002 allowing them to actively manage the condition of their rolling stock. Initially, the number of wheel impact alarms, as a percentage of total wheels, was almost 0.3 %. By about March 2005, the number of wheel impact alarms recorded at Port Germein had reduced to less than 0.1 % with a negligible number of medium and high level alarms.

The previous three trains to travel this section of track were 5MP4, 5MP5 and 5MP9. Data from the ARTC Wheel Impact and Load Detection (WILD) systems at Port Germein and Kalgoorlie, WA were examined to identify any undesirable wheel impacts. Only train 5MP9 recorded any wheel impact alarms. This was recorded at the Port Germein site and was categorised as a low level alarm. The data recorded at the Kalgoorlie site showed no alarm condition for the same train.

It is evident that the number of harmful wheel impacts detected by the WILD system had been very low for some years. Similarly, the previous three trains to traverse the area showed no evidence of harmful wheel impacts. Consequently, it is unlikely that harmful wheel impacts contributed to the rapid propogation of a pre-existing bolt-hole crack or contributed to the eventual fracture of the rail.

Environmental conditions

The rail’s temperature can increase its internal stresses due to metal contraction (cold conditions) and metal expansion (hot conditions). Cold temperatures are more

[10] The Wheel Impact and Load Detection (WILD) system at Port Germein (SA) was initially installed as a pilot system, before progressive installation at other locations, including Kalgoorlie (WA). Data from Port Germein site was used to illustrate the trend in wheel impact alarms since a larger sample of data was available.

likely to contribute to broken rails as the rail metal contracts. Conversely, hot temperatures are more likely to contribute to buckled rails as the rail metal expands.

Rail will generally accommodate the range of expected minimum and maximum rail temperatures[11] expected for the region. This is achieved by the design of the track structure and installation such that the rail is in neither compression nor tension at a specified temperature (neutral temperature) between the expected minimum and maximum. However, if (for any reason) a section of rail is in a state of imminent failure, it is more likely to break during the colder periods of the day, such as just before sunrise.

Train 5PS6 encountered the broken rail at 0650 on 19 April 2008, about 10 minutes before sunrise at 0701[12]. However, it is likely that the initial break occurred under train 5MP5, approximately 1.5 hours earlier. While, there were no temperature recording stations located in the vicinity, an estimate of the air temperature was obtained by examining the data from recording sites in the region. It is likely that the minimum temperature at Bates occurred between 0500 and 0700; the temperature was likely to have been between 10 and 12 degrees Celsius[13]. Those temperatures are considered to be average for the area at this time of the year and above the minimum rail temperature that would be expected for this region.

While it is likely that the rail was in tension due to its low temperature at the time of the incident, it is unlikely that the temperature alone contributed to the failure of the rail.

2.4 Theoretical fracture analysis

To assist in identifying the fracture behaviour of rail, the ATSB engaged technical experts in fracture mechanics to conduct theoretical finite element, crack initiation and crack growth analysis. As with most theoretical models, there is a level of assumption applied to some parameters. Consequently, the results should only be used as an indicator in conjunction with other analysis to draw appropriate conclusions.

The analysis considered finite element models for four rail configurations, each supported on the concrete sleeper geometry that existed at the time of the derailment:

- New rail profile with unused bolt-holes
- Worn rail profile with unused bolt-holes
- New rail profile without bolt-holes
- Worn rail profile without bolt-holes.

An example of the cross sectional finite element mesh for dot-points one and four are shown in Figure 8. Similar meshes were also developed for the other two rail configurations.

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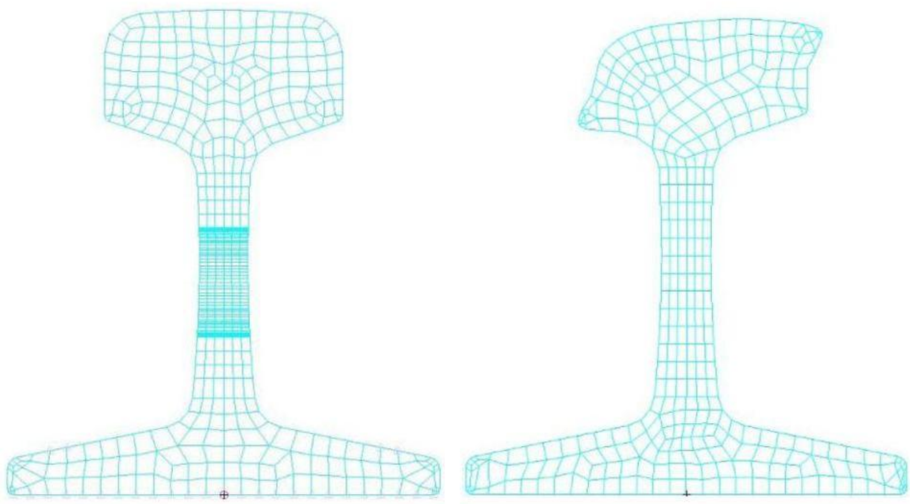
[11] Rail temperature can range (approximately) between the minimum ambient air temperature and about 20 degrees above the maximum ambient air temperature.

[12] Astronomical information obtained from Geoscience Australia.

[13] Temperature derived from Bureau of Meteorology sites at Ceduna, Nullarbor and Tarcoola.

Figure 8: Cross sectional finite element mesh



Linear static stress analysis indicated that the highest tensile stresses occurred at the edge of the bolt-hole, at an angle of approximately 45 degrees from the vertical. This is consistent with the bolt-hole crack observed in the rail recovered from the Bates derailment site (Examination of the track near the point of derailment found evidence of rail fracture. The pieces of rail were recovered and placed in their original configuration, allowing investigators to conduct an initial on-site examination of the fracture surfaces and determine a likely sequence of failure.). The magnitude of the calculated stresses was almost three times greater than the stresses calculated in the web of the rail that did not have bolt-holes. It is evident that a bolt-hole in the web of a rail introduces a stress concentrating effect under cyclic loading typical of actual rail traffic[14].

Crack initiation analysis was conducted to examine rail steel's response to cyclic loading typical of actual rail traffic. The analysis indicated that a crack would initiate at the outside edge of the bolt-hole for both the new and worn rail profiles. This is consistent with the fracture surface on the rail recovered from the Bates derailment site (Figure 6) where the crack appeared to be about 5 mm longer on the outer edge of the bolt-hole, implying that it was likely to have initiated at the outer edge as reflected in the theoretical analysis. It should be noted that the rail models used for the theoretical analysis assumed a 'perfect' hole through the web of the rail. In practice, bolt-holes exhibit imperfections (machine marks, surface scoring, corrosion etc.) all of which act as stress concentrators and are likely to significantly vary the time taken for a crack to initiate at a specific bolt-hole. However, it can be concluded that a crack is likely to develop at an unused bolt-hole (in the web of a rail) under cyclic loading typical of actual rail traffic.

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14 Typical cyclic loading was derived from the ARTC Wheel Impact and Load Detection system. The axle loading from 66 trains (one week period) was repetitively cycled for calculations.

Theoretical analysis was also conducted to predict the likelihood of crack growth if a small crack already existed at the edge of an unused bolt-hole in the web of the rail. The analysis indicated that, under typical cyclic rail loading, a crack at a bolt-hole in the web of a rail would grow in both new and worn rail profiles. The analysis also indicated that as the crack grew to about 10 mm in length, the rate of growth would increase significantly such that uncontrolled crack development was predicted to continue until the inevitable failure of the rail. It should be noted that, due to assumptions made while modelling rail steel for fracture analysis, the growth rate for cracks that exist in rail at specific bolt-holes is likely to vary significantly. However, it can be concluded that a crack (at an unused bolt-hole in the web of a rail) is likely to increase in size until inevitable failure under cyclic loading typical of actual rail traffic.

2.5 Track construction, inspection and assessment

Track construction is the process of building track infrastructure in accordance with the approved designs. Guidelines for construction are documented in the ARTC Track and Civil Code of Practice (CoP). The CoP documents the acceptance criteria for the procurement of rail and the process of installation.

It was evident that the bolt-holes in the section of rail that failed on 19 April 2008 were originally drilled for the purpose of joining of two sections of rail using bolted fishplates. In this case, the two lengths of rail were joined using a flash-butt[15] weld (it is not known when the weld was made). The ARTC CoP states that 'the distance from the edge of the bolt-hole to the rail end should be no less than 65 mm'. The reason for this requirement is stated as; 'distances less than 65 mm may cause masking of weld defects during ultrasonic testing and poor heat distribution during welding'. While the CoP only specifies this requirement as relevant to installation of partly worn rail, the intent of the requirement is relevant to installations of both worn and new rail.

Rail measurements show that the flash-butt weld was between two bolt-holes located about 95 mm apart (centre of bolt-holes). This implies that the bolt-hole centres were about 45mm to 50 mm from the rail ends before welding, resulting in the bolt-hole edges being less than 65 mm from the rail ends as required by the ARTC CoP.

It likely that the rail was welded well before the ARTC CoP existed and at that time, welded joints such as this were relatively common practice. While the requirements of the CoP are not considered to be retrospective, the CoP should reflect the risks known to be associated with bolt-holes adjacent to welded joints. In this case, the consequence was not to mask the weld from ultrasonic testing, but allowed the transition between original metal and heat affected metal to interface with the bolt-hole at the point where the fatigue crack later originated. The ARTC CoP does not recognise the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding. However, it is also noted that stress concentration due to heat-affected metal is only one of many factors that may (or may not) contribute to the development of a crack at a specific bolt-hole.

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15 A flash-butt weld is achieved by heating the rail ends using an electric current and pressing the two surfaces together under high pressure.

2.5.1 Inspection and assessment

Track inspections are a critical part of the infrastructure maintenance process. It is the process by which the track condition is monitored to identify possible defects that may affect, or have the potential to affect, the capability of the infrastructure to safely perform its required function. Guidelines for inspection and assessment are documented in the ARTC CoP.

The process for scheduled rail and welded joint inspections consists of three complementary inspection types:

- patrol inspections
- general inspections
- detailed inspections.

Patrol inspections are usually performed while travelling in a road/rail vehicle at intervals not exceeding seven calendar days. Patrol inspections look for visible rail defects such as broken rails, damaged rail surfaces, rail deformation or any obvious indications of possible rail defects. General inspections are usually performed in response to previously identified defects or unusual rail conditions.

Detailed inspections usually take the form of continuous (vehicle mounted) and/or manual (hand held) ultrasonic testing. Manual ultrasonic testing is used to verify and size suspected defects identified by continuous testing or visual inspection.

Identified rail defects are assessed based on a series of defect categories such as transverse defect, horizontal/vertical split weld defect, and bolt-hole crack. The classification, position and size of defects are analysed with reference to a table of defect limits and associated response codes. The response codes define the appropriate response required to control any risk to railway operational safety. In the context of a bolt-hole crack, Table 2 shows the relevant response (ARTC CoP) to a defect identified on a single main line track similar to the derailment site.

Table 2: Bolt-hole crack response codes

Defect size (Note 1)	Response time	Action
20 – 40 mm	30 days	Reassess or remove
41 – 75 mm	7 days	Reassess or remove
>75 mm	Prior to next train	Speed restrict and reassess daily or remove
Broken rail	Prior to next train	Pilot or remove (Note 2)

Note 1: No response is specified for bolt-hole cracks that have been identified and sized as less than 20 mm.

Note 2: Trains may only pass over the defect when under the control of a pilot (qualified worker).

Detailed inspection - continuous ultrasonic testing

Ultrasonic rail testing involves passing sound waves into the rail and monitoring the echo returned by the sound waves reflecting off internal and external surfaces (reflectors). Defects within the rail create reflectors which return unique echo patterns depending on their type, location and size. Examination of the echo patterns allows an operator to deduce the existence, type and size of suspected rail defects.

The ARTC CoP states that continuous ultrasonic testing should be carried out '…at a frequency of 15 MGT[16] during the service life of the rail.' About 15 MGT was recorded travelling the Port Augusta to Tarcoola section between 1 May 2007 and 30 April 2008, after which about 4 MGT travelled towards Darwin and about 11 MGT continued to Perth. Consequently, the testing period specified in the ARTC CoP equates to about one continuous ultrasonic testing inspection per year. However, following a derailment near Bates on 10 June 2007 and the subsequent ATSB investigation[17], the ARTC initiated a review of the frequency of ultrasonic testing of track on the Trans-Australian Railway to include a mid-period inspection.

Continuous ultrasonic testing was conducted through the Barton – Bates track section by Rail Technology International (RTI) on 16 April 2008, 3 days before the derailment of train 5PS6. Three vehicles were used for continuous ultrasonic testing through this section of track. The lead vehicle was operated by Transfield, who liaised with the ARTC train controller to gain access to each track section. The second vehicle was the RTI ultrasonic test vehicle, operated by a single person. The final vehicle, described as a chase car, provided the facility to use hand held ultrasonic test equipment to verify and size suspected defects identified by the ultrasonic test vehicle.

The RTI ultrasonic test vehicle is a 4WD vehicle modified to travel on both road and rail. Mounted at the rear of the vehicle is RTI's 8000SX test carriage (Figure 9). The test carriage supports the ultrasonic probe wheels and associated equipment while the electronics are mounted inside the vehicle. A computer monitor is provided in the vehicle cabin to allow the operator to monitor the ultrasonic test equipment.

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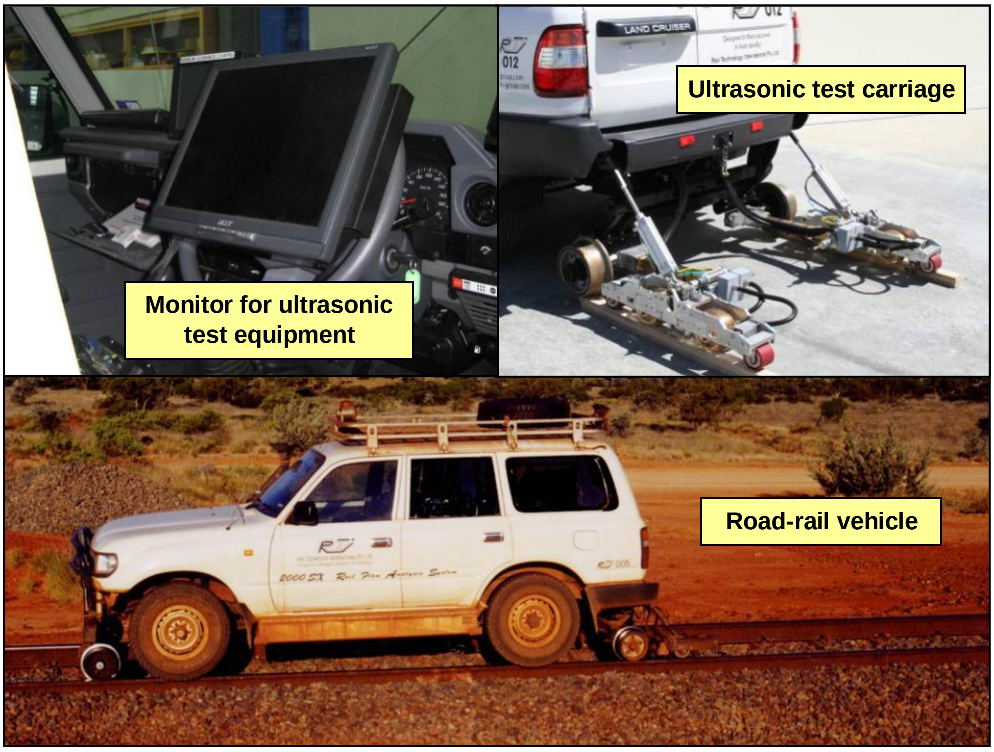
16 MGT – Million Gross Tonnes

17 ATSB Transport Safety Investigation Report No. 2007/004

Figure 9: RTI 8000SX ultrasonic test vehicle



Seven ultrasonic probes are used on each rail:

- A 0 degree probe scans the central part of the rail head, the whole of the rail web and the central part of the rail foot perpendicular to the rail.
- Forward and reverse 38 degree probes scan the central part of the rail head, the whole of the web and the central part of the rail foot.
- Forward and reverse 70 degree probes scan the rail head and part of the upper web.
- Two opposing lateral 45 degree probes scan the centre of the head for vertical split head defects and inclusions.

Reflective surfaces within the rail that indicate possible bolt-hole cracks are usually detected by the forward and reverse 38 degree probes.

There were no suspected bolt-hole defects reported by the test vehicle operator in the vicinity of the point where train 5PS6 derailed. However, post derailment examination of the recorded test vehicle data showed echo patterns that were consistent with a series of six bolt-holes, one of which showed an extended echo recorded by the reverse 38 degree probe on the right rail[18] (Figure 10). The location of this echo pattern is consistent with the bolt-hole crack observed in the broken rail following the derailment of train 5PS6 (sizing this echo pattern is discussed in Section 2.5.3 Standards).

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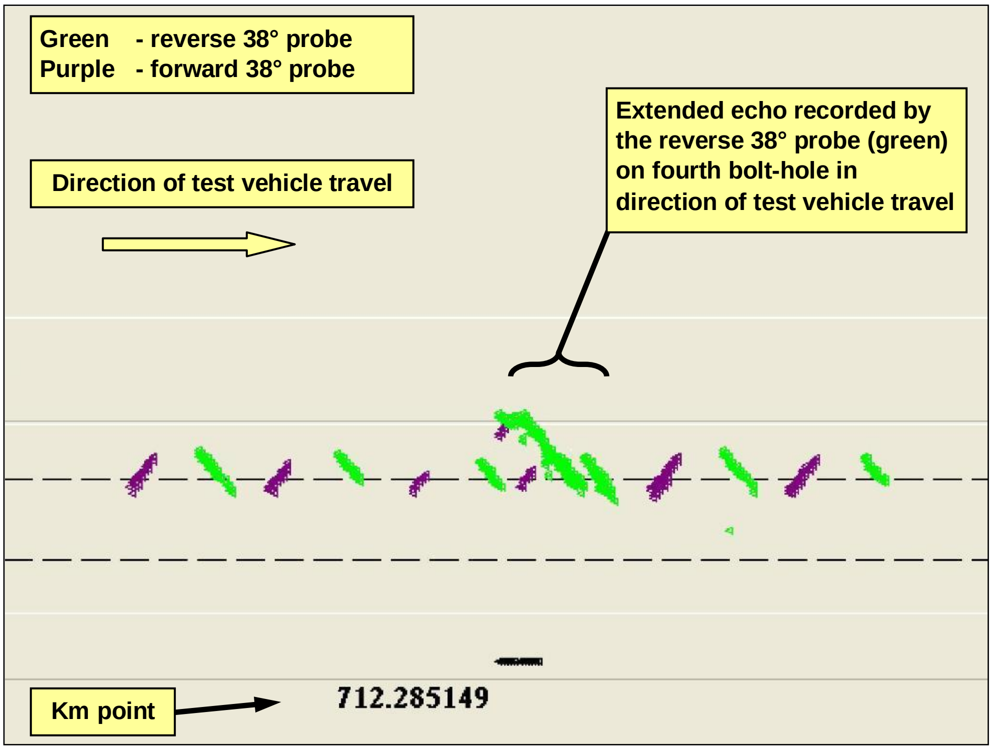
[18] Referenced in the direction of travel for the ultrasonic test vehicle which was opposite to that of train 5PS6.

Figure 10: Extract from recorded ultrasonic test data



2.5.2 Limitations of ultrasonic testing

Ultrasonic rail testing process relies on equipment detecting an echo from sound waves reflecting off internal and external surfaces (reflectors). The ability for the process to reliably detect a clear echo and interpret the echo as a potential rail defect is dependent on a number of factors, such as:

- Grease, dirt or uneven rail surfaces (due to shelling, pitting and/or worn rail profiles) can reduce the quality of the interface between the ultrasonic probe wheels and the rail surface.
- The geometry of the defect may reflect the sound waves away from the probe wheels thereby attenuating the echo signal received by the ultrasonic test equipment.
- Low reflectivity of the defect surfaces may result in greater attenuation of the reflected sound waves than those of a surface with high reflectivity.
- Compressive forces within the rail (due to high rail temperature) may push the surfaces of a defect together such that the sound waves are transmitted through the defect rather than reflecting off the surfaces of the defect.
- Equipment calibration.
- Operator dependence.

In this case, recorded data verifies that the ultrasonic test equipment detected an echo pattern consistent with a bolt-hole crack. However, the operator did not refer the suspected defect to the chase car for examination and sizing. Two possible scenarios exist as to why no action was taken by the operator. Either the operator observed the echo pattern and assessed it as below the defect limits specified in the

ARTC CoP, or the operator completely missed the echo pattern displayed by the ultrasonic test equipment.

Operator dependence

The RTI ultrasonic test vehicle is operated by a single person. This operator is required to drive the vehicle (does not require steering when on track) while operating the test equipment. Detection of potential defects is achieved by monitoring a video display and recognising 'patterns' that indicate ultrasonic reflections. Figure 9 illustrates the location of the video display mounted on the steering wheel of the test vehicle. As the vehicle moves along the track, data is continuously recorded and passed to a data buffer for operator viewing. The operator accesses the buffered data by sequentially viewing predetermined linear sections of rail (commonly 2.4 m segments). The rate at which each screen is viewed is controlled by the operator, who in turn can control the data recording rate by varying vehicle speed.

In this case, the operator of the RTI ultrasonic test vehicle advised the ATSB that he did not recall seeing this particular echo pattern on the day. When asked what his action would have been, had he noticed the pattern recorded by the test equipment, he replied that he would 'probably' have referred it to the chase car for closer examination and sizing. The failure to notice an echo pattern that could represent a defect highlights the limitation that operator dependence has on accurate detection and assessment of rail faults during an ultrasonic inspection.

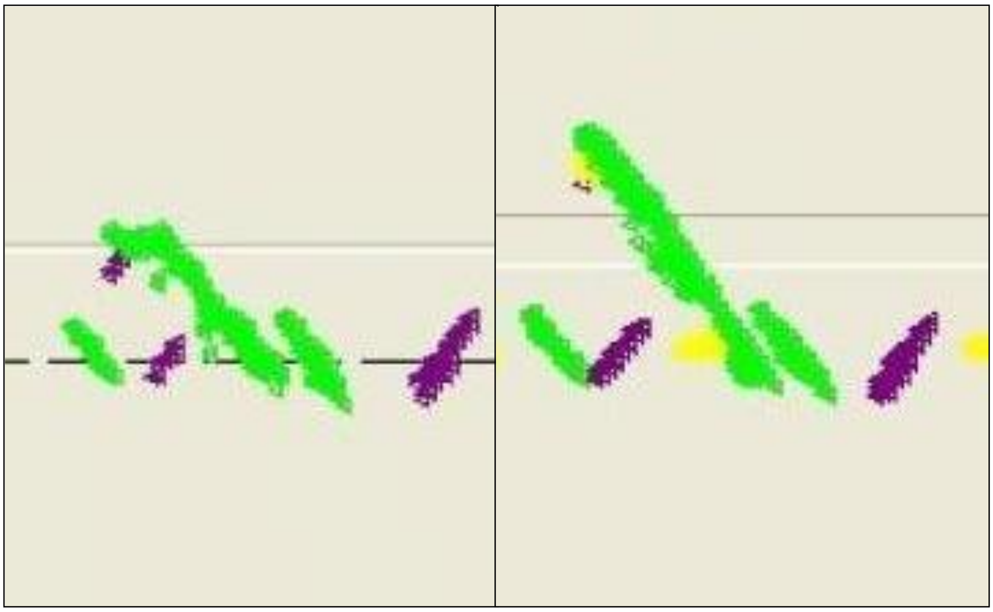
2.5.3 Standards

The standard relevant to the section of track near Bates is the ARTC CoP. Table 2 shows the relevant response to a bolt-hole defect identified on a single main line track.

The requirements of the CoP imply that a bolt-hole crack that is identified and sized at less than 20 mm does not represent a risk to train operations. Even cracks between 40 mm and 75 mm in length only require action within 7 days.

Figure 11 compares the ultrasonic echo pattern detected near the 712.285 km point (Bates derailment site) with another echo pattern detected near the 1680.813 km point (about 95 km east of Parkeston, near Kalgoorlie, WA). The latter was referred to the chase car for examination and sizing. This echo pattern, which is slightly longer than that detected at Bates, was assessed as a suspected bolt-hole crack and sized at approximately 20 mm in length.

Figure 11: Comparison – 712.285 km point (left), 1680.813 km point (right)



Even if the echo pattern detected at the 712.285 km point (Bates) was referred to the chase car for sizing, it is possible that the suspected defect may not have been reported for any maintenance response since its measured size may have been assessed as below the response 20 mm threshold documented in the ARTC CoP. However, in this case the rail completely failed 3 days later, even though the bolt-hole crack apparently did not exceed 20 mm in length.

A similar accident near Pura Pura, Vic. (refer to Section 2.6 History of similar accidents) also involved the complete failure of rail that exhibited bolt-hole cracks that did not exceed 11 mm. When considering those incidents and the results of the theoretical analysis, it is evident that all bolt-hole cracks are likely to increase the risk to train operations, even if they are less than 20 mm in length.

Alternative standards

The ARTC have standards for inspection and assessment that vary depending on what area of the ARTC network the standards refer to. The standard relevant to track in New South Wales was the ARTC Rail Defect Standards (TES 02). Similar to the ARTC CoP, this standard does not specify a response for bolt-hole cracks identified and sized at less than 20 mm. However, this standard is more stringent than the ARTC CoP if the bolt-hole crack is greater than 20 mm in length, requiring removal of the defect within a specified time and, depending on the crack size, the immediate application of a speed limit.

For some sections of ARTC track in Victoria, the relevant standard was the Track Access, Rail – Inspection and Assessment Specification. This document is more stringent than both the CoP and TES02 and specifies a response for any sized bolt-hole cracks that have been identified. Under the Track Access specification, a bolt-hole crack sized at less than 20 mm requires removal of the defect within 90 days. This specification may be appropriate if the inspection regime is sufficient to identify the defect well before it grows to 20 mm. However, a 90 day response is unlikely to be suitable for potential defects that are assessed at the upper end of this range, especially considering ultrasonic detection of the bolt-hole crack at Bates was likely to be within this range but failed only 3 days later.

The most common reason for bolt-holes to be drilled in the web of a rail is to accommodate the joining of two sections of rail using bolted fishplates. Under those conditions, the bolted fishplates are likely to provide additional support to any weakness in the rail due to a bolt-hole crack. However, if the mechanical joint is removed and the two sections of rail welded together, the extra support afforded by the fishplates is no longer available. If complete rail failure occurs in a mechanical joint, the rail is still supported by the fishplates thereby retaining rail alignment for the passage of the train. However, if the failure occurs near a welded joint, the absence of any additional support allows the rail to misalign and significantly increases the risk of derailment. Consequently, cracks at unused bolt-holes are likely to expose rail operations to higher risk than similar sized cracks at bolt-holes being used in conjunction with mechanical joints.

It is possible that the standards relating to bolt-hole cracks were originally developed on the basis that the rail sections were joined using bolted fishplates. As the fishplates were progressively removed and the joints welded (continuous welded rail), it is possible that the standards were not reviewed to reflect the increased risk of rail failure at unused bolt-holes. This is reflected in each of the ARTC standards where any bolt-hole defect related to a bolted joint is to be assessed in accordance with the same standards as if it were a welded joint (with adjacent bolt-holes), regardless of the different risks evident between the two configurations. None of the standards specify a more stringent response associated with bolt-hole cracks detected in unused bolt-holes located in the web of the rail.

2.6 History of similar accidents

International

A search for similar accidents found a number of international examples of failed rail due to bolt-hole cracks. However, almost all involved bolt-holes that were being used for the purpose of joining two sections of rail using bolted fishplates. The limited number of occurrences relating to unused bolt-holes is thought to be due to a relatively common practice of removing sections of rail that have bolt-holes when track was converted to continuously welded rail.

The practice of removing bolt-holes was reinforced by the findings into a derailment in Canada[19] on 24 October 2002. The investigation report recommended that bolt-holes be removed when jointed rail was converted to continuously welded rail. The report stated that leaving unused bolt-holes in continuously welded rail was not recommended due to stress raisers and the risk of cracking.

Australia

On 30 March 2008, freight train 1MA6Q derailed on the Mt Emu Creek Bridge near Pura Pura, Vic.[20]. The investigation found that the rail had fractured at two points. The fractures occurred at two bolt-holes where jointed rail had been converted to continuously welded rail. A section of rail was ejected and 21 wagons derailed.

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[19] The Transportation Safety Board of Canada (TSB) report number R02D0113

[20] ATSB Transport Safety Report, Rail Occurrence Investigation RO-2008-004

Examination of the fracture surfaces found evidence of fatigue cracking extending out from both bolt-holes. The oxidised surface of those cracks, indicating they had existed for some time, did not exceed 11 mm. The rail material conformed to the relevant standards and was not excessively worn. However, the crack had developed at the unused bolt-hole and increased in size until the failure of the rail.

The investigation concluded that the bolt-holes in the rail web were sufficient stress concentrators to result in the initiation and propagation of fatigue cracking, ultimately leading to the rapid failure of the rail section.

2.7 Actions taken

Continuous ultrasonic testing

At the time of this derailment, RTI was actively involved in further development of its ultrasonic testing process. To address the issue of operator dependence, RTI was developing software based on 'Artificial Neural Networks'. Artificial neural networks are aimed at emulating biological neural networks (such as the human brain). In more practical terms, the software uses non-linear statistical data techniques to evaluate complex data inputs to find specific data patterns.

For example, RTI was developing their software to recognise ultrasonic reflection patterns that represent potential rail defects such as bolt-hole cracks. It could be expected that successful implementation of this software may reduce the reliance on the operator to observe and react to specific data patterns. Further enhancements are also proposed whereby the data may be transmitted back to a central computer system for assessment and prompt notification to rail maintainers for corrective action.

The ARTC and RTI discussed the ultrasonic test procedures in light of the derailment at Bates on 19 April 2008. All recorded data from the previous continuous ultrasonic test inspection was re-examined using the 'Artificial Neural Networks' software. The software was configured to recognise potential bolt-hole cracks and all identified locations flagged for closer inspection.

During subsequent ultrasonic testing, RTI's software has identified in excess of 100 locations with potential bolt-hole cracks. The locations were re-inspected using hand held ultrasonic testing equipment and where bolt-hole cracks have been confirmed, the section of rail has been replaced. However, the ARTC have identified some limitations in the process, especially the use of GPS as a means of accurately locating the potential defect, and continue to work with RTI to improve the process for detecting and rectifying internal rail defects.

Revised standard

The ARTC initiated a review of their standards relating to inspection and assessment of bolt-hole cracks. In December 2008, the ARTC issued *Engineering (Track & Civil) Instruction, ETI-01-05, Bolt-hole Crack Limits*. Table 3 shows the revised defect limits and the relevant response to a bolt-hole defect identified on a single main line track.

Table 3: Revised bolt-hole crack response codes ARTC CoP

Defect size	Response time	Action
0 – 10 mm	90 days	Remove
11 – 20 mm	30 days	Remove
21 – 40 mm	7 days	Reassess until removed
>40 mm	Prior to next train	Speed restriction (Max. 60k/h) Reassess daily until removed

Under this instruction, all bolt-hole cracks are recorded as defects and require removal, irrespective of the crack size.

3 FINDINGS

3.1 Context

At approximately 0650 on 19 April 2008, freight train 5PS6 derailed near Bates, SA. Fourteen wagons were derailed but there were no injuries.

The investigation found that the rail had fractured through an unused bolt-hole in the web of the rail. It was likely that the rail fractured under the previous west-bound train 5MP5. As the wheels of east-bound train 5PS6 passed over the fracture, the impact forces caused the progressive failure of sleepers, a secondary rail fracture and the ejection of a small section of rail. Once a section of rail was missing, the impact forces on the rail increased significantly, causing the progressive failure of rail and sleepers until freight wagons inevitably derailed.

From the evidence available, the following findings are made with respect to the derailment of train 5PS6 and should not be read as apportioning blame or liability to any particular organisation or individual.

3.2 Contributing safety factors

- It was evident that a crack, consistent with high cycle fatigue cracking, had existed in the web of the rail for some time. The crack was almost 20 mm in length, started at the bolt-hole and radiated out towards a welded rail joint. The crack increased in size relatively quickly, in a manner consistent with progressive overload, before the rail completely fractured through the weld to the outer surface of the rail.
- It is likely that internal stresses placed the rail under tension since the fracture occurred near the coldest part of the day.
- It is likely that the rail fractured due to the forces exerted on the rail during the passage of west bound train 5MP5 (about 1.5 hours before the derailment of train 5PS6).
- The data recorded by the ultrasonic test vehicle on 16 April 2008, 3 days before the derailment of train 5PS6, showed an echo pattern that was consistent with the bolt-hole crack observed in the broken rail following the derailment of train 5PS6. However, the possible defect was not observed by the test vehicle operator and was therefore not flagged for closer examination.
- The process for identifying potential rail defects is limited by the ultrasonic test vehicle operator's ability to detect and assess the echo patterns correctly. *[Significant safety issue]*
- Analysis showed that any unused bolt-hole in the web of the rail acts as a stress concentrator increasing the risk of a fatigue crack. It is likely that any fatigue crack originating from a bolt hole will increase in size until the inevitable failure of the rail.
- The ARTC Code of Practice at the time of the derailment did not categorise bolt-hole cracks as defects requiring action unless they exceeded 20 mm in length. *[Significicnat safety issue]*

- Metallurgical examination found that the microstructural transition between the weld heat affected zone and the original metal coincided with the fatigue origin at the bolt-hole. This transition was likely to have acted as a localised stress concentrator at the bolt-hole.
- The ARTC Code of Practice does not recognise the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding. *[Minor safety issue]*

3.3 Other safety factors

- It is possible that the standards relating to bolt-hole cracks were originally developed on the basis that the rail sections were joined using bolted fishplates. As the fishplates were progressively removed and the joints welded (continuous welded rail), it is possible that the standards were not reviewed to reflect the increased risk of rail failure at unused bolt-holes.

3.4 Other key findings

- Metallurgical examination found that the chemical composition and the microstructure of the metal conformed to the relevant standards.
- It is likely the rail had broken before the passage of train 5PS6. Consequently, it is unlikely that train handling contributed in any way to its subsequent derailment.
- It was considered unlikely that the condition of rolling stock, in the previous trains to traverse the area, contributed to the failure of the rail.
- Had the bolt-hole crack been detected and sized during ultrasonic testing, it is likely that the crack would have been assessed at less that 20mm in length, would not have exceeded the intervention limits specified in the ARTC CoP at that time, and would not have required a response to conduct maintenance.

4 SAFETY ACTION

The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

4.1 Australian Rail Track Corporation

It is recognised that some safety actions may be best actioned by service providers to the Australian Rail Track Corporation (ARTC). However, since the actions of those service providers are subject to contractual arrangements, recommendations have been directed to the Australian Rail Track Corporation as the contract manager.

4.1.1 Operator dependence for ultrasonic testing

Safety issue

The process for identifying potential rail defects is limited by the ultrasonic test vehicle operator’s ability to detect and assess the echo patterns correctly.

Action taken by the ARTC

Rail Technology International (RTI) is actively conducting further development of their ultrasonic testing process. For example, RTI are developing software based on ‘Artificial Neural Networks’ for recognising ultrasonic reflection patterns that represent potential rail defects such as bolt-hole cracks. RTI have conducted post test re-analysis of ultrasonic test data using the neural network software to identify any defects that may have been missed during the test run. RTI’s plan is to run the neural network software in the background and conduct this analysis while ultrasonic testing is being undertaken. RTI have indicated that implementation is planned for early 2010.

ATSB assessment of action

The ATSB acknowledges that the ARTC and RTI are developing processes to reduce the risks associated with operator dependence. While some of those initiatives have been introduced, especially in relation to bolt-hole cracks, other rail defects are also exposed to the issue of operator dependence. The opportunity exists for continued development and implementation of strategies aimed at reducing operator dependence.

ATSB safety advisory notice RO-2008-005-SAN-035

The Australian Transport Safety Bureau advises that the ARTC should consider the implications of this safety issue and take action where considered appropriate.

4.1.2 Bolt-hole crack defect categories under the Code of Practice

Safety issue

The Australian Rail Track Corporation (ARTC) Code of Practice at the time of the derailment did not categorise bolt-hole cracks as defects requiring action unless they exceeded 20 mm in length.

Action taken by the Australian Rail Track Corporation

The ARTC initiated a review of their standards relating to inspection and assessment of bolt-hole cracks. In December 2008, the ARTC issued *Engineering (Track & Civil) Instruction, ETI-01-05, Bolt-hole Crack Limits*.

Under this instruction, all bolt-hole cracks are recorded as defects and require removal, irrespective of the crack size.

ATSB assessment of action

The ATSB is satisfied that the action taken by the ARTC adequately addresses the safety issue.

4.1.3 Interaction between heat-affected metal and bolt-hole

Safety Issue

The ARTC Code of Practice does not recognise the relationship between heat-affected metal and stress concentration when specifying how far a bolt-hole should be from the rail ends before welding.

ATSB safety advisory notice RO-2008-005-SAN-036

The Australian Transport Safety Bureau advises that the ARTC should consider the implications of this safety issue and take action where considered appropriate.

APPENDIX A : SOURCES AND SUBMISSIONS

Sources of Information

Australian Rail Track Corporation

Pacific National

Rail Technology International

Transfield Services

References

ARTC Track and Civil Code of Practice, April 2007

Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the Transport Safety Investigation Act 2003, the ATSB may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to:

- Australian Rail Track Corporation
- Pacific National
- Rail Technology International
- South Australian Railway Safety Regulator, and
- a small number of individuals.

Submissions were received from the Australian Rail Track Corporation and Pacific National. The submissions were reviewed and where considered appropriate, the text of the report was amended accordingly.

Derailment of Train 5PS6 Bates, South Australia on 19 April 2008.