Australian Government
Australian Transport Safety Bureau

# Partial separation of Express Passenger Train (XPT) ST24

Broadmeadows, Victoria | 11 August 2011

Investigation

**ATSB Transport Safety Report**
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# Safety summary

## What happened

On 11 August 2011, a scheduled Melbourne to Sydney Express Passenger Train (XPT) partially separated as it passed over a dip in the track near Broadmeadows, Victoria. The train suffered a total loss of power and was unable to continue its journey.

## What the ATSB found

The ATSB found that the tail pin in the draft gear between the lead power car and first carriage failed as a result of a brittle overstress fracture that was initiated by fatigue cracking. Recent routine ultrasonic testing had not detected the presence of the fatigue crack and post incident material testing established that the mechanical properties of the tail pin were below the required standard.

Following this incident, the ultrasonic testing procedure was revised to improve the detection of smaller cracks in the tail pin. However, the separation of another XPT near Seymour, Victoria, on 1 August 2012 in similar circumstances highlighted the fact that the ultrasonic testing regime was still not detecting all small fatigue cracks in critical areas of the tail pin.

This investigation did not examine how the track irregularities near Broadmeadow may have contributed to the partial separation of train *ST24*, why the track condition deteriorated significantly in the 6 weeks between when it was last rehabilitated and the day of the partial separation or why the inspection and maintenance regimes in place at the time did not detect the deterioration in track conditions. These issues will be considered as part of the broader safety issue investigation RI-2011-015 *Safety of rail operations on the interstate rail line between Melbourne and Sydney*.

## What's been done as a result

A new batch of tail pins has been manufactured to an upgraded standard which includes improved quality control and acceptance testing and RailCorp, the operator of the XPT fleet, is currently in the process of fitting these new tail pins. RailCorp has also further revised the tail pin inspection regime with the aim of improving its effectiveness.

## Safety message

It is important that components are fit for purpose and meet the appropriate requirements for service and that inspection regimes are effective in providing assurance of continuing equipment reliability.

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# The occurrence

At 0831 on 11 August 2011, Express Passenger Train (XPT) *ST24* departed Southern Cross Station Melbourne, on the standard gauge line, bound for Sydney Central Station. The train was operating in a 'push-pull' configuration with a power car at each end of six passenger cars. It was approximately 180 m long with an un-laden weight of about 407 t. Like all XPT trains, it had a maximum permitted speed of 160 km/h depending on track condition and posted speed limits.

About 25 minutes into the 11.5 hour journey, at the 16.7 km point[1], train *ST24* lurched as it passed over a 'twist'[2] in the track at a speed of 93 km/h (22 km/h below the speed limit of 115 km/h for that section). The train was approaching Broadmeadows station at the time and the lurch was felt by the driver and a track inspector who was in the lead power car cab at the time.[3] The passenger services supervisor, who was riding in the carriage directly behind the lead power car, also reported the rough ride to the driver.

The driver increased speed to 110 km/h and, about 1 minute later, at the 18.15 km point, the train travelled over a 'dip'[4] in the track. The train's movement as a result of the dip was also quite noticeable. Almost immediately, the train lost power to its motive traction system and the passenger car. Both power cars shut down and the train's brakes applied automatically[5], stopping it at about the 19.2 km point.

The driver advised the Junee Train Control Centre (NSW) that train *ST24* had lost power and had come to stop before he alighted to inspect the train.

While inspecting the train, the driver found that the coupling between the leading power car (XP2009) and the first passenger car (XFH2106) had been overextended, damaging the diaphragm (Figure 1). While the diaphragm between the lead power car and passenger car was still intact, it had been significantly stretched. He also found that the electrical jumper cable

**Figure 1: Overextended diaphram**

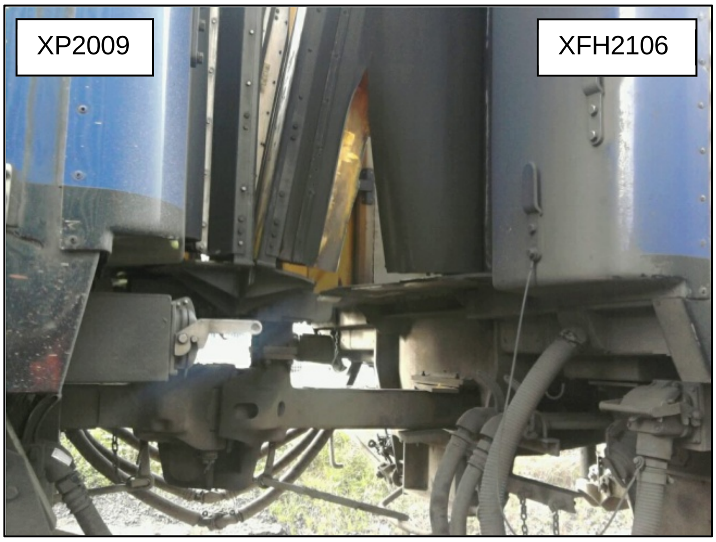


**Figure 2: Torn jumper**

Source: The passenger services supervisor

1 Measured from Southern Cross Station.
2 "Twist' in a rail is when there is a greater-than-normal difference in height between the two running rails.
3 The inspector was travelling on the train to inspect the track.
4 A downward variation in the running surface of a rail such as may occur, for example, at welds or rail ends.
5 Train braking systems are designed so that in the event of a train separation (or in this instance a partial separation), the brakes apply on all vehicles, providing a 'fail safe' condition.

between the two cars had been torn from its mount on the passenger car (Figure 2), but that the air brake hoses remained connected. While the train had parted, it had not completely separated.

The coupler on the passenger car was damaged to an extent that it could not be repaired on site. As a result, the journey to Sydney could not be completed.

In consultation with Junee Train Control, the driver detached the lead power car from the train so that it could be moved to the Somerton yard where it was stabled. The remainder of the train was checked and then driven back to Broadmeadows by the rear power car. The passengers then detrained and alternative arrangements were made for them to complete their journey by road.

The train was later taken to Tottenham and reversed around the Tottenham/Brooklyn triangle so that it could return to Sydney once it had been fully inspected.

A track inspection was conducted following the incident which resulted in the immediate application of a 50 km/h temporary speed restriction near the Broadmeadows platform for all trains.

# Context

## Train crew

The driver of train *ST24* signed on fit for duty and was appropriately qualified for the task. He was employed as a CountryLink driver based at Junee, NSW, and had 11 years of experience driving XPT trains between Melbourne and Sydney.

The on board staff consisted of a passenger services supervisor, a senior passenger attendant and two passenger attendants. There were about 70 passengers on board at the time of the incident.

## Operations management

The Defined Interstate Rail Network (DIRN) at Broadmeadows is a standard gauge single track with colour light signals to control bidirectional train movements to and from Melbourne. Network controllers and their managers/supervisors, located at the Australian Rail Track Corporation (ARTC) Network Control Centre at Junee, are responsible for the day to day operational management of the rail corridor between Tottenham Yard (Melbourne, Vic) and Glenlee (NSW)[6].

Network controllers are stationed at control boards that are allocated geographically according to distances and traffic density. Trains through Broadmeadows are managed by a network controller using the ARTC Phoenix control system. The Phoenix control system is a 'non-vital'[7] 'CTC'[8] system that provides real-time monitoring and/or control of field hardware including signals, points, track circuits and the associated management of train movements. Signal, points, track and train movement data is captured by the Phoenix event logger.

Voice communication between train drivers and the network controller is via the Victorian and NSW train-to-base radio systems.

## Track structure and condition

The track near Broadmeadows rises from Melbourne with a slight curve through Broadmeadows platform after which it is predominantly straight and level. It consisted of 60 kg/m rail anchored to concrete sleepers with resilient fasteners at spacings of about 667 mm in a bed of ballast with a nominal depth of 300 mm.

### *The twist*

Following the incident, an inspection of the track was conducted by investigators from the Chief Investigator Transport Safety Victoria (CITS)[9] and a twist was identified in the down rail of the track at the 16.790 km point on the approach to the Broadmeadows platform (Figure 3). The twist was examined and a maximum deviation of 46 mm was recorded (Figure 4).

On 12 August 2011, the ARTC conducted track geometry recordings which confirmed the onsite measurements. The track defect was at a level requiring immediate maintenance intervention. Of note is the fact that no rough riding reports which would have triggered immediate track maintenance action had been received from trains transiting that area prior to the incident.

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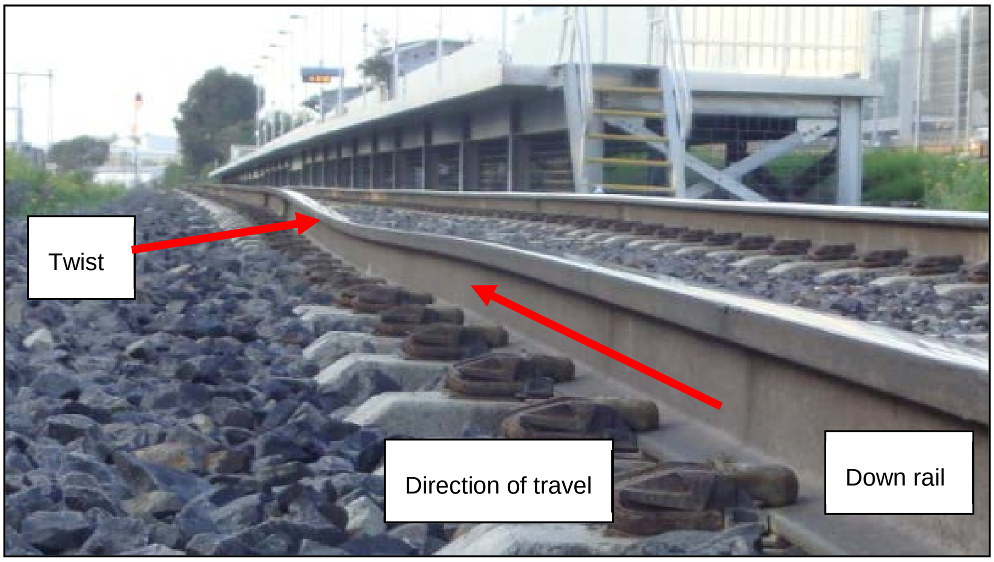
6 This function has since been transferred to ARTC in Mile End, Adelaide.

7 Non-vital: signalling equipment and circuits are considered non-vital where failure to function correctly would not cause an unsafe outcome of the signalling system. Non-vital equipment and circuits do not affect the safe operation of the signalling system.

8 Centralised Traffic Control (CTC): a safeworking system of remotely controlling the points and signals at a number of locations from a centralised control room.

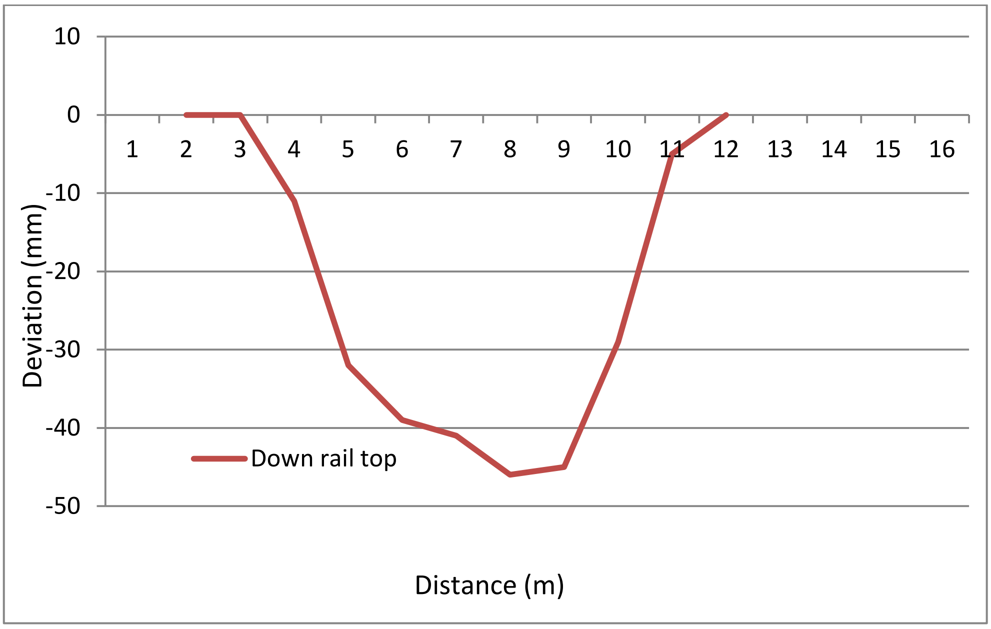
9 CITS assisted with an onsite inspection and collection of evidence on behalf of the ATSB.

**Figure 3: Twist at 16.790 km**




Source: Chief Investigator Transport Safety Victoria

**Figure 4: Twist measurement**




Source: ATSB

## *The dip*

An inspection of the track was also conducted by the investigators to confirm the existence of a dip in the track near the point of power loss (Figure 5). The dip, which was visually clearly apparent, was located at the 18.150 km point, about 1.36 km from the earlier identified twist.

The track was surveyed recording the 'track top'[10], 'cant'[11], and 'void'[12] measurements. Reference points were marked at 2 m intervals from the 18.147 km point until the 18.179 km point (Figure 6).

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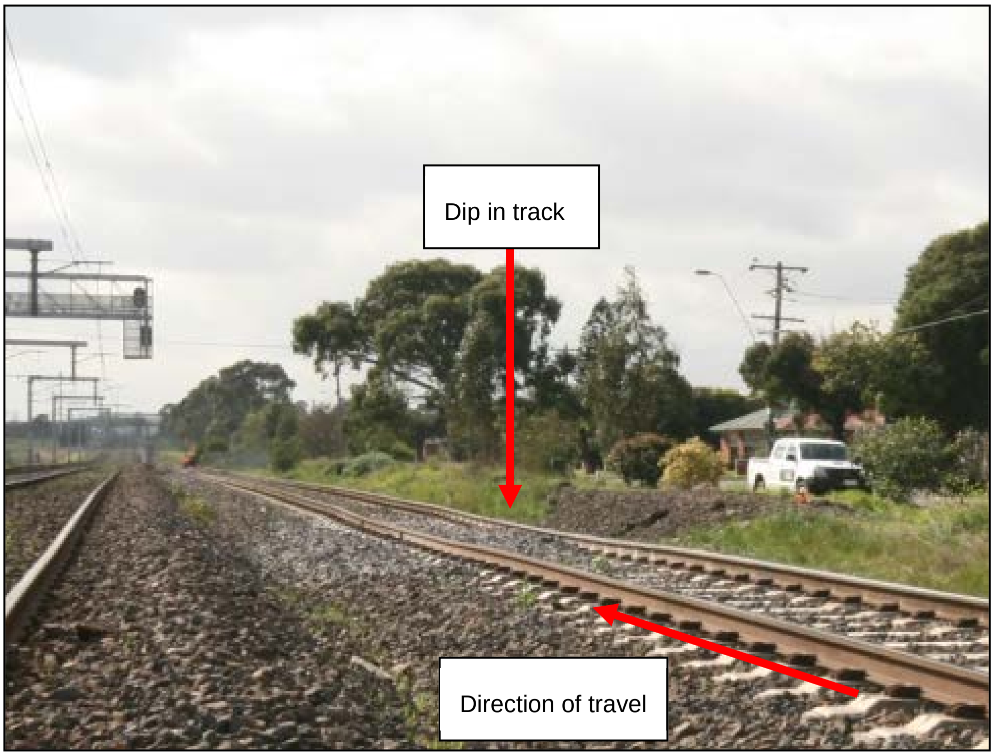
10 Vertical alignment of rails.

11 The height difference, at a common location, between the running surface of both rails. Also known as 'superelevation' or 'cross level'.

12 Measurement of the vertical deflection of the track structure whilst under load.

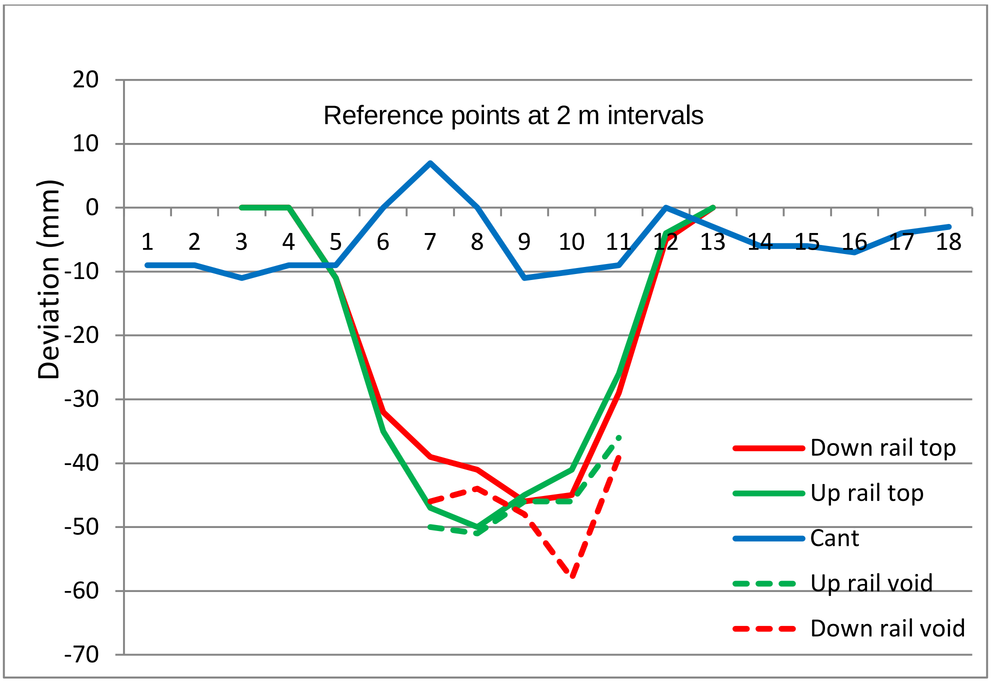
Void measurements were only recorded between 18.157 km and 18.169 km (Figure 6). Track gauge, although not actually measured as the track was concrete-sleepered, was noted to be within tolerance during the measurement of cant and there was no significant lateral deviation in the track.

**Figure 5: Dip at 18.150 km**




Source: Chief Investigator Transport Safety Victoria

**Figure 6: Dip measurements**




Source: ATSB

Information received from staff on site was that the track was re-sleepered with concrete sleepers in the first half of 2009 and, on 1 July 2011, the section of track where the dip was located had been resurfaced to address an ongoing mud hole issue that had existed in the area since early 2010. However, there were no speed restrictions on that section of track at the time of the incident.

On 12 August 2011, the ARTC conducted track geometry recordings which confirmed the on-site measurements taken by the investigators. The track had deteriorated to a point that required immediate intervention. Similar to the twist at 16.790 km, no rough riding reports which would have triggered an immediate maintenance response had been received from trains transiting the area in the time preceding the incident.

### *Summary*

Post incident site measurements showed that the defects in the track required immediate intervention. While the track had been regularly inspected prior to the incident, no significant faults had been identified in this time. Furthermore, there were no train reports of 'rough track' in the area. The area was known to suffer reoccurring mud holes and, as a result, was regularly rehabilitated with freshly packed ballast. On this occasion, the track had deteriorated rapidly since it was last rehabilitated on 1 July 2011.

On 16 August 2011, the Hon Anthony Albanese MP, Minister for Infrastructure and Transport, requested that the ATSB undertake a systemic investigation of the safety of rail operations on the interstate rail line between Sydney and Melbourne. In accordance with the Minister's request, the ATSB commenced safety issue investigation RI-2011-015 which is considering:

- The condition of the interstate rail track and measures that have been put in place to maintain the safety of rail operations where track quality is below acceptable operational standards.
- Actions undertaken by the ARTC to remediate the track and address the safety of operations.
- Safeworking practices in relation to the track.
- A systemic review of safety systems; including signalling and the quality assurance of work undertaken on the track.
- Any other matters considered relevant by the ATSB.

This investigation did not examine how the track irregularities near Broadmeadow may have contributed to the partial separation of train *ST24*, why the track condition deteriorated significantly in the 6 weeks between when it was last rehabilitated and the day of the partial separation or why the inspection and maintenance regimes in place at the time did not detect the deterioration in track conditions. These issues will be considered as part of the broader safety issue investigation.

## The draft gear assembly

The draft gear assembly[13], which connected the power car rear end and the trailer cars, consisted of two main components: the coupler and the draft gear (Figure 7). The draft gear consisted of the drawbar tail pin, two nests of rubber springs with dividing plates (items 3 and 5) and the front and back followers. The front set of five rubber springs and four dividing plates handled the 'buffing' (compressive) loads and the back set of three rubber springs and two dividing plates handled the 'draft' (tensile) loads.

The coupler was attached to the draft gear by a pin, which secured the drawbar tail pin to the coupler shank. A retaining nut and washer was fitted to the inboard end of the tail pin to provide pre-compression of the springs.

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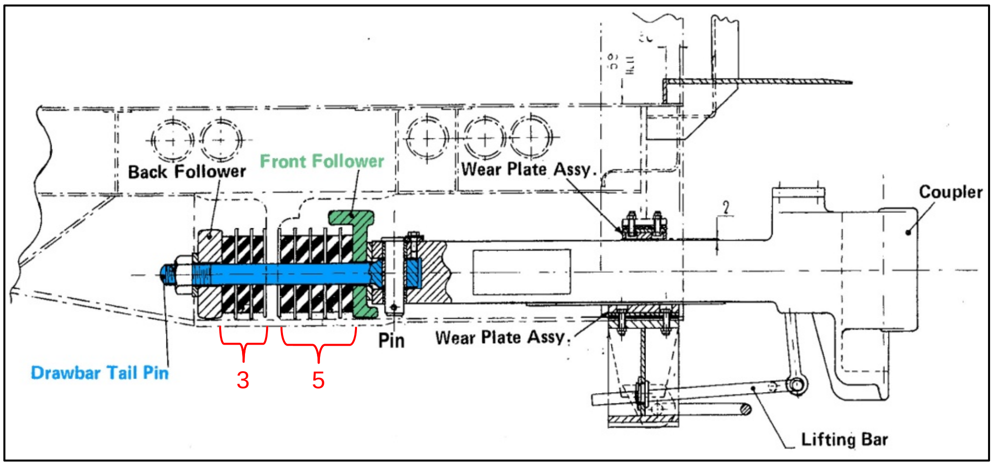
[13] Drawing number 110-390, *XPT Draft gear Drawbar Tail Pin and Bush assembly.*

**Figure 7: Coupler and draft gear assembly**

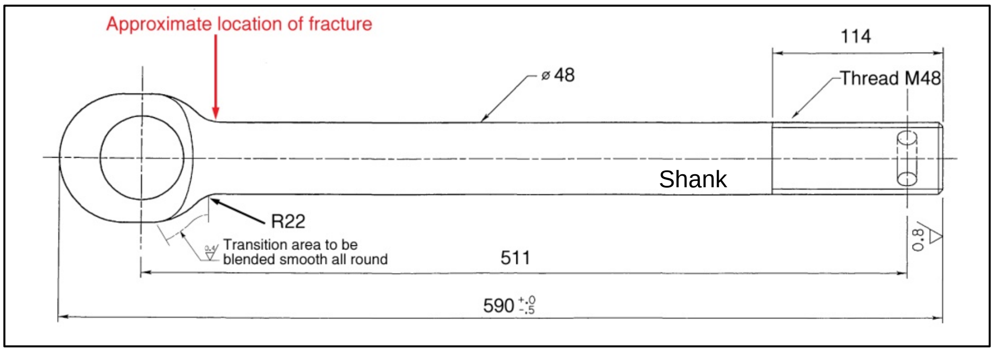



Source: RailCorp

## *Tail pin*

The RailCorp engineering drawing of the drawbar tail pin specified that it be 590 mm in length with a diameter of 48 mm (Figure 8). The drawing also specified that the tail pin be machined from AS 2506[14] steel, a low-alloy steel with a specified hardness of 269-331 Brinell[15] (HBN) and that there be no subsequent heat treatment.

**Figure 8: Drawbar tail pin schematic showing location of fracture.**




Source: RailCorp

The tail pin from carriage XFH2106, stamped with the batch number BU 06 04 indicating the manufacturer and date of fabrication (Bradken Rail, June 2004) was retained and examined by the ATSB.

The examination[16] determined that the tail pin failed as a result of low stress high cycle reverse bending fatigue that had initiated fatigue cracks on both sides of the tail pin in the region adjacent to the change in section from the boss to the shank. This location was also coincident with the area of the tail pin in contact with the front follower. The fatigue crack (Figure 9) had propagated to a depth of about 3 mm on one side before the final fracture occurred due to a brittle overstress mechanism.

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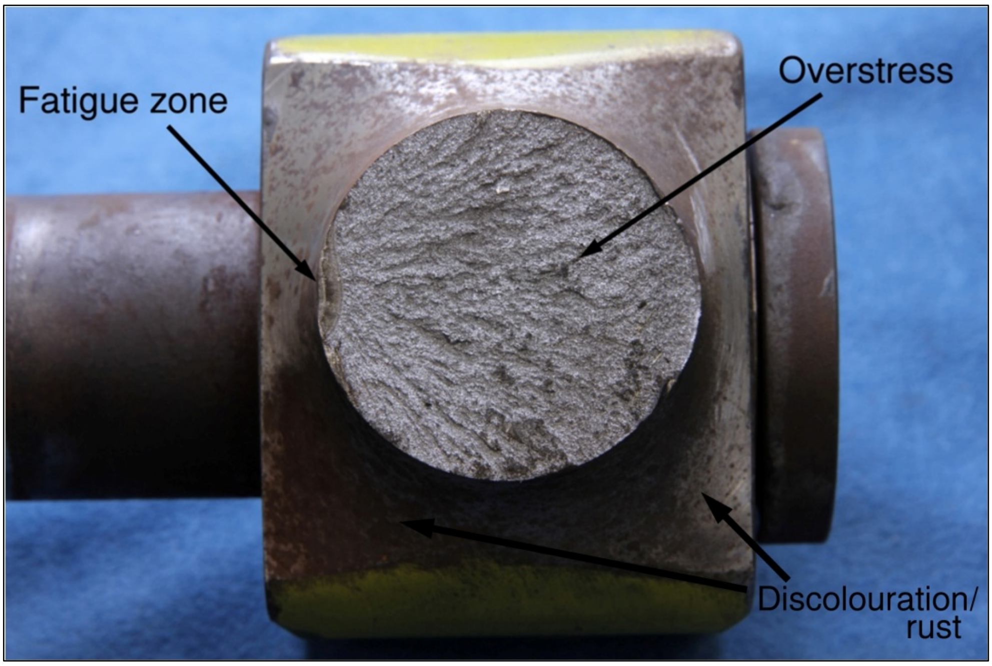
14 Wrought alloy steels - Hardened and tempered to designated mechanical properties (superseded by AS 1444 Wrought alloy steels - Standard, hardenability (H) series and hardened and tempered to designated mechanical properties) X9931U

15 The Brinell scale characterises the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece

16 A more detailed description of the examination can be found in Appendix 1 of this report.

**Figure 9: Fracture face on boss side of the fracture**




Source: ATSB

The machined surfaces of the tail pin exhibited evidence of widespread corrosion/rust, which was particularly evident on the boss side of the fracture. A number of additional fatigue cracks identified in the region surrounding the primary fracture surface appeared to have initiated from these small depressions/pits in the surface.

The material properties of the tail pin were generally below those specified for the material specification on the engineering drawing. While the hardness and chemical analysis for the pin were within the specified limits, albeit towards the lower end, the tensile and Charpy[17] impact results were well below that specified for the material type.

The likely contributors to the fatigue crack initiation and propagation were the normal in-service stresses, the change in cross sectional area, the surface finish and the corrosion that had developed on the surface of the tail pin. The small area of the fatigue zone and the mostly brittle fracture surface was most likely the result of a combination of the inherent low material toughness, and high cyclic load/stress on the tail pin causing the final overstress fracture.

The evidence indicates that fatigue cracking was initiated in the tail pin by normal in service cyclic stressing and that this cracking propagated over time. Then, on 11 August 2011, when the lead power car of train *ST24* passed over a dip in the track, the pin fractured as a result of brittle overstress mechanism.

## *Front follower*

The engineering drawing for the front follower specified that all existing front followers be modified by machining an 8 mm radius on the coupler side of the hole. [18] The purpose of the radius was to remove the likelihood of interference with the tail pin and consequential wear at a high stress point.

The front follower from train *ST24* had a radius around a portion of the hole on the coupler side (Figure 10 and Figure 11). However, the radius was not present around the entire circumference

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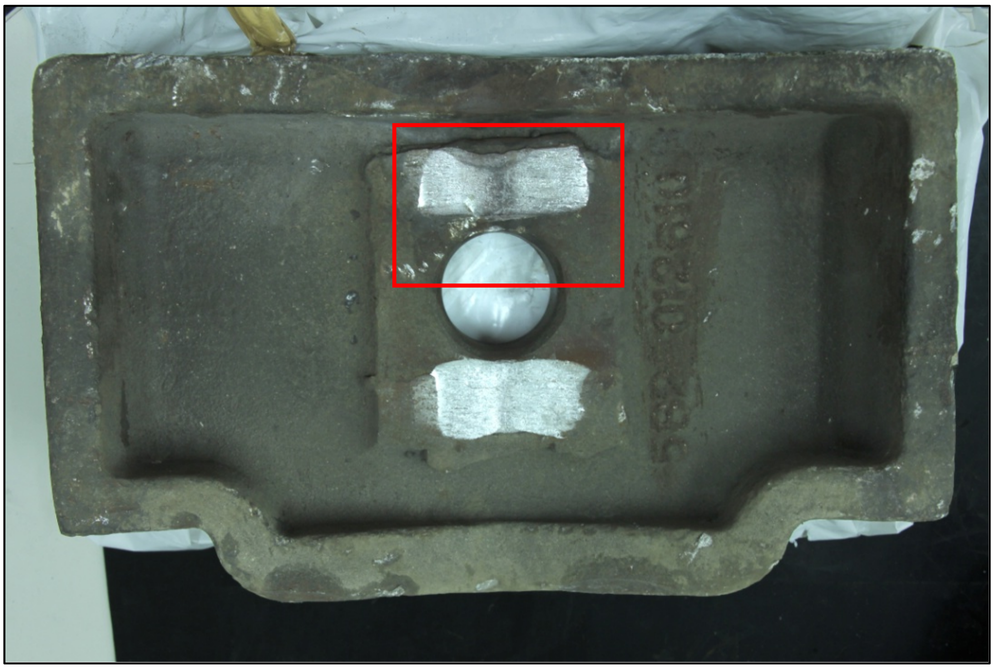
[17] A standardised high strain-rate test which determines the amount of energy absorbed by a material during fracture.

[18] Drawing Nos. 109-179, *Railcars draftgear front follower.*

of the hole, particularly on the lower side of the hole. Furthermore, where present, the radius was not a consistent 8 mm.

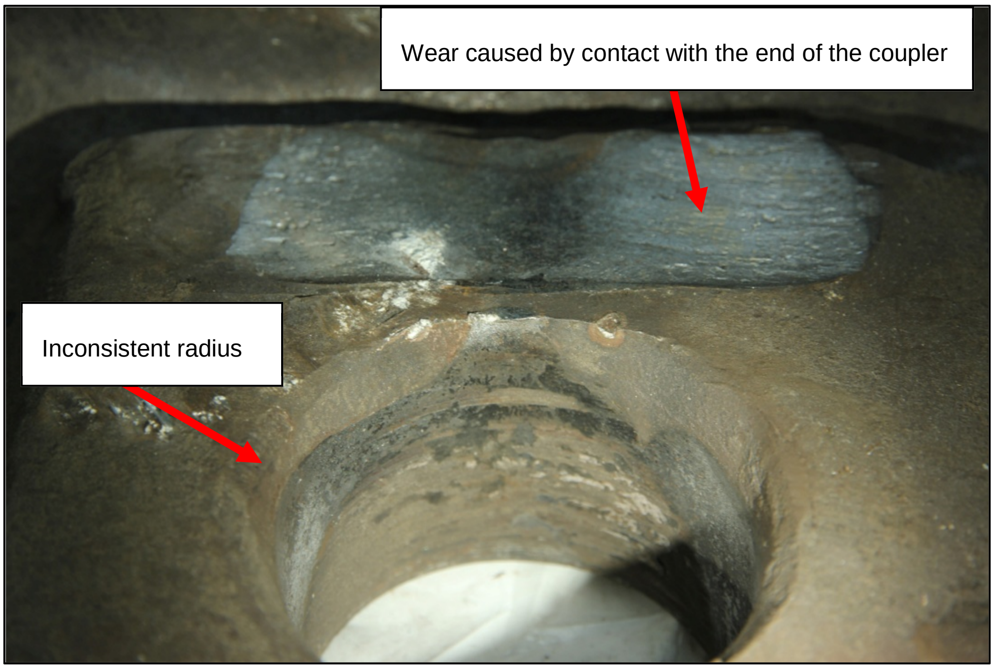
**Figure 10: Overview of front follower**



Source: ATSB

Although the ATSB's examination provided no evidence of interference between the front follower and tail pin, the possibility that the missing follower hole radius may have contributed in some way to the stress on the tail pin cannot be completely discounted.

**Figure 11: Magnified view of the front follower hole in contact with tail pin**




Source: ATSB

## History of XPT tail pin failures

Since the XPT was introduced in 1982, there have been a number of draft gear tail pin failures. In October 1986, the first XPT tail pin failure occurred at Redfern, NSW. In response to this failure, a regime of 6 monthly in-situ ultrasonic testing was introduced.

In January 1987, a second failure occurred at Tamworth, NSW. In response, metallurgical studies were carried out on the tail pins. These studies revealed that substandard material had been used in the original pin forging process. As a result, the tail pin manufacturing process was respecified and new tail pins, machined from bar stock (rather than forged), were ordered and a complete XPT fleet change out took place.

In 2002, it was identified that ineffective record keeping had led to a situation where the installation date of tail pins and their specifications could not be identified. In response, a new requirement was introduced to engrave the date of manufacture/batch on the head of the tail pin, in a position visible when in service. A new batch of tail pins were procured and a fleet change-out took place.

In 2004, changes were made to the XPT draft gear. These changes required the removal of the tail pins, a process that damages the pins and renders them unfit for re-use. Consequently, all tail pins were once again changed in 2004. These 2004 tail pins were in service on the XPT fleet when the Broadmeadows incident occurred.

## Testing by RailCorp

As a result of the incident at Broadmeadows on 11 August 2011, RailCorp commissioned finite element analysis (FEA) of XPT tail pins. The analysis included the fitment of strain gauges to highly stressed areas of a new tail pin, of the same type which failed, installed in an XPT power car to determine typical loading during in-service operations. The data was collected between 14 and 17 September 2011 on the Melbourne, Brisbane and Dubbo sectors. The resulting data was analysed and, in summary, an internal briefing note[19] concluded that:

- FEA has confirmed that the identified high stress 'hotspots' on the tail pin are the areas where cracks have been found (Figure 12).
- The failure mode for the tail pin has been confirmed as being primarily through vertical and lateral bending near the head of the tail pin.
- Maximum top bending stress of 450 MPa was recorded, which corresponds to 580 MPa in the critical area. Whilst this stress exceeds the fatigue limit but not the yield limit, some damage would have occurred.
- The initial run to Melbourne has shown indications that some plastic deformation has possibly occurred on the tail pin when traversing over sections of rough track (level crossing at Culcairn, and a combination of level crossings and short bridges at Balmattum).

The briefing note concluded that:

> A follow-up test run to Melbourne is recommended on XP2010 in order to resolve the two instances on the Main South Line where strain readings suggest that plastic deformation has occurred on the tail bolt...

The data obtained from the FEA was used by RailCorp to develop new requirements and tests for tail pins.

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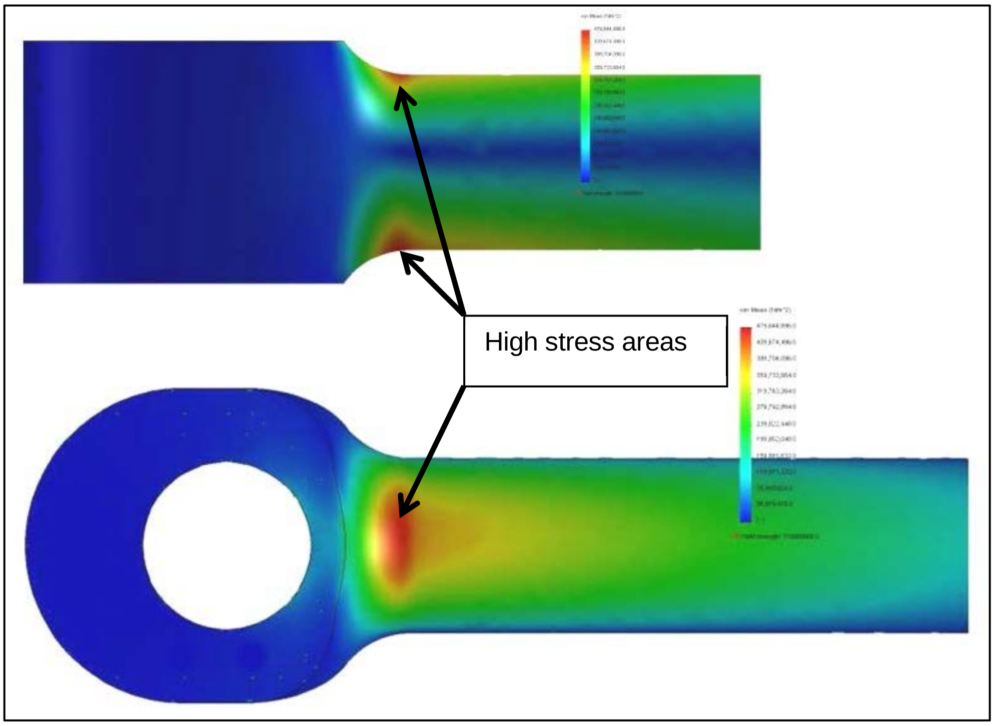
[19] Internal RailCorp briefing note dated 7 November 2011.

**Figure 12: FEA results of tail pin high stress areas**




Source: RailCorp

### *RailCorp actions following the Broadmeadows incident*

RailCorp's tests and review of the in-service loads on the tail pin assembly led to the following improvements being implemented:

- The introduction of a change in manufacturing method using a forged pin.
- The introduction of a more stringent control of the surface roughness of the boss to shank radius.
- The addition of a treatment to assist in reducing the formation of rust/corrosion on the surface.
- The development of a new tail pin drawing reflecting the above and specifying quality measures including Charpy impact, tensile strength, chemical analysis and hardness tests.
- An inspection of all front followers to ensure that the radius has been correctly machined.
- The replacement of tail pins after a maximum of 5 years service, based on the average age of failure being 7 years.
- The replacement of all existing tail pins by April 2013.
- Non destructive (ultrasonic) testing was conducted across the fleet to check all tail pins and the time between in-service ultrasonic testing was reduced from 3 months to every six weeks between passenger cars, and between power cars and passenger cars to 3 weeks. The method of conducting the testing was also respecified to improve the reliability of the results.

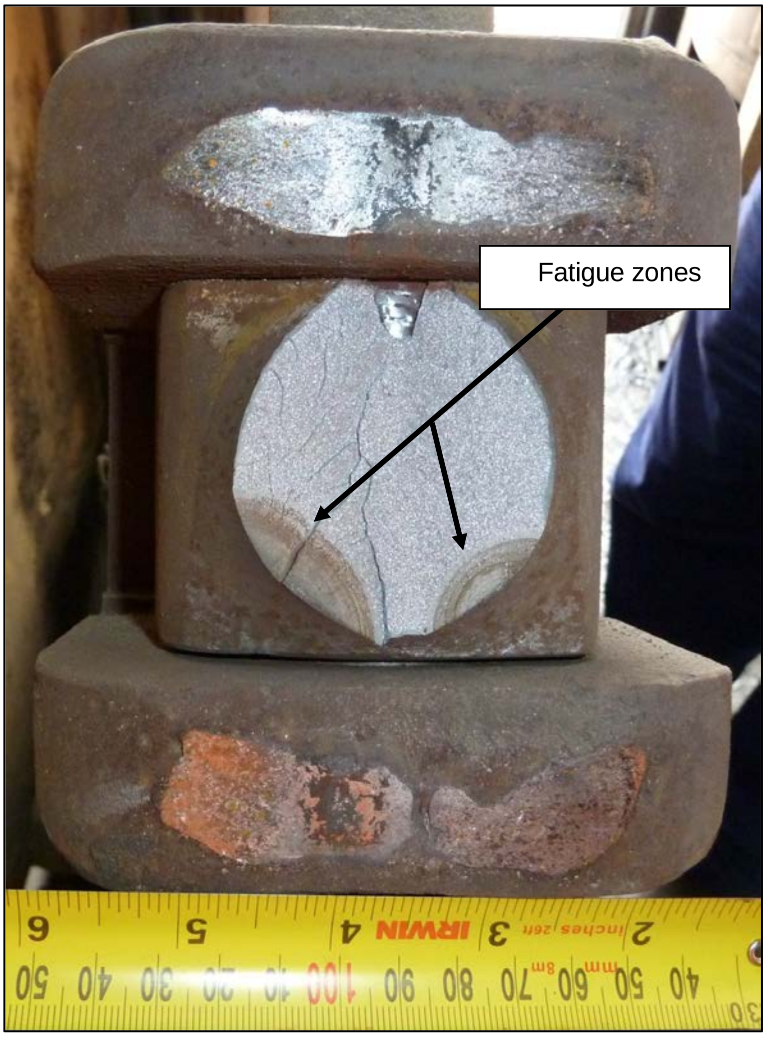
## Subsequent incident near Seymour on 1 August 2012

At about 1802 on 1 August 2012, XPT *ST23* was en route from Sydney to Melbourne when its driver reported a loss of air pressure shortly after traversing a level crossing between Longwood and Seymour, Victoria.

On investigation, it was determined that the tail pin in the coupler between the lead power car and the adjoining passenger car had failed and, as a result, the brake line and other service connections had been overextended and damaged.

The ATSB examined the failed tail pin from train *ST23* and found that its failure was initiated from two areas of fatigue cracking (Figure 13). The failure was very similar in nature to that of train *ST24* at Broadmeadows on 11 August 2011.

**Figure 13: Fractured tail pin from *ST23***




**Source: ATSB**

# Safety analysis

## Tail pin quality

The tail pin which failed on train *ST24* at Broadmeadow on 11 August 2011 and the tail pin which failed on train *ST23* at Seymour on 1 August 2012 were both from the same batch (stamped BU 06 04). The pins were manufactured by Bradken Rail in June 2004 and when received by RailCorp were tested in accordance with their engineering drawing which stipulated that 10 per cent of the batch delivered shall be tested for hardness and material compliance. Tests included chemical composition, hardness, dimensional and surface roughness but did not include tensile strength or Charpy[20] mechanical tests.

The RailCorp test report, dated 30 July 2004, indicated that chemical testing revealed that the tail pin material complied with the relevant Australian Standard AS 1444/X9931. Hardness testing determined a result of 270 HBN which was at the bottom of the acceptable range of 269-331 HBN. The test report also stated:

> The tailpin has been made from the specified grade of steel and has the specified hardness.
>
> The machining quality falls short of requirements in two critical areas, namely the shank/head transition is not blended smoothly, and the surface roughness of the shank and shank/head transition are much coarser than specified. These defects make the tailpin highly susceptible to fatigue cracking during operation.

The report recommended:

> The batch of tailpins from Bradken Rail should be rejected, as the critical requirements of surface roughness and shank/head transition geometry are significantly sub-standard.

The tail pins were subsequently returned to the manufacturer for rework. A second assessment report dated 23 December 2004 on the reworked tail pins noted that:

> The tailpin has been re-machined by abrasive linishing, forming a fine circumferential crosshatch pattern.
>
> The radius between shank and head is specified on the drawing as; “transition area to be blended smooth all round”. The transition area on the sample is not smoothly radiused, but has localised changes in radius forming faint ridges around the circumference. This feature remains from the original supplied condition but has been reduced slightly by the remedial linishing.

With regard to the surface roughness issue identified in the first report, the second report noted:

> The surface roughness is greatly improved on the previous sample but falls slightly short of the 0.4 μm requirement for the shank/head transition area.
>
> Re-machining of the tailpin has slightly improved the surface profile and greatly improved the surface roughness. The surface quality still falls slightly short of requirements for smooth blending and surface roughness of the shank/head transition.

The report recommended:

> Although the test results are slightly below requirements, the surface quality is within an acceptable range and should give satisfactory service. Thus the re-machined batch of tailpins from Bradken Rail should be accepted on concession.

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20 Charpy V-notch test is a standardised high strain-rate test which determines the amount of energy absorbed by a material before fracture.

RailCorp advised that acceptance of the tail pins in 2004 'on concession' meant that although the tail pins were not completely within specification they were close enough to be considered acceptable.

However, the RailCorp acceptance testing did not include mechanical property tests other than Brinell hardness and consequently RailCorp was not aware that the tail pins fell well short of the requirements of Australian Standard AS 1444-2007 alloy X9931 for tensile strength and toughness (see Appendix 1).

Tensile strength testing is used to determine a material's properties such as yield strength, ultimate strength and ductility. Charpy testing provides a measure of a material's notch toughness, which is the ability of a material to absorb energy before final fracture. Both tests would have indicated the unsuitability of the BU 06 04 batch of tail pins to resist the type of failure which ultimately resulted in the train parting's which occurred at Broadmeadows and Seymour. Had RailCorp's acceptance testing been more rigorous, it is likely that the 2004 batch of tail pins would have been identified as below standard and, hence, would not have been accepted.

As a result of the Broadmeadows incident, RailCorp has revised the engineering drawing for the XPT tail pin. The drawing now specifies forged components and states that Charpy, tensile strength, chemical composition and hardness tests are required on a sample of tail pins. Additionally, RailCorp has commenced fatigue, fracture mechanics and fracture toughness tests on the new forged tail pins.

## Draft gear maintenance

The XPT passenger train fleet is regularly inspected and maintained in accordance with RailCorp's engineering procedures. Inspection frequencies were divided into four categories:

- Running inspections done while at the depot between runs.
- Trip inspections done on a distance travelled basis.
- 45 day traction motor inspection.
- Major inspections (A to H) carried out on a 90 day to 2 year cycle.

The draft gear forms part of the above inspections, notably through the major inspections which include ultrasonic testing of the tail pin.

### *Ultrasonic testing and inspections*

Prior to the incident at Broadmeadow, XPT tail pins were ultrasonically inspected in-situ every 3 months and it was not uncommon for a crack to be detected and for the pin to be condemned. However, the failed tail pin from train *ST24* was ultrasonically tested 2 weeks prior to its failure during a regular inspection and no cracks were detected. Therefore, it was returned to service.

While the failure occurred only 2 weeks after ultrasonic inspection, the small size of the fatigue zone (3 mm deep) would have been difficult to detect. Since the ultrasonic testing was carried out in-situ from the threaded end of the pin, the threads (approximately 3 mm deep in an M48 thread) may have interfered with the detection of small fatigue cracks at the boss end of the pin.

Following this incident, RailCorp updated the ultrasonic inspection procedures to reduce the risk of masked cracks and lowered the inspection interval for tail pins between passenger cars to 6 weeks, and between power cars and passenger cars to 3 weeks.

### *Subsequent incident near Seymour (RO-2012-008)*

The subsequent incident at Seymour highlighted the fact that the revised ultrasonic method had failed to detect two large fatigue cracks (Figure 13 on page 12).

While the failure occurred only days after an ultrasonic inspection, the fatigue cracks were not detected. It is likely that the location and orientation of the fatigue zone (further towards the boss end, off centre and at an angle to the principal axis) would have been difficult to detect using the inspection regime in place due to the geometry of the sample and the interference of the split pin hole.

A fatigue crack had also initiated on the lower side at the generally expected location. However, it had not grown to a size that was large enough to be detected during the scheduled inspection.

Given the similarities of both occurrences, and the apparent ineffectiveness of the corrective action taken by RailCorp following the Broadmeadows occurrence, the ATSB had significant concerns regarding RailCorp's ongoing coupler maintenance regime. Therefore, on 3 August 2012, the ATSB advised RailCorp that:

> As a result of the apparent ineffectiveness of the ultrasonic testing regime in detecting fatigue cracks in tail pins, the probability of a future in-service failure has increased. Compounding this, is the progressive growth behaviour of the fatigue cracking mechanism, meaning that the likelihood of such an event is further increased as service time accrues.
>
> While the ATSB understands and agrees that there is a low likelihood of such a failure leading to a separation of the draft gear package and a subsequent derailment, the consequences of such an event, should it occur at speed, are significant.

RailCorp has since worked on developing an enhanced Non-Destructive Testing (NDT) process to address the failure which occurred further along the tail pin radius than had previously been encountered. The procedure has been modified to include testing using 45 degree probes on the tail pin head for the 12 o’clock and 6 o’clock positions. The new procedure also resulted in revision of the engineering drawing to relocate the manufacturer’s marking on the tail pin head. Validation testing of the new procedure has been completed.

# Findings

On 11 August 2011, a scheduled Melbourne to Sydney Express Passenger Train (XPT *ST24*) partially separated as it passed over a dip in the track near Broadmeadows, Victoria. The train suffered a total loss of power and was unable to continue its journey.

From the evidence available, the following findings are made with respect to the partial separation of train *ST24*. They should not be read as apportioning blame or liability to any particular organisation or individual.

This investigation did not examine how the track irregularities near Broadmeadow may have contributed to the partial separation of train *ST24*, why the track condition deteriorated significantly in the 6 weeks between when it was last rehabilitated and the day of the partial separation or why the inspection and maintenance regimes in place at the time did not detect the deterioration in track conditions. These issues will be considered as part of the broader safety issue investigation RI-2011-015 *Safety of rail operations on the interstate rail line between Melbourne and Sydney*.

## Contributing safety factors

- Train *ST24* partially separated when the tail pin in the draft gear package of carriage XFH2106 failed after the train travelled over a dip in the track at the 18.150 km point.
- The final fracture of the tail pin was the result of a brittle overstress mechanism that originated from a small area of pre-existing fatigue cracking.
- The tensile properties and Charpy impact results of tail pins stamped BU 06 04 were well below those for the material type specified by RailCorp.
- RailCorp's acceptance testing regime for tail pins did not identify that the tail pins stamped BU 06 04 were below standard and, hence, not suitable for service. *[Significant safety issue]*
- The fatigue crack located on the boss-to-shank fillet radius of the tail pin was not detected during routine scheduled inspections.
- The method used to ultrasonically test the tail pins in-situ was not reliable and resulted in small fatigue cracks going undetected. *[Significant safety issue]*

## Other key findings

- The hole through the front follower on the coupler side was not machined with a minimum radius of 8 mm around the edge as per the engineering drawing.
- Based on the data recorded by the Hasler system and the driver's statement, train handling is not considered to be a contributing factor.
- The chemical properties of tail pins stamped BU 06 04 were within standard for Alloy X9931.

# Safety issues and actions

The safety issues identified during this investigation are listed in the Findings and Safety issues and 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. 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.

Depending on the level of risk of the safety issue, the extent of corrective action taken by the relevant organisation, or the desirability of directing a broad safety message to the rail industry, the ATSB may issue safety recommendations or safety advisory notices as part of the final report.

## XPT tail pin acceptance

| | |
|---|---|
| Number: | RO-2011-012-SI-01 |
| Issue owner: | RailCorp |
| Operation type: | Rail – owner/operator/maintainer |
| Who it affects: | Operators of trains with this arrangement of tail pin |
| Risk: | Significant |

***Safety issue description:***

RailCorp's acceptance testing regime for tail pins did not identify that the tail pins stamped BU 06 04 were below standard and, hence, not suitable for service.

***Current status:***

Residual risk: Minor
Issue status: Adequately addressed
Justification: Proactive safety action taken by RailCorp

***Proactive safety action taken by: RailCorp***

RailCorp has revised the engineering drawing for the XPT tail pin. The drawing now specifies forged components and states that; Charpy, tensile strength, chemical composition, surface finish, hardness tests, and quality control tests are required. Additionally, RailCorp has commenced fatigue, fracture mechanics and fracture toughness tests on the new forged tail pins to determine the period at which mandatory tail pin replacement should occur.

## XPT tail pin testing

| | |
|---|---|
| Number: | RO-2011-012-SI-02 |
| Issue owner: | RailCorp |
| Operation type: | Rail – owner/operator/maintainer |
| Who it affects: | Operators of trains with this arrangement of tail pin |
| Risk: | Significant |

***Safety issue description:***

The method used to ultrasonically test the tail pins in-situ was not reliable and resulted in small fatigue cracks going undetected.

***Current status:***

| | |
|---|---|
| Residual risk: | Minor |
| Issue status: | Adequately addressed |
| Justification: | Proactive safety action taken by RailCorp |

***Proactive safety action taken by: RailCorp***

Ultrasonic testing procedures for XPT tail pins have undergone continuous development following both the Broadmeadow and Seymour incidents.

A revised procedure for conducting ultrasonic testing of tail pins has been developed and published on 15 March 2013. The new procedures have been in use for testing tail pins since February 2013.

The latest testing procedure involves three different tests; a single probe along the shaft of the tail pin, two 45 degree angle probes on the head of the tail pin and a single 60 degree angle probe on the head of the tail pin. The latter two tests were introduced after the Seymour incident and are able to detect fatigue cracks that the original test did not.

Additionally, the ultrasonic test provider has undertaken to conduct proficiency examinations and certify their technicians who perform these tests. Certification results will be provided to RailCorp and only certified technicians will be used to undertake tail pin testing on the XPT fleet.

# General details

## Occurrence details

| | | |
|---|---|---|
| Date and time: | 11 August 2011 | |
| Occurrence category: | Incident | |
| Primary occurrence type: | Separation | |
| Type of operation: | Passenger, *ST24* | |
| Location: | Near Broadmeadows, Victoria | |
| | Latitude: 37° 40.18' S | Longitude: 144° 55.26' E |

## Occurrence details

| | | |
|---|---|---|
| Date and time: | 1 August 2012 | |
| Occurrence category: | Incident | |
| Primary occurrence type: | Separation | |
| Type of operation: | Passenger, *ST23* | |
| Location: | Near Seymour, Victoria | |
| | Latitude: 36° 58.28' S | Longitude: 145° 09.47' E |

## Train details

| | | |
|---|---|---|
| Train operator: | RailCorp | |
| Train number: | *ST24* and *ST23* | |
| Type of operation: | Passenger | |
| Injuries: | Crew – Nil | Passengers – Nil |
| Damage: | Minor | |

# Appendix 1

## Technical Analysis Report

### *Examination of fractured tail pin from train ST24*

#### *Visual examination*

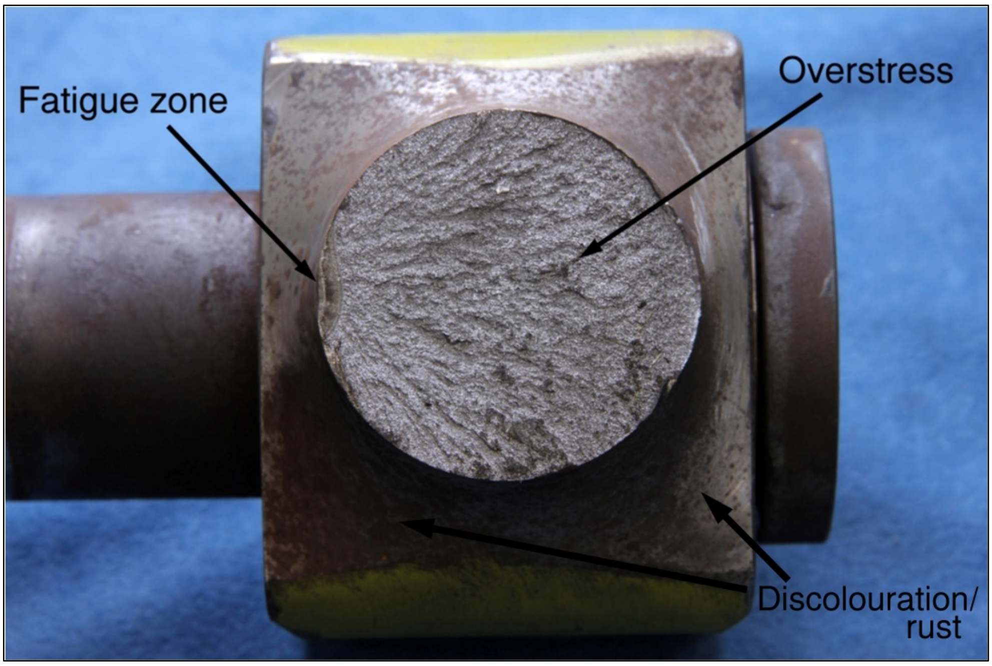
The drawbar tail pin had fractured at a location coincident with the change in cross sectional area at the boss end of the shank (Figure 14).

**Figure 14: Fractured segments of drawbar tail pin**

Source: ATSB

A number of circumferential grooves/wear marks were also observed along the length of the shaft section of the pin, as a result of their contact with the rubber spring/dividing plates. The external surface of the tail pin exhibited widespread discolouration/rust spots, particularly on the boss side of the fracture (Figure 15). The boss was stamped with BU 06 04, a batch number indicating the manufacturer, the year and month of fabrication.

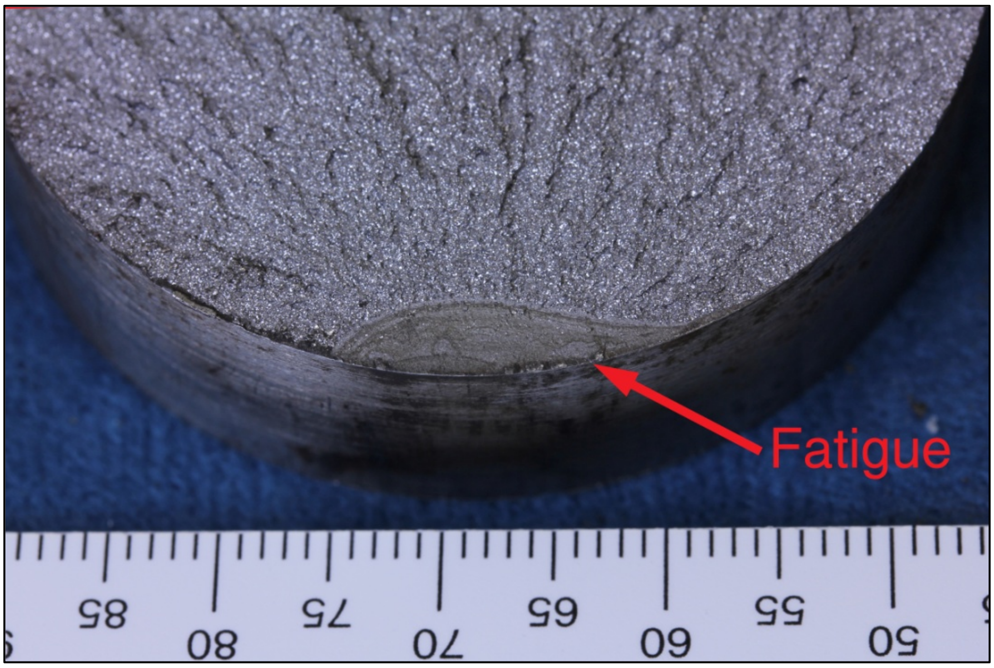
**Figure 15: Fracture face on boss side of the fracture**




Source: ATSB

The fracture face was perpendicular to the principal axis of the tail pin and was smooth and flat. Evidence of cyclic fatigue crack progression (beach[21]) marks were observed radiating outward from one side of the fracture face, which coincided with the lower side of the pin in situ. The beach marks extended radially from the lower surface and extended across a small area (approximately 3 mm) of the fracture surface (Figure 15). The largest proportion of the fracture surface was consistent with a brittle overstress failure.

**Figure 16: Magnified view of the fatigue zone on the shaft side of the fracture**




Source: ATSB

The fatigue zone on the boss side of the fracture face exhibited minor smearing along the edge which is consistent with post fracture mechanical damage. The fatigue area on the shaft side was obscured by dirt, however once this was cleaned, the fracture face was evident. The fracture face was perpendicular to the principal axis of the tail pin and was smooth and flat. Evidence of cyclic fatigue crack progression (beach) marks were observed radiating outward from one side of the fracture face, which coincided with the lower side of the pin in situ. The beach marks extended radially from the lower surface and extended across a small area (approximately 3 mm) of the fracture surface (Figure 15). The largest proportion of the fracture surface was consistent with a brittle overstress failure (Figure 16). Some ratchet marks were observed, but no damage on the surface of the shaft was identified that may have contributed to the fatigue crack initiation.

The physical dimensions of the tail pin were measured (length, diameter, thread characteristics) and found to be consistent with those specified in the engineering drawing. The surface finish of the radius could not be measured due to the surface contours.

### *Non-destructive examination – Magnetic particle inspection*

Both sections of the fractured tail pin were examined using a fluorescent magnetic particle inspection technique. Linear indications (may be a precursor to fatigue cracking) were observed on the boss side of the fracture face in the region adjacent to the primary fracture face. Multiple parallel indications were oriented in the circumferential direction on opposite sides of the section, and varied in length from 5 mm to 25 mm (Figure 17).

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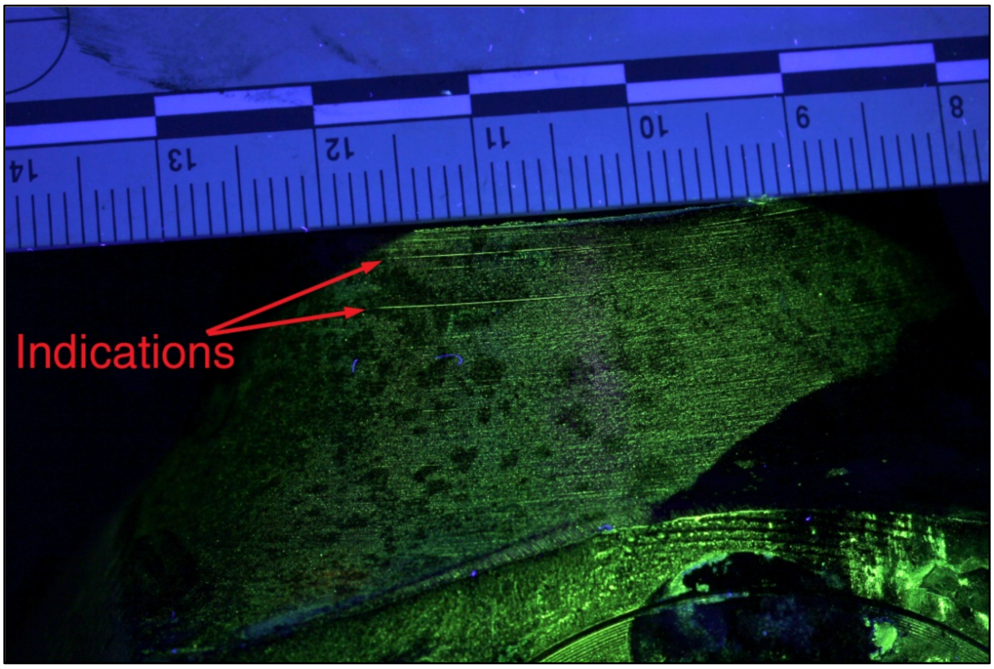
21 Macroscopic (visible) progression marks on a fracture surface that indicate the successive positions of the advancing crack front.

**Figure 17: Fractured tail pin, boss side, showing indications identified using fluorescent magnetic particle inspection**

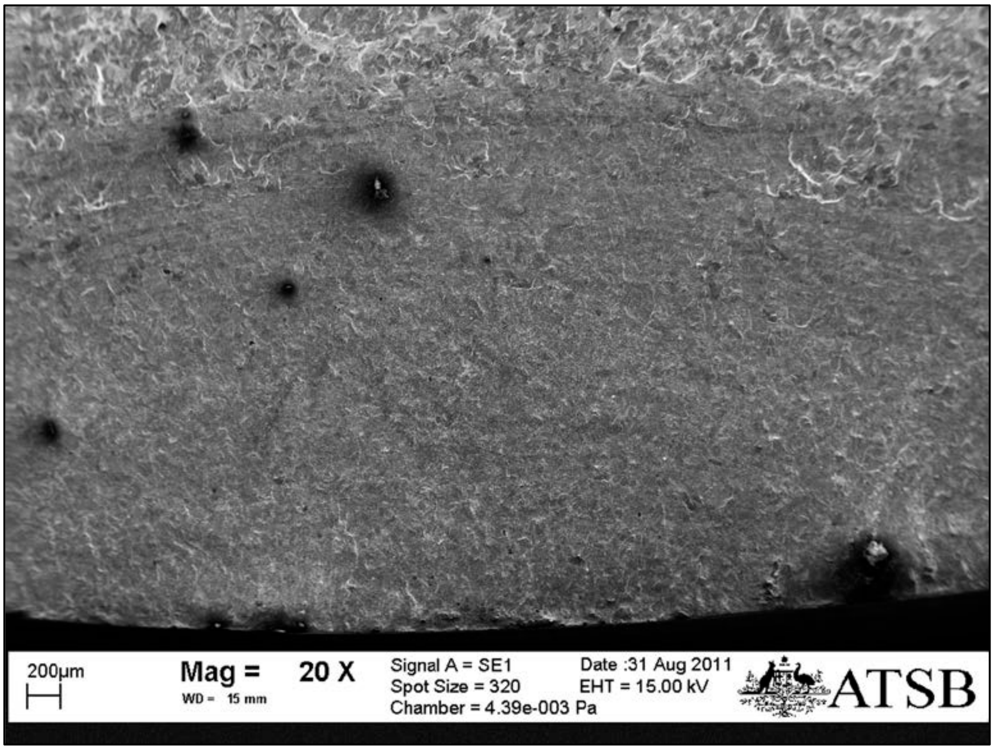



Source: ATSB

## *Scanning Electron Microscopy*

The fracture face was cut away from the shank side (Figure 8) of the tail pin and examined using a scanning electron microscope (SEM). The fracture face exhibited finely spaced striations indicative of low stress high cycle fatigue at the outer edges (Figure 18).

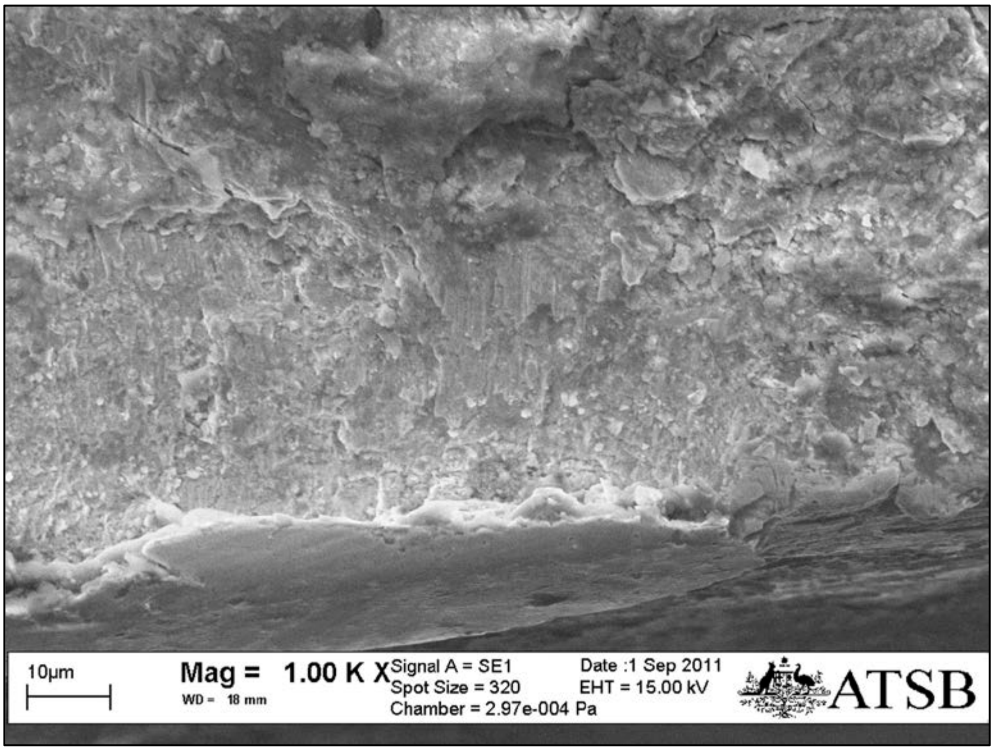
**Figure 18: Scanning electron microscope image of the fatigue area of the fracture face from the shank side of the fracture**




Source: ATSB

No anomalies were detected at the likely origin points that may have contributed to crack initiation (Figure 19). However, a brittle faceted fracture surface was observed towards the centre of the tail pin, consistent with an overstress failure.

**Figure 19: Magnified view of the outer surface, showing no clear evidence of an obvious initiator**




**Source: ATSB**

### *Microstructural examination*

Sections were removed from the fatigue zone on the shank side of the fracture, and from the side opposite the fatigue from both the shank and boss halves of the fracture, in the locations where indications had been previously identified using fluorescent penetrant inspection (Figure 17).

The tail pin exhibited a microstructure consisting of tempered transformation products such as martensite with medium to coarse size grains, with some retained austenite. The structure was generally consistent with the material type in the heat treated condition.

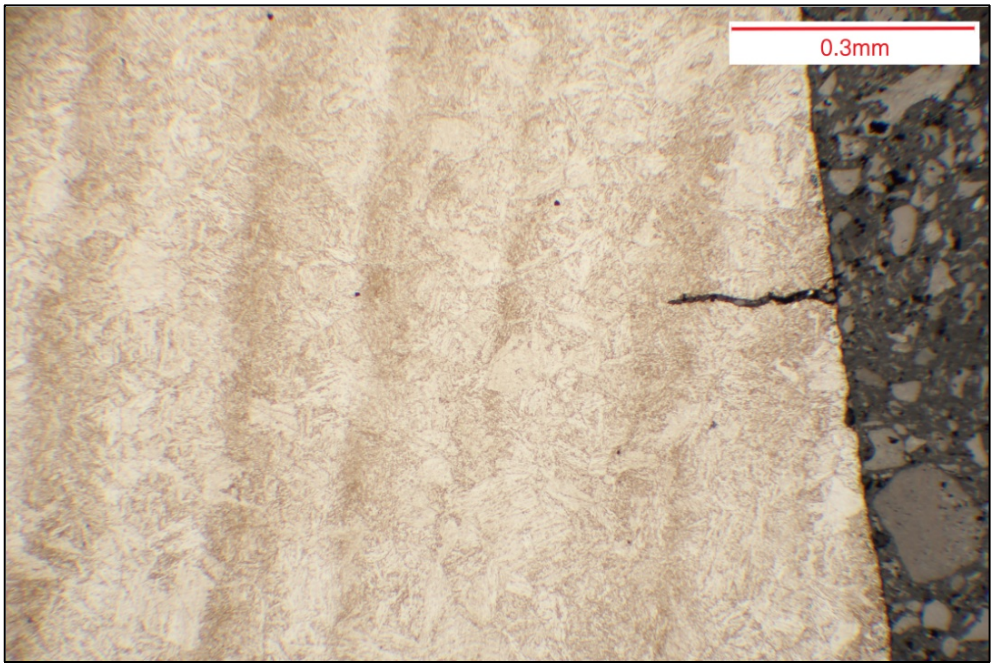
The primary fracture path morphology was transgranular in nature towards the surface of the shank. However, it transitioned to an intergranular crack propagation towards the centre.

A number of secondary cracks extending from the external surface were observed. The secondary cracks were linear and had propagated in a transgranular manner. These features were consistent with fatigue crack propagation (Figure 20 and Figure 21)

An examination of the surface near the secondary cracks showed that they appeared to have initiated at small corrosion pits/depressions in the surface. Evidence of debris/oxide product was observed both at the surface in the depressions, and within the crack itself.

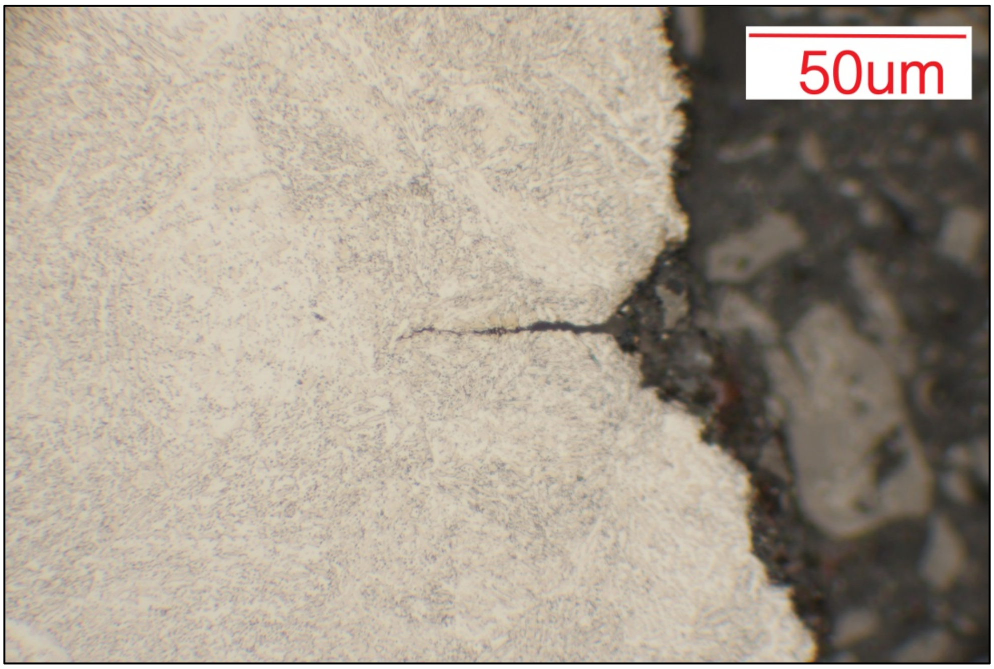
No evidence of any detrimental phases or microstructural anomalies was identified in the sections examined.

**Figure 20: Larger crack identified on the boss side of the fracture face, on the opposite side of the tail pin to the observed fatigue crack**




Source: ATSB

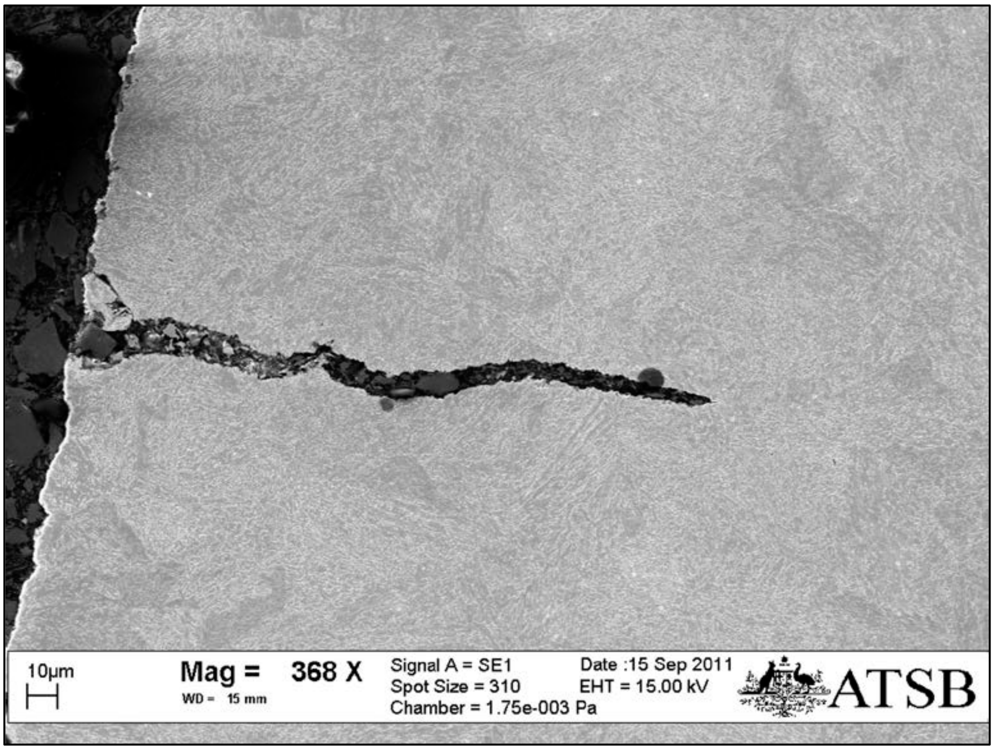
**Figure 21: Another smaller crack that extended from the external surface. Note the corrosion pit/depression at the external surface**




Source: ATSB

The microstructural sample was also examined using the scanning electron microscope (Figure 22) which was equipped with an energy dispersive x-ray system (EDS). Analysis of the debris product within the crack revealed the presence of iron and oxygen, consistent with a ferrous corrosion product (rust).

**Figure 22: Crack shown in Figure 20 viewed under the SEM**




Source: ATSB

## *Tail pin material properties*

### *Chemical analysis*

Sections were removed from the fractured tail pin from train *ST24* and a 'new' sample with the same batch marking BU 06 04 and they were submitted for chemical analysis. The results are given below;

**Table 1: Chemical analysis results**

| Fe | C | Mn | Si | S | P | Ni | Cr | Mo | Cu | V | Nb | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Sample: Fractured tail pin ex *ST24*** | | | | | | | | | | | | |
| 95.1 | 0.32 | 0.60 | 0.30 | 0.01 | 0.01 | 2.27 | 0.66 | 0.54 | 0.17 | 0.01 | 0.01 | 0.037 |
| **Sample: 'New' tail pin** | | | | | | | | | | | | |
| 95.01 | 0.32 | 0.58 | 0.26 | 0.01 | <0.01 | 2.40 | 0.65 | 0.52 | 0.18 | 0.01 | <0.01 | 0.029 |
| **Sample: AS 1444-2007, Alloy X9931U** | | | | | | | | | | | | |
| Rem* | 0.27-0.35 | 0.42-0.70 | 0.10-0.35 | 0.040 max | 0.040 max | 2.30-2.80 | 0.50-0.80 | 0.45-0.65 | - | - | - | - |

* Rem = Remainder

The tail pin from train *ST24* was consistent with Alloy X9931, a low-alloy steel, as specified on the supplied engineering drawing. The nickel was noted to be slightly below the lower specified limit, and the levels of copper (Cu) and aluminium (Al) were slightly higher than trace levels.

### *Hardness testing*

A section was removed from the fractured tail pin and prepared for hardness testing. The tail pin was tested using the Brinell hardness method using a 1 m diameter ball and a 30 kg weight (HB1/30).

**Table 2: Hardness test results, Brinell**

| Sample | Hardness values (HBN 1/30) | Average hardness (HB 1/30) |
|---|---|---|
| Fractured tail pin ex *ST24* | 272 266 275 266 274 263 261 269 | 269 |
| AS 1444-2007, Alloy X9931 | | 269 – 331 |

A section was removed from the fractured tail pin from train *ST23* and a used sample pin marked AE 2 04 and prepared for hardness testing. The tail pins were tested using the Vickers[22] hardness method using a 20kg weight (HV20).

**Table 3: Hardness test results, Vickers**

| Sample | Hardness values (HV20) | Average hardness (HV20) |
|---|---|---|
| Fractured tail pin ex *ST23*, BU 06 04 | 260 269 272 252 267 265 | 264 |
| AE 2 04 | 312 325 330 327 330 327 | 325 |
| AS1444-2007, Alloy X9931 | | 269 – 331 HB (284 – 349) |

The average hardness value of the tail pin was consistent with AS 1444-2007 Alloy X9931. However, a number of the individual readings were below the acceptable range. The corresponding results between the fractured and new tail pins indicate a broader issue with the quality of all XPT tail pins of batch BU 06 04, which was recognised by RailCorp during acceptance tests conducted in 2004.

### *Tensile testing*

Tensile samples from the fractured tail pins and a new sample were prepared and tested in accordance with AS 1444-2007. The results of the tests are shown below;

**Table 4: Tensile test results**

| Sample | Tensile Strength (MPa) | Yield Strength (0.2% proof) (MPa) | Elongation (%) |
|---|---|---|---|
| Fractured tail pin ex *ST24* (BU) | 874 | 470 | 18 |
| Fractured tail pin ex *ST23* (BU) | 914 | 490 | 20 |
| New tail pin (BU) | 889 | 508 | 19 |
| Used sample (AE manufacturer) | 1051 | 910 | 17 |
| AS 1444-2007, Alloy X9931 | 930 – 1080 | 740 min | 12 |

The tensile tests confirm that the material was well below the acceptable range in both the new and the fractured samples indicating a broader issue with the quality of all XPT tail pins of that batch.

22 The Vickers hardness method characterizes the indentation hardness of materials through the scale of penetration of an indenter, loaded on a material test-piece

### *Charpy impact testing*

Sections from the fractured tail pins were removed and prepared for testing in accordance with AS 1444-2007, along with a section from a 'new' tail pin from the same batch (BU 06 04). Charpy V-notch test is a standardised high strain-rate test which determines the amount of energy absorbed by a material before fracture. This absorbed energy is a measure of a given material's toughness and acts as a tool to study temperature-dependent ductile-brittle transition.

The results are given below;

**Table 5: Charpy impact test results**

| Sample | Charpy impact results | Charpy impact (average) |
|---|---|---|
| Fracture tail pin ex *ST24* (BU) | 11 12 12 | 12 |
| Fracture tail pin ex *ST23* (BU) | 10 12 11 | 11 |
| "New" tail pin (BU) | 13 14 14 | 14 |
| Used sample (AE manufacturer) | 77 80 79 | 79 |
| AS 1444-2007, Alloy X9931 | | 42 min for 150 mm section<br>28 min for 250 mm section |

The Charpy impact tests confirm that the material was well below the acceptable range in both the new and the fractured samples indicating a broader issue with the quality of all XPT tail pins of that batch.

# Sources and submissions

## Sources

Investigators from the Australian Transport Safety Bureau (ATSB) sourced evidence pertaining to the incident near Broadmeadows on 11 August 2011 from the Australian Rail Track Corporation (ARTC), V/Line and the Rail Corporation, New South Wales (RailCorp).

Following the incident, investigators from the Chief Investigator Transport Safety Victoria assisted with an onsite inspection and collection of evidence on behalf of the ATSB. Evidence included initial statements, measurements of track and rolling stock, photographs, preliminary component testing and collection. The ATSB acknowledges the assistance of the Chief Investigator and his staff.

## Submissions

A draft of this report was provided to RailCorp, Transport Safety Victoria, Office of the Chief Investigator Victoria, Independent Transport Safety Regulator of New South Wales, Australian Rail Tack Corporation, and a number of individuals.

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

# 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 identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, 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 initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred 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 to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept 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.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes it appropriate. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

# 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, current risk controls and organisational influences.

***Contributing safety factor***: a safety factor that, had it not occurred or existed at the time of an occurrence, 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 in the interests of improved transport safety.

***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.

***Risk level***: The ATSB's assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level as it existed at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety action taken by individuals or organisations during the course of an investigation.

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

- **Critical safety issue:** associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant safety issue:** associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor safety issue:** associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

***Safety action***: the steps taken or proposed to be taken by a person, organisation or agency in response to a safety issue.

**Australian Transport Safety Bureau**

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Investigation

**ATSB Transport Safety Report**
Rail Occurrence Investigation
Partial separation of Express Passenger Train (XPT) ST24
Broadmeadows, Victoria, 11 August 2011
RO-2011-012
Final – 26 April 2013