Report 09-101 (incorporating 08-105): express freight train derailments owing to the failure of bogie side frames, various locations on the North Island Main Trunk, between 21 June 2008 and 7 May 2009

Final Report

Rail Inquiry 09-101 (incorporating 08-105):

express freight train derailments owing to the failure of bogie side frames, various locations

on the North Island Main Trunk,

between 21 June 2008 and 7 May 2009

Approved for publication: September 2010

Transport Accident Investigation Commission

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Information derived from interviews during the Commission's inquiry into the occurrence is not cited in this final report. Documents that would normally be accessible to industry participants only and not discoverable under the Official Information Act 1980 have been referenced as footnotes only. Other documents referred to during the Commission's inquiry that are publically available are cited.

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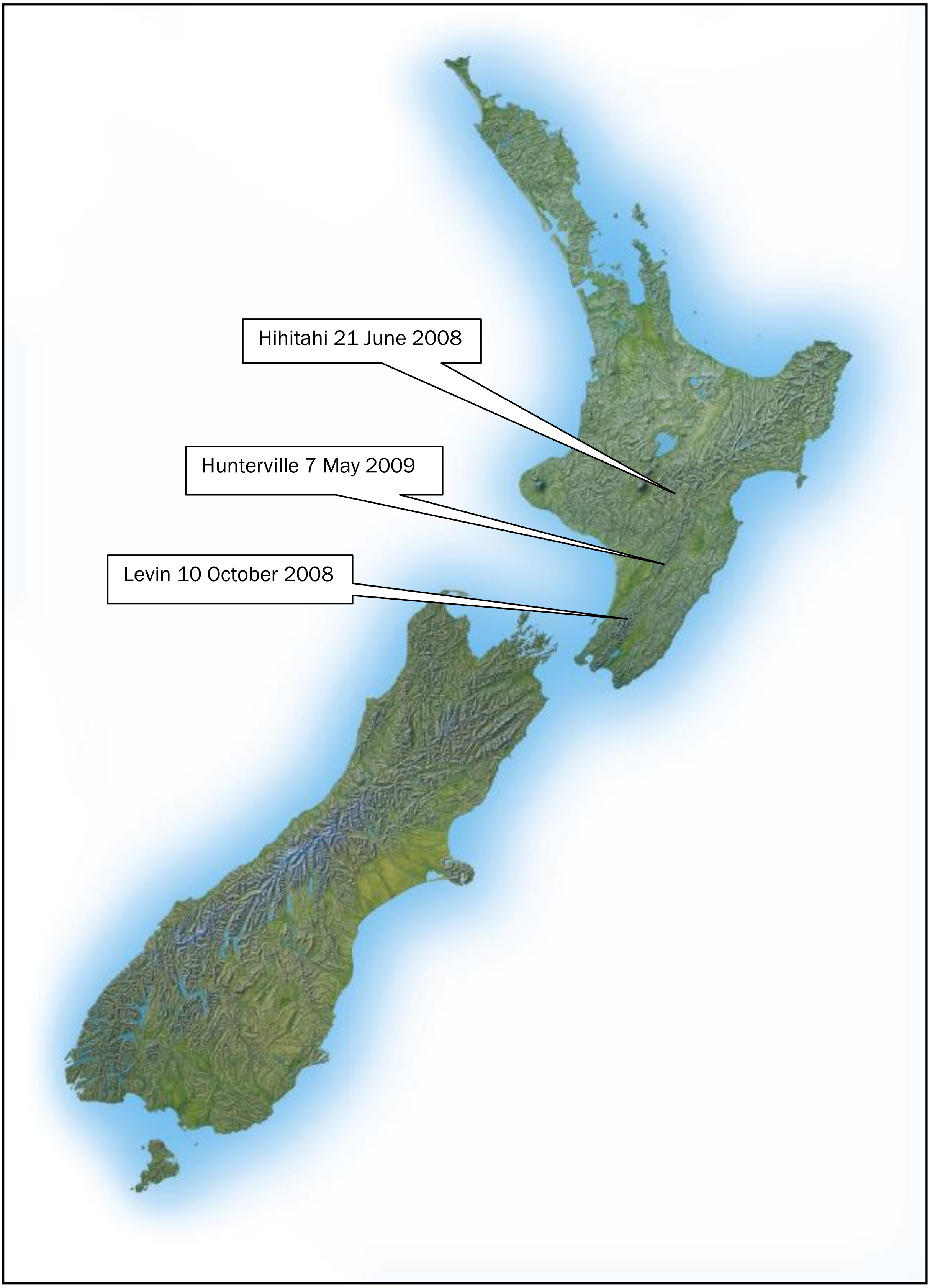

Source: mapsof.net

Location map

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Abbreviations

AAR	American Association of Railroads
km	kilometre(s)
km/h	kilometre(s) per hour
m	metre(s)
mm	millimetre(s)
MPa	mega Pascal(s)
MPI	magnetic particle inspection
NIMT	North Island Main Trunk
t	tonne(s)

Glossary

Annealing	heat treatment of steel that produces some softening of the structure
Austenite	formed when carbon steel is heated to temperatures above 723ºC
Bainite	formed in steels at temperatures between 250ºC and 550ºC
Crossing loop	a place on a single-line railway where trains from opposing directions can pass
Decarburisation	occurs when steel is heated, leading to oxidation and loss of carbon, losing its strength and ductility
EM80	a specialised, self-propelled, in-motion track vehicle used for measuring and recording track geometry
Failed in overload	means when any undamaged section of a component distorts because it can no longer carry the load needed
Ferrite	material with iron as the main constituent and very low carbon content, typically 0.02%
Gib clearance	the clearance between the bolster giband the side frame. Worn gibs are primarily an indicator of bogie instability, particularly with regard to bogie hunting
Heat-affected zone	the area of the base material that has had its microstructure altered by welding or grinding
Magnetic particle inspection	a non-destructive testing process using a magnetic field to detect surface and sub-surface discontinuation in ferrous materials
Metal fatigue	the progressive and localised structural damage that occurs when a material is subjected to repeated loading and unloading
Normalising	when steel is heated until it starts to form austenite; it is then cooled in air
Pandrol "e" clip	an indirect elastic fastening that secures the rail to the sleeper
Pearlite	a mixture of alternate strips of ferrite and cementite in a single grain

Data Summary

Vehicle particulars

Type	express freight trains
Operators	Toll NZ Consolidated Limited[1] KiwiRail
Dates	between 21 June 2008 and 7 May 2009
Location	various locations on the North Island Main Trunk
Persons involved	one locomotive engineer in each case
Injuries	nil
Damage	extensive damage to wagons and track

[1] The New Zealand Government purchased the rail business from Toll NZ Consolidated Limited in July 2008 and re-branded it as KiwiRail.

1. Executive summary

Introduction

1.1. This executive summary summarises the main points contained in this report to provide the reader with an overview of the circumstances and causes of the occurrence, and the Transport Accident Investigation Commission's (Commission's) findings and recommendations. For the full details of these matters, readers should refer to the main part of this report and its appendices.

Summary

1.2. Between 21 June 2008 and 7 May 2009, 3 express freight trains derailed at various locations on the North Island Main Trunk (NIMT) line. All 3 derailments were caused by the failure and collapse of bogie side frames on wagons. The side frame failures were all similar in that they started with a fatigue crack that propagated over a period of days rather than weeks, through the box section of the side frame, until the remaining material failed in overload during normal train operations.

1.3. The side frame failures were also similar to previous side frame failures investigated and reported on by the Commission.

1.4. The cracks started in an area that would have been difficult to detect during normal operational and maintenance wagon checks. The side frames sometimes lacked identifying marks and historically there had been no records kept of their age and maintenance history, so the operator had started a programme of magnetic particle inspections (MPIs) to detect the presence of fatigue cracking in the side frames when the bogies were brought in for overhaul.

1.5. The inspection programme found over 4 years an average 60% of side frames with cracks that required repair. At the current inspection rate, all side frames will not be inspected before 2020. Until all side frames are tested for cracks and repaired, the potential for main-line derailments attributed to bogie side frame failures remains. Given the risk that main-line derailments pose to people and infrastructure, the Commission has made a recommendation to the Chief Executive of the NZ Transport Agency to conduct a risk assessment and if necessary require the inspection rate of side frames to be accelerated.

2. Conduct of the inquiry

2.1. On Saturday 21 June 2008, a wagon on express freight Train 237 derailed owing to a collapsed bogie side frame. The Commission opened inquiry 08-105 that same day and conducted a site examination. On Friday 10 October 2008 a wagon on express freight Train 220 derailed, also owing to a collapsed bogie side frame. The Commission conducted a site examination and, because of the similar mode of failure, included the second derailment in inquiry 08-105.

2.2. On Thursday 7 May 2009, a third derailment occurred that was also due to a collapsed bogie side frame. A consequential fire broke out in the derailed wagon. Owing to the circumstances surrounding the derailment, the Commission opened a separate inquiry 09-101 and conducted a site examination.

2.3. After reviewing the circumstances around each derailment, the Commission combined all 3 events into this single report.

2.4. On 21 July 2010 the Commission approved draft final report 09-101 for circulation to interested persons for comment, which included operating staff, management for the operating company and the Regulator.

2.5. Submissions were received from the Operator and the Regulator, whose comments have been considered and included in the final report where appropriate.

3. Factual information

Narrative

3.1. ZH Class Wagon

3.1.1. A ZH wagon is a high--volume "plug" door wagon on a modified ZA class wagon under-frame. These wagons were modified at Hillside workshops from 1995, to create a higher, wider body wagon with a capacity of 95 cubic metres (see Figure 1). The wagons generally carry palletised goods, often double stacked. Each wagon has a tare weight of 19.96 tonnes (t) and is designed to carry a payload of 36.8 t, giving a gross weight of 56.76 t.

Figure 1
A ZH class wagon

3.1.2. The ZH wagons were fitted with standard 3-piece bogies commonly used on freight wagons throughout the world. The 3 main "pieces" were one bolster and 2 side frames (see Figure 2). The bolster was supported by 2 sets of coil springs. The larger-diameter coil springs, known as the primary suspension, provided vertical support. The smaller-diameter coil springs, known as wedge springs, applied pressure to a friction wedge to provide wagon damping to reduce the oscillation of a wagon while in motion. Effective functioning of the ride control feature relies on friction between spring-loaded wedges and surfaces on the bolster and side frames.

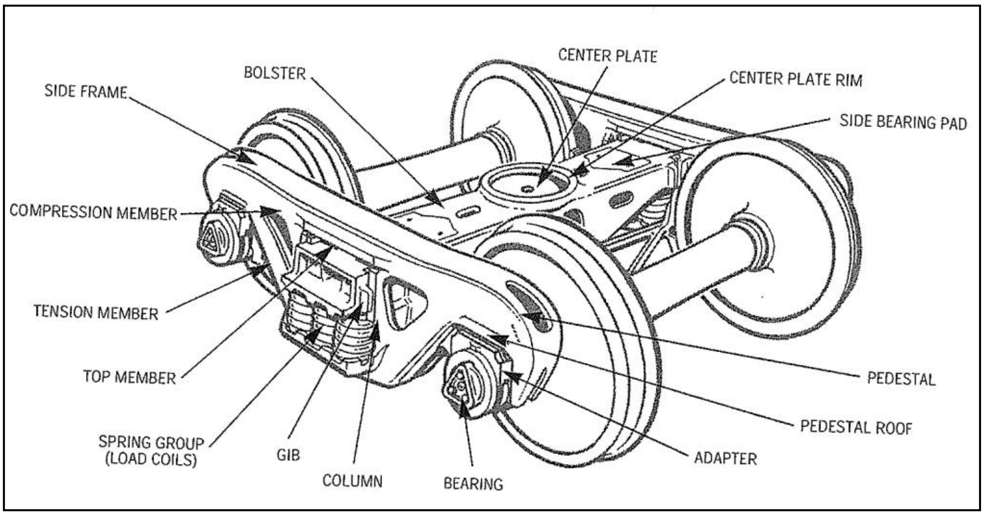

Figure 2
Nomenclature of bogie components

3.1.3. The bogie side frames were designed to carry a load equal to the rated load of the bearing. The Type 14 bogie on ZH class wagons used Class C American Association of Railroads (AAR) package bearings, rated at 15.2 t per axle. The Type 14 bogie was rated at 14.3 t per axle or 6% less than the bogie side frame rating.

3.1.4. The Type 14 bogie was an old design, dating from the late 1960s, so the current AAR material standards were not relevant. Type 14 bogies were purchased between 1969 and 1982.

3.1.5. The original Australian design/manufacture of the Type 14 bogie specified that the side frame material was to have a minimum tensile strength of 460 megapascals (MPa) and a maximum carbon content of 0.30%. The original New Zealand manufacturing specification required nothing more than "cast steel" having a carbon content of between 0.2% and 0.22%, giving a tensile strength in the range of 450 MPa to 460 MPa. However, the New Zealand version of the side frame was used on a bogie carrying a lower axle load than in Australia.

3.2. Hihitahi derailment

3.2.1. On Friday 20 June 2008, Train 237 was an express freight "pack" service travelling from Auckland to Wellington. After a locomotive exchange at Hamilton, the train departed with a consist of 2 EF class electric locomotives in multiple[2] hauling 36 wagons, with a gross weight of 1380 t and an overall length of 611 metres (m).

3.2.2. At about 0557, as Train 237 approached Down Home Signal 8LABC at Hihitahi, the left-hand bogie side frame on the leading bogie of the 27th wagon, ZH560, collapsed and dropped. As a consequence the leading wheel set lifted and the spring nest dropped and ran along the left-hand running rail. Because there were no witness marks to determine the exact point of derailment, the impact marks where the spring nest first made contact with the rail at 278.366 kilometres (km) NIMT was considered the point of derailment.

3.2.3. When derailed wagon ZH560 passed over the north-end main-line points at Hihitahi (278.307km), the derailed leading bogie diverged to the crossing loop while its trailing bogie and all 9 wagons behind the derailed wagon continued on the main line. The running train pulled the derailed bogie from the loop towards the main line about 20 m past the main-line points.

3.2.4. The train continued through Hihitahi crossing station dragging derailed wagon ZH560. The derailed wagon struck and damaged the trailing main-line points at the south end of Hihitahi, causing wagon ZH2264, immediately behind wagon ZH560, to derail to the right. The train parted behind wagon ZH2264. The following 3 wagons remained on the track but the trailing bogies of the fifth wagon and third wagon from the rear of the train derailed to the right-hand side.

3.2.5. The train parting caused a sudden loss of brake pipe pressure and the brakes automatically applied. Wagon ZH560 stopped at 277.020 km, some 1.346 km past the point of derailment (see Figure 3). The locomotive engineer informed train control of the derailment after inspecting the train.

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[2] Multiple means that locomotives are coupled and controlled from the lead locomotive.

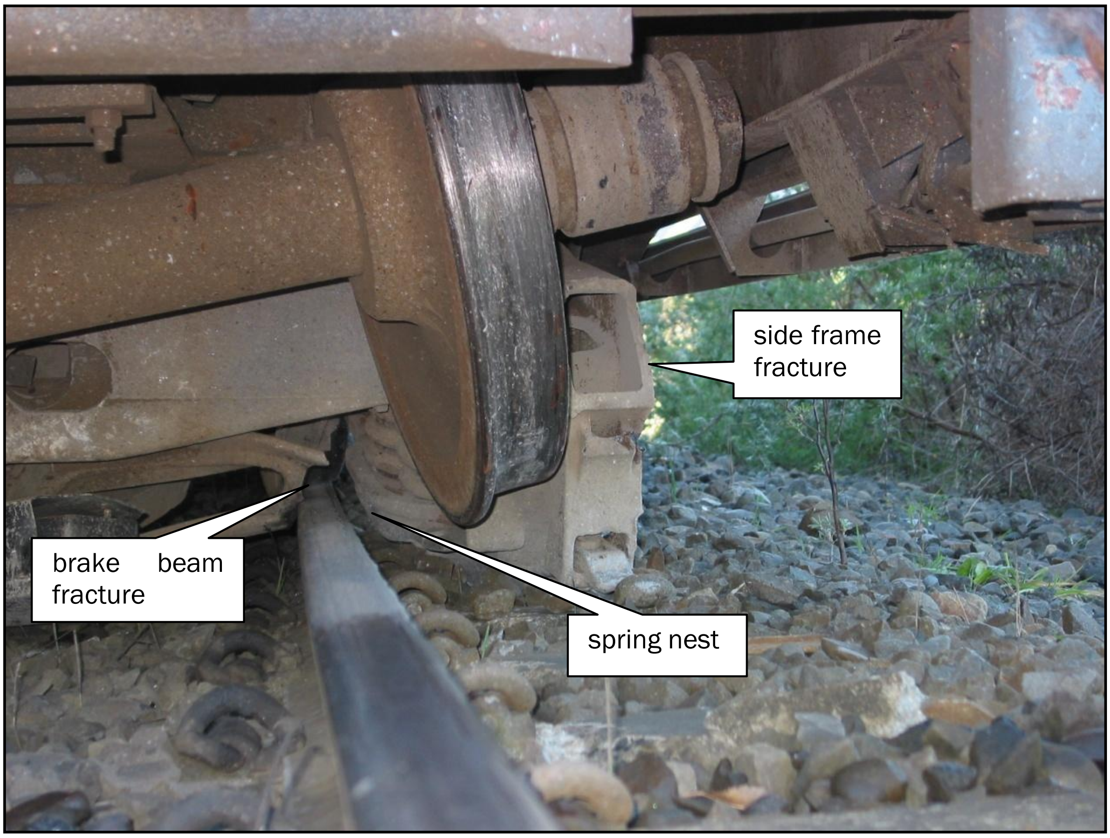

Figure 3
Failed side frame on wagon ZH560

Site and operating information

3.2.6. The track between Waiouru and Hihitahi was single line. The signalling and interlocking at these locations were remotely controlled from the national train control centre in Wellington.

3.2.7. The maximum authorised speed between Waiouru and Hihitahi for express freight trains was 80 kilometres per hour (km/h).

3.2.8. The alignment of the track was straight and level at the point of derailment. The track consisted of 50 -kilogram-per-metre (kg/m) rail fastened to 29-year-old treated Pinus radiata sleepers with Pandrol "e" clip fastenings and supported by clean ballast with full cribs and shoulders. The track measure up confirmed that the track geometry was within acceptable maintenance tolerance limits.

3.2.9. Three components that separated from the bogie were found beside the track within 55 m of the initial impact marks. The bearing adapter had come to rest on the left-hand side[3] of the crossing loop, 23 m past the first impact marks. The brake beam end was located between the loop and main line 13 m past the bearing adapter, and the fractured bogie side frame pedestal section had come to rest between the main line and loop, 19 m past the brake beam end.

3.2.10. Data from the event recorder was downloaded, which showed that at the time of the derailment the train speed was about 43 km/h with the locomotives operating with regenerative braking applied.

Wagon ZH560

3.2.11. Wagon ZH560 was conveying consolidated freight from Auckland to Christchurch that included coils of wire. The wagon had a declared weight of 49.5 t. Individual axle weights could not be confirmed because the in-motion weighbridge site at Westfield was not operational.

[3] All reference to left and right means in relation to the direction of travel.

3.2.12. From reference mark BK 10606 Serial 434 on the failed side frame it was confirmed that the side frame had been manufactured by Bradken Australia in January 1975. Bradken advised that the side frame had been traced from NZ Railways Drawing X27851 and the material was E7-1938 Grade B, which has a present-day equivalent of AS2074 Grade C4-1. The mechanical properties of the material were reported by the manufacturer as complying with:

- tensile strength 460 MPa
- yield strength 245 MPa
- elongation 21%
- Izod impact value 27 J minimum
- reduction of area 35%

The chemical composition was:

- carbon 0.30% maximum
- silicon 0.60%
- manganese 1.0%

There were no foundry records available for the specific casting from which the side frame had been made.

3.2.13. Refurbished Type 14S bogies, with Stuki constant-contact side bearers to control bogie rotation and hunting, had been fitted to wagon ZH560 on 1 May 2004.

3.2.14. The derailed bogie had last been overhauled at Hillside workshops on 28 September 2000. The bogie bolster had been crack tested but no repairs had been necessary. A visual examination only of the side frame had been completed in accordance with code requirements at the time. The bogie check sheet and work order, referenced SAP 300272, had been completed to confirm that the side frame, column liners, adapter liners and pocket liners had been examined.

Maintenance checks

3.2.15. No cracking in the pedestal roof area of the 4 bogie side frames on wagon ZH560 had been recorded during the 10 most recent B and C maintenance checks (see section 3.5).

Examination of the failed side frame

3.2.16. The separated portion of the bogie side frame was recovered and taken to an independent metallurgy laboratory for examination (see Figure 4). There was a large fracture extending through about 80% of the box section. The remaining 20% had failed in overload. Refer to Appendix 1 for a full laboratory report on the failed side frame.

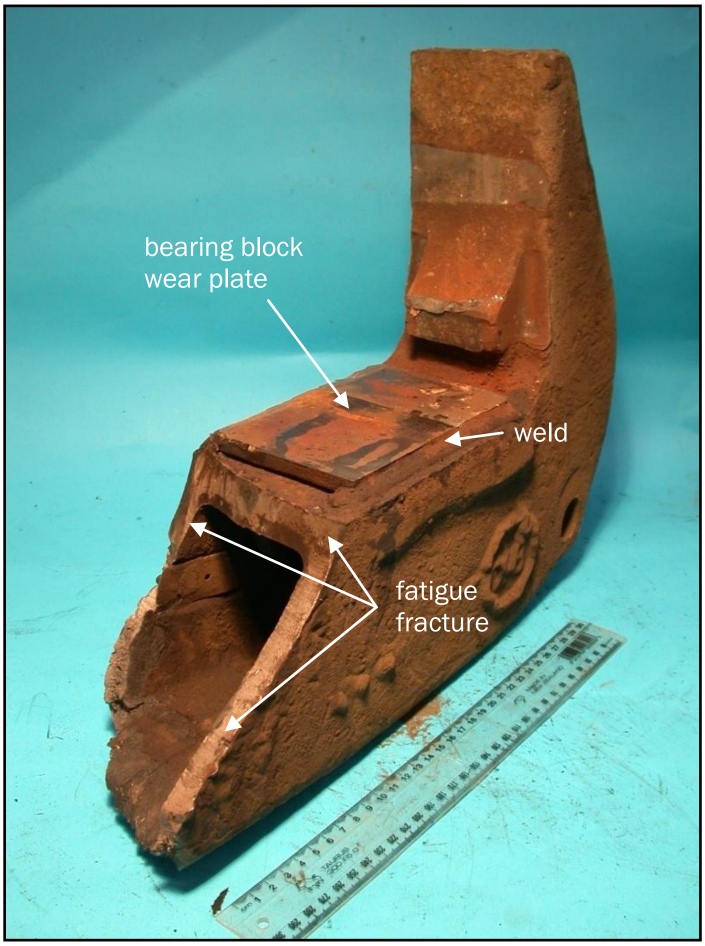

Figure 4
Side frame section inverted from normal orientation on wagon

3.3. Levin derailment

3.3.1. On Friday 10 October 2008, Train 220 was an express freight "ZH-Pack" service travelling from Wellington to Auckland Freight Branch. The train consisted of diesel locomotive DFT7145 hauling 18 loaded wagons and 4 empty wagons, with a gross weight of 909 t and an overall length of 356 m.

3.3.2. At 1416, Train 220 approached Levin Station travelling at about 70 km/h. After passing the platform, the driver took a quick glance back to check his train while entering the short right-hand curve before Makomako Road level crossing (see Figure 5). He noticed a cloud of dust and ballast being projected outwards from wagons immediately behind the locomotive, so he made a brake reduction of 80 kilopascals and sounded the locomotive horn to warn pedestrians and motorists waiting at the level crossing.

3.3.3. The train stopped with the trailing bogie of the eighth wagon over the north-end main-line points. Members of the public approached the locomotive engineer as soon as the train stopped to advise him of grain discharging from derailed wagons (see Figure 6). Eight wagons at the head of the train had derailed. Wagon ZH1766 was coupled directly to the locomotive. The rear pedestal leg on the right-hand side of the trailing bogie had fractured and separated from the side frame (see Figure 7).

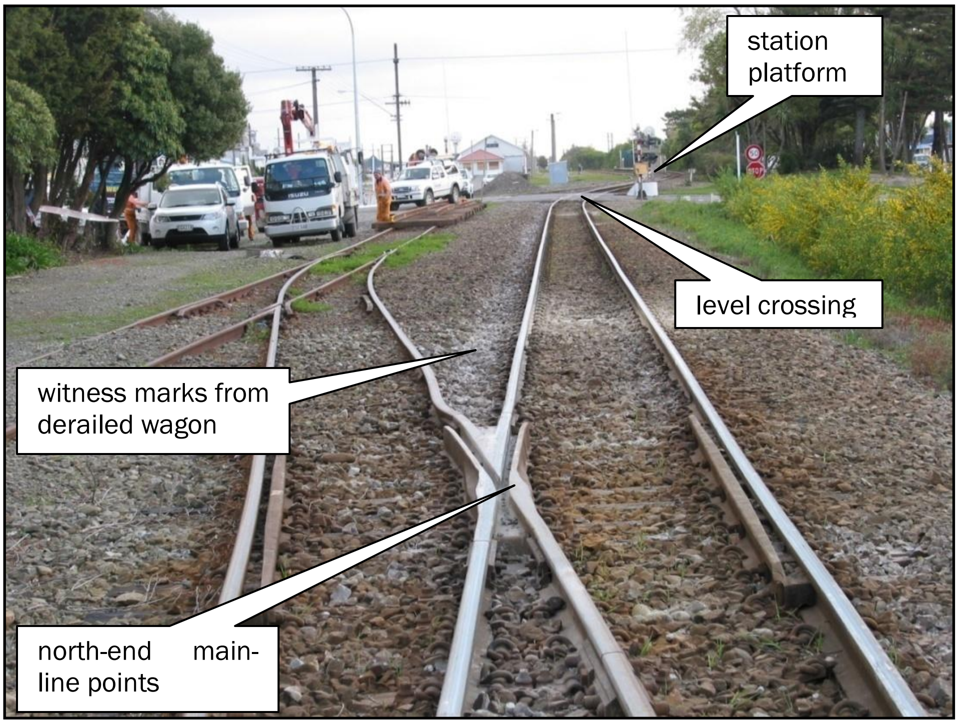

Figure 5
Witness marks from the derailed wagon

Figure 6
Grain spilt from one of the derailed wagons

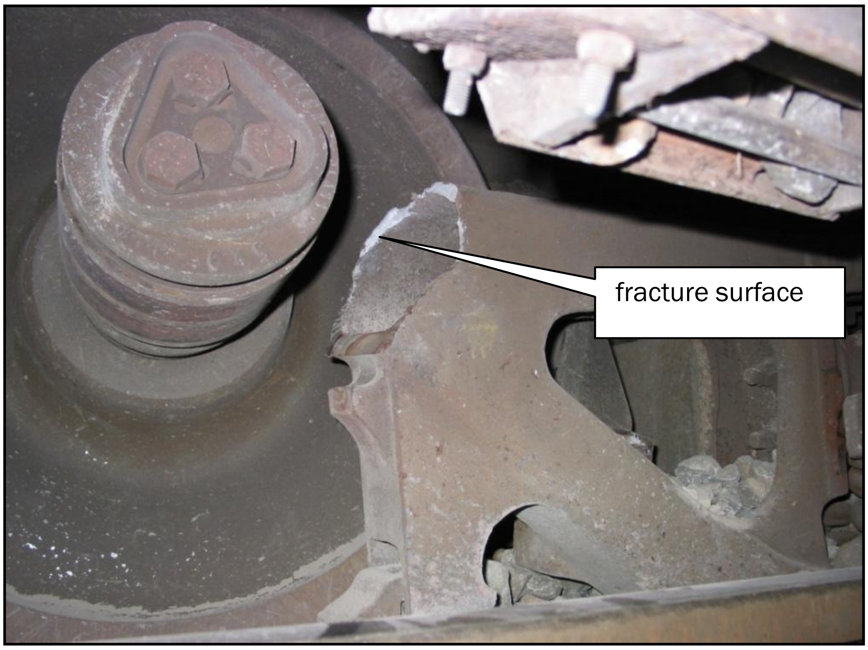

Figure 7
Side frame on wagon ZH1766

Site and operating information

3.3.4. The point of derailment was determined as 89.846 km, 10 m before the south-end main-line points at Levin. The bearing adapter from the derailed wheel set was found on the right-hand side of the track about 320m before the point of derailment. Witness marks on the rail confirmed that the derailed wheel had travelled 4 m across the head of the rail to drop off. The pedestal leg had separated from the side frame and was found on the right-hand side of the track some 51 m past the point of derailment. The train came to a stop at 90.91 km, having travelled a little over 1km from the point of derailment.

3.3.5. The track alignment at the point of derailment was straight on a gentle 1 in 660 down grade. The track materials consisted of 50 kg/m rail manufactured in 1975 fastened to 23- year-old concrete sleepers with Pandrol "e" clips, all in good condition.

3.3.6. The most recent EM80 track evaluation run over the section had been undertaken on 9 June 2008. No track condition outside maintenance tolerance limits had been identified.

3.3.7. Locomotive DFT7145 was fitted with a Tranzlog event recorder. Data from the event recorder was downloaded and showed that the train speed had reached 75 km/h within a 70 km/h speed restricted area. Because of a variance between the true speed and the speedometer in the cab, the driver would have observed a speed of 69 km/h on the speedometer. The train had taken 379 m to stop once the driver made the first brake application.

3.3.8. Wagon ZH1766 was conveying bagged salt with a declared weight of 55.5 t. The product was evenly distributed on the wagon deck and there was no evidence of the load having moved in transit.

3.3.9. The failed side frame had been manufactured by Sumitomo to NZ Railways C.M.E. Specification NO. 550, which included in part:

> *Specification for Materials: In New Zealand, British Standards are adopted for materials, and where particular specifications are not quoted, the appropriate British Standard (B.S.) will be accepted.*
>
> *Detailed Specifications of Materials: (a) Castings*
>
> *(ii) Steel Castings for general purposes shall comply with B.S. 592 (B.S. 3100) Grade A. Notwithstanding the acceptance of any alternative specification the carbon content of the cast steel shall not exceed 0.25 per cent.*

3.3.10. Sumitomo advised that its records had been checked but it could not trace the materials used to comply with the specification.

3.3.11. On 24 June 2004, refurbished Type 14S bogies, without wheel sets, had been fitted to wagon ZH1766. All 4 wheel sets had been subsequently exchanged on 14 March 2007.

Maintenance checks

3.3.12. The scheduled 10-year brake check on wagon ZH1766 had been completed on 13 September 2007.

3.3.13. The scheduled 2-yearly scheduled C-Checks had been carried out within the maximum allowable timeframe of 27 months. No cracking in the pedestal roof area of the bogie side frame had been identified during any of the B and C maintenance checks.

Examination of failed bogie side frame

3.3.14. The pedestal leg that separated from the side frame was recovered and taken to an independent metallurgy laboratory for examination (see Figure 8). A major fatigue fracture had propagated through about 70% of the cross-section of the side frame, with the remaining 30% having failed in overload. Refer to Appendix 2 for a full laboratory report.

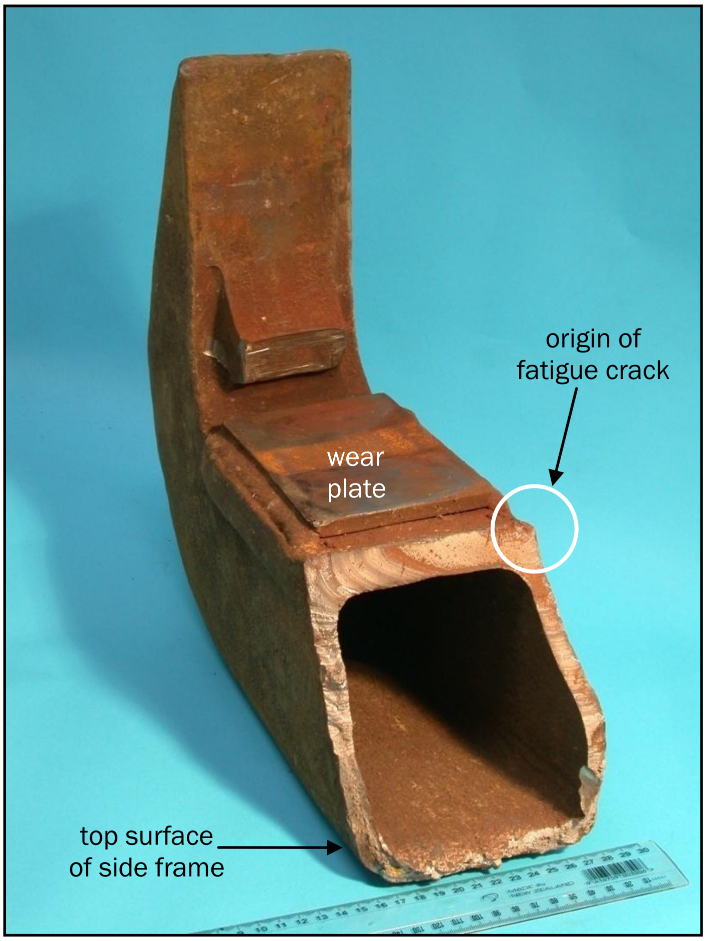

Figure 8
Pedestal leg of side frame from wagon ZH1766
inverted from normal orientation when fitted

3.4. Hunterville derailment

3.4.1. On Wednesday 6 May 2009, Train 211 was a south-bound Auckland to Wellington express freight train. After a locomotive exchange and the attachment of 3 ZH class wagons to the head of the train, the train departed from Hamilton with a consist of 2 EF class electric locomotives hauling 29 wagons, with a gross weight of 1069 t and an overall train length of 515 m. The train documentation in the locomotive cab identified 5 wagons conveying hazardous goods.

3.4.2. At about 0411, the dragging equipment detector, near Hunterville, sent an alert to train control. A few seconds later, the locomotive engineer happened to look back to check his train and saw sparks coming from under the train.

3.4.3. The train controller radioed the locomotive engineer to tell him about the alert he had received. The locomotive engineer acknowledged the call and said that he had just seen sparks and he would stop and inspect his train before the Down Home Signal (206.39 km).

3.4.4. By 0422, the locomotive engineer had stopped and checked his train. He radioed the train controller and reported that the left-hand side frame on the leading bogie of the second wagon, ZH554, had broken and its trailing wheel set was off the track. He had checked the rest of the train and confirmed that it was complete and that all wagons remained connected and no other wagons had derailed.

3.4.5. About 2 hours later, while the locomotive engineer was waiting for the recovery operation, a fire broke out in the derailed wagon. The locomotive engineer radioed the train controller asking for the overhead power to be shut down.

3.4.6. The Fire Service attended and extinguished the wagon fire and a small trackside scrub fire. The fire did not spread to other wagons.

Site and operating information

3.4.7. The track between Mangaonoho and Hunterville was single line. The maximum authorised line speed for express freight trains was 80km/h.

3.4.8. Intermittent marks on the left-hand railhead from 212.5km indicated that the side frame on wagon ZH554 had failed and dropped at that point and continued in such condition until striking a private level crossing about 5.3 km away, where the trailing wheel set on the leading bogie derailed to the left. The derailed wagon ran a further 600m before the train stopped.

3.4.9. The bearing adapter and pedestal leg from the derailed wheel set were recovered trackside at 206.743 km, some 486m past the point of derailment and about 111 m from where the wagon had stopped.

3.4.10. The point of derailment was within the body of a 600m long, 500m-radius right-hand curve. Trains were authorised to travel the curve at 80 km/h. The track materials within the derailment curve consisted of 50 kg/m continuous welded rail fastened to concrete sleepers with Pandrol "e" clips. The track geometry throughout the curve was within maintenance tolerances.

3.4.11. Electric locomotive EF30232 was fitted with an older style "Locolog" event recorder. Data downloaded from the event recorder showed that the train had been travelling at 73 km/h when it passed over the dragging equipment detector. Because detailed train operation information was retained for the 6 minutes only, no data was available for the time when the bogie side frame collapsed.

3.4.12. The Wagon Load Manifest for wagon ZH554 on 6 May 2009 showed a declared weight of 22 t. The hazardous column was blank. Wagon ZH554 conveyed a variety of palletised goods, including bagged ground plastic particles, metal wheelbarrow components, metal tubing, stock feed, melteca, pails, cheese aerosols and 14 litres of paint[4]. The paint and a quantity of aerosol cans were at the forward end of the wagon, on the opposite side to the failed side frame.

3.4.13. There were no visible reference marks on the failed side frame from which to determine its age. The general appearance of the side frame suggested it could have been in service for 40 years. The manufacturer's name, Sumitomo, was visible. KiwiRail confirmed that the specification and standard to which the failed side frame had been manufactured were as per C.M.E Specification No. 550, details of which have been given earlier in this report.

3.4.14. The derailed wheel set did not have a unique identifier to determine its operational history. The wheel sets were a stock item and were not associated with a particular bogie or a particular wagon. Without this information, the Commission was unable to determine when the leading bogie on wagon ZH554 had last been overhauled.

3.4.15. The most recent B-Checks had been carried out on 24 April 2009 and 25 March 2009. The recording sheet used on 24 April 2009 made no reference to a check for cracks on the side frames. The most recent scheduled maintenance C-Check on wagon ZH554 had been performed on 29 June 2007. All critical bogie components had been recorded as having passed the checks, including the side frames and bolsters, which had been visually examined for cracks.

Post-derailment examination of wagon ZH554

3.4.16. The wagon was completely burnt out following the derailment (see Figure 9). The wagon travelled about 5 km with a failed side frame until it derailed, then it was dragged a further 597 m until the train stopped. Heat generated from the wheel set of the derailed bogie rubbing on the steel deck conducted to a timber pallet stowed above.

Figure 9
Deck of wagon ZH554 after the fire

[4] The amount of paint was such that it was classed as limited quantity and not required to be declared as dangerous goods.

Examination of the failed bogie side frame

3.4.17. The recovered side frame section was taken to the same independent metallurgy laboratory that had examined the 2 previous failed side frames (see Figure 10). Fatigue cracking had worked its way through about 60% of the box section and the remainder had failed in overload, similar to the previous 2 failures. A full laboratory report has been included in Appendix 2.

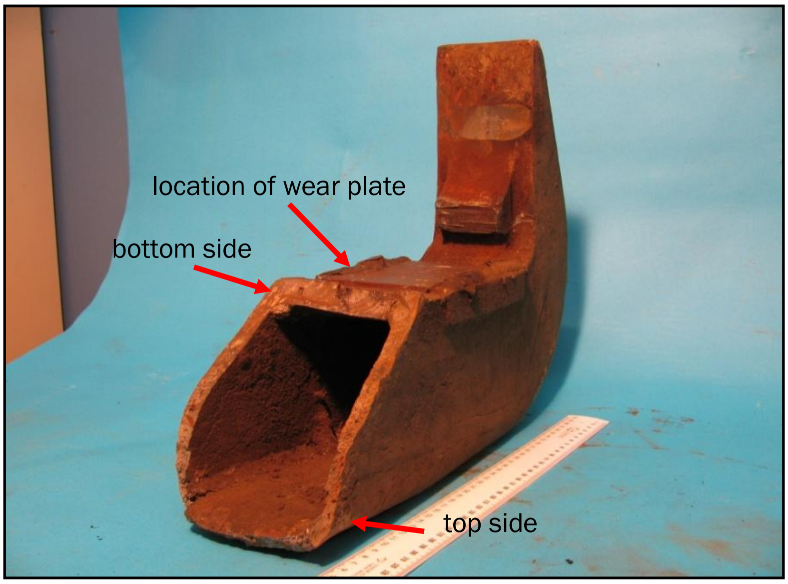

Figure 10
Failed side frame section from wagon ZH544
inverted from normal orientation when fitted

3.5. Wagon Inspections

3.5.1. KiwiRail's Mechanical Code M2000, Issue 7, effective from 1 April 2007, required all freight wagons to have pre-departure checks in accordance with the Rail Operating Code. The pre-departure checks were made by operational yard staff and were more aimed at ensuring that the make-up of the trains was secure: brake block condition, conditions of air hoses, the status of the hand brakes and the like.

3.5.2. B-checks and C-checks were performed in accordance with code supplement M9202. B-checks covered safety-critical items and were performed each time 2 or more brake blocks were replaced. The more detailed C-check was generally performed at 24-month intervals with an upper limit of 27 months. The C-check was brought forward when a wagon was involved in a collision or derailment or had a fault with braking.

3.5.3. The C-check requirements for the bogie/suspension included the following checks:

Springs:	In place, secure and intact.
Bearing keeps:	Held securely in place.
Liners:	Secure and not broken. Not worn more than 50% of original thickness.
Wedge heights:	Within gauge limits.
Bearing adapters:	In place and not damaged or worn.
Side bearer:	Not damaged or worn.
Dampers:	Secure and no excessive oil leaks.

Bearings:	No sign of overheating. Cap bolts in place. Backing rings secure. No excessive grease leaks.

3.5.4. An amendment to Clause 3.4 (b) of the Code, dated 23 May 2008, stated in part:

> *Each side frame and bolster must be intact. No cracking is permitted in the pedestal roof radius and no crack longer than 10 mm is permitted elsewhere on the side frame or bolster. All cracks must be reported.*

3.5.5. All 3 wagons involved in these occurrences whose bogie side frames failed had undergone the prerequisite pre-departure checks and their B- and C-checks. No cracking had been identified in any of the failed bogie side frames.

3.6. Bogie overhaul programme

3.6.1. While a ZH class wagon body was refurbished on a condition basis rather than in any specific 10-year mandatory timeframe, the Type 14 bogies associated with the wagon were interchangeable and were generally overhauled at intervals that could vary between 5 and 10 years depending on the in-service life. The wagon body and associated bogie components were tracked separately. The bogie bolster had a tracking number but the respective side frames did not.

3.6.2. The major factors that determined when a bogie was overhauled included:

- derailment damage
- the combined wear gauge 13050014 (moustache) indicates that the ride control elements have worn out
- the gib clearances have reached the maximum
- wheel set requires replacement and other bogie parts are well worn.

3.6.3. KiwiRail's Mechanical Code M9200-02, Issue 2 dated 16 September 2008, Type 14 Bogie Overhaul Manual identified the following acceptable operating limits:

- the rotational gib clearances must not exceed 15 millimetres (mm) and the lateral gib clearance must be less than 25 mm
- the friction wedge heights must not exceed 42 mm.

3.6.4. KiwiRail is currently reviewing the friction wedge height condemning limit of 42 mm. Bogies have been withdrawn from service and overhauled when friction wedge height measurement exceeding 39 mm is recorded at the time of a scheduled check. The primary objective of the reduction in condemning wedge height limits is to improve bogie performance and optimise costs. This reduction in time between major overhauls will result in increases in the number of bogie side frame defect/crack inspections carried out each year.

3.6.5. The pedestal wear liners on a bogie side frame were replaced at the time of the bogie overhaul. A 6mm fillet weld was applied down both sides of the wear liner but not across the end of the liner (see Figure 11). The origin of the fatigue cracks on the failed side frames was in the highly stressed area in the radius between the pedestal roof and the inner pedestal leg.

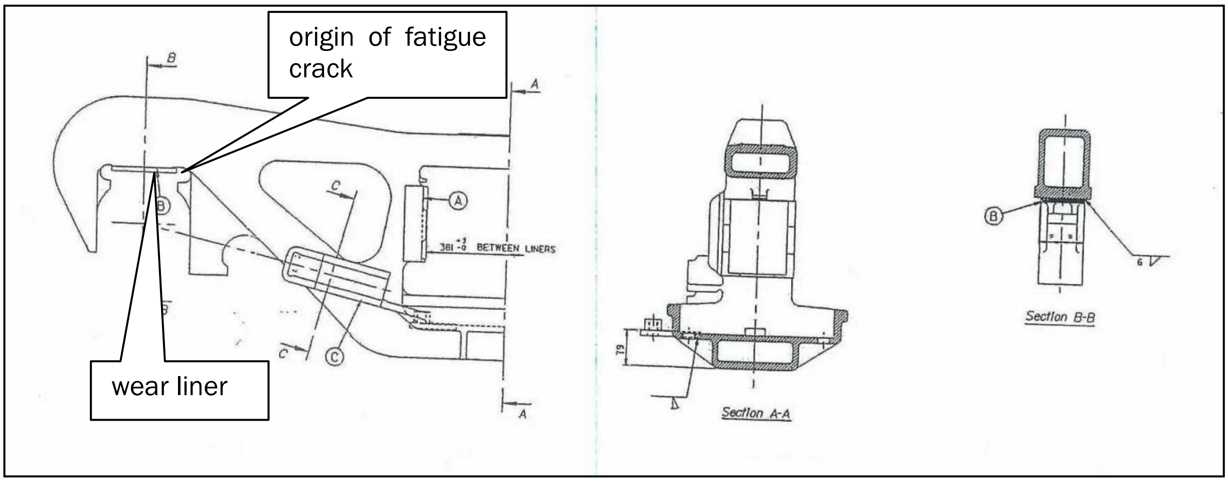

Figure 11
Attaching the pedestal roof wear liner

3.6.6. On 13 March 2006, as a result of previous investigation report 05-126 into the derailment of express freight Train 246, near South Junction, between Muri Station and Paekakariki Station on the NIMT, the Commission recommended to the Chief Executive of Toll NZ Consolidated Limited that he:

> *Include within the existing procedure for overhauling bogies, an inspection other than visual only, to confirm the structural integrity of specified components before a bogie is returned to service. (007/06)*

3.6.7. On 2 April 2006, the Chief Executive of Toll NZ Consolidated Limited stated in part:

> Toll Rail intends to formally implement this recommendation.
>
> The "Overhaul Manual for Bogies" will be amended specifying bogie components that will require other than visual inspections. The inspection method will also be specified.
>
> However, it should be noted that specific testing is now being applied to side frames, bolsters and specified areas of brake beams in anticipation of this Code change.

3.6.8. Tranz Rail PSG Group's Specification No. 380 for the inspection and repair of horn area cracking in Type 14/16/18 and 22 bogie side frames, issued on 11 May 2006, required that during the bogie overhaul process, side frames must be carefully examined for distortion and cracking, particularly in the horn/adapter area, referred to as Zone 1A. The acceptance criterion for Zone 1A is nil cracking using MPI methods.

3.6.9. Should a crack be identified, the side frame casting would be sent to Hillside workshops, where the following repair process in accordance with AAR Specifications M-201 "Steel Castings", M210 "Purchase and Acceptance of Side frames and Bolsters" and M214 "Classification and Repair of Side frames and Bolsters" would be carried out. A check sheet document was used to record and verify the repair process of the side frames and was signed off by the person performing the work or inspection. The repair process is summarised as follows:

- heat treat (650ºC stress relief)
- grit blast/shot blast all surfaces for abrasive cleaning
- inspect side frame Zone 1A using MPI
- weld repair any cracks or casting defects located in Zone 1A as per AAR requirements and using special requirements for grinding

- all repaired side frames are to be marked with repair shop initials (Hillside "H"), the day/month/year repaired and a symbol showing the nature of the repair in the area designated e.g. WRZ1 for a repair in Zone 1A
- temper side frame in accordance with AAR requirements
- carry out final inspection for cracking, including MPI of Zone 1A
- independent third party to verify inspection and all repairs.

3.6.10. KiwiRail's M9200-02 Bogie Overhaul Manual Issue 3, effective from 17 September 2010 was amended to include the acceptance criteria of Specification 380, requiring all side frames to undergo MPI when a bogie is overhauled.

3.6.11. As at August 2008, there were about 6350 Type 14 bogies in service plus 140 un-refurbished, 60 refurbished and 160 under laid-up wagons. Since 2002, there had been an average of about 650 Type 14 bogies overhauled annually.

3.6.12. Up until October 2009, a total of 3854 bogie side frames had been MPI tested in the pedestal roof area. Of those tested, 1512 had passed inspection. The 2346 defective units had been sent to the foundry at Hillside workshops for weld repair and heat treatment. The repaired side frames were re-inspected and passed the MPI test before being acceptable for the bogie refurbishment programme.

3.6.13. Since 27 July 2005, there have been 13 in-service Type 14 bogie side frame failures, and all were the result of cracks initiating in the pedestal radius area. Of these 13 failures, 11 resulted in derailments where the cause was attributed to failures of the side frames.

4. Analysis

4.1. With each of these 3 occurrences there was nothing in the way the trains were being driven that contributed to the trains derailing. They were all being driven within the relevant speed limits, with the exception of a minor exceedance owing to an inaccurate speedometer reading.

4.2. The track conditions at all 3 derailment sites were within maintenance tolerance limits and there were no track anomalies that should have caused a derailment. The witness marks along the rail corridor, together with the debris trail, showed that the failure of the bogie side frames was the initiating event leading to each derailment. The consequent dropping of the bogie spring nest onto the rail then catching on some track feature such as facing points or timbered crossings was the cause of the actual derailments.

4.3. The derailment of Train 237 was attributed to the failure of the bogie side frame on wagon ZH560. The side frame had been in service for 33 years. The side frame failed due to extensive fatigue cracking covering about 80% of the cross-sectional area of the box section. Fatigue was followed by overload failure in the remainder of the section in a combination of bending and tensile forces.

4.4. The derailment of Train 220 was attributed to the failure of the bogie side frame on wagon ZH1766. There were no records available to confirm the length of time for which the failed side frame had been in service, but it was likely to have been in the order of 30 to 40 years. The side frame failed due to fatigue followed by failure in overload, in a manner similar to that on wagon ZH560 and on other wagons mentioned in earlier Commission reports 05-118 and 05-126. However, with wagon ZH1766, the fatigue crack initiated in parent material not modified by welding.

4.5. The derailment of Train 211 was attributed to the failure of a bogie side frame on wagon ZH554. There was no visible reference mark on the failed side frame, so its age could not be determined with any precision, but its general appearance suggested it could have been in service for up to 40 years. The side frame had failed due to fatigue, followed by ductile overload fracture, in a manner similar to the failures described above. The location of the fatigue cracking initiation was generally similar as well, occurring at a highly stressed area in the radius between the pedestal roof and the inner pedestal leg. However, while previous failures exhibited a single fatigue crack propagating most of the way around the cross-sectional area of the side frame before the material failed in overload, this failure showed more than one initiation point, which eventually joined up and propagated through the cross-section, ultimately failing in overload.

4.6. The mode of failure was similar in these 3 cases as well as in previous side frame failures the Commission has investigated. There were small variations in what had initiated the fatigue cracks. In one case the heat-affected-zone material from previous welding of the wear plate was present at the crack origin. The weld bead contracted when it cooled during the welding of a wear plate, or the repeated replacement of plates, and probably introduced weld residual tensile stresses in the material beyond the weld bead at the crack origin. Since the crack initiated in a region that was already highly stressed during normal operation, the tensile stresses induced by operational loading would have added to the residual stresses to exceed the fatigue limit.

4.7. With wagon ZH554, it was possible that stresses were present owing to the repeated welding of replacement wear plates during the many years the side frame had been in service. However, the origin of the fatigue was 20 mm from the present wear plate, and examination of the microstructure confirmed that the material was visibly unaffected by welding. The only imperfection observed at the fatigue crack origin was decarburisation. The hardness tests confirmed that the material in the decarburised region was no less hard, and therefore probably no less strong, than the bulk material.

4.8. In another case the condition of the casting material was not considered to be influential in the initiation of the crack. There was little evidence of material imperfection that initiated the fatigue cracks. Although the crack initiation was close to a depression in the metal in one case, the depression was not considered to have been influential in the failure. The depression may have been present in the original casting or it may have been made when a replacement wear plate was fitted during one of possibly 3 overhauls. For example, it may have been made by a grinding disc. There was no evidence indicating that the side frame had been impacted by an object during the derailment sequence.

4.9. The number of arrest marks to failure was estimated to be about 870 in one case, and this was of similar order to fatigue cracks in other cases. These macro features represent major changes in loading and usually incorporate many cycles. However, what constitutes a load change has not been determined.

4.10. In all cases the wagons were loaded at the time of failure; how heavily loaded could not be determined because the in-motion weighbridges within the rail network were not working reliably and had not been for some time. Weights were often taken from the customers' weight declarations, which have been shown in the past to not always be accurate. It is possible then that wagon maximum loadings were exceeded from time to time, bringing forward the onset of fatigue failure. A safety recommendation concerning weighbridges has been made previously and the safety actions are included in section 6.

4.11. The spacing of the arrest marks, where they could be measured, was similar. The absence of substantial, aged corrosion product within the first few millimetres of cracking would suggest that the entire fractures had occurred over a short period of time, days rather than weeks.

4.12. KiwiRail's Mechanical Code wagon B-Check and C-Check required a visual check of the side frames. Mostly, the visual inspections of the side frames occurred with the wheels in place, thereby precluding an examination of the pedestal roof area. Therefore, it was likely that a visual examination would not identify a potentially defective side frame and the bogie would be returned to service.

4.13. One of the most reliable means of identifying a fatigue crack in the pedestal roof area was by MPI. During the 4 years since Toll Rail started its MPI testing in this area during a bogie overhaul, some 3854 Type 14 bogie side frames had been tested. Of these, 2346 were identified as having cracks in the pedestal roof area. This was close to a consistent 60% failure for each of the previous 4 years. With a total of about 6500 Type 14 bogies (13 000 side frames) in service and in inventory, and given the current bogie overhaul rate of fewer than 500 bogies annually, it will take until 2010 before all Type 14 bogie side frames have been through an initial MPI.

4.14. The scheduling of when a side frame was to be given an MPI was determined by the condition of the bogie and its ride characteristics, without regard to the age profile of the bogie side frame. Indeed, because side frames had no unique identifiers, the operational histories and ages of the side frames could not be readily determined, so a higher priority could not be given to testing the older side frames.

4.15. The history of this type of failure has shown that the Type 14 bogie side frames were susceptible to fatigue cracking in the region of the radius, just beyond the wear plate. No reason for the failures has been found other than that all of the side frames that failed had been in service for some 30 to 40 years. It is highly likely that the side frames had simply reached the end of their fatigue lives and had failed in their weakest point, the region of the radius just beyond the wear plate in the pedestal roof area, possibly exacerbated by welding repairs conducted around the wear plate.

4.16. Because the age of the side frames cannot be accurately determined, the failure rate of 60% will likely continue throughout the programme until all of the untested side frames have been put through the programme. As the number of untested side frames reduces, 60% will represent a decreasing number of at-risk side frames in the system.

4.17. Derailments represent a high risk to the rail industry, certainly with respect to damage of rolling stock and freight, and damage to the rail infrastructure. The other risk to consider is that to people.

4.18. In each of the derailments, the damage to rolling stock, the freight being conveyed and track structures was not insignificant, possibly exacerbated by the fact that wagons behind an already derailed wagon are likely also to derail when the derailed wagon strikes a set of facing main-line points.

4.19. Of all the derailments caused by collapsed side frames, none has resulted in injury. This can be attributed in part to only one person generally being on board freight trains and the fact that the locomotives are rarely affected, and also to the high percentage of the rail network being routed through remote areas.

4.20. The consequences, however, could be high. The trains do travel over numerous level crossings and past station platforms. Large sections of the track are located adjacent to public highways. The Levin derailment occurred adjacent to a busy level crossing and just after the train passed a station platform. The Hunterville derailment resulted in a fire.

4.21. One derailment the Commission has investigated resulted in rolling stock falling across the adjacent State Highway 1 (investigation 07-114). That derailment was caused by a failed wheel roller bearing. Fortunately the derailment occurred early in the morning when highway traffic was light.

4.22. Given the high probability of derailments causing damage to rolling stock and track infrastructure, and the possibility of a derailment being causing injury to people, the Commission is strongly of the view that the current rate of MPI of side frames, and the length of time it will take to complete the testing programme, may not be acceptable from a risk perspective. Given the results of the side frame testing to date and the 11 in-service bogie side frame failures since 2005 that have led to derailments, it is highly likely that there will be more derailments due to the same failure of bogie side frames until all the side frames have been inspected and remedial work carried out where necessary. A recommendation has been made to address this safety issue.

5. Findings

5.1. The following findings are not listed in any order of priority.

5.1.1. The derailment of all 3 trains was initiated by the failure of a bogie side frame allowing the bogies to drop onto the track and derail.

5.1.2. The failure mode of each collapsed side frame was similar, with fatigue cracking propagating from the same localised area, through the box section until the remaining material failed in overload from normal operating loads.

5.1.3. While there were some small variations in what initiated the fatigue cracks, they likely initiated at the weakest point of the structure when the side frames had reached the end of their fatigue lives.

5.1.4. The propagation of the fatigue cracks occurred rapidly (within days rather than weeks) and they would have been difficult to detect during routine operational and maintenance checks.

5.1.5. With little known of the age of the some 13,000 Type 14 bogie side frames in the network fleet, there is no practicable method to predict fatigue cracking within each bogie side frame. With the current MPI programme set to take until 2020 before all side frames have been tested, the likelihood of more derailments due to collapsed side frames is high.

5.1.6. The material damage to rolling stock and track infrastructure likely to occur from main-line derailments, and the potential risk to people, suggest that the programme for MPI testing will need to be accelerated.

5.1.7. There was no train handling or track-related issues that could have contributed to the derailments.

6. Safety actions

General

6.1. The Commission classifies safety actions by 2 types:

(a) safety actions taken by the regulator or an operator to address safety issues identified by the Commission that would otherwise have resulted in the Commission issuing a recommendation

(b) safety actions taken by the regulator or an operator to address other safety issues that would not normally have resulted in the Commission issuing a safety recommendation.

6.2. The following safety action has been taken by KiwiRail.

Safety action addressing proposed recommendation

(a) In March 2010, a Bearing Acoustic Detection device (RailBAM) and an accompanying continuous-in-motion weighbridge were installed at Bunnythorpe, near Palmerston North, on the NIMT and at Rolleston, near Christchurch. Identical units were scheduled to be installed near Tauranga during August 2010. Another 3 stand-alone continuous-in-motion weighbridges were scheduled to be installed on the NIMT Down Main line near Westfield, at 193.5 km on the Midland line east of Stillwater and at Wellington.

7. Recommendations

General

7.1. The Transport Accident Investigation Commission Act 1990 requires the Commission to issue its recommendations to the appropriate regulator even though another person or organisation may appear to be the more appropriate recipient. This is because the regulator will be better placed to ensure that these recommendations are, if appropriate, implemented across the industry rather than just by a single operator.

New Recommendations

7.2. The following recommendations are not listed in any order of priority:

7.2.1. On 4 October 2010 it was recommended to the Chief Executive of New Zealand Transport Agency that:

The most likely reason for the side frame failures is that they had reached the end of their fatigue lives. A lack of identifying marks and records of side frame age and maintenance history means that it will be difficult to predict the onset of fatigue cracking in bogie side frames. The presence of fatigue cracking initiating in the region of the radius, just beyond the wear plate of the side frames, is difficult to detect by normal visual inspections, and at the current rate of MPIs the entire inventory of bogie side frames will not be completed until 2020. With 60% of the side frames tested consistently requiring weld repairs before being returned to service, the failure and collapse of a bogie side frame have resulted, and will continue to result, in significant damage to rolling stock and track infrastructure and the risk of serious harm to people.

The Commission recommends that the Chief Executive of the NZ Transport Agency give high priority to working with industry to conduct a formal assessment of the risks that main-line derailments pose to rolling stock and track infrastructure, and the risk of serious harm to people (industry and the general public). The results of the risk assessment should then be used to set appropriate remedial measures to reduce the likelihood of bogie side frame failures, and could also be used to set appropriate measures to reduce main-line derailments from other causes. (043/10)

On 8 October 2010 the Rail Safety Manager replied:

> We intend to work closely with KiwiRail with an aim to implementing and closing this recommendation as soon as practicable.
>
> Discussions on it will commence on publication of the report and will be ongoing. Any outstanding Transport Accident Investigation Commission (TAIC) recommendations also form and integral part of our annual safety assessments of the rail industry. Discussions on the bogie component issues this report highlights have already commenced.
>
> When these discussions are concluded and the appropriate evidence has been gathered, we will be liaising with TAIC with a view to closing this safety recommendation.

Appendix 1: Laboratory reports on 3 failed bogie side frames

Failed bogie side frame from Wagon ZH 560 (Hihitahi derailment)

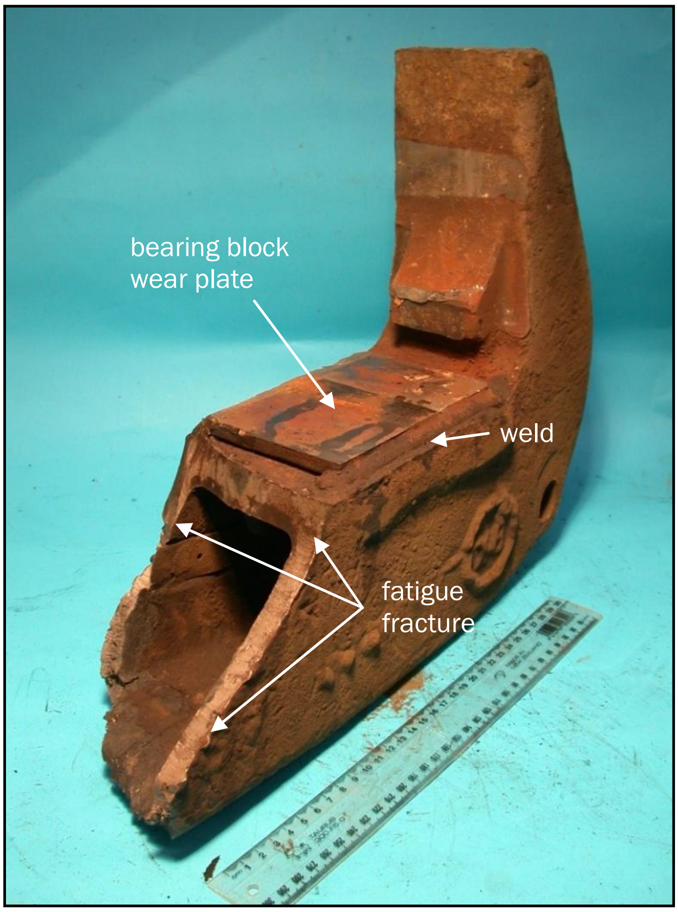

Figure 12 (copy of Figure 4)
Side frame section inverted from normal orientation on wagon

Visual examination

1.1. The side frame was visually examined with the aid of a stereoscopic microscope and the following observations were made:

- there was a large fracture extending through about 80% of the box section
- the fatigue fracture had a single origin, labelled "O" (see Figure 13), at the corner of the outside of the side frame. The origin was about 10mm from the end of the fillet weld that attached a wear plate
- the initiation point of the fatigue crack was near but not at the base of the depression and possibly not directly influenced by the depression
- the fatigue crack showed numerous arrest marks that indicated the progression of the crack, shown by the yellow arrows in Figure 13. The spacing of the arrest marks was estimated using a ruler with 0.5mm graduations. The approximate number of arrest marks along the propagating fatigue crack was 871
- mechanical impact damage had occurred on the fatigue fracture after the failure
- occasional weld spatter balls were present near the end of the fillet weld but none was seen at the fracture origin
- the pedestal wear plate had a small amount of wear.

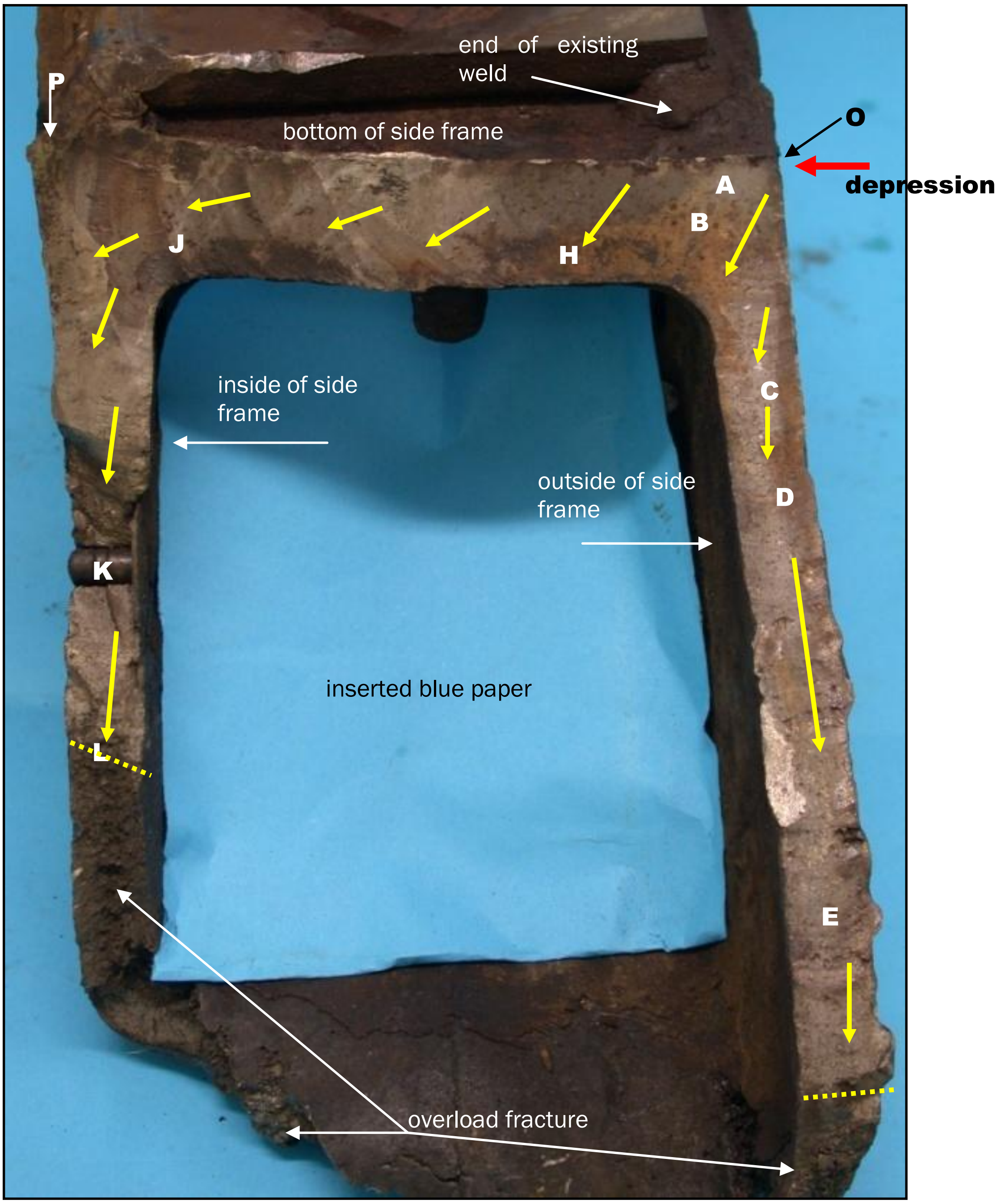

Figure 13
Fatigue fracture surface with regions marked

Microscopic examination

1.2. A section of material was taken from region A that included origin O (see Figure 13). The specimen was ground and polished in the direction indicated by the red arrow in Figure 13.

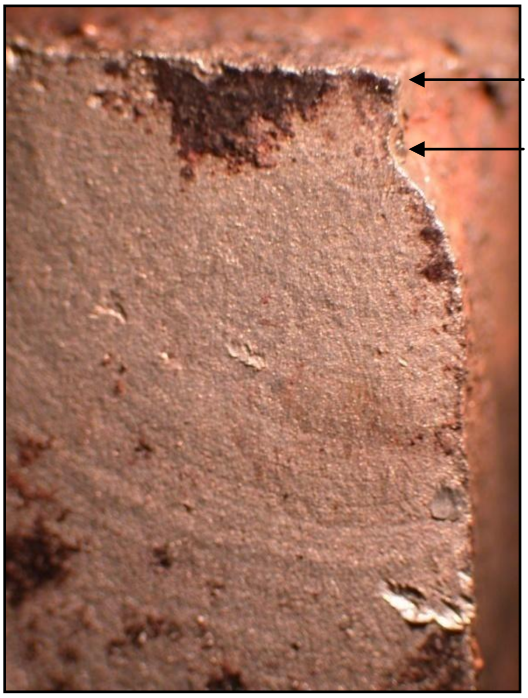

Figure 14
Origin of the fatigue fracture

1.3. The specimen preparation was halted for examination at various stages before reaching the bottom of the depression. The following observations were noted:

- before reaching the bottom of the depression there was surface corrosion/oxidation product present. There were no substantial internal imperfections such as porosity and non-metallic inclusions observed
- the base material at the bottom of the depression was also sound, with no appreciable imperfections
- there were no imperfections in the material that could have initiated the fatigue crack
- the material in the origin region exhibited 2 distinctly different microstructures. The microstructure remote from the origin resembled the base material structure. In contrast, the microstructure at the origin resembled heat-affected material typical of a heat-affected zone from welding
- no appreciable grain deformation was observed in the depression, indicating that the depression was likely not to have resulted from impact or compression but may have resulted from gouging by a grinder or alternative tool
- the microstructure of the base metal was consistent with normalising and tempering
- an additional section was taken from material in the overload fractured region at the end of K, Figure 13. The microstructure was similar to that observed for the base material seen in the first section, i.e. normalised and tempered steel.

Hardness tests

1.4. Vickers micro-hardness tests were conducted in the region of the origin, using a 0.1kg load. In addition, Vickers macro-hardness tests were conducted on the base metal using a 10kg load. The macro-hardness values indicated a probable tensile strength for the base material of 545MPa and 676MPa for the heat-affected material. The difference in hardness between the 2 regions was consistent with base and as-welded materials.

Chemical analysis

1.5. Chemical analysis was performed by Metal Test Ltd, Auckland using Optical Emission Spectroscopy. The elemental composition results by weight percentage were:

Description	C	Si	Mn	S	P	Ni	Cr	Mo	Cu	Al
Side frame	0.19	0.18	0.62	0.007	0.010	0.07	0.08	0.01	0.07	0.26

1.6. The chemical analysis was consistent with the requirements of the specification.

Failed bogie side frame from Wagon ZH 1766 (Levin derailment)

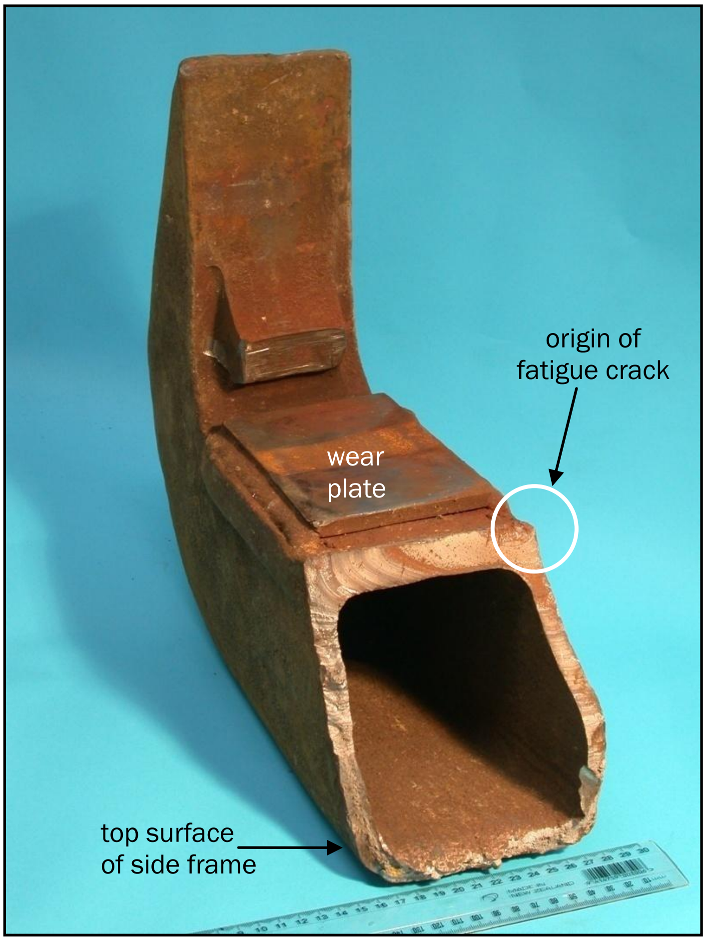

Figure 15 (copy of Figure 8)
Pedestal leg of side frame from wagon ZH1766
inverted from normal orientation when fitted

Visual examination

1.7. The separated section of the bogie side frame was examined using a stereoscopic microscope. Findings from the examination included:

- the side frame was manufactured as a box section, with a slight broadening taper towards the top side of the side frame (see Figure 15)
- a major fatigue fracture had propagated through about 70% of the cross-section of the side frame. A general origin was about 20 mm from the corner of a welded wear plate

- several castellations were present at the general origin in region A (Figure 16) and these exhibited substantial steps. They also fanned out from a nearly common general origin, indicating that several separate fatigue cracks had initiated in close proximity to each other. After propagating about 8mm to 10 mm, these individual cracks joined to form a major crack propagation front. The major crack propagated right through the section in region A

- the common general origin of the individual fatigue cracks exhibited a distinctly irregular morphology over a surface length of about 19 mm and to a depth of about 3 mm

- the thickness of the box section in region A was about 20 mm. Where the fatigue crack propagated through the section thickness it was about 43 mm along the exterior surface of region A. This gave an aspect ratio of 43:20 or about 2:1

- the relatively small area where the first few individual fatigue cracks formed and merged, within region A, was labelled A1. This area had darker corrosion product than the remainder of the fatigue region, suggesting that the crack was somewhat older than the remainder. The dimensions for A1 were about 30 mm along the surface and 10 mm deep, giving an aspect ratio of about 3:1

- the second area of corrosion product, labelled A3, was beyond a relatively corrosion-free area, labelled A2. The corrosion in this area was not as old in appearance as that seen in A1

- there were several patches, following the contours of the arrest marks, where polishing had occurred. One such area was labelled A4. Another was present much further along the fatigue crack and was labelled A3

- the surface of the fatigue crack was free of substantial corrosion. The light corrosion product in region A was consistent with very recent corrosion resulting from exposure to the atmosphere after the final overload failure.

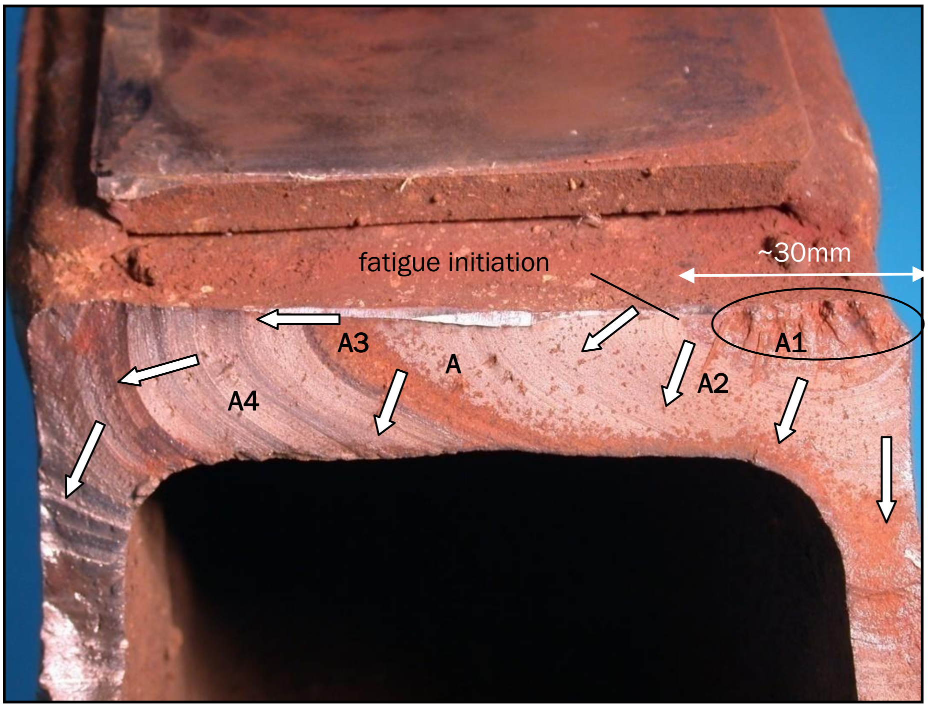

Figure 16
The major fracture regions

Microscopic examination

1.8. Four sections were taken at the origin to examine for the cause of the crack initiation. The sections were metallographically prepared and examined under an optical microscope, with the following noted:

- decarburisation was present all along the surface of the side frame in all 4 sections examined
- some porosity was present near the origin but none was observed at the origin in all 4 sections
- non-metallic inclusions were fairly frequent but considered typical for a casting manufactured about 40 years ago
- the microstructure consisted of fine equiaxed grains of ferrite and pearlite, consistent with the material having been annealed after casting. The microstructure resembled that of other failed side frames examined
- general corrosion was present on the surface of the material but none was observed sub-surface.

Hardness

1.9. Hardness tests were performed using a Vickers hardness tester with a 10 kg load (HV 10) in the bulk material, a 2.5 kg load in the decarburised and bulk material and a Leitz micro-hardness tester with a 0.1 kg load in the decarburised and bulk material. The latter test was to provide a comparison with the HV10 values. The tests indicated that the decarburised region was slightly harder than the bulk material, probably owing to a faster cooling rate of the surface material. The hardness values indicated a tensile strength in the range of 448-510 MPa in the bulk material and 510-607MPa in the decarburised material.

1.10. Vickers micro-hardness tests were conducted in the region of the origin, using a 0.1 kg load. In addition, Vickers macro-hardness tests were conducted on the base metal using a 10 kg load. The macro-hardness values indicated a probable tensile strength for the base material of between 545 MPa and 676 MPa for the heat-affected material. The difference in hardness between the 2 regions was consistent with base and as-welded materials.

Chemical analysis

1.11. Chemical analysis was not performed. From the micro-structural examination, the carbon content was estimated to be about 0.3% and consistent with previous side frames examined.

Failed bogie side from Wagon ZH 554 (Hunterville derailment)

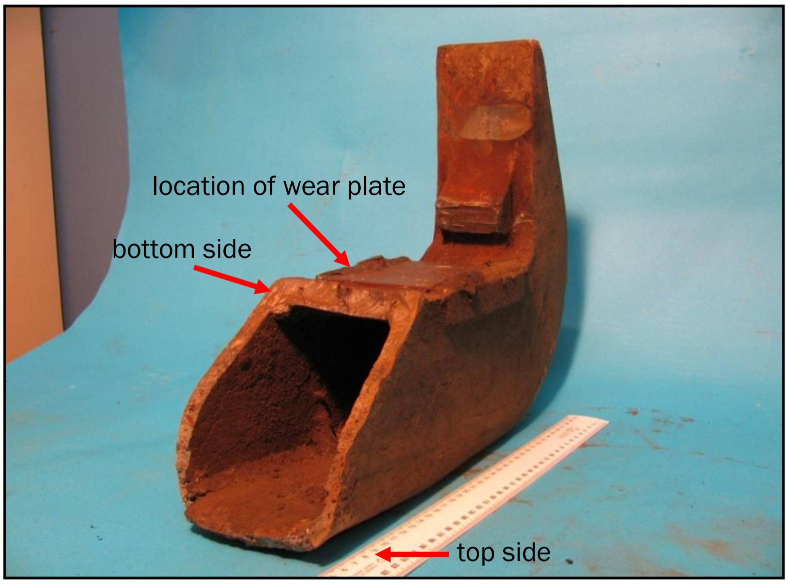

Figure 17 (copy of Figure 10)
Failed side frame section from wagon ZH544
inverted from normal orientation when fitted

Visual examination

1.12. The failed side frame section was visually examined and the following observations were made:

- the welded wear plate had come away from the box section
- a fatigue crack was noted in what remained of the wear plate weld, but this was not considered to be the focus of the investigation
- a fatigue fracture had propagated completely through the bottom side of the box section, halfway up the left-hand side and about two-thirds of the right-hand side
- fatigue initiation appeared to have occurred at 3 locations along the bottom side (see Figure 1). The most significant of these were close to a corner in the radiused section of the original frame geometry and close to a void resembling a casting defect
- the corner crack had propagated through another void that also resembled a casting defect
- the initial propagation region of the corner crack showed an aspect ratio of about 2:1, which was consistent with cracks on other failed side frames
- the fatigue crack propagation regions were mostly smooth and flat, with many closely spaced arrest marks present, which would be consistent with a high number of changes in service conditions
- the remainder of the box section appeared to have failed under ductile overload. The top side failed in bending overload that produced a lip, which experienced some mechanical damage, most likely to have occurred after the failure of the part.

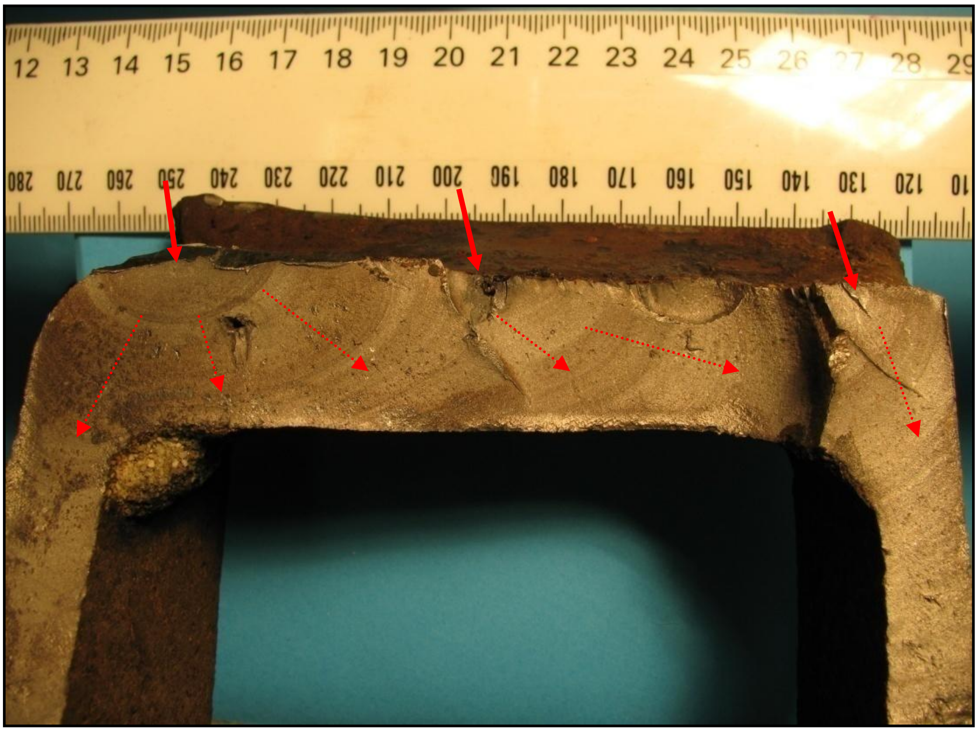

Figure 18
Initiation points and fatigue cracking propagation

Microscopic examination

1.13. A section from the corner crack initiation region, as well as one from the suspected casting defect initiation region, were removed and metallographically prepared. The following observations were made:

- non-metallic inclusions and some instances of casting porosity were present. Neither the inclusions nor the porosity showed evidence of any influence on the initiation regions
- the microstructure contained fine grains of ferrite and pearlite, consistent with casting
- decarburisation was observed along the surfaces of the sections examined
- a distinct line of predominantly ferrite grains was noted just below the surface of the corner crack cross-section, signifying lower carbon content along those lines. This was likely to be an original casting imperfection, such as a cold shut
- the density and distribution of ferrite and pearlite varied, consistent with non-uniform pouring practice and differential cooling
- the edge close to the initiation point on the corner crack cross-section showed a ferrite and bainite microstructure, typical of as-deposited weld metal and heat-affected-zone material
- the parent material close to the welded region showed a modified heat-affected-zone material microstructure.

Hardness

1.14. The decarburised region showed higher hardness values when compared with the bulk material. Generally the hardness values were within the range of other failed side frames. The welded region showed a much higher hardness than the bulk material, as expected. The hardness values were indicative of tensile strengths within the range of 406-420 MPa in the bulk material, 439-598 MPa in the decarburised region, and 1247-1332 MPa in the bainitic region.

Chemical analysis

1.15. An energy-dispersive X-ray analysis was carried out on the side frame cross-sections to confirm their composition. The results are shown in the following table. However, the analysis method is not sensitive to elements with an atomic mass lighter than boron (10.8), and will not reliably quantify carbon.

	Area 1	**Area 2**	**Grade B Nominal**
C	NQ	NQ	0.32 max
Si	0.6	0.7	1.50 max
S	ND	ND	0.04 max
P	ND	ND	0.04 max
Ca	ND	0.3	Not specified
Mn	1.0	0.9	0.90 max
Fe	98.3	98.1	Balance

NQ denotes not quantified

ND denotes not detected

1.16. From the microstructural examination, the carbon content was estimated to be about 0.3%. The estimated carbon content, alloying addition levels and hardness of the material correspond to AAR M-201 Grade B, closer to the lower bound of the specified material properties.

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07-113	express freight Train 239, wagons left in section at 514.9km, between Te Awamutu and Te Kawa, 22 September 2007
07-110	collision, express freight Train MP2 and Work Train 22, Ohinewai, 19 June 2007
06-110	passenger train 4045, uncontrolled movement, between Britomart and Quay Park Junction, 9 October 2006
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