Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Rail Occurrence Investigation 2007/003

Final

Derailment of Train 3MR2
near Roopena, South Australia

22 May 2007

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Abstract

At approximately 0428 on 22 May 2007, ballast train 3MR2 derailed near Roopena, SA (between Whyalla and Port Augusta). The derailment occurred about 28 track kilometres north of Whyalla. Twenty seven ballast wagons were derailed but there were no injuries.

The investigation concluded that a number of factors combined to cause the derailment. A cross-level track geometry defect caused body roll on the first wagon to derail which led to dynamic unloading of the wagon's leading, right-hand wheel. When combined with a horizontal and vertical alignment defect, wheel unloading increased further and the right-hand wheel moved into flange contact with the right-hand rail such that the risk of a flange-climb increased at the point of derailment. Non-compliant side bearer gaps, uneven load distribution and the wagon's sensitivity to spring compression length also combined to cause the front left-hand suspension springs to become fully compressed thereby increasing the amount of wheel unloading at the point of derailment.

All these factors combined to indicate that body roll, spring compression, train speed, wheel unloading and flange contact at the point of derailment were of sufficient magnitude that a flange-climb derailment would be expected to occur. A range of safety actions were taken or recommended to seek to prevent similar incidents in the future.

THE AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal bureau within the Australian Government Department of Infrastructure, Transport, Regional Development and Local Government. ATSB investigations are independent of regulatory, operator or other external bodies.

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

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

Purpose of safety investigations

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

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

Developing safety action

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

The ATSB has decided that when safety recommendations are issued, they will focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on the method of corrective action. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations. It is a matter for the body to which an ATSB recommendation is directed (for example the relevant regulator in consultation with industry) to assess the costs and benefits of any particular means of addressing a safety issue.

TERMINOLOGY USED IN THIS REPORT

Occurrence: accident or incident.

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

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

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

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

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

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

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

EXECUTIVE SUMMARY

At approximately 0428[1] on 22 May 2007, ballast train 3MR2 derailed near Roopena, SA (between Whyalla and Port Augusta). The derailment occurred about 28 track kilometres north of Whyalla. Twenty seven ballast wagons were derailed and about 400 metres of track was damaged but there were no injuries.

Ballast train 3MR2 was owned by the Australian Rail Track Corporation (ARTC) and operated by South Spur Rail Services. It consisted of two locomotives hauling a ballast plough, 35 loaded AHWX and AHWY class ballast wagons with a second ballast plough at the rear of the train. The train was 426 metres long and weighed a total of 2978 tonnes. The maximum allowable speed for train 3MR2 was 80 km/h.

Train 3MR2, loaded with track ballast, departed Whyalla at about 0400 and was travelling towards Port Augusta. About 28 kilometres north of Whyalla, while travelling at 79 km/h, the drivers noticed a reduction of brake pipe pressure, the train brakes began to apply and train 3MR2 came to a stop. The second driver walked back to investigate the cause of the brake application and discovered that train 3MR2 had derailed and a significant portion of track had been destroyed.

Examination of on-site evidence showed wheel flange markings over the rail head soon after an unsealed level crossing at the 138.100 track kilometre point[2]. The track geometry was surveyed and showed a significant dip in the eastern rail just before the level crossing. The western rail also showed a dip but much smaller in size. The dips were followed by a hump in both rails as the track passed over the unsealed level crossing. The location of the defect was where the track had been repaired after flood damage some four months earlier.

A track inspector had identified the track geometry defect on 18 May, four days before the derailment, while travelling by road/rail vehicle between Whyalla and Port Augusta. The inspector stated that the dip didn't seem too bad and visually assessed that it was suitable for trains to traverse at 80 km/h. Post derailment assessment of the defect against the ARTC Track and Civil Code of Practice (CoP) also indicated that the track should have been suitable for a train travelling at a maximum of 80 km/h. However, train 3MR2 derailed while travelling at slightly less than 80 km/h.

To assist in identifying the mechanism for the derailment, the ATSB engaged experts in simulation to model and analyse the dynamic response of the ballast wagons to the track defect found at Roopena. The modelling revealed a number of factors, that when combined, were likely to have resulted in the derailment of train 3MR2.

A cross-level track geometry defect caused body roll on the first wagon to derail (AHWX-12) which led to dynamic wheel unloading of the wagon's leading, right-hand wheel. When combined with a horizontal and vertical alignment defect, wheel unloading increased further and the right-hand wheel moved into flange contact

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

2 Track kilometre points are measured from Coonamia (0.000 km) via Port Augusta (92.000 km) to Whyalla (166.591km).

with the right-hand rail such that the risk of a flange-climb increased at the point of derailment.

On site observations found that the loads in each of the ballast wagons on train 3MR2 were not evenly distributed across the entire width of the wagon. Computer simulation showed the wagon to be sensitive to spring compression length such that the body roll would have been sufficient to cause the front left-hand suspension springs to become fully compressed. It is likely that the uneven load distribution on wagon AHWX-12 caused the left-hand suspension springs to compress more than if the load had been evenly distributed.

Close examination of wagon AHWX-12 revealed that the side bearer gaps, on both the front and rear bogies, exceeded the specified limits documented in the *Railways of Australia – Manual of Engineering Standards and Practices*. It is likely that the excessive side bearer gaps on AHWX-12 provided less control over body roll than a wagon with correctly gapped side bearers or constant contact side bearers.

The modelling also predicted that the loaded wagon was at risk of derailment when traversing the track geometry defect at 80 km/h, even though the defect had been assessed as suitable for trains to traverse at 80 km/h. If train speed had been reduced to 50 km/h, it was predicted that the magnitude of the wheel unloading would have been less and thereby decreased the risk of a flange-climb derailment when traversing the track geometry defect.

All these factors combined to indicate that body roll, spring compression, train speed, wheel unloading and flange contact at the point of derailment were of sufficient magnitude to indicate that flange-climb was the likely mechanism for the derailment.

The investigation also identified a number of other safety issues that may have increased ARTC's safety risk. These safety factors are documented in the interests of improving railway safety and relate to:

- The identification, measurement, assessment, monitoring and repair prioritisation of track geometry defects.
- The track speed limit on the Whyalla/Port Augusta rail corridor.

The investigation acknowledged a number of actions that had been taken by the ARTC to address the identified safety issues, including:

- An upgrade program to retrofit the AHWX class ballast wagons with constant contact side bearers.
- Changes to the ballast loading process to ensure that even load distribution is achieved.

However, the investigation concluded that there were further opportunities for improvement. The ATSB recommended that the Australian Rail Track Corporation undertake further work to address safety issues relating to:

- Consideration of the combined effects of track geometry defects when assessing a track speed suitable for safe rail operations.
- Consideration of poorer riding rolling stock when assessing a track geometry defect for the application of a temporary speed restriction.

1 FACTUAL INFORMATION

1.1 Overview

At approximately 0428[3] on 22 May 2007, ballast train 3MR2 derailed near Roopena, SA. Twenty seven ballast wagons were derailed and about 400 metres of track damaged. There were no injuries.

1.1.1 Location

Roopena is located on the Spencer Junction[4] to Whyalla railway corridor and is part of the Defined Interstate Rail Network (DIRN) in South Australia. The derailment occurred about 28 track kilometres north of Whyalla.

Figure 1: Location of Roopena, SA.

Map - Geoscience Australia. Crown Copyright ©.

The track at the Roopena derailment site is predominantly continuously welded rail secured to concrete sleepers by resilient fasteners and supported on ballast. The track is owned and operated by the Australian Rail Track Corporation (ARTC), and track maintenance has been contracted to Transfield Services.

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

4 Spencer Junction is located near Port Augusta where the Whyalla rail line joins the main east-west rail line running between Adelaide and Perth.

1.1.2 Train information

Ballast train 3MR2 was owned by the ARTC and operated by South Spur Rail Services (SSRS). It consisted of two locomotives (NA1874 and Cs5) hauling a ballast plough, 35 loaded ballast wagons (34 AHWX class wagons and one AHWY class wagon) with a second ballast plough at the rear of the train. The train was 426 metres long and weighed a total of 2978 tonnes. The maximum allowable speed for train 3MR2 was 80 km/h.

The driver at the time of the accident had about 30 years train driving experience. At the time of the derailment, both train drivers were appropriately qualified, assessed as competent and medically fit for duty.

The AHWX class wagon is an open top hopper style wagon designed to carry track ballast. Loaded wagons are usually hauled to a worksite where ballast is discharged through discharge chutes located in the base of each wagon. The wagons ride on three-piece 'Ride Control' bogies with gap/friction style side bearers. The AHWY class wagon is an AHWX class wagon that has been modified to accommodate constant contact side bearers (CCSB). At the time of the derailment, only one wagon in the train had been modified with CCSB's as a 'proof of concept' (AHWY-13). Due to dynamic behaviour limitations, AHWX class ballast wagons are not permitted to exceed 80 km/h. Each of the 35 ballast wagons in the train had been recently refurbished with a remote door operating system replacing the original manual system.

Figure 2: AHWX class wagon

Table 1: AHWX and AHWY class ballast wagon

Tare weight	19.1 tonnes
Length	10.4 metres
Max gross weight	75.7 tonnes
Capacity	56.6 tonnes
Max allowable speed	80 km/h (Note 1)
Bogies	Three-piece 50 ton Ride Control AHWX - gap/friction style side bearers AHWY - CCSB style side bearers

Note 1: The theoretical speed limit for the AHWY class wagon is maximum track speed. However, as only one wagon had been developed as a 'proof of concept', it had only ever travelled in a train consist with wagons limited to 80 km/h.

1.2 The occurrence

Train 3MR2 derailed soon after passing over an unsealed level crossing located at the 138.100 track kilometre point[5]. About four months before the derailment, the railway track north of Whyalla had been damaged due to heavy flooding. The flood damage occurred after heavy rains (about 92 mm recorded at Whyalla[6] on the 19th and 20th of January 2007) washed ballast and earth away from under the track resulting in significant track damage over almost 30 track kilometres, including the area either side of the unsealed level crossing (Figure 3).

5 Track kilometre points are measured from Coonamia (0.000 km) via Port Augusta (92.000 km) to Whyalla (166.591km).

6 Bureau of Meteorology - automatic weather station located at the Whyalla airfield.

Figure 3: Track damage due to flooding (photograph, 22 January 2007)

Photograph – Australian Rail Track Corporation ©

The flood damaged track was repaired and train services resumed on 27 January subject to a restricted speed limit of 40 km/h. The temporary speed restriction was removed on 9 February and no defects were identified in the area when the track geometry car travelled the Port Augusta/Whyalla line the following day, 10 February.

On 29 March a track geometry defect[7] in the area was repaired and three weeks later on 20 April another track geometry defect was identified and recorded at the 138.100 kilometre point. On 18 May 2007 the defect was again observed and reported by a track inspector. The defect was located on the southern side of the level crossing.

Train 3MR2

The ballast wagons on train 3MR2 were loaded at Whyalla using a wheel loader. When lifting the ballast into the wagons, the loader could not reach to the centre and consequently the loads in the wagons were unevenly distributed (Figure 4).

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7 Described as a hole in the track, the defect was most likely associated with vertical alignment.

Figure 4: Wheel loader and uneven loading on AHWX-12

Note: While the load in wagon AHWX-12 is likely to have been disturbed during the derailment, the load profile illustrated in Figure 4 is generally consistent with the profiles observed in the wagons that did not derail.

At about 0400 on 22 May 2007, train 3MR2 departed from Whyalla and began travelling towards Port Augusta. The train's destination was the 155 km point between Port Augusta and Tarcoola where it was intended to unload ballast while demonstrating the new remote door operation recently installed on the ballast wagons.

About 28 kilometres north of Whyalla, while travelling at about 80 km/h, the train drivers noticed a reduction of brake pipe pressure indicating that brake pipe air was exhausting to the atmosphere and the train brakes would begin to apply. Train 3MR2 came to a stop and the driver contacted the ARTC train controller to advise that train 3MR2 had stopped due to a loss of brake pipe pressure.

The second driver walked back to investigate the cause of the brake application and discovered that only seven of the 37 wagons were coupled behind the locomotives, and two of the seven were derailed. As he was unable to see the rest of the train in the darkness, the driver walked further back along the track before finding the remainder of the wagons, most of which had also derailed. The drivers contacted the ARTC train controller and advised that train 3MR2 had derailed and a significant portion of track had been destroyed.

The drivers stated that, as visibility improved with the rising sun, wheel flange markings could be seen over the rail head immediately behind the last wagon of the train. When looking a little further back towards Whyalla, the driver could see a dip in one rail just before the track crossed an unsealed level crossing. One of the drivers noted that the location of the dip was where the track had been repaired after flood damage about four months earlier.

Post occurrence

Investigators and recovery crews progressively arrived on site and examined the site throughout the remainder of the day (22 May 2007). Heavy lift cranes arrived on site later that day and began the recovery of derailed wagons.

The undamaged front and rear portions of the train were hauled to Port Augusta and Whyalla respectively. Excavators were used to remove the ballast from the derailed wagons before the cranes lifted the wagons clear of the track to allow track restoration work to progress. The track was reopened for traffic at about 1700 on Saturday 26 May 2007 and the damaged rollingstock progressively recovered from the track side over the following weeks. A total of twenty seven wagons were damaged along with about 400 metres of track.

Figure 5: Derailment site

2 ANALYSIS

On 22 May 2007 an investigation team from the Australian Transport Safety Bureau (ATSB) was dispatched to investigate the derailment of train 3MR2 near Roopena, SA.

Investigators examined and photographed the derailment site before releasing the site to permit recovery operations to begin. Initial observations indicated that a wheel had rolled over the rail head soon after traversing a section of track that exhibited a dip in one rail. Evidence was sourced from various witnesses and rail companies including the ARTC, Transfield and SSRS.

2.1 Sequence of events analysis

After departing Whyalla at about 0400, train 3MR2 accelerated to its running speed and was generally travelling at speeds between 65 km/h and 75 km/h. When approaching the level crossing (138.100 km), the locomotive data logs indicate that the train throttle control was at idle. Train speed had increased slightly to 79 km/h, probably as a result of the track's slight descending gradient.

About 60 metres past the level crossing, train 3MR2 started to round a left-hand curve. Soon after entering the curve, the driver noticed the reduction of brake pipe air pressure which resulted in the automatic application of the train brakes.

Examination of on-site evidence showed wheel flange markings over the rail head, starting about 8.5 metres after the centre line of the unsealed level crossing at the 138.100 track kilometre point and continuing for approximately 6.5 metres until the 'point of drop' (POD). A track geometry defect, in the form of a significant dip in one rail immediately before the level crossing, was noted.

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

- The right-hand wheel from the leading axle of wagon AHWX-12 climbed and travelled over the top of the rail to the right-hand side of the track.
- As train 3MR2 continued towards Port Augusta, the derailed wheels impacted with the concrete sleepers. The sleepers ultimately failed to maintain track gauge which allowed further wagons to derail.
- It is likely that the train initially parted between 9th and 10th wagon as the 10th and subsequent wagons began to jack-knife. Wagons continued to derail and jack-knife as the rear portion of train collided with the rapidly slowing derailed wagons.
- It is likely that the front portion of the train continued before the 8th and 9th wagons uncoupled and came to a stop. The train continued further until it finally stopped with the last two wagons (6th and 7th) completely derailed.
- Only the two locomotives, five wagons at the front of the train and five wagons at the rear of the train remained on the rails. The other 27 ballast wagons were derailed.

The investigation determined that train 3MR2 was handled in a manner consistent with normal train driving practice. There was no evidence to suggest that train handling contributed in any way to the derailment of train 3MR2.

2.2 Track geometry defect

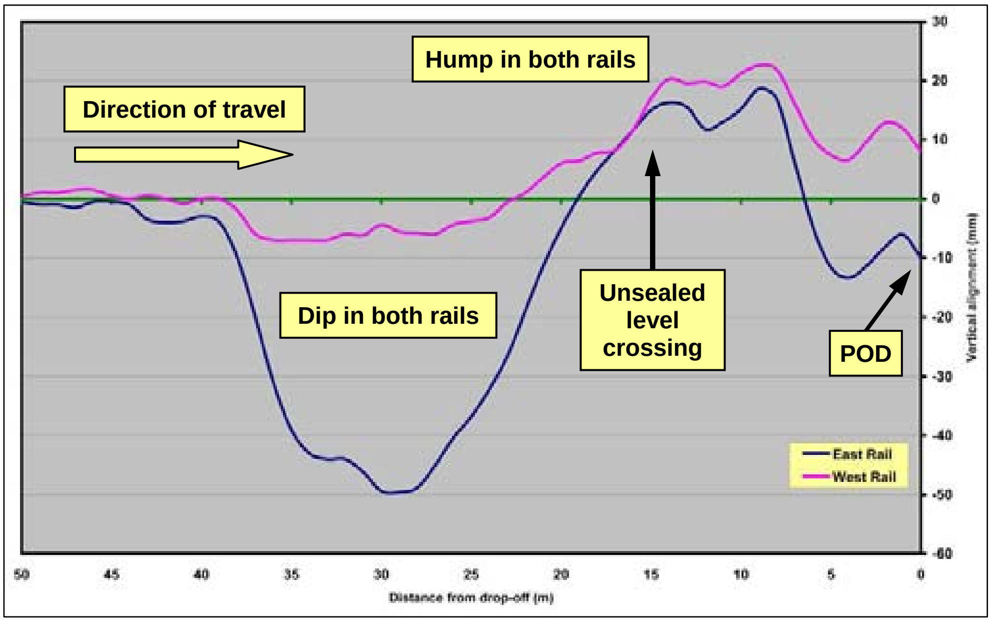
The track geometry leading into the derailment site was surveyed by the ARTC, Transfield Services and a civil engineering contractor. The survey was taken over a distance of 100 metres back from the point of drop-off (POD).

Figure 6: Track geometry defect (Photograph, 22 May 2007)

Note: The angle and magnification of the photograph provides an enhanced view of the track geometry defect.

The main feature of the geometry defect was a significant dip in the eastern rail between 18 and 39 metres from the POD. The western rail also showed a dip but of a much smaller size. The dips were followed by a hump in both rails as the track passed over the unsealed level crossing. The point of drop-off was about 15 metres past the centre line of the level crossing. Figure 7 illustrates the dips and humps in terms of the variation in track level from the estimated design level.

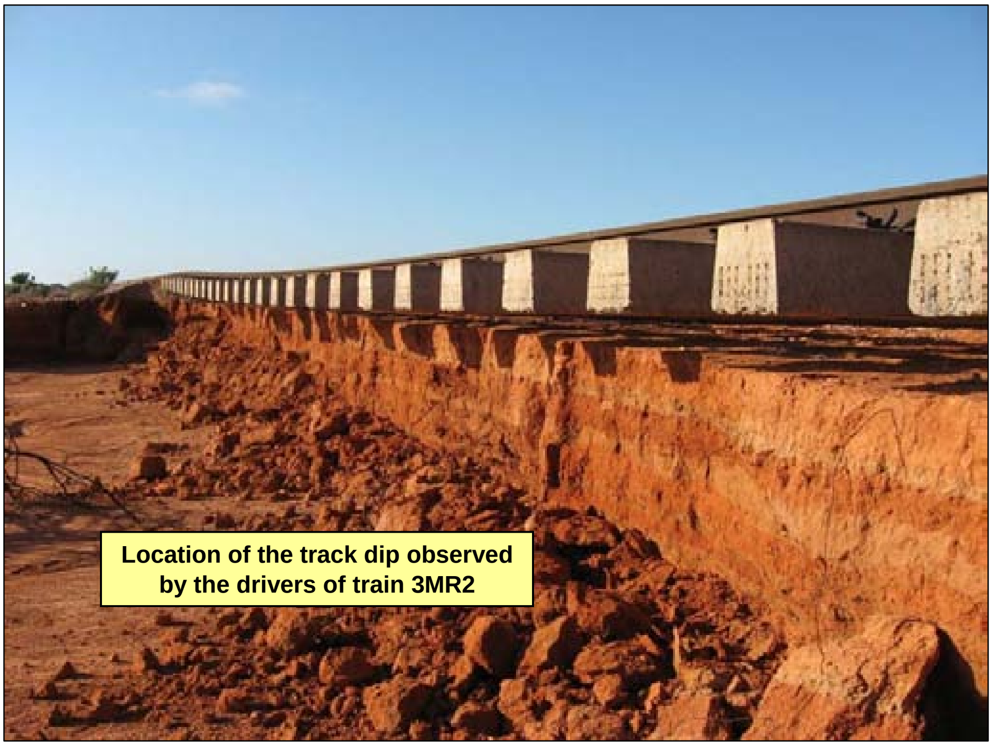
Figure 7: Vertical Alignment



The opportunity was taken during the retrieval of non-derailed wagons to measure the track's deflection under load. Since data could only be obtained from a few points, no conclusive assessment could be made as to the extent to which the vertical alignment parameters would be affected by deflections under load. However, the data did indicate that the effect was likely to be insignificant.

The flood damage that had occurred in January 2007 had left this section of track completely suspended as the track foundation was washed away from beneath the sleepers (Figure 8). It is possible that the earth below the repaired track formation had compacted and settled thereby allowing the track dip to develop. Further rain during late March may also have contributed to the development of the track defect at this location (50 mm of rain was recorded at Whyalla on 20 March 2007).

Figure 8: Track damage due to flooding (photograph, 22 January 2007)



Photograph – Australian Rail Track Corporation ©

2.3 Dynamic analysis

To assist in identifying the mechanism for the derailment, the ATSB engaged experts in simulation to model and analyse the dynamic response of the ballast wagons to the track defect found at Roopena.

The Vampire[8] software package was used to assist in calculating the predicted dynamics of train 3MR2 travelling over the point of derailment. Vampire is one of the world's leading rail vehicle simulation packages. As with most computer based simulations, there is a level of assumption within both the software and the data used. Consequently, the results should only be used as an indicator in conjunction with other analysis to draw appropriate conclusions.

8 'Vampire' is a rail vehicle dynamics simulation package allowing the modelling of a virtual rail vehicle traversing measured track geometry.

Four rolling stock models were developed within Vampire, each based on the ARTC ballast wagons that derailed at Roopena. A combination of measured data and original construction drawings were used to best estimate the actual condition of the first wagon to derail[9] (predicted to be wagon AHWX-12). An AHWY class ballast wagon was also modelled to identify the behaviour of a ballast wagon with constant contact side bearers.

Model 1 - AHWX class wagon (gap/friction style side bearers) with a full evenly distributed load and equal side bearer gaps of 12 mm.

Model 2 - AHWX class wagon (gap/friction style side bearers) with a full evenly distributed load and side bearer gaps as measured.

Model 3 - AHWX class wagon (gap/friction style side bearers) with unevenly distributed load. This model best represents wagon AHWX-12.

Model 4 - AHWY class wagon (constant contact side bearers) with a full evenly distributed load.

A static wheel unloading test was simulated on a tare version of Model 4 to test the validity of the rolling stock models. The simulated results were compared to test results conducted on AHWY-13 in January 2007. The comparison was considered sufficiently close to provide confidence in the simulated rolling stock model.

The track geometry model used in the Vampire simulations was based on the geometry surveyed by the ARTC, Transfield Services and the civil engineering contractor. To gain an understanding of the factors which may have contributed to the derailment, the defect in cross level was considered in isolation followed by the incremental addition of gauge variation, vertical alignment and lateral alignment.

2.3.1 Simulation results

The initial simulation test was conducted using rolling stock Model 1, travelling at the derailment speed of 79 km/h over straight track superimposed with the surveyed cross level variation. The result showed about 55% wheel unloading at the leading right-hand wheel at the POD. However, the lateral position of this wheel-set was such that its left-hand wheel was in flange contact with the left-hand rail. Consequently, the L/V ratio[10] at the leading right-hand wheel was negligible, and flange-climb unlikely.

The other track defects (gauge variation, vertical alignment and lateral alignment) were progressively added into the simulation for the following tests. The addition of

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9 Side bearer gaps were measured on wagon AHWX-12 after it was recovered from the derailment site and reassembled on its bogies in Port Augusta. The four side bearer gaps varied between 10 and 15 millimetres.

Wheel loads were measured on the four wagons at the front of the train that did not derail and the average used for modelling purposes. On average, there was a weight differential of about five tonnes with the heavier weight loaded to the left (in the direction of travel) for these four wagons.

10 Safety against flange-climbing derailment is assessed by calculation of the ratio L/V where:

- L is the lateral force of a wheel on the rail
- V is the vertical load of that wheel on the rail.

Generally, an L/V ratio of 1.20 or more indicates that a flange-climb derailment is likely.

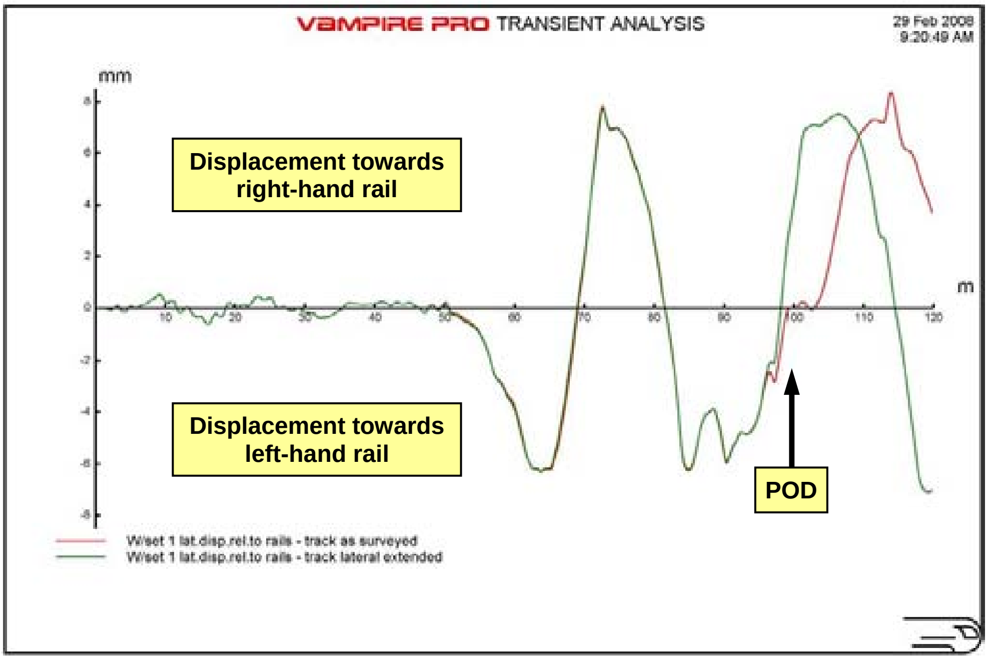
gauge variation returned almost no change, while adding the vertical alignment component increased wheel unloading to about 65% but had little effect on lateral position or the L/V ratio. However, adding the lateral alignment defect returned more significant results, even though this geometry defect was the least significant from a track inspection perspective. In this test, wheel unloading of the leading right-hand wheel increased to about 90% at the POD. The lateral alignment defect also had a considerable effect on wheel-set lateral displacement, but since the wheel-set was central between the rails and not in right-hand flange contact at the POD, L/V at the leading right-hand wheel remained small.

However, it was noticed that the leading wheel-set lateral displacement was heading away from left-hand flange contact just before the POD, seemed to 'hesitate' at the POD, and then continued to move towards right-hand flange contact just after the POD (Figure 9 – red trace). It was considered that this behaviour was a result of the track survey measurements stopping at the POD.

The track geometry model was modified by estimating the shape of the track beyond the POD. The estimation was based on a continuation of the alignment trend immediately before the POD and assuming that the track was likely to continue this directional trend beyond the POD. This was considered a reasonable assumption since the track beyond the POD had also experienced flood damage and could have exhibited similar geometry deterioration as the area before the POD. Examination of photographic evidence provided further support for this assumption.

It was found that modifying the lateral track alignment component had a significant effect on the lateral displacement of the wheel-set, placing it in flange contact with the right-hand rail at the POD (Figure 9 – green trace).

Figure 9: Wheel-set lateral displacement



As a result, the L/V ratio at the leading right-hand wheel became significant, reaching a peak value of 0.98 at this point. While the simulated L/V ratio remained within the usual limit of 1.20, it still indicated an increased risk of a flange-climb derailment as the leading right-hand wheel passed the POD in this case.

The result also demonstrated the need, from a dynamic simulation point of view, for the track survey to continue beyond the POD (for example 25 m); assuming the track had not been significantly damaged.

Wagon and load configuration

Continuing with the modified track geometry model, the other rolling stock models were simulated to identify any wagon or load configuration factors.

There was minimal effect on wheel-set lateral displacement between any of the rolling stock models with all showing that the leading right-hand wheel would be in flange contact at the POD. Similarly, there was very little difference in the lateral wheel force (16.3 - 17.8 kN) on the rails between the different rolling stock models (i.e. the 'L' force in L/V). Hence, the variation in L/V values (0.77 - 1.09) is due more to the different dynamic wheel unloading performance of each model as they traverse the geometry defect. The worst performance was exhibited by Model 3 (uneven load distribution) while the best performing wagon was Model 4 (CCSB).

Further tests were conducted to examine why the vehicle with uneven wheel load showed greater propensity for a flange-climb derailment. It was found that for Model 3, the side bearer gap on the front left bogie was fully closed at the POD. Similarly, the leading left-hand suspension coil springs became fully compressed (solid) at the POD and the centre bowl lifted slightly out of its seat. When this occurred, the wagon body at the front was momentarily supported on the leading left-hand side bearer only. This caused additional unloading of the right-hand wheels on the leading bogie at the POD. This was the only instance throughout the simulation where any of the coil springs were predicted to become solid.

Figure 10: Front bogie, left-hand spring pack

Figure 10 shows evidence of the front left-hand coil springs going solid on wagon AHWX-12. However, there is similar evidence on the trailing left and trailing right-hand springs. In each case, it is evident that the instances of solid running have been minor. While it is likely that these occurred at some point during the derailment, it was not possible to determine if they occurred at the POD. It should also be noted that some coil springs in the undamaged wagons also showed evidence of going solid.

The spring details used in the rolling stock models were based on original construction drawings and assumed that the springs were in as-new condition. Additional tests found that spring compression length (the distance required to fully compress the spring) was a critical element affecting L/V ratio. Table 2 illustrates the change in L/V ratio with respect to any change of spring compression length on wagon Model 3 (uneven load distribution). A reduction in spring compression length of 2.5 mm or more resulted in an L/V ratio increase which exceeded the 1.20 limit such that flange-climb derailment would be expected to occur.

Table 2: Change in spring compression length and L/V ratio

Change in spring compression length	L/V ratio
-5.0 mm	1.38
-2.5 mm	1.23
0.0 mm	1.09
+2.5 mm	0.96
+5.0 mm	0.89

Considering the wagon’s sensitivity to spring compression length, the onset of fully compressed suspension was examined on the other wagon models. It was evident that in a static condition, the spring compression length for the leading left-hand suspension on wagon Model 3 was shorter than that on wagon Model 1 due to the uneven load distribution. However, similar to wagon Model 3, it was found that the leading left-hand suspension coil springs also fully compressed at the POD on wagon Model 1. It was also evident that the wagon with constant contact side bearers (Model 4) consistently showed lower levels of dynamic spring compression than the wagons with gap style side bearers.

It was concluded that, in this case, any reduction in spring compression length was a critical element that increased the risk of a flange-climb derailment. This condition could occur if the spring heights were lower than expected due to the installation of springs with alternative specifications, weakening of the springs due to age, increased load or uneven load distribution. It was also concluded that CCSB provide a level of control over body roll such that these wagons generally perform better than wagons with gap style side bearers over this type of track geometry.

Wagon speed

The modified track geometry model and rolling stock Model 1 were used to identify how train speed affected the risk of flange-climb derailment. Tests were conducted at speeds between 40 km/h and 80 km/h.

It was found that the L/V ratio reduced from a maximum of 0.98 (at 79 km/h) down to 0.68 (at 70 km/h) and 0.40 (at 60 km/h). This would imply that reducing train speed to 60 km/h would significantly reduce the likelihood of flange-climb derailment. However, this is not the case when considering the lateral and vertical components in isolation.

At all speeds tested, the lateral displacement of the leading wheel-set showed minimal change and remained in contact with the right-hand rail at the POD. Similarly, the magnitude of wheel unloading measured at the leading right-hand wheel remained above 80% for speeds of 60 km/h and higher. However, it was found that train speed had an effect on the position along the track where maximum wheel unloading occurred such that it no longer occurred at the POD. Consequently, the L/V ratio indicating the risk of a flange-climb derailment at the POD reduced, even though the individual components did not.

It was concluded that, although the calculations for this track site show that the risk of a flange-climb derailment decreased as speed decreased, if the twist defect was combined with an alternative horizontal alignment defect the L/V ratio could remain high. It was not until track speed was reduced to 50 km/h that the critical component of wheel unloading showed evidence of reducing and measured 58% at the leading right-hand wheel.

Tare wagon

The modified track geometry model and tare versions of rolling stock Model 1 and Model 4 were used to investigate the likelihood of derailment of the wagon in an empty condition.

As observed previously, the lateral displacement of the leading wheel-set showed minimal change and remained in contact with the right-hand rail at the POD. Wheel unloading at the leading right-hand wheel showed a completely different behaviour when compared to a loaded version. In general, the magnitude of wheel unloading was lower than that of the loaded wagon. Rolling stock Model 1 (gap/friction style side bearers) showed a slightly greater peak value of wheel unloading than the laden wagon, but the duration was short. For both tare wagon models, the L/V ratio was small for both left and right-hand wheels indicating that the risk of a flange-climb derailment was low for these wagons (tare) at this site.

2.3.2 Summary of dynamic analysis

Dynamic simulation showed that a combination of factors were required before the wagon model (based on wagon AHWX-12) would be expected to derail due to flange-climb after traversing the simulated track geometry (based on the defect measured at Roopena on 22 May 2007).

Track geometry factors

The cross-level track geometry defect caused body roll leading to dynamic wheel unloading of the wagon model’s leading, right-hand wheel. When combined with a horizontal and vertical alignment defect, wheel unloading increased further and the right-hand wheel moved into flange contact with the right-hand rail at the point of derailment thereby increasing the risk of a flange-climb derailment.

Rollingstock factors

The wagon models (based on the AHWX class wagon) were found to be sensitive to spring compression length such that the body roll was sufficient to cause the front left-hand suspension springs to become fully compressed, causing additional unloading of the right-hand wheels at the POD. Uneven load distribution on the wagon model showed more compression of the left-hand suspension springs than if the load had been evenly distributed. Any further reduction in spring compression length, by 2.5 mm or more, was predicted to exceed the 1.20 L/V ratio limit such that a flange-climb derailment would be expected to occur.

Further tests indicated that the risk of a flange-climb derailment was lower for empty wagons travelling at 80 km/h over the track geometry model simulated. However, this conclusion may not hold for different track speeds, different track defects or different load configurations, especially if some wagon resonance occurs.

It was also found that the AHWY wagon model (with CCSB) showed a level of control over body roll such that these wagons generally perform better than wagons with gap style side bearers over this type of track geometry.

Train speed

The modelling predicted that the risk of a flange-climb derailment decreased at the site of the track defect if the train speed was decreased. However, the decrease was mostly due to the lateral and vertical components not synchronising to act at the same position along the track and if the twist defect was combined with an alternative horizontal alignment defect the risk of derailment could remain high. It was not until track speed was reduced to 50 km/h that the critical component of wheel unloading at the leading right-hand wheel showed evidence of reducing.

2.4 Track geometry inspection and assessment

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

The inspection process consists of two complementary inspection types:

- scheduled inspections, and
- unscheduled inspections.

Scheduled inspections are usually performed by track patrols (at intervals not exceeding seven calendar days) or the track geometry car[11] (at intervals not exceeding four months). While the inspection conducted by the track geometry car prior to the derailment (10 February 2007) did not detect any defects near the 138.100 kilometre point, the patrol inspection before the derailment (18 May 2007) did (refer to section 2.4.2 Scheduled track patrol inspection).

Unscheduled inspections occur in response to defined events such as extreme weather conditions or reports from train drivers. In this case, there were no events that would have initiated an unscheduled inspection.

Identified track geometry defects are assessed based on a series of defect categories such as vertical and horizontal alignment, cross level variation, twist and gauge.

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11 A rail vehicle with electronic recording equipment.

Actual track measurements are analysed with reference to the defect categories and compared to a table of defect limits and associated response codes. The response codes define the appropriate response required to control any risk to railway operational safety (Table 3).

Table 3: Definition of response codes

Response category	Inspect	Action
E (Emergency)	Prior to next train	Stop trains, carry out repairs, see note [3]
U1 (Urgent Class 1)	within 12 hrs	Reinspect within 24 hrs, See Note [1]
U2 (Urgent Class 2)	within 48 hrs	Reinspect within 7 days, See Note [1]
P1 (Priority Class 1)	within 7 days	Reinspect within 28 days, See Note [1]
P2 (Priority Class 2)	within 14 days	Inspect by exception on regular patrols

Note [1]
Repair the defect or apply an appropriate TSR[12]. If a TSR is applied, reinspect within the defined period, assess rate of deterioration and continue to reinspect defect until repaired.

Note [2]
Combination of faults at U1 or U2 levels - if faults occur within 20 m of each other, apply TSR at appropriate lower speed band and inspect within 24 hrs. Then reinspect every 24 hrs until repaired.

Note [3]
Trains can pass over the defect when under the control of a pilot.

2.4.1 Assessment based on surveyed measurements

The track geometry measurements from the survey following the derailment of train 3MR2 were examined and assessed against the ARTC CoP and used as a reference for investigating the effectiveness of the ARTC/Transfield maintenance process.

Vertical Alignment

Vertical alignment refers to the difference in rail level over a defined distance. Manual measurement and analysis of vertical alignment is achieved using the mid-ordinate offset of a 20 metre chord.

- The east rail dip measured 49.5 mm. When assessed against the CoP, this geometry defect equates to a response code of P1 for the rated track speed of 100 km/h and P2 for a track speed of 80 km/h.
- The east rail hump measured 38 mm. When assessed against the CoP, this geometry defect equates to a response code of P2 for track speeds up to 100 km/h and below the minimum response code for a track speed of 80 km/h.

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12 TSR – Temporary Speed Restriction.

Cross level variation

The cross level measurement (cant) is the difference in level of the two rails at a single point along the track. The cross level variation is the difference between this measurement and the design cant.

The track at the derailment site was tangent track where the design cant was zero. Survey measurements show that the maximum variation from zero cant was 45 mm at a point 30 metres before the POD. When assessed against the CoP, this geometry defect equates to a response code of P1 for all track speeds.

Twist

Twist is the variation in actual track cross level over a defined distance (14 m). Survey measurements show that the maximum twist measurement was 45 mm. When assessed against the CoP, this geometry defect equates to a response code of U2 for the rated track speed of 100 km/h and P1 for a track speed of 80 km/h.

Horizontal alignment

Horizontal alignment refers to the difference in lateral rail alignment over a defined distance. Manual measurement and analysis of horizontal alignment is achieved using the mid-ordinate offset of a 10 metre chord.

Survey measurements show that the maximum offset from a 10 metre chord was between 9 and 10 mm. When assessed against the CoP, these measurements are below the documented defect limits and associated response codes.

Gauge

Track gauge is measured between the inside face (gauge face) of each rail. Survey measurements show track gauge as tight (less than design gauge) with a maximum recorded tight gauge of 10 mm measured 12 metres before the POD. When assessed against the CoP, this measurement is below the documented defect limits and associated response codes.

2.4.2 Scheduled track patrol inspection

The patrol inspection on 18 May 2007 was carried out using a road/rail vehicle. While not the regular inspector for the Port Augusta/Whyalla line, the track inspector was suitably qualified. The inspector started his inspection at Whyalla and travelled towards Spencer Junction at a speed of about 60 km/h. As he approached the unsealed level crossing at the 138.100 km point he observed a dip in the eastern rail. He stopped the road/rail vehicle, reversed and examined the dip more closely. The inspector stated that the dip didn't seem too bad and assessed that it was suitable for trains to travel at 80 km/h.

The inspector also noted that a train that had travelled over this section of track only a short time earlier. It would be normal for train drivers to report a track defect if they considered it significant and could affect safe operation of trains. However, in this case the drivers of the train did not report any abnormalities.

The inspector spoke to his coordinator by telephone to report that he had detected a dip in the rail and recommended that the track was only suitable for trains to travel at 80 km/h. The coordinator advised that the track was already limited to 80 km/h; consequently the defect was recorded but no further action was taken to post a temporary speed restriction in this area.

Inspection process deficiencies

Based on post derailment measurement of the track defect and assessment against the ARTC CoP, the most restrictive response category for track rated at 100 km/h was U2 (due to twist) requiring action to inspect/repair within 48 hours. If an 80 km/h speed restriction were to be implemented, the response category reduces to P1 which requires action to inspect/repair within 7 days. In this case, the inspector's recommendation that an 80 km/h speed limit would appear consistent with the ARTC CoP, assuming that the intent was to re-inspect or repair the defect within 7 days.

However, when examining the records documented in the ARTC/Transfield fault database, there is a significant discrepancy in relation to prioritising response to an identified defect. The ARTC/Transfield fault database recorded a priority rating of '3' which requires action to inspect or repair within 90 days, not 7 days as would be required under the ARTC CoP.

It can be argued that the requirement to re-inspect within 7 days is met by the scheduled track inspections. However, the CoP states that re-inspection is required to assess the rate of deterioration until the defect is repaired. Track inspections are usually visual and detailed measurements are not generally taken, nor is it mandatory under the ARTC CoP. Since the size of this defect was not recorded, an estimate of the rate of deterioration could only be achieved informally through inspection (or monitoring) by the same person. In this case, a relief inspector identified the defect on 18 May 2007 that may well have been identified previously on 20 April 2008. However, with no knowledge of the defect's history, the relief inspector would have been unable to assess the rate of deterioration as required by the ARTC CoP.

There also appears to be no correlation between the priorities used in the ARTC/Transfield fault database and the response categories documented in the ARTC CoP (Table 4). For example, the highest response category in the ARTC CoP requires inspection before the next train. Defects rated at this level can only be traversed under the control of a pilot[13]. However, the highest priority relevant to the ARTC/Transfield fault database requires repair or inspection within 7 days.

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13 A qualified worker who accompanies, directs and advises the driver of each train as they traverse a worksite or infrastructure defect.

Table 4: Fault response comparison

ARTC Code of Practice		ARTC/Transfield Fault Database	
Response category	**Inspect**	**Priority**	**Repair or Inspect**
E (Emergency)	Prior to next train	**1**	<7 days
U1 (Urgent Class 1)	within 12 hrs	**2**	<28 days
U2 (Urgent Class 2)	within 48 hrs	**3**	<90 days
P1 (Priority Class 1)	within 7 days	**4**	<180 days
P2 (Priority Class 2)	within 14 days	**5**	>180 days

ARTC and Transfield were unable to provide any documentation describing the criteria for assigning priority ratings (ARTC/Transfield fault database) to track geometry defects. Nor could they provide any documentation describing the relationship between the database priority ratings and the ARTC CoP. Similarly, there was no documented evidence that the ARTC CoP was referenced in relation to assessment and repair of track geometry defects identified through scheduled inspections.

It would appear that the process for assessment and prioritising repair of track geometry defects was based only on the knowledge and experience of maintenance personnel with no formal link or reference to the requirements documented in the ARTC CoP. While track inspectors may be trained in the requirements of the ARTC CoP, there remains a risk that assessment of defects identified through scheduled inspections may not be consistent with the requirements of the ARTC CoP due to:

- Assessment by less experienced maintenance personnel.
- Lack of defect measurements to accurately assess the rate of deterioration.
- No reference to the ARTC CoP for track defect assessment.

Track speed discrepancies

There appeared to be a misunderstanding as to the actual maximum allowable track speed at Roopena. The speed documented in the ARTC Code of Practice for Operations and Safeworking (dated 30 June 2004) was 100 km/h. However, the Transfield maintenance coordinator expressed a belief that the rated track speed was 80 km/h. It would appear that this was a common belief since it was also expressed by other maintenance personnel and the locomotive drivers of train 3MR2.

The defect identified at the 138.100 km point illustrates the potential risk associated with a track speed misunderstanding. In this case, the track was recommended as suitable for 80 km/h. However, a temporary speed restriction was not put in place since the maximum track speed was believed to be 80 km/h. While not a contributing factor in this case, it was possible that a train could have traversed the unmarked 80 km/h track defect at 100 km/h, thereby increasing its derailment risk.

Track defect combinations

When the various elements of the track defect at Roopena are assessed using the ARTC CoP, the element of twist required the most urgent/stringent response followed by the vertical alignment and the cross level variation. The measured results for horizontal alignment and track gauge were both below the documented defect limits and associated response codes. However, the computer simulation indicated that the minor horizontal alignment defect was required before the leading right-hand wheel came into flange contact at the POD and a flange-climb derailment became possible.

The table of geometry defect response categories documented in the CoP is used to assess defects as single isolated defects or irregularities. However, the CoP also recognises that it is common for a combination of defects to occur, as was the case over this section of track. While the defects may not require action to be taken when assessed individually, the defects in combination may require action to provide for safe railway operations.

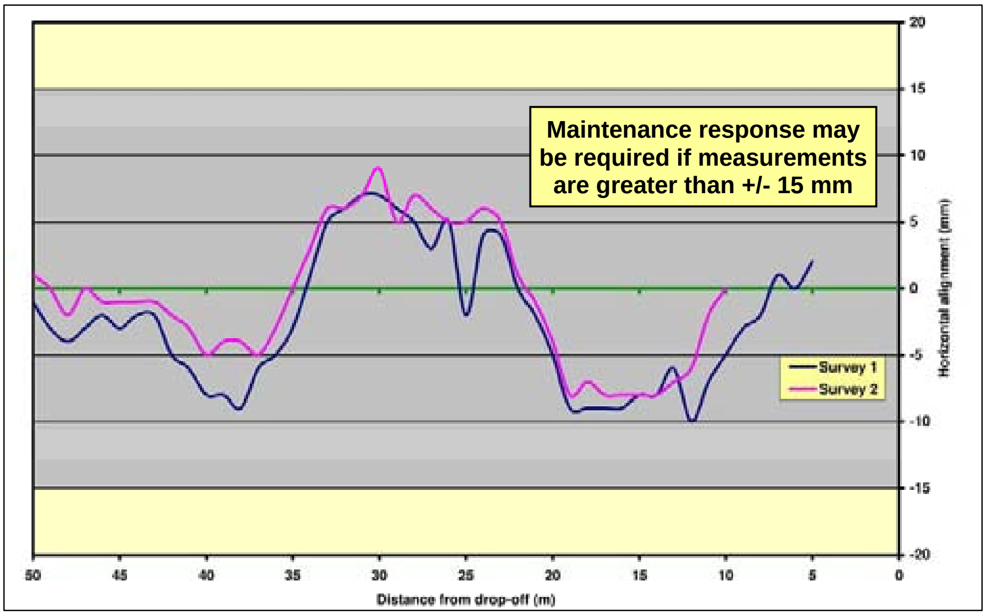
The CoP states that where a combination of defects exist the more stringent response of any individual defect should be selected, but also goes on to state:

> Unusual combinations of defects that are considered to act together, for example horizontal alignment with twist, should be subject to special consideration. A more stringent response than that specified for rectifying the defects individually should be considered.

However, the CoP does not provide any guidance on how to evaluate possible combinations of defects.

When considering the horizontal alignment defect at Roopena, the CoP does not require a response, on track rated at 100 km/h, until the defect exceeds 15 mm. If the speed is reduced to 80 km/h, a response is not required until the defect exceeds 19 mm. Figure 11 illustrates the results from two surveys for measurement of horizontal alignment at Roopena. The horizontal alignment defect does not exceed 10 mm for either survey. Without any guidance to the contrary, it is unlikely that a horizontal alignment defect of this size would be considered critical, even when considered in combination with other track defects.

Figure 11: Horizontal alignment



2.4.3 Summary of inspection and assessment

Based on post derailment measurement of the track defect and assessment against the ARTC CoP as single isolated defects or irregularities, an 80 km/h speed restriction and action to inspect/repair within 7 days would have been appropriate action. In this case, the inspector's recommendation of an 80 km/h speed limit would appear consistent with the ARTC CoP, assuming that the intent was to re-inspect or repair the defect within 7 days.

However, examination of the inspection and assessment process identified a number of deficiencies that may increase the safety risk relating to railway operations and track geometry defects.

Assessment and prioritising defects

The ARTC/Transfield fault database recorded a priority rating of '3' which requires action to inspect or repair within 90 days, not 7 days as would be required under the ARTC CoP.

There was no documented evidence that the ARTC CoP was referenced in relation to assessment and repair of track geometry defects identified through scheduled inspections. Similarly, there was no documentation describing the criteria for assigning priority ratings (ARTC/Transfield fault database) to track geometry defects or describing the relationship between the database priority ratings and the ARTC CoP.

Track inspections are usually visual and detailed measurements are not generally taken, nor mandatory under the ARTC CoP. Since the size of a defect is not measured or recorded, the rate of deterioration cannot be reliably assessed as required by the ARTC CoP.

Track speed

There appeared to be some confusion in relation to the track speed limit in the area of the derailment. The common view was that the speed limit was 80 km/h even though the ARTC Code of Practice for Operations and Safeworking (dated 30 June 2004) indicated the track speed was 100 km/h. While not a contributing factor in this case, it was possible that a train may have traversed the unmarked 80 km/h track defect at 100 km/h, thereby increasing the risk to safe rail operations.

Track defect combinations

The ARTC CoP provides no guidance on how to evaluate possible combinations of defects. In this case, it is unlikely that the combined effects of the track geometry defects were considered when assessing a track speed suitable for safe rail operations, especially considering that the horizontal alignment defect was below the documented defect limits and associated response codes.

2.5 Rolling stock

Rolling stock standards describe the minimum requirements applicable to the design, construction, operation and maintenance of railway rolling stock. At the time when train 3MR2 derailed, the relevant rolling stock standards were a combination of the *Railways of Australia – Manual of Engineering Standards and Practices* (ROA Manual) and a series of new Australian Rolling Stock Standards under development by the Rail Industry Safety and Standards Board (RISSB).

2.5.1 Designed performance

The minimum standard for testing and performance of new or substantially modified rolling stock is the ROA Manual, *Section 3 – Road Worthiness Acceptance Standards for Rail Freight Vehicles*. This standard describes the minimum requirements for dynamic behaviour of freight rolling stock in order to reduce the risk of derailment when vehicles traverse track defects. While a new Australian Rolling Stock Standard for *Dynamic Behaviour – Freight Rolling Stock* was also under development by the RISSB, the test methodology and acceptance criteria documented are generally consistent with the ROA Manual.

Train 3MR2 traversed a track defect that exhibited a combination of conditions, two of which are relevant to tests documented in the rolling stock standards. The first was a variation in rail levels that resulted in a track twist. This was combined with the second condition of an overall dip in both rails followed by a hump in both rails.

Static twist test

A wagon’s performance in relation to twist is termed as the ‘Static Twist Test’ and is conducted while the wagon is unloaded and stationary. The test simulates a wagon moving over track where one rail begins to ramp up to a higher level than the other rail, thereby exerting twist through the wagon body. The acceptance criteria is that the maximum wheel unloading shall not exceed 60% at any location and the wagon centre plate shall remain engaged in the bogie bolster centre casting by at least 14 mm.

A static twist test had been conducted on ballast wagon AHWY-13 (constant contact side bearers) in January 2007. This test showed that wheel unloading did not exceed 50%, well within the 60% acceptance criteria. Similarly, bogie engagement measurements remained above the 14 mm acceptance criteria. The results derived from computer simulation of an AHWY class wagon were consistent with these test measurements (refer to section 2.3 Dynamic analysis).

Static twist test results were not available for the AHWX class wagon (gap/friction style side bearers). However, computer simulation showed that the AHWX wagon performed slightly better than the AHWY wagon under static twist conditions. This result was expected since side bearer gaps allow for a proportion of twist to occur before spring compression results in wheel unloading.

Pitch and bounce

A wagon's performance in relation to track dips and humps is termed as the test for 'Pitch and Bounce' and is conducted while the wagon is fully loaded. The test is designed to ensure satisfactory dynamic performance when negotiating vertical track irregularities. The ROA Manual states an example of the '…negotiation of level crossings and bridges where changes in vertical track stiffness may lead to sudden changes in the loaded track profile.' The acceptance criteria are that the maximum wheel unloading shall not exceed 90% on any wheel at any speed.

Test measurements for pitch and bounce could not be provided for the AHWX or AHWY class of ballast wagons. However, considering the close relationship between simulation and test results for the static twist test, the acceptance criteria were evaluated using the computer simulation results (refer to section 2.3 Dynamic analysis). In each simulated test, wheel unloading results remained below 90% although in some cases the results where high (up to 86% wheel unloading). The wagon model based on the AHWY class wagon (with CCSB) showed less dynamic wheel unloading than the model based on the AHWX class wagon when travelling at 80 km/h.

AHWY class ballast wagon (CCSB)

It should be noted that the analysis above does not verify that the AHWY class ballast wagon fully conforms to the ROA standard. The dynamic behaviour of the AHWY class ballast wagons was estimated using computer simulation and was based on a maximum train speed of 80 km/h. While the maximum allowable speed is 80 km/h for the AHWX class wagon, the AHWY class wagon has CCSB's which would theoretically allow the wagon to travel at the maximum track speed. On the DIRN, maximum track speed is often 100 km/h or higher. While dynamic behaviour testing of the AHWY class wagon (at speeds above 80 km/h) has not been undertaken, it is recognised that only one wagon had been developed as a 'proof of concept', and was only likely to travel in a train consist with wagons limited to 80 km/h.

2.5.2 Inspection and assessment

The examination of the on-site evidence indicated that the first wagons to have derailed were most likely wagon numbers AHWX-12 and AHWY-13. These wagons were examined; both in their derailed state and after the bogies and wagon bodies had been removed from and placed adjacent to the track. Each wagon appeared to have received only minor damage and, in general, looked to be in good condition.

The undamaged wagons from the front and rear of train 3MR2 were examined at Port Augusta and Whyalla[14]. In general, each wagon appeared to be in a well maintained condition. However, some wagons showed evidence that the suspension coil springs had fully compressed and the side bearer gap measurements on most wagons did not conform to the required standards.

The minimum standard for in-service inspection and assessment of rolling stock is the ROA Manual, *Section 24 – Freight Vehicle Field Inspection Limits for In-Service Use*. This standard defines the inspection and assessment procedures to identify possible defects that may affect, or have the potential to affect the capability of the rolling stock to safely perform its required function.

The bogies under the AHWX class wagon were typical AAR[15] 3-piece bogies. The specified limits for side bearer gap, relevant to AAR type bogies, are documented in Section 24.2.3.2 of the ROA Manual, which states:

> The clearance between the bogie and body side bearer contact surfaces of all AAR type bogies shall be within the limits of 5 mm and 8 mm when measured on level track … The sum of the two side bearer clearances on any bogie shall be within the range of 10 mm to 16 mm to allow for variations in track levels.

Of the eight undamaged ballast wagons, six were found to have side bearer gaps that exceeded the ROA standard while the remaining two did not have sufficient side bearer gap. Insufficient side bearer gap can affect a bogie’s ability to negotiate curved track while excessive side bearer gap may allow undesirable levels of body roll. Considering the derailment occurred on tangent track, it is unlikely that insufficient side bearer gap was a contributing factor. However, it is possible that large side bearer gaps may have contributed to excessive body roll as train 3MR2 traversed the track defect.

Considering the observations regarding side bearer gaps on the undamaged ballast wagons, a decision was made to reassemble wagons AHWX-12 and AHWY-13 for closer examination. Compliance against the ROA standard could not be assessed for wagon AHWY-13 since the compression elements in the constant contact side bearers could not be reassembled. The side bearer gaps on AHWX-12 were found to exceed the specified limits documented in the ROA standard. The sum of the two side bearer gaps were 25 mm on the front bogie and about 32 mm on the rear.

2.5.3 Summary of rolling stock

From a design perspective, the AHWX and AHWY class ballast wagons were assessed against the ROA standards with respect to the track conditions traversed by train 3MR2. Computer simulation verified that the AHWX and AHWY class ballast wagons, travelling at 80 km/h, would be likely to behave in a manner that

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14 The examination of rollingstock was conducted in conjunction with the ARTC and consulting engineers engaged by the ARTC. The observations of all parties have been considered and reflected in the findings of this investigation.

15 The Association of American Railroads (AAR), among other responsibilities, oversees the technical standards for rolling stock in North America.

was compliant with the requirements documented in the *Railways of Australia – Manual of Engineering Standards and Practices*.

From a maintenance perspective, wagon AHWX-12 was found to be non-compliant when assessed against the requirements documented in the *Railways of Australia – Manual of Engineering Standards and Practices*. The side bearer gaps were found to exceed (almost double) the specified limits on both the front and rear bogies.

It is likely that the excessive side bearer gaps on AHWX-12 provided less control over body roll than a wagon with correctly gapped side bearers or constant contact side bearers. Combined with uneven load distribution it is likely that excessive body roll would cause the suspension springs to fully compress thereby increasing the amount of dynamic wheel unloading.

2.6 History of similar incidents

On 23 September 2004, Train 4VM9-V derailed while travelling southwards between Glenrowan and Benalla, Victoria[16]. The train consisted of a single locomotive hauling 15 wagons loaded with dry bulk cement, four of which derailed while travelling at about 75 km/h. The wagons were a covered hopper style construction (VPBX class wagon) that have a very rigid body structure and are rated for a maximum speed of 80 km/h.

Figure 12: VPBX class wagon

The section of track where the derailment occurred was rated for a track speed of 115 km/h. Due to uneven track and a number of pronounced dips, a temporary speed restriction of 80 km/h had been applied. However, since the cement wagons were rated for 80 km/h, there was no requirement to reduce the speed of train 4VM9-V.

The investigation concluded that the combination of wagon stiffness and deteriorated track condition associated with track twist created conditions where the cement wagon sustained roll-induced wheel unloading and subsequent flange-climb followed by derailment.

16 ATSB Transport Safety Investigation Report, Rail Occurrence Investigation 2004/005.

It was also noted that ARTC had recognised that the application of temporary speed restrictions primarily considered rolling stock certified to operate at a maximum speed of 115 km/h and not the poorer riding rolling stock restricted to a maximum speed of 80 km/h. After this incident, the 80 km/h temporary speed restrictions were reduced to 60 km/h in order to limit both classes of rolling stock within the one speed restriction. However, it is evident that the ARTC CoP has not been modified to address this issue across the entire ARTC rail network. Consequently, it would appear that this action was only applied to address the risk at this location.

2.7 Temporary speed restrictions

It is common for sections of track to have permanent speed limits that are relevant to a specific train type. For example, some sections in NSW are rated at a maximum of 160 km/h for the XPT, 140 km/h for the Xplorer, 115 km/h for locomotive hauled passenger trains and 110 km/h (or less) for freight trains. Since the track is identical for each train, these proportional speed limits are generally a direct reflection of each train's performance and ride dynamics. However, temporary speed restrictions due to track geometry defects are not usually proportional, but rather a one speed fits all approach.

When considering both the derailment of train 3MR2 at Roopena (22 May 2007) and the derailment of train 4VM9-V at Benalla (23 September 2004), many factors appear to be similar. In both derailments, very rigid bodied hopper style wagons rated for a maximum speed of 80 km/h derailed due to track geometry defects that had been assessed as suitable to traverse at 80 km/h. These derailments illustrate how assessments of track geometry defects do not appear to consider the dynamics of poorer riding rolling stock that may already be restricted to a maximum speed of 80 km/h.

Computer simulation of the AHWX/AHWY class ballast wagons (Section 2.3) illustrated the complexity of rolling stock dynamics. In this case, body roll induced by the twisted track caused significant wheel unloading while the minor horizontal misalignment placed the appropriate wheel in flange contact at the POD. Reducing the wagon speed to 60 km/h significantly reduced the likelihood of flange-climb derailment, but the magnitude of wheel unloading remained high. It is possible that a slightly different horizontal misalignment would again place the appropriate wheel in flange contact and the risk of flange-climb derailment could remain high, even at 60 km/h. It was not until track speed was reduced to 50 km/h that wheel unloading showed evidence of reducing when traversing this geometry defect.

3 FINDINGS

3.1 Context

At approximately 0428 on 22 May 2007, ballast train 3MR2 derailed near Roopena, SA. Twenty seven ballast wagons were derailed. There were no injuries.

From the evidence available, the following findings are made with respect to the derailment of train 3MR2 and should not be read as apportioning blame or liability to any particular organisation or individual.

3.2 Contributing safety factors

The investigation determined that it was likely that a number of factors combined to cause the derailment. Any one factor in its own right was unlikely to have resulted in a derailment, but all factors acting together greatly increased the likelihood of the derailment:

- A cross-level track geometry defect caused body roll on the first wagon to derail which led to dynamic wheel unloading of the wagon's leading, right-hand wheel. When combined with a horizontal and vertical alignment defect, wheel unloading increased further and the right-hand wheel moved into flange contact with the right-hand rail at the point of derailment thereby increasing the risk of a flange-climb derailment.
- It is unlikely that the combined effects of the track geometry defects were considered when assessing a track speed suitable for safe rail operations, especially considering that the horizontal alignment defect was below the documented defect limits and associated response codes. *[Safety issue]*
- It is likely that the excessive side bearer gaps on AHWX-12 provided less control over body roll than if the gaps had been correctly adjusted. *[Safety issue]*
- It is likely that the gap/friction style side bearers on the AHWX class ballast wagons provided less control over body roll than the AHWY class ballast wagon that had constant contact side bearers. *[Safety issue]*
- It was found that a loaded AHWX class wagon was at risk of a flange-climb derailment when traversing this geometry defect at 80 km/h, even though the defect had been assessed as suitable for trains to traverse at 80 km/h. If train speed had been reduced to 50 km/h, it was predicted that the magnitude of wheel unloading would reduce thereby decreasing the risk of flange-climb derailment when traversing the track geometry defect.
- It is unlikely that the dynamics of poorer riding rolling stock were considered when assessing the track geometry defect and determining a suitable speed limit for train operations. *[Safety issue]*
- The AHWX class wagon was found to be sensitive to spring compression length such that the body roll was sufficient to cause the front left-hand suspension springs to become fully compressed, causing additional unloading of the right-hand wheels at the POD. Any reduction in spring compression length (2.5 mm or more), due to weakened springs or springs of an alternative specification, was

predicted to increase the L/V ratio to more than the 1.20 limit such that a flange-climb derailment would be expected to occur.

- It is likely that an uneven load distribution within the first wagon to derail caused the left-hand suspension springs to compress more than if the load had been evenly distributed and this contributed to a reduction in spring compression length. *[Safety issue]*

3.3 Other safety factors

- The track defect identified during a scheduled track patrol inspection on 18 May 2007 was recorded in the ARTC/Transfield fault database with a priority rating of '3' which requires action to inspect or repair within 90 days, not seven days, the requirement under the ARTC Code of Practice (CoP).
- There was no documentation describing the criteria for assigning priority ratings (ARTC/Transfield fault database) to track geometry defects or describing the relationship between the database priority ratings and the ARTC CoP. Similarly, there was no documented evidence that the ARTC CoP was referenced in relation to the assessment and repair of track geometry defects identified through scheduled inspections. *[Safety issue]*
- There appeared to be some confusion in relation to the track speed limit in the area of the derailment. The common view was that the speed limit was 80 km/h even though the ARTC Code of Practice for Operations and Safeworking (dated 30 June 2004) indicated the track speed was 100 km/h. It is possible that a train could traverse an unmarked 80 km/h track defect at 100 km/h, thereby increasing the risk to safe rail operations. *[Safety issue]*
- The size of a track defect is not always measured and recorded even if the ARTC CoP states that re-inspection is required to assess the rate of deterioration until the defect is repaired. Consequently, an estimate of the rate of deterioration can only be achieved informally through inspection (or monitoring) by the same person. In this case, a relief inspector identified the defect on 18 May 2007 that may well have been identified previously on 20 April 2008. With no knowledge of the defect history, the relief inspector would not have been able to assess the rate of deterioration when required by the CoP. *[Safety issue]*
- Track patrol inspection and assessment is generally visual and based on ride quality while travelling by road/rail vehicle. If a track defect is identified, it is not common for the inspector to take detailed measurements for assessment purposes, nor is it mandatory under the ARTC CoP. Other than inspections by the track geometry car, assessment is wholly dependent on the experience and judgement of the track inspector. *[Safety issue]*

3.4 Other key findings

- Examination of the wagons involved in the derailment in tare condition verified that the magnitude of wheel unloading was generally lower than that of the loaded wagon. It was concluded that the risk of a flange-climb derailment was low for these wagons (in tare condition) when travelling at 80 km/h over the track defects present at Roopena on 22 May 2007. However, this conclusion may not hold for different track speeds, different track defects or different load configurations, especially if some wagon resonance occurs.

4 SAFETY ACTIONS

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

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

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.

4.1 Australian Rail Track Corporation

It is recognised that some safety actions may be best actioned by the track maintenance organisation (Transfield Services). However, since the actions of Transfield Services are subject to contractual arrangements, recommendations have been directed to the Australian Rail Track Corporation as the contract managers.

4.1.1 Combination of track geometry defects

Safety Issue

It is unlikely that the combined effects of the track geometry defects were considered when assessing a track speed suitable for safe rail operations, especially considering that the horizontal alignment defect was below the documented defect limits and associated response codes.

ATSB safety recommendation RR20080029

The Australian Transport Safety Bureau recommends that the Australian Rail Track Corporation takes safety action to address this safety issue.

4.1.2 Side bearers

Safety Issue

It is likely that the excessive side bearer gaps on AHWX-12 provided less control over body roll than if the gaps had been correctly adjusted.

Safety Issue

It is likely that the gap/friction style side bearers on the AHWX class ballast wagons provided less control over body roll than the AHWY class ballast wagons that had constant contact side bearers.

Safety actions already taken

The undamaged wagons were emptied and moved at low speed to maintenance workshops where the wagon bodies were lifted and adjustments made to the side bearer gaps to bring them within the limits defined in the ROA standard.

Before the derailment at Roopena, the Australian Rail Track Corporation (ARTC) had considered constant contact side bearers (CCSB) as positive step towards improving the dynamic ride performance of the AHWX wagons in lieu of the traditional gap type side bearers. As a proof of concept, wagon AHWY-13 had already been converted as a trial. Following the derailment, and in conjunction with a number of consulting engineers, the ARTC concluded that the installation of CCSB's would give the best overall improvement.

The ARTC has implemented an upgrade program to retrofit AHWX class ballast wagons with constant contact side bearers. For the wagons that were damaged during the derailment at Roopena, constant contact side bearers were to be retrofitted during the repair process. The remainder of the operational fleet were to be retrofitted under contract to suitably qualified engineering facilities.

As part of the CCSB upgrade, the ARTC also arranged to have spring lengths checked and replace any non-conforming springs.

4.1.3 Dynamics of poorer riding rolling stock

Safety Issue

It is unlikely that the dynamics of poorer riding rolling stock were considered when assessing the track geometry defect and determining a suitable speed limit for train operations.

ATSB safety recommendation RR20080030

The Australian Transport Safety Bureau recommends that the Australian Rail Track Corporation takes safety action to address this safety issue.

4.1.4 Uneven load distribution

Safety Issue

It is likely that an uneven load distribution within the first wagon to derail caused the left-hand suspension springs to compress more than if the load had been evenly distributed and this contributed to a reduction in spring compression length.

Safety actions already taken

The Australian Rail Track Corporation (ARTC) initiated reviews of the ballast loading processes at Whyalla and other ballast sidings. Where suitably sized loaders have not been available (such as at Whyalla), a loading ramp has been constructed beside the track to improve the smaller loader’s reach capability.

The ARTC have advised that these actions have proved successful and have continued to monitor the loading processes to ensure that an even load distribution in ballast wagons is achieved.

4.1.5 Assessment of track geometry defects

Safety Issue

There was no documentation describing the criteria for assigning priority ratings (ARTC/Transfield fault database) to track geometry defects or describing the relationship between the database priority ratings and the ARTC CoP. Similarly, there was no documented evidence that the ARTC CoP was referenced in relation to the assessment and repair of track geometry defects identified through scheduled inspections.

Safety actions already taken

The Australian Rail Track Corporation advised that these issues have been addressed such that compliance against the ARTC CoP would be achieved when assessing track geometry defects for action to inspect or repair.

4.1.6 Track speed

Safety Issue

There appeared to be some confusion in relation to the track speed limit in the area of the derailment. The common view was that the speed limit was 80 km/h even though the ARTC Code of Practice for Operations and Safeworking (dated 30 June 2004) indicated the track speed was 100 km/h. It is possible that a train could traverse an unmarked 80 km/h track defect at 100 km/h, thereby increasing the risk to safe rail operations.

Safety actions already taken

The Australian Rail Track Corporation advised that the relevant contractors had been notified that the maximum line speed is 100 km/h (not 80 km/h) and that reference to the ARTC CoP for Operations should be made to determine maximum track speed for any part of the ARTC rail network.

4.1.7 Rate of deterioration

Safety Issue

The size of a track defect is not always measured and recorded even if the ARTC CoP states that re-inspection is required to assess the rate of deterioration until the defect is repaired. Consequently, an estimate of the rate of deterioration can only be achieved informally through inspection (or monitoring) by the same person. In this case, a relief inspector identified the defect on 18 May 2007 that may well have been identified previously on 20 April 2008. With no knowledge of the defect history, the relief inspector would not have been able to assess the rate of deterioration when required by the CoP.

Safety actions already taken

The ARTC CoP requires re-inspection and assessment of the rate of deterioration only when a Temporary Speed Restriction is imposed.

The Australian Rail Track Corporation advised that the relevant contractors had been notified to ensure compliance with the ARTC CoP with a particular emphasis on the need to comply in the assessing or reassessment of defects that require the application of a Temporary Speed Restriction.

4.1.8 Measurement of track geometry defects

Safety Issue

Track patrol inspection and assessments are generally visual and based on ride quality while travelling by road/rail vehicle. If a track defect is identified, it is not common for the inspector to take detailed measurements for assessment purposes, nor is it mandatory under the ARTC CoP. Other than inspections by the track geometry car, assessment is wholly dependent on the experience and judgement of the track inspector.

Safety actions already taken

The Australian Rail Track Corporation advised that all track inspectors had been trained in the requirements of the ARTC CoP. However, a need to review elements of the current CoP had been identified and is being actioned by the ARTC.

APPENDIX A : SOURCES AND SUBMISSIONS

Sources of information

Australian Rail Track Corporation

South Spur Rail Services

Transfield Services

References

ARTC Track and Civil Code of Practice, April 2007

Submissions

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

A draft of this report was provided to:

- Australian Rail Track Corporation
- South Spur Rail Services
- South Australian Railway Safety Regulator, and
- a small number of individuals.

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