Australian Government

Australian Transport Safety Bureau

ATSB TRANSPORT SAFETY INVESTIGATION REPORT

Rail Occurrence Investigation 2004/005

Final

# Derailment of Train 4VM9-V
## Benalla, Victoria

23 September 2004

Australian Government

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## Benalla, Victoria

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**Abstract**

Train 4VM9-V, a loaded dry bulk cement train consisting of locomotive EL61 and 15 VPBX class cement wagons, was running at about 79 km/h in the Up direction (towards Melbourne) when the 12$^{th}$ last wagon derailed, followed by the last three wagons. The train was running through an infrastructure restriction with temporary speed restriction of 80 km/h at the time. This restriction was in place due to weak track structure and inadequate track geometry. The train came to a stop with the last four wagons still coupled to the train but leaning at various angles away from the opposite broad gauge line. Investigations found that the track structure had deteriorated and a number of undulations had formed in the eastern side rail. Approximately 530 metres of track was affected by the derailment.

# AUSTRALIAN TRANSPORT SAFETY BUREAU

The Australian Transport Safety Bureau (ATSB) is an operationally independent multi-modal Bureau within the Australian Government Department of Transport and Regional Services. 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. Accordingly, the ATSB also conducts investigations and studies of the transport system to identify underlying factors and trends that have the potential to adversely affect safety.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and, where applicable, relevant international agreements. The object of a safety investigation is to determine the circumstances to prevent other similar events. The results of these determinations form the basis for safety action, including recommendations where necessary. As with equivalent overseas organisations, the ATSB has no power to implement its recommendations.

It is not the object of an investigation to determine blame or liability. However, it should be recognised that an investigation report must include factual material of sufficient weight to support the analysis and findings. That material will at times contain information reflecting on the performance of individuals and organisations, and how their actions may have contributed to the outcomes of the matter under investigation. 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.

Central to ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. While the Bureau issues recommendations to regulatory authorities, industry, or other agencies in order to address safety issues, its preference is for organisations to make safety enhancements during the course of an investigation. The Bureau is pleased to report positive safety action in its final reports rather than make formal recommendations. Recommendations may be issued in conjunction with ATSB reports or independently. A safety issue may lead to a number of similar recommendations, each issued to a different agency.

The ATSB does not have the resources to carry out a full cost-benefit analysis of each safety recommendation. The cost of a recommendation must be balanced against its benefits to safety, and transport safety involves the whole community. Such analysis is a matter for the body to which the recommendation is addressed (for example, the relevant regulatory authority in aviation, marine or rail in consultation with the industry).

# EXECUTIVE SUMMARY


Train 4VM9-V operated by Freight Australia, derailed at 0444 Eastern Standard Time (EST) on Thursday 23 September 2004 as it was travelling southwards between Glenrowan and Benalla, Victoria. The train departed from the Blue Circle Southern Cement Ltd works at Berrima, New South Wales the previous day and was proceeding to Somerton, Victoria.

Four of the 15 wagons carrying dry bulk cement on the train derailed. The train passed through a section of track where an infrastructure restriction (IR) and a temporary speed restriction (TSR) of 80 km/h had been in place due to weak track structure and geometry. The IR and TSR had been imposed on the section of track by the infrastructure maintainer as a result of earlier track inspection.

The 12th wagon in the train was first to derail. The leading wheel set's right-hand wheel climbed up and over the western side rail as it passed over two consecutive track dips in the IR area. Track damage caused a loss of gauge retention and the spread of the eastern side rail which in turn led to the rear bogie of the wagon and the bogies of the last three wagons on the train dropping between the rails.

The driver became aware of the derailed state of the train and controlled the locomotive power and the induced emergency brake application to bring the train to a stop. Train speed at this time was approximately 79 km/h. The first derailed wheel set travelled a distance of approximately 525 metres from the point of derailment until the train stopped.

Up to 400 mm of rain had fallen on the area between 1 July 2004 and 16 September 2004. Inadequate drainage of the track structure resulted in further deterioration of the track geometry at the occurrence site. Although a TSR had been in place at the occurrence site, track inspection had apparently not identified the potential for derailment or the need for a lower TSR speed limit as a consequence of this deterioration.

The track geometry was measured by the 'AK' track recording car (AK Car) less than two months prior to the derailment. Data from the AK Car was compared against the *AK Car Defect and Response Tables, Standard and Victorian* (AK Geo.). The track was also compared to the common *Victorian Civil Engineering Circular* (CEC) standards in use at the time.

Track inspection and recording had not identified the potential for derailment at the dips. Both the AK Geo. and CEC standards suggested the need for track geometry to be considered as a whole, and all geometrical parameters to be considered together to identify the potential for track condition that could lead to a derailment. Although analysis of the AK Car data showed no AK Geo. exceedences, a survey was made of the track after the derailment and CEC exceedences were identified.

Approximately 530 metres of track was damaged as a result of the derailment. No injuries were reported and no hazardous conditions resulted.

The report concludes that train 4VM9-V derailed as a result of the deteriorated condition of the track. The TSR imposed was not appropriate to the conditions existing at the time. A combination of infrastructure flaws associated with severe track twist faults appearing under rail traffic led to the occurrence. While weak track structure and geometry at the occurrence site were known, appropriate remedial action had not taken place.

Both AK Geo. and CEC standards note the need for track geometry to be considered as a whole. It was apparent that all geometrical parameters were not considered collectively to identify the potential for track conditions that led to the derailment.

Although the AK Car parameter graphs and raw data were available to infrastructure maintainers for further interpretation, no exceedences were identified or considered. In addition, the AK Car calibration, setup, measurement and analysis procedures appeared to have generated data inconsistencies.

The combination of wagon stiffness and compromised infrastructure state associated with track twist created conditions where it was most likely that the $12^{th}$ cement wagon sustained roll-induced wheel unloading and subsequent flange climb followed by derailment.

Following the occurrence, safety actions corresponding with the evidence determined were initiated by the track infrastructure owner, the Australian Rail Track Corporation.

As a result of the investigation, a number of recommendations have been made in relation to:

- Modifications to track infrastructure inspection
- Track geometry parameters as a whole
- Standardised infrastructure methodology
- Modifications to the methods of assessment and use of the AK Car and its data

# 1 INTRODUCTION

As a result of the occurrence where four cement carrying wagons derailed in train 4VM9-V north of Benalla, Victoria on 23 September 2004, the Executive Director of the Australian Transport Safety Bureau (ATSB) authorised an independent investigation into the causal factors contributing to the accident with a view to encouraging safety action and to prevent future accidents.

The ATSB conducted an on-site investigation involving an examination of track infrastructure and rollingstock. External specialist assistance was engaged at the site of the derailment to assess track infrastructure evidence. Specialist assistance was also sought to provide vehicle and track interface modelling. Subsequent off-site investigation and analysis by the ATSB included issues related to the electronic data recorders, safety management systems, records, personnel and organisational actions and responsibilities.

# 2 OVERVIEW

## 2.1 Location

At 0444 Eastern Standard Time (EST) on 23 September 2004, Freight Australia Ltd (FA)[1] owned and operated train, numbered 4VM9-V, derailed north of Benalla on the Victorian North Eastern Line approximately 200 kilometres from Melbourne. The line forms part of the Sydney – Melbourne section of the standard gauge[2] Defined Interstate Railway Network (DIRN) managed by the Australian Rail Track Corporation (ARTC).

**Figure 1: Location of Benalla, Victoria**


Geoscience Australia, Crown Copyright ©

The railway consists of a bi-directional single line where opposing trains are regulated to pass around each other at short double track section crossing loops. The line runs opposite and parallel to the Victorian broad gauge[3] line connecting Albury with Melbourne. The broad gauge line was managed by FA.

The derailment occurred in the 22.5 kilometre long section of Glenrowan to Benalla which is mostly an isolated section of the line situated away from areas of population.

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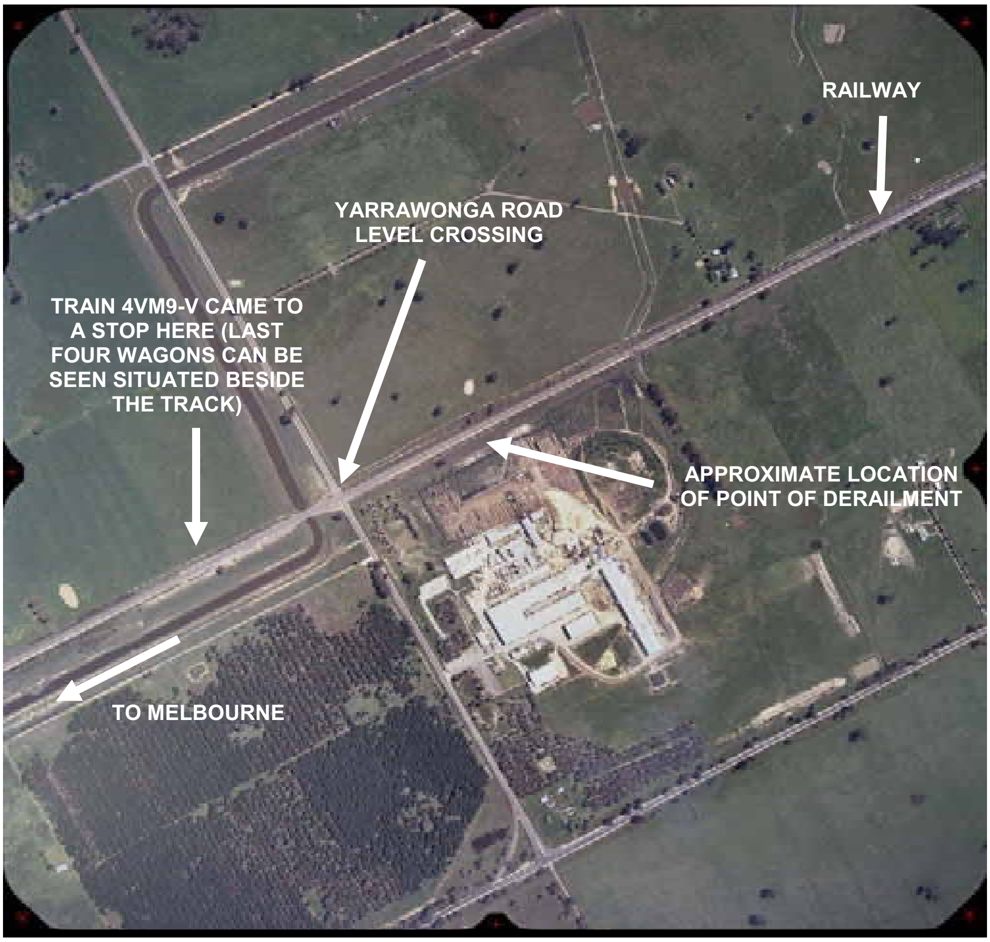
1 Since the occurrence, Freight Australia has been incorporated into the Pacific National Pty Ltd

2 Standard gauge – a measurement of 1435 mm between the inside rail faces.

3 Broad gauge – a measurement of 1600 mm between the inside rail faces.

**Figure 2: Aerial photograph of the occurrence site north of Benalla, Victoria. (Photograph taken in October 2004 soon after the derailment)**




## 2.2 The Occurrence

Train 4VM9-V is a regularly scheduled operation carrying dry bulk cement between the Blue Circle Southern Cement Ltd works at Berrima, New South Wales and its Somerton works north of Melbourne. Both cement works incorporate sidings which directly access the Sydney to Melbourne main line.

The train had completed loading and departed Berrima for Somerton without incident at 1655 EST, Wednesday 22 September 2004. The train departed Junee, New South Wales at 0008 on Thursday 23 September 2004 after a routine locomotive crew change.

Approximately six kilometres north of Benalla, train 4VM9-V reached an infrastructure restriction[4] (IR) which was subject to a temporary speed restriction (TSR) of 80 km/h – a speed reduction from the maximum allowed of 115 km/h. The TSR had been in place following the detection of a sequence of track dips, the result of inadequate track support from areas of soft formation and ballast contamination.

4 A condition related to civil, electrical, and signalling and communications engineering that required modified operations.

The wagons of train 4VM9-V were limited to a maximum speed of 80 km/h[5] and the train was travelling at approximately 79km/h to 81 km/h when it reached the IR.

**Figure 3: Train 4MV9-V after coming to a stop following the derailment. The train is standing on the standard gauge line with the parallel broad gauge line opposite**

The locomotive and leading 11 wagons passed over the track dips in the IR area before the leading right-hand wheel of the 12th wagon unloaded and climbed up and over the western side rail. The wheel set initially continued along the top of the sleepers and passed over a level crossing before the second wheel set derailed to the same side as the first wheel set. Sufficient track damage was then caused to effect a loss of track gauge retention and to spread the rails which in turn led to all remaining wheels of wagon 12 and all wheels of wagons 13, 14 and 15 to drop between the rails. The time of the occurrence was 0444.

The driver became aware of the derailed state of the train because of a loss of brake pipe pressure. He controlled the locomotive power and the induced emergency brake application to bring the train to a stop. Although the train was braked to a stop in approximately 400 metres from a speed at the time of derailment of approximately 79 km/h, the derailed wheel had travelled approximately 525 metres from the point of derailment (POD).

Emergency actions were initiated by ARTC and FA following the reporting of the derailment by the train crew of 4VM9-V.

5 Maximum train speed class was termed as 'Standard' (ARTC Code of Practice for Operations and Safeworking)

## 2.3 Injuries

No person was injured.

There was no report of post-incident stress or related conditions to the train crew or other personnel. The occurrence did not involve any other trains.

The damage to wagons and track infrastructure was well behind the hauling locomotive and did not result in any conditions hazardous to the train crew.

**Figure 4: The second last wagon in the train, amidst severe track damage**


## 2.4 Personnel Involved

Personnel directly involved with the running of train 4VM9-V on the day of the occurrence were locomotive driver crews from FA and an ARTC train controller.

Each locomotive crew consisted of two drivers, rotating through the positions of operating driver and second driver during each shift. A Junee based crew prepared and started the train from Berrima earlier on the day of 22 September 2004. A Melbourne based crew took over the train at Junee. The operating driver at the time of the derailment assumed driving control at Wodonga, approximately 106 kilometres from Benalla.

The train controller from the Adelaide train control centre regulated the passage of trains over the line between Albury and Melbourne.

The personnel records of those immediately involved with the occurrence showed that they were experienced, appropriately qualified and current in their respective positions of responsibility.

## 2.5 Medical and Toxicology Information

The driver and second driver operating the locomotive hauling the train were requested to undertake a breath test following the occurrence. The tests, administered by an officer of the Victoria Police, Benalla Station, returned a 'negative result.'

Records indicated that both drivers were medically 'fit for duty' at the time of the occurrence.

## 2.6 Loss or Damage

Approximately 530 metres of track was damaged including sleepers, broken and crippled rails, fastenings and formation damage. Severe track damage occurred over approximately 80 metres underneath and immediately behind the location where the last three derailed wagons came to a stop.

Repairs to the track infrastructure started on the day of the occurrence and were sufficiently completed by 0253 on Friday 24 September 2004 to permit reopening of the line.

Damage to the rollingstock was restricted to the bogies and other under-wagon equipment of the last four wagons of the train. Most damage occurred to the last three wagons with the fourth last wagon sustaining minor damage, mainly to the wheel treads and flanges.

By late afternoon on the 23 September 2004, the four derailed wagons were detached at the occurrence site, allowing the lead portion of the train to continue to Somerton. Repairs were carried out to the four derailed wagons and after being fitted with replacement bogies, were later removed to their destination by another locomotive.

The adjacent broad gauge line was not affected by the occurrence.

A number of trains were affected by the obstruction of the line. In all, 13 trains, in addition to the derailed train 4VM9-V, incurred consequential delays. Train 4VM9-V incurred a delay of 737 minutes.

## 2.7 Dangerous Goods

There were no releases of dangerous goods or toxic spillage of any kind as no dangerous goods were carried on train 4VM9-V.

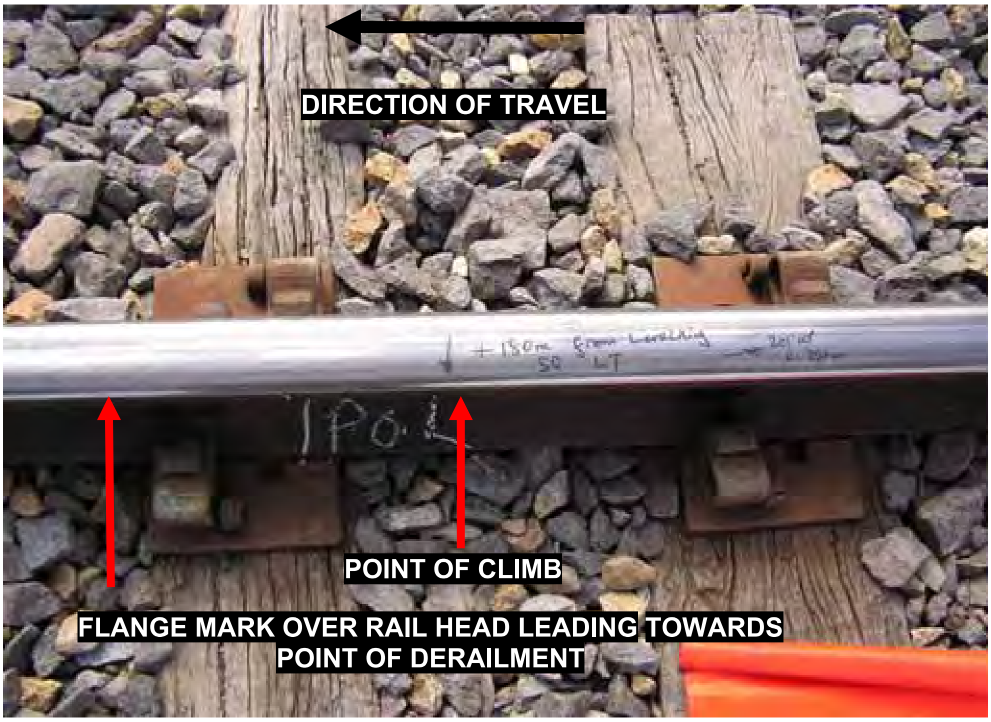
## 2.8 Environmental Factors

Records obtained from the Australian Government Bureau of Meteorology indicate that at the time of the derailment the weather surrounding and inclusive of Benalla was fine with an overnight minimum temperature of 6° to 9° Celsius with no rainfall. While no rain had fallen since 16 September 2004, up to 400 mm of rain had fallen in the area from 1 July 2004. Up to 200 mm of rain had fallen in August 2004.

## 2.9 Accident Site Information

The initial mark of the occurrence appeared at a point 200.767 route kilometres from Melbourne. (Refer to figure 5). This indication of where a wheel flange left its proper location inside the western side or right-hand rail, known as the point of climb (POC)[6], was approximately four metres north of the POD (200.763 km). From the POD, indications of wheel set flange marks appeared on the sleepers – one on the outside of the western rail and one on the inside of the eastern or left-hand rail.

**Figure 5: Photograph showing the point at 200.767 km where the wheel flange started to climb the inside face and travelled over the western rail**




The set of flange marks continued to the Yarrawonga Road level crossing (200.614 km) to the south and continued over the bitumen surface to the sleepers on the other side. An increased level of track damage occurred south of the level crossing. Referring to figure 6, the red coloured arrows indicate the course of a derailed wheel set. The second wheel set of the same bogie, while still running on the rails at that stage, was being steered in the direction of and parallel to the leading wheel set. The much lighter flange marks left by the second wheel set are indicated in yellow.

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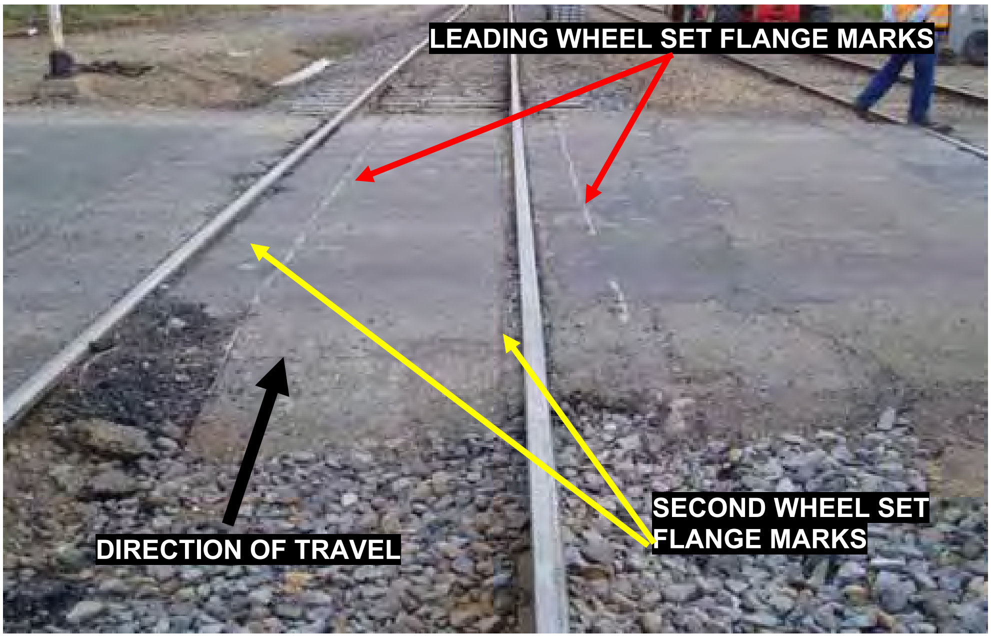
6 The Point of Climb is synonymous with the term Point of Lift (POL).

**Figure 6: Wheel flange marks of the first wagon to derail at Yarrawonga Road level crossing. Photograph taken following partial restoration of derailment damage**




At about 200.360 km, a point approximately 250 metres to the south of Yarrawonga Road level crossing, the damage to sleepers caused by a left-hand wheel, and possibly a second left-hand wheel, increased markedly. This heavier damage to the sleepers resulted in a number being broken in two. Combined with evidence of variable ballast support, a large number of sleepers were also found with signs of considerable deterioration. At this point, the effective sleepers in the track had become so severely damaged that the eastern side rail no longer held track gauge. The trailing bogie wheels of wagon 12 and all wheels of wagons 13, 14 and 15 dropped between the rails and accelerated the derailment sequence and the damage to the track. The leading and second wheel set of wagon 12 derailed to the same side of the western rail. The rear of the train came to a stop at 200.297 km.

It is apparent that the lead bogie of wagon 12 was the first to derail and impacted on the sleepers. As a result, the seven following bogie sets dropped between the rails.

**Figure 7: VPBX 155-S, the 12th wagon in the train, sustained relatively minor damage. Photograph shows the derailed left-hand leading wheels and evidence of broken sleepers which led to a loss of gauge retention**


**Figure 8: Wagon VPBX 155-S showing the leading wheel sets during recovery following the removal of the forward portion of the train. Note the sinking of the left side wheels into the sleepers and ballast**

## 2.10 Infrastructure Information

ARTC is the accredited Railway Manager for the North Eastern Line section of the DIRN in Victoria. ARTC is also responsible for maintenance of this infrastructure and has contracted this function to Works Infrastructure[7] (WI) under an alliance agreement.

The track infrastructure at the derailment site is steel rail weighing 47 kilograms per metre secured to timber sleepers with resilient fastenings, on ballast. The track alignment is tangential and practically level. The track formation is located in an area surrounded by flat country with a number of drains along the side of the formation. Cross drains[8] are also in place at intervals under the formation.

A Centralised Traffic Control (CTC) system was used to regulate the movement of trains on the corridor. Voice communication over open channel Ultra High Frequency (UHF) radio between the train and train control is in use and is recorded at the control centre.

## 2.11 Train Information

### 2.11.1 Train 4VM9-V

Train 4VM9-V was hauled by EL class locomotive number 61 which had been under lease from the Chicago Freight Car Leasing Australia (CFCLA). The train consisted of 15 wagons loaded with dry bulk cement weighing 1051.2 tonnes and a length of 232 metres including the locomotive. The train had been loaded, weighed, and was brake tested before leaving Berrima.

**Table 1: Details of the four derailed VPBX wagons**

| Wagon Number | Position in Train | Gross Weight |
|---|---|---|
| VPBX 155-S | 12 (first derailed wagon) | 68.3 tonnes |
| VPBX 140-L | 13 | 68.9 tonnes |
| VPBX 136-L | 14 | 68.5 tonnes |
| VPBX 154-J | 15 (end of train) | 69.0 tonnes |

In records from 1999 to 2004, the wagon class were found not to have had figured in any derailments apart from those with causes linked to track infrastructure or shunting operations. Wagon VPBX 155-S had derailed during a shunting move at North Geelong on 11 December 2002. The three other wagons, VPBX 140-L,

7 A division of Downer EDI Limited

8 A ‘cross drain is a drain cut underneath the sleepers, usually in the track formation structure and perpendicular to the track. The drain is usually a porous pipe such a slotted pipe surrounded by porous fill and slopes down to and empty into a track-side drain. They are often found in multiple track areas and are intended to drain water that is pooling in the ballast layer between the tracks or under the track, usually as a result of subsurface settlement. If water is allowed to pool in the ballast, it can saturate the capping layer and allow it and the track formation layer to mix with and foul the ballast. This occurs by the weight of passing axles hydraulically ‘pumping’ the saturated materials upwards. The fouled ballast is unable to distribute the load of trains downwards from the sleepers, the track bed becomes overloaded and the track subsides at that location.

VPBX 136-L and VPBX 154-J involved in the 23 September 2004 occurrence were also involved in derailments on two previous occasions when being shunted at the Somerton cement works on 1 September 2004 and 2 September 2004. No damage was sustained and there was no indication in the records to suggest that these occurrences had contributed to the Benalla occurrence.

The four derailed wagons had been subject to the service and inspection requirements specified by FA procedures. None of the derailed wagons were found to be overdue for preventative maintenance.

### 2.11.2 VPBX Wagon Class

The wagons were of the VPBX class designed specifically to carry dry bulk cement. The wagon class is a covered hopper style construction with three compartments, which is loaded through a hatch at the top and discharged through an outlet at the base. The discharge of the cement from the hoppers is facilitated by air pressure. The wagon type entered service in 1970 with the Victorian Railways.

**Table 2: VPBX Class Wagon Details**

| | |
|---|---|
| TARE WEIGHT | 26 tonnes |
| LENGTH | 14.1 metres |
| MAX GROSS WEIGHT | 76 tonnes |
| CAPACITY | 50 tonnes |
| MAX ALLOWABLE SPEED | 80 km/h |
| NUMBER IN CLASS | 50 wagons |
| DATE BUILT | 1970 as the JX class, Ballarat North Workshops |
| USE | Bulk dry cement, usable on either broad or standard gauges lines |
| BOGIES | Three-piece 50 ton Ride Control with fixed side bearers, types VXC and VXSC |

**Figure 9: The VPBX class of wagon photographed at Blue Circle Southern Cement Ltd works, Berrima, New South Wales.**

# 3 KEY ISSUES

## 3.1 Introduction

The investigation examined the available evidence and considered a number of significant factors likely to have contributed to the derailment of train 4VM9-V. The circumstances of the occurrence were consistent with deteriorated track infrastructure conditions leading to an unloading and subsequent wheel climb in the train.

Rail safety management in Australia is based on a system of co-regulation. Legislation requires the track manager or train operator to have in place a safety management plan that is consistent with Australian Standard 4292. However, equivalent or superior standards may be nominated by the track manager or train operator for their safety management system. The overall objective is to make sure that a robust process for effective rail safety is in place.[9]

The investigation concentrated on two relevant areas – the safety management system applying to the maintenance of track infrastructure and the characteristics of the rollingstock.

To assist in the investigation of the occurrence, the Australian Transport Safety Bureau (ATSB) engaged a number of consulting firms to provide expert analysis of track infrastructure and rollingstock dynamics. Booze Allen and Hamilton (Australia) Ltd and Steelcon Consultants Pty Ltd provided these services for the track infrastructure, while Interfleet Technology Pty Ltd provided vehicle and track interface modelling of the VPBX wagon type.

## 3.2 Track Infrastructure

### 3.2.1 Conditions leading to derailment

The VPBX type wagon, when loaded, is a very rigid structure and is resistant to longitudinal and lateral twist. (A full discussion of the track condition is at 3.2.3 and the VPBX wagon description is at 3.3.1). In the section of track in which the derailment occurred, the wagon had to interact with an uneven track structure, particularly the left-hand rail. The track had pronounced dips, peaked welds and identifiable vertical track wave forms; one nine metre and one 25 metre. At a speed of 75 km/h the VPBX wagon would experience a ‘body bounce’ wave length of 9.5 metres.

Train 4VM9-V passed through two consecutive track dips in a space of 50 metres before the POD. This path was uneven but relatively level. While the actual dynamically deflected track shape is not known, the dips were at least 40 mm deep. When passing over the section of track, in sequence, the cement wagons would have leaned to the left, return to an upright position, and then leaned somewhat to the right.

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9 Rail Safety Co-Regulation, Accreditation Authorities Group, Australia 2001.

At the POD the wagon would have been supported diagonally by the leading left-hand wheels and the trailing right-hand wheels. The leading right-hand wheels in particular would have had most of the load transferred from them due to the high resistance to twist in the wagon body. The wavelength of the track deformation (dips) resulted in dynamic forces acting on the cement wagon at frequencies close to its natural frequency of motion causing resonance to occur. In other words, the combination of track shape and train speed produced a wagon reaction resulting in its rolling sufficiently to lose wheel load and consequently led to a wheel climb derailment.

**Figure 10: In a direction looking away from Melbourne, using a telephoto lens to augment and clarify the observation, the photograph shows the eastern side rail vertical profile and the two dips, over a distance of approximately 50 metres north of the POL**


An analysis of the likely vertical reaction of the first cement wagon to derail showed that the nine metre vertical track wave form evident, would approximately match the 9.5 metre body bounce wave length at a speed of about 75 km/h. This condition induced body roll in the wagons of the train. (Refer to Appendix 7.2).

Railway line is made up of three subsystems – the sub-grade, the ballast bed and the track. The sub-grade is made up of the formation and on top of that, the capping layer. The capping layer is the surface on which the ballast is laid. The track supports and distributes the loads from the trains and is made up of the sleepers and the rails. The ballast is stone material placed between the sub-grade and the track as well as surrounding the sleepers to provide support and stability. The ballast also provides load diffusion from the sleepers to the sub-grade and provides drainage of the track. The fouling by external impurities such as mud degrades the ballast whereby its strength and drainage properties are compromised, especially after rainfall. This can lead to the loss of geometrical profile.

A number of peaked or dipped rail weld joints were also present at approximately 25 metre wavelengths. These wavelengths also aligned with cross drains excavated at approximately 25 metre intervals along the track. There was evidence of water beside the formation and visible track settlement at the cross drains, mainly along the eastern rail. There was also evidence that the cross drains had become blocked and ineffective. Given the presence of relatively sharply peaked welds and poor sub-grade, the extra impact load over soft formation appears to have led to dynamic deflections exceeding 8.5 mm and would have caused progressive track settlement. The sleepers at the lowest point in the dips were found to be 'hanging' in that there was considerable space between the sleeper plates and the sleeper. Some spaces were filled with ballast particles.

**Figure 11: Example of peaked welds in the western rail just north of the POD (enhanced through telephoto lens)**

**Figure 12: Example of cross drain location showing ballast contamination from poor sub-grade/damp/soft formation, pooled water and separation of sleeper and sleeper plate (hanging sleeper)**


Two main factors are involved in the derailment of a wheel. These are the angle at which the rail and wheel-flange meet and the amount of friction present between the two.

The four metre long flange mark was consistent across the top of the western rail. This indicated the presence, for the train speed, of an even combination of vertical and lateral forces acting at the point of the wheel to rail contact. The continuation of flange marks on the sleepers from the POD to the level crossing, and beyond for some distance, remained light but relatively consistent over this distance. This indicated the likelihood of only one wheel set derailing initially. From the evidence obtained at the site, it was clear that the leading wheel set of wagon VPBX 155-S was the first to derail. It was likely that a contributing factor to the derailment was body roll, excited by the dips in the track, and followed by wheel unloading associated with track twist. Twist is the rate of change of cross-level[10] over a given distance and becomes a problem if it exceeds the suspension travel of a bogie. This means that a wheel is likely to lift. The cement wagon would have been torsionally stiff and consequently unforgiving of this twist in the track, leading to wheel climb as the lateral to vertical force ratio at the wheel/rail interface decreased.

It is not known at what stage the secondary derailment occurred in which the second wheel set of the leading bogie of VPBX 155-S also left the rails. Although no evidence was found to indicate at what location this occurred, it would have been somewhere south of Yarrawonga Road level crossing but before the trailing wheel sets on wagons 12, 13, 14 and 15 had dropped between the rails.

Immediately following the derailment of the leading wheel set, the second wheel set would have been steered by the bogie in the direction of and parallel to the leading wheel set. Although there was no evidence of scrubbing on either flange of the second wheel set, the resultant increase in positive angle of attack would have reduced the critical lateral to vertical load value (L/V) and lessened the required lateral force to initiate a flange climb, also causing it to derail to the outside of the western rail.

### 3.2.2 Safety Documentation

The track infrastructure on the DIRN in Victoria is maintained contractually by ARTC to the requirements of the *Victorian Civil Engineering Circulars* (CECs). The CECs provide technical and procedural information for ARTC and WI and are known as 'legacy documents' as they were previously managed by the Public Transport Corporation of Victoria prior to its break up and sale. An annex is used by ARTC and WI to index the CECs and their relevance and record if they had been superseded by other documents. ARTC and WI have been progressively reviewing all CECs.

*Australian Standard 4292.2 — 1997, Railway safety management, Part 2: Track, civil and electrical infrastructure*, specifies technical requirements to be considered for inclusion in railway engineering systems safety standards. Of relevance to the derailment, are the following items:

- Section 1.8. *Hazard Identification and Risk Analysis*, 'Determination of the matters to be included in standards and procedures for each phase of the life

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10 Cross-level is the difference in height between immediately adjacent rails.

cycle should include identification of hazards which might affect the following: (a) Integrity of the track and civil infrastructure…'

- Section 6.2. *Monitoring and Maintenance Requirements*, 'Standards and procedures shall be established and maintained for the monitoring and maintenance of track, civil and electrical infrastructure. These standards and procedures should include the following: … (b) Assessment of serviceability by means of either – (i) condition standards; (ii) assessment rules; (iii) detailed analysis; or (iv) any combination of the above; (c) Carrying out of preventative or corrective action, including the following items … (iv) Use of appropriate maintenance practices, procedures and records; (v) Procedures to ensure restoration of works to the required Standard.'
- Section 6.3.1. *General requirements*. 'Standards and procedures shall be established and maintained for the handling of temporary infrastructure restrictions arising from an unsafe infrastructure condition or a track obstruction, and imposing operating restrictions for the control of traffic. These standards and procedures should include the following: (a) Determination of conditions and events which are likely to result in reduced operating safety or obstruction of the track … (c) Methods of detection and reporting of the onset of conditions and events described in Item (a).'
- Section 6.3.2. *Factors to be considered*. 'These standards and procedures should take into consideration the following factors: … (d) Potential problems noted at scheduled inspections such as changes in condition.'

The introduction of a standardised approach through a revised National Code of Practice (NCoP) to Victoria has been the subject of review by ARTC and the Victorian Rail Regulator, the Department of Infrastructure (DOI). An application from ARTC for the introduction of the NCoP to the DIRN in Victoria was received by the DOI on 15 September 2003. At the time of the derailment, the application had not been approved and ARTC were still working though a number of outstanding issues. NCoP intervention levels are provided in Appendix 7.3.

Both ARTC and WI have been working to the CECs as well as other procedures and a modified component of the NCoP for use with the 'AK' track recording car (AK Car). However, the AK Car when operating in Victoria, reports against the *AK Car Defect and Response Tables, Standard and Victorian* (AK Geo.), used by the AK Car owners, Rail Infrastructure Corporation of NSW.

The intervention levels of the AK Geo. standard are a revised version of the NCoP.[11] These AK Geo. Std intervention levels are defined in the tables titled '*AK-Car Track Condition Monitoring System – Geometric Defects*'. (Refer to Appendix 7.5).

The AK Geo. Std geometric standards differ from the CEC standards. The applicable track geometry standard in Victoria is CEC 8/86 and includes standards to be used for track inspection purposes. (Refer to Appendix 7.6).

11 *Part 3 – Volume 4, Track, Civil and Electrical Infrastructure, table 5.5 Geometry Defects – Response Codes*, known as *Table 5.5B Geometry Defects – Response Codes*. (Refer to Appendix 7.4)

Instruction CEC 7/86 for the use of another track recording car, the Plasser EM100 track, was also examined by the investigation team. The applicable exceedence levels for use with this track recording car are shown in Appendix 7.7.

Track geometry standards in Australia were written in terms of earlier chord based measurement systems. To provide usable information from the AK Car that could be compared with the standards, an emulation[12] of the chord data set was produced mathematically from the inertial data set. These results are then used for determining whether the track meets with the standards. Thus, to make sure that track faults recorded by the AK Car are comparable with data taken from the earlier EM80 track recording car, correlations of the results of both cars were made. Based on the results, ARTC made adjustments to the intervention standards.

The AK Geo. identifies acceptable limits of geometrical profile. For twist, these express the difference in the level of the two rails of the track at one point (known as the cross-level) by comparison with the cross-level at other points two metres away and 14 metres away. CEC standards 7/86 and 8/86 on the other hand require twist to be determined over 3.5 metre and 10 metre intervals.

Both AK Geo. and CEC standards require consideration of not only specific exceedences such as twist, but also of combinations such as twist and cant. CEC 8/86 requires that, 'Where necessary, attention must be given to the track before these tolerances are reached.'

The AK Geo. standard includes notes stating that geometry data cannot be considered by an individual parameter, or in isolation from track performance expectations and traffic. It states that:

- All geometry parameters used are based on the loaded conditions. Where static or unloaded measurements are taken, due allowances should be made for the additional impact of loading and dynamics.
- The measured parameter limits set in the above table (of the AK Geo. standard) are derived from the commonly occurring defects in actual conditions. Normally occurring multiple defects are provided for in the limits set. For example top[13] and twist defects would commonly be expected to occur together. In such cases the most stringent response criterion of the two should be selected. Unusual combinations of defects which are considered to act together, for example with horizontal alignment and twist, require special consideration. A more stringent

12 The process of successfully duplicating the performance of a computer device or program

13 'Top' is the variation from the design of the vertical position of a rail in space. It is a measure of the variation from level of the top of the rail from a straight line drawn between two points on the rail and measured at a specified distance from one of these points. Vertical curves, for example at the crest of a hill, are gradual enough to be irrelevant for the purposes of these measurements. The first 'Short Top' refers to the measured variation from a straight line taken 1.8 metres from one point when the points are 10 metres apart. The second 'Short Top' refers to the measured variation from a straight line two metres from one point when the points are five metres apart. These measurements are no longer directly taken, but are a calculated empirically on the basis of AK Car data and are recorded typically at 0.5 metre intervals. The 'Long Top' refers to the measured variation from a straight line taken in the centre of the line when the points are 20 metres apart. This measurement can be empirically calculated from AK car data, but is more commonly the standard manual method of measuring top used by field staff.

response than that specified for rectifying the defects individually should be considered.

- Defect parameters selected represent only one range of defects historically specified by railway systems. Defect types including cyclic, excess cant deficiency and other types giving rise to rough track should not be ignored. Assessments should be made by observation and experience, which should include on-train ride. Each defect located in this manner is to be classified by an accredited worker using the same response categories specified in the lower tables (of the AK Geo. standard). Acceleration based measuring devices may also be used to identify defects of this type.

Similar requirements are noted in NCoP *Table 5.5 Geometry Defects – Response Codes, Notes 11, 12 and 13a.*

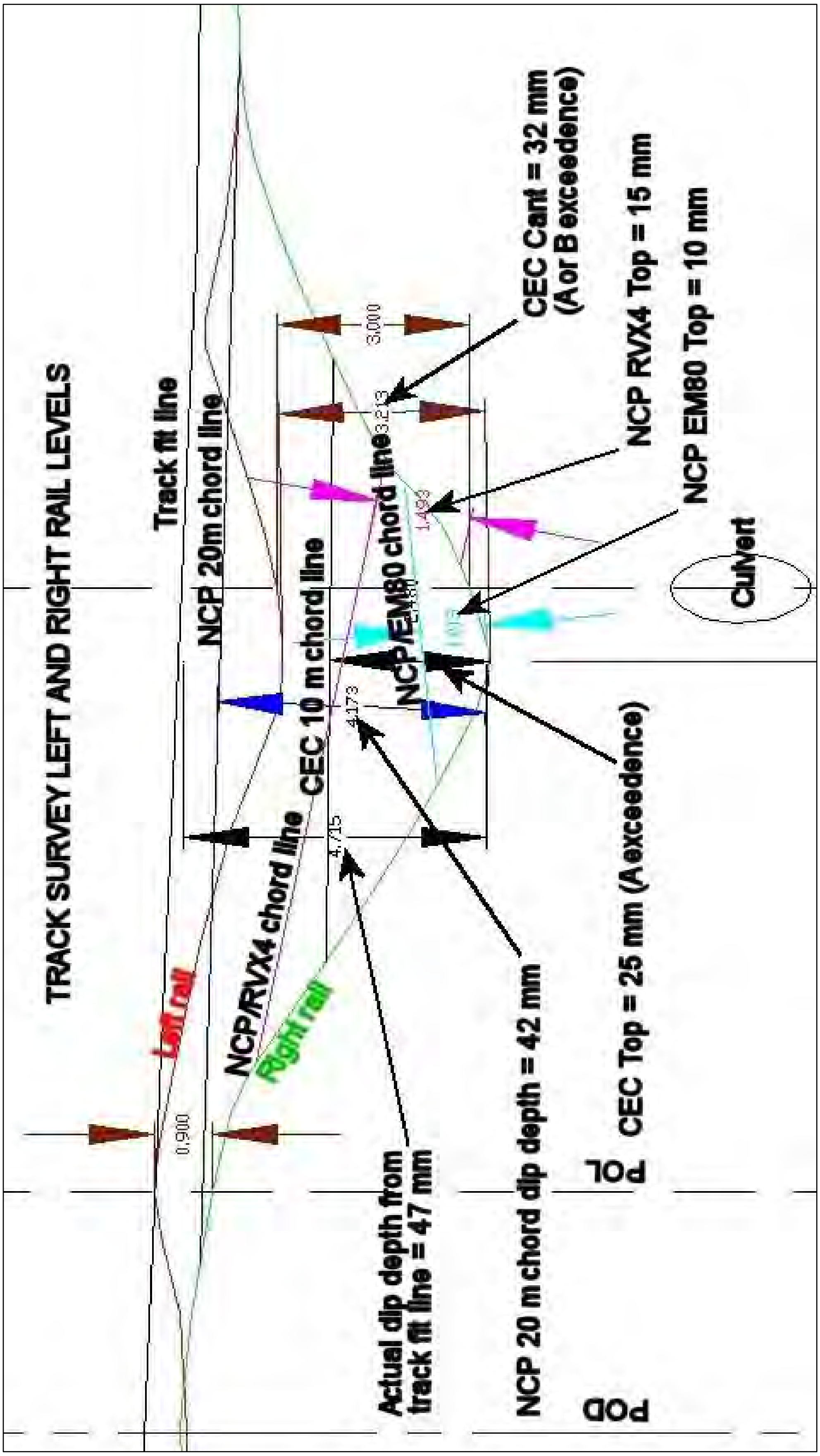
No evidence was found of effective post analysis interpretation of the AK Car information during the period from its operation over the track on 4 August 2004 to the 23 September 2004 derailment of 4VM9-V.

Referring to Appendix 7.3, the NCoP defines a number of parameters – three 'Top', two 'Short' and one 'Long'. The first 'Short - Top' reflected an emulation of the earlier RVX4 track recording car, which the AK Car replaced in New South Wales, hence the reference to RVX4 in Figure 13. The second 'Short - Top' reflected an emulation of the EM 80 track recording car, which the AK Car replaced in South Australia (and effectively Victoria). In Victoria the 'Short - Top' in column three applies and this was the column used for checking 'Top' exceedences. The 'Long - Top' was not used by the AK Car, but used by track inspectors.

Although the AK Car did not reference CEC standards, the data overall showed that the AK Car data was well within the tolerances set by both AK Geo. and CEC standards.

Further, in comparing the NCoP and the AK Geo. standards, the former requires that the fault levels determined should be repaired before the passage of the next train whereas the AK Geo. standard requires 'immediate' repairs which do not necessarily preclude the passage of a train.

**Figure 13: Diagram of track surveyed with CEC and NCoP standards overlaid**



The application of the NCoP ‘top’ and ‘short’ twist limits would have provided a further insight into the track condition because it allows ready interpretation of track geometrical shape by a track inspector. The AK Geo. standard ‘top’ and ‘short’ twist measurements cannot be readily or precisely interpreted by a track inspector. In addition, the AK Car had possibly become the arbiter of track geometrical defects. This left track inspectors and engineers in practice, dependent upon the geometry measurement system without being able to check on the outcome’s veracity. That is, the AK Geo. standard used should have included additional manual measurement procedures to determine the presence and scope of any defect reported by the AK Car.

### 3.2.3 Inspection and Testing

Following the occurrence, a WI team surveyed the vertical profile of the track between 100 metres north and 100 metres south of the POD. The track survey provided measurements of the track at regular intervals. This enabled a vertical profile of each rail to be plotted.

The AK Car had passed over the track on 4 August 2004 and provided relative rail levels of the location. The AK Car is equipped with relatively new inertial geometry measuring instruments. Placing the geometry data in the context of railway maintenance standards, the objective of railway track management is to make sure that the physical shape of the track is maintained within prescribed limits. For example, a dip in the track could be compared with the standards to determine whether it is in acceptable limits or in need of corrective maintenance work.

The benefit of the AK Car is its concentration (close spacing) of measurements, typically in the range of 0.25 metre to one metre intervals. The AK Car is of considerable weight and travels at speed – compared to a surveyor who would take static measurements of unloaded track. The AK Car, however, cannot discriminate in its measurement, meaning that, although a manual survey would not have the concentration of data points, the human eye would identify potential points of concern, such as dipped rails or peaked rail joints.

In this case, the manual track survey data was provided in the form of reduced levels of the east and west rails at two metre to five metre intervals and the AK Car data was provided at 0.5 metre intervals.

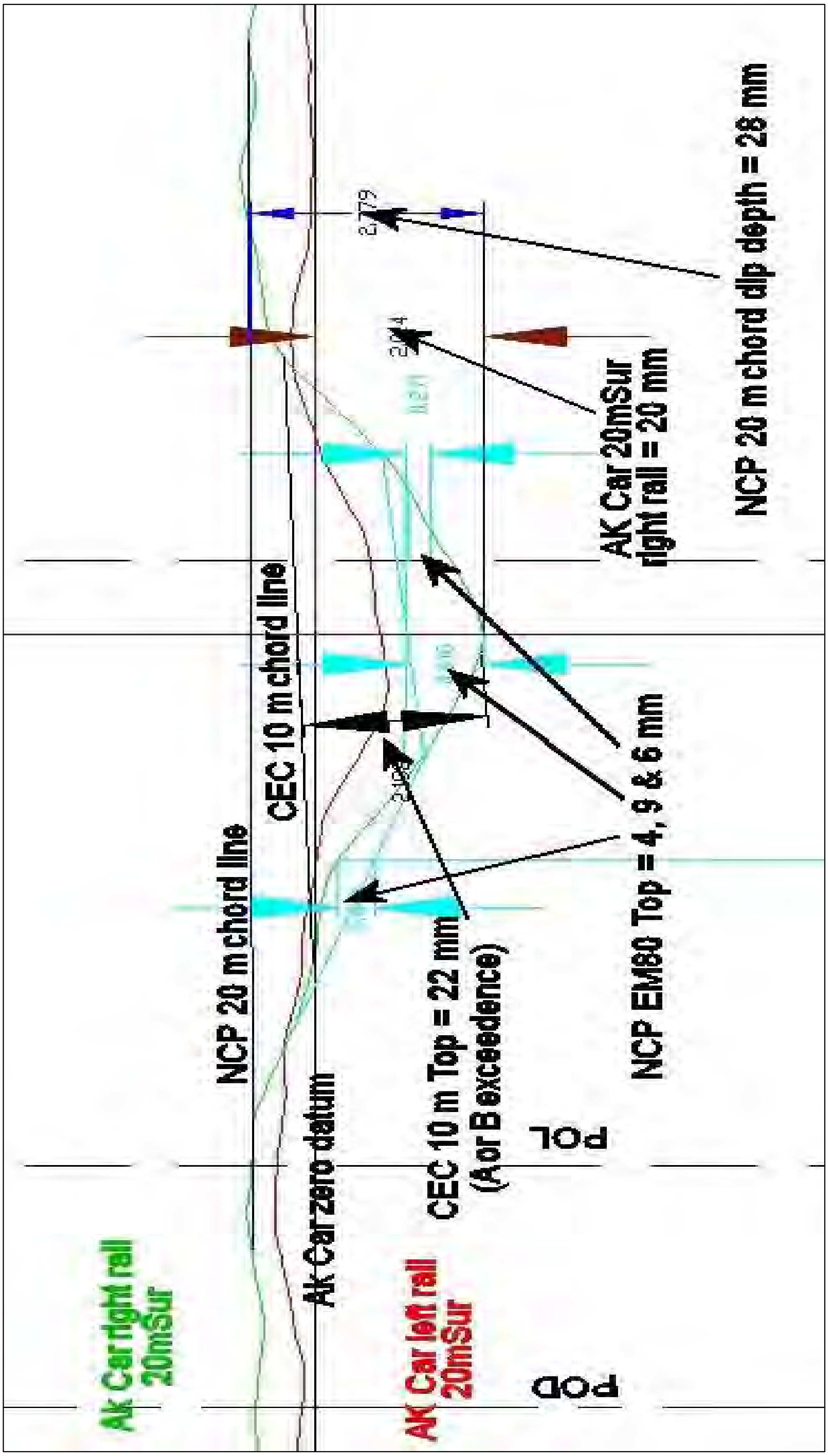
There are a number of subtle issues associated with use of either of the chord or the inertial measurement systems. Certain track shapes tend to be blind to chord systems and various filters are applied to inertial systems that can affect interpretation.

**Figure 14: A profile cut into the ballast at the occurrence site indicates the presence of contamination which contributed to the development of voids under sleepers**

At the location immediately before the POD, the eastern rail dip was about 47 mm deep and the western rail dip was about 15 mm deep. (Refer to figure 14). The cross-level at the bottom of the dip was approximately 32 mm, which is an exceedence under CEC 8/86 for tracks of Class 1, 2 and 3, and was an 'A' type exceedence under CEC 7/86 for track Class 1 and a 'B' type exceedence for track Class 2. However, this is not an exceedence under the AK Geo. standard. It is very likely that the figures would have increased under load as these survey measurements were made with unloaded track.

Figure 15 shows the AK Car '20Sur' data from which is derived the 'Top' data for comparison with the AK Geo. standard. It also shows the AK Car basic rail vertical profile data, called '20mSur' (for eastern and western rails, red and green respectively), which follows the same general form as the survey data and shows a lesser depth of dip. This might have been a consequence of the passage of time, an artefact of the measurement system and its associated physics and maths, or the setup and operation of the AK Car. In any event, the 'Short - Top' data used for comparison with AK Geo. standard limits were the 4 mm, 6 mm and 9 mm figures shown progressively around the dip.

**Figure 15: AK Car 20mSur data**



The ‘Top’ data set was checked against the AK Geo. standard requirements. This is shown graphically in figure 16. It is clear that the significant dip shown in the AK Car ‘20mSur’ data, and even more obviously in the survey data, had gone undetected. The ‘Short - Top’ measurements are about half the allowable AK Geo. standard limits. In other words, it would appear that the dip in the track could have been twice the depth before triggering an AK Geo. standard ‘Top’ exceedence.

The reason for this situation was that the earlier EM80 uses a five metre chord length in which a two metre offset (to find variations in ‘Top’) is recorded. If a dip in the track happened to have a relatively gradual gradient, the offsets were relatively small. In consequence, the depth of a dip is not reflected in the ‘Top’ data used by the AK Car in Victoria, but rather the shape of the dip. The intent in setting up the standards and measurement procedures is presumably to reflect the situation experienced by a passing train. If the dip has a reasonably even ‘Top’ shape then the train will simply ride through the dip with relatively little effect. However, this approach gives relatively little recognition to the gross vehicle dynamics. The benefit that the AK Car offers in its measurement system is its ability to recognise much longer wavelengths of track deformation.

**Figure 16: AK Car reported ‘short’ ‘top’ data**

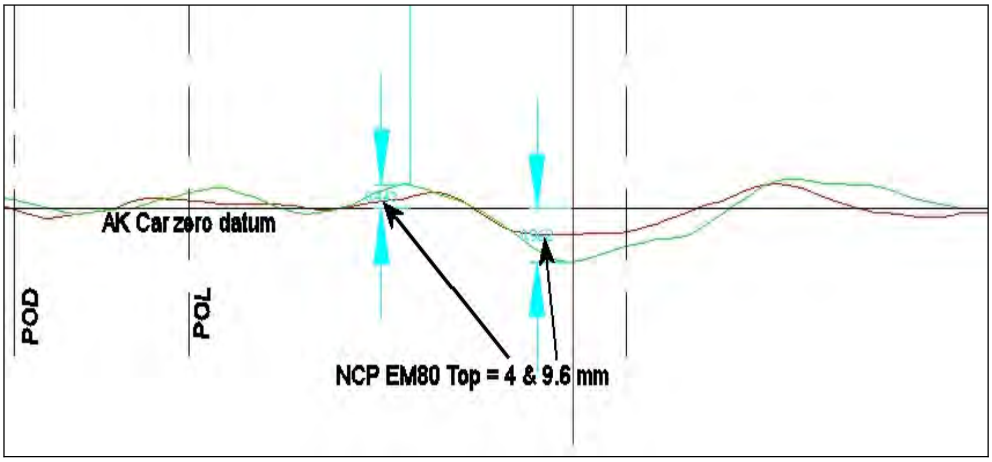
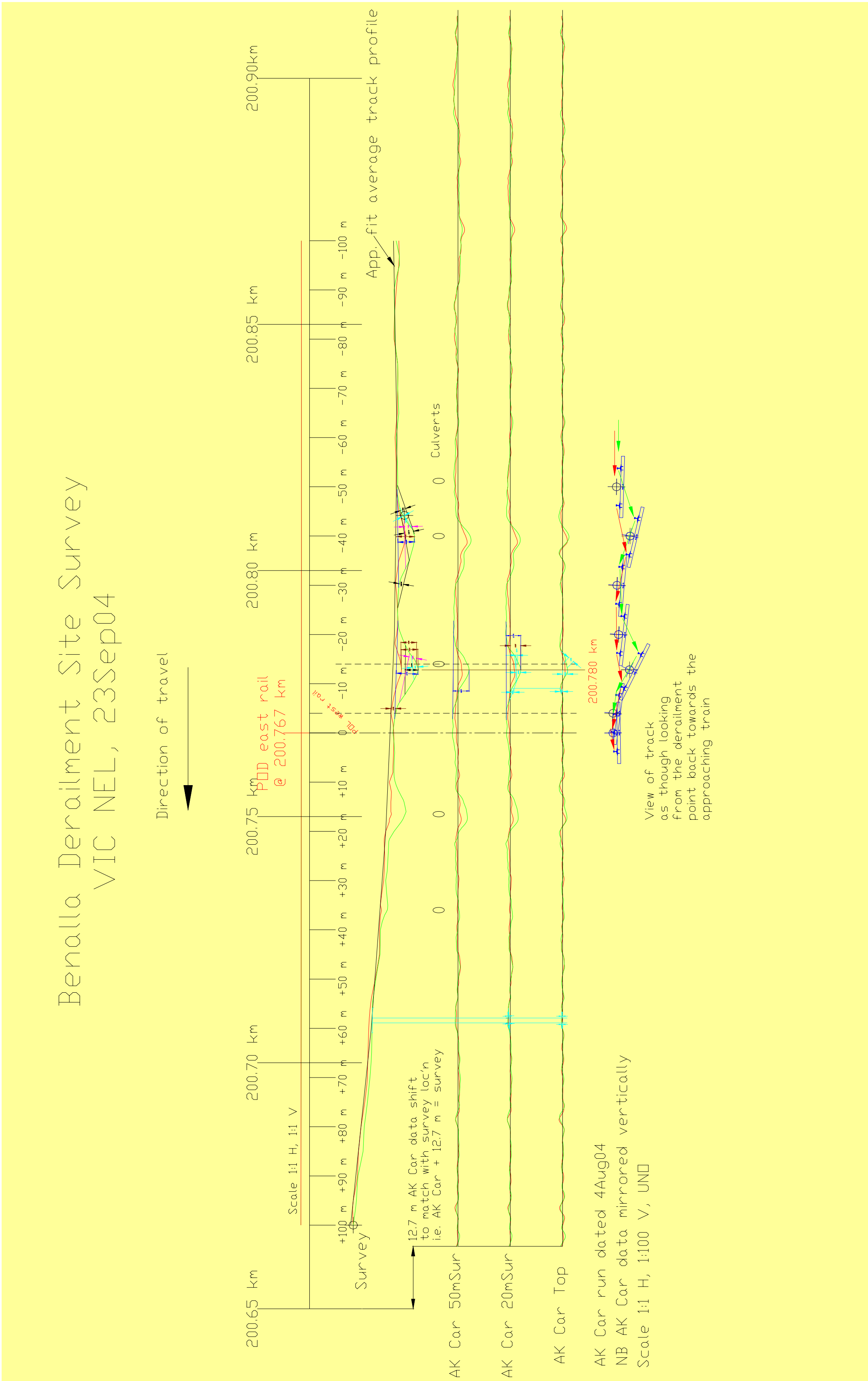



Figure 17 shows the area of the derailment with several data plots. The upper-most shows the site survey at 1:1 vertical scale, the next down at 1:100 vertical scale, followed by three AK Car plots. The plots marked ‘AK Car 50mSur’ and ‘AK Car 20mSur’ show approximately the same track profile as the plot marked ‘Survey’. The plot marked ‘AK Car Top’ however shows little resemblance to the ‘Survey’ plot.

The AK Car ‘20mSur’ data approximately matches the survey data, though the latter shows a much deeper dip, (28 mm compared to 42 mm, using the AK Geo. standard 20 metre ‘Long - Top’ measure).

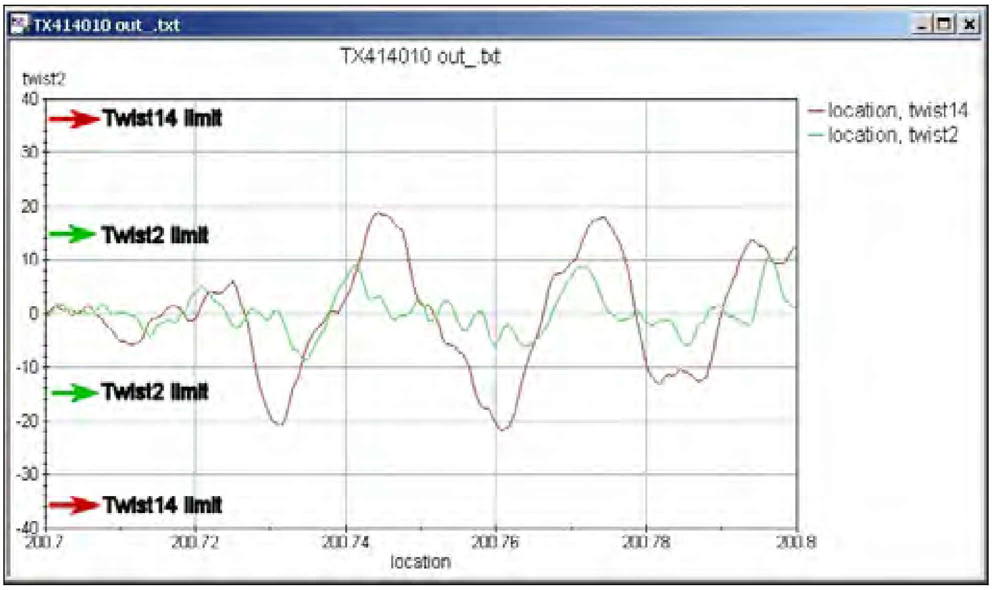
**Figure 17: Survey plot and AK Car vertical profiles of east rail (green) and west rail (red)**



Track recording car data does not set out to replicate track shape but rather seeks to identify any track shape that could cause unsafe or inefficient operation of trains over that track. The mismatch between 'Survey' and 'AK Car Top' need not necessarily be significant but in this instance, the difference is that the 'AK Car Top' data gives no particular indication of the series of dips in the track.

The AK Car data shows that there are 25 metre wavelength characteristics in the '20mSur' and '50mSur' eastern and western rail data at the location immediately before the POD between 200.9 km and 200.65 km.

**Figure 18: AK Car twist data at derailment site**

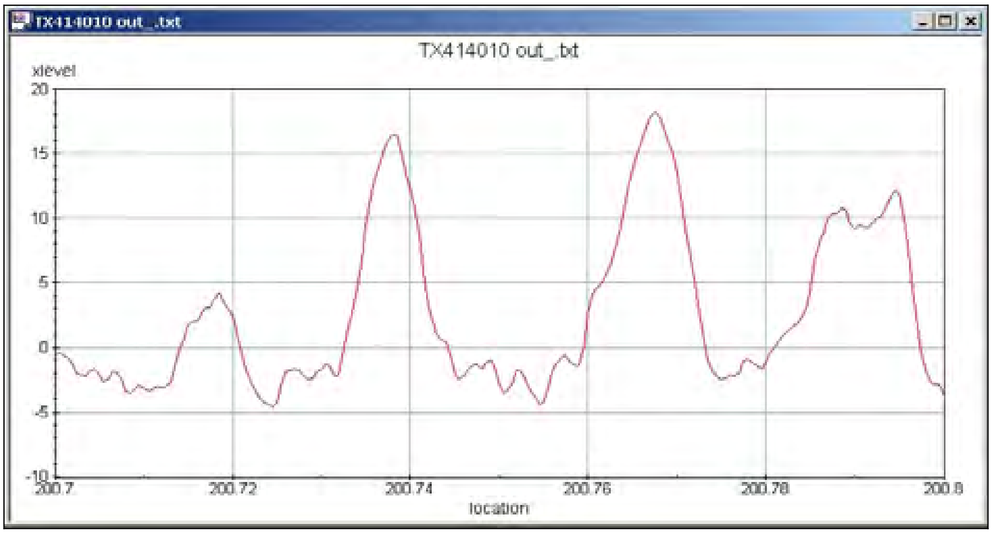



The AK Car long and short twist data, shown in Figure 18, also does not produce measurements indicating an exceedence of limits.

Twist data over two metres, 10 metres and 14 metres all show the same characteristic intervals. Over the full data set taken between the 205 km and 195 km posts, the '20mSur' data shows characteristic wavelengths of around 23 metres to 27 metres in the eastern rail and 9.1 metres and 27 metres in the western rail. The '50mSur' data shows characteristic wavelengths at 9.1 metres and 27.3 metres. Twist over 10 metres is not as clear but 25 metre intervals feature quite strongly. Similarly, for twist over two metres, 10 metre intervals feature, and for twist over 14 metres, 28 metres featured, both amongst a clutter of other characteristic intervals. This geometry will generally impart dynamic loads into railway vehicles both vertically and in twist at around nine metre and 25 metre intervals.

The cant or cross-level data shows a pattern that also raises concern in a vehicle/track dynamic interaction context. Figure 19 shows the variation in cant at the derailment site. Over a distance of 10 kilometres of AK Car data, the derailment site was found to be one of the worst areas for cross-level.

**Figure 19: Track Cant or Cross-level at derailment site**




Computing allows any number of twist intervals to be considered in real time or in post analysis, matching vehicles that actually operate on the track. Similarly, computing allows analysis of track recording car data to be assessed in real time or in post analysis to identify characteristic wave forms in track that could adversely affect wagon performance.

There are CEC 'Top' and cant exceedences in the survey and AK Car data. However CEC standards are not used by ARTC when interpreting and reporting AK Car measurement results. Against standard CEC 8/86, for a speed limit of 80 km/h over the TSR section of track, a number of exceedences were also found.

The AK Car data shows no AK Geo. standard exceedences for any parameter except gauge for the maximum allowable train speed of 115 km/h between 200.7 km and 200.8 km. According to the AK Geo. standard, the track is deemed to be satisfactory for passenger trains travelling at more than 115 km/h and for freight trains travelling at up to 115 km/h. At 115 km/h, the gauge parameter would require 'Priority 1' repairs within seven days. This maximum gauge measurement is less than 25 mm for which condition the AK Geo. and NCoP requirements at 80 km/h are to monitor track condition.

Gauge defects are usually an indication that sleeper ties are deteriorating and allowing the rails to move apart. They are not related to twist or top defects and would only contribute marginally to alignment deviations. The initial derailment mechanism due to excessively wide gauge is for a wheel to drop inside the rail. The initial derailment mechanism in this incident was for a wheel to climb up and over the rail. Therefore, this gauge defect did not contribute in any significant way to the initial derailment due to wheel climb.

### 3.2.4 Identification of Risk and Corrective Actions

The conditions of ARTC's accreditation require that the organisation establish procedures for the detection of potential causes of accidents and incidents. Preventative action in relation to risk includes the elimination of hazards or controlling them to tolerable levels and by controlling or preventing the consequences.

An additional responsibility of ARTC is to identify and record any safety problems or issues. In risk registers provided by ARTC, a number of safety related issues had been identified and the occurrence of mud holes and fouled ballast was known before the derailment of 4VM9-V. These safety issues were also supported by train crew observations and subsequent reports as shown in table 3.

ARTC's *Engineering Risk Register* PP-139.4 revised to 9 August 2004 describes a relevant risk issue, 'Vic – Extensive mud holes & fouled ballast throughout Vic following extensive rain can make it difficult for Track Inspectors to pick up track geometry defects. Recent survey of NE Line included an average of 4 visible mud holes per km over 70 kms of track.' Control measures in place at the time are described as, 'Shoulder cleaning & slot drains have helped. Clean out fouled ballast – under cutter, plough, and panelling. Improved drainage. Better track measurements between TRC runs'.

The state of the sleepers was also known. An ARTC risk register describes the NE Line timber sleepers as 'poor'. While it had been proposed to develop and implement a sustainable sleeper renewal program to commence in 2003/04, it is not know how far this program had advanced.

The ARTC safety management system was also considered by the risk register, 'Pending full implementation of NCoP there are gaps in codes & standards. An accident could result in ARTC & WI liabilities'. This situation was being addressed as, 'ARTC E&I Code of Practice being developed for implementation in 03/04. Individual problems being addressed as detected'.

Clearly, the introduction of the NCoP was fundamental to alleviating the inadequate state of affairs with the CECs and the ad hoc application of selected components of the NCoP and other infrastructure standards.

A list of identified track exceedences for the year prior to the derailment for the section of track was examined. In the 100 metre section of track relevant to the occurrence between 200.8 km and 200.7 km, there were seven exceedences reported. One for 'Top', four for 'Twist', one for 'Cant' (or cross-level, typically associated with twist) and one for 'Gauge'. Of these, three reports were annotated as 'reported', one as 'programmed', one as 'repaired' and two as 'discarded' .[14]

Leading up to the time of the occurrence, the Seymour based WI track supervisor had sent infrastructure workers to lift and pack the line manually and made further inspections of the section. A track tamping machine was working south from Wangaratta, Victoria and had run over the section approximately two months before the derailment.

The AK Car ran over the section approximately every three months. Regular WI track patrols were undertaken with the last one before the occurrence taking place on 17 September 2004.

The section of track was known to the track maintainers as being susceptible to twist defects in particular and a TSR had been applied. In the period September 2003 to September 2004, there were eight instances of reports made by train crew on the condition of track in the immediate area of the occurrence.

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14 While the reasons are unknown, 'discarded' can arise following checking of the AK report by an inspector when no fault is found or a fault has already been repaired.

A TSR of 65 km/h rather than the 80 km/h was in place at the time of the derailment.

**Table 3: A 12 month summary of train crew condition of track reports**

| Date | Train | Approximate Location | Report and Annotations |
|---|---|---|---|
| 10/10/03 | 8611 | 200.900km | 'Driver reported rough track. Gang to rectify. Soft formation, lifted and packed over length of 24 sleepers' |
| 11/10/03 | 8611 | 200.000km – 200.800km | 'Driver reported rough track. Poor top due to poor foundation. Tamper to lift and pack' |
| 03/11/03 | 8611 | 200.500 km | 'Driver reported rough track. Gang advised and inspected and advice that no restriction necessary at this stage. Line and top. Soft formation, track OK for line speed' |
| 03/12/03 | 8611 | 200km – 201km | 'Driver reported rough track' |
| 13/12/03 | 8611 | 200.900km – 201.000km | 'Driver advised bad hole. Inspected and repaired. Top fault, lack of ballast under 200.750 km to 200.800 km. Lifted and packed, needs mechanical tamping. Speed restriction applied' |
| 03/08/04 | 3MB4 | Benalla – Glenrowan | 'Driver advised that speed restriction was too high. Track inspected, OK for 80 km/h speed' |
| 20/08/04 | 8612 | 200.500km | 'Driver reported rough track. Supervisor was advised and will inspect. Foul ballast and flogging on first four timbers Up leg Up side in level crossing. Gang lifted and packed either side of crossing' |
| 30/08/04 | XPT | 200.700km | 'Driver reported hole. Temporary repairs made to hole in track by gang who lifted and packed the affected track and no TSR imposed. Rain previous night and faults in new cross drains. Lifted and packed' |

According to the WI *Railway Safety Management System*, 'If operation at the authorised normal operating speed is considered to be inappropriate for the infrastructure conditions, then a TSR is to be imposed to reduce the track loading, improve the ride quality, increase response time for sight distances, reduce the risk of derailment or mitigate the impact of a derailment.'

The survey results (see Figure 17) represent unloaded track. Taking into account hanging sleepers, the top measurements would have been worse under load and a CEC 'A' exceedence of 25 mm, which marginally requires a 65 km/h TSR by CEC 8/86, would have existed at the derailment site. Therefore, the cant and top exceedences would each merit a TSR of 65 km/h rather than 80 km/h in place at the time of the derailment.

## 3.3 Rollingstock

The operation of the train approaching the occurrence site was consistent with normal practice and the train speed was constant with the brakes released and a locomotive power setting of RUN 5[15]. The driver sounded the locomotive horn as a warning approximately 335 metres from the Yarrawonga Road level crossing. An acknowledgement of the train crew vigilance system was made at approximately 80 metres from the POD.

From the locomotive data logger information, it was apparent that the driver became aware of the derailed state of the train as the locomotive was in the vicinity of Yarrawonga Road. At this point, an air brake hose connection between two wagons parted and an induced emergency application of the train brakes occurred. Train speed at this time was approximately 79 km/h. It was apparent by the subsequent operation of the controls that the driver attempted to stabilise the train by maintaining locomotive power against the brake until it came to a stop.

The first derailed wheel set travelled a distance of approximately 525 metres from the POD until it came to a stop.

From the evidence, neither the operation of the train nor the actions of the train crew, were contributing factors to the derailment.

### 3.3.1 Testing

A model of the VPBX type wagon in a loaded condition was set up using the railway vehicle dynamics simulation program called *Vampire*. The track irregularities recorded by the survey and AK Car were also converted into a suitable format for use in *Vampire*. Based on the results of this modelling and of other calculated results, an assessment of the likely dynamic performance of the wagon on the track was determined.

Calculations were made for a maximum allowed speed of 80 km/h and the speed at which the wagon was travelling at the time of the accident. Calculations were also made for speed increments above and below this speed within the range of 60 km/h to 90 km/h in order to find the sensitivity of the wagon to speed.

Two versions of the modelling were set up:

1. a model representative of the vehicle in new condition
2. a model representative of the vehicle with some wear:
   - friction control spring pre-load reduced from 10.2 to 8.0kN [16]
   - centre plate effective diameter reduced from 325mm to 250mm[17]

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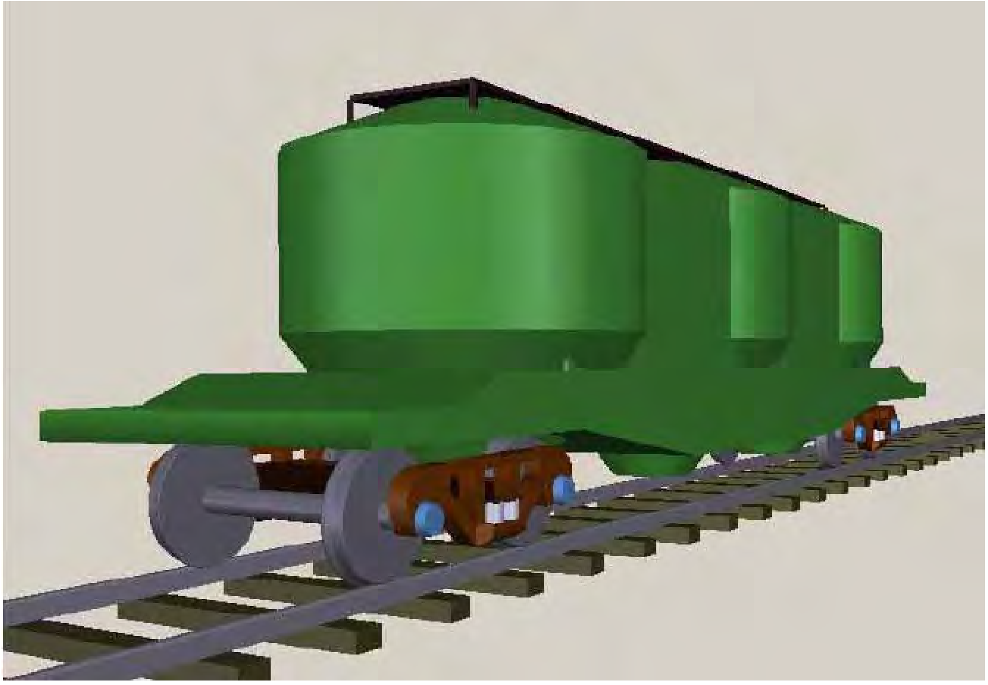
15 A tractive power setting of notch 5 where RUN 1 is minimum power and RUN 8 is maximum power

16 Based on design fitted length of spring to minimum spring length

17 Estimate based on age of vehicle

**Figure 20: Vampire generated model of VPBX type wagon and track**



The vehicle simulation was run over 5000 metres of irregular track. Vertical and lateral accelerations were predicted at various points on the body, plus rotational acceleration at the body centre of gravity in roll, pitch and yaw directions. The dominant body frequencies were identified as follows:

- body lower sway - 0.8Hz
- body yaw - 1.2Hz
- body upper sway - 2.2Hz
- body vertical bounce - 2.2Hz[18]
- body pitch - 3.2Hz

The vehicle was most 'lively' over the AK Car measured track input. Maximum wheel unloading at 80 km/h was 80 per cent but at 75km/h 100 per cent wheel unloading was seen at two wheels. Looking at the range of speeds, 75 km/h gave the worst wheel unloading results for this vehicle. At 75 km/h (20.8 m/s) the track dip spacing of approximately 25 metres corresponds to a frequency of 0.83Hz which was very close to the lower sway frequency of the vehicle. However, a Power Spectral Density (PSD)[19] of the wheel unloading shows that the lower sway and vertical bounce modes are both dominant in the vehicle response.

A calculation was made to assess the rollover performance for the wagon using a suitable rollingstock dynamic performance standard as a reference. While not entirely related to this wagon, it was useful as a reference point and an indicator of its performance. The reference point required that when curving at maximum cant

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18 Note that body vertical bounce and upper sway mode are coincident although the upper sway mode is well damped. The upper sway mode is not excited on the vehicle response.

19 PSD – the distribution of power in the frequency domain or distribution of power versus frequency

deficiency the minimum wheel load on the rail should not fall below 40 per cent of the static wheel load on average or 20 per cent instantaneously in response to track irregularities. That is, maximum permitted wheel unloading is 60 per cent and 80 per cent respectively.

Railways of Australia standards (ROA) show that normal cant deficiency is 80 mm and exceptional cant deficiency is 130 mm. For an older wagon such as the VPBX the 80 mm limit would be expected to apply unless the VPBX had been tested to the exceptional limit. However, simulations were made for the normal and exceptional limits in order to see how the vehicle would perform.

Two pieces of track were set up in *Vampire*, one that caused 80 mm of cant deficiency at 80 km/h and another that caused 130 mm of cant deficiency at 80 km/h. The curves were perfectly smooth with no irregularities, but were set up with the shortest transitions permitted by ROA standards. Therefore, the maximum wheel unloading should exceed 60 per cent of the static wheel load on the steady-state part of the curves, and should not exceed 80 per cent at the transitions. The results show that the vehicle is compliant to the standard at both 80 mm and 130mm cant deficiency, which is indicative of a good quasi-static roll performance.

Data was also available from the survey that gave top level of left-hand and right-hand rails for 100 metres on each side of the POD, and gauge for 100 metres before the point of derailment and 30 metres beyond. This was converted to the *Vampire* track format of vertical profile at the track centreline, cross-level and gauge variation. AK Car data was provided for the one kilometre section that included the point of derailment. The '20mlSur' and '20mrSur' columns of data were used for the left and right rail top levels and a factor of two applied in order represent the original track shape as well as possible. Gauge variation was taken from the 'Gauge' column of data.

The track at the derailment site is nominally straight. While no data was available for lateral irregularity of the track, it was noted that the gauge tended to widen on the left-hand rail in the vicinity of the dips. Therefore, in the analysis, some runs were made with a track centreline lateral irregularity added such that the left-hand rail contained all the gauge variation and the right rail-hand remaining perfectly straight.

The track at the derailment site was noted to have voids at many positions between the base plates and sleepers. The track would have been surveyed in the unloaded condition. Therefore, in the analysis, some runs were made with the track irregularity as measured increased by 30 per cent in order to take some account of the effect of the voids. Calculations were made using both a new Australian and New Zealand Railways (ANZR) 1[20] wheel profile on new rails as well as for a coned wheel set at 0.20 conicity in order to represent a worn wheel profile.

Flange thickness of the wheels of wagon VPBX 155-S were inspected at the site and found to be within serviceability limits.

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20 Note that a new ANZR 1 wheel profile is 0.05 conicity

**Figure 21: Flange height and tread thickness (left) and flange thickness (right) of the leading right-hand wheel of wagon VPBX 155-S**

The surveyed track data was probably a better representation of the track shape as there is a defined datum. However, the surveyed data was coarse in its measurement spacing and the track was unloaded. The voids that were visible between base plates and sleepers would not be accounted for in this measurement. Also, neither of these track data sources had information on the lateral irregularity.

Although the track was nominally straight, the detailed geometry of the dips in all planes is important. Calculations were made to check the effect of hunting and gauge irregularity on the left-hand rail for the surveyed track irregularity. This caused a large increase in wheel unloading and an L/V close to the 1.20 limit[21]. The effect shows 100 per cent wheel unloading at the right-hand wheels of wheel sets one and two. The leading right-hand wheel tread lifts 14 mm above the rail head for a distance of 2.2 metres. Applying a two metre running filter to L/V at the leading right-hand wheel shows the L/V exceeds 1.20 for a sufficient distance that derailment could occur.

A modification was made to the track input. Instead of the gauge irregularity being about the track centreline, the lateral irregularity was adjusted such that the right-hand rail was straight, and all the gauge irregularity was at the left-hand rail. The resulting L/V values at 75 km/h and 80 km/h were further increased. The magnitude of wheel flight predicted is still small at 5.5mm maximum (the second leading right-hand wheel at 80km/h). L/V is sustained over the 1.2 limit for about 0.35 metres at 75 km/h and 0.50 metres at 80 km/h (both for the leading left-hand wheel). This distance however is still unlikely to cause a derailment.

A further calculation was made for the VPBX wagon in a likely worn condition of 0.20 conicity wheel sets for the track as measured by the AK Car. This showed an increase in wheel unloading. For a conicity of 0.20 (or greater), the wheel set oscillation increases from the initial value (indicating negative damping or instability) and 'hunts' with flange contact to each rail. A speed of 75 km/h still gave the worst results with 100 per cent wheel unloading on six wheels (up from two wheels with new wheel profiles), and at 80 km/h, 100 per cent wheel unloading is predicted at five wheels (up from one wheel with new wheel profiles). Analysis of L/V values shows that the hunting vehicle produces much higher L/V values – hunting with 0.20 conicity wheel sets to stable with new wheel profiles.

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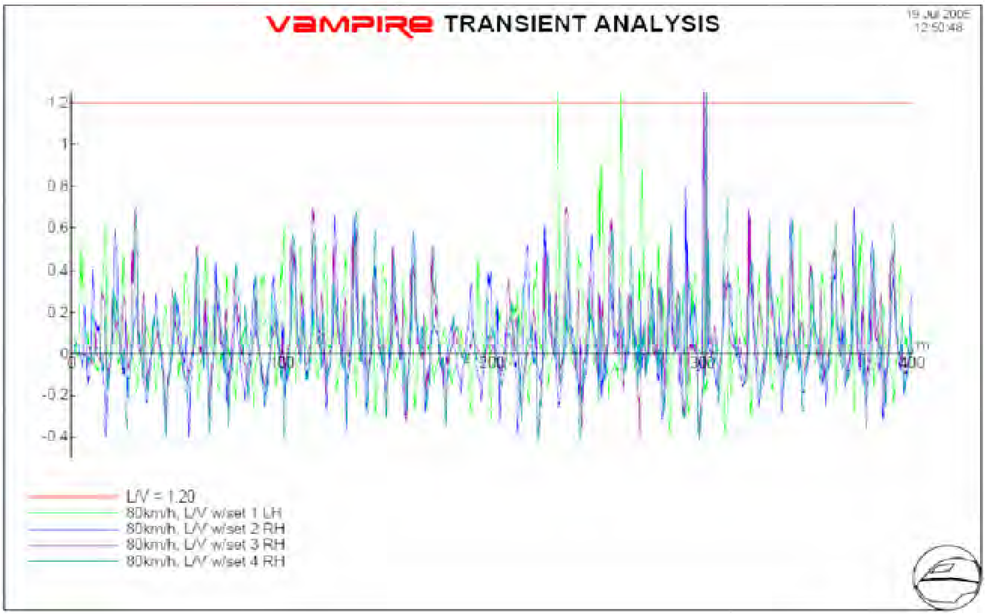
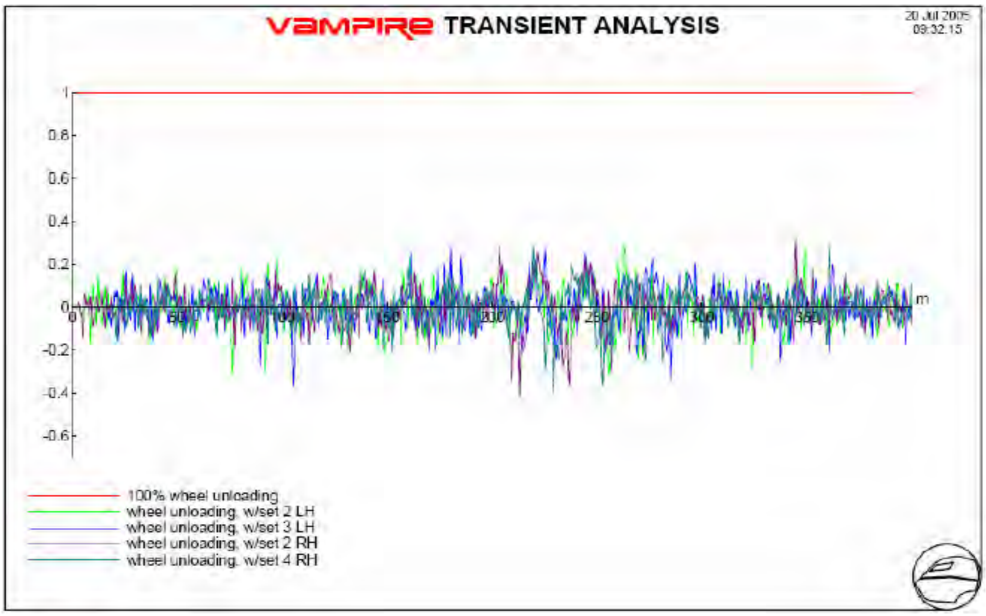
21 Based on Nadal's formula, this is the usual L/V safety limit

**Figure 22: Vampire output of L/V – Using AK Car track data. Including: gauge (lateral) irregularity on left-hand rail; VPBX wagon worn and hunting; and 80 km/h speed of wagon**




By way of comparison, one run was made for a passenger vehicle over the track as measured by the AK Car. The passenger vehicle was a *Vampire* model of a United Kingdom (UK) Mark three (Mk3) coach, a 200km/h vehicle that has proven very good performance for safety against derailment and a compliant suspension. The Australian eXpress Passenger Train (XPT) passenger vehicles are based upon the Mk3 coach design and would be very similar in terms of dynamic performance.

**Figure 23: Comparison Mk3 coach wheel unloading on AK Car data track**




Very little wheel unloading occurs on the Mk3 coach, around 25 per cent maximum compared to 100 per cent for the VPBX wagon. The passenger vehicle has much better performance than the freight wagon, since the passenger vehicle has a more compliant suspension and hydraulic damping. This also serves to illustrate that although the track is very irregular, it is possible to negotiate it safely with a good suspension system.

While some wheel unloading was predicted for some combinations of factors, the required unloading and lateral force necessary to predict a derailment occurred with all of the following factors in place:

- Rail top and cant from the AK Car data[22]
- Wear of wagon components
- Conicity of wheels
- Gauge irregularity adjusted to appear as left-hand rail alignment, (i.e. right-hand rail straight)

The effect of these combinations was that the vehicle is predicted to derail by the leading right-hand wheel climbing over the right-hand rail. This is the mechanism of derailment indicated by the site evidence, although some predictions indicate the point of derailment to be about 60 metres further along the track than the point of derailment seen in practice. The study however validates the mechanism by which the derailment was likely to have occurred.

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22 Some simulations were run using survey data instead and with irregularities enhanced by a 30 % allowance for settlement under load

# 4 CONCLUSIONS

## 4.1 Cause of Derailment

Based on the available evidence, it is concluded that a combination of infrastructure flaws associated with track geometry and wagon stiffness created conditions under which the cement wagon VPBX 155-S sustained roll-induced wheel unloading and subsequent flange climb followed by derailment.

## 4.2 Findings

1. Train 4VM9-V was a regularly scheduled operation carrying bulk cement between Berrima, New South Wales and Somerton, Victoria.
2. The operation of train 4VM9-V had been appropriate and without incident up until the time of the occurrence and did not contribute to the derailment.
3. The locomotive and leading 11 wagons passed over a series of track dips in an area of track covered by an Infrastructure Restriction before the leading right-hand wheel of the 12th wagon unloaded and climbed up and over the western side rail.
4. No person was injured and no dangerous goods were involved in the derailment.
5. All persons directly associated with the occurrence were appropriately qualified to carry out their assigned duties.
6. Emergency response was carried out effectively and immediately following the occurrence.
7. Minor damage was sustained by the rear-most four wagons of train 4VM9-V. Approximately 530 metres of track was damaged, including approximately 80 metres of severe track damage.
8. Although all four derailed wagons on train 4VM9-V had been involved in previous derailments, there was no evidence to suggest that these events had contributed to the 23 September 2004 Benalla occurrence.

## 4.3 Contributing Factors

1. Two consecutive track dips in a space of 50 metres, cross-level settlement of ballast and sub-grade, a number of rail weld joints being sharply peaked and gaps between sleepers and sleeper plates had resulted in twist faults appearing under traffic.
2. The torsional stiffness of the cement wagon, given the conditions described above, was also a contributing factor.
3. Up to 400 mm of rain had fallen on the area between 1 July 2004 and 16 September 2004, which, combined with inadequate drainage of the track structure, contributed to weak track structure and deterioration in geometry at the occurrence site.

4. Track inspection had apparently not identified the potential for derailment.
5. A 65 km/h TSR over the derailment site track was not in place.
6. While the condition of weak track structure and geometry at the occurrence site was known, appropriate remedial action had not occurred.
7. No effective post analysis interpretation of the AK Car information for the occurrence site between its most recent run on 4 August 2004 and the date of occurrence had been undertaken.
8. Although the introduction of a standardised approach through a revised NCoP to Victoria had been the subject of review by ARTC and the DOI, the application had not been approved and a number of outstanding issues existed.
9. The data collected by the AK car on 4 August 2004 did not reflect the apparent severity of the dips in the track and led to a significant loss of data integrity, utility and relevance.
10. There was a lack of identification of cant (cross-level) in the *Victorian Civil Engineering Circulars* type A and B exceedences.
11. A holistic assessment of geometrical parameters was not considered collectively to identify the potential for track condition that led to the derailment.
12. Although the AK Car parameter graphs and raw data were available to infrastructure maintainers for further interpretation, no exceedences were identified or considered.
13. No use was made of offset from the centre of 20 m chord data that could have been derived from the AK Car data set.
14. The AK Car calibration, setup, measurement and analysis procedures appeared to have generated data inconsistencies.
15. The use of predetermined specified twist intervals resulted in a lack of useful data for vehicles having lengths other than that reflected in the NCoP standard.

# 5 SAFETY ACTIONS

## 5.1 Actions Taken

Following the occurrence on 23 September 2004, at Benalla, safety actions corresponding with the evidence determined had been initiated by Australian Rail Track Corporation. A statement of these actions was provided by the ARTC and is summarised as follows:

1. A more conservative approach has been taken to the application of temporary speed restrictions which considers the poorer riding qualities of class 'B' rollingstock.
2. After the incident, all 80 km/h track restrictions were reduced to 60 km/h in order to effectively limit the vehicle/track interaction to cover both classes of rollingstock within the one speed restriction. The application of temporary speed restrictions has primarily considered the characteristics associated with class 'A' rollingstock certified to operate at a maximum speed of 115 km/h. This type of vehicle is fitted with bogies of a more recent design and carries rollingstock having a lower centre of gravity and an extended wheel base. The type of rollingstock involved in the above incident was class 'B', this type of vehicle has in the most part a higher centre of gravity, short wheelbase, reduced body flexibility and harsher riding qualities and is restricted to a maximum speed of 80 km/h.

## 5.2 Recommendations

As a result of its investigation, the ATSB makes the following recommendations with the intention of improving railway operational safety and associated safety management systems by overcoming shortfalls identified. Rather than provide prescriptive solutions, these recommendations are designed to guide the interested parties on what situations need to be considered. Recommendations should not be seen as a mechanism to apportion blame or liability. Recommendations are directed to those agencies that should be best able to give effect to the safety enhancement intent of the recommendations, and are not, therefore, necessarily reflective of deficiencies within those agencies.

### 5.2.1 Australian Rail Track Corporation

***RR20050050***

The ATSB recommends that the Australian Rail Track Corporation consider appropriate modifications to the assessment of track infrastructure by inspection to identify deteriorated conditions such as those which led to this derailment.

***RR20050051***

The ATSB recommends that the Australian Rail Track Corporation consider appropriate modifications to the assessment of track geometry as a whole so that all geometrical parameters are taken into account to identify the potential for track that could compromise the integrity of rail safety.

***RR20050052***

The ATSB recommends that the Australian Rail Track Corporation consider the introduction of a standardised infrastructure methodology by way of the National Code of Practice to the DIRN in Victoria.

***RR20050053***

The ATSB recommends that the Australian Rail Track Corporation consider appropriate modifications to the assessment, including post analysis interpretation, of track infrastructure by AK Car data to identify successive dips, twists and cross-levels (cants) that could cause dynamic roll of railway vehicles.

***RR20050054***

The ATSB recommends that the Australian Rail Track Corporation give appropriate level of consideration to assessing AK Car data for repeated dips in one rail, or alternating between rails. This assessment should be considered together with variations in cross-level (cant).

***RR20050055***

The ATSB recommends that the Australian Rail Track Corporation revise the emulation procedure used with the AK Car to provide a data set for comparison with standards, and consider a procedure using AK Car inertial data.

***RR20050056***

The ATSB recommends that the Australian Rail Track Corporation undertake a comparative track survey and track recording car measurement run to determine calibration, measurement, calculation and reporting errors, and how best to use AK Car data.

### 5.2.2 Victorian Railway Safety Regulator, Department of Infrastructure

***RR20050057***

The ATSB recommends that the Victorian Department of Infrastructure monitor the Australian Rail Track Corporation’s consideration of the introduction of a standardised infrastructure methodology by way of the establishment of the National Code of Practice to the DIRN in Victoria.

# 6 SUBMISSIONS

Section 26, Division 2, and Part 4 of the *Transport Safety Investigation Act 2003*, requires that the Executive Director may provide a draft report, on a confidential basis, to any person whom the Executive Director considers appropriate, for the purposes of:

a) Allowing the person to make submissions to the Executive Director about the draft: or

b) Giving the person advance notice of the likely form of the published report.

The final draft of this report was provided for comment to the following directly involved parties:

a) Australian Rail Track Corporation

b) Department of Infrastructure, Victoria

c) Freight Australia (now Pacific National)

# 7 APPENDICES

## 7.1 List of acronyms used in report

| | |
|---|---|
| AK Geo. Std | AK Car Defect and Response Tables, Standard and Victorian |
| ANZR | Australian and New Zealand Railways |
| ARTC | Australian Rail Track Corporation |
| ATSB | Australian Transport Safety Bureau |
| CEC | Victorian Civil Engineering Circular Standards |
| CFCLA | Chicago Freight Car Leasing Australia |
| CTC | Centralised Traffic Control |
| DIRN | Defined Interstate Rail Network |
| DOI | Department of Infrastructure, Victoria |
| EST | Eastern Standard Time [Coordinated Universal Time (UTC) plus 10 hours] |
| FA | Freight Australia Ltd |
| Hz | Hertz (equal to one cycle per second) |
| IR | Infrastructure Restriction |
| L/V | Lateral force over vertical load of Nadal's theory |
| km/h | kilometres per hour |
| Mk3 | Mark three |
| mm | millimetre |
| m/s | metres per second |
| NCoP | National Code of Practice |
| POC | Point of Climb |
| POD | Point of Derailment |
| POL | Point of Lift |
| PSD | Power Spectral Density |
| ROA | Railways of Australia |
| TSI Act | Transport Safety Investigation Act 2003 |
| TSR | Temporary Speed Restriction |
| UHF | Ultra High Frequency |
| UK | United Kingdom |
| WI | Works Infrastructure |
| XPT | eXpress Passenger Train |

## 7.2 Wagon bounce wavelength, dynamic track loads and deflection

| | | | | | | |
|---|---|---|---|---|---|---|
| Input green cells | Output yellow cells | | | | | |
| Track modulus = | 18 | MPa = | 2628 | lbs/in/in | | |
| Vehicle maximum weight = | 63 | t | | | | |
| Vehicle net payload = | 44 | t | | | | Typical values of track wavelengths: |
| Gross to tare spring travel = | 35 | mm | | | | Rail, corrugation, 50-450mm |
| Overall vehicle length between couplers = | 15 | m | | | | Track, short pitch, 1-2m |
| Length between bogie centrepins = | 10 | m | | | | Track, cyclic top, 5-10m |
| Weight of bogie below secondary springs = | 3.5 | t | | | | |
| Bogie wheel base = | 1.9 | m | | | | |
| Bogie side frame length = | 2.2 | m | | | | |
| Total ramp angle at top change, 2xAlpha = | 5 | milliradians | | | | |
| Vehicle speed = | 75 | kph | 21 | m/s | | |
| Eisenmann track condition factor d = | 0.4 | range is 0.1=good to 0.6=bad, typical (Aus main line) = 0.3 | | | | |
| Choose rail from underlined i.d.s below: | | 47kg | Note that 136RE is close to 68kg | | | |
| 30kg, 41kg new, 41kg old, 47kg, 50kg, 53kg, 60kg, 60kg HH, 68kg, 68kgHH, 113old, 113new, 113WB or 115RE | | | | | | |
| Deduced Beta factor = | 0.00108 | $mm^{-1}$, and | 653 | mm "characteristic length" | | |
| Deduced Eisenmann Impact Factor = | 1.89 | | | | | |
| Hence impact factored wheel load = | 160 | kN | 132.89 | kN/mm per bogie for primaries - using track stiffness | | |
| Unsprung mass = 1/4xbogie below secs.= | 875 | kg | 6.17 | kN/mm per bogie secondary spring stiffness | | |
| NB, impact factored wheel load without $P_2$ gives | | | | | 4.80 | mm deflection - should not exceed 5mm |
| Nom.wheel load, $P_0$ = 85 kN | | **$P_2$** force = | 103 | kN, gives | 3.1 | mm deflection - should not exceed 5mm |
| If a impact factored wheel load were considered due to general track perturbation, the $P_0$ element would increase accordingly | | | | | | |
| Adding the impact factor to $P_0$, then the **$P_2$** force = | | | 178 | kN, giving | 5.4 | mm deflection - if exceeds 10mm track will |
| Note, unfactored **$P_1$** force = 119 | | kN & $P_{1IF}$= | 194 | kN, with IF on $P_1$ | | deteriorate rapidly -see BTE Fig. 3.16 |
| The resulting **bogie bounce** and **pitch** frequencies are:- | | Bounce = | 31.7 | Hz,Pitch = | 43.9 | Hz |
| And the resulting wavelengths at selected speed are:- | | Bounce | 0.7 | m, Pitch = | 0.5 | m |
| The resulting **body bounce** frequencies are:- | | Bounce = | 2.2 | Hz, and/or | 31.7 | Hz |
| And the resulting wavelengths at selected speed are:- | | Bounce = | 9.5 | m, and/or | 0.7 | m |
| The resulting **body pitch** frequencies are:- | | Pitch = | 2.0 | Hz, and/or | 31.7 | Hz |
| And the resulting wavelengths at selected speed are:- | | Pitch = | 10.3 | m, and/or | 0.7 | m |

## 7.3 Part 3 of the NCoP – Volume 4, Track, Civil and Electrical Infrastructure, Response Codes in table 5.5 Geometry Defects

| Measured parameters in mm under loaded track | | | | | | | | | | Maximum speed (see Note 1) | | | | | | Detect band |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gauge | | Horizontal alignment | Top (SEE Note 2) | | | Twist | | | | | | | | | | |
| | | | | | | Long 14m | | Short | | | | | | | | |
| Wide | Tight | 10m chord | Short 10m chord (1.8m offset) | Short 5m chord (2m offset) | Long 20m chord (see Note 3) | Transition | Non Transition | 2m | | 20/20 | 40/40 | 60/65 | 80/90 | 100/115 | 115/- | |
| >38 | >20 | >156 (see Note 4) | >37 | >36 | >90 | >74 | >70 | >25 | | E1 | E1 | E1 | E1 | E1 | E1 | A |
| 35-38 | 19-20 | 125-156 (see Note 4) | 32-37 | 30-36 | 72-90 | 65-74 | 61-70 | 23-25 | | E2 | E2 | E2 | E1 | E1 | E1 | B |
| 29-34 | 17-18 | >45 | 28-31 | 26-29 | 67-71 | 56-64 | 53-60 | 21-22 | | P2 | P1 | P1 | E2 | E1 | E1 | C |
| 27-28 | 15-16 | 35-45 | 25-27 | 22-25 | 57-66 | 50-55 | 47-52 | 19-20 | | N | N | P2 | P1 | E2 | E1 | D |
| 25-26 | | 25-34 | 22-24 | 19-21 | 52-56 | 43-49 | 41-46 | 17-18 | | N | N | N | P2 | P1 | E2 | E |
| 23-24 | | 19-24 | 19-21 | 16-18 | 47-51 | 38-42 | 36-40 | 15-16 | | N | N | N | N | P2 | P1 | F |
| 21-22 | 10-14 | 15-18 | 15-18 | 13-15 | 38-46 | 33-37 | 31-35 | 12-14 | | N | N | N | N | N | P2 | G |

| | Cross-level Variation (see Note 5) | Tangent track (Tangent Radii ≥ 2000m) | Curved track including transitions (Radii <200m) | | |
|---|---|---|---|---|---|
| | | | Insufficient cant based on maximum design speed | Excess cant based on maximum design speed | |
| | Absolute superelevation >170 mm requires E1 response (see Note 6) | | | | |
| | >60 | E2 | E2 (see Note7) | E2 (see Note 8) | A |
| | 50-60 | P1 | P1 (see Note 8) | P1 (see Note 9) | B |

## 7.4 Table 5.5B Response Codes

TABLE 5.5B GEOMETRY DEFECTS—RESPONSE CODES (See Table 5.6)

| Measured parameters in mm under loaded track | | | | | | | | Max. speed (f/p) [1] | | | | | | Defect band |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gauge | | Horiz. align. | Top [2] | | Twist | | | | | | | | | |
| | | | | | Long 14m | | Short | | | | | | | |
| Wide | Tight | 10 m chord | Short 5 m chord (2 m offset) | Long 20 m chord [3] | Transition | Non Transition | 2 m | 20/20 | 40/40 | 60/65 | 80/90 | 100/115 | 115/ - | |
| >38 | >20 | >156 [4] | >36 | >90 | >74 | >70 | >25 | E1 | E1 | E1 | E1 | E1 | E1 | A |
| 35-38 | 19-20 | 125-156 [4] | 31-36 | 72-90 | 65-74 | 61-70 | 24-25 | E2 | E2 | E2 | E1 | E1 | E1 | B |
| 29-34 | 17-18 | >45 | 27-30 | 67-71 | 56-64 | 53-60 | 23-24 | P2 | P1 | P1 | E2 | E1 | E1 | C |
| 27-28 | 15-16 | 35-45 | 23-26 | 57-66 | 50-55 | 47-52 | 22-23 | N | N | P2 | P1 | E2 | E1 | D |
| 25-26 | | 25-34 | 20-22 | 52-56 | 43-49 | 41-46 | 21- 22 | N | N | N | P2 | P1 | E2 | E |
| 23-24 | | 19-24 | 17-19 | 47-51 | 38-42 | 36-40 | 18-21 | N | N | N | N | P2 | P1 | F |
| 21-22 | 10-14 | 15-18 | 14-16 | 38-46 | 33-37 | 31-35 | 15-18 | N | N | N | N | N | P2 | G |

| Cross level Variation [5] | Tangent track (Tangent & Radii ≥ 2000m) | Curved track including transitions (Radii <2000m) | | |
|---|---|---|---|---|
| | | Insufficient cant based on maximum design speed | Excess cant based on maximum design speed | |
| Absolute superelevation >170 mm requires E1 response[6] | | | | |
| >60 | E2 | E2 [7] | E2 [9] | A |
| 40-60 | P1 | P1 [8] | P1 [9] | B |
| 15-40 | N | P1 [8] | P2 [9] | C |

Table 5.5B Response Codes cont. (Notes)

[11] All geometry parameters used are based on the loaded conditions. Where static or unloaded measurements are taken, due allowance should be made for the additional impact of loading and dynamics.

[12] The measured parameter limits set in the above table are derived from commonly occurring defects in actual conditions. Normally occurring multiple defects are provided for in the limits set, for example top and twist defects would commonly be expected to occur together. In such cases the most stringent response criterion of the two should be selected. 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.

[13] Defect parameters selected represent only one range of defects historically specified by railway systems. Defect types including cyclic, excess cant deficiency and other types giving rise to rough track should not be ignored. Assessments should be made by observation and experience, which should include on-train ride. Each defect located in this manner is to be classified using the same response categories specified in Table 5.6. Acceleration based measuring devices may also be used to identify defects of this type.

## 7.5 AK Car Track Monitoring System Geometric defects

AK-Car Track Condition Monitoring System

RAILINFRASTRUCTURE CORPORATION

# Geometric Defects

The tables below show the AK-Car's current defect thresholds for processing track geometry exceedences. They set out the defect limit sizes, corresponding allowable train speeds and the minimum response requirements in terms of inspection and repair.

The upper table is in accordance with the current ARA Code of Practice, while the values in the lower table are generally in accordance with the draft Code of Practice, except that those in the SURFACE and SHORT TWIST columns have been altered. The changed SURFACE values have resulted from the fact that vertical alignment is now measured using data from the inertial system (20-metre wavelength) instead of from a chord-based measuring technique. The changes to the SHORT TWIST thresholds result from the different dynamics of the AK-Car when compared to the EM80 Track Recording Car.

**Response Requirement Definitions for Track Geometry Conditions**

| RESPONSE CATEGORY | INSPECTION | REPAIR | OTHER REQUIREMENTS |
|---|---|---|---|
| **U1** Urgent Class 1 | Immediate | Immediate | Where the response category cannot be reduced below U1 by a reduction in operating speed, trains may only pass the site under the control of a pilot. The site must first be assessed by a qualified worker to determine if trains can be piloted. |
| **U2** Urgent Class 2 | Within 2 hours or before the next train | Within 24 hours | If the defect site cannot be inspected or repaired within the times shown and the response category cannot be reduced below U2 by a reduction in operating speed, trains may only pass the site at 20 km/h if authorised by a qualified worker |
| **P1** Priority Class 1 | Within 24 hours | Within 7 days | |
| **P2** Priority Class 2 | Within 7 days | Within 28 days | |
| **M** Monitor | | | Monitor during routine track inspection and consider for planned maintenance |

**Minimum Response Requirements for Track Geometry Conditions and Allowable Train Speeds**

| MEASURED PARAMETERS IN MM UNDER LOADED CONDITIONS (round to nearest mm) | | | | | | | | MAXIMUM SPEED (freight/passenger) | | | | | | DEFECT BAND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GAUGE | | H-ALIGN | SURFACE | TWIST | | | XLEVEL | | | | | | | |
| WIDE (note 8) | TIGHT | 10m chord | 20m inertial (note 9) | LONG, 14m Non-Trans | LONG, 14m Transition | SHORT, 2m | (note 2) | 20/20 | 40/40 | 60/65 | 80/90 | 100/115 | 115/- | |
| >35 | >20 | >156 note 1 | >40 | >70 | >74 | >25 | >75 | U1 | U1 | U1 | U1 | U1 | U1 | A |
| 32-35 | 19-20 | >125 note 1 | 38-40 | 61-70 | 65-74 | 24-25 | 69-75 | U2 | U2 | U2 | U1 | U1 | U1 | B |
| 29-31 | 17-18 | >45 | 35-37 | 53-60 | 56-64 | 23-23 | 61-68 | M | P2 | P1 | U2 | U1 | U1 | C |
| 27-28 | 15-16 | 35-45 | 32-34 | 47-52 | 50-55 | 22-22 | 51-60 | Nil | M | P2 | P1 | U2 | U1 | D |
| 25-26 | | 25-34 | 29-31 | 41-46 | 43-49 | 21-21 | 43-50 | Nil | Nil | M | P2 | P1 | U2 | U |
| 23-24 | | 19-24 | 27-28 | 36-40 | 38-42 | 18-20 | 38-42 | Nil | Nil | Nil | M | P2 | P1 | F |
| 21-22 | | 15-18 | 24-26 | 31-35 | 33-37 | 15-17 | 33-37 | Nil | Nil | Nil | Nil | M | P2 | G |

**Notes:**

1. These are absolute versine measurements (not variation from design) for simple and compound curves. Where curves are reversing, the actual versine should not exceed 156mm.
2. For trains to run, the absolute maximum limit for the difference in rail levels is 150mm.
3. For operational track where train speeds are above 40kph the absolute maximum negative superelevation limit is 10mm. For operational track where train speeds are 40kph and less the absolute maximum negative superelevation limit is 50mm.
4. All geometry parameters used are based on the loaded conditions. Where static or unloaded measurements are taken, due allowance should be made for the additional impact of loading and dynamics.
5. The measured parameter limits set in the above table are derived from commonly occurring defects in actual conditions. Normally occurring multiple defects are provided for in the limits set, for example top and twist defects would commonly be expected to occur together. In such cases the most stringent response criterion of the two should be selected. Unusual combinations of defects which are considered to act together, for example with horizontal alignment and twist, require special consideration. A more stringent response than that specified for rectifying the defects individually should be considered.
6. Defect parameters selected represent only one range of defects historically specified by railway systems. Defect types including cyclic, excess cant deficiency and other types giving rise to rough track should not be ignored. Assessments should be made by observation and experience, which should include on-train ride. Each defect located in this manner is to be classified by an accredited worker using the same response categories specified in the lower table. Acceleration based measuring devices may also be used to identify defects of this type.
7. Wide gauge on curves due to curve wear may be permitted up to a maximum of 30mm without action, provided that the track is secure against further widening due to lateral movement of the rail and the rail side wear limits are not exceeded.
8. The table applies to track well tied with timber sleepers only. For tracks with concrete and steel sleepers, where a higher than expected deterioration in gauge has been detected between inspections, the track should be subjected to an unscheduled detailed inspection and appropriate actions taken.
9. Vertical surface on the AK-Car is measured using a 20-metre wavelength inertial system. Long Top (20m chord) defect limits have also been defined in the ARA Code to assist track inspectors making manual measurements.

C:\...\AK-Car Defect Response Tables Std Vic Aug04 (2) Pg2 (Values last revised: November 2002)

# Geometric Defects



The tables below show the AK-Car's current defect thresholds for processing track geometry exceedences. They set out the defect limit sizes, corresponding allowable train speeds and the minimum response requirements in terms of inspection and repair.

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**Response Requirement Definitions for Track Geometry Conditions**

| RESPONSE CATEGORY | INSPECTION | REPAIR | OTHER REQUIREMENTS |
|---|---|---|---|
| **U1** Urgent Class 1 | Immediate | Immediate | Where the response category cannot be reduced below U1 by a reduction in operating speed, trains may only pass the site under the control of a pilot. The site must first be assessed by a qualified worker to determine if trains can be piloted. |
| **U2** Urgent Class 2 | Within 2 hours or before the next train | Within 24 hours | If the defect site cannot be inspected or repaired within the times shown and the response category cannot be reduced below U2 by a reduction in operating speed, trains may only pass the site at 20 km/h if authorised by a qualified worker |
| **P1** Priority Class 1 | Within 24 hours | Within 7 days | |
| **P2** Priority Class 2 | Within 7 days | Within 28 days | |
| **M** Monitor | | | Monitor during routine track inspection and consider for planned maintenance |

**Minimum Response Requirements for Track Geometry Conditions and Allowable Train Speeds**

| MEASURED PARAMETERS IN MM UNDER LOADED CONDITIONS (round to nearest mm) | | | | | | | | MAXIMUM SPEED (freight/passenger) | | | | | | DEFECT BAND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| GAUGE | | H-ALIGN | SURFACE | TWIST | | | XLEVEL | | | | | | | |
| WIDE (note 8) | TIGHT | 10m chord | 20m inertial (note 9) | LONG, 14m Non-Trans | LONG, 14m Transition | SHORT, 2m | (note 2) | 20/20 | 40/40 | 60/65 | 80/90 | 100/115 | 115/ - | |
| >35 | >20 | >156 note 1 | >36 | >70 | >74 | >25 | >75 | U1 | U1 | U1 | U1 | U1 | U1 | A |
| 32-35 | 19-20 | >125 note 1 | 31-36 | 61-70 | 65-74 | 24-25 | 69-75 | U2 | U2 | U2 | U1 | U1 | U1 | B |
| 29-31 | 17-18 | >45 | 27-30 | 53-60 | 56-64 | 23-23 | 61-68 | M | P2 | P1 | U2 | U1 | U1 | C |
| 27-28 | 15-16 | 35-45 | 23-26 | 47-52 | 50-55 | 22-22 | 51-60 | Nil | M | P2 | P1 | U2 | U1 | D |
| 25-26 | | 25-34 | 20-22 | 41-46 | 43-49 | 21-21 | 43-50 | Nil | Nil | M | P2 | P1 | U2 | U |
| 23-24 | | 19-24 | 17-19 | 36-40 | 38-42 | 18-20 | 38-42 | Nil | Nil | Nil | M | P2 | P1 | F |
| 21-22 | | 15-18 | 14-16 | 31-35 | 33-37 | 15-17 | 33-37 | Nil | Nil | Nil | Nil | M | P2 | G |
| 18-20 | 10-14 | 11-14 | 11-13 | 26-30 | 28-32 | 12-14 | 25-32 | Nil | Nil | Nil | Nil | Nil | M | H |

**Notes:**
1. These are absolute versine measurements (not variation from design) for simple and compound curves. Where curves are reversing, the actual versine should not exceed 156mm.
2. For trains to run, the absolute maximum limit for the difference in rail levels is 150mm.
3. For operational track where train speeds are above 40kph the absolute maximum negative superelevation limit is 10mm. For operational track where train speeds are 40kph and less the absolute maximum negative superelevation limit is 50mm.
4. All geometry parameters used are based on the loaded conditions. Where static or unloaded measurements are taken, due allowance should be made for the additional impact of loading and dynamics.
5. The measured parameter limits set in the above table are derived from commonly occurring defects in actual conditions. Normally occurring multiple defects are provided for in the limits set, for example top and twist defects would commonly be expected to occur together. In such cases the most stringent response criterion of the two should be selected. Unusual combinations of defects which are considered to act together, for example with horizontal alignment and twist, require special consideration. A more stringent response than that specified for rectifying the defects individually should be considered.
6. Defect parameters selected represent only one range of defects historically specified by railway systems. Defect types including cyclic, excess cant deficiency and other types giving rise to rough track should not be ignored. Assessments should be made by observation and experience, which should include on-train ride. Each defect located in this manner is to be classified by an accredited worker using the same response categories specified in the lower table. Acceleration based measuring devices may also be used to identify defects of this type.
7. Wide gauge on curves due to curve wear may be permitted up to a maximum of 30mm without action, provided that the track is secure against further widening due to lateral movement of the rail and the rail side wear limits are not exceeded.
8. The table applies to track well tied with timber sleepers only. For tracks with concrete and steel sleepers, where a higher than expected deterioration in gauge has been detected between inspections, the track should be subjected to an unscheduled detailed inspection and appropriate actions taken.
9. Vertical surface on the AK-Car is measured using a 20-metre wavelength inertial system. Long Top (20m chord) defect limits have also been defined in the ARA Code to assist track inspectors making manual measurements.

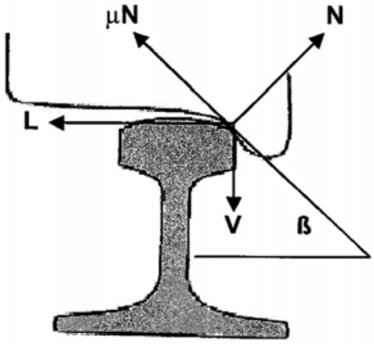
## 7.6 Extract from CEC 8/86, Exceedence Levels

| | Class 1, 2 | Class 3 | Class 4 | Class 5 |
|---|---|---|---|---|
| Passenger Train Speed kph | Over 100 | 80-100 incl | Below 80 | N/A |
| Goods Train Speed kph | Over 80 | Over 65-80 | 50-65 | Below 50 |
| Gauge | | | | |
| Curves(*) - Measured in field | 16mm wide | 20mm wide | 25mm wide | 25mm wide |
| - Measured by track recorder(**) | 20mm " | 24mm " | 30mm " | 30mm " |
| Straights - Measured in field | 8 mm " | 12mm " | 16mm " | 20mm " |
| - Measured by track recorder(**) | 15mm " | 15mm " | 18mm " | 20mm " |
| Line on 10m chord | 16mm | 20mm | 25mm | 35mm |
| Twist In 3.5 chord | 15mm | 16mm | 20mm | 22mm |
| In 10m chord | 30mm | 35mm | 40mm | 50mm |
| Cant : (Super-elevation) | | | | |
| (i) Deviation from design cant on straights or curves | 25mm | 30mm | 45mm | 45mm |
| (ii) Deviation from design cant on transitions | 20mm | 25mm | 30mm | 40mm |
| Top : Defects in 10m chord | 20mm | 22m | 25mm | 30mm |

# 7.7 Extract from CEC 7/86 Class One and Two Exceedence Levels

| | | | |
|---|---|---|---|
| Exceedence Levels in mm | | | |
| Class 1 | | | |
| Sub-Level | C | B | A |
| Top | 12.0 | 14.0 | 20.0 |
| Line | 12.0 | 15.0 | 20.0 |
| Wide Gauge | 8.0 | 12.0 | 15.0 |
| Cant | 20.0 | 25.0 | 30.0 |
| Twist 3.5 m | 12.0 | 15.0 | 18.0 |
| Twist 10.0 m | 20.0 | 25.0 | 35.0 |
| | | | |
| Class 2 | | | |
| Sub-Level | C | B | A |
| Top | 14.0 | 20.0 | 25.0 |
| Line | 15.0 | 18.0 | 25.0 |
| Wide Gauge | 8.0 | 15.0 | 18.0 |
| Cant | 20.0 | 25.0 | 35.0 |
| Twist 3.5 m | 12.0 | 16.0 | 25.0 |
| Twist 10.0 m | 25.0 | 30.0 | 40.0 |

## 7.8 Nadal's theory of flange climb[23]




$$\frac{L}{V} = \frac{\tan \beta - \mu}{1 + \mu \tan \beta}$$

Where: L is the lateral force at the wheel flange
V is the vertical load on the wheel
ß is the wheel flange angle at the plane of contact
μ is the coefficient of friction at flange to rail contact point
N is Normal force.

Example lateral to vertical ratios (L/V)

| L/V RATIO | LIKELY OUTCOME |
|---|---|
| 1.29 | Wheel may climb new rail |
| 0.82 | Wheel lift impending |
| 0.75 | Wheel may climb worn rail |
| 0.64 | Rail overturn force starts |

Example of wheel flange to rail face friction

| FRICTION COEFFICIENT (μ) | LIKELY CONDITION |
|---|---|
| 0.6 | Extremely course rail face |
| 0.45 | Dry rail and rough face |
| 0.35 | Dry rail and smooth face |
| 0.25 | Wet and clean rail face |
| 0.15 | Damp rail face and rust |
| 0.1 | Grease/oil on rail face |

23 Part reference: RAILWAY ENGINEERING, V A Profillidis 2000 and DERAILMENT CAUSE ANALYSIS, QR 2001