University of Southern Queensland
Faculty of Engineering and Surveying

Track Stability and Buckling - Rail Stress Management

A dissertation submitted by

Zayne Kristian Ole

in fulfillment of the requirements of

Courses ENG4111 and 4112 Research Project

towards the degree of

Bachelor of Engineering (Civil)

Submitted: October, 2008

Abstract

Buckling of railroad track continues to be problematic for railway engineers and maintenance personnel across all railway networks.

Thermal forces are the principal longitudinal load on railroad track. In an effort to ensure track stability under dynamic loads, the magnitude to which longitudinal thermal stresses develop is controlled by the choice of an appropriate Design Neutral Temperature (DNT). The longitudinal movement of rail, referred to as creep, causes a deviation of the rails' neutral temperature (RNT) from that of the DNT. It is crucial that the RNT is maintained at or near the DNT to provide the necessary leeway for dynamic traffic loads and ensure lateral stability of the track. However, techniques for monitoring the RNT are very limited and difficult to employ. Railway networks generally rely on preventative measures, such as track strengthening work, to control the risk of buckles occurring. This approach to managing the risk of track buckles is resource hungry and time consuming.

This project develops a recursive methodology for identifying situations where the longitudinal movement of rail is likely to result in the accumulation of longitudinal stresses, which is conducive to buckling. The methodology has been developed for the Western and South-Western systems of Queensland Rail. The approach presented in this paper focuses on identifying certain trends in rail creep observed at locations that result in the development of stress condition that are conducive to buckling. The trends in the rate and extent of creep displayed at the locations and the locations' proximity to fixed track structures are used to predict potential high stress areas.

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111 & ENG4112 *Research Project*

Limitations of Use

Prof Frank Bullen
Dean
Faculty of Engineering and Surveying

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Zayne Kristian Ole
Student Number: 0050025752

Signature

Date

Acknowledgements

The author would like to thank: Associate Professor Ron Ayers for his valued assistance and guidance throughout this project; Mr Gary Smith, the technical support team and all staff in the MIM Toowoomba district of Queensland Rail for their valuable contribution and technical advice during the project; and all of my family and friends for their support and patients during the preparation of this dissertation.

Table of Contents

List of Figures

List of Tables

Glossary

Buckle	A sudden track misalignment caused by temperature and/or rail creep induced stress, which requires the placement of a speed restriction and/or immediate attention by the Infrastructure Maintainer to allow trains to proceed safely.
CETS	Civil Engineering Track Standards. QR’s standards pertaining to the construction and maintenance of railroad track.
Creep	Longitudinal movement of the rails relative to the sleepers or the rails and sleepers relative to the ballast bed induced by traffic and variations in temperature.
CWR	Continuously Welded Rail.
DNT	Design Neutral Temperature. The stress free temperature at which the rail is to be maintained, to mitigate the risk of either a buckle or a rail break.
Down (direction)	The direction of decreasing kilometres. See figure 1.4.
Fixed tracks structure	A structure such as a bridge, level crossing or turnout, which restrict or eliminate the longitudinal movement of the rail.
LWR	Long Welded Rail, mechanical joints spaced greater than 110m apart.
Pumping	Vertical deflection of the sleepers, ballast and formation in response to passage of a train.
QR	Queensland Rail
RNT	Rail Neutral Temperature. The temperature at which the rail is neither in compression nor tension, that is, when the rail is stress free.

ROA	Railways of Australia
SFT	Stress Free Temperature. The temperature at which the rail is neither in compression nor tension, that is, when the rail is stress free.
TEAR	Track Asset and Equipment Register. QR's asset database.
Track structure	Rails, Fastenings, Sleepers and Ballast. The superstructure supported by the formation.
Up (direction)	The direction of increasing kilometres. See figure 1.4.

1 Project Introduction

1.1 Introduction

1.1.1 Problem Identification

Throughout Australia, over five hundred incidents of track buckling are reported annually (ROA 1988). Statistics from the QR network indicate 115 incidents of buckle on average, per year, between 1993 and 2005 (Howie 2005). Track buckles give rise to the possibility of train derailments. Howie suggests as much as 10% of buckles cause derailments (Howie 2005). This would represent considerable cost to any rail network. The consequences of less catastrophic buckles include:

- post buckle repairs and increased maintenance expenditure;
- traffic delays;
- reduced safety margin; and
- adverse effects on customers' perceptions of the network's safety.

Rail stress management continues to be problematic across the QR network. There are processes and procedures in place which attempt to identify which areas are more susceptible to track buckling, however the existing methods are somewhat ineffective or cumbersome and obscure. QR believes the application of data on the track structure and creep behaviour at locations would be a more practical, accurate and consistent method of checking whether adjusted rail stays within a safe range of the design neutral temperature. (Powell, J 2007, pers. comm., 21 November)

1.1.2 Queensland Rail

Queensland Rail (QR) is the owner of Australia's largest rail network with some 9,500km of narrow gauge, standard gauge and dual gauge track. QR's rail infrastructure network is worth $AUD5.5 billion. QR supplies the state with rail infrastructure to provide metropolitan commuter services, regional freight and tourism lines and bulk haulage for Queensland's prosperous coal and mineral industries. Over 1000 train services operate daily on QR's rail network.

QR's rail network is divided into 13 distinct systems. The boundaries for each system are illustrated in figure 1.1.

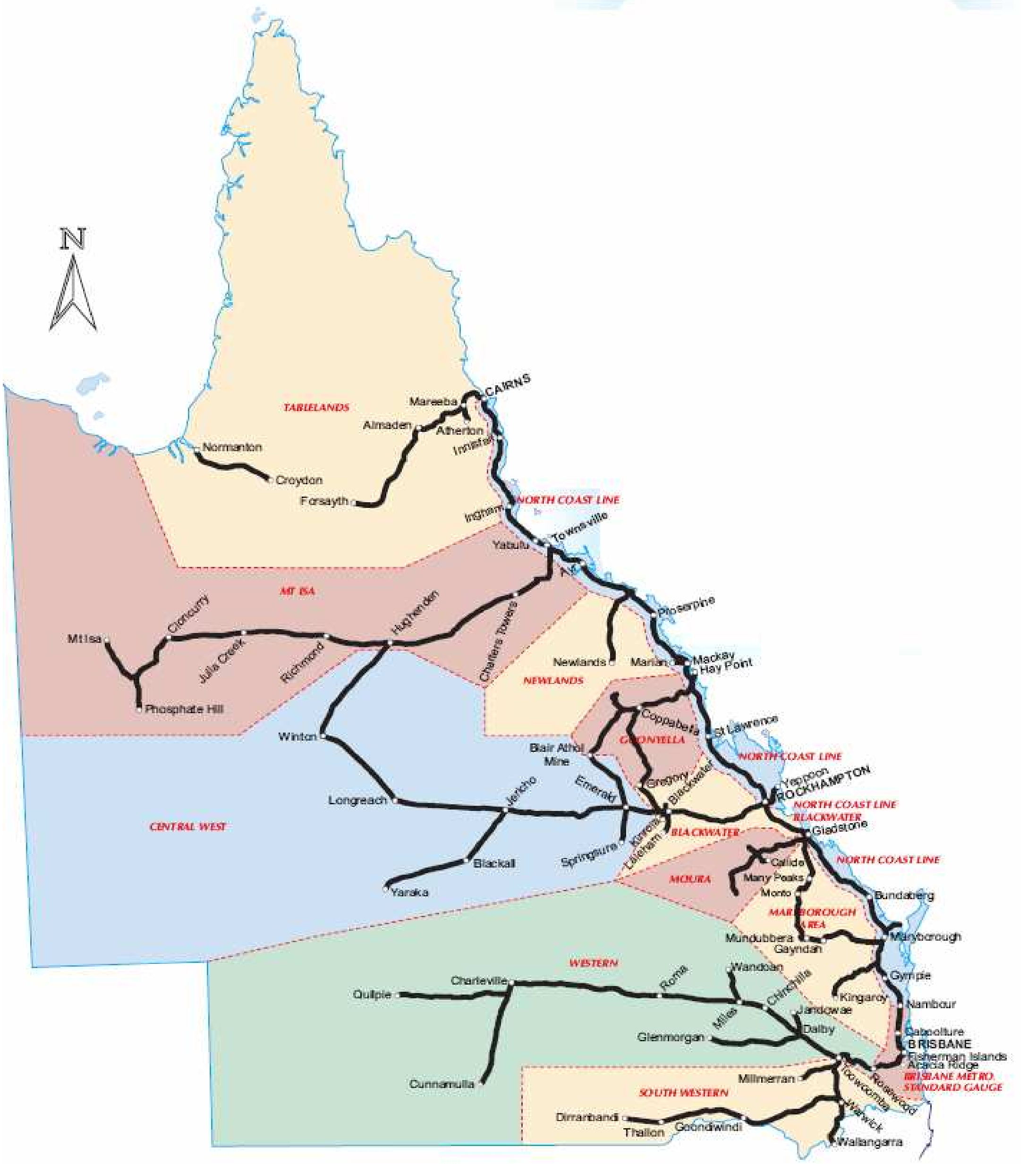


Figure 1.1 A system map of QR's infrastructure network and the system boundaries.
http://www.networkaccess.qr.com.au/Images/Network_System_Information_tcm10-2862.pdf

The investigation area for this project is that bounded by the Western and South Western Systems, as depicted in figure 1.1. The two systems are the responsibility of the Toowoomba Manager of Infrastructure Maintenance and as such, the systems are considered as one district, henceforth, the two systems may be referred to as the Toowoomba district. The Toowoomba district is responsible for 2080km for railway track. This represents 22% of the Queensland Rail network. Figures 1.2 and 1.3 illustrate the extents of the Western and South Western systems respectively.

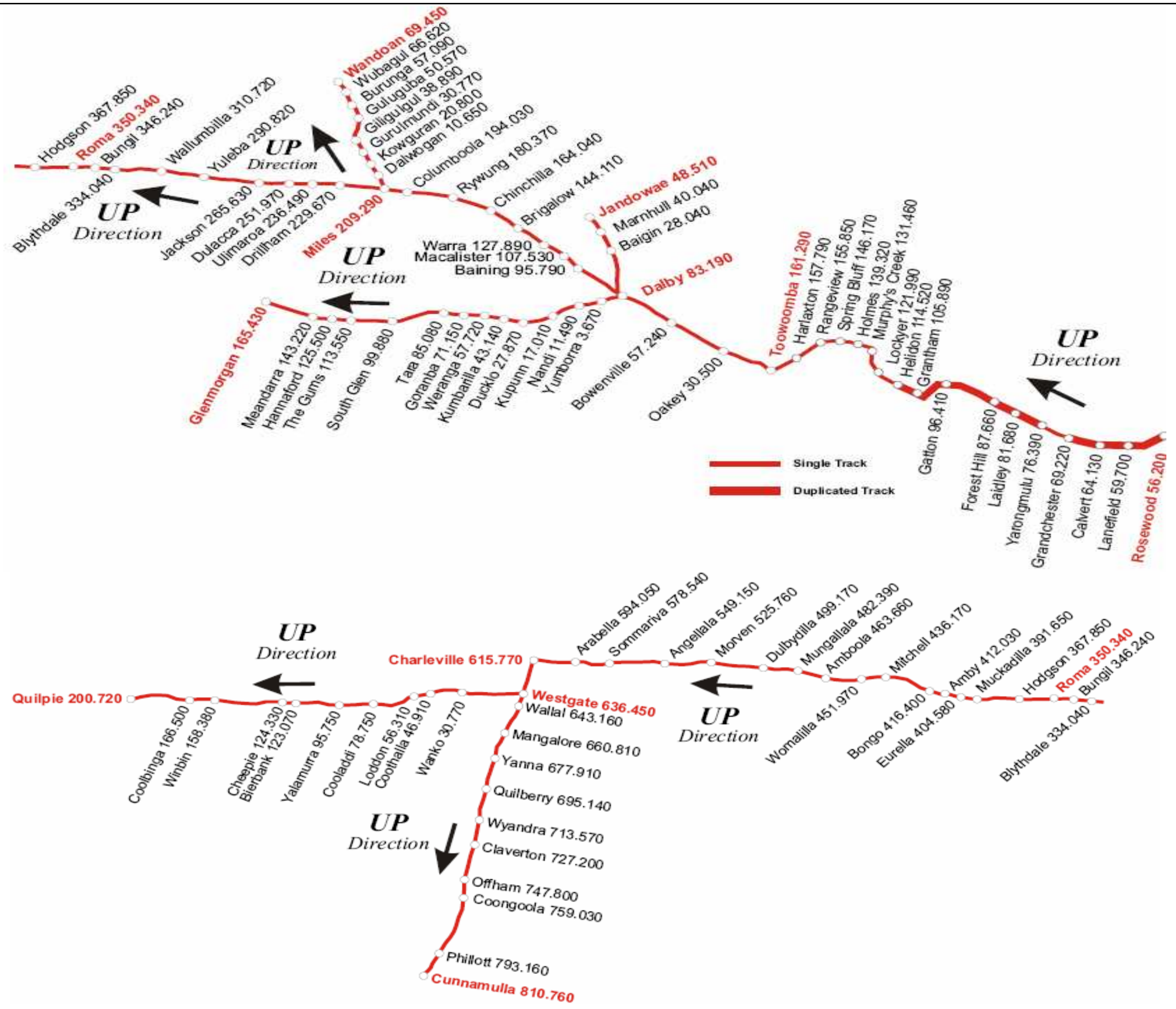


Figure 1.2 Western System
www.networkaccess.qr.com.au

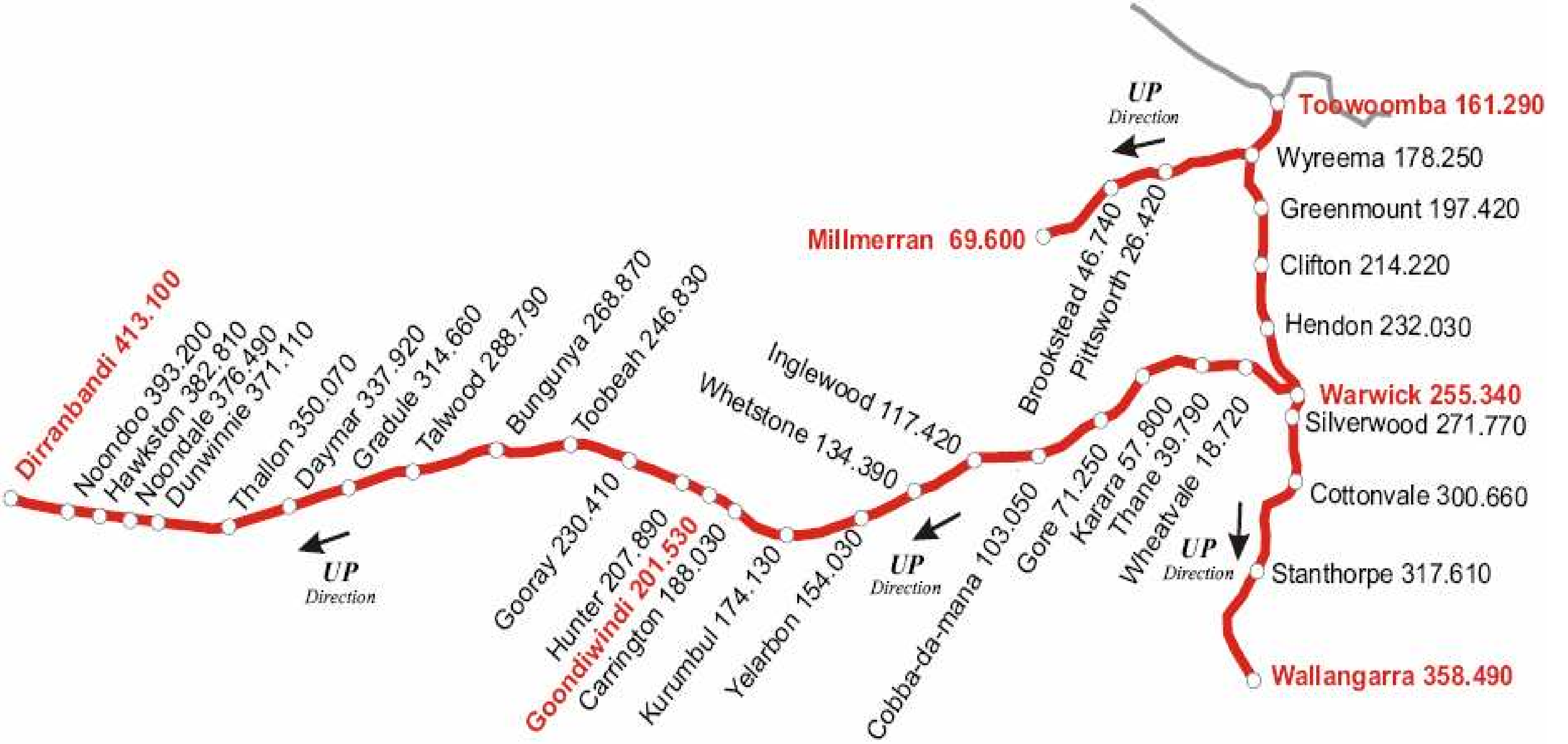


Figure 1.3 South Western System
www.networkaccess.qr.com.au

The table below gives the Line Section Codes for the sections of railroad in the Toowoomba district. These are the convention by which a section of track is identified.

Table 1.1 Line Section Codes in the Toowoomba district.

Prefix	LS Code	From	To	Long Description	Start km	End km	Length
ML	889	ROSEWOOD	HELIDON	Beyond ROSEWOOD to & including HELIDON	56.600	115.059	58.459
ML	546	HELIDON	TOOWOOMBA	Beyond HELIDON to but excluding TOOWOOMBA	115.059	160.395	45.336
SL	718	TOOWOOMBA	WYREEMA	From TOOWOOMBA to but excluding WYREEMA	160.395	178.620	18.225
SL	719	WYREEMA	HENDON	Beyond WYREEMA to & including HENDON	178.620	232.330	53.710
SL	720	HENDON	WARWICK	From HENDON to & including WARWICK	232.330	255.692	23.362
SL	550	WARWICK	STANTHORPE	Beyond WARWICK to & including STANTHORPE (318km)	255.692	318.000	62.308
SL	324	STANTHORPE	WALLANGARRA	Beyond STANTHORPE (318km) to WALLANGARRA	318.000	359.107	41.107
SW	551	WARWICK	INGLEWOOD	Beyond WARWICK to & including INGLEWOOD	0.358	117.587	117.229
SW	553	INGLEWOOD	GOONDIWINDI BGQ SDG	Beyond INGLEWOOD to & including GOONDIWINDI BGQ SDG	117.587	201.718	84.131
SW	721	GOONDIWINDI BGQ SIDING	THALLON	Beyond GOONDIWINDI BGQ SIDING to & including THALLON	201.718	350.490	148.772
SW	722	THALLON	DIRRANBANDI	Beyond THALLON to DIRRANBANDI	350.490	413.473	62.983
WL	711	TOOWOOMBA	OAKEY	From TOOWOOMBA to & including OAKEY	-0.215	31.25	31.465
WL	353	OAKEY	JONDARYAN	Oakey to Jondaryan Coal Siding	31.25	44.012	12.762
WL	354	JONDARYAN	DALBY	Jondaryan Coal Siding to Dalby	44.012	83.921	39.909
WL	463	DALBY	TYCANBA	Beyond DALBY to but excluding TYCANBA	83.921	86.158	2.237
WL	355	TYCANBA	MACALISTER	Tycanba to MacAlister Coal Siding	86.158	109.696	23.538
WL	356	MACALISTER	CHINCHILLA	MacAlister Coal Siding to Chinchilla	109.696	164.271	54.575
WL	563	CHINCHILLA	MILES	Beyond CHINCHILLA to & including MILES	164.271	210.016	45.745
WL	565	MILES	ROMA WEST	Beyond MILES to & including ROMA WEST	210.016	352.439	142.423
WL	567	ROMA WEST	MUNGALLALA	Beyond ROMA WEST to & including MUNGALLALA	352.439	482.51	130.071
WL	568	MUNGALLALA	CHARLEVILLE	Beyond MUNGALLALA to & including CHARLEVILLE	482.51	616.896	134.386
WL	713	CHARLEVILLE	WESTGATE	Beyond CHARLEVILLE to but excluding WESTGATE	616.896	636.373	19.477
WL	714	WESTGATE	WYANDRA	From & including WESTGATE to & including WYANDRA	636.373	713.659	77.286
WL	715	WYANDRA	CUNNAMULLA	Beyond WYANDRA to & including CUNNAMULLA	713.659	811.016	97.357
GW	716	WESTGATE	COOLADDI	Beyond WESTGATE to & including COOLADDI	-0.079	79.035	79.114
GW	717	COOLADDI	QUILPIE	Beyond COOLADDI to & including QUILPIE	79.035	201.405	122.370
GL	559	DALBY	MEANDARRA	Beyond DALBY to MEANDARRA	0.397	144.200	143.803
GL	345	MEANDARRA	GLENMORGAN	From MEANDARRA TO GLENMORGAN	144.200	165.861	21.661
JE	561	DALBY	JANDOWAE	From TYCANBA to JANDOWAE	2.971	48.555	45.584
MN	556	WYREEMA	MILLMERRAN	Beyond WYREEMA to MILLMERRAN	0.399	71.071	70.672
WD	564	MILES	WANDOAN	Beyond MILES to & including WANDOAN	0.000	69.650	69.650

Figure 1.4 shows the Line Section Codes in the Toowoomba District in context.

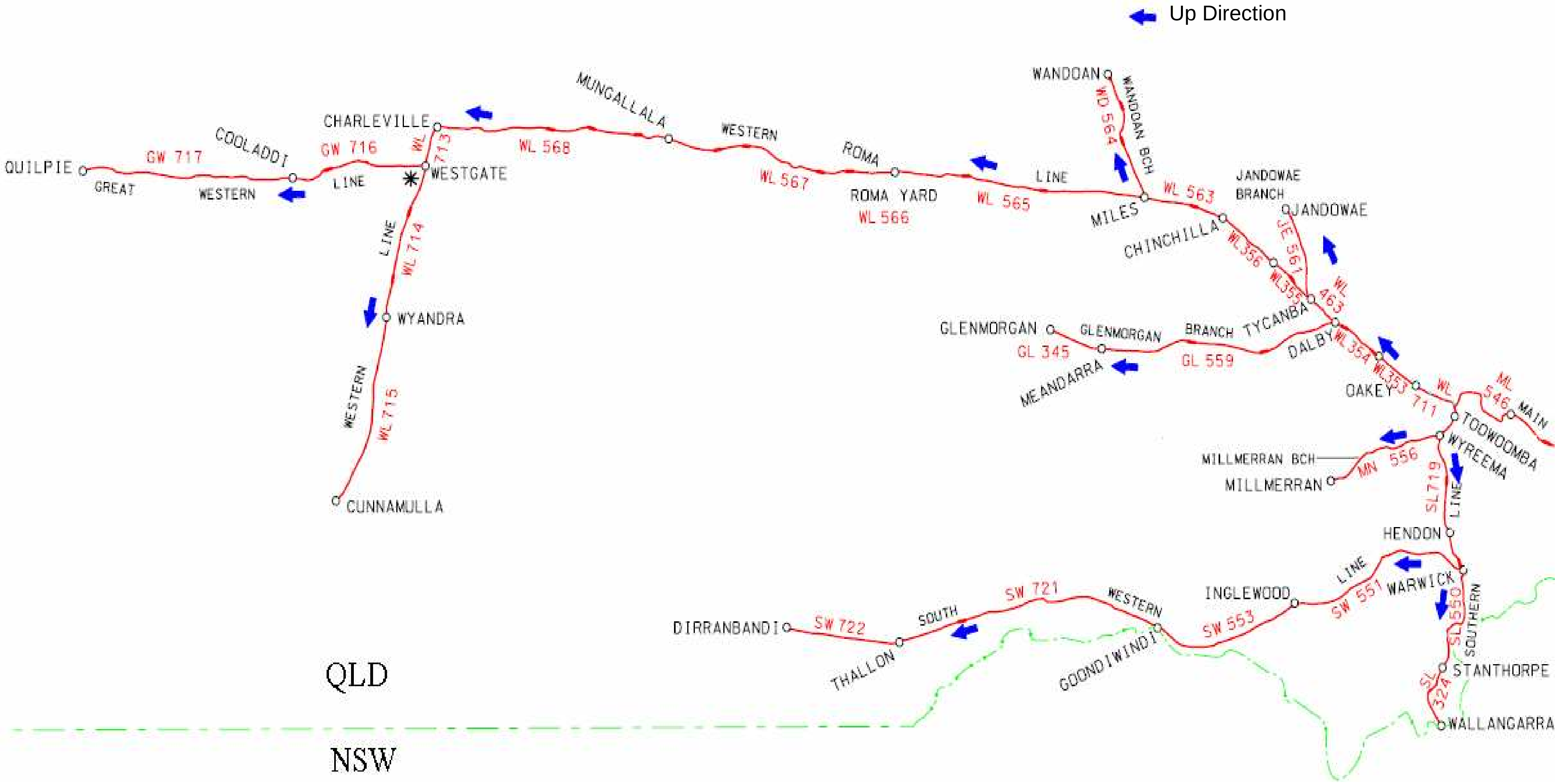


Figure 1.4 The Line Section Codes of the Toowoomba District in context.

1.1.3 Toowoomba District Buckle History

To illustrate the need for this project on the rail stress management and the development of a buckle prevention scheme, it is necessary to examine a brief history of the number of buckles recorded in the district over the past few years.

Figure 1.5 presents the number of buckles recorded in the Toowoomba district from 2001/2002 to 2007/2008. Information conveyed in figure 1.5 indicated the necessity for a more consistent method of identifying locations that are susceptible to track stability problems. It is, however, worth mentioning that a rather effective but cumbersome track stability assessment form was introduced into the district towards the end of 2005, this coincides with a decline in the number of buckles in the years that follow.

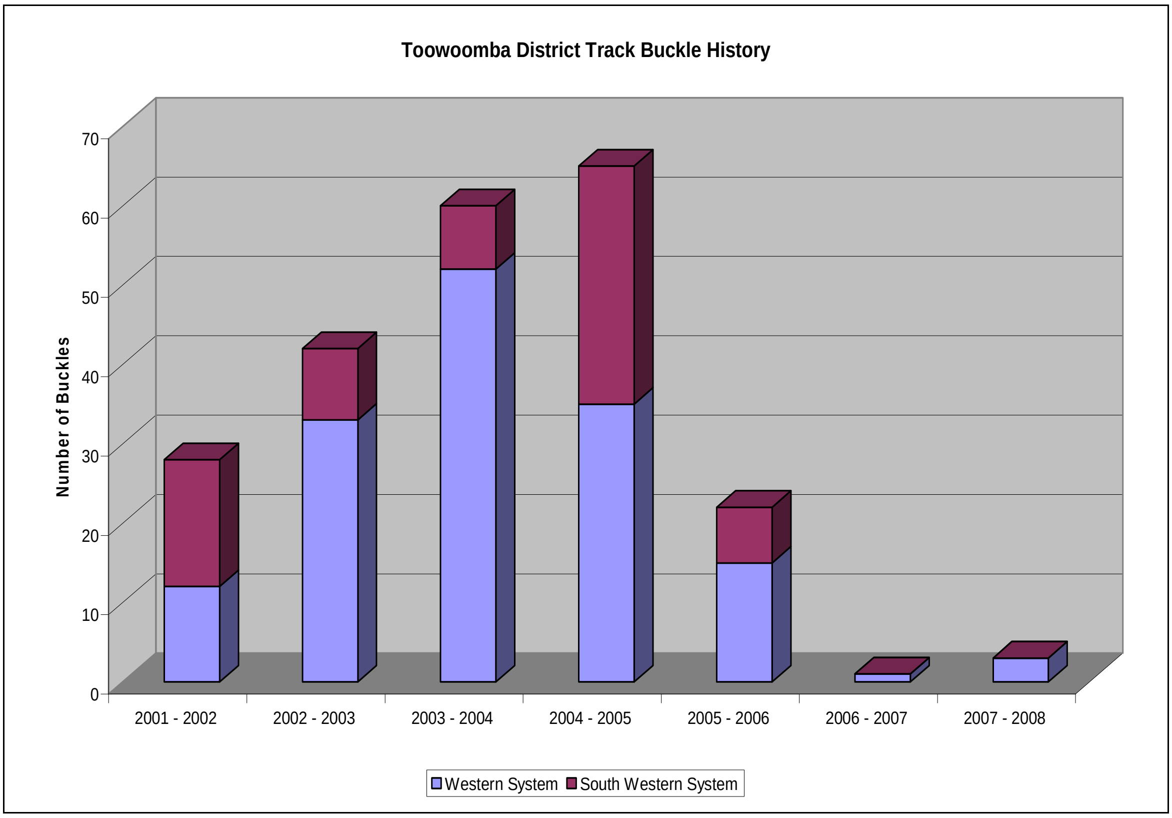


Figure 1.5 A history of buckles recorded within the Toowoomba district.

1.2 Project Aim

This project seeks to develop a practical method of determining situations where the longitudinal stress in rail is likely to cause operational problems in the track, within the Western and South West systems of Queensland Rail (QR).

1.3 Specific Objectives

The specific objectives of this project are presented in the Project Specification, see Appendix A, and repeated hereafter with justification and explanations of the tasks as appropriate:

I. Research any necessary background information relating to track stability and rail stress management.

   Initiating this project was a review of material relating to rail stress management and track stability. A logical starting point for the review was to commence with a study of the general railway track structure pertaining to the interaction between track components and the manner in which the track is restrained both laterally and longitudinally. Another key constituent of the review is an investigation into the mechanisms by which longitudinal stresses are induced in the rails.

   After identifying the passive, restraining forces that resist buckling and the opposing actions that promote buckling, the review outlines some existing rail stress management strategies and track buckling prevention procedures currently being implemented by railway networks.

II. Critically evaluate rail stress management strategies and track buckling prevention procedures currently being implemented by railway networks.

   The existing rail stress management strategies and track buckling prevention procedures detailed in the review are critically evaluated to establish both their merits and perceived limitations or drawbacks.

III. Compile data relevant to rail stress management and buckle prevention for the investigation area.

At the inception of this project it was apparent that data regarding the track structure at test locations within the investigation area will be required to facilitate a thorough assessment of the track's lateral resistance. The interaction between track components and the means by which the track is restrained both laterally and longitudinally, as well at the track geometry will govern the tracks resistance to buckling and dictate the magnitude of the longitudinal stress after which track stability will become an issue.

IV. Establish the necessary field investigations and/or data that will be required, and obtain this data, to facilitate the development of an effective method of identifying track locations that are most susceptible to track stability problems.

V. Analyse the data for each key parameter that influences the longitudinal rails stress in conjunction with the data on the track structure and geometry at the test locations.

Data relating to the track structure and the parameters which influence track stability by inducing stresses in the rails will be analysed to determine any trends in the track behaviour, regarding track stability. Correlations between the identified trends and the track's structure at test locations known to be buckle prone will be extended to the whole of the Western and South West system of Queensland Rail to identify areas of potential track stability problems.

VI. Develop an accurate and consistent method of identifying locations that are most susceptible to track stability problems.

The development of an objective, accurate and consistent method of identifying locations that are most susceptible to track stability problems is the main aim of this project. This is to be achieved by developing a database that contains the necessary data on the track structure at any location in the Western and South West system. Data on parameters identified as being predominant in their influence over rail stress shall be permitted to be entered into, and repeatedly updated in this database. An algorithm will determine trends in these parameters and correlations between these trends and the track structure and geometry at locations then identify the locations that are most susceptible to track stability problems.

VII. Recommend possible procedures for further investigation of the track stability problems pertaining to the Western and South West system.

This project does not intend to be a complete and exhaustive investigation into track stability, nor will it recommend procedures to resolve all operational problems due to buckling. It is primarily an academic exercise and as such will be worked to a logical point of conclusion. Recommendations on possible procedures for further investigations into track stability problems will be presented at the conclusion of this project.

2 Literature Review

2.1 Definition of the Track Axes

Throughout this project reference to the x, y and z axes of the track will be made. These are defined in figure 2.1 below.

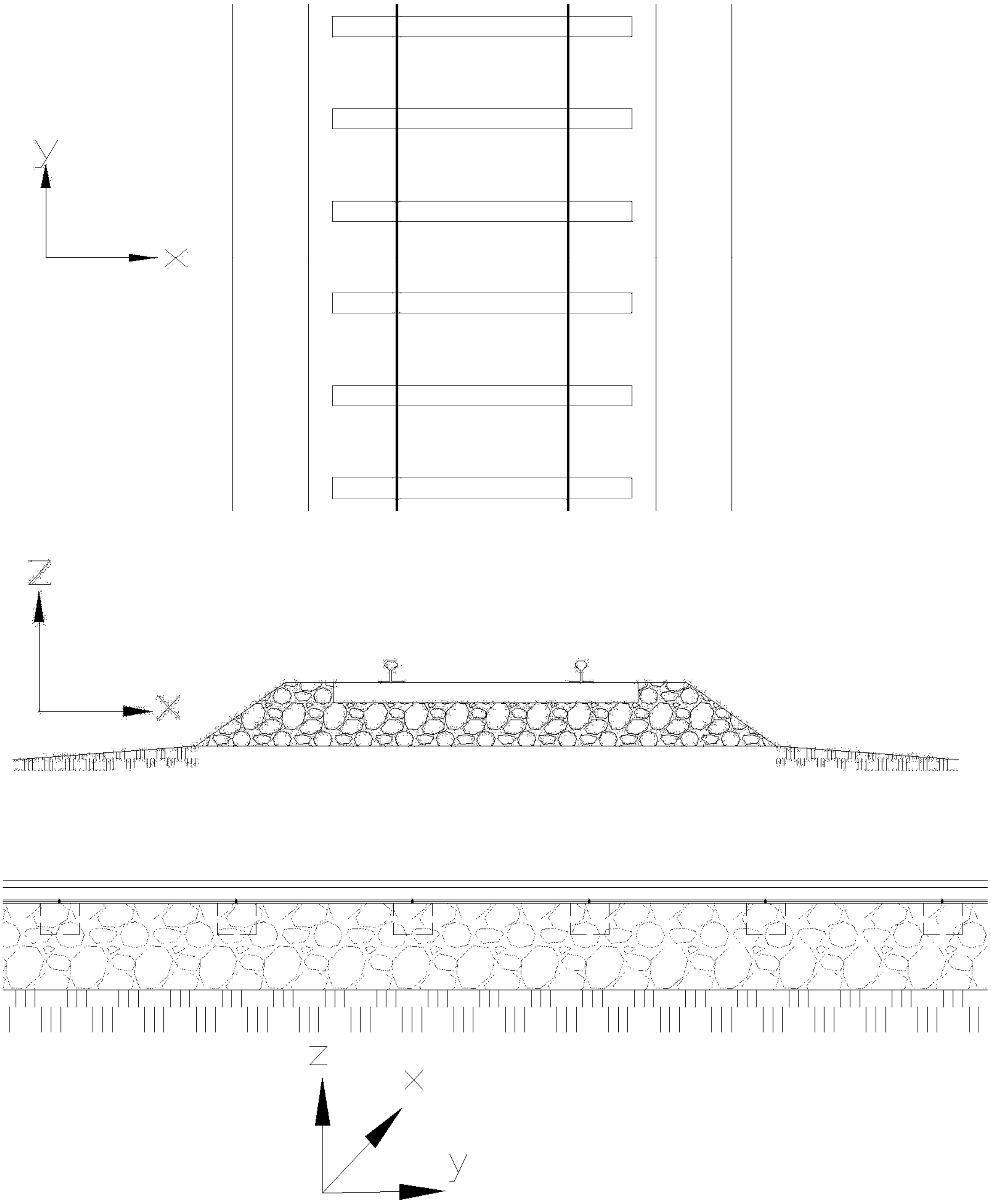


Figure 2.1 Defining the X, Y and Z axes of the Track

The x, y and z directions may also be referred to as the lateral, longitudinal and vertical directions respectively.

2.2 Track Components

The purpose of railway track is to transfer and distribute the loads from trains to the formation. The load transfer works on the principle of stress reduction, as described by Esveld (2001) and Profillidis (1995), whereby, the train loads are distributed over a greater area and transferred by each component or layer, adequately dissipating the stress on the layer below. The following diagram, adapted from Esveld (2001), illustrates the load transfer and principle of stress reduction and shows the components that constitute a railway track.

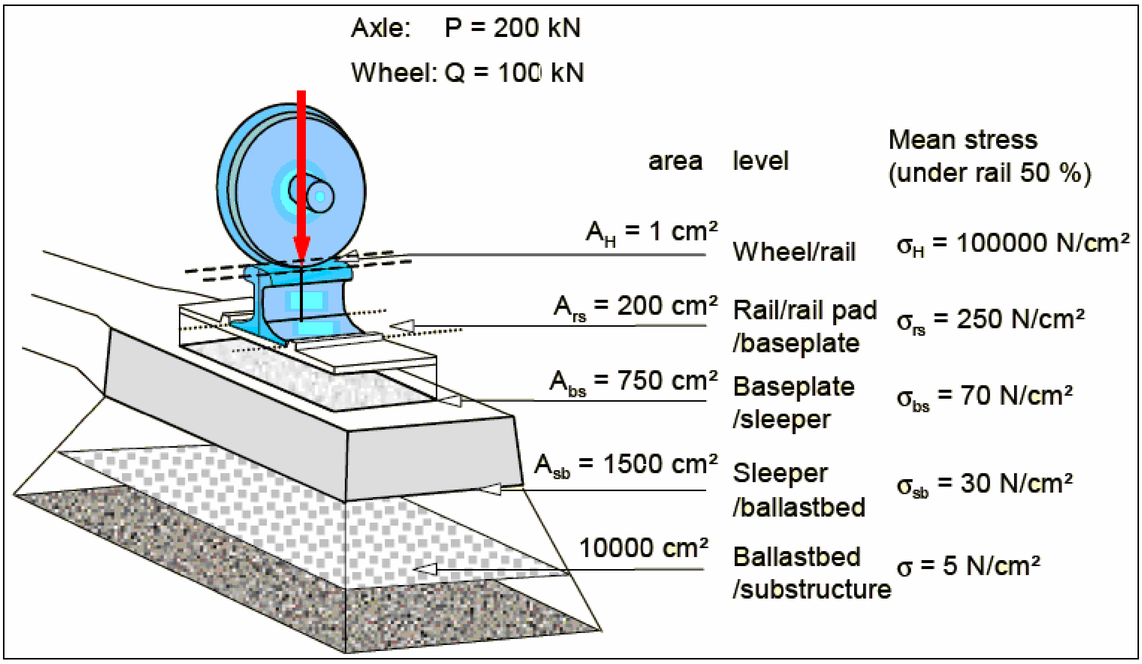


Figure 2.2 Railway track structure, load transfer & principle of stress reduction.
(Source: *Modern Railway Track*, Esveld 2001)

The principal components of a typical track structure are: Rails; Fastenings; Sleepers; Ballast; Sub-ballast and Formation (see figure 2.3). Each track component and their purpose will be describes in the subsequent sections.

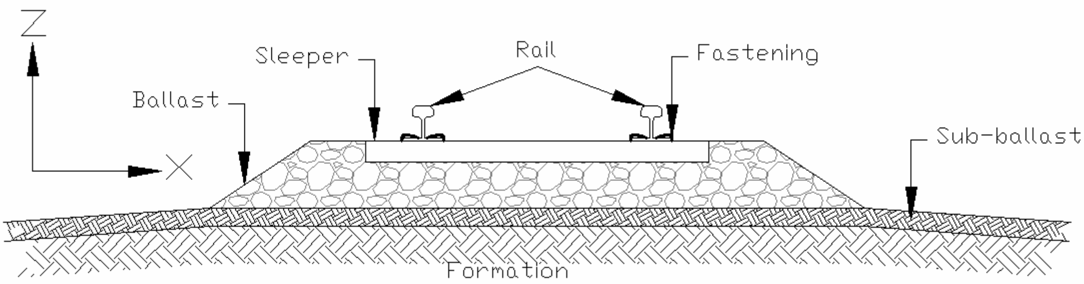


Figure 2.3 A typical section of railroad track showing the major components.

2.2.1 Rails

Rail is the principal component of the railway track structure, providing a smooth running surface. It is a hard, unyielding medium that carries the rigid wheels with limited damage to the rail and the wheels (Heeler 1979). The other functions of the rail, as described by Esveld (2001) are:

- Rail act as a beam (Heeler 1979), distributing the loads over the sleepers.
- Rail guides the wheels laterally.
- Rail distributes traction and braking forces.

Rail comes in varying sizes and shapes, to suit various applications. The size of rail is specified in the weight per linear meter. Rail consists of the foot, web and head and is typically made from low carbon steel. Figure 2.4 shows a section of typical rail.

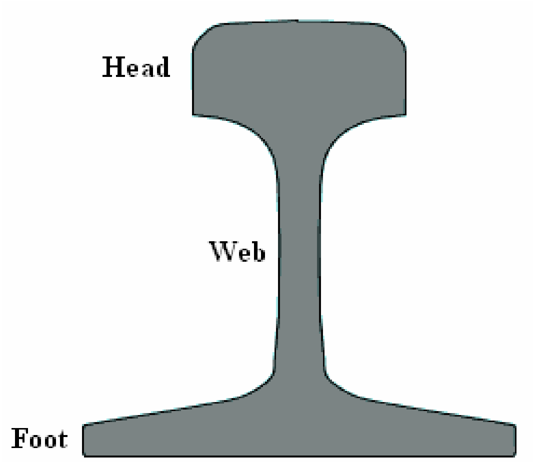


Figure 2.4 A typical section of Flat bottom rail.

The configuration of rail lengths can also vary. The desired length of rail can be made from consecutive lengths joined together by means of a mechanical joint, leaving a slight gap between each rail to allow for thermal expansion. This is referred to as jointed rail. More common today is the use of Continuous Welded Rail (CWR) or Long Welded Rail (LWR). CWR involves joining lengths of rail through flash butt, electric arc, or Thermit welding (Esveld 2001). CWR is, in essence, an infinite length of rail with no gaps to allow for thermal expansion, the thermal forces are therefore ‘locked’ in the rail. Thermal forces in the rail are the predominant causal factor of buckles.

2.2.2 Rail - Sleeper Fastenings

The primary function of rail fastenings is to hold the rails at the correct gauge and absorb lateral rail forces elastically, transferring them to the sleeper (Esveld 2001). Rail-sleeper fastenings also transfer longitudinal forces to the sleepers, resisting rail creep and thus reducing the likelihood of buckles.

Fastenings may be resilient of non-resilient. Resilient fasteners provide greater torsional resistance than non-resilient fasteners, increasing the rigidity of the track so that it behaves as a ladder type structure and increasing the resistance to buckling.

Rail anchors are a type of auxiliary fastener used on track with timber sleeper. They are effective in anchoring the rail to the sleepers, providing better resistance to creep than dog spikes alone and increasing torsional resistance. Double shouldered sleeper plates, sometimes used with timber sleeper, also provide better rigidity than dog spikes alone.

2.2.3 Sleepers

Sleepers are an important structural component of the track structure, they serve many purposes. The important structural functions of sleepers, as reported by Heeler (1979) are as follows:

- Distribute vertical axle loads to the ballast, preventing the overstressing the ballast and formation.
- Hold the rail to the correct position, including gauge and inclination. This is provided that an adequate load carrying rail-sleeper fastener is used.
- Restrain the rails from rolling under traffic loading. Again this is provided that an adequate load carrying rail-sleeper fastener is used.
- Resist longitudinal movement under traction, braking and thermal forces. That is, sleepers provide creep resistance. The extent of the resistance will depend on the sleeper type, weight, sleeper spacing and several factors related to the track ballast, which will be explained in the subsequent sections.
- Resist lateral and vertical displacement of track under both thermal and traffic loads.

Sleepers are generally timber, steel or concrete, but there are composite sleepers being trialled.

2.2.4 Ballast

Ballast consists of coarse grained, angular material capable of withstanding the compressive stresses transferred to the ballast by the sleepers. As a unit, ballast behaves as an elastic material which supports the sleepers and provides a medium for distributing the load applied to the track through to the formation.

Ballast which is packed around the end of the sleepers is referred to as shoulder ballast. (See figure 2.5)

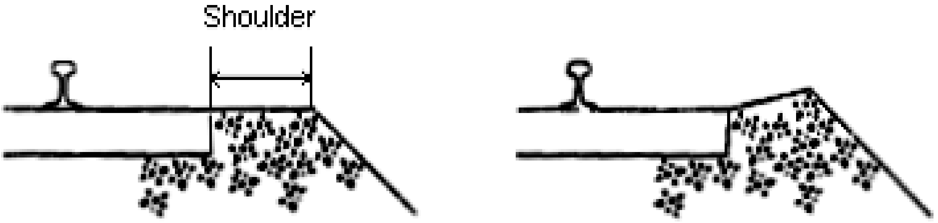


Figure 2.5 Ballast Shoulder (ROA 1988)

Ballast packed between the sleepers is referred to as crib ballast. Crib ballast contributes to the longitudinal resistance of the track.

Lateral resistance is provided by a number of interactions between the ballast and the sleepers. Resistance to lateral forces is generally developed though the following mechanisms (ROA 1988):

- Shoulder ballast.
- The weight of the sleeper.
- The extent of the embedment of ballast particles in to the bottom of the sleeper (for timber sleepers).
- Frictional resistance developed by the ballast and the surfaces of the sleeper parallel to the x-axis.
- A ballast-ballast interface on the underside of steel sleepers.

The exact mechanisms through which lateral resistance is developed depend on the specific sleeper type; timber, steel or concrete.

Ballast must be clean and free draining. This is for three reasons:

- Clean, free draining ballast prevents the accumulation of moisture around timber sleepers, which would otherwise cause them to rot and become ineffective.
- Finer particles in the ballast medium entrap moisture which leads to pumping of the sleepers/track which degrades the ballast material and introduces more fine particles from the underlying formation, leading to, or indicating formation damage and the development of mud holes.
- The presence of pumping sleepers causes the ballast particle adjacent to the pumping sleepers to align with their smoother sides parallel to the sleeper. This reduces the effectiveness of the track as a whole in resisting lateral loads and buckling.

2.2.5 Formation

The formation is the supporting structure for the track it is required to have sufficient bearing strength and stability including settlement and consolidation characteristics. Similar to roadways, the formation has a slight grade from the centre line to the edges to help with natural drainage (Esveld 2001).

2.3 Buckling Theory

Leonhard Euler, a Swiss mathematician and physicist, is universally recognised as being the originator of the critical buckling formula. Euler accepted the hypothesis that the curvature at any point along a member is proportional to the bending moment at that point in the member. He examined the case of an ideal column, described as follows:

An ideal column

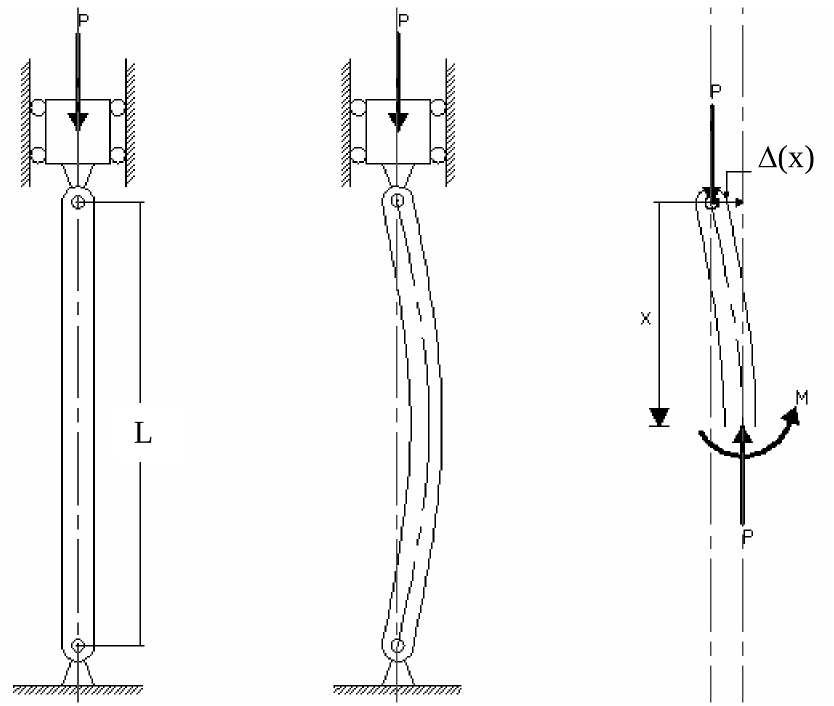
i. is initially straight;

ii. has perfect pinned connections at both ends, providing no rotational resistance as the buckle develops;

iii. is loaded directly through the centroid of the section;

iv. has a constant modulus of elasticity, E, and no yielding occurs prior to buckling.

In the case of an ideal column under an axial load, the column remains straight, (figure 2.6 (a)), until the critical load is reached, at which point the column becomes shapely curved (figure 2.6 (b)).



(a) (b) (c) Free Body Diagram

Figure 2.6 Buckling of an ideal column and associated FBD.

An ideal column is not representative of any real column. Real columns:

i. are seldom initially straight;
ii. do not have perfect pinned connections that provide no rotational resistance;
iii. are rarely loaded directly through the centroid of the section; and
iv. usually display yielding as a buckle develops.

For these reasons, Euler's critical buckling formula for an ideal column is included for completeness only:

$$\mathrm{P} = \frac{\pi^2 EI}{L^2} \qquad \text{Equation 2.1}$$

Where,

P is the critical buckling load (kN).
E is the modulus of elasticity of the column material (MPa).
I is the second moment of area of the section (mm^4).

L is the length of the column (see figure 2.6) (mm)

The exact derivation of Euler’s critical buckling formula is unnecessary for the intents of this project, as such it will be left to any introductory text on engineering statics. Beer et al (2004) provides a complete derivation of the formula.

Buckling is not strictly observed in columns only. Any eccentrically loaded axial compression member will typically buckle about its minor axis before it fails in compression.

Buckling, pertaining to its occurrence in railroad track is a complex phenomenon, owing to the following:

- The effective length of the rails is essentially infinite.
- The “end" conditions of the rails are neither perfectly fixed nor perfectly pinned nor free, but provide varying rotational and lateral resistance depending on numerous factors.
- Resistance to lateral deflection is provided by virtue of the strength and stiffness about the vertical axis of the rails and the distributed resistant of sleeper–ballast interactions, which are proportional to the lateral deflection (Esveld 2001).
- Railroad track invariably contains initial curvature and imperfections.
- Axial loading through the centroid of the track would seldom occur.

It follows that the previously discussed Euler buckling theory and all associated extensions, pertaining to end conditions, are not directly applicable to buckling observed in railroad track. The modelling and determination of the critical buckling load for a particular section of track is a complex process which is best left to finite element analysis packages.

2.3.1 Condition Conducive to Buckling

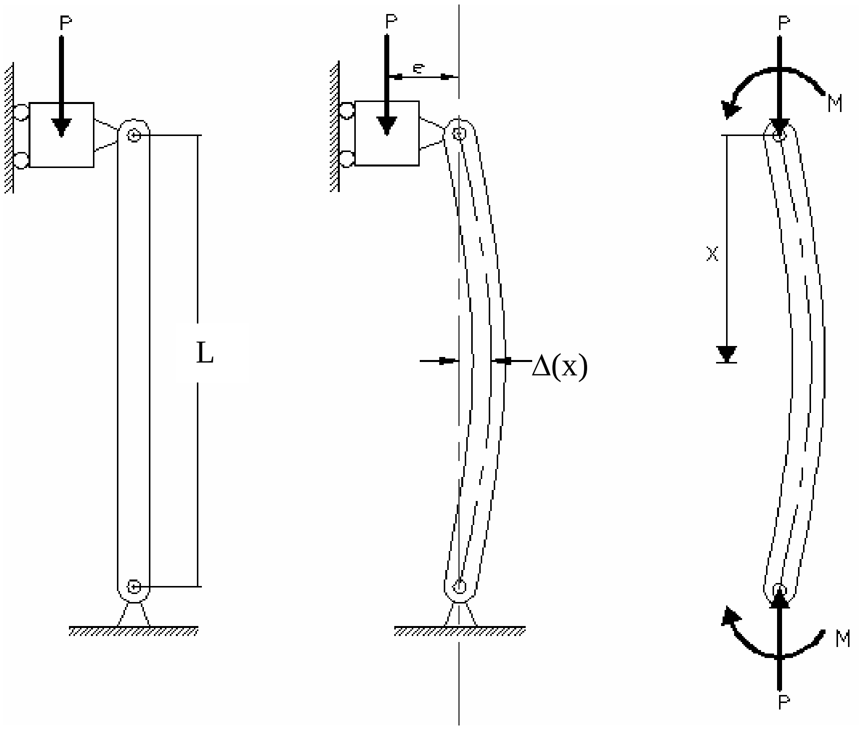
This project seeks to develop a practical method of identifying potential buckle location, thus it is sufficient to examine and explain qualitatively the conditions that are conducive the development of buckles, namely:

- Eccentric loading of an axial compression member and the incidental bending moment; and

- Concurrent primary moment couple and axial compression.

2.3.1.1 Eccentric Loading

Note that axial loading through the centroid of the track would seldom occur and that railroad track invariably contains initial curvature. Figure 2.7 is representative of a simply supported column with pinned end connections under an eccentric load.



(a) (b) (c) Free Body Diagram

Figure 2.7 Pin-pin connected column under an eccentric axial load

The eccentricity (*e*) of the load on the column in figure 2.7 induces a moment couple (M = P*e*). The eccentric load can therefore be represented by a centric load and the induced moment couple. The application of a bending moment to an axial compression member causes a lateral deflection, Δ(x), to occur along the length of the member, resulting in increased eccentricity (e + Δ(x)) of the axial load along the member. Hence as the eccentric load P increased the magnitude of the moment couple increases proportionately causing further lateral deflection and bending.

So, the accumulation of compressive forces in track with initial curvature represents a possible buckle location. Railroad track invariable contains some degree of initial curvature, thus identifying areas of compression is pertinent to this project.

2.3.1.2 Concurrent Moment Couple and Axial Compression

Another situation that is conducive to the development of a buckle is the existence of a primary moment couple and concurrent axial force, such as that observed in the column supporting a bending moment transferred from loaded beam. The free body diagram in figure 2.7(c) is equally representative of this scenario as that explained in section 2.3.1.1. In reference to railroad track, a primary moment may arise due to disparity in the longitudinal forces in the left and right rails of the track, stemming from;

- thermal forces - influenced by the orientation of the track and the adjacency of shadow casting structures; and/or
- rail creep induced stresses.

Not dissimilar to that explanation in section 2.3.1.1, the application of a bending moment to an axial compression member causes a lateral deflection, $\Delta(x)$, to occur along the length of the member, resulting in increased eccentricity of the axial load along the member, introducing a secondary moment ($=P\Delta(x)$), causing bending and lateral deflection.

The development of a moment couple, arising from disparity in the longitudinal forces in the left and right rails will cause a small lateral deflection, introducing eccentricity and an incidental moment under the application of and axial force. This may cause the track to buckle, hence identifying disparity in the longitudinal forces in the left and right rails of the track is pertinent to this project.

2.4 Lateral Track Stability and Buckling

An eccentrically loaded axial compression member will often buckle about its minor axis before it fails in compression. This has proven to be the case when railway track is subjected to significant compressive forces.

The Civil Engineering Track Standards (QR 2005) defines a buckle as:

> “A sudden track misalignment caused by temperature and/or rail creep induced stress, which requires the placement of a speed restriction and/or immediate attention by the Infrastructure Maintainer to allow trains to proceed safely.”

Figure 2.8 shows several examples of track buckles.

Figure 2.8 Examples of track buckling (Volpe Centre 2002)

Buckles predominantly occur in the lateral direction but may on occasions take place in the vertical direction (ROA 1988).

Track buckles occurs when the compressive forces, induced by thermal expansion, creep and dynamic vehicle loads produce a lateral buckling load that exceeds the passive restraining forces provided by the track structure (ROA 1988).

The cause of buckling is typically attributed to the following factors (Volpe Centre 2002):

1. cumulative high compressive forces in rail;
2. weakened track conditions and track disturbing works (ROA 1988); and
3. vehicle loads (train dynamics)

Ensuring stability of railroad track requires equilibrium between the active buckling forces and incidental lateral load, and the passive restraining forces developed by the track structure, which are proportional to the lateral deflection of the track. The passive resistance of the track, induced by the lateral deflection, has a limiting value for any combination of rail, fasteners, sleepers and ballast profile. A pronounced track misalignment will occur if the lateral loads on the track exceed the upper limit of passive resistance developed by the track structure. Thus it is necessary to address two broad aspects when managing buckles:

1. Factor promoting buckling; and
2. The passive resistance developed by the track structure.

Figure 2.9 gives a structured breakdown of the considerations involved in managing track stability and buckling. The left hand branch of figure 2.9 shows the components considered in addressing the passive resistance to buckles, whereas the right hand branch is concerned with the factors promoting buckling. This project focuses on the qualitative assessment of the right hand branch in figure 2.9 (factors promoting buckling), though each aspect of managing track stability and bucking will be covered to some extent for completeness.

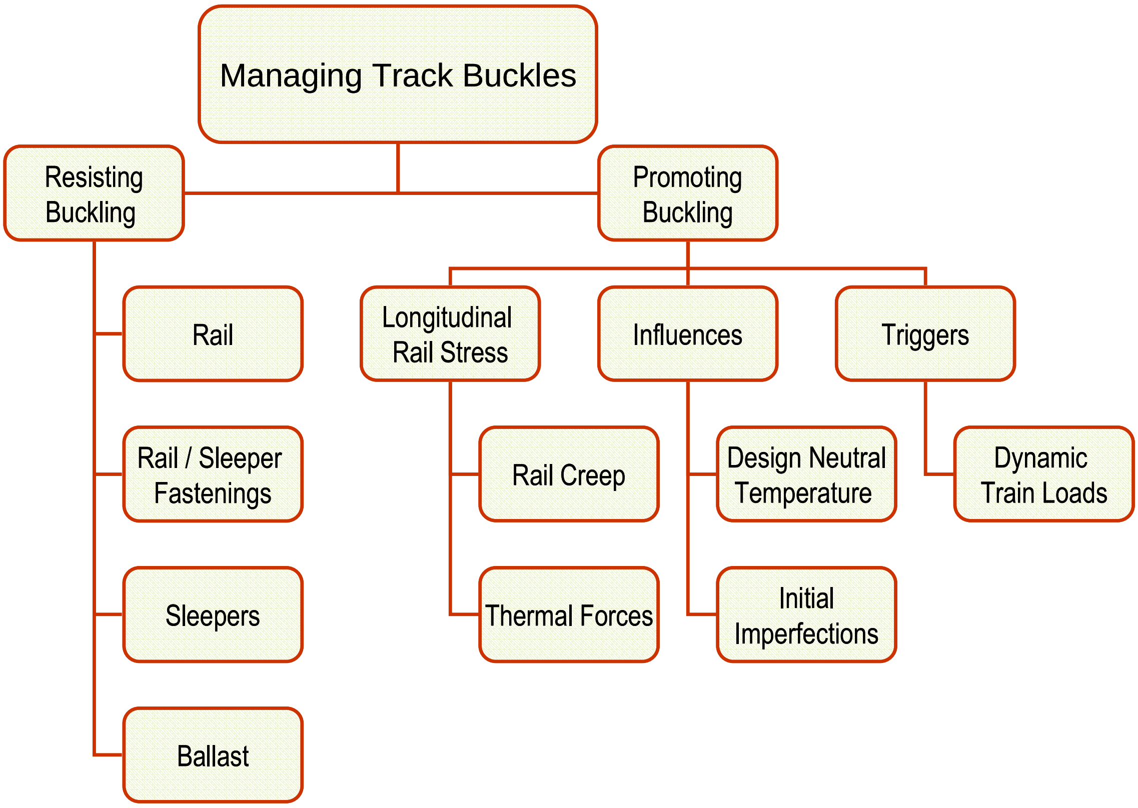


Figure 2.9 The components of managing track buckles.

2.5 Factors Promoting Buckling

A number of factors promote buckling, either in the generation of compressive forces in the rail or in their influence on triggering a buckling, see figure 2.9. These factors will now be discussed.

2.5.1 Longitudinal Rail Stress

2.5.1.1 Thermal Forces

In a study of buckles over period from 1980 – 1985, Railways of Australia (ROA 1988) observes that the number of buckles occurring during the summer months was distinctly higher than in the cooler months. This indicates that high temperature and incidental thermal forces are a predominant cause of buckles.

Thermal expansion and contraction leads to variations in the longitudinal stress in rails that are restricted in their longitudinal movement or confined at the ends, inducing either compression or tension forces in the rails (Marks 2001). Longitudinal forces in rail induced by temperature are the primary contributing factor in the occurrence of track buckles. (ATSB 2005)

The convention is to report the magnitude of the longitudinal stress in the rails as the temperature at which the rails would be stress free. This is based around the coefficient of thermal expansion for the steel rails and the rail temperature. The neutral temperature of the rail, often referred to as the Rail Neutral Temperature (RNT), is the temperature at which the rails are neither in compression nor tension, that is, when the rail is stress free. It is equally as common to refer to this as the Stress Free Temperature (SFT). Compressive stresses are generated in the rails when the temperature of the rails increases beyond their neutral temperature. Track buckling theory indicates that the potential for track buckling is directly associated with the increase in rail temperature above the neutral temperature of the rails.

The tendency for the steel rails to freely expand and contract due to temperature changes is eliminated, owing to the longitudinal resistance force distribution provided by the rail fastenings and sleepers-ballast interactions (Esveld 2001). This restriction on thermal expansion results in the generation of high longitudinal forces which are ‘locked in’ the rails.

Consider the linear expansion of a free section of rail subjected to a temperature change, ΔT above the initial temperature of the rail. The change in length due to the temperature change or thermal strain is:

$$\Delta l = \alpha \Delta T l_0 \qquad \text{Equation 2.2}$$

Where:

Δl is the change in length.

α is the coefficient of thermal expansion for steel rail.

ΔT is the change in temperature.

l_0 is the original length of the rail.

However, assuming this change in length does not occur in rails fixed in the track because of the longitudinal resistance to the axial displacement emanating from friction forces between the rails and sleepers and the sleepers and ballast (Esveld 2001), the rails will be in a state of compressive strain. These strains are equal and opposite to the thermal strain (Bonnett 2005).

Now rearranging equation 2.2 we can get:

$$\frac{\Delta l}{l_0} = \alpha \Delta T$$ Equation 2.3

The term on the left hand side of equation 2.3 is recognised as stain, **ε.**

And

$$\mathrm{E} = \frac{\sigma}{\varepsilon}$$ Equation 2.4

Where:

E is the modulus of elastic for the steel rail

ε is the strain in the rail, $\frac{\Delta \mathrm{l}}{l_o}$

σ is the stress in the rail.

So the longitudinal normal force in the rail resulting from a temperature change can be expressed as follows:

$$N = EA\alpha\Delta T$$ Equation 2.5

Where:

N is the longitudinal normal force in the rail.

A is the cross sectional area of the rail; and

All other terms have previously been explained

So the total force for two rails is:

$$P = 2(EA\alpha\Delta T) \qquad \text{Equation 2.6}$$

Consider the following:

- The maximum expected rail temperature in the Western and South western systems is 62℃ (ROA 1988)
- The design neutral temperature is 38℃
- Cross-sectional area of typical 41kg/m rail is 5192mm^2.
- Coefficient of thermal expansion for steel taken as 11.7x10^{-6} (ROA 1988)
- E is taken as 200GPa for steel

So the longitudinal normal force, in each rail, for the temperature change of (62℃-38℃) = 24℃ is 292kN from equation 2.5, and 584kN for both rails. This illustrates the magnitude of the thermal forces generated in rails.

Equation 2.5 and 2.6 were developed on the assumption that thermal expansion is does not occur at all, that is, the change in length due to the temperature change is completely restricted.

Generating longitudinal forces in the rails is not the only effect on buckling that thermal expansion and contraction has, it can change the neutral temperature of the rail in the track by inducing creep. Railways of Australia, (ROA 1988), uses the example of a curve pulling in due to the rails contracting in a cold winter, after which the track does not return to the original alignment, thus lowering the neutral temperature and leaving the track susceptible to buckling in the following summer.

2.5.1.2 Rail Creep

Through a number of mechanisms induced by traffic and variations in temperature, the rail in the track moves longitudinally. The gradual movement can be the longitudinal displacement of the rail relative to the sleepers or the rail and sleepers relative to the ballast bed. This longitudinal movement of the rail is referred to as creep. Creep will result in the build up of compressive forces in some areas of the track, accompanied by tension in another area. Creep causes a deviation of the rails' neutral temperature from that of design neutral temperature, leaving different areas of the track susceptible to either buckles or rail breaks (ROA 1988).

On the approach side of a fixed track structure or track anchor or some point of increased creep resistance, creep can induce compressive axial stress in the rail. This is exacerbated by the effects of the thermal forces and the dynamic loads from the traffic, which continued to induce creep, and can lead to buckles. Railways of Australia (ROA 1988) refers to Queensland Rail's statistics which show that the majority of buckles occur within 100m of a track anchor or some point of increased creep resistance. A track anchor refers to any fixed track structure such as bridges, level crossings and turnouts, which limit the longitudinal movement of the rail to a minimum. An area of increased creep resistance could be in the form of a transition from timber sleepers to concrete sleepers or a transition between grades.

The mechanisms through which creep is induced, as reported by Railways of Australia (ROA 1988), are as follows:

- Thermal expansion and contraction - variations in the rail temperature cause the rail to move longitudinally as it expands and contract. Part of this project will be determining how the rail in track behaves in response to variations in temperature (winter/summer). It is sought to determine if the rails remain in the displaced location after each cycle of hot weather followed by cold weather, and if this results in an overall increase in the compressive stresses in the rails with each consecutive cycle of summer/winter, or if the cyclic fluctuations in temperature are mirrored in the movement of the rails, resulting in no net change in the longitudinal stress in the rail.
- Traffic – Predominantly unidirectional laden traffic causes the rails to creep in the direction of the traffic. The permissible Tonne Axle Load (TAL) and the amount of traffic will influence the magnitude of the creep. The tractive forces of traffic climbing grades will tend to pull the rails down hill and breaking forces when traffic descends steep grades tends to push it down hill. The vertical alignment of the track tends to govern which areas the rails will be in tension and areas of

compression. The rails on crests tend to be in tension while the areas in sags tend to be in compression.

The implications of creep as reported by (Esveld 2001) are as follows:

- exacerbates the thermal forces in the rails;
- results in too small or too large expansion gaps in mechanically jointed rail;
- disparity in the rate and extent of creep in the left and right rails causes misalignment of the sleepers as a result of the bending moment apply to the rails; and
- disturbance to the stability of the track structure resulting from the movement of the rail and sleepers relative to the ballast bed.

So, creep not only causes a deviation of the rails' neutral temperature, but can also cause disturbances to the track structure that reduce its passive resistance to lateral loads.

Queensland Rail's Civil Engineering Track Standards (CETS), which conform to the requirements of AS 4292 Railway Safety Management and the National Codes of Practice, provides a template by which managers can control risks and allocate priority actions within the confines of their resources. CETS specifies a limit on creep of 50mm into or out of 500m of track, after which the rails shall be restressed. However, the magnitude of the deviation of the RNT, from that of the DNT, caused by creep is not obvious. Theoretically 50mm creep into or out of 500m of track could cause a strain equivalent to an 8.55℃ increase in temperature of a 500m rail confined at both ends, as determined through the application of equation 2.3. Or expressed more appropriately, this is equivalent to an 8.55℃ reduction in the RNT.

2.5.2 Influences and Triggers of track Buckles

2.5.2.1 Lateral Imperfections in Rail

Lateral imperfections in rails include; joints, defective welds and initial lateral rail alignment imperfections or initial curvature of the rails. These act as triggers for buckles.

The presence of any joints or defective welds in the rail will result in a 'weak spot' as the stiffness about the vertical axis at the joint or defective weld is less than that of the rail adjacent to it, thus creating a trigger point for a buckle. At a joint in 82lb rail (≈41kg/m) formed by angle fishplates, the strength is half that of the adjacent rail. In 63lb rail (≈31kg/m) the joint has only 40% of the strength of the adjacent rail. These values are further reduced if flat bar fishplates are used (QR 1972). Thus, if a joint is frozen, (not allowing free expansion and contraction of the adjacent rail), the joint may present as a weak point in the rail and trigger for a buckle.

Railways of Australia, (ROA 1988), plainly states the influence that initial curvature of rails has on buckling:

> “If a rail were completely straight, then it would be impossible for an axial force of any magnitude to cause it to buckle.” (ROA 1988, p.23)

Imperfection, in the form of the initial curvature in a section of track provides the eccentricity required for axial compression forces to cause buckle. An area of interest for this project is the eccentricity of axial forces in the rail induced by the effects of creep.

The extent of the initial curvature of the rails will effect the axial compression forces required to cause a buckle. Inspection of any section of track will illustrate that there is, intrinsically, initial curvature in the track. Railways of Australia (ROA 1988) suggests that an initial curvature of 45mm or more over 10m of track could be expected in lower classes of track.

2.5.2.2 Design Neutral Temperature

In an effort to ensure track stability under the dynamic loads associated with the designated traffic, the magnitude of longitudinal thermal stresses is safeguarded by the choice of an appropriate Design Neutral Temperature (DNT) as part of the track design process. The design neutral temperature is determined by examining the maximum and minimum temperature that the rails could be expected to reach with consideration of the local and seasonal conditions and an assessment of the risk of either a buckle or a rail break occurring. In determining an appropriate DNT for existing track, the track structure and history of track buckles and/or rail breaks for that location should be considered.

Ambient temperatures vary with geographic location, as shall the design neutral temperature. The DNT is also influenced by local condition such as shade and the orientation of the track. Typically for the Toowoomba district the DNT is 38℃ for west of Roma and 37℃ for the remainder of the district.

Initially the RNT will be the temperature at which the rail is laid or installed, which should be equal to the DNT. The neutral temperature of rails in track inevitably deviates from the design neutral temperature. Changes in the neutral temperature are caused by creep, curve “breathing”, track settlement and maintenance practices such as welds (Kish & Samavedam 2001).

When the neutral temperature of the rails is reduced from the design neutral temperature, the track will become susceptible to buckling. Conversely if it is increased the track will become susceptible to rail breaks. More specifically, if the RNT is less than the actual temperature of the rail, the rail will be in a state of compression, leading to the possibility of buckles. Again the converse is true, an RNT greater than the actual temperature of the rail indicates that the rail is in tension, thus susceptible to rail breaks.

2.5.2.3 Rolling Out of Rail

Rolling out of rail is the elongation and plastic deformation of the top layer of the rail head caused by traffic. Rolling out of rail caused the residual tensile stresses in new rail to change to compression due to the rolling contact. Railways of Australia, (ROA 1988), suggests that this can reduce the neutral temperature of the rail by up to 9℃.

Rolling out is a phenomenon observed in new rail, up to a year old, and is only a concern for newly constructed or re-railed track. It will not be considered in this project.

2.5.2.4 Dynamic Vehicle Loads

Dynamic loading from trains is a causal factor in the occurrence of buckles. The wheels of a fast moving, heavily-laden train tends to generate a dynamic uplift wave in the rail and this often triggers the buckle process (Samavedam, Kish & Jeong 1986; Volpe Centre 2002). Lateral wheel forces exerted on the rail will induce a lateral bending stress and can trigger a buckle. Lateral wheel/rail loading is caused by hunting and nosing actions on tangents and curves (Hay 1982; Volpe Centre 2002). Heavy dynamic braking such as emergency braking is a vehicle load that may trigger a buckle (Volpe Centre 2002)

2.6 Resisting Buckling

Resisting buckling by providing passive lateral restraints are those track components outlined in section 2.2. These components will be discussed in further detail, concerning their role in providing lateral restraint and restricting longitudinal creep.

Track lateral resistance is an important part of assessing the buckling resistance of a track structure. The passive restraining forces developed by the track structure are proportional to the lateral deflection of the track, i.e. as the lateral deflection of the track increases, the shear resistance between the sleepers and the ballast also increases. However there is an upper limiting value of the restraining force for any combination of rail, fasteners, sleepers and ballast profile (Esveld 2001).

For the “RATING” program developed by Railways of Australia to identify areas with weakened track structure, it was suggested (ROA 1988) that the maximum lateral resistance, expressed as a percentage of total lateral resistance for rail, sleeper–fastener and ballast resistance was 15%, 25% and 60% respectively. This was revised in the ROA (1991) publication, *A Review of Track Design Procedures*, and the figures for maximum lateral resistance of rail, fasteners and ballast were presented as 12-18%, 13-37% and 50-70% respectively.

2.6.1 Rails

The strength of steel and the stiffness about the vertical axis of the rail provides resistance to buckling in the lateral direction. Larger sizes of rail will provide greater resistance to buckling. However, a larger rail will intrinsically produce a greater buckling force for the same temperature increase than a smaller rail as the stress in both the large rail and small rail will be the same, the difference coming from the cross-sectional area of the rails. (ROA 1988)

2.6.2 Rail – Sleeper connections

Rail fastenings provide torsional resistance and some lateral restraint. Resilient fasteners are more effective in resisting rail creep and provide a stronger connection and greater rigidity. The increased rigidity provided by resilient fasteners creates a ladder type structure – evenly spaced lateral restraints and moment resistance, thus affecting the effective buckling length of the rails and “end” conditions, making the track structure more resistant to buckling.

Good connection between the rail and sleepers are also essential for inducing the longitudinal ballast resistance to creep under the actions of traffic. (ROA 1988)

2.6.3 Sleeper – Ballast Interactions

Interactions between sleepers and the ballast provide the majority of the passive restraint both longitudinally, providing resistance to creep, hence inhibiting variations in the RNT from the DNT, and laterally in preventing buckles.

Sleepers are important to buckling resistance as they provide the connection between the rail and the ballast. Longitudinal forces developed in the rail and lateral forces exerted by the rail are transferred through to the ballast and formation. The effectiveness with which these forces can be transferred will depend on these factors, as reported by the Railways of Australia (ROA 1988):

- Sleeper type, size, shape, weight and spacing.
- Contact area with ballast for the development of friction forces.
- Ballast type and compaction.
- Ballast profile – crib ballast and shoulder ballast.

2.7 Measuring the Rail Stress

The convention is to report the magnitude of the stress in the rails as the temperature at which the rails would be stress free (SFT). It is crucial that the SFT is maintained at or near the design neutral temperature to provide the necessary leeway for dynamic traffic loads and ensure lateral stability of the track. If the variation of the SFT from the design neutral temperature exceeds some margin (±10℃ is practiced by the Toowoomba district in QR), the rail shall be restressed to the design neutral temperature.

In order to maintain the rails at or near the design neutral temperature it is understandably necessary that first the SFT can be determined before any remedial action, that is restressing, can be carried out.

In the late 1990’s QR carried out a project to identify, develop and adopt an appropriate technology for measuring the stress in rails. A multitude of methods for measuring the stress in rails were identified. Various technologies and proprietary systems are outlined hereafter, the focus lying on the RailFrame equipment, the technique adopted by QR.

2.7.1 RailFrame Equipment

The RailFrame equipment is a variation of a technology devised by the Spoornet Track Testing Centre of South Africa. This technology is suitable for determining the rail stress in the field to within ±3℃. The equipment consists of a hydraulic lifting frame that is used to lift 20m of unclipped rail (unclipped 10m either side of the test location) to a height of 70mm.

The underlying concept to the RailFrame equipment is that if the rail is in tension, the force required to lift the rail will be greater that the weight of the rail. This is because the longitudinal tensile force component increases the magnitude of the force required to lift the rail (Marks 2001). The force required to lift the rail to 70mm and the rail temperature are recorded and used to determine the SFT from a series of ‘stress free temperature tables’ that take into consideration the rail size, sleeper type and temperature. Once the SFT is determined it can be decided if the magnitude of the stress in the rail is within an acceptable range of the DNT or if it should be restressed.

Before the use of the RailFrame equipment was adopted across the QR network, the Civil Design Division identified several shortcomings of the technology:

- The RailFrame equipment can only be used, with any accuracy, if the rail is in tension. This means that the actual temperature of the rail, read from a thermometer at the time that the test is performed, must be less that the resulting SFT read from the associated table.
- The test is ‘destructive’, in that it disturbs the track structure, which reduces the tracks passive resistance to buckling.

The implication of both of these shortcomings is that the RailFrame equipments can only be used during the cooler months.

A further limitation of the RailFrame equipment is that it can only be used on CWR and LWR and cannot be used on mechanically jointed track with joints spaced less than 110m.

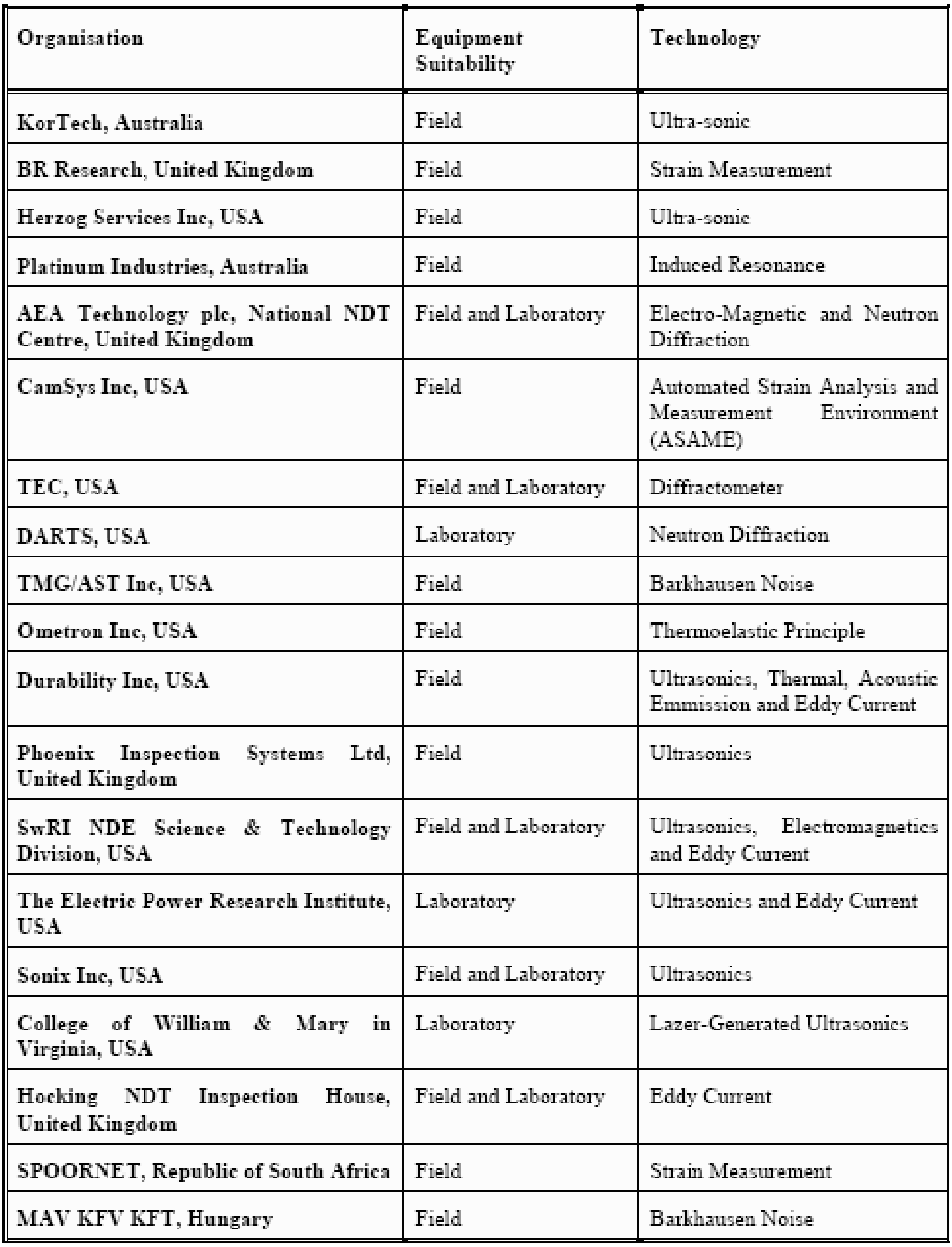
A practical limitation is introduced by the fact that the lifting force/temperature combination may lie outside the range of the ‘stress free temperature tables’. This means that the SFT lies far outside the acceptable range of neutral temperatures, which intrinsically implies that the rail should be restressed. However, Queensland Rail’s Civil Engineering Publication No. 44, *Measurement of Rail Stress Free Temperature* (see Appendix D), suggests that the test result be recorded as invalid and the procedure shall be repeated at a lower temperature. This is time consuming and will essentially verify that the rails should be restressed.

Understandably, stress testing using the RailFrame equipment can only be performed at a number of discrete locations in the network within the available time. Stress testing is performed at locations as nominated by the Track Planners, which is a subjective process. This project will develop a practical and objective method of identifying appropriate locations at which stress testing should be performed.

2.7.2 Proprietary Systems

In the late 1990’s QR carried out a project to identify, develop and adopt an appropriate technology for measuring the stress in rails. A multitude of methods for measuring the stress in rails were identified. Various proprietary systems are outlined hereafter, purely to illustrate that there are alternative technologies available for measuring the longitudinal stress in rails and monitoring the RNT.

Table 2.1 Summary of technologies available for rail stress measurement



Organisation	**Equipment Suitability**	**Technology**
KorTech, Australia	Field	Ultra-sonic
BR Research, United Kingdom	Field	Strain Measurement
Herzog Services Inc, USA	Field	Ultra-sonic
Platinum Industries, Australia	Field	Induced Resonance
AEA Technology plc, National NDT Centre, United Kingdom	Field and Laboratory	Electro-Magnetic and Neutron Diffraction
CamSys Inc, USA	Field	Automated Strain Analysis and Measurement Environment (ASAME)
TEC, USA	Field and Laboratory	Diffractometer
DARTS, USA	Laboratory	Neutron Diffraction
TMG/AST Inc, USA	Field	Barkhausen Noise
Ometron Inc, USA	Field	Thermoelastic Principle
Durability Inc, USA	Field	Ultrasonics, Thermal, Acoustic Emmission and Eddy Current
Phoenix Inspection Systems Ltd, United Kingdom	Field	Ultrasonics
SwRI NDE Science & Technology Division, USA	Field and Laboratory	Ultrasonics, Electromagnetics and Eddy Current
The Electric Power Research Institute, USA	Laboratory	Ultrasonics and Eddy Current
Sonix Inc, USA	Field and Laboratory	Ultrasonics
College of William & Mary in Virginia, USA	Laboratory	Lazer-Generated Ultrasonics
Hocking NDT Inspection House, United Kingdom	Field and Laboratory	Eddy Current
SPOORNET, Republic of South Africa	Field	Strain Measurement
MAV KFV KFT, Hungary	Field	Barkhausen Noise

(Marks 2001)

2.8 Track Buckle Prevention Systems

Only rail stress management strategies and track buckle prevention procedures relating to existing track will be considered in this study.

2.8.1 Prevention of Buckles in Existing Track

A brief summary of track buckle preventative measures and remedial work is presented in this report for completeness only. The project will be more concerned with the identification of areas that are susceptible to track buckles, thus facilitating the performance of targeted preventative work at the identified locations.

There are two areas of interest in relation to the prevention of buckles on existing track:

I. Reduction/prevention of the compressive stresses in the rails.
II. Maximising the track structure's resistance to lateral and longitudinal movement.

The Railways of Australia (ROA 1988) recommends the following method of reducing the extent to which compressive stresses develop in the rails:

- Selection of a high design neutral temperature to suite the tracks immediate environmental conditions.
- Regular monitoring of the neutral temperature. Check rail gap in jointed rail. CWR may require regular restressing to the appropriate design neutral temperature, restressing is to be completed before summer.
- Monitor the alignment of the track, looking for any curves that may have pulled-in over winter.
- Reduce the temperature of the rails. For this ROA recommends providing shade trees or for a more immediate effect, painting the rails white, which, ROA suggests, can result in rail temperatures 5℃ - 7℃ less than unpainted rail on a clear, hot day.

To maximise the track structure's resistance to lateral and longitudinal movement Railways of Australia (ROA 1988) recommends:

- Regular monitoring of sleepers, fasteners and ballast condition and profile and perform any remedial work before the onset of summer.

Ballasting, tamping and regulation and compaction of the ballast profile should be carried out directly after track disturbing work. This is because track disturbing work adversely affects the degree of compaction of the ballast.

2.8.2 Identification of Areas with Weakened Track Structure

The Railways of Australia (ROA 1988) has developed a Track Buckling Prevention System in order to limit the number of buckles occurring. This particular track buckling prevention system is a method for prioritising track strengthening work. It based on an empirical, relative rating of the track's passive resistance to buckling.

This method of identifying areas of weakened track structure requires the measurement and/or assessment of specific track parameters for each homogeneous section of track. The following parameters are required for determining the relative passive resistance for each homogeneous section of track:

- Rail temperature
- Rail length
- Joint gaps
- Four measurement to establish the ballast profile
- Curve radius
- Presence of pumping sleepers
- Presence of loose or defective fasteners
- Rail size
- Sleeper and fastener types
- Indications of rail creep
- Sleeper thickness
- Ballast type

Each of these parameters is weighted and factored and the relative rating of Total Passive Resistance to buckles is determined for each homogeneous section of track.

Areas requiring track strengthening work are prioritised based on the relative rating of the tracks passive resistance to buckling and the method does not pay particular attentions on the state of stress in the rails. As a result, tracks strengthening work may be performed in areas that do not display stress conditions that are conducive to buckling, unnecessarily consuming limited resources. For example, a certain location at which the track condition is assessed may score poorly for the passive resistance of the track, however, if the neutral temperature of the rails is high, then a buckle is not likely to occur. Therefore the resources consumed in performing track strengthening work have not been used appropriately.

2.9 Summary

Track buckling is a failure mode observed in railroad when an increase in rail temperature above that of the neutral temperature causes excessive longitudinal rail forces such that the incidental lateral forces overcome the lateral resistance of the track structure leading to a pronounced track misalignment. Track buckling continues to be problematic for railway engineers and maintenance personnel.

Thermal forces are the principal longitudinal load on railroad track. In an effort to ensure track stability under dynamic loads, the magnitude to which longitudinal thermal stresses develop is controlled by the choice of an appropriate Design Neutral Temperature. The longitudinal movement of rail, referred to as creep, causes a deviation of the rails' neutral temperature from that of the DNT. It is crucial that the RNT is maintained at or near the DNT to provide the necessary leeway for dynamic traffic loads and ensure lateral stability of the track. However, techniques for monitoring the RNT are very limited and difficult to employ. Railway networks generally rely on preventative measures, such as track strengthening work, to control the risk of buckles occurring. This approach to managing the risk of track buckles is resource hungry and time consuming.

3 Methodology

3.1 Introduction

The review of literature pertaining buckling and its occurrence in railroad track indicated the complexity in applying a theoretical approach to identify potential buckle locations. Parameters required for the application of buckling theory are ill-defined in the context of a railroad. Consequently, any theoretical approach to the problem was abandoned in favour of a more practical method, as indicated in the project specification.

The approach presented hereafter is a practical methodology for identifying and predicting possible buckle locations without placing undue burden on maintenance staff, by utilising readily available, site-specific information collected on routine inspections of the track. The methodology is design for large scale applications, to identify and predict potential buckle locations across the entire Western and South-Western systems of Queensland Rail. The approach presented here was used to highlight locations that require more thorough investigation and/or follow up preventative actions.

It was identified in the literature review that the development of the longitudinal thermal forces, which tend to buckle the track can be controlled, to some degree, by adopting an appropriate DNT. Moreover, it is crucial that the RNT is maintained at or near the DNT to provide the necessary leeway for dynamic traffic loads, thus ensuring the lateral stability of the track. However, creep causes a deviation of the RNT from that of the DNT, making it difficult to maintain the rail at the desired neutral temperature. The majority of available technologies for monitoring the RNT are very limited in application, expensive and difficult to employ. This makes the implementation of such technologies an unattractive alternative for the Toowoomba district, which operates on limited resources.

It has been found, in practice that creep contributes significantly to the deviation in the RNT over time. Moreover disturbance to the stability of the track structure resulting from the movement of the rail and sleepers relative to the ballast bed reduces the track’s lateral resistance and disparity in the rate and extent of creep in the left and right rails causes misalignment of the sleepers as a result of the bending moment apply to the rails, further reducing the track’s capacity to resist a buckle. The methodology presented in this paper focuses on identifying certain trends in rail creep observed at numerous locations, that result in the development of stress condition that are conducive to buckling. The trends in the rate and extent of creep displayed at the locations and the locations' proximity to fixed track structures are used to predict potential buckle locations.

3.2 Overview of the Approach

A record of the longitudinal movements of the rails at numerous locations in the Western and South-Western systems has been compiled over several years in the hope that it can be used to highlight locations that are susceptible to track stability issues.

The record of rail creep measurements at numerous sample locations was examined to identify the general trends in the rate and direction at which the rails are moving. Several recurring trends were identified and examined qualitatively to determine if they are likely to cause any appreciable deviation of the RNT from that of the DNT, leading to the development of stress conditions that are conducive to buckling. Engineering judgment by experienced personnel knowledgeable in track buckling behaviour was also employed in determining the implications of the major trends observed at the sample locations. Several of the major recurring trends were identified as being "trends of concern".

The volume of data available and the desire for consistency and accuracy in identifying the trends of concern influenced the decision to develop an algorithm, *CreepTrend*, to analyse the creep data at the numerous locations. This required the development of a set parameters and limiting values for the rate and extent of creep, such that a recursive computational procedure could be used to objectively identify any locations displaying a trend of concern. The limiting values and parameters were derived through empirical means and conform to the requirements of CETS.

Research and engineering judgment indicate that the adjacency of fixed track structures is pertinent to the development of stress conditions that are conducive to track buckling. The adjacency of fixed track structures in the vicinity of locations identified as displaying the trends of concern was noted, facilitating the reasonable assumption that certain locations possess characteristics indicating that they are susceptible to buckling. A module in the algorithm, *CreepTrend*, is dedicated to retrieving information concerning the adjacency of fixed track structures to locations displaying the trends of concern. The information pertaining to the location of fixed track structures was exported from the Track Equipment and Asset Register.

For a more thorough assessment of the risk of buckling occurring, the *CreepTrend* algorithm has the capacity to retrieve information pertaining to the track structure and geometry at any location, which should be available in the Track Equipment and Asset Register for export in to the Rail Creep Analysis program file.

The *CreepTrend* algorithm identifies the locations that display the trends of concern and identified them as potential high stress areas if they are in close proximity to a fixed track structure. Validation of this methodology involved stress testing of the rails in the areas identified as being potential high stress location and a comparison of the areas identified to known buckle location and buckle prone areas. The results of the analysis and the validation process will be presented in chapter four.

A detailed description of this methodology for identifying and prediction potential buckle locations in the Western and South-Western systems of Queensland Rail is presented in the subsequent sections.

3.3 Rail Creep Monitoring

This project adopted the established method of measuring rail creep that is used by the Infrastructure Maintenance team for the Western and South-Western systems of QR. This facilitated the used of the existing data on rail creep. The method for measuring creep, as employed by the Toowoomba district, is detailed in the following sections.

3.3.1 Creep Monuments

In response to a persistent buckling problem in the Western and South-Western systems of QR, the Infrastructure Maintenance team of the Toowoomba district has established numerous creep measurement locations in these systems, facilitating the documentation and monitoring of the longitudinal movements of the rails at these location over time. The creep monitoring locations consist of a post or monument fixed permanently beside the track (figure 3.2) and permanent reference marks on both of the rail adjacent to the monument (figure 3.3). The reference points on the rails are marked at the intersection of a line perpendicular to the track, originating at the creep monument and are established at the time that the monuments are installed. Figure 3.1 shows the general plan and elevation of the creep monument setup employed by the maintenance staff.

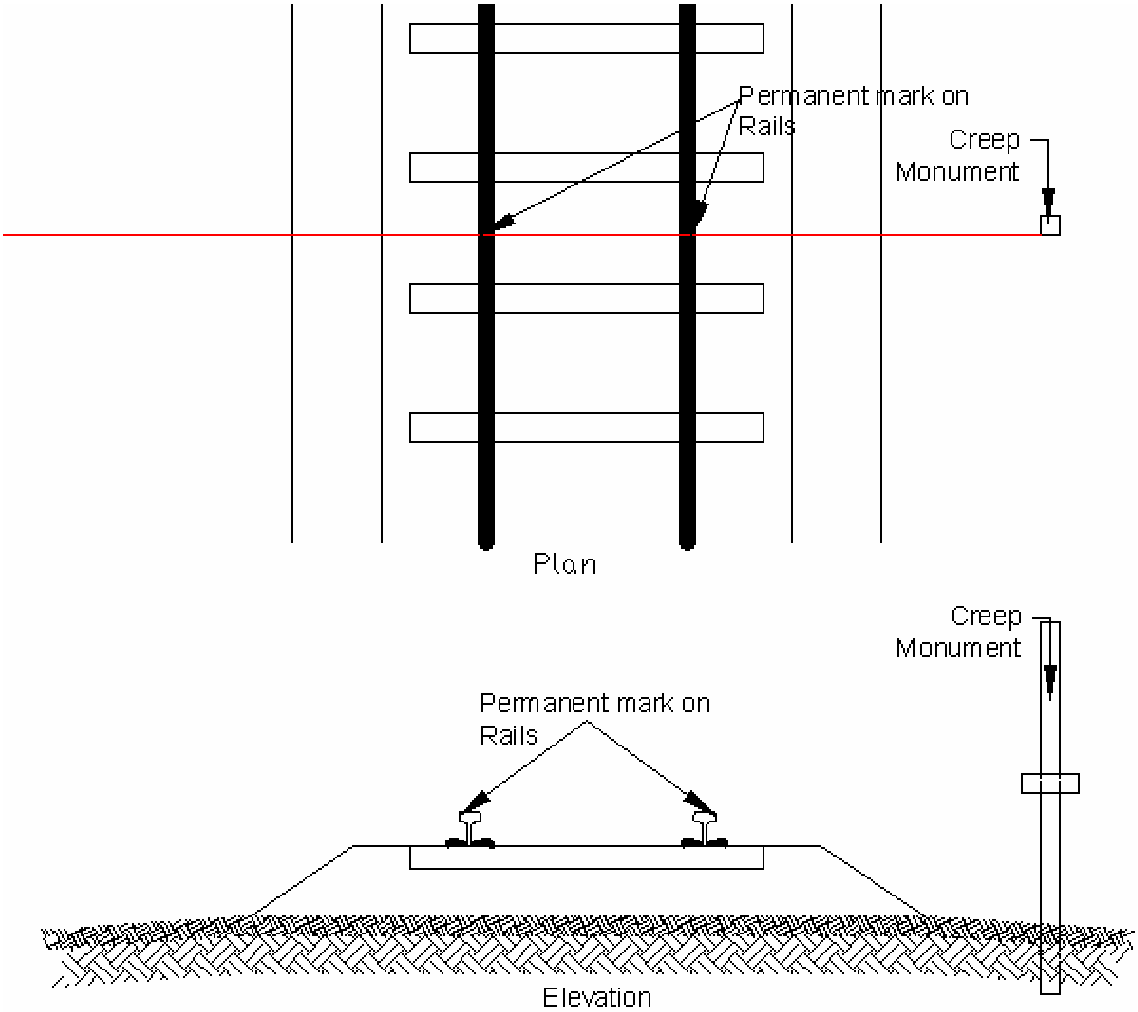


Figure 3.1 General plan and elevation of a creep monitoring location.

There are 429 creep monuments established in the Western and South-Western systems, the locations of each can be found in Appendix B. Some general information pertaining to the creep monitoring regime for the Toowoomba district is presented in table 3.1.

Table 3.1 Creep monitoring régime

Operation	Location of Creep Monuments	Maximum Period between Inspection
Coal Corridor (High Gross tonnage & block Trains)	• Every 2.000km • Known Buckle Locations	4 months
Seasonal Grain (Block Trains)	• Every 5.000km • Known Buckle Locations	4 months
Scheduled Service	• Every 10.000km • Known Buckle Locations	6 months
Branch Line	• Known Buckle Locations	6 months

3.3.2 Measuring and Recording Creep

The longitudinal displacement of the rails can be measured relative to a fixed point i.e. the creep monument. A spirit level that incorporates a laser can be attached to the monument (figure 3.2).

Figure 3.2 A creep monument with a spirit level that incorporates a laser.

The laser is projected on to a panel with a light coloured background that is centred at the reference mark on the rail (figure 3.3).

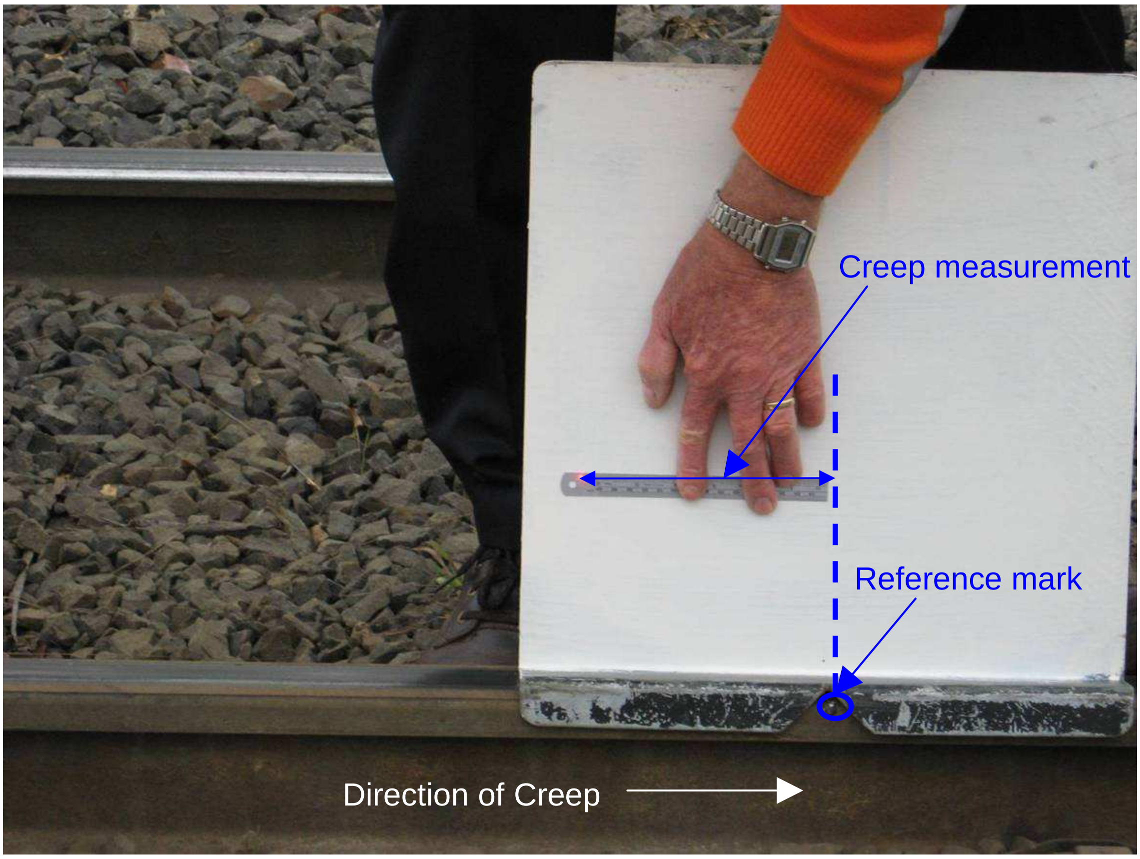


Figure 3.3 Measuring the rail creep.

The distance between the centre of the panel, therefore the reference mark on the rail, and the laser dot projected on to the panel is measured and recorded to the nearest millimetre. This is illustrated in figures in figure 3.3.

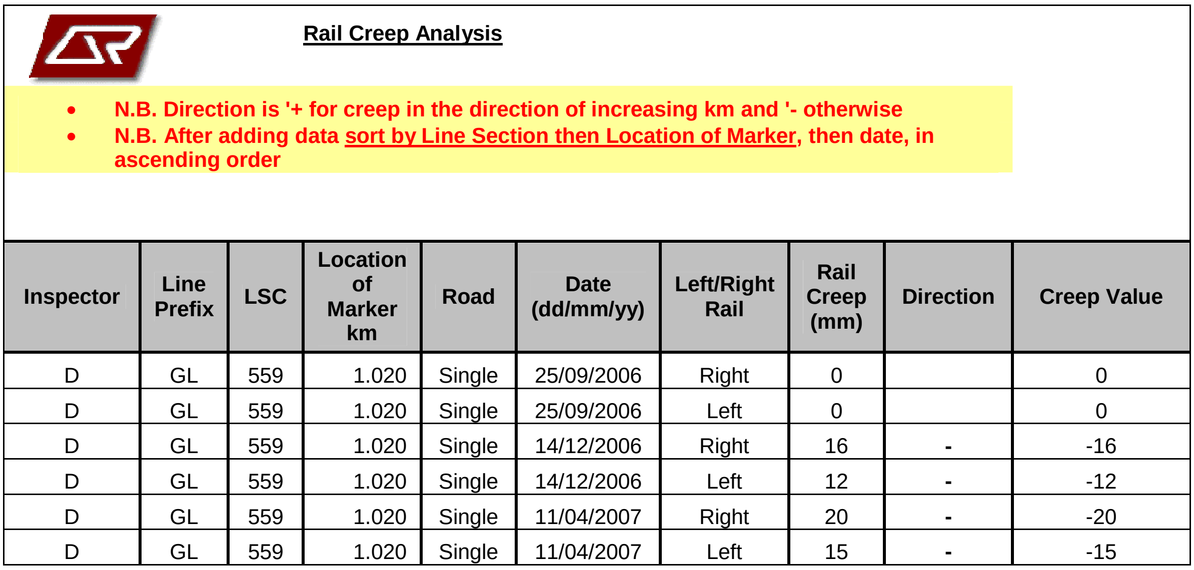
The direction that the rail has move is denoted as either positive (+) or negative (-). The convention is to record the direction as (+) for a displacement in the direction of increasing kilometres and (-) in the direction of decreasing kilometres. The direction of increasing kilometres (Up Direction) for each line section is shown in Chapter 1, figure 1.4.

The displacement of each rail is measured relative to the creep monument. The usual convention is adopted; the left rail is identified as the rail that is on the left hand side when facing in the direction of increasing kilometres.

The creep measurement data for this project has been collected by seven Track Planners (TPs). The data dates back to 2005. While collecting the data, the TPs record the following information:

- the Line Prefix;
- the Line Section Code (LSC);
- the Location of the creep marker/monument (km);
- the road (Up, Down or Single);
- date of measurement;
- the creep measurement and direction for the left and right rails.

Though the information that is recorded by the TPs is consistent, there is no consistency in format that it is recorded. The development of a recursive computational process for analysing the trends in the data required consistency in the format in which the data is recorded. The figure below gives the format adopted for this project. The information provided by the TPs was collated into this format in an MS Excel worksheet.



Rail Creep Analysis

- **N.B. Direction is '+ for creep in the direction of increasing km and '- otherwise**
- **N.B. After adding data sort by Line Section then Location of Marker, then date, in ascending order**

Inspector	Line Prefix	LSC	Location of Marker km	Road	Date (dd/mm/yy)	Left/Right Rail	Rail Creep (mm)	Direction	Creep Value
D	GL	559	1.020	Single	25/09/2006	Right	0		0
D	GL	559	1.020	Single	25/09/2006	Left	0		0
D	GL	559	1.020	Single	14/12/2006	Right	16	-	-16
D	GL	559	1.020	Single	14/12/2006	Left	12	-	-12
D	GL	559	1.020	Single	11/04/2007	Right	20	-	-20
D	GL	559	1.020	Single	11/04/2007	Left	15	-	-15

Figure 3.4 A snapshot of the creep data, recorded in an appropriate format.

The data set containing the creep measurements for this project contains over 4400 entries, this constitutes 85 pages. Consequently the full dataset has not been included in this dissertation. It can be found in the associated MS Excel file.

3.4 Identifying Creep Trends Conducive to Buckling

3.4.1 Recurring Trends

The rail creep data was initially examined manually. This process involved plotting the creep measurements against the date at which they were recorded at the particular location. This gave a graphical representation of the temporal rate of rail creep from the initial position of the rails. Numerous locations were selected at random and examined. The general trend in the movement of the rails at each location was described qualitatively. The qualitative descriptions of the trends observed in the creep data lead to the development of nominal classification system and several recurring trends were identified. The nominal classifications for the recurring trends are as follows:

- Little or No Creep Observed;
- Cyclic Fluctuations;
- Non-Recovering Creep;
- “Diverging” Rails; and
- Rapidly “Diverging” Rails.

Each recurring trend will be described in subsequent sections.

3.4.1.1 Little or No Creep Observed

‘Little or No Creep Observed’ is the nominal classification for locations that display little or no variation in the creep measurements over time. Figure 3.5 gives a typical example of a location the displays little or no variation in creep over time.

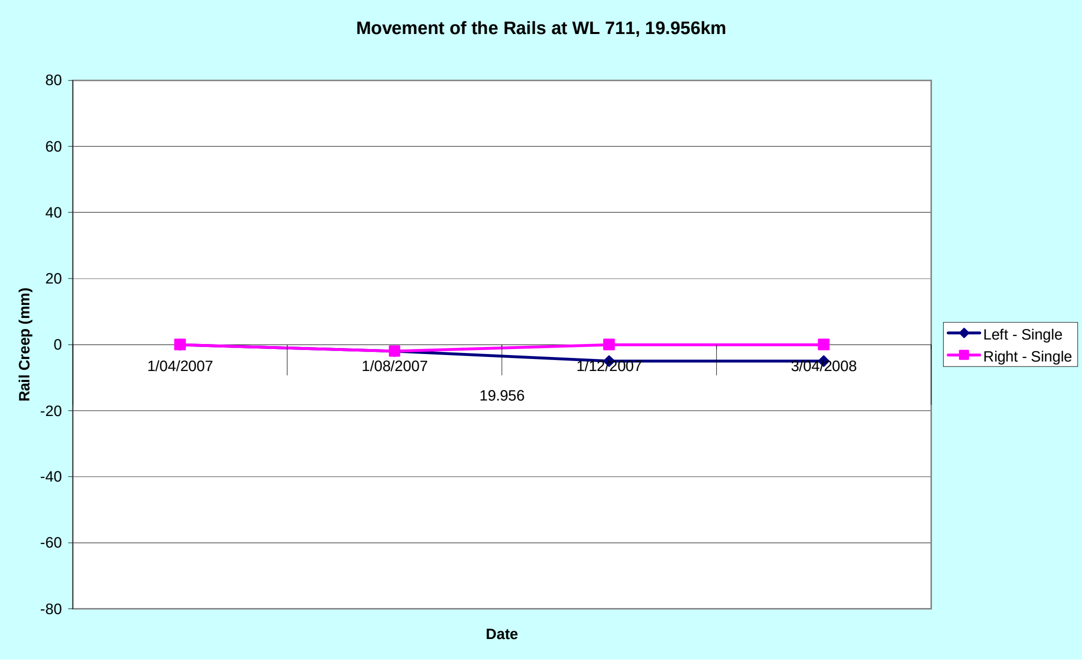


Figure 3.5 An example of a location classified as **'Little or No Creep Observed'**.

3.4.1.2 Cyclic Fluctuations

Of the locations examined manually it was observed that many display a tendency for the longitudinal displacement of rails to fluctuate about some mean value. This trend has been called Cyclic Fluctuations. The example in figure 3.6 shows a location where the creep displays the tendency to fluctuate about 0mm displacement.

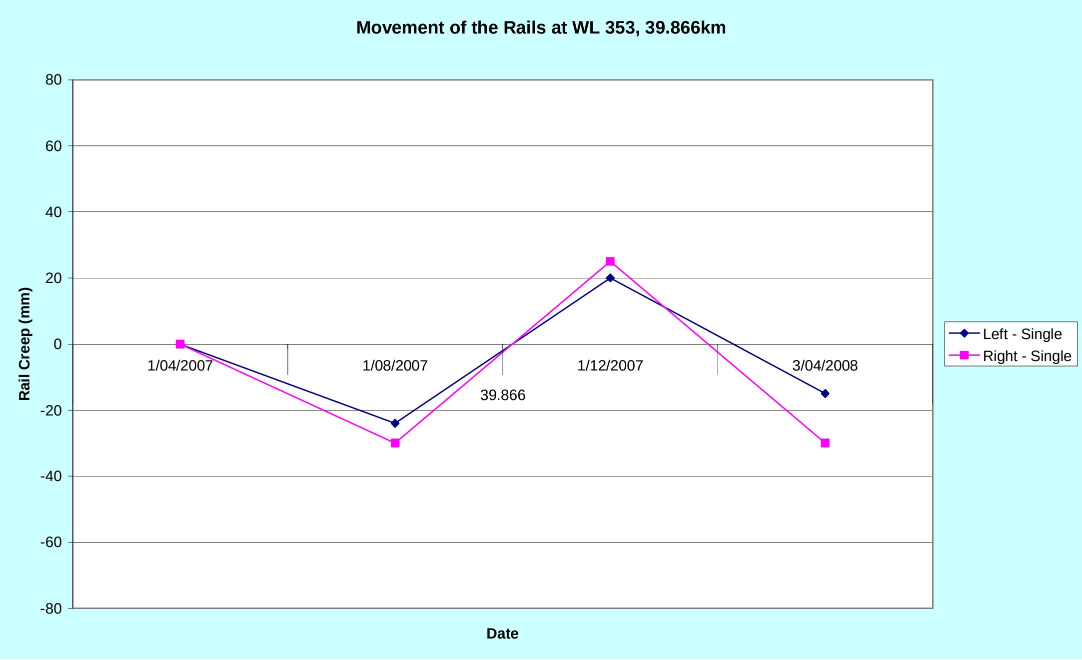


Figure 3.6 An Example of **Cyclic Fluctuations** about a mean value.

3.4.1.3 Non-Recovering Creep

Non-Recovering Creep is the nominal classification that describes the creep at a location where the reference marks on the rails tend to creep continually in the one direction, failing to return to their initial position. Figure 3.7 gives an example of Non-Recovering Creep and it can be seen that the longitudinal displacement of the rails has increased in magnitude in the same direction at each consecutive inspection.

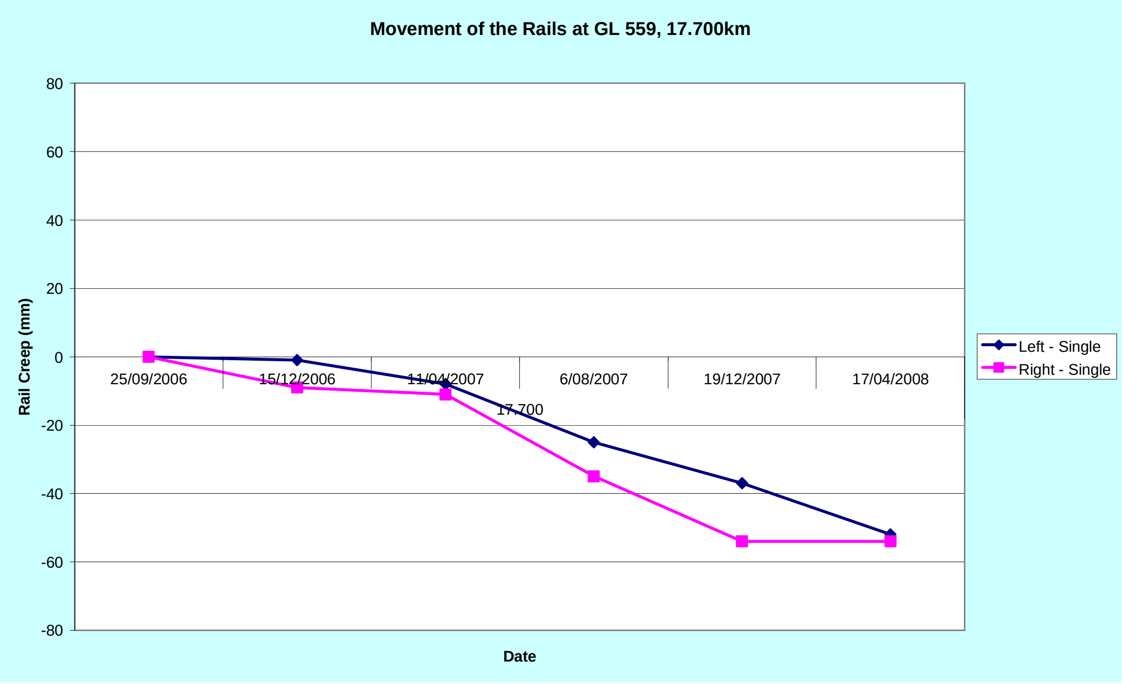


Figure 3.7 An example of **Non-Recovering Creep**.

Locations classified as Non-Recovering Creep display little or no tendency for the creep to fluctuate about some mean value of displacement. Fluctuations may be observed but there is a general tendency for the rails to displace in one direction. This becomes apparent when a linear trend line is fitted to the data, as illustrated in figure 3.8.

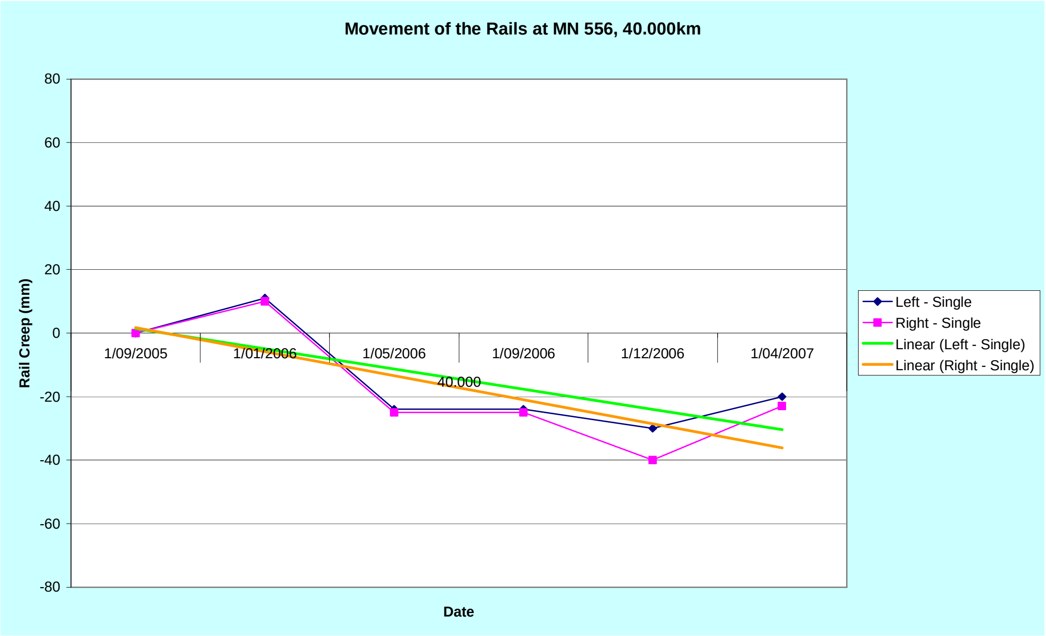


Figure 3.8 An example of **Non-Recovering Creep** combined with fluctuations.

3.4.1.4 "Diverging" Rails

"Diverging" Rails described the movement of the rails at a location which displays disparity in the rate of creep between the left and right rails. Both rails may move in the same direction, but at appreciably different rates, or the rails may creep in opposite directions. When the displacement of the rails is plotted against the date of the inspections, it produces lines that are diverging from one another (figure 3.9), hence the name.

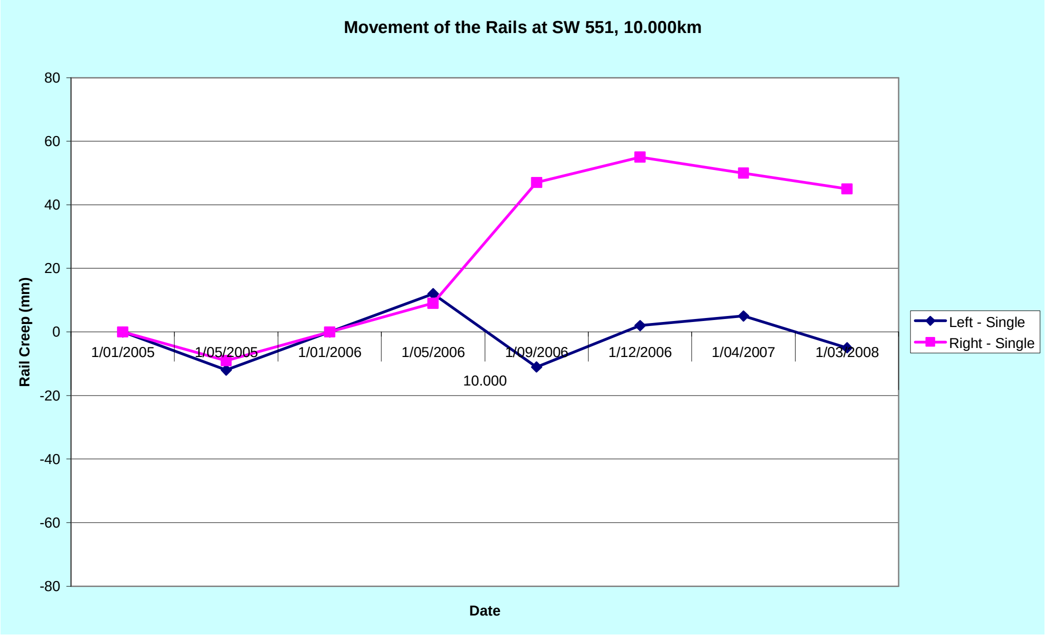


Figure 3.9 An example of **"Diverging" Rails**.

3.4.1.5 Rapidly "Diverging" Rails

Again, this describes disparity in the rate of creep between the left and right rails at a location. Rapidly "Diverging" Rails is used to describe the movement of the rails when there is considerable disparity in the rate of creep between the left and right rails.

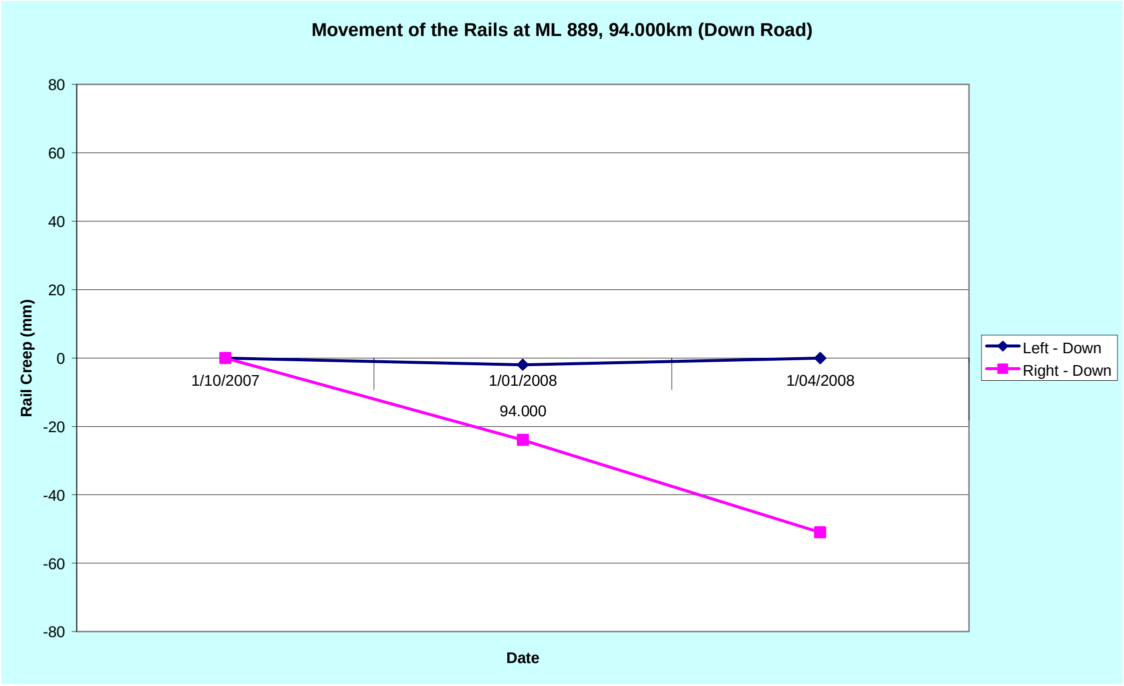


Figure 3.10 An example of **Rapidly "Diverging" Rails**.

3.4.2 Implication of each Recurring Trend

The implications of each recurring trend was examined qualitatively to determine if it is likely to cause any appreciable deviation of the RNT from that of the DNT, leading to the development of stress conditions that are conducive to buckling. Engineering judgment by experienced personnel knowledgeable in track buckling behaviour was also employed in determining the implications of the major trend observes.

3.4.2.1 Little or No Creep Observed

It was identified that this trend is not likely to cause any appreciable deviation of the RNT from that of the DNT as there is minimal displacement of the rails over time. Therefore it is not considered to contribute to the development of stress conditions that are conducible to buckling.

3.4.2.2 Cyclic Fluctuation

It has been assumed that cyclic fluctuations in creep have no appreciable cumulative affect on the RNT at locations that display this trend. It is acknowledged that the cyclic fluctuations in creep may have a short term influence over the RNT depending on the magnitude and direction of the displacement and the proximity to fixed track structures. It will be illustrated later, that the *Creep Trend* algorithm has the capacity to identify location that display excessive creep. Thus, if the magnitude of the fluctuations in creep at locations displaying this trend is considered to be excessive, the location will be identified as requiring further investigation.

3.4.2.3 Non-Recovering Creep

The tendency for the rails to continually displace in the one direction will cause a strain, $\varepsilon = \frac{\Delta \mathrm{l}}{l_o}$, resulting in the accumulation compressive stress in the rails, lowering the RNT. This is assuming that the longitudinal movement of the rails is in the direction of a fixed track structure that restricts or eliminates the movement of the rails past that point.

The accumulation of compressive stress and the inherent initial curvature of railroad track constitute conditions that are conducive to track buckling.

3.4.2.4 “Diverging” Rails

Disparity in the rate and extent of creep in the left and right rails will give rise to differential strains in the rails. Hence the magnitude and sense of the induced forces on the rails may result in the development of a moment couple. The development of a moment couple, arising from disparity in the longitudinal forces in the left and right rails will cause a small lateral deflection, introducing eccentricity and an incidental moment under the application of and axial force. This may cause the track to buckle.

Disparity in the rate and extent of creep in the left and right rails also causes misalignment of the sleepers as a result of the bending moment apply to the rails, reducing the tracks ability to resist buckle.

3.4.3 Trends of concern

The trends in rail creep that are considered to contribute to the development of condition that are conducive to buckling are:

- Non-Recovering Creep;
- “Diverging” Rails; and
- Rapidly “Diverging” Rails.

3.5 Parameters for Identifying Trends of Concern

The development of a recursive computational procedure for autonomously identifying the creep trends displayed at the numerous creep monitoring locations required the development of appropriate limits on the permissible rate and extent of creep. QR’s Civil Engineering Track Standards states that the rails shall be restressed if the creep exceeds 50mm into or out of 500m of tracks. Thus, it is appropriate that this is used to guide the limits on the rate and extent of creep observed at a location.

The first parameter to be adopted was a limit on the magnitude of creep that is permissible. This was a direct application of the standard. Locations that exceed the permissible limit of 50mm creep are identified as displaying excessive creep as per CETS. Similarly, the difference between the longitudinal displacements of the rails at a location that displays disparity in the rate of creep in the left and right rails was limited to 50mm, after which the location is identified as requiting further investigation.

As the inspection schedule for creep monitoring is based on a maximum period between inspections it was considered appropriate to examine the temporal rate of creep. Examining the rate of creep facilitates a degree of forward planning in identifying potential buckle locations. In determining appropriate limits on the temporal rate of creep, it was assumed that the rate of creep can be approximated as linear. Adopting the limit of 50mm displacement and noting the maximum period between inspections is six months it can be deduced that the maximum rate of creep that is permissible is:

$$\frac{50mm}{(365/2)days} = 0.274\text{mm/day}$$

If the rate of creep exceeds 0.274mm/day, it intrinsically implies that the limit of 50mm of displacement will be reached before the date of the next scheduled inspection, thus the location will become susceptible to buckling and will require further investigation.

Linear trend lines were fitted to the creep data for the left and right rails at each location using the method of least squares. From the equation of the trend lines it was possible to determine the rate of creep in each rail at the location with respect to time.

The difference in the rate of creep between the two rails was examined to identify the extent of the disparity in the rates. That is, the rate of displacement of one rail with respect to the other was examined. If the rate at which the rails are “diverging” exceeded the limit of 0.274mm/day, the creep trend displayed at the location was identified as Rapidly “Diverging” Rails.

The magnitude of the creep in each rail at the time of the latest inspection was considered in conjunction with the rate of creep in each rail. If the rate at which the rails were “diverging” was less than 0.274mm/day, but would result in the displacements of the rails with respect to one another exceeding 50mm before the next scheduled inspection, the creep trend displayed at the location was identified as “Diverging” Rails.

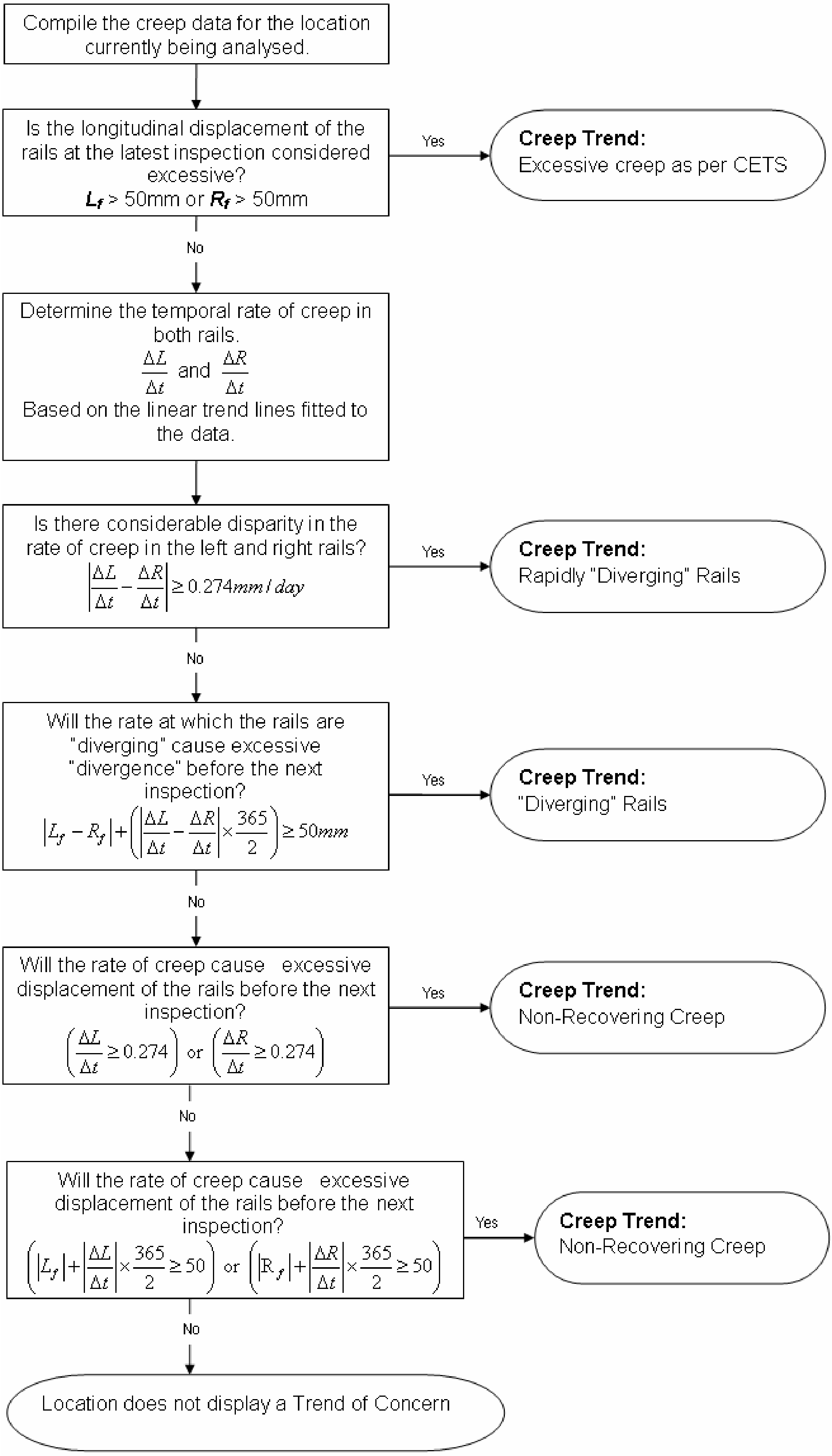
When it was identified that the rate of creep in both rails was approximately equal and exceeded 0.274mm/day the location was classified as displaying Non-Recovering creep. Considering the displacement of the rails at the time of the latest inspection, if the rate at which the creep is occurring would cause in excess of 50mm creep before the next scheduled inspection, the location would be identified as displaying Non-Recovering Creep as well.

The process of identifying the trend displayed at the creep monitoring locations is summarised in figure 3.11 in the form of a flowchart. Before examining figure 3.11, accept the following notations:

Let ***L*** denote the displacement of the left rail [mm];
Let ***R*** denote the displacement of the right rail [mm];

Hence, $\frac{\Delta L}{\Delta t}$ is the temporal rate of creep in the left rail [mm/day]; and

$\frac{\Delta R}{\Delta t}$ is the rate of creep in the right rail [mm/day]



Compile the creep data for the location currently being analysed.

Is the longitudinal displacement of the rails at the latest inspection considered excessive?

$L_f > 50\text{mm}$ or $R_f > 50\text{mm}$

Yes → **Creep Trend:** Excessive creep as per CETS

No ↓

Determine the temporal rate of creep in both rails.

$\frac{\Delta L}{\Delta t}$ and $\frac{\Delta R}{\Delta t}$

Based on the linear trend lines fitted to the data.

Is there considerable disparity in the rate of creep in the left and right rails?

$$\left|\frac{\Delta L}{\Delta t} - \frac{\Delta R}{\Delta t}\right| \geq 0.274 mm/day$$

Yes → **Creep Trend:** Rapidly "Diverging" Rails

No ↓

Will the rate at which the rails are "diverging" cause excessive "divergence" before the next inspection?

$$|L_f - R_f| + \left(\left|\frac{\Delta L}{\Delta t} - \frac{\Delta R}{\Delta t}\right| \times \frac{365}{2}\right) \geq 50mm$$

Yes → **Creep Trend:** "Diverging" Rails

No ↓

Will the rate of creep cause excessive displacement of the rails before the next inspection?

$$\left(\frac{\Delta L}{\Delta t} \geq 0.274\right) \text{ or } \left(\frac{\Delta R}{\Delta t} \geq 0.274\right)$$

Yes → **Creep Trend:** Non-Recovering Creep

No ↓

Will the rate of creep cause excessive displacement of the rails before the next inspection?

$$\left(|L_f| + \left|\frac{\Delta L}{\Delta t}\right| \times \frac{365}{2} \geq 50\right) \text{ or } \left(|R_f| + \left|\frac{\Delta R}{\Delta t}\right| \times \frac{365}{2} \geq 50\right)$$

Yes → **Creep Trend:** Non-Recovering Creep

No ↓

Location does not display a Trend of Concern

Figure 3.11 A flowchart illustrating the process of identifying Trends of Concern

3.6 Rail Creep Analysis

3.6.1 Overview

The volume of data available and the desire for consistency and accuracy in identifying the trends of concern influenced the decision to develop a recursive computational procedure for analysing the creep data at the numerous locations. Two options were exploded for the development of such an algorithm, pertaining to programming languages, namely:

- MATLAB 7.1; and
- Visual Basic for Applications (VBA).

MATLAB was available to the author, who is also familiar with this programming language, however QR does not hold a corporate license for it. While this project is primarily an academic exercise contributing to the undergraduate degree of the author, this methodology has also been developed for implementation in the Western and South-Western systems of QR. Accordingly, the programming of the algorithm has been developed in Visual Basis for Applications (VBA), which is built into most Microsoft Office applications including, Word, Excel and Access. Hence it is readily available, facilitating the implementation of this methodology as appropriate.

CreepTrend is the algorithm programmed in VBA and is operates though the host application Microsoft Excel. The functions of the algorithm are to:

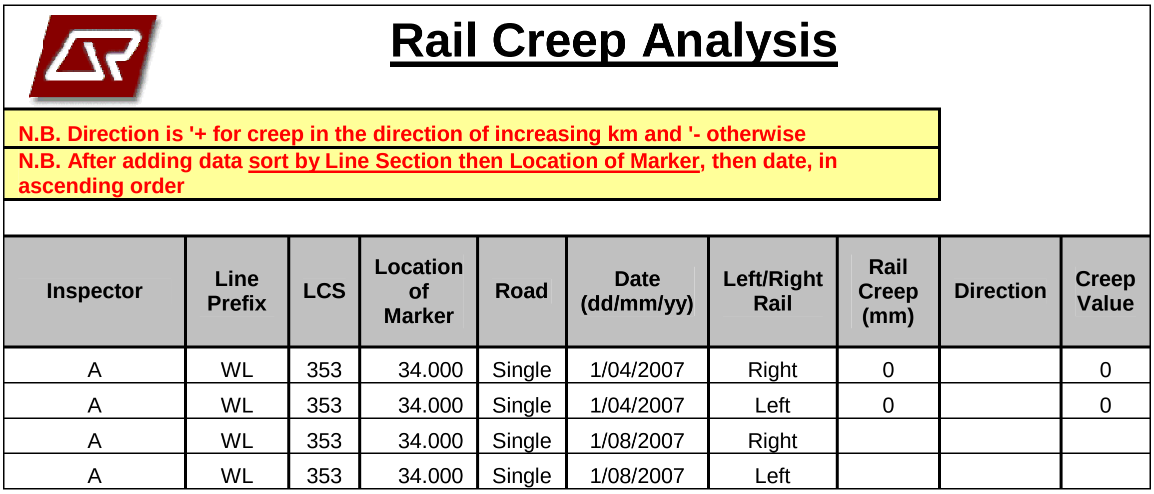
- analyse the rails creep data for each creep monitoring location and identify locations that display the trends of concern;
- retrieve information pertaining to the locations of fixed tracks structures in the vicinity of the creep monument (bridges, level crossings and turnouts);
- retrieve information pertaining to the track structure at each location, to facilitate a more thorough assessment of the risk of a buckle occurring in the vicinity of the creep monitoring locations; and
- produce a concise tabulated report of possible buckling location, recommending appropriate actions to be taken.

3.6.2 Rail Creep Analysis.xls

The Microsoft Excel file, *Rail Creep Analysis.xls*, consists of several worksheets, each containing different information pertinent to the different functions of the algorithm. The file essential operates as and independent database and information system with the capacity to analyse the data and produce a concise tabulated report, recommending follow up actions as required.

The worksheet titled "Data" contains all available records of the rail creep at the creep monuments. This was complied from the records of seven Track Planners. Further creep data can be entered into the dataset as it becomes available. Table 3.2 shows a sample the information complied in the "Data" worksheet.

Table 3.2 Information recorded in the "Data" worksheet.



Rail Creep Analysis

N.B. Direction is '+ for creep in the direction of increasing km and '- otherwise

N.B. After adding data sort by Line Section then Location of Marker, then date, in ascending order

Inspector	Line Prefix	LCS	Location of Marker	Road	Date (dd/mm/yy)	Left/Right Rail	Rail Creep (mm)	Direction	Creep Value
A	WL	353	34.000	Single	1/04/2007	Right	0		0
A	WL	353	34.000	Single	1/04/2007	Left	0		0
A	WL	353	34.000	Single	1/08/2007	Right			
A	WL	353	34.000	Single	1/08/2007	Left			

The worksheet titled "Fixed Track Structure" contains a comprehensive list of all of the bridges, level crossings and turnouts, and their locations in the entire Western and South-Western systems. This information was imported into the spreadsheet form QR's Track Equipment and Asset Register (TEAR). The information contained in the worksheet is used to identify the adjacency of any fixed track structures to the location of the creep monuments. Table 3.3 shows a sample the information complied in the "Fixed Track Structure" worksheet.

Table 3.3 Information recorded in the "Fixed Track Structure" worksheet.

Short Text	Line Section	Start km	End km	Class
WW T/O 0.035 #34	304	0.035	0.036	Turn Out
WW T/O 0.035 # 36 SHELL	304	0.035	0.036	Turn Out
WW T/O 0.083 # 35 CP	304	0.083	0.084	Turn Out
WW T/O 0.782 # 37 CP	304	0.782	0.783	Turn Out

The worksheet titled “Track Details” contains all available information about the track in the Western and South-Western Systems. This includes the rail size and sleeper type for homogeneous sections of track as well as the curve details, radius, cant and speed limit on sections of track. The intent is to include this information in the assessment of the risk of a buckle occurring at the locations identified as displaying stress conditions conducive to buckling. Table 3.4 shows a sample of the information that is complied in the “Track Details” worksheet. This information was exported from TEAR.

Table 3.4 Information recorded in the “Track Details” worksheet.

Line Section	Start km	End km	Rail Type	Sleeper Type	Direction	Radius	Cant	Speed	Curve or Tangent
324	317.809	317.993	61lb			Tangent			Tangent
324	317.993	318.110	61lb		L	240	50	40	Curve
324	318.110	318.152	61lb			Tangent			Tangent
324	318.152	318.361	60lb A.S		R	200	45	40	Curve

Evidently, the information in the database was not sufficient to facilitate and adequate assessment of the passive resistance of the track. Consequently, field investigations are still required to do so.

Please appreciate that the three above mentioned worksheets are substantial datasets of thousands of entries, constituting hundreds of pages. Consequently the datasets are not included in this dissertation. They can be found in the associated MS Excel file.

The worksheet titled “Report” is the spreadsheet into which the report is generated. Each location is identified, information pertaining to the track structure is presented, the creep trend displayed at the location is indicated and comments on further actions to be taken are presented.

The worksheet titled “dummy_sheet” is a facilitating sheet only. It will always appear blank to the user. It is used by the algorithm to temporally store information and perform calculations.

3.6.3 The *CreepTrend* Algorithm

The *CreepTrend* algorithm operated through the host application MS Excel. It is contained in the file called *Rail Creep Analysis.xls*. This file contains all of the information required for the analysis. The keyboard shortcut Ctrl+Shift+C is used to execute the algorithm. The program script for *CreepTrend* is in Appendix C. A brief description of recursive computational procedure performed by the algorithm is presented hereafter.

The algorithm examines the data for each creep monitoring location in the rail creep dataset. It identifies a location then extracts and compiles all records of creep for the location currently being analysed. Excel's inbuilt liner regression function is used to determine the temporal rate of creep in the left and right rails. The algorithm examines the rate and extent to creep in the rails at the location and identified the creep trend display at the location according to the methodology and parameters derived in Section 3.5.

Having identified the trend displayed at the location currently being analysed, the algorithm examines the data pertaining to the location of fixed track structures in the network. If the location being analysed is within 300 metres of a fixed track structure, and the rails have been found to be creeping in the direction of the fixed track structure, the location is identified as a potentially high stress area requiring further investigation such as stress testing and appropriate follow up actions. The 300 metre limit is arbitrary but appropriate as the majority of buckles occur within 100 metres of a fixed track structure. Adopting 300 metres as the limit is purely exercising caution. The area proposed for stress testing is the section of track from the identified fixed track structure to the point 500 metres from the fixed track structure in the direction of the creep monument, such that the creep monument lies within the proposed stress testing area. This is illustrated in figure 3.12. The decision to recommend stress testing in a 500 metre region was influenced by the guideline in CETS pertaining to excessive creep.

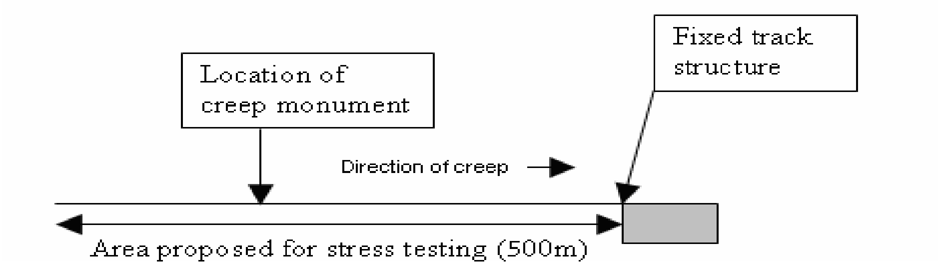


Figure 3.12 Representative of an area proposed for stress testing.

The algorithm proceeds to compile information about the structure of the tracks in the vicinity of the observed movement to facilitate a better assessment of the risk of a buckle occurring.

A concise tabulated report is generated for the location. The procedure is repeated for all of the creep monitoring locations.

The results of the analysis will be presented in Chapter 4.

3.7 Validation of the Approach

Three approaches were adopted in examining the validity of this methodology for identifying and predicting situations where the longitudinal stress in rail is likely to cause operational problems in the track, namely:

- Stress testing in areas identified by the Rail Creep Analysis;
- Stress testing in areas not identified by the analysis; and
- Retrospective analysis of past buckle locations.

3.7.1 Stress Testing

The area identified by the *CreepTrend* program as requiring stress testing and appropriate follow up actions were proposed for stress testing using the RailFrame equipment. The methodology for stress testing of the rails using the RailFrame equipment has been covered in the literature review, for further clarification and information refer to Appendix D. The results of stress testing at the proposed locations were used to examine the validity of the *CreepTrend* program in predicting high stress location based on the creep trends.

As will be discussed in Chapter 4, the results for stress testing in the proposed locations were limited. In an attempt to further assess the validity of the approach, the results of stress testing performed in areas that coincide with a creep monument, which were not identified by the analysis, were examined to facilitate a comparative assessment of the effectiveness of the existing method of identifying possible high stress areas against the methodology developed in this paper.

3.7.2 Retrospective Analysis of Past Buckle Locations

A track buckle is defined as a sudden track misalignment caused by temperature and/or rail creep induced stress, which requires the placement of a speed restriction and/or immediate attention by the Infrastructure Maintainer to allow trains to proceed safely. A comprehensive list of all track misalignments fitting this description for the period between summer 2007 and 2008 was compiled. The rail creep analysis methodology was performed on all creep data that predates each of the recorded buckles to determine, in retrospect, if the *CreepTrend* algorithm would have accurately predicted each of the buckles.

4 Results and Discussion

The aim of this project was to develop a methodology for identifying potential high stress area. It was identified that the major stresses in the rails is generated by thermal forces which can be controlled to some extent by adopting and maintaining an appropriate DNT. Creep can cause a deviation of the RNT from that of the DNT and monitoring this deviation is a complicated endeavour. A recursive methodology for identifying situation where a deviation of the RNT may lead to track stability issues has been developed, based on the trends displayed at numerous creep monitoring locations and their proximity to fixed track structures. The results of this analysis are presented in section 4.1 and the validity of the methodology and analysis is examined in section 4.2. Further discussion pertaining to the results is presented in section 4.3.

4.1 Rail Creep Analysis

The results of the rail creep analysis in their entirety are included in Appendix E. A truncated table of results containing the principal information is presented in table 4.1.

Table 4.1 Results of the rail creep analysis

Line Prefix	LSC	Location of Marker	Road	Creep Trend @ location	Comment
WL	353	42.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 41.751km and 42.251km
ML	546	132.020	Single	Non Recovering Creep	Possible high stress area. Stress test between 132.008km and 132.508km
ML	546	145.811	Single	Non Recovering Creep	Possible high stress area. Stress test between 145.325km and 145.825km
ML	546	156.287	Single	Non Recovering Creep	Possible high stress area. Stress test between 156.269km and 156.769km
ML	546	159.900	Single	Non Recovering Creep	Possible high stress area. Stress test between 159.408km and 159.908km
ML	889	57.915	Up	Excessive Creep as per CETS	Possible high stress area. Stress test between 57.841km and 58.341km
ML	889	57.915	Down	Rapidly 'Diverging' Rails	Possible high stress area. Stress test between 57.841km and 58.341km
ML	889	77.935	Up	Excessive Creep as per CETS	Possible high stress area. Stress test between 77.55km and 78.05km
ML	889	82.000	Up	'Diverging' Rails	Possible high stress area. Stress test between 81.771km and 82.271km
ML	889	106.000	Up	Non Recovering Creep	Possible high stress area. Stress test between 105.56km and 106.06km

SL	550	317.000	Single	Non Recovering Creep	Possible high stress area. Stress test between 316.67km and 317.17km
SW	551	15.000	Single	Non Recovering Creep	Possible high stress area. Stress test between 14.64km and 15.14km
SW	551	20.000	Single	Excessive Creep as per CETS - Left Rail	Possible high stress area. Stress test between 19.931km and 20.431km
SW	551	33.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 32.781km and 33.281km
SW	551	40.000	Up	Excessive Creep as per CETS	Possible high stress area. Stress test between 39.826km and 40.326km
MN	556	39.000	Single	Non Recovering Creep	Possible high stress area. Stress test between 38.74km and 39.24km
MN	556	68.000	Single	'Diverging' Rails	Possible high stress area. Stress test between 67.65km and 68.15km
SW	721	233.990	Single	'Diverging' Rails	Possible high stress area. Stress test between 233.5km and 234km
SW	721	263.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 262.951km and 263.451km
GL	559	17.700	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 17.526km and 18.026km
GL	559	81.000	Single	Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 80.941km and 81.441km
GL	559	86.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 85.793km and 86.293km
WL	356	110.000	Single	Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 109.961km and 110.461km
WL	356	122.000	Single	Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 121.971km and 122.471km
WL	563	170.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 169.961km and 170.461km
WL	563	192.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 191.851km and 192.351km
WL	563	208.000	Single	Non Recovering Creep	Possible high stress area. Stress test between 207.68km and 208.18km
WL	567	411.200	Single	Non Recovering Creep	Possible high stress area. Stress test between 410.891km and 411.391km
WL	567	441.200	Single	'Diverging' Rails	Possible high stress area. Stress test between 441.167km and 441.667km
GW	716	40.000	Single	Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 39.75km and 40.25km
GW	717	149.950	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 149.841km and 150.341km

This is a list of the locations identified by the analysis as being potential high stress areas. Of the 429 creep monitoring locations on which the analysis was performed, thirty one were identified as being potentially high stress based on the creep trends displayed and the adjacency of fixed track structures.

The development of the *CreepTrend* algorithm, though initially time consuming, enabled the creep data to be examined in a timely manner. The procedure is recursive. This is most satisfying as the analysis can be repeated readily at any time that additional creep data becomes available. The algorithm eliminated the issues of human error and bias in assessing the likelihood that rail creep observed at a location is causing a deviation in the RNT and it produces consistent, objective results.

4.2 Validation of the Rail Creep Analysis

4.2.1 Stress Testing in the Identified areas

The thirty one locations identified as potential high stress were proposed to the Track Operations Coordinator for stress testing using the RailFrame equipment.

The stress testing program in the Westerns and South-Western systems operates during the cooler month of the year such that the rails are most probably in tension, producing valid results for the RNT. Hence the period for the stress testing program was restricted to between April and August. The locations to be included in the stress testing program are complied and proposed in late February each year, at which time this project was still in the conceptual stage. By early August, when rail creep analysis algorithm was completed and operational and the list of potentially high stress locations was compiled, the stress testing program was drawing to an end. Several requests were made for the thirty one proposed locations to be included in the final stages of the stress testing program. However, this proved difficult under the time constraints and with the warmer weather approaching. Consequently, stress testing was performed at only two of the proposed locations. The results are presented in table 4.2 (page over).

Figure 4.1 is a graphical representation of the stress testing results at the two locations. It shows the measured RNT of the rails relative to the DNT and the safe range of neutral temperature based on the limit of a ±10℃ deviation of the RNT from that of the DNT. All of the measured RNTs at the proposed locations were below the DNT but were within the acceptable safe range of neutral temperatures. This indicated that they are more susceptible to buckling but pose no immediate threat. The mean deviation in the RNT at these locations was -4.33℃. The results will be discussed in more detail in the subsequent sections.

Table 4.2 Results of stress testing in the proposed areas.

						Left Rail					**Right Rail**				
Line Prefix	**LSC**	**Location of Marker**	**Road**	**Creep Trend @ location**	**Comment**	**Temp. °C**	**Force Tonnes**	**SFT °C**	**DNT °C**	**Deviation °C**	**Temp. °C**	**Force Tonnes**	**SFT °C**	**DNT °C**	**Deviation °C**
SW	721	233.990	Single	'Diverging' Rails	Possible high stress area. Stress test between 233.5km and 234km	27	0.95	**37**	**38**	**-1**					
SW	721	263.000	Single	Excessive Creep as per CETS	Possible high stress area. Stress test between 262.951km and 263.451km	26	1	**29**	**38**	**-9**	**27**	**1.1**	**35**	**38**	**-3**

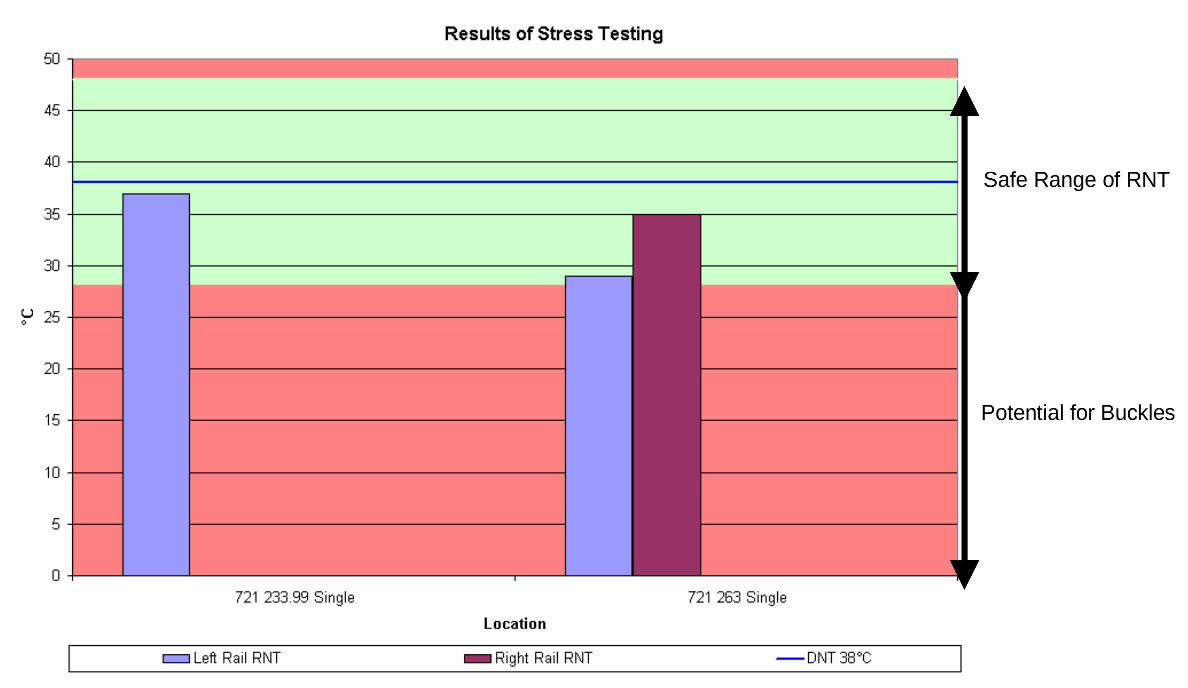


Figure 4.1 A chart of the results in table 4.2, shows the RNTs relative to the DNT and the safe range of neutral temperatures.

4.2.1.1SW 721 233.990km

Examining the trend in rail creep displayed at SW 721 233.990km, figure 4.2, indicated the creep in both rails is excessive, however this location was identified by the algorithm as “Diverging” Rails. This can be explained by the linear trend lines fitted to the data, which shows that the rails are “diverging”. This inaccuracy indicates that there is a minor error in the order of logic in the programming of the algorithm. Examining the program script will indicate that the location was initially identified as displaying excessive creep, then as the procedure advanced the trend was identified again, this time as “Diverging” Rails. Nevertheless the location was identified as requiring stress testing.

The stress testing at this location was only performed on the left rail. It is not apparent to the author as to why this is so. The results for the left rail showed that the RNT had reduced to 37℃, a deviation of -1 ℃ from the DNT. This deviation is minimal and would not warrant further actions being taken. The reduction in the RNT is too insignificant to endorse or reject the validity of the Rail Creep Analysis in this instance.

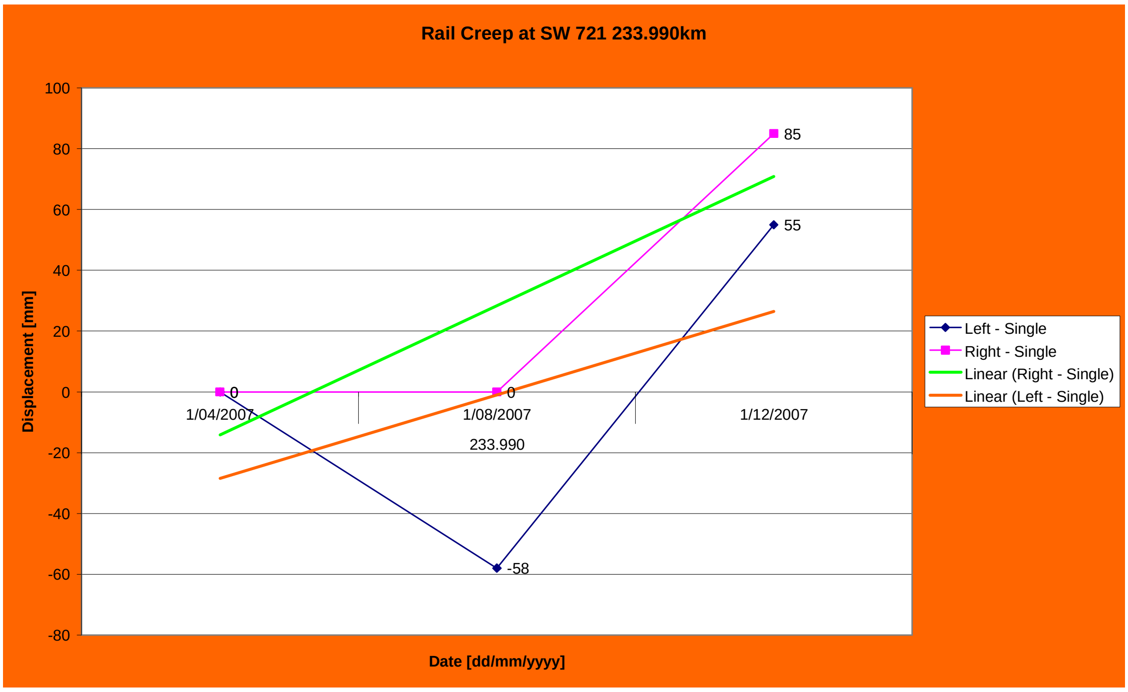


Figure 4.2 Rail creep at SW 721 233.990

It was anticipated that the stress testing results at this location would verify that it was a high stress area, as it was identified as so by the rail creep analysis. The ‘poor’ result in the minimal deviation in the RNT can be explained by the type of fixed track structure identified in the vicinity of the location. Table 4.3 is an extract form the Fixed Track Structure dataset, it identifies a Flood Opening in the vicinity of the creep monitoring location.

Table 4.3 The Fixed Track Structure identified in the vicinity of SW 721 233.990km

Short Text	Line Section	Start KM	End KM	Class
SW F/OPENING 234.000	721	234.000	234.001	Bridge

The rails are creeping in the direction this structure, however the flood opening, the structure identified, is a ballast deck bridge and as such the structure provides little resistance to creep. The accumulation of compressive stress will not generally occur in the direct vicinity of this location as the resistance to creep over the structure is the same as the track adjacent to it. Hence the observed movement must be continuing past the flood opening. Thus, explaining the stress testing result.

The information in the Fixed Track Structure dataset was exported from TEAR. All bridges, level crossing and turnouts in the district were included in the dataset. In retrospect, flood openings, which are considered as bridges for maintenance and inspection scheduling purposes, should not have been included in the Fixed Track Structure dataset as they do not resist or eliminate creep past the structure.

4.2.1.2SW 721 263.000km

The stress testing at SW 721 263.000km showed a 9℃ reduction in the RNT in the left rail and a 3℃ reduction in the right rail. A deviation of -9℃ is a significant result as the limit practiced by the Toowoomba district is a ±10℃ deviation from the DNT, after which the rails shall be restressed. Thus the rail is on the verge of requiting attention, which was indicated by the analysis. The 3℃ reduction in the RNT of the right rail is too insignificant to endorse or reject the validity of the Rail Creep Analysis.

SW 721 263.000km was a location identified as displaying Excessive Creep as per CETS. Inspecting the records of the creep measurements at this location reveal the extent to which the displacement of the rails was excessive, see figure 4.3. The right rail had moved 190mm in the Down direction from its original position and the left rail had moved 150mm, again in the Down direction at the time of the last inspection. Thus it was an oddity to see that the RNT left rail was significantly lower than the DNT and the right rail only slightly.

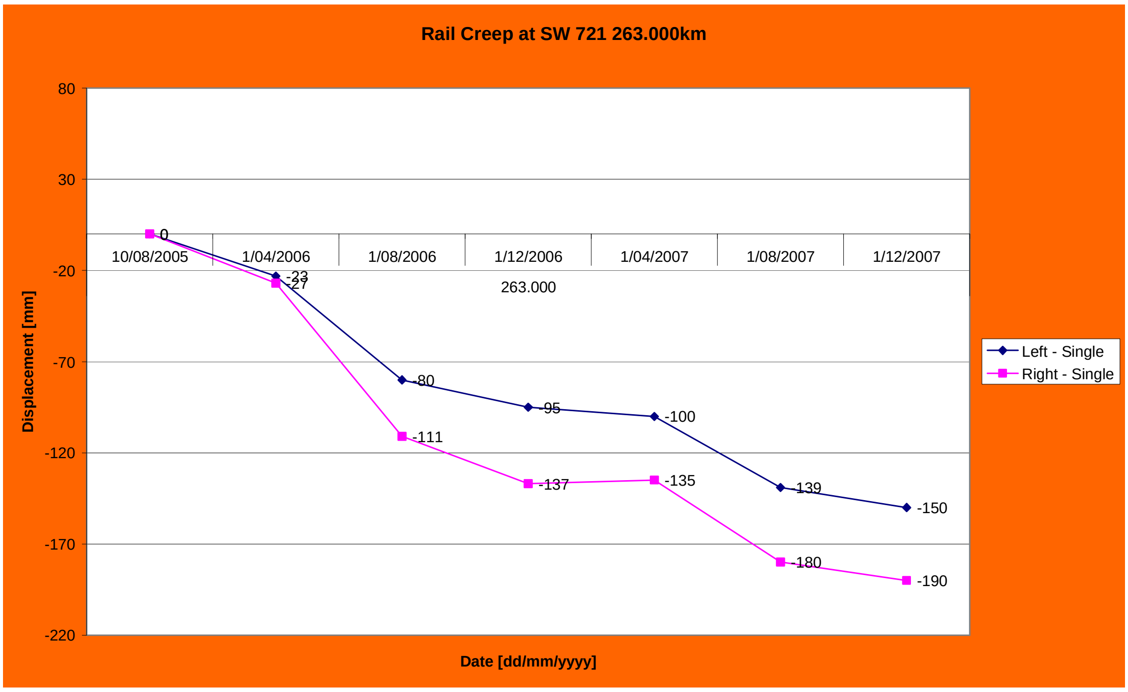


Figure 4.3 Rail creep at SW 721 263.00km

Table 4.4 is an extract from the Fixed Track Structure dataset, it identifies a fixed track structure, in the form of a level crossing, at SW 721 262.950km.

Table 4.4 Fixed Track Structure identified in the vicinity of SW 721 263.000km

Short Text	Line Section	Start km	End km	Class
SW LXING 262.950 SOUTH WELLTOWN RD	721	262.950	262.951	Level Crossing

It is generally accepted that a level crossing will eliminate all longitudinal movement of the rails through the crossing. Therefore the 190mm and 150mm of creep has moved into 50m of track. It was shown in the literature review that the limit 50mm creep into or out of 500m of track could cause a reduction of 8.55℃ in the RNT. This raises the question as why the deviation of the RNT in the rails at this location was not more significant.

Theoretical 190mm of creep into 50m of track would cause a strain of 0.0038, as calculated below:

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{190}{50 \times 10^3} = 0.0038$$

And,

$$\frac{\Delta l}{l_0} = \alpha \Delta T$$

Thus,

$$\Delta T = \frac{\left(\frac{\Delta l}{l_0}\right)}{\alpha}$$

$$\Delta T = \frac{0.0038}{11.7 \times 10^{-6}}$$

$$\Delta T = 325°C$$

For 41kg/m rail the equivalent force is,

$$N = EA\alpha\Delta T$$

$$N = \frac{200 \times 10^3 \times 5192 \times 11.7 \times 10^{-6} \times 325}{1000}$$

$$N = 3950kN$$

This is equivalent to a reduction in the RNT of 325℃ or equivalent to a force in the rail in the order of 3950kN. This is unrealistic as the track would have buckled. It has been deduced that there must be a small misalignment in the track that gradually developed over time, sufficiently alleviating the majority of the stress in the rails. This illustrates the complexity in applying theory to the phenomenon of buckling in its occurrence in railroad.

The results of the stress testing at this location were not as definitive as was anticipated after examining the creep trend, extent of creep and the location’s proximity to a fixed track structure. However as whole it may be considered a success that this location was identified by the Rail Creep Analysis as one of the rails at this location is on the verge of requiring attentions due to the considerable reduction in the RNT.

4.2.2 Stress Testing in Other Areas that coincide with Creep Monuments

The limited results for the stress testing preformed in the proposed areas could not facilitate an adequate assessments of the validity of the approach. In an attempt to further examine the validity of the methodology the results of all stress testing performed in the Western and South-Western systems was sought. Only the results of stress testing performed in areas that could be considered by the Rail Creep analysis were examined. This limited the results of the stress testing to be examined, to discrete areas that coincide with, or are in the vicinity of a creep monument (±200m). The results of stress testing performed in areas that satisfy these conditions are presented in tables 4.5, 4.6 and 4.7 (pp 72-74).

Recall that a location was proposed for stress testing if it displayed a trend of concern and the observed movement of the rails was in the direction of an adjacent fixed track structure. Table 4.5 (page 72) contains the results of stress testing in areas that display a trend of concern and are adjacent to a fixed track structure. However, these locations were not proposed for stress testing as the observed movement in the rail was in the direction away from a fixed track structure. The principle on which this project is based indicated that these locations should most probably in tension or the RNT will be higher than the DNT, thus presenting no appreciable risk of buckling.

Figure 4.4 shows the stress testing results from table 4.5 in the context of the safe range of neutral temperatures for the locations with DNT of 38℃.

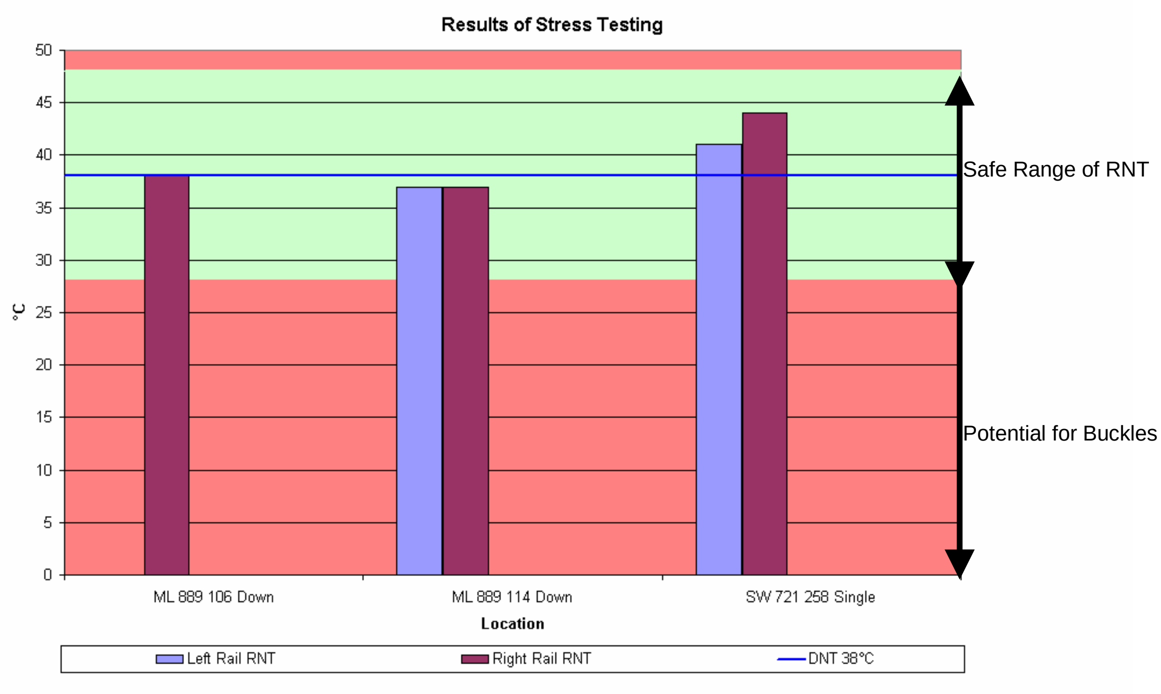


Figure 4.4 A chart of the results in table 4.5, shows the safe range of RNT about the 38℃ DNT

Figure 4.5 shows the stress testing results from table 4.5 in the context of the safe range of neutral temperatures for the locations with DNT of 37℃.

Figure 4.5 A chart of the results in table 4.5, shows the safe range of RNT about the 37℃ DNT

As was anticipated from the results of the Rail Creep Analysis, none of these locations present any appreciable risk of buckling. Thus, it is some consolation that these locations were not indicated as requiring stress testing, and the stress testing performed in these areas was redundant but confirmed that these locations present no appreciable risk of buckling. The mean deviation of the RNT in these areas was +1.33℃.

Table 4.6 (page 73) contains the results of stress testing for location that display a trend of concern but were not in the vicinity of a fixed track structure. These locations were not identified as requiring stress testing. Figure 4.6 shows the stress testing results from table 4.6 in the context of the safe range of neutral temperatures for the locations with DNT of 37℃.

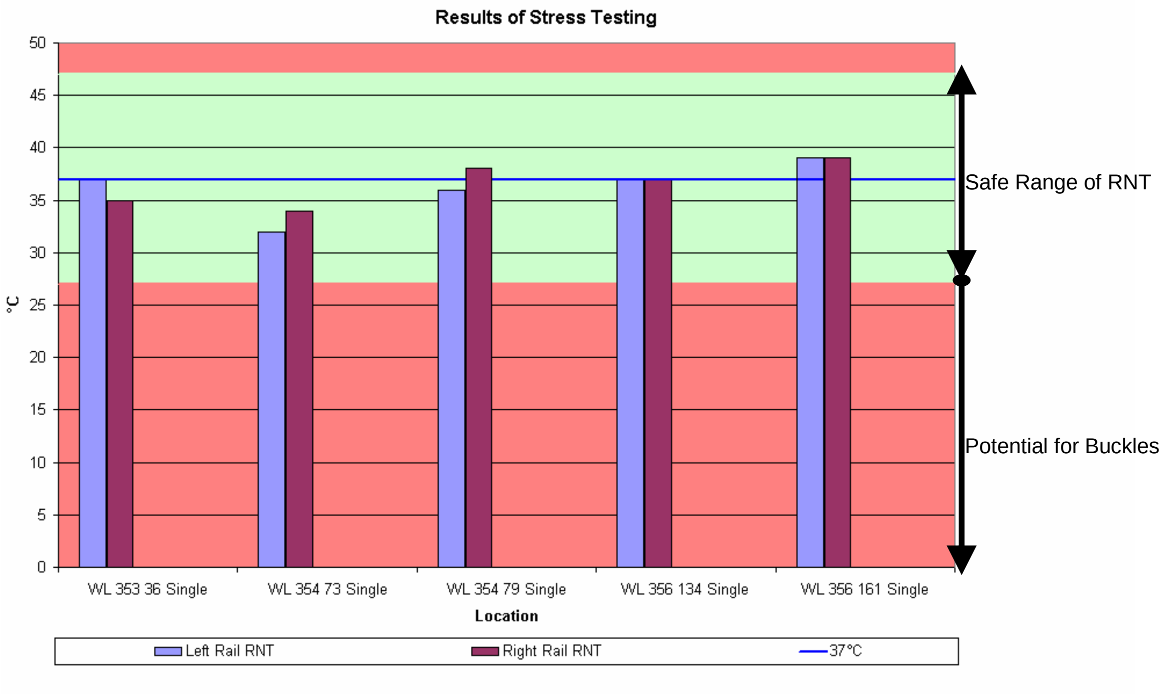


Figure 4.6 A chart of the results in table 4.6, shows the safe range of RNT about the 37℃ DNT

Figure 4.7 shows the stress testing results from table 4.6 in the context of the safe range of neutral temperatures for the locations with DNT of 38℃.

Figure 4.7 A chart of the results in table 4.6, shows the safe range of RNT about the 38℃ DNT

As was anticipated from the results of the Rail Creep Analysis, none of these locations present any appreciable risk of buckling. Again stress testing in these areas was redundant but confirmed that these locations present no appreciable risk of buckling. The mean deviation of the RNT in these areas was +1.14℃.

Table 4.7 (page 74) contains the stress testing results at location that were not identified as displaying a trend of concern, nor are they in the vicinity of a fixed track structure. Figure 4.8 shows the stress testing results from table 4.7 in the context of the safe range of neutral temperatures for the locations with DNT of 37℃.

Figure 4.8 A chart of the results in table 4.7, shows the safe range of RNT about the 37℃ DNT

Figure 4.9 shows the stress testing results from table 4.7 in the context of the safe range of neutral temperatures for the locations with DNT of 38℃.

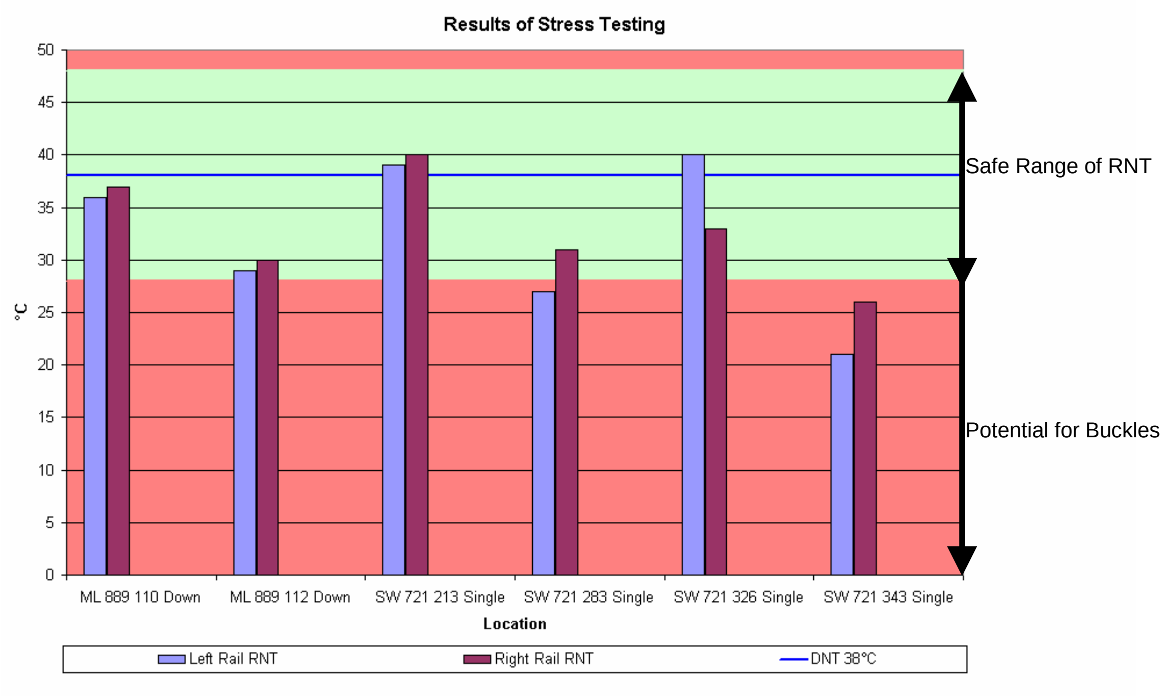


Figure 4.9 A chart of the results in table 4.7, shows the safe range of RNT about the 38℃ DNT

The mean deviation of the RNT in the areas in table 4.7 was -1.29℃.

Some of the locations not identified by the analysis as displaying a trend of concern were found to have deviated quite considerably from the DNT. This indicated that this initial analysis, concentrating on certain trend in rail creep at discrete location and the proximity of these locations to fixed track structures is not sufficient for identifying all potential high stress areas.

The mean deviation of the RNTs in the areas identified as requiring stress testing, at which the tests were performed, was -4.33℃. The mean deviation of the RNTs for the other areas that were stress tested was -0.25℃. These initial results suggest that there is some potential in using the Rail Creep Analysis to better predict potential high stress areas.

Table 4.5 Stress testing results in other areas that coincide with Creep Monuments

						Left Rail					**Right Rail**				
Line Prefix	**LSC**	**Location of Marker**	**Road**	**Creep Trend @ location**	**Comment**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**
WL	711	30	Single	Excessive Creep as per CETS - Right Rail	Close proximity to Fixed Track Structure	16	1.1	38	37	**1**					
ML	889	106	Down	Rapidly 'Diverging' Rails	Close proximity to Fixed Track Structure						14	1.45	38	38	**0**
ML	889	114	Down	'Diverging' Rails	Close proximity to Fixed Track Structure	31	0.9	37	38	**-1**	32	0.9	37	38	**-1**
SW	721	258	Single	'Diverging' Rails	Close proximity to Fixed Track Structure	23	1.3	41	38	**3**	23	1.35	44	38	**6**

Table 4.6 Stress testing results in other areas that coincide with Creep Monuments

						Left Rail					**Right Rail**				
Line Prefix	**LSC**	**Location of Marker**	**Road**	**Creep Trend @ location**	**Comment**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**
WL	353	36	Single	Excessive Creep as per CETS		27	0.95	37	37	**0**	22	0.95	35	37	**-2**
ML	546	120	Single	Non Recovering Creep		21	1.55	43	38	**5**	22	1.65	48	38	**10**
ML	889	108	Down	Rapidly 'Diverging' Rails		24	1.1	40	38	**2**	23	1.2	43	38	**5**
WL	354	73	Single	Excessive Creep as per CETS		27	0.85	32	37	**-5**	25	0.9	34	37	**-3**
WL	354	79	Single	Non Recovering Creep		33	0.85	36	37	**-1**	33	0.9	38	37	**1**
WL	356	134	Single	Excessive Creep as per CETS - Right Rail		23	1	37	37	**0**	23	1	37	37	**0**
WL	356	161	Single	Non Recovering Creep		25	1.05	39	37	**2**	25	1.05	39	37	**2**

Table 4.7 Stress testing results in other areas that coincide with Creep Monuments

						Left Rail					**Right Rail**				
Line Prefix	**LSC**	**Location of Marker**	**Road**	**Creep Trend @ location**	**Comment**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**	**Temp. ℃**	**Force Tonnes**	**SFT ℃**	**DNT ℃**	**Deviation ℃**
WL	711	19.956	Single			13	1.4	45	37	**8**	13	1.35	43	37	**6**
ML	889	110	Down			26	0.95	36	38	**-2**	24	1	37	38	**-1**
ML	889	112	Down			24	0.85	29	38	**-9**	25	0.85	30	38	**-8**
SW	551	70	Single			26	0.9	34	37	**-3**	26	0.85	30	37	**-7**
SW	721	213	Single			17	1.15	39	38	**1**	15	1.2	40	38	**2**
SW	721	283	Single			24	1	27	38	**-11**	23	1.1	31	38	**-7**
SW	721	326	Single			23	1.1	40	38	**2**	24	0.9	33	38	**-5**
SW	721	343	Single			16	1.05	21	38	**-17**	18	1.1	26	38	**-12**
WL	356	114	Single			25	0.95	36	37	**-1**	25	0.9	34	37	**-3**
WL	356	118	Single			21	1.2	42	37	**5**	23	1.3	45	37	**8**
WL	356	124	Single			15	1.2	40	37	**3**	17	1.25	42	37	**5**
WL	356	156	Single			13	1.3	42	37	**5**	15	1.3	43	37	**6**
WL	356	158	Single			21	1	36	37	**-1**	21	1	36	37	**-1**
WL	356	159.92	Single			25	1.1	41	37	**4**	25	0.9	34	37	**-3**

4.2.3 Retrospective Analysis of Past Buckle Location

The third avenue for assessing the validity of the methodology and analysis developed in this paper was a retrospective analysis of past buckle locations. A comprehensive list of all track misalignments for the period between summer 2007 and 2008 was compiled. These are shown in table 4.8. Where possible, the rail creep analysis methodology was performed on all creep data that predates each of the recorded buckles to determine, in retrospect, if the *CreepTrend* algorithm would have accurately predicted each of the buckles.

Table 4.8 Recorded buckles in the Toowoomba district, summer 2007 - 2008

Reported Track Buckles summer 2007 - 2008				
Date	**Prefix**	**LSC**	**Location km**	**Road**
31/08/2008	WL	711	5.000	Single
1/08/2008	WL	711	5.000	Single
13/05/2008	WL	463	84.000	Single
10/05/2008	WL	355	91.800	Single
28/02/2008	WL	354	61.000	Single
23/02/2008	ML	546	134.800	Single
22/02/2008	WL	353	44.160	Single
30/01/2008	WL	563	96.450	Single
29/01/2008	WL	355	91.700	Single
28/01/2008	ML	546	134.850	Single
28/01/2008	ML	546	129.300	Single
28/01/2008	ML	546	141.750	Single
28/01/2008	ML	889	105.900	Down
24/01/2008	WL	711	6.900	Single
4/12/2007	WL	355	98.200	Single
21/11/2007	WL	568	609.950	Single
21/11/2007	WL	711	4.985	Single
9/11/2007	ML	546	135.300	Single
2/11/2007	WL	568	605.500	Single

The two buckles at WL 711 5.000km could not have been predicted by the analysis as the creep monitoring locations nearest to this point are a 4.031km and 6.016km.

For the buckle at WL 463 84.000km on the 13/05/2008, the creep data that predates this buckle was examined for the creep monument at WL 463 83.900km. The results of the analysis are presented in table 4.9.

Table 4.9 Result of the retrospective analysis for the buckle at WL 463 84.000km.

Line Prefix	LSC	Location of Marker	Road	Creep Trend @ location	Comment
WL	463	83.900	Single		

The location was not identified as displaying a trend of concern. Thus, this area was not identified by the analysis as being a possible high stress area.

The buckle at WL 355 91.800km could not have been predicted by the analysis as the creep monitoring locations nearest to this point are a 91.000km and 93.000km.

For the buckle at WL 354 61.000km on the 28/02/2008, the creep data that predates this buckle was examined for the creep monument at WL 354 61.000km. The results of the analysis are presented in table 4.10.

Table 4.10 Results of the retrospective analysis for the buckle at WL 354 61.000km.

Line Prefix	LSC	Location of Marker	Road	Creep Trend @ location	Comment
WL	354	61.000	Single	'Diverging' Rails	

The results of the analysis indicate movement in the rails at WL 354 61.000km but the location could not be definitively identified as a high stress area by the analysis.

The buckle at ML 546 134.800km on the 23/02/2008 could not have been predicted by the analysis as the creep monitoring location nearest to this point is a 134.175km.

The retrospective analysis could not be preformed for the buckle at WL 353 44.160km on 22/02/2008 as there was insufficient data to permit the analysis.

The retrospective analysis could not be preformed for the buckle at WL 563 96.450km on 30/01/2008 as there was insufficient data to permit the analysis.

The buckle at WL 355 91.700km could not have been predicted by the analysis as the creep monitoring locations nearest to this point are a 91.000km and 93.000km.

The buckle at ML 536 134.850km on the 28/01/2008, could not have been predicted by the analysis as the creep monitoring location nearest to this point is a 134.175km.

The retrospective analysis could not be preformed for the buckle at ML 546 129.300km on 28/01/2008 as there was insufficient data to permit the analysis.

The retrospective analysis could not be preformed for the buckle at ML 546 141.750km on 22/02/2008 as there was insufficient data to permit the analysis.

For the buckle at ML 889 105.900km on the down road on the 28/01/2008, the creep data that predates this buckle was examined for the creep monument at ML 889 106.000km. The results of the analysis are presented in table 4.11.

Table 4.11 Results of the retrospective analysis for the buckle at ML 889 106.000km.

Line Prefix	LSC	Location of Marker	Road	Report @ location	Comment
ML	889	106.000	Down	Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 105.76km and 106.06km

The rail creep analysis would have predicted that this area was high stress, thus the buckle could have been prevented.

The buckle at WL 711 6.900km on 24/01/2008 could not have been predicted by the analysis as the creep monitoring locations nearest to this point are a 6.016km and 7.877km.

The buckle at ML 355 98.200km on 4/12/2007 could not have been predicted by the analysis as the creep monitoring locations nearest to this point are a 97.000km and 99.000km.

The retrospective analysis could not be preformed for the buckle at WL 568 609.950km on 21/11/2007 as there was insufficient data to permit the analysis.

The retrospective analysis could not be preformed for the buckle at WL 711 4.985km on 21/11/2007 as there was insufficient data to permit the analysis

The retrospective analysis could not be preformed for the buckle at ML 546 135.300km on 9/11/2007 as there was insufficient data to permit the analysis.

The retrospective analysis could not be preformed for the buckle at WL 568 605.500km on 2/11/2007 as there was insufficient data to permit the analysis.

Three out of the nineteen locations of the recorded buckles could be analysis retrospectively using the rails creep analysis. Of these three, one buckle location was identified by the retrospective analysis as being a possible high stress location and the buckle could have been prevented. This suggests that there is some potential for this analysis for identify potential buckle location.

The majority of the buckle location could not be analysed because they were not in the vicinity of a creep monument. The methodology developed in this paper relies in the records of rail creep at discrete locations, hence the analysis is only valid in the direct vicinity of these location. An overall indication of the stress conditions in the track of the entire Western and South-Western systems of QR can not be obtained from the creep trends displayed at the limited number creep monitoring locations. To identify the probable stress condition at intermediate location would require the installation of additional creep monuments such that the distance between the monuments is reduced significantly, and an investigation into the creep trends displayed at adjacent creep monuments.

The analysis developed in this paper can only indicate that a location is potentially high stress if it is in the vicinity of a fixed track structure, as research suggested that the majority of buckle occur with 100m of a fixed track structure. However, two out of three buckle locations that were analysed were not adjacent to, or in the vicinity of a fixed track structure and the one that was, was correctly identified as a high stress area.

4.3 Further Discussions

4.3.1 Validity of the Approach

Despite the considerable effort invested in attempting to validate the approach presented in this project, it can not be definitively stated that the methodology is valid or otherwise. The process of validating the methodology for identifying potential high stress areas was impeded by the fact the stress testing was not performed in the areas identified. Two alternative avenues were explored in an attempt to prove the validity or otherwise of the approach but these processes were cumbersome and obscure and contributed little to the project outcome.

It was identified that the mean deviation of the RNTs in the areas proposed for stress testing by the author was -4.33℃ and the me an deviation of the RNTs in the areas proposed by alternative methods was -0.25℃. This suggests that there is some potential in the methodology for better identifying potential high stress areas.

Valid or not, this investigation into the identification of potential high stress areas indicates that the number of discrete creep monitoring location is not sufficient to generate an accurate overall depiction of the development of stress conditions in the rails due to creep. Creep monuments space at every 2.000km, 5.000km or 10.000km cannot be used to accurately assess the stress condition at intermediate location.

4.3.2 Grade and Stress Conditions

It was identified in the literature review that the grade of the track is equally as relevant to the development of stresses in the rails as the location of fixed track structures. Considerable effort was made in attempting to obtain information pertaining to the grades at the locations' of the creep monuments. No source for this information was identified, thus it was excluded from the analysis.

4.3.3 Passive Resistance of the Track

It is indicated in the project aims and objective that the methodology developed would consider the stress in the rails and the passive resistance to buckling provided by the track structure, thus providing an all-inclusive assessment of the risk of buckling at the creep monitoring location.

The *CreepTrend* algorithm has the capacity to retrieve information about the structure of homogeneous section of track. However it was identified at the early stages of this project that the information in the asset database pertaining to track structure was not sufficient to facilitate a thorough assessment of the track's passive resistance to buckling. Consequentially this aspect was pursued no further.

The intention was to incorporate, in the Rail Creep Analysis, the methodology developed by the ROA for assessing the relative passive resistance of the track. Thus, having determined the probable stress conditions in the rails and the passive resistance of the track, an educated assessment of risk of buckling could be developed and used to prioritise the locations for track strengthening work, restressing and other preventative measures.

If sufficient information was available in the asset database, pertaining to the track structure and grades for homogeneous sections of track, correlations between the locations identified as potential buckle location, based on the probable stress condition, the passive resistance of the track structure and track grade and geometry could have been identified. These correlations could have been used to examine the risk of buckling in comparable sections of track, extending the analysis from the discrete creep monitoring locations to the entire district.

5 Conclusions and Recommendations

This project has developed a recursive methodology for identifying situations where the longitudinal movement of rail is likely to result in the accumulation of longitudinal stresses which is conducive to buckling. The approach presented in this paper is a practical methodology for identifying and predicting possible buckle locations without placing undue burden on maintenance staff, by utilizing readily available, site-specific information collected on routine inspections of the track. The methodology is appropriate for large scale applications in identifying and predicting potential high stress areas across the entire Western and South-Western systems of Queensland Rail.

It was identified that the major stresses in the rails is generated by thermal forces which can be controlled to some extent by adopting and maintaining an appropriate DNT. Rail creep can cause a deviation of the RNT from that of the DNT and monitoring this deviation is a complicated endeavour. The methodology developed for identifying situation where a deviation of the RNT may lead to track stability issues has been based on the creep trends displayed at numerous creep monitoring locations and their proximity to fixed track structures.

An initial investigation into the success of the methodology developed in this project was undertaken. The results of the assessment where somewhat inconclusive and it requires further investigation, but there was some indication of the potential for such a methodology. It was identified that the intervals at which the creep monuments in the district are spaced can not facilitated the identification of probable stress condition at intermediate location using the analysis developed in this paper. It may be necessary to install additional creep monuments in the district to enable further identification of potential high stress area. It would also be appropriate to investigate the creep trends displayed at adjacent creep monuments in an attempt to assess the probable stress conditions at intermediate locations. Further recommendations on future work have been reserved for later in this chapter.

5.1 Achievement of Objectives

The aim and specific objectives of this project are presented in the Project Specification in Appendix A. These specific objectives are repeated hereafter accompanied with explanations on how they were achieved.

I. **Research any necessary background information relating to track stability and rail stress management**.

Initiating this project was a review of material relating to rail stress management and track stability. The review commenced with a study of the general railway track structure pertaining to the interaction between track components and the manner in which the track is restrained both laterally and longitudinally. The mechanisms by which longitudinal stresses are induced in the rails were examined.

After identifying the passive, restraining forced that resist buckling and the opposing actions that promote buckling, the review outlined some existing rail stress management strategies and track buckling prevention procedures currently being implemented by railway networks.

Thus, this objective was achieved, the proof of which can be seen in Chapter 2 of this dissertation. The knowledge gained from the literature review is applied throughout this project.

II. **Critically evaluate rail stress management strategies and track buckling prevention procedures currently being implemented by railway networks.**

The existing rail stress management strategies and track buckling prevention procedures detailed in the review were critically evaluated to establish both their merits and perceived limitations or drawbacks. Evidence of this is in Chapter 2 of this dissertation.

The need to improve the approaches to buckle prevention was recognised and this governed the approach taken in developing a methodology which addresses the identified shortcomings of the existing methods.

III. Determine the geographical boundaries for the data and field investigation in the Western and South West system of Queensland Rail.

Though this project is primarily an academic exercise contributing to the undergraduate degree of the author, this project has also been undertaken for the development of a methodology appropriate for implementation in the Western and South-Western systems of QR. By default, the investigation area for this project was the Western and South-Western systems in their entirety.

IV. Compile track location data relevant to rail stress management and buckle prevention for the investigation area.

The data relevant to rails stress management was identified as the rail creep measurements at the numerous creep monuments in the Western and South-Western systems. This project adopted the established method of measuring rail creep that is used by the Infrastructure Maintenance team for the Western and South-Western systems of QR. This facilitated the used of the existing data on rail creep, and the data set continued to grow as it became available throughout the project.

At the inception of this project it was apparent that data regarding the track structure at test locations within the investigation area will be required to facilitate a thorough assessment of the track's lateral resistance. This information was sought from the asset database but it was found that the information contained in the database was not sufficient to facilitate a thorough assessment of the track's lateral resistance. This did not influence the project to a significant degree as methods exist for assessing the lateral resistance and this project was focused on addressing the 'other side of the coin' – the stress conditions in the rails.

V. Analyse the above mentioned data to determine the influence of each parameter on the longitudinal rails stress.

It was identified in the literature review that the longitudinal movement of rail can cause a deviation of the RNT from that of the DNT, leading to the development of stress condition that are conducive to buckling.

The rail creep data was examined to identify the general trend in the movement of the rails at numerous sample locations. The trends were initially described qualitatively and the qualitative descriptions of the trends observed in the creep data lead to the development of nominal classification system and several recurring trends were identified. The implication of each recurring trend was identified through the application of buckling theory and knowledge of stress conditions that are conducive to buckling. Engineering judgment by experienced personnel knowledgeable in track buckling behaviour was also employed in determining the implications of the major trends observed at the sample locations. Several of the major recurring trends were identified as being “trends of concern”. This procedure is described in Chapter 3.

VI. Develop an accurate and consistent method of identifying locations that are most susceptible to track stability problems.

The development of an objective, accurate and consistent method of identifying locations that are most susceptible to track stability problems is the main aim of this project. This was achieved by developing an algorithm that to analyse the creep data at the numerous locations and identify locations displaying the trends of concern. The recursive computational procedure has the capacity to identify the adjacency of fixed track structures and determine if the location is a potential high stress area. The algorithm produced a concise tabulated report for each location analysed. The development of the analysis is presented in Chapter 3 and the results of the analysis are presented in Chapter 4.

VII. Recommend possible procedures for further investigation of the track stability problems pertaining to the Western and South West system.

Recommendations on possible procedures for further investigations into track stability problems will be presented at later in this Chapter.

VIII. Report on the investigation in the required oral and written formats.

The project is presented in the required written format in this dissertation. This project has been presented in the appropriate oral format at the 2008 University of Southern Queensland Project Conference.

Evidently, the achievements of this project align well with the objectives outlined in the Project Specification.

5.2 Conclusions

The existing approaches to ensuring track stability have been employed with some success in the past few years, however methods such as the Track Stability Form, developed by the ROA, concentrate only on the passive resistance of the track structure. As a result, the track strengthening work performed is resource hungry and the approach is time consuming.

The need to address the stress conditions in the rails was identified. To make better use of the resources it is necessary to identify location at which the stress conditions are conducive to buckling as well as assessing the passive resistance of the track.

The methodology develop in this project was used predict the probable stress condition in the rails in the vicinity of the discrete creep monitoring locations in the network. The creep trend displayed at a location and the adjacency of fixed track structures to the location facilitated an assessment of the probable stress conditions in the rails at the location. The development of the methodology incorporating a recursive computational procedure for identifying possible high stress areas was the main objective of the project and a result in itself. Attempts to validate the results of the methodology were impeded by the fact the stress testing was only performed at two of the thirty one proposed locations, this was beyond the author control. Repercussions of this meant that it was not possible to definitely determine the success of the approach.

This initial investigation indicated that there may be some potential in using the methodology developed in this paper. In the areas proposed for stress testing as a result of this project at which the stress testing was performed, the mean deviation of the RNT was -4.33℃ whereas the mean deviation for areas identified using alternative methods was -0.25℃. In the retrospective analysis of past buckle location, out of the three buckles that could be assess with the rail creep methodology, one location was identified as a potential high stress area.

This methodology can only reasonably predict the probable the stress condition in an area if it is in the vicinity of a creep monument and adjacent to a fixed track structure. This is because of the parameter on which the project methodology was based and the information available. The methodology developed in this project is appropriate for determining situations where the longitudinal stress in rail is likely to cause operational problems in the track. However, the location identified as being possible high stress areas will not be the only high stress areas in the district. It is not reasonable to expect that all high stress area could be predicted based on the rail creep analysis as the locations of the creep monuments are spaced up to 10.000km apart. The rail creep analysis cannot predict the stress condition at intermediate locations.

To identify further location that may presents track stability issues using this approach, there is a need to install additional creep monuments in the district. Another avenue would be to investigate the creep trends displayed at adjacent creep monuments to predict the probable stress condition at intermediate locations, though this would still require the installation of additional creep monuments.

The information available in the asset database is not sufficient to thoroughly asses the passive resistance of the track, thus it is necessary to perform field investigations to do so. If the database had the capacity to handle the necessary information, pertaining to track structure, to facilitate an assessment of the passive resistance of the track by employing the method developed by the ROA, it would facilitate a degree of remote condition monitoring. The author appreciates that it would be an onerous task to compile this information and keep it up to date.

The approach to identifying potential high stress area developed in this project is somewhat cumbersome and obscure and the success of which has yet to be verified. The approach is purely a qualitative assessment of the probable stress conditions in the rails and no measureable value of the magnitude of the stresses in the rails is determined. But this initial investigation indicated that there is some potential in adopting the rail creep analysis in identifying potential high stress areas.

5.3 Recommendations

5.3.1 Incorporating the Rail Creep Analysis into the Track Stability Management Strategy

An appropriate procedure for incorporating the Rail Creep Analysis developed in this project into the Track Stability Managements Strategy in the Western and South-Western Systems of QR is presented in figure 5.1. The modified procedure is intended to facilitate the prioritisation of track strengthening work and preventative measures to better utilise the available resources and ensure track stability throughout the Systems.

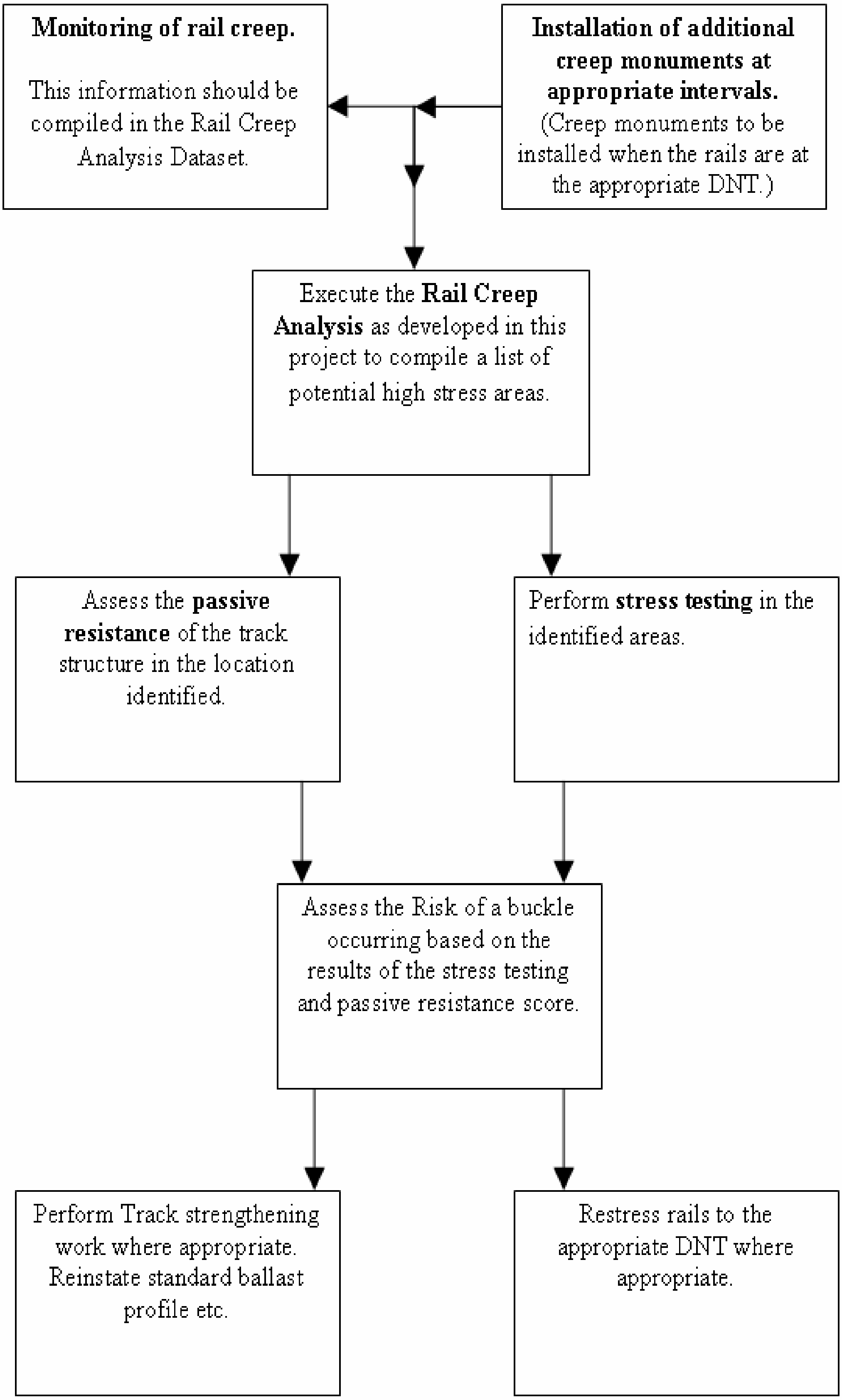


Figure 5.1 An appropriate procedure for incorporating the Rail Creep Analysis into the Track Stability Management Strategy.

5.3.2 Further Work

Recommendations pertaining to further work that would improve the processes for identifying potential buckle location in the Western and South-Western Systems are outlined below.

- Perform stress testing in the areas identified by the analysis as potential high stress areas and examine the results to assess the validity of the approach.
- Installation of additional creep monuments at appropriate intervals to facilitate a more thorough assessment of the stress condition developing in the track. This is because the analysis developed can not predict the stress conditions at intermediate locations.
- Examine the relationships between the trends displayed adjacent creep monuments to facilitate the prediction of stress condition at intermediate locations.
- Expand the capability of the Track Equipments and Asset Register to accept the necessary information to facilitate remote assessment of the passive resistance of the track structure for homogeneous section of track. It will be necessary to compile the necessary data and maintain current information.
- Incorporate the methodology for the Track Stability Form, as developed by the ROA, into the algorithm to assess the passive resistance of homogeneous section of track. This would facilitate the development of an all-inclusive semi-remote assessment of the risk of buckling at the creep monitoring location.
- Examine correlations between the locations identified as potential buckle location, based on the probable stress condition, the passive resistance of the track structure and track grade and geometry and examine the risk of buckling in comparable sections of track, thus extending the analysis from the discrete creep monitoring locations to the entire district.
- A project to identify, develop and adopt an appropriate technology for measuring the stress in rails or for monitoring the RNT of the rails in track.

List of References

Australian Transport Safety Bureau, (ATSB) 2005, *Derailment of Pacific NationalTrain 6MP4 Koolyanobbing, Western Australia and Pacific National Train 6SP5 Booraan, Western Australia Report.*

Bonnett, CF 2005*, Practical Railway Engineering,* 2nd edn, Imperial College Press, London.

Esveld, C 2001, *Modern Railway Track*, 2nd edn, MRT-Productions, The Netherlands.

Hay, WW 1982, Railroad Engineering, 2nd edn, Wiley-Interscience, New York, USA.

Heeler, C L 1979, *British Railway Track: Design, Construction, Maintenance*; The Permanent Way institution; Nottingham, UK

Howie, A 2005, *Track Buckle Report, 2004/2005*; Network Access, QR.

Kish, A & Samavedam, G 2001, *Risk Analysis Based CWR Track Buckling Safety Evaluations*, Volpe Centre, Cambridge.

Marks, I 2001, ‘Management of Continuously Welded Rail Track in Queensland Rail’, *Proceedings the 7th international heavy haulage conference,* Perth Australia, pp. 379-402.

Profillidis, VA 1995, *Railway Engineering*, University Press, Cambridge England.

QR, 2005, *Civil Engineering Track Standards (CETS): Track Stability*

QR, 2005, Hot Weather precautions for Track Stability; Standard: SAF/STD/0075/CIV

QR, 2005, *Civil Engineering Publication No. 44; Measurement of Rail Stress Free Temperature.*

Railways of Australia, (ROA) 1991, *A Review of Track Design Procedures – Volume 1 & 2.*

Railways of Australia, (ROA) 1988, *Track Buckling – Technology development and application report*.

Volpe Centre, 2002 Track Buckling Research, Structures and Dynamics Division, viewed 20 May 2008 www.volpe.dot.gov/sdd/buckling.html

Samavedam, G, Kish, A & Jeong, D 1986, *Experimental Investigation of Dynamic Buckling of CWR Tracks*, Dept. of Transportation USA, Federal Railroad Administration, cited in Railways of Australia, (ROA) 1988, *Track Buckling – Technology development and application report*, p.19.

Bibliography

Beer, FP, Johnston, ER Jr. & DeWolf, JT 2004, *Mechanics of Materials*, 3rd edn in SI Units, McGraw-Hill Education, New York.

Foster, SJ & Kilpatrick AE 2007, ‘Elastic Column Buckling’, *Reinforced Concrete Basics; Analysis and Design of Reinforced Concrete Structures*, p. 235, Pearson Education, Australia.

Moyar, GJ, Pilkey WD & Pilkey BF (ed.) 1978, *Track/Train Dynamics & Design*: *Advanced Techniques*, Pergamon Press, Sydney.

Queensland Rail - Network Access, 2008, *Network Access*, viewed May 14 2008 www.networkaccess.qr.com.au

QR, 1972, Civil Engineering Publication No. 2; Trackman’s Manual.

Wasserman, S 2000, ‘Remote Condition Monitoring – a user’s perspective’, *Railtex – International Railway Engineering Conference: Railway Infrastructure*, Birmingham UK.

Appendix A – Project Specification

University of Southern Queensland

FACILITY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

For: Zayne Ole

Topic: Rail Stress Management – Track Stability and Buckling.

Supervisor: A/Prof. Ron Ayers

William Bolton, District Planning Coordinator, QR

Industry Organisation: Queensland Rail

Project Aim: This project seeks to develop a practical method of determining situations where the longitudinal stress in rail is likely to cause operational problems in the track. The project will focus particularly on long welded rail sections, although continuous welded rail and jointed rail may also be investigated.

Programme: *(Issue A, 25 March 2008)*

1) Research background information relating to track stability and rail stress management.
2) Critically evaluate rail stress management strategies and track buckling prevention procedures currently being implemented by railway networks.
3) Determine the geographical boundaries for the data and field investigation in the Western and South West system of Queensland Rail.
4) Compile track location data relevant to rail stress management and buckle prevention for the investigation area.
5) Analyse the above mentioned data to determine the influence of each parameter on the longitudinal rails stress.
6) Develop an effective method of identifying track locations that are most susceptible to track stability problems.
7) Recommend possible procedures for further investigation of the track stability problems pertaining to the Western and South West system.
8) Report on the investigation in the required oral and written formats.

If time permits:

9) Devise a method of determining the longitudinal stress in rail in track.

Agreed: ____________________ (Student) ______________________ (Supervisor)

Date: / / 2008 Date: / / 2008

Examiner/Co-examiner: ____________________________

Appendix B – Locations of the Creep Monuments in the Western and South-Western Systems

Inspector	Line Prefix	LSC	Location of Marker	Road
A	WL	353	34.000	Single
A	WL	353	36.000	Single
A	WL	353	38.000	Single
A	WL	353	39.866	Single
A	WL	353	42.000	Single
A	ML	546	116.000	Single
A	ML	546	118.000	Single
A	ML	546	120.000	Single
A	ML	546	122.000	Single
A	ML	546	124.000	Single
A	ML	546	125.977	Single
A	ML	546	128.015	Single
A	ML	546	130.000	Single
A	ML	546	132.020	Single
A	ML	546	134.175	Single
A	ML	546	135.931	Single
A	ML	546	138.075	Single
A	ML	546	140.038	Single
A	ML	546	142.032	Single
A	ML	546	144.010	Single
A	ML	546	145.811	Single
A	ML	546	148.052	Single
A	ML	546	149.927	Single
A	ML	546	152.082	Single
A	ML	546	154.000	Single
A	ML	546	156.287	Single
A	ML	546	157.837	Single
A	ML	546	159.900	Single
A	WL	711	1.930	Single
A	WL	711	4.031	Single
A	WL	711	6.016	Single
A	WL	711	7.877	Single
A	WL	711	10.172	Single
A	WL	711	11.835	Up
A	WL	711	11.835	Down
A	WL	711	13.883	Single
A	WL	711	15.901	Single
A	WL	711	17.849	Single
A	WL	711	19.956	Single
A	WL	711	22.219	Single
A	WL	711	24.000	Single
A	WL	711	26.000	Single
A	WL	711	28.000	Single
A	WL	711	30.000	Single
A	WL	711	32.000	Single
A	SL	718	162.380	Single
A	SL	718	168.780	Single
A	SL	718	173.900	Single
A	SL	718	180.000	Single
A	SL	718	186.000	Single
A	SL	718	190.000	Single
A	SL	718	195.000	Single
A	SL	718	200.000	Single
A	ML	889	57.915	Up
A	ML	889	57.915	Down
A	ML	889	60.000	Up
A	ML	889	60.000	Down
A	ML	889	62.000	Up
A	ML	889	62.000	Down
A	ML	889	63.973	Up
A	ML	889	63.973	Down

A	ML	889	65.672	Up
A	ML	889	65.672	Down
A	ML	889	67.959	Up
A	ML	889	67.959	Down
A	ML	889	69.988	Single
A	ML	889	72.013	Single
A	ML	889	73.932	Single
A	ML	889	76.080	Single
A	ML	889	77.935	Up
A	ML	889	77.954	Down
A	ML	889	80.038	Up
A	ML	889	80.040	Down
A	ML	889	82.000	Up
A	ML	889	82.000	Down
A	ML	889	84.050	Up
A	ML	889	84.050	Down
A	ML	889	86.000	Up
A	ML	889	86.000	Down
A	ML	889	88.000	Up
A	ML	889	88.000	Down
A	ML	889	89.966	Up
A	ML	889	89.966	Down
A	ML	889	92.000	Up
A	ML	889	92.000	Down
A	ML	889	94.000	Up
A	ML	889	94.000	Down
A	ML	889	96.000	Up
A	ML	889	96.000	Down
A	ML	889	98.000	Up
A	ML	889	98.000	Down
A	ML	889	100.000	Up
A	ML	889	100.000	Down
A	ML	889	102.000	Up
A	ML	889	102.000	Down
A	ML	889	104.071	Up
A	ML	889	104.071	Down
A	ML	889	106.000	Up
A	ML	889	106.000	Down
A	ML	889	108.000	Up
A	ML	889	108.000	Down
A	ML	889	110.000	Up
A	ML	889	110.000	Down
A	ML	889	112.000	Up
A	ML	889	112.000	Down
A	ML	889	114.000	Up
A	ML	889	114.000	Down
B	SL	550	260.000	Single
B	SL	550	270.000	Single
B	SL	550	280.000	Single
B	SL	550	290.000	Single
B	SL	550	300.000	Single
B	SL	550	310.000	Single
B	SL	550	317.000	Single
B	SW	551	5.000	Single
B	SW	551	10.000	Single
B	SW	551	15.000	Single
B	SW	551	20.000	Single
B	SW	551	25.000	Single
B	SW	551	30.000	Single
B	SW	551	33.000	Single
B	SW	551	35.000	Single

B	SW	551	36.400	Single
B	SW	551	40.000	Up
B	SW	551	40.000	Down
B	SW	551	42.000	Single
B	SW	551	45.000	Single
B	SW	551	50.000	Single
B	MN	556	0.700	Single
B	MN	556	8.800	Single
B	MN	556	9.500	Single
B	MN	556	21.300	Single
B	MN	556	31.600	Single
B	MN	556	39.000	Single
B	MN	556	39.500	Single
B	MN	556	40.000	Single
B	MN	556	41.000	Single
B	MN	556	42.000	Single
B	MN	556	44.000	Single
B	MN	556	50.000	Single
B	MN	556	58.000	Single
B	MN	556	63.000	Single
B	MN	556	68.000	Single
B	SL	718	208.600	Single
B	SL	718	210.600	Single
B	SL	718	212.600	Single
B	SL	718	215.000	Single
B	SL	718	220.000	Single
B	SL	718	223.000	Single
B	SL	718	226.000	Single
B	SL	718	231.000	Single
B	SL	718	234.000	Single
B	SL	718	237.200	Single
B	SL	718	238.700	Single
B	SL	718	240.000	Single
B	SL	718	243.800	Up
B	SL	718	243.800	Down
B	SL	718	246.000	Single
B	SL	718	250.200	Single
C	SW	551	55.000	Single
C	SW	551	60.000	Single
C	SW	551	65.000	Single
C	SW	551	70.000	Single
C	SW	551	75.000	Single
C	SW	551	80.000	Single
C	SW	551	85.000	Single
C	SW	551	90.000	Single
C	SW	551	95.000	Single
C	SW	551	100.000	Single
C	SW	551	105.000	Single
C	SW	551	110.000	Single
C	SW	551	115.000	Single
C	SW	553	120.000	Single
C	SW	553	125.000	Single
C	SW	553	130.000	Single
C	SW	553	135.000	Single
C	SW	553	140.000	Single
C	SW	553	145.000	Single
C	SW	553	150.000	Single
C	SW	553	155.000	Single
C	SW	553	160.000	Single
C	SW	553	165.000	Single
C	SW	553	170.000	Single
C	SW	553	175.000	Single

C	SW	553	180.000	Single
C	SW	553	185.000	Single
C	SW	553	190.000	Single
C	SW	553	195.000	Single
C	SW	721	203.000	Single
C	SW	721	208.000	Single
C	SW	721	213.000	Single
C	SW	721	218.000	Single
C	SW	721	223.000	Single
C	SW	721	228.000	Single
C	SW	721	233.000	Single
C	SW	721	233.990	Single
C	SW	721	238.000	Single
C	SW	721	242.550	Single
C	SW	721	243.000	Single
C	SW	721	248.000	Single
C	SW	721	248.375	Single
C	SW	721	250.225	Single
C	SW	721	253.000	Single
C	SW	721	258.000	Single
C	SW	721	263.000	Single
C	SW	721	268.000	Single
C	SW	721	273.000	Single
C	SW	721	278.000	Single
C	SW	721	283.000	Single
C	SW	721	284.400	Single
C	SW	721	288.000	Single
C	SW	721	292.000	Single
C	SW	721	296.000	Single
C	SW	721	303.000	Single
C	SW	721	308.000	Single
C	SW	721	313.000	Single
C	SW	721	316.615	Single
C	SW	721	318.000	Single
C	SW	721	323.000	Single
C	SW	721	326.000	Single
C	SW	721	328.000	Single
C	SW	721	333.000	Single
C	SW	721	338.000	Single
C	SW	721	343.000	Single
C	SW	721	346.000	Single
C	SW	721	348.000	Single
C	SW	722	361.000	Single
C	SW	722	371.000	Single
C	SW	722	381.000	Single
C	SW	722	391.000	Single
C	SW	722	400.000	Single
D	GL	559	1.020	Single
D	GL	559	6.000	Single
D	GL	559	11.000	Single
D	GL	559	16.000	Single
D	GL	559	17.700	Single
D	GL	559	21.000	Single
D	GL	559	26.000	Single
D	GL	559	31.000	Single
D	GL	559	36.000	Single
D	GL	559	41.000	Single
D	GL	559	46.000	Single
D	GL	559	51.000	Single
D	GL	559	56.000	Single
D	GL	559	61.000	Single

D	GL	559	66.000	Single
D	GL	559	71.000	Single
D	GL	559	76.000	Single
D	GL	559	81.000	Single
D	GL	559	86.000	Single
D	GL	559	91.000	Single
D	GL	559	96.000	Single
D	GL	559	101.000	Single
D	GL	559	106.000	Single
D	GL	559	111.100	Single
D	GL	559	116.000	Single
D	GL	559	121.000	Single
D	GL	559	126.000	Single
D	GL	559	131.000	Single
D	GL	559	136.000	Single
D	GL	559	141.000	Single
D	GL	559	143.000	Single
E	WL	353	43.900	Single
E	WL	354	45.010	Single
E	WL	354	47.002	Single
E	WL	354	49.000	Up
E	WL	354	49.000	Down
E	WL	354	51.000	Single
E	WL	354	53.000	Single
E	WL	354	55.000	Single
E	WL	354	57.000	Up
E	WL	354	57.000	Down
E	WL	354	59.000	Single
E	WL	354	61.000	Single
E	WL	354	63.000	Single
E	WL	354	65.000	Single
E	WL	354	67.110	Up
E	WL	354	67.110	Down
E	WL	354	69.000	Single
E	WL	354	71.000	Single
E	WL	354	73.000	Single
E	WL	354	75.000	Single
E	WL	354	77.000	Single
E	WL	354	79.000	Single
E	WL	354	81.000	Single
E	WL	355	85.000	Single
E	WL	355	87.000	Single
E	WL	355	89.000	Single
E	WL	355	91.000	Single
E	WL	355	93.000	Single
E	WL	355	95.000	Single
E	WL	355	97.000	Single
E	WL	355	99.000	Single
E	WL	355	101.000	Single
E	WL	355	103.000	Single
E	WL	355	105.000	Single
E	WL	355	107.000	Down
E	WL	355	107.000	Up
E	WL	356	108.000	Single
E	WL	356	110.000	Single
E	WL	356	112.000	Single
E	WL	356	114.000	Single
E	WL	356	115.900	Single
E	WL	356	118.000	Single
E	WL	356	120.000	Single
E	WL	356	122.000	Single

E	WL	356	124.000	Single
E	WL	356	126.000	Single
E	WL	356	127.600	Down
E	WL	356	127.600	Up
E	WL	356	130.000	Single
E	WL	356	132.000	Single
E	WL	356	134.000	Single
E	WL	356	136.000	Single
E	WL	356	138.000	Single
E	WL	356	140.000	Single
E	WL	356	142.000	Single
E	WL	356	144.000	Single
E	WL	356	146.000	Single
E	WL	356	148.000	Single
E	WL	356	150.000	Single
E	WL	356	152.000	Single
E	WL	356	154.000	Single
E	WL	356	156.000	Single
E	WL	356	158.000	Single
E	WL	356	159.920	Single
E	WL	356	161.000	Single
E	WL	356	163.750	Single
E	WL	463	83.900	Single
E	WL	563	166.000	Single
E	WL	563	168.000	Single
E	WL	563	170.000	Single
E	WL	563	172.000	Single
E	WL	563	174.000	Single
E	WL	563	176.000	Single
E	WL	563	178.000	Single
E	WL	563	180.000	Single
E	WL	563	182.000	Single
E	WL	563	184.000	Single
E	WL	563	186.000	Single
E	WL	563	188.000	Single
E	WL	563	190.000	Single
E	WL	563	192.000	Single
E	WL	563	194.000	Down
E	WL	563	194.000	Up
E	WL	563	196.000	Single
E	WL	563	198.000	Single
E	WL	563	200.000	Single
E	WL	563	202.000	Single
E	WL	563	204.000	Single
E	WL	563	206.000	Single
E	WL	563	208.000	Single
E	WL	565	208.400	Single
E	WL	565	213.400	Single
E	WL	565	218.400	Single
E	WL	565	223.400	Single
E	WL	565	228.400	Single
E	WL	565	233.400	Single
E	WL	565	238.400	Single
E	WL	565	243.400	Single
E	WL	565	248.400	Single
E	WL	565	253.400	Single
E	WL	565	258.400	Single
E	WL	565	263.400	Single
E	WL	565	268.400	Single
E	WL	565	273.400	Single
F	WL	565	278.400	Single

F	WL	565	283.400	Single
F	WL	565	288.400	Single
F	WL	565	293.400	Single
F	WL	565	298.400	Single
F	WL	565	303.400	Single
F	WL	565	308.400	Single
F	WL	565	313.400	Single
F	WL	565	318.400	Single
F	WL	565	323.400	Single
F	WL	565	328.400	Single
F	WL	565	333.600	Single
F	WL	565	338.400	Single
F	WL	565	343.400	Single
F	WL	565	348.500	Single
F	WL	567	351.200	Single
F	WL	567	361.200	Single
F	WL	567	371.200	Single
F	WL	567	381.200	Single
F	WL	567	391.200	Single
F	WL	567	401.200	Single
F	WL	567	411.200	Single
F	WL	567	421.200	Single
F	WL	567	431.200	Single
F	WL	567	441.200	Single
F	WL	567	451.200	Single
F	WL	567	461.200	Single
F	WL	567	471.200	Single
F	WL	567	481.200	Single
F	WL	568	491.200	Single
F	WL	568	501.200	Single
F	WL	568	511.200	Single
F	WL	568	521.200	Single
F	WL	568	531.200	Single
F	WL	568	541.200	Single
F	WL	568	551.200	Single
F	WL	568	561.200	Single
F	WL	568	571.000	Single
F	WL	568	581.000	Single
F	WL	568	591.000	Single
F	WL	568	601.000	Single
F	WL	568	611.000	Single
G	GW	716	0.000	Single
G	GW	716	10.500	Single
G	GW	716	19.800	Single
G	GW	716	30.370	Single
G	GW	716	40.000	Single
G	GW	716	50.000	Single
G	GW	716	60.000	Single
G	GW	716	70.000	Single
G	GW	716	80.500	Single
G	GW	717	90.100	Single
G	GW	717	100.000	Single
G	GW	717	110.000	Single
G	GW	717	120.000	Single
G	GW	717	130.500	Single
G	GW	717	140.000	Single
G	GW	717	149.950	Single
G	GW	717	160.000	Single
G	GW	717	170.000	Single
G	GW	717	180.000	Single
G	GW	717	190.000	Single
G	GW	717	200.000	Single

Appendix C – *CreepTrend* program Script

```
Sub CreepTrend()


' CreepTrend Macro

' Macro recorded 18/05/2008 by Zayne Ole


'''''''''''''''''''''''''''''''''

' Keyboard Shortcut: Ctrl+Shift+C

'''''''''''''''''''''''''''''''''

'   ******************************

'   ****Clearing the Contents****

    Sheets("dummy_sheet").Select

    Cells.Select

    Selection.ClearContents


    Sheets("Report").Select

    Cells.Select

    Selection.ClearContents

'   ******************************




'   ******************************

    Application.ScreenUpdating = False

    Sheets("Data").Select

    Selection.AutoFilter Field:=8, Criteria1:="="

    Range("J8").Select

    ActiveCell.Offset(1, 0).Range("A1").Select

    Range(Selection, ActiveCell.SpecialCells(xlLastCell)).Select

    Selection.ClearContents

    ActiveWindow.ScrollRow = 1

    Selection.AutoFilter Field:=8

'   ******************************




'   ******************************
```

```
'   Set the END point in data set

    Range("C8").Select

    Do Until ActiveCell.Value = ""

    ActiveCell.Offset(1, 0).Range("A1").Select

    Loop

    ActiveCell.Value = "END"

'   *****************************




'   ************************************************************

'   Setting up the column heading for the Report table.

    Sheets("Report").Select

    Range("A1").Select


    ActiveCell.FormulaR1C1 = "Inspector"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Line Prefix"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "LSC"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Location of Marker"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Road"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Rail Weight"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Sleeper Type"


    ActiveCell.Offset(0, 1).Range("A1").Select
```

```
    ActiveCell.FormulaR1C1 = "Anchor Pattern"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Straight or Curve"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Radius"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Direction"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Speed"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Grade"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Creep Trend @ location"


    ActiveCell.Offset(0, 1).Range("A1").Select

    ActiveCell.FormulaR1C1 = "Comment"
'   ************************************************************



    Sheets("Data").Select

    Range("A8").Select

    i = 0


Do Until ActiveCell.Value = ""


'   Identifying the location to be assessed

    Inspector = ActiveCell.Value

    ActiveCell.Offset(0, 1).Range("A1").Select
```

```
    Prefix = ActiveCell.Value

    ActiveCell.Offset(0, 1).Range("A1").Select


    LSC = ActiveCell.Value  'Line Section Code

    ActiveCell.Offset(0, 1).Range("A1").Select


    Location = ActiveCell.Value 'Location

    ActiveCell.Offset(0, 1).Range("A1").Select


    Road = ActiveCell.Value 'Road





'   *****************************************

      If Prefix = "WL" And Location >= 644.16 Or Prefix = "GW" Then

      Inspector = "G"

      ElseIf Prefix = "WL" And Location >= 273.9 Then

      Inspector = "F"

      ElseIf Prefix = "WL" And Location >= 42.73 Or Prefix = "WD" Or Prefix = "JE" Then

      Inspector = "E"

      ElseIf Prefix = "GL" Then

      Inspector = "D"

      ElseIf Prefix = "SW" And Location >= 51.89 Then

      Inspector = "C"

      ElseIf Prefix = "SL" And Location >= 200.522 Or Prefix = "MN" Or Prefix = "SW" And Location <= 51.89 Then

      Inspector = "B"

      Else

      Inspector = "A"

      End If

      ActiveCell.Offset(0, -4).Range("A1").Select

      ActiveCell.Value = Inspector

'   ******************************************


    Sheets("Report").Select

    Range("A2").Select
```

```
k = 0

j = 0


    Do Until ActiveCell.Value = ""

        A = ActiveCell.Value

        ActiveCell.Offset(0, 1).Range("A1").Select

        B = ActiveCell.Value

        ActiveCell.Offset(0, 1).Range("A1").Select

        C = ActiveCell.Value

        ActiveCell.Offset(0, 1).Range("A1").Select

        D = ActiveCell.Value

        ActiveCell.Offset(0, 1).Range("A1").Select

        E = ActiveCell.Value


        If A = Inspector And B = Prefix And C = LSC And D = Location And E = Road Then

            k = k + 1

            ActiveCell.Offset(1, -4).Range("A1").Select


            Else

            ActiveCell.Offset(1, -4).Range("A1").Select

            End If


        j = j + 1

    Loop




If k = 0 Then

    Sheets("Report").Select

    Range("A2").Select

    Do Until ActiveCell.Value = ""

    ActiveCell.Offset(1, 0).Range("A1").Select

    Loop


    ActiveCell.Value = Inspector

    ActiveCell.Offset(0, 1).Range("A1").Select
```

```
    ActiveCell.Value = Prefix
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.Value = LSC
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.Value = Location
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.Value = Road

    Sheets("Data").Select
    Range("C8").Select



' This loop looks through the data and extracts each of the
' measurements for the Location currently be analysed,
' then puts the data in a 'Dummy Sheet'
' ('dummy_sheet' always appears blank to the user)
'***** DO NOT DELETE THE 'BLANK' DUMMY SHEET *******

' look at each and every data entry
g = 0 ' start count
Do Until ActiveCell.Value = "END"
    ' if the LSC (in data) matches the LSC(of the location being analysed)

    If ActiveCell.Value = LSC Then
    ' go to the Location (in data)
    ActiveCell.Offset(0, 1).Range("A1").Select

        """"""""""""""""""""
        ' Check if Location(in Data) is equal to  Location (of the location being analysed)
        If ActiveCell.Value = Location Then
        ' go to the Road (in data)
        ActiveCell.Offset(0, 1).Range("A1").Select

            If ActiveCell.Value = Road Then
            'if it is then:
```

```
'first store the date(of measurement)in variable DDMMYY

ActiveCell.Offset(0, 1).Range("A1").Select

DDMMYY = ActiveCell.Value


' store Creep as variable

ActiveCell.Offset(0, 4).Range("A1").Select

Crp = ActiveCell.Value



'Put the data on to the Dummmy_Sheet

ActiveCell.Offset(0, -3).Range("A1").Select


   If ActiveCell.Value = "Right" Then

   Sheets("dummy_sheet").Select

   Range("A1").Select


   Do Until ActiveCell.Value = ""

   ActiveCell.Offset(1, 0).Range("A1").Select

   Loop


   ActiveCell.Value = DDMMYY

   ActiveCell.Offset(0, 2).Range("A1").Select

   ActiveCell.Value = Crp



   ElseIf ActiveCell.Value = "Left" Then


   Sheets("dummy_sheet").Select

   Range("A1").Select


   Do Until ActiveCell.Value = ""

   ActiveCell.Offset(1, 0).Range("A1").Select

   Loop


   ActiveCell.Value = DDMMYY
```

```
          ActiveCell.Offset(0, 1).Range("A1").Select
          ActiveCell.Value = Crp


          Else
          Sheets("Data").Select
          Range("C8").Select
          End If




        Else
        Sheets("Data").Select
        Range("C8").Select


        End If


      Else
      Sheets("Data").Select
      Range("C8").Select


      End If
""""""""""""""""""""""""""""""""""""""""""""""'
    Sheets("Data").Select
    Range("C8").Select
    Else
    Sheets("Data").Select
    Range("C8").Select
    End If
    Sheets("Data").Select
    Range("C8").Select
""""""""""""""""""""""""""""""""""""""""""""""'
  g = g + 1 'update count


  ActiveCell.Offset(g, 0).Range("A1").Select
  Loop
'************************************************************************************************
```

```
'**************************************************************************************************************************
 ' Just setting up end points and tidying up the data in the dummy sheet


 Sheets("dummy_sheet").Select
 Range("A1").Select
 Do Until ActiveCell.Value = ""
 ActiveCell.Offset(1, 0).Range("A1").Select
 Loop
 ActiveCell.Value = "END"
 ActiveCell.Offset(0, 1).Range("A1").Select
 ActiveCell.Value = "END"
 ActiveCell.Offset(0, 1).Range("A1").Select
 ActiveCell.Value = "END"
 ActiveCell.Offset(0, 1).Range("A1").Select
 ActiveCell.Value = "END"

 Range("A1").Select
 Do Until ActiveCell.Value = "END"
 Q = ActiveCell.Value
 ActiveCell.Offset(1, 0).Range("A1").Select

     If ActiveCell.Value = Q Then
     ActiveCell.Offset(-1, 0).Range("A1").Select
         k = 0
         Do Until ActiveCell.Value = ""
         ActiveCell.Offset(0, 1).Range("A1").Select
         k = k + 1
         Loop
     ActiveCell.Offset(1, 0).Range("A1").Select
     x = ActiveCell.Value
     Selection.EntireRow.Delete
     ActiveCell.Offset(-1, 0).Range("A1").Select
     ActiveCell.Value = x

     ActiveCell.Offset(1, -k).Range("A1").Select
```

```
    Else
    End If

Loop

Range("B1").Select
Do Until ActiveCell.Value = "END"
one = ActiveCell.Value
ActiveCell.Offset(0, 1).Range("A1").Select
two = ActiveCell.Value
If one = "" Or two = "" Then
Selection.EntireRow.Delete
ActiveCell.Offset(0, -1).Range("A1").Select
Else
ActiveCell.Offset(1, -1).Range("A1").Select
End If
Loop

    Sheets("dummy_sheet").Select
Range("B1").Select
' count the data points
n = 0
Do Until ActiveCell.Value = "END"

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
If ActiveCell.Value = "Reset Marker" Then                   ''''
u = n                                                 ''''
ActiveCell.Value = 0                                  ''''
ActiveCell.Offset(0, 1).Range("A1").Select                 ''''
ActiveCell.Value = 0                                  ''''
ActiveCell.Offset(0, -1).Range("A1").Select                ''''
                                                     ''''
E = 0                                                 ''''
```

```
    Do Until E = n                                    ''''
    ActiveCell.Offset(-1, 0).Rows("1:1").EntireRow.Select          ''''
    Selection.Delete Shift:=xlUp                         ''''
    E = E + 1                                         ''''
    Loop                                              ''''
    n = n - u                                         ''''
    ActiveCell.Offset(0, 1).Range("A1").Select               ''''
    Else                                              ''''
    End If                                            ''''
    ActiveCell.Offset(1, 0).Range("A1").Select               ''''
    n = n + 1                                         ''''
    Loop                                              ''''
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''



'''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''Creep Trend Script'''''''''''''''''''''''''''''''''''''
'''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
'''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' if there is less than 3 measurements at the location there is Insufficient Data to reliably identify the trend.
    If n < 3 Then
       Trend_type = "Insufficient Data"

    ''''''''''''''''''''''''''''''''''''''''''''''''''''''
    '''''''''check for excessive creep as per cets''''
    Sheets("dummy_sheet").Select
    Range("A1").Select
    Do Until ActiveCell.Value = ""
    ActiveCell.Offset(1, 0).Range("A1").Select
    Loop
    ActiveCell.Offset(-2, 1).Range("A1").Select
    L = ActiveCell.Value
    ActiveCell.Offset(0, 1).Range("A1").Select
    R = ActiveCell.Value
```

```
If Abs(L) >= 50 And Abs(R) >= 50 Then
Trend_type = "Excessive Creep as per CETS"
ElseIf Abs(R) >= 50 Then
Trend_type = "Excessive Creep as per CETS - Right Rail"
ElseIf Abs(L) >= 50 Then
Trend_type = "Excessive Creep as per CETS - Left Rail"
Else
Trend_type = Trend_type
End If

Comment = ""

    If Trend_type <> "" And Trend_type <> "Insufficient Data" Then

    Sheets("Fix Track Structure").Select
    Range("B2").Select

    Do Until ActiveCell.Value = ""

    If LSC = ActiveCell.Value Then
    ActiveCell.Offset(0, 1).Range("A1").Select
    start_km = ActiveCell.Value
    ActiveCell.Offset(0, 1).Range("A1").Select
    end_km = ActiveCell.Value

    'Proximity to fixed track structure, within 300m
    If Location <= start_km And Location >= (start_km - 0.3) And (L > 0 Or R > 0) Then
    Comment = "Possible high stress area. Stress test between " & start_km - 0.5 & "km and " & start_km & "km"

    ElseIf Location <= start_km And Location >= (start_km - 0.3) Then
    Comment = "Close proximity to Fixed Track Structure"

    ElseIf Location >= end_km And Location <= (end_km + 0.3) And (L < 0 Or R < 0) Then
    Comment = "Possible high stress area. Stress test between " & end_km & "km and " & end_km + 0.5 & "km"
```

```
    ElseIf Location >= end_km And Location <= (end_km + 0.3) Then
    Comment = "Close proximity to Fixed Track Structure"

    Else
    ActiveCell.Offset(1, -2).Range("A1").Select
    End If

    Else
    ActiveCell.Offset(1, 0).Range("A1").Select
    End If
    Loop

    Else
    End If

    Sheets("Report").Select
    Range("N2").Select
    ActiveCell.Offset(j, 0).Range("A1").Select
    ActiveCell.Value = Trend_type
    ActiveCell.Offset(0, 1).Range("A1").Select
    ActiveCell.Value = Comment
    Application.ScreenUpdating = True
    Application.ScreenUpdating = False
    Trend_type = ""
    Comment = ""
'''''''''''''''''''''''''''''''''''''''''''''''''''''''



'''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
' Else there is more 3 or more records for the location then analyse the Creep trend
Else

''''''''''''''''''''''''''''''''''''''''''''''''''''''
```

```
"""""""""check for excessive creep as per cets""

Sheets("dummy_sheet").Select

Range("A1").Select

Do Until ActiveCell.Value = ""

ActiveCell.Offset(1, 0).Range("A1").Select

Loop

ActiveCell.Offset(-2, 1).Range("A1").Select

L = ActiveCell.Value

ActiveCell.Offset(0, 1).Range("A1").Select

R = ActiveCell.Value


If Abs(L) >= 50 And Abs(R) >= 50 Then

Trend_type = "Excessive Creep as per CETS"

ElseIf Abs(R) >= 50 Then

Trend_type = "Excessive Creep as per CETS - Right Rail"

ElseIf Abs(L) >= 50 Then

Trend_type = "Excessive Creep as per CETS - Left Rail"

Else

End If


''''''''''''''''''''''''''''''''''''''''''''''''

''''''''''''''''''''''''''''''''''''''''''''''''


    'Find average rate of change of creep, cell E1(left) F1(right), (mm per day)

    ' using excel's built in linear regression.

    Sheets("dummy_sheet").Select

    Range("E1").Select


        If n = 3 Then                              '              '

        ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[2]C[-3],RC[-4]:R[2]C[-4]),1)"

        ActiveCell.Offset(0, 1).Range("A1").Select

        ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[2]C[-3],RC[-5]:R[2]C[-5]),1)"


        ElseIf n = 4 Then

        ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[3]C[-3],RC[-4]:R[3]C[-4]),1)"
```

```
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[3]C[-3],RC[-5]:R[3]C[-5]),1)"

ElseIf n = 5 Then
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[4]C[-3],RC[-4]:R[4]C[-4]),1)"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[4]C[-3],RC[-5]:R[4]C[-5]),1)"

ElseIf n = 6 Then
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[5]C[-3],RC[-4]:R[5]C[-4]),1)"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[5]C[-3],RC[-5]:R[5]C[-5]),1)"

ElseIf n = 7 Then
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[6]C[-3],RC[-4]:R[6]C[-4]),1)"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[6]C[-3],RC[-5]:R[6]C[-5]),1)"

ElseIf n = 8 Then
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[7]C[-3],RC[-4]:R[7]C[-4]),1)"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[7]C[-3],RC[-5]:R[7]C[-5]),1)"

ElseIf n = 9 Then
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[8]C[-3],RC[-4]:R[8]C[-4]),1)"
ActiveCell.Offset(0, 1).Range("A1").Select
ActiveCell.FormulaR1C1 = "=INDEX(LINEST(RC[-3]:R[8]C[-3],RC[-5]:R[8]C[-5]),1)"

Else
Sheets("Report").Select
Range("N2").Select
ActiveCell.Offset(j, 0).Range("A1").Select
Application.ScreenUpdating = True
ActiveCell.Value = "Modify Macro to analyse more points  - see line 407 to 440"
Application.ScreenUpdating = False
```

```
  End If
Range("E1").Select
mL = ActiveCell.Value ' Left rail gradient
ActiveCell.Offset(0, 1).Range("A1").Select
mR = ActiveCell.Value ' Right rail gradient
'dm=absolute value of the difference in the rate of creep between left and rignt rails
dm = Abs(mL - mR)

' Find the difference(mm) between the left and right rail(wrt each other)
Sheets("dummy_sheet").Select
Range("D1").Select
p = 0
Do Until p = n
ActiveCell.FormulaR1C1 = "=ABS(RC[-2]-RC[-1])"
ActiveCell.Offset(1, 0).Range("A1").Select
p = p + 1
Loop

Sheets("dummy_sheet").Select
Range("B1").Select
ActiveCell.Offset(n - 1, 0).Range("A1").Select
Lf = ActiveCell.Value
ActiveCell.Offset(0, 1).Range("A1").Select
Rf = ActiveCell.Value

ActiveCell.Offset(0, 1).Range("A1").Select
C = ActiveCell.Value
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


  'if the rails are diverging at >= 50/(356/2), they are rapidly diverging
  If dm >= 0.274 Then
  Trend_type = "'Rapidly 'Diverging' Rails"
```

```
ElseIf (C + dm * (356 / 2)) > 50 Then

Trend_type = ""Diverging' Rails"


Else





'How far has the left rail moved (net)

Sheets("dummy_sheet").Select

Range("B1").Select

l1 = ActiveCell.Value

ActiveCell.Offset(n - 1, 0).Range("A1").Select

dl = Abs(ActiveCell.Value - l1)


'How far has the right rail moved (net)

Range("C1").Select

r1 = ActiveCell.Value

ActiveCell.Offset(n - 1, 0).Range("A1").Select

dr = Abs(ActiveCell.Value - r1)




  If n = 3 Then

    ' 3 points often isn't enough to call the creep non recovering, but some times is, depending on the pattern

    ' so check if all the measurements are increasing in the same direction, then you can reasonably say the behaviour is

    ' non recovering creep, based on the three points. Otherwise wait for further data to analyse the location.


    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    Range("B1").Select

    L = 1

    Do Until ActiveCell.Value = "END"

    y = ActiveCell.Value

    ActiveCell.Offset(1, 0).Range("A1").Select

      If ActiveCell.Value = "END" Then

      ElseIf (ActiveCell.Value > y And (mL > 0)) Or (ActiveCell.Value < y And (mL < 0)) Then
```

```
        L = L + 1
        Else
        End If

    Loop
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''


    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    Range("C1").Select
    R = 1
    Do Until ActiveCell.Value = "END"
    y = ActiveCell.Value
    ActiveCell.Offset(1, 0).Range("A1").Select
        If ActiveCell.Value = "END" Then
        ElseIf (ActiveCell.Value > y And (mR > 0)) Or (ActiveCell.Value < y And (mR < 0)) Then
        R = R + 1
        Else
        End If
    Loop
    ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
        If L = n Or R = n Then
        Trend_type = "Non Recovering Creep"

        Else
            Trend_type = Trend_type

        End If




Else
    If Abs(mL) > 0.274 Or Abs(mR) > 0.274 Then
    Trend_type = "Non Recovering Creep"
```

```
    ElseIf (Lf + mL * (365 / 2)) > 50 Or (Rf + mR * (365 / 2)) > 50 Then
    Trend_type = "Non Recovering Creep"


    Else
    Trend_type = Trend_type


    End If
  End If
End If



''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
Sheets("Fix Track Structure").Select
Range("B2").Select




Do Until ActiveCell.Value = ""


If LSC = ActiveCell.Value Then
ActiveCell.Offset(0, 1).Range("A1").Select
start_km = ActiveCell.Value
ActiveCell.Offset(0, 1).Range("A1").Select
end_km = ActiveCell.Value


Comment = ""
'Proximity to fixed track structure, with in 300m
If Location <= start_km And Location >= (start_km - 0.3) And (mL > 0 Or mR > 0) Then
Comment = "Possible high stress area. Stress test between " & start_km - 0.5 & "km and " & start_km & "km"


ElseIf Location <= start_km And Location >= (start_km - 0.3) Then
Comment = "Close proximity to Fixed Track Structure"


ElseIf Location >= end_km And Location <= (end_km + 0.3) And (mL < 0 Or mR < 0) Then
Comment = "Possible high stress area. Stress test between " & end_km & "km and " & end_km + 0.5 & "km"
```

```
        ElseIf Location >= end_km And Location <= (end_km + 0.3) Then
        Comment = "Close proximity to Fixed Track Structure"


        Else
        ActiveCell.Offset(1, -2).Range("A1").Select
        End If


        Else
        ActiveCell.Offset(1, 0).Range("A1").Select
        End If
        Loop
        If Trend_type = "" Then
        Comment = ""
        Else
        Comment = Comment
        End If
        ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
        Sheets("Report").Select
        Range("N2").Select
        ActiveCell.Offset(j, 0).Range("A1").Select
        ActiveCell.Value = Trend_type
        ActiveCell.Offset(0, 1).Range("A1").Select
        Application.ScreenUpdating = True
        ActiveCell.Value = Comment
        Application.ScreenUpdating = False
        Trend_type = ""




    End If
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
    ' Clear dummy_sheet and do next location
    Sheets("dummy_sheet").Select
```

```
    Cells.Select
    Selection.ClearContents

    Else
    End If

    i = i + 1
    Sheets("Data").Select
    Range("A8").Select
    ActiveCell.Offset(i, 0).Range("A1").Select

   Loop

''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

    Sheets("Report").Select
    Range("C2").Select

    k = 0
    Do Until ActiveCell.Value = ""
    LSC = ActiveCell.Value
    ActiveCell.Offset(0, 1).Range("A1").Select
    km = ActiveCell.Value

    Sheets("Track Details").Select
    Range("A2").Select

        Do Until ActiveCell.Value = ""
            If LSC = ActiveCell.Value Then
            ActiveCell.Offset(0, 1).Range("A1").Select
            S = ActiveCell.Value
            ActiveCell.Offset(0, 1).Range("A1").Select
            F = ActiveCell.Value

                If km >= S And km <= F Then
```

```
        ActiveCell.Offset(0, 1).Range("A1").Select
        RW = ActiveCell.Value
        ActiveCell.Offset(0, 1).Range("A1").Select
        ST = ActiveCell.Value
        ActiveCell.Offset(0, 1).Range("A1").Select
        Direction = ActiveCell.Value
        ActiveCell.Offset(0, 1).Range("A1").Select
        Radius = ActiveCell.Value
        ActiveCell.Offset(0, 1).Range("A1").Select
        Cant = ActiveCell.Value
        ActiveCell.Offset(0, 1).Range("A1").Select
        Speed = ActiveCell.Value



        Sheets("Report").Select
        Range("E2").Select

        ActiveCell.Offset(k, 1).Range("A1").Select
        ActiveCell.Value = RW
        ActiveCell.Offset(0, 1).Range("A1").Select
        ActiveCell.Value = ST
        ActiveCell.Offset(0, 3).Range("A1").Select
        ActiveCell.Value = Radius
        ActiveCell.Offset(0, 1).Range("A1").Select
        ActiveCell.Value = Direction
        ActiveCell.Offset(0, 1).Range("A1").Select
        ActiveCell.Value = Speed

        Else
        ActiveCell.Offset(0, -2).Range("A1").Select
        End If

    Else
    End If
    ActiveCell.Offset(1, 0).Range("A1").Select
```

```
        Loop


    k = k + 1

    Sheets("Report").Select

    Range("C2").Select

    ActiveCell.Offset(k, 0).Range("A1").Select

    Loop


''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''

End Sub
```

Appendix D – Queensland Rail’s Civil Engineering Publication No. 44, *Measurement of Rail Stress Free Temperature*

NETWORK ACCESS

Civil Engineering Division

MEASUREMENT OF RAIL STRESS FREE TEMPERATURE

For measurement of rail SFT using the RailFrame equipment.

Civil Engineering Publication No. 44

Engineering to Keep Your Business on Track to the Future… *Track Engineering Section*

CIVIL ENGINEERING

NETWORK ACCESS

CIVIL ENGINEERIN
PUBLICATION NO. 4
ISSUE : C
DATE : 20/09/2005
PAGE : 1 OF 22
APPENDICES : 3

MEASUREMENT OF RAIL STRESS-FREE TEMPERATURE

ISSUE	DATE	DESCRIPTION/REASON
Initial	24/02/99	
A	31/05/99	Review of operating procedure
B	01/02/01	Review of rail temperature tables Appendix 1, changes to Figures and changes to clauses 1, 2, 4 & 5
C	20/09/2005	Additional and amended rail temperature tables Appendix 1, change to clause 2 and Figures 1, 4 and 6.

AUTHORISED BY : Original signed by B R Hagaman DATE : 23 September 2005
MANAGER CIVIL ENGINEERING

FILE T20051.8

TABLE OF CONTENTS

1.0 BACKGROUND

A RailFrame has been developed to determine to within ±3^{0}C the actual stress-free (neutral) temperature of rail in track. This frame can be used on any size rail provided that the relevant "Stress Free Rail Temperature Table" is used (see Appendix 1).

The frame is used to determine the stress-free rail temperature of continuous welded rail (CWR) and long welded rail (LWR).

The frame is **not** to be used on:
- track with fish plated joints spaced at less than 110 metre intervals;
- curved track with a radius less than 800 metres; or,
- track with cant greater than 70mm.

Basic Principle

The basic principle behind the operation of the RailFrame is that the more a rail is in tension, the greater the amount of force required to lift it.

The RailFrame is used to lift a 20 metre section of unclipped rail to a height of 70mm. The amount of force required to lift the rail is recorded along with the current rail temperature. These values are then used to calculate the actual stress-free rail temperature using the applicable "Stress-free Rail Temperature Table" (Appendix 1). Once the actual stress-free rail temperature is known, the operator may then decide if the rail is within the acceptable range or whether re-stressing is required.

However there are some constraints in the capacity of the frame to accurately measure the stress-free temperature of rail. It must be stressed that the RailFrame can only be used with accuracy when the rail is in tension, that is, when the rail temperature is below the actual stress-free temperature.

If the actual stress-free temperature (shown on the table) is less than the rail temperature at the time of testing, the value of the actual stress-free temperature will be incorrect. Examples of this are shown later in the manual.

The RailFrame

The RailFrame is constructed from aluminium plate and extrusion. It contains a hydraulic pump and ram to provide the force needed to lift the rail. A gauge indicates the amount of force measured in tonnes. Fitted to the ram is a set of grips that hook under the foot of the rail. A digital depth gauge is used to determine the exact amount the rail is lifted (70mm).

The maximum safe working load of the frame is 4 tonnes

See figures 1-5 on the following pages.

Figure 1: RailFrame

Pictured left is the RailFrame 2. It is positioned centrally between two sleepers. Ballast is removed to enable the lifting hooks to fit underneath the rail. As can be seen in the photo, the rail fastenings have been removed.

Figure 2: Pressure Gauge

The pressure gauge measures the force (in tonnes) required to lift the rail. Each unit of 1 tonne (1.0) is subdivided into smaller graduations of 0.1 tonne. Graduations are divided further into units of 0.05 tonne. It should be noted that readings off the gauge will be required to the nearest 0.05 tonne during testing.

A rectangular block and spacer plates are supplied with the RailFrame. These are shown right. The block and spacer plates are used to take up the gap between the grips and the foot of the rail.

The hydraulic ram can extend only 75mm. The block and spacer plates must be used to make sure that the ram will have a full 70mm extension before it reaches the end cap. If the ram reaches the end cap before 70mm is reached and more hydraulic pressure is applied, the force indicated on the gauge will be incorrect.

Figure 3: Rail Clamp and Spacer Plates

Figure 4: Digital Depth Gauge

A digital depth gauge is bolted to the centre cross bar (new design, shown in Figure 4) or with two wing bolts to the cross bar at the top of the RailFrame (old design).

During testing, the rail must be lifted 70mm ± 0.20mm on every size rail.

The digital display makes it easy for the operator to accurately measure the amount of lift achieved.

Figure 5: Regulating and Gauge Isolation Valves

The regulating valve situated on the hydraulic pump is used to regulate the flow of hydraulic fluid to the ram. It must be screwed in when raising the ram, and screwed out when lowering the ram.

The gauge isolation valve is a device to protect the force gauge from damage when releasing the pressure from the ram. It is simply screwed in prior to releasing the regulating valve. It must be tightened after the ram has been raised to the height of 70mm and the force gauge has been read.

2.0 STRESS-FREE (NEUTRAL) TEMPERATURE

An important concept when using this equipment to calculate the stress-free temperature is that the rails to be tested ***must be in tension*** to obtain valid results.

It is only possible to assess whether the rails are in tension or compression by actually conducting a test on the rails with the RailFrame. Therefore, perform the test on the rails but pay particular attention to the ***rail temperature*** measured during the test and the ***recorded actual stress-free temperature*** read off the relevant stress free rail temperature table.

Rail Temperature

An accurate measure of rail temperature is important to determine the actual stress free temperature. The best method for measuring rail temperature is to use a magnetic surface thermometer. However these are relatively slow at reading the rail temperature.

Digital thermometers are quick and perform best at night when the temperature is stable. During the day these devices may give inaccurate temperature readings due to fluctuations in the rail surface temperature caused by reflected sunlight or wind. The correct method for measuring the temperature of the rail using a digital thermometer is shown in figure 6. An **average of three measurements**, taken on the shaded side under the rail head is recommended.

Figure 6 - Measuring Rail Temperature

Appendix 1 provides stress free temperature tables for AS 31 kg/m, 41 kg/m, 47 kg/m, 50 kg/m, 53 kg/m and 60 kg/m section rails on particular types of sleeper. The appropriate rail/sleeper table is to be used when determining the stress free temperature of a rail with the RailFrame. Note that the tables contain values for stress-free temperatures up to rail temperatures of up to 34^{0}C only. If the rail temperature is **greater than 34^{0}C** on site, **do not** conduct measurements.

Remember if the force recorded during testing is *lower* or near the lowest force shown on the relevant stress free temperature table the result recorded may be incorrect. Another measurement should be taken when rail temperature is lower.

3.0 DISTANCE BETWEEN TEST LOCATIONS

Where an assessment of stress-free temperature is required over a section of track, it is recommended that tests be conducted at the intervals given below. These intervals are based on the maximum lengths of rail allowable for re-stressing operations. It is acceptable to measure at intervals down to 50m if required.

Concrete sleepered track	500m
Steel sleepered track	500m
Interspersed track (timber/steel)	300m
Timber sleepered track	250m

4.0 OPERATING PROCEDURE

1. Ensure all trackside safety precautions appropriate for the area have been observed.

2. Inspect all equipment for cracks and damage prior to use.

3. Determine the location where the stress-free temperature is to be determined and mark the rail (between two sleepers).

4. Check the temperature of the rail. If temperature is **greater than 34^0C, do not conduct tests**.

5. Measure a distance of 10 metres in each direction from the central point. If the 10 metre point falls between two sleepers the last sleeper to be unclipped is the one just back from 10m point. Mark the foot of the rail at the next sleeper and continue the mark onto the sleeper. This mark will be used to monitor if there is any movement of the rail at each end of the section. A test section of 20 metres has now been established.

For dogspiked track, the marked 20 metre section must have ten sleepers box anchored at each end.

Note: *Dogspiked track interspersed with clipped track should be treated as dogspiked track, unless equivalent anchorage can be demonstrated. Anchors are not required for concrete, steel or clipped timber track unless there is doubt of the anchoring effect of these fasteners.*

6. Unfasten the 20 metre section of rail, including the marked end sleepers. The rail must be unfastened in such a way as to allow the rail to be lifted freely. It is recommended that Fist fasteners be removed completely. Insulators for Pandrol and Trakloc clips may jam when lifting the rail. If insulators cannot be removed, they may be released by lightly tapping the rail with hammers during the initial lift.

7. Dig out sufficient ballast from under the rail to enable the RailFrame's lifting hooks to be positioned under the foot of the rail at the centre point.

8. Position the RailFrame as shown in Figure 1. The frame sits evenly between two sleepers at the central point in the testing section. Ensure the frame is level. The hand pump must always be positioned on the outside of the track, and on the outside of a curve. The operator is to remain on the outside throughout the lifting operation. This is to prevent injury if the forces in the rail are sufficient for the rail to straighten as it is lifted.

9. The rail grips, with the spacer block and plates, are positioned under the rail foot as shown in Figure 3. Use as many spacers as possible to take up the space between the rail foot and grip.

10. Close the pump regulating valve and open the gauge isolation valve (Figure 5). Use the hand pump to raise the rail grips until the force gauge indicates 0.05 tonne. This is the first graduation mark above zero.

11. The depth gauge ruler is pushed down until it stops on the lug situated on the top crosspiece of the rail grips or the top of the rail (this depends on the model of the RailFrame). The depth gauge is then switched on and zeroed.

12. Operate the hand pump to lift the rail. As the rail is lifted the force gauge should show a corresponding increase in load. If the gauge does not show a load increase as the rail is lifted, the rail is not in tension. **Stop lifting the rail**. Lower and re-fasten the rail. Do not attempt to lift the rail until the rail temperature has lowered at least 5 °C.

13. Providing the force gauge shows an increase in load as the rail is lifted, continue until the depth gauge indicates a reading of 70.0 mm ± 0.20mm. Check that the rail is free of shoulders, fasteners, insulators, ballast etc.

14. Record the reading shown on the force gauge to the nearest 0.05t. The gauge needle will tend to drop backwards and stabilise after a few seconds at the end of the lift. Once the gauge needle has stabilised the force reading is recorded. Close the gauge isolation valve.

15. Ensure that all personnel, equipment and materials (eg fingers, thermometer, ballast etc) are clear of the rail seat before releasing. Release the rail into its original position by opening the regulating valve on the hand pump. It is recommended that pressure be released rapidly from the pump to ensure the rail sits back firmly onto the sleeper. The rail **must** return to its original seat on the sleeper before each lift, or final readings will not be consistent.

16. Repeat the process described in steps 10-15 until the same force gauge reading is achieved twice consecutively.

17. Use the applicable stress free temperature table from Appendix 1 to determine the actual stress free temperature of the rail. From the left hand column of the table locate the lifting force (recorded from the force gauge) and travel across the row until it intercepts with the recorded rail temperature. The cell where they meet will show the actual stress-free temperature of the rail.

Example of how to measure stress-free temperature

rail temperature	is obtained from measuring the rail temperature at the time of testing,	
rail mass	is obtained from the markings on the rail web,	
force measured	is the reading taken from the force gauge after lifting the rail (step 10)	
reading the table	*Rail mass*	*47 kg/m concrete sleepers (check top of the relevant table)*
	Rail temperature measured:	*16°C (top line of table)*
	Gauge reading taken:	*1.35 tonnes (left side of the table)*
	Stress-free temperature	*30°C (read on the table)*

Design Neutral Temperature: 38^{0}C in this example.

Design Neutral Temperature is set between 36^{0}C and 40^{0}C by the Infrastructure Maintainer to suit local conditions. (refer STD/0077/TEC Module CETS 2 section 2.8.2.)

The actual stress-free rail temperature read from the 47kg/m table will be **30°C**. This result is minus 8^{0}C below neutral temperature.

Note that the actual stress-free temperature (30°C) in this example is ***greater than*** the rail temperature measured and is therefore a valid result as explained in section 2.

18. Use the blank 'Stress Free Temperature Worksheet' (Appendix 2) to record all details. An example of a completed worksheet is shown in Appendix 2 also.

19. **Subtract** the *design neutral temperature* from the *recorded stress-free temperature* and enter the result in the *variance from design* column. This value indicates the amount by which the recorded stress-free temperature varies from the neutral temperature required in the district. For existing track it is recommended that if this value is not within ±10^{0}C of the design neutral temperature then arrange appropriate rail adjustment of the track. For new or re-laid track refer to the requirements in STD/0077/TEC Module CETS 2 section 2.8.2.

Example of invalid test result

A test is conducted on 47kg/m rail and concrete sleepers. The following results are recorded on the "Stress- free Temperature Worksheet".

Force Measured = 1.00 tonne

Rail Temp (taken with thermometer) = 24^{0}C

Stress-Free Temp recorded (from tables) = ?? (This force is not shown on the table. No result can be determined. Retest at a lower rail temperature, <19^{0}C.)

From this example it can be seen that the stress-free temperature **cannot be calculated** using the table because the force reading does not appear on the table. If the force reading is less than 1.05 Tonne the rail is at neutral temperature or below. To obtain the correct stress-free temperature at this site, another reading would have to be taken when the rail is **5^0C cooler.**

Note: At all times when lifting the rail with the lift frame, ensure that all personnel and equipment are clear of the rail.

If at any time during lifting:

- **the rail appears to be unstable,**
- **the rail begins to move towards buckling, or**
- **the force gauge fails to register a load,**

Stop Lifting Immediately. Lower the rail and commence re-fastening. Do not attempt to lift the rail until the rail temperature has lowered by at least 5^0C.

5.0 BLEEDING THE PUMP

To ensure correct gauge readings, the hydraulic system must not contain any entrapped air.

To check for entrapped air close both the pump regulating valve and gauge isolation valve and operate the pump handle 3 or 4 times. If the ram does not move the system air may be entrapped and must be bled.

To bleed the pump:

1. Place the pump at a higher level than the ram. This will require the ram to be unbolted from the frame and laid on the ground.

2. Ensure the ram is connected to the pump correctly and that the gauge isolation valve is closed.

3. Check the fluid level in the reservoir and top up if necessary. Rotate the hydraulic fluid reservoir cap to the “close” setting and then close the pump regulating valve.

4. Operate the pump lever until the ram stops extending and the pressure begins building in the hoses.

5. Operate the pump lever several more times to increase hose pressure.

6. Release pressure by opening the regulating valve on the pump.

7. Repeat the process until the ram begins extending on the forth or fifth stroke of the pump lever. This indicates that there is no air in the system.

8. Rotate the reservoir cap back to the “vent” position for one moment to bleed any air present and then return to the “close” position. Replace the ram onto the lifting frame.

The pump is now ready for operation.

6.0 TROUBLE SHOOTING

Problem	**Reason**	**Solution**
Load gauge increases without rail lifting	rail is held by obstruction eg: fastener, track equipment	- release pressure and remove obstruction
	insulators are jamming rail to sleepers.	- ensure pressure less than 1.5 t and tap the rail with a hammer to release the insulators
	ram is at full extension or touching the upper frame	- lower the rail and put more packing between rail and spacer block
	hydraulics are not connected to ram	- release pressure and check connections
On **second** lift, load gauge increases without rail lifting	rail was not lowered fully and ram is at full extension	- lift rail and check rail seat for obstructions eg: insulators, ballast, tools
	depth gauge was not correctly zeroed	- check rail seat for obstructions - lower rail fully; ensure rail is resting solidly on sleepers - raise rail grips until they just touch. - zero depth gauge here.
Force gauge will not return to zero	the liquid in the gauge has thickened	- GENTLY tap the gauge housing until returns to zero

APPENDIX 1 – STRESS-FREE TEMPERATURE TABLES

Stress-Free Rail Temperatures (°C) for 31 Kg/m Rail on Steel/Timber Sleepers

20/09/2005

Rail Temperature (°C)

Lifting Force (tonnes)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
0.70	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	35
0.75	10	12	14	16	18	20	22	24	26	28	30	32	34	35	36	37
0.80	14	16	18	20	22	24	26	28	30	32	34	35	36	37	38	38
0.85	18	20	22	24	26	28	30	32	34	35	36	37	38	38	39	40
0.90	22	24	26	28	30	32	34	35	36	37	38	38	39	40	41	41
0.95	26	28	30	32	34	35	36	37	38	38	39	40	41	41	42	43
1.00	28	32	34	35	36	37	38	38	39	40	41	41	42	43	43	44
1.05	34	35	36	37	38	38	39	40	41	41	42	43	43	44	45	45
1.10	36	37	38	38	39	40	41	41	42	43	43	44	45	45	46	47
1.15	37	38	39	40	41	41	42	43	43	44	45	45	46	47	48	48
1.20	38	40	41	41	42	43	43	44	45	45	46	47	48	48	49	50
1.25	40	41	42	43	43	44	45	45	46	47	48	48	49	50	50	51
1.30	42	43	43	44	45	45	46	47	48	48	49	50	50	51	52	52
1.35	43	44	45	45	46	47	48	48	49	50	50	51	52	52	53	54
1.40	44	45	46	47	48	48	49	50	50	51	52	52	53	54	55	55
1.45	45	46	47	48	49	50	50	51	52	52	53	54	55	55	56	57
1.50	46	47	48	49	50	50	51	52	52	53	54	55	55	56	57	58
1.55	47	48	49	50	50	51	52	52	53	54	54	55	56	57	58	60
1.60	48	49	50	50	51	51	52	53	53	54	55	56	57	58	60	62

Stress-Free Rail Temperatures (°C) for 41 Kg/m Rail on Steel/Timber Sleepers

20/09/2005

Rail Temperature (°C)

Lifting Force (tonnes)	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33
0.85	8	10	12	14	16	18	20	22	24	26	28	30	32	34	35	36
0.90	12	14	16	18	20	22	24	26	28	30	32	34	35	36	37	38
0.95	16	18	20	22	24	26	28	30	32	34	35	36	37	38	38	39
1.00	20	22	24	26	28	30	32	34	35	36	37	38	38	39	40	41
1.05	24	26	28	30	32	34	35	36	37	38	38	39	40	41	41	43
1.10	28	30	32	34	35	36	37	38	38	39	40	41	41	42	43	44
1.15	32	34	35	36	37	38	38	39	40	41	41	42	43	43	44	45
1.20	35	36	37	38	38	39	40	41	41	42	43	43	44	45	45	47
1.25	37	38	38	39	40	41	41	42	43	43	44	45	45	46	47	48
1.30	38	39	40	41	41	42	43	43	44	45	45	46	47	48	48	50
1.35	40	41	41	42	43	43	44	45	45	46	47	48	48	49	50	51
1.40	41	42	43	43	44	45	45	46	47	48	48	49	50	50	51	52
1.45	43	43	44	45	45	46	47	48	48	49	50	50	51	52	52	54
1.50	44	45	45	46	47	48	48	49	50	50	51	52	52	53	54	55
1.55	45	46	47	48	48	49	50	50	51	52	52	53	54	55	55	57
1.60	46	48	48	49	50	50	51	52	52	53	54	55	55	56	57	58
1.65	47	48	49	50	50	51	52	52	53	54	55	55	56	57	58	60
1.70	48	49	50	50	51	52	52	53	54	54	55	56	57	58	60	62
1.75	49	50	50	51	51	52	53	53	54	55	56	57	58	60	62	64

Stress-Free Rail Temperatures (°C) for 41 Kg/m Rail on Concrete Sleepers

20/09/2005

Rail Temperature (°C)

Lifting Force (tonnes)

	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
0.90	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
0.95	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38
1.00	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
1.05	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42
1.10	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
1.15	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46
1.20	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
1.25	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50
1.30	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
1.35	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54
1.40	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56
1.45	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58
1.50	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
1.55	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62
1.60	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64
1.65	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66
1.70	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68
1.75	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70
1.80	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72

Stress-Free Rail Temperatures (°C) for 47 Kg/m Rail on Timber Sleepers

20/09/2005

Rail Temperature (°C)

Lifting Force (tonnes)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
1.00	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35
1.05	8	10	12	14	16	18	20	21	23	25	27	29	31	33	35	37
1.10	11	13	15	17	19	21	23	24	26	28	30	32	34	36	38	40
1.15	14	16	18	20	22	24	26	27	29	31	32	34	37	39	41	42
1.20	17	19	21	23	25	26	28	30	32	34	35	37	40	42	44	45
1.25	20	22	24	25	27	29	31	33	34	36	37	40	43	44	47	48
1.30	23	25	26	28	30	32	34	35	36	38	40	43	45	47	49	50
1.35	26	27	29	30	33	35	36	38	39	40	43	45	46	49	52	53
1.40	28	30	32	33	35	37	39	41	42	43	45	47	49	52	54	55
1.45	31	33	35	36	38	40	42	43	45	46	48	49	52	54	55	56
1.50	33	36	37	40	41	43	44	46	48	49	50	52	54	55	57	58
1.55	36	38	40	42	43	45	47	49	51	52	53	54	56	57	59	60
1.60	38	41	43	45	46	48	50	52	54	55	56	57	58	60	61	63
1.65	41	44	45	47	48	50	52	54	55	56	57	59	60	62	63	65
1.70	44	45	47	49	50	52	54	55	57	58	59	61	62	64	65	67
1.75	45	47	49	51	52	54	55	57	59	60	61	63	64	66	67	69
1.80	47	49	51	53	54	56	57	59	60	62	63	65	66	68	69	71
1.85	49	51	53	55	56	57	59	60	62	63	65	66	68	69	71	73
1.90	51	53	55	56	57	59	60	62	63	65	66	68	69	71	73	75

Stress-Free Rail Temperatures (°C) for 47 Kg/m Rail on Concrete Sleepers

20/09/2005

Rail Temperature (°C)

Lifting Force (tonnes)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
1.05	5	7	9	12	14	16	18	20	22	24	26	28	30	32	34	35
1.10	7	9	12	14	16	18	20	22	24	26	28	30	32	34	35	36
1.15	9	12	14	16	18	20	22	24	26	28	30	32	34	35	36	37
1.20	12	14	16	18	20	22	24	26	28	30	32	34	35	36	37	38
1.25	14	16	18	20	22	24	26	28	30	32	34	35	36	37	38	39
1.30	16	18	20	22	24	26	28	30	32	34	35	36	37	38	39	40
1.35	18	20	22	24	26	28	30	32	34	35	36	37	38	39	40	42
1.40	20	22	24	26	28	30	32	34	35	36	37	38	39	40	42	44
1.45	22	24	26	28	30	32	34	35	36	37	38	39	40	42	44	46
1.50	24	26	28	30	32	34	36	37	38	39	40	41	43	45	47	49
1.55	26	28	30	32	34	36	37	38	39	40	41	43	45	47	49	51
1.60	28	30	32	34	36	37	38	39	40	41	43	45	47	49	51	53
1.65	30	32	34	36	37	38	39	40	41	43	45	47	49	51	53	55
1.70	32	34	36	37	38	39	40	41	43	45	47	49	51	53	55	57
1.75	34	36	37	38	39	40	41	43	45	47	49	51	53	55	57	59
1.80	36	37	38	39	40	41	43	45	47	49	51	53	55	57	59	61
1.85	37	38	39	40	41	43	45	47	49	51	53	55	57	59	61	62
1.90	38	39	40	41	43	45	47	49	51	53	55	57	59	61	62	63
1.95	39	40	41	43	45	47	49	51	53	55	57	59	61	62	63	64

Stress-Free Rail Temperatures (°C) for 50 Kg/m Rail on Concrete Sleepers

20/09/2005

	Rail Temperature (°C)															
Lifting Force (tonnes)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
1.10	4	6	7	9	11	13	15	17	19	21	23	25	27	29	31	33
1.15	6	8	10	12	14	16	19	20	22	24	26	28	29	31	33	35
1.20	9	11	13	15	18	20	22	23	25	27	29	30	32	34	36	38
1.25	12	14	16	19	20	22	25	26	28	29	32	34	36	37	39	41
1.30	15	17	19	21	22	25	28	29	30	31	34	36	38	40	42	43
1.35	17	19	21	23	25	28	29	31	33	35	36	38	40	42	44	45
1.40	20	22	25	27	29	30	32	34	36	37	38	40	42	44	46	47
1.45	22	24	27	29	30	32	34	36	37	38	40	42	44	46	48	49
1.50	25	27	29	31	33	35	36	38	39	40	42	44	47	48	49	50
1.55	27	31	33	33	35	37	38	39	41	42	44	47	48	49	51	51
1.60	31	33	35	36	37	39	40	41	43	45	47	48	49	51	51	52
1.65	34	35	36	38	39	40	41	43	45	47	48	49	50	51	52	53
1.70	36	37	38	39	40	42	43	45	47	48	49	50	51	52	53	54
1.75	38	39	40	41	42	44	45	47	48	49	50	51	52	53	54	55
1.80	39	40	41	43	44	46	47	48	49	50	51	52	53	54	55	56
1.85	40	42	43	45	46	47	48	49	50	51	52	53	54	55	56	57
1.90	42	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58
1.95	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59
2.00	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60
2.05	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61

Stress-Free Rail Temperatures (°C) for 53 Kg/m Rail on Concrete Sleepers

20/09/2005

Lifting Force (tonnes)	Rail Temperature (°C)															
	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
1.15	3	6	9	11	13	15	17	19	21	23	25	27	29	30	32	34
1.20	6	9	11	13	15	17	19	21	23	25	27	29	30	32	34	36
1.25	9	11	13	15	17	19	21	23	25	27	29	30	32	34	36	38
1.30	11	13	15	17	19	21	23	25	27	29	30	32	34	36	38	40
1.35	13	15	17	19	21	23	25	27	29	30	32	34	36	38	40	42
1.40	15	17	20	21	23	25	27	29	30	32	34	36	38	40	42	44
1.45	17	20	21	23	25	27	29	31	32	34	36	38	40	42	44	45
1.50	20	21	23	25	27	29	31	32	34	36	38	40	42	44	45	47
1.55	21	23	25	27	29	31	32	34	36	38	40	42	44	45	47	48
1.60	23	25	27	29	31	32	34	36	38	40	42	44	45	47	48	49
1.65	25	27	29	31	32	34	36	38	40	42	44	45	47	48	49	51
1.70	28	30	31	32	34	36	38	40	42	44	45	47	48	49	51	53
1.75	30	31	32	34	36	38	40	42	44	45	47	48	49	51	53	55
1.80	31	32	34	36	38	40	42	44	45	47	48	49	51	53	55	56
1.85	32	34	36	38	40	42	44	45	47	48	49	51	53	55	56	57
1.90	34	36	38	40	42	44	45	47	48	49	51	53	55	56	57	58
1.95	36	38	40	42	44	45	47	48	49	51	53	55	56	57	58	59
2.00	38	40	42	44	45	47	48	49	51	53	55	56	57	58	59	60
2.05	40	42	44	45	47	48	49	51	53	55	56	57	58	59	60	61
2.10	42	44	45	47	48	49	51	53	55	56	57	58	59	60	61	62

Stress-Free Rail Temperatures (°C) for 60 Kg/m Rail on Concrete Sleepers

20/09/2005

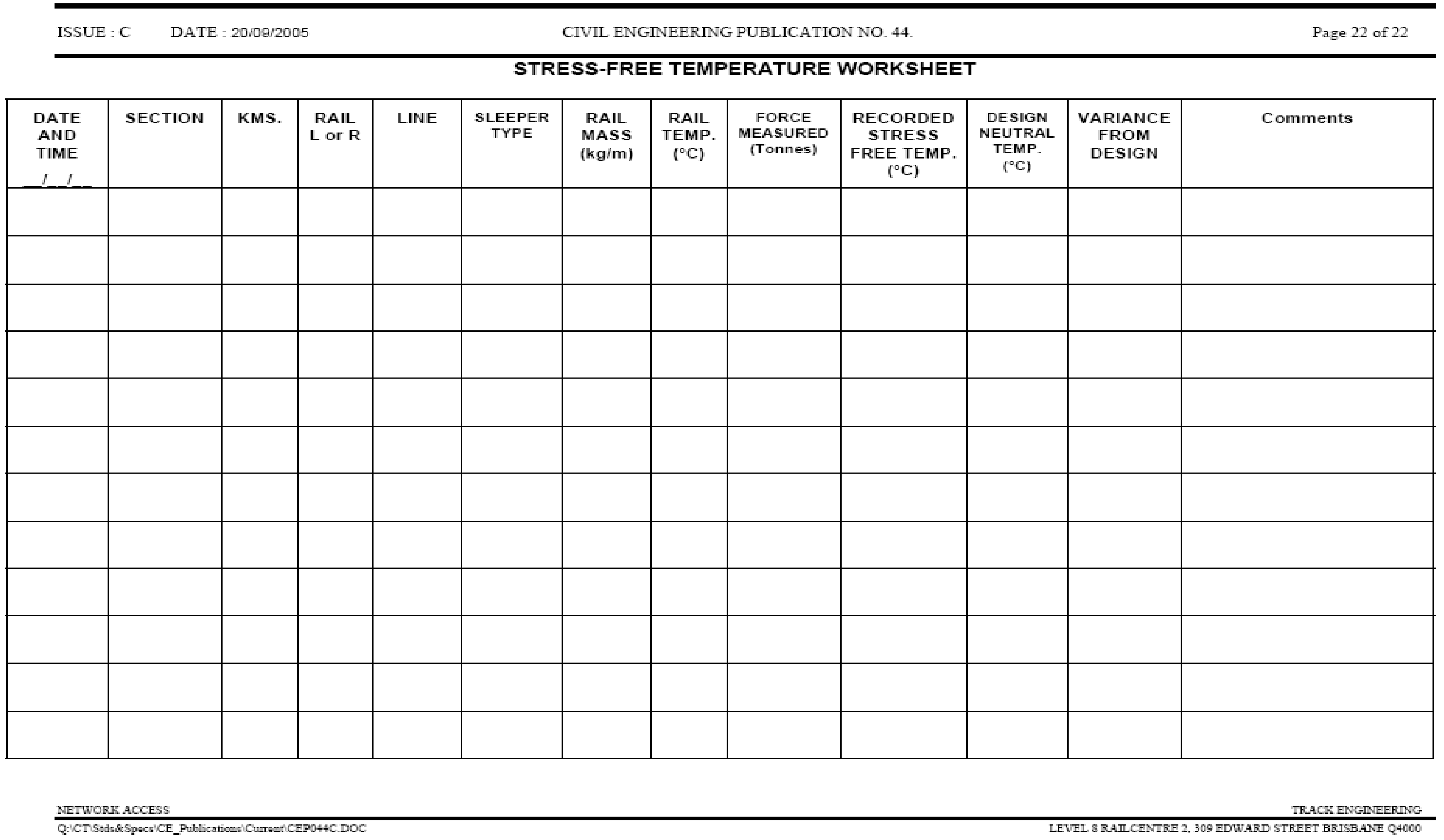
Rail Temperature (°C)

Lifting Force (tonnes)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32
1.30	4	5	7	9	11	13	15	17	19	21	23	25	27	29	30	32
1.35	5	7	9	11	13	15	17	19	21	23	25	27	29	30	32	33
1.40	7	10	12	14	16	17	19	21	23	25	27	29	30	32	34	35
1.45	10	12	14	16	18	20	22	24	26	28	29	30	32	34	35	36
1.50	12	14	16	18	20	22	24	26	28	29	30	32	34	35	36	37
1.55	14	16	18	20	22	24	26	28	29	30	32	34	35	36	37	39
1.60	16	18	20	22	24	26	28	29	30	32	34	35	36	37	39	40
1.65	18	20	22	24	26	28	29	30	32	34	35	36	37	39	40	42
1.70	20	22	24	26	28	29	30	32	34	35	36	37	39	40	42	44
1.75	22	24	26	28	29	30	32	34	35	36	37	39	40	42	44	46
1.80	24	26	28	29	30	32	34	35	36	37	39	40	42	44	46	48
1.85	26	28	29	30	32	34	35	36	37	39	40	42	44	46	48	50
1.90	28	29	30	32	34	35	36	37	39	40	42	44	46	48	50	52
1.95	29	30	32	34	35	36	37	38	40	42	44	46	48	50	52	54
2.00	30	32	34	35	36	37	38	40	42	44	46	48	50	52	54	56
2.05	32	34	35	36	37	38	40	42	44	46	48	50	52	54	56	58
2.10	34	35	36	37	38	40	42	44	46	48	50	52	54	56	58	60
2.15	35	36	37	38	40	42	44	46	48	50	52	54	56	58	60	61
2.20	36	37	38	40	42	44	46	48	50	52	54	56	58	60	61	62
2.25	37	38	40	42	44	46	48	50	52	54	56	58	60	61	62	63
2.30	38	40	42	44	46	48	50	52	54	56	58	60	61	62	63	64

APPENDIX 2 – STRESS-FREE TEMPERATURE WORKSHEETS

STRESS-FREE TEMPERATURE WORKSHEET EXAMPLE

DATE & TIME 22/1/05	SECTION	KMS.	RAIL L or R	SLEEPER TYPE	RAIL MASS kg/m	RAIL TEMP. °C	FORCE MEASURED Tonne	RECORDED STRESS FREE TEMP. °C	DESIGN NEUTRAL TEMP. °C	VARIANCE FROM DESIGN	COMMENTS
0733h	EPALA-AMBROSE	574.256	L	Concrete	60	19	1.85	38	37	+1	Within Tolerance.
0740h	EPALA-AMBROSE	574.256	R	Concrete	60	20	1.85	39	37	+2	Within Tolerance.
0800h	EPALA-AMBROSE	574.500	L	Concrete	53	20	1.55	38	37	+1	Outside Tolerance. A difference of 11°C between rail legs. Restressing required.
0811h	EPALA-AMBROSE	574.500	R	Concrete	53	20	1.25	27	37	-10	
23/01/05 0645h	OGMORE	775.910	L	Concrete	47	24	1.40	47	37	+10	Within Tolerance
0650h	OGMORE	775.910	R	Concrete	47	25	1.55	55	37	+18	Potential to pull-apart. Requires Restressing.
24/01/05 0415h	KUTTABUL -MT OSSA	998.660	L	Steel	50	22	1.15	26	37	-11	Potential to buckle. Restressing required.
0422h	KUTTABUL -MT OSSA	998.660	R	Steel	50	22	1.05	??	37	??	Result lower than force shown on SFT table. Retest at cooler rail temperature, <17°C.

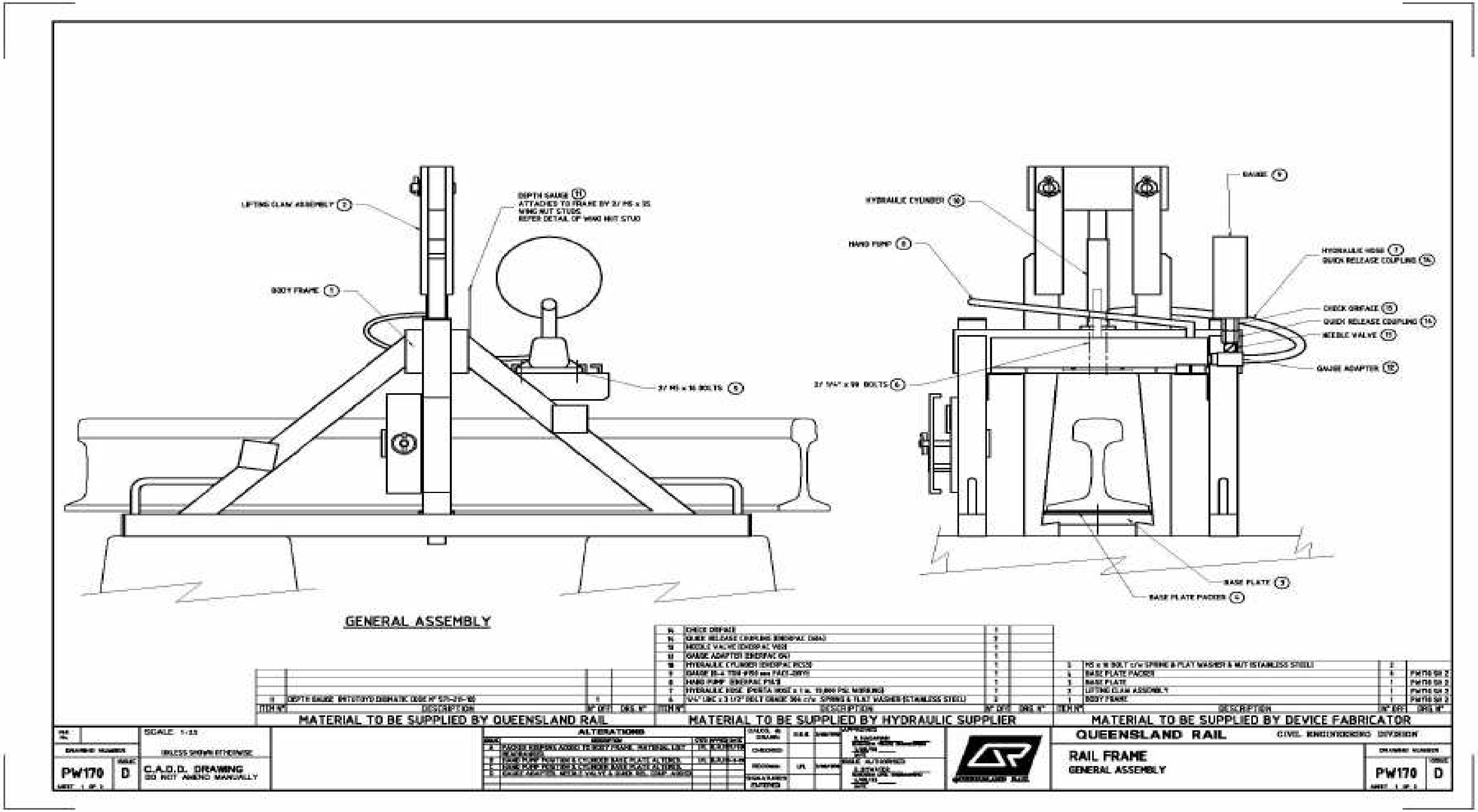


STRESS-FREE TEMPERATURE WORKSHEET

DATE AND TIME __/__/__	SECTION	KMS.	RAIL L or R	LINE	SLEEPER TYPE	RAIL MASS (kg/m)	RAIL TEMP. (°C)	FORCE MEASURED (Tonnes)	RECORDED STRESS FREE TEMP. (°C)	DESIGN NEUTRAL TEMP. (°C)	VARIANCE FROM DESIGN	Comments

APPENDIX 3 - GENERAL ASSEMBLY DRAWING OF THE RAILFRAME

QR STANDARD DRAWING PW170 Issue D



Appendix E – Results of the Rail Creep Analysis

Inspector	Line Prefix	LSC	Location of Marker	Road	Rail Weight	Sleeper Type	Anchor Pattern	Straight or Curve	Radius	Direction	Speed	Grade	Creep Trend @ location	Comment
A	WL	353	34.000	Single	41KG				Tangent				Excessive Creep as per CETS	
A	WL	353	36.000	Single	41KG				Tangent				Excessive Creep as per CETS	
A	WL	353	38.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
A	WL	353	39.866	Single	41KG				2000	R	80			
A	WL	353	42.000	Single	41KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 41.751km and 42.251km
A	ML	546	116.000	Single	41KG				Tangent					
A	ML	546	118.000	Single	50KG				334.5	L	40			
A	ML	546	120.000	Single	50KG				161.123	L	40		Non Recovering Creep	
A	ML	546	122.000	Single	41KG				Tangent					
A	ML	546	124.000	Single	50KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
A	ML	546	125.977	Single	50KG				201	R	40			
A	ML	546	128.015	Single	50KG				404	L	60			
A	ML	546	130.000	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
A	ML	546	132.020	Single	41KG				Tangent				Non Recovering Creep	Possible high stress area. Stress test between 132.008km and 132.508km
A	ML	546	134.175	Single	41KG				Tangent				Rapidly 'Diverging' Rails	
A	ML	546	135.931	Single	50KG				181.15	L	40		Excessive Creep as per CETS - Left Rail	
A	ML	546	138.075	Single	50KG				131.47	L	30		Non Recovering Creep	
A	ML	546	140.038	Single	50KG				151.31		30			

A	ML	546	142.032	Single	41KG				Tangent				Non Recovering Creep	
A	ML	546	144.010	Single	50KG				550	R	30			
A	ML	546	145.811	Single	41KG				100	R	30		Non Recovering Creep	Possible high stress area. Stress test between 145.325km and 145.825km
A	ML	546	148.052	Single	50KG				200	R	30			
A	ML	546	149.927	Single	50KG				Tangent				Non Recovering Creep	
A	ML	546	152.082	Single	50KG				141	R	30		Non Recovering Creep	
A	ML	546	154.000	Single	50KG				105	R	30		Excessive Creep as per CETS - Right Rail	
A	ML	546	156.287	Single	50KG				102.5	R	30		Non Recovering Creep	Possible high stress area. Stress test between 156.269km and 156.769km
A	ML	546	157.837	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Close proximity to Fixed Track Structure
A	ML	546	159.900	Single	50KG				735	L	60		Non Recovering Creep	Possible high stress area. Stress test between 159.408km and 159.908km
A	WL	711	1.930	Single	41KG				375.95	R	60			
A	WL	711	4.031	Single	50KG				301.5	R	25		Non Recovering Creep	Close proximity to Fixed Track Structure
A	WL	711	6.016	Single	50KG				195.25	R	40			
A	WL	711	7.877	Single	50KG				304	L	60			
A	WL	711	10.172	Single	41KG				Tangent					
A	WL	711	11.835	Up	41KG				633.3		25			
A	WL	711	11.835	Down	41KG				633.3		25			
A	WL	711	13.883	Single	41KG				1397	R	80			
A	WL	711	15.901	Single	41KG				805	R	80			
A	WL	711	17.849	Single	41KG				408	R	60		Excessive Creep as per CETS	
A	WL	711	19.956	Single	41KG				Tangent					

A	WL	711	22.219	Single	41KG				2000	R	80			
A	WL	711	24.000	Single	41KG				Tangent				Insufficient Data	
A	WL	711	26.000	Single									Insufficient Data	
A	WL	711	28.000	Single									Insufficient Data	
A	WL	711	30.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Close proximity to Fixed Track Structure
A	WL	711	32.000	Single									Excessive Creep as per CETS - Right Rail	
A	SL	718	162.380	Single	41KG				Tangent					
A	SL	718	168.780	Single	41KG				400	R	60			
A	SL	718	173.900	Single	41KG				Tangent				Excessive Creep as per CETS	Close proximity to Fixed Track Structure
A	SL	718	180.000	Single									Non Recovering Creep	
A	SL	718	186.000	Single										
A	SL	718	190.000	Single										
A	SL	718	195.000	Single										
A	SL	718	200.000	Single										
A	ML	889	57.915	Up	60KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 57.841km and 58.341km
A	ML	889	57.915	Down	60KG				Tangent				Rapidly 'Diverging' Rails	Possible high stress area. Stress test between 57.841km and 58.341km
A	ML	889	60.000	Up	60KG				Tangent				'Diverging' Rails	
A	ML	889	60.000	Down	60KG				Tangent				Non Recovering Creep	
A	ML	889	62.000	Up	60KG				Tangent				Excessive Creep as per CETS	
A	ML	889	62.000	Down	60KG				Tangent				Non Recovering Creep	
A	ML	889	63.973	Up	60KG				1600	L	80		Non Recovering Creep	
A	ML	889	63.973	Down	60KG				1600	L	80		Non Recovering	

													Creep	
A	ML	889	65.672	Up	60KG				Tangent					
A	ML	889	65.672	Down	60KG				Tangent					
A	ML	889	67.959	Up	60KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
A	ML	889	67.959	Down	60KG				Tangent					
A	ML	889	69.988	Single	50KG				Tangent				Non Recovering Creep	
A	ML	889	72.013	Single	50KG				Tangent				Non Recovering Creep	
A	ML	889	73.932	Single	50KG				Tangent				Rapidly 'Diverging' Rails	
A	ML	889	76.080	Single	53KG				560		40			
A	ML	889	77.935	Up	41KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 77.55km and 78.05km
A	ML	889	77.954	Down	41KG				221.3	L	30			
A	ML	889	80.038	Up	41KG				Tangent				Excessive Creep as per CETS	
A	ML	889	80.040	Down	41KG				Tangent				Excessive Creep as per CETS	
A	ML	889	82.000	Up	41KG				Tangent				'Diverging' Rails	Possible high stress area. Stress test between 81.771km and 82.271km
A	ML	889	82.000	Down	41KG				Tangent					
A	ML	889	84.050	Up	41KG				2418		80		Excessive Creep as per CETS - Left Rail	Close proximity to Fixed Track Structure
A	ML	889	84.050	Down	41KG				2418		80		Non Recovering Creep	Close proximity to Fixed Track Structure
A	ML	889	86.000	Up	41KG				Tangent				Non Recovering Creep	
A	ML	889	86.000	Down	41KG				Tangent					
A	ML	889	88.000	Up	41KG				Tangent					
A	ML	889	88.000	Down	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
A	ML	889	89.966	Up	41KG				Tangent				Non Recovering Creep	

A	ML	889	89.966	Down	41KG				Tangent				Non Recovering Creep	
A	ML	889	92.000	Up	41KG				Tangent					
A	ML	889	92.000	Down	41KG				Tangent				Non Recovering Creep	
A	ML	889	94.000	Up	41KG				Tangent				Non Recovering Creep	
A	ML	889	94.000	Down	41KG				Tangent				Rapidly 'Diverging' Rails	
A	ML	889	96.000	Up	41KG				Tangent					
A	ML	889	96.000	Down	41KG				Tangent					
A	ML	889	98.000	Up	60KG				Tangent					
A	ML	889	98.000	Down	60KG				Tangent				'Diverging' Rails	
A	ML	889	100.000	Up	41KG				Tangent					
A	ML	889	100.000	Down	41KG				Tangent				Rapidly 'Diverging' Rails	
A	ML	889	102.000	Up	41KG				Tangent				Non Recovering Creep	
A	ML	889	102.000	Down	41KG				Tangent				'Diverging' Rails	
A	ML	889	104.071	Up	41KG				800.7		80		Non Recovering Creep	
A	ML	889	104.071	Down	41KG				800.7		80		'Diverging' Rails	
A	ML	889	106.000	Up	41KG				352		60		Non Recovering Creep	Possible high stress area. Stress test between 105.56km and 106.06km
A	ML	889	106.000	Down	41KG				352		60		Rapidly 'Diverging' Rails	Close proximity to Fixed Track Structure
A	ML	889	108.000	Up	41KG				Tangent					
A	ML	889	108.000	Down	41KG				Tangent				Rapidly 'Diverging' Rails	
A	ML	889	110.000	Up	41KG				Tangent					
A	ML	889	110.000	Down	41KG				Tangent					
A	ML	889	112.000	Up	41KG				1605.3		80			
A	ML	889	112.000	Down	41KG				1605.3		80			
A	ML	889	114.000	Up	41KG				Tangent					

A	ML	889	114.000	Down	41KG				Tangent				'Diverging' Rails	Close proximity to Fixed Track Structure
B	SL	550	260.000	Single	61lb				Tangent				Non Recovering Creep	
B	SL	550	270.000	Single	61lb				Tangent					
B	SL	550	280.000	Single	31KG				100	R	30			
B	SL	550	290.000	Single	61lb				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
B	SL	550	300.000	Single	61lb				Tangent					
B	SL	550	310.000	Single	61lb				Tangent					
B	SL	550	317.000	Single	31KG				300	L	60		Non Recovering Creep	Possible high stress area. Stress test between 316.67km and 317.17km
B	SW	551	5.000	Single	41KG				Tangent					
B	SW	551	10.000	Single	41KG				Tangent				'Diverging' Rails	Close proximity to Fixed Track Structure
B	SW	551	15.000	Single	41KG				805.4	L	80		Non Recovering Creep	Possible high stress area. Stress test between 14.64km and 15.14km
B	SW	551	20.000	Single	41KG				Tangent				Excessive Creep as per CETS - Left Rail	Possible high stress area. Stress test between 19.931km and 20.431km
B	SW	551	25.000	Single	41KG				Tangent					
B	SW	551	30.000	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
B	SW	551	33.000	Single	41KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 32.781km and 33.281km
B	SW	551	35.000	Single	41KG				Tangent					
B	SW	551	36.400	Single	41KG				Tangent				Insufficient Data	
B	SW	551	40.000	Up	50KG				279	R	50		Excessive Creep as per CETS	Possible high stress area. Stress test between 39.826km and 40.326km
B	SW	551	40.000	Down	50KG				279	R	50		Non Recovering Creep	Close proximity to Fixed Track Structure
B	SW	551	42.000	Single	41KG				Tangent				Insufficient Data	
B	SW	551	45.000	Single	41KG				Tangent					

B	SW	551	50.000	Single	41KG				283	L	40			
B	MN	556	0.700	Single	60lb O.S				320	R	30			
B	MN	556	8.800	Single	60lb O.S				Tangent					
B	MN	556	9.500	Single	31KG				400	L	50			
B	MN	556	21.300	Single	60lb O.S				Tangent					
B	MN	556	31.600	Single	31KG				200	R	30			
B	MN	556	39.000	Single	31KG				Tangent				Non Recovering Creep	Possible high stress area. Stress test between 38.74km and 39.24km
B	MN	556	39.500	Single	31KG				Tangent					
B	MN	556	40.000	Single	31KG				Tangent					
B	MN	556	41.000	Single	60lb O.S				Tangent					
B	MN	556	42.000	Single	60lb O.S				Tangent				Non Recovering Creep	
B	MN	556	44.000	Single	60lb O.S				Tangent					
B	MN	556	50.000	Single	60lb A.S				Tangent					
B	MN	556	58.000	Single	60lb O.S				Tangent					
B	MN	556	63.000	Single	31KG				Tangent					
B	MN	556	68.000	Single	60lb O.S				Tangent				'Diverging' Rails	Possible high stress area. Stress test between 67.65km and 68.15km
B	SL	718	208.600	Single									Excessive Creep as per CETS	
B	SL	718	210.600	Single										
B	SL	718	212.600	Single									'Diverging' Rails	
B	SL	718	215.000	Single										
B	SL	718	220.000	Single										
B	SL	718	223.000	Single										
B	SL	718	226.000	Single										
B	SL	718	231.000	Single										

B	SL	718	234.000	Single										
B	SL	718	237.200	Single										
B	SL	718	238.700	Single										
B	SL	718	240.000	Single										
B	SL	718	243.800	Up										
B	SL	718	243.800	Down									Excessive Creep as per CETS - Right Rail	
B	SL	718	246.000	Single										
B	SL	718	250.200	Single										
C	SW	551	55.000	Single	41KG				Tangent					
C	SW	551	60.000	Single	41KG				Tangent					
C	SW	551	65.000	Single	41KG				Tangent					
C	SW	551	70.000	Single	41KG				Tangent					
C	SW	551	75.000	Single	41KG				Tangent					
C	SW	551	80.000	Single	41KG				Tangent					
C	SW	551	85.000	Single	41KG				580	L	80			
C	SW	551	90.000	Single	41KG				608	L	80			
C	SW	551	95.000	Single	41KG				Tangent					
C	SW	551	100.000	Single	41KG				600	R	80			
C	SW	551	105.000	Single	41KG				Tangent					
C	SW	551	110.000	Single	41KG				Tangent					
C	SW	551	115.000	Single	41KG				Tangent					
C	SW	553	120.000	Single	41KG				Tangent					
C	SW	553	125.000	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
C	SW	553	130.000	Single	41KG				Tangent					
C	SW	553	135.000	Single	41KG				1600		80			
C	SW	553	140.000	Single	41KG				Tangent					
C	SW	553	145.000	Single	41KG				Tangent					
C	SW	553	150.000	Single	41KG				Tangent					
C	SW	553	155.000	Single	41KG				Tangent					

C	SW	553	160.000	Single	41KG				Tangent					
C	SW	553	165.000	Single	41KG				Tangent					
C	SW	553	170.000	Single	41KG				2400	R	80			
C	SW	553	175.000	Single	41KG				Tangent					
C	SW	553	180.000	Single	41KG				Tangent					
C	SW	553	185.000	Single	41KG				Tangent					
C	SW	553	190.000	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
C	SW	553	195.000	Single	41KG				Tangent					
C	SW	721	203.000	Single										
C	SW	721	208.000	Single	41KG				1600	R	70			
C	SW	721	213.000	Single	41KG				Tangent					
C	SW	721	218.000	Single	47KG				Tangent					
C	SW	721	223.000	Single	41KG				Tangent					
C	SW	721	228.000	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
C	SW	721	233.000	Single	41KG				Tangent					
C	SW	721	233.990	Single	41KG				Tangent				'Diverging' Rails	Possible high stress area. Stress test between 233.5km and 234km
C	SW	721	238.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
C	SW	721	242.550	Single	41KG				Tangent				Insufficient Data	
C	SW	721	243.000	Single	41KG				Tangent					
C	SW	721	248.000	Single	47KG				800	R	60		'Diverging' Rails	
C	SW	721	248.375	Single	47KG				Tangent				Insufficient Data	
C	SW	721	250.225	Single	47KG				Tangent				Insufficient Data	
C	SW	721	253.000	Single	47KG				Tangent				Non Recovering Creep	
C	SW	721	258.000	Single	47KG				Tangent				'Diverging' Rails	Close proximity to Fixed Track Structure
C	SW	721	263.000	Single	47KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 262.951km and 263.451km

C	SW	721	268.000	Single	47KG				Tangent					
C	SW	721	273.000	Single	47KG				Tangent					
C	SW	721	278.000	Single	47KG				Tangent				Excessive Creep as per CETS - Right Rail	Close proximity to Fixed Track Structure
C	SW	721	283.000	Single	47KG				Tangent					
C	SW	721	284.400	Single	47KG				Tangent					
C	SW	721	288.000	Single	47KG				Tangent					
C	SW	721	292.000	Single	47KG				Tangent					
C	SW	721	296.000	Single	47KG				Tangent					
C	SW	721	303.000	Single	47KG				Tangent					
C	SW	721	308.000	Single	47KG				Tangent					
C	SW	721	313.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
C	SW	721	316.615	Single	41KG				Tangent				'Diverging' Rails	
C	SW	721	318.000	Single	41KG				Tangent					
C	SW	721	323.000	Single	41KG				Tangent					
C	SW	721	326.000	Single	41KG				Tangent					
C	SW	721	328.000	Single	41KG				Tangent					
C	SW	721	333.000	Single	41KG				Tangent					
C	SW	721	338.000	Single	41KG				Tangent					
C	SW	721	343.000	Single	41KG				Tangent					
C	SW	721	346.000	Single	41KG				Tangent					
C	SW	721	348.000	Single	41KG				Tangent					
C	SW	722	361.000	Single	42lb				Tangent					
C	SW	722	371.000	Single	42lb				Tangent					
C	SW	722	381.000	Single	42lb				Tangent				'Diverging' Rails	
C	SW	722	391.000	Single	42lb				Tangent					
C	SW	722	400.000	Single	42lb				Tangent					
D	GL	559	1.020	Single	61lb				402.3	L	50			
D	GL	559	6.000	Single	60lb				Tangent					

					A.S.									
D	GL	559	11.000	Single	61lb				Tangent					
D	GL	559	16.000	Single	60lb A.S.				Tangent					
D	GL	559	17.700	Single	60lb A.S.				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 17.526km and 18.026km
D	GL	559	21.000	Single	60lb R				Tangent					
D	GL	559	26.000	Single	60lb R				Tangent					
D	GL	559	31.000	Single	60lb R				Tangent					
D	GL	559	36.000	Single	31KG				Tangent					
D	GL	559	41.000	Single	31KG				4023	R	60			
D	GL	559	46.000	Single	41KG				Tangent					
D	GL	559	51.000	Single	41KG				Tangent					
D	GL	559	56.000	Single	41KG				Tangent					
D	GL	559	61.000	Single	41KG				Tangent					
D	GL	559	66.000	Single	41KG				Tangent					
D	GL	559	71.000	Single	60lb A.S.				Tangent					
D	GL	559	76.000	Single	41KG				Tangent					
D	GL	559	81.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 80.941km and 81.441km
D	GL	559	86.000	Single	31KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 85.793km and 86.293km
D	GL	559	91.000	Single	60lb A.S.				Tangent				Excessive Creep as per CETS	
D	GL	559	96.000	Single	60lb A.S.				Tangent					
D	GL	559	101.000	Single	60lb A.S.				Tangent					
D	GL	559	106.000	Single	60lb A.S.				Tangent				Excessive Creep as per CETS	Close proximity to Fixed Track Structure
D	GL	559	111.100	Single	60lb				Tangent					

					A.S.									
D	GL	559	116.000	Single	60lb A.S.				Tangent					
D	GL	559	121.000	Single	60lb A.S.				Tangent					
D	GL	559	126.000	Single	60lb A.S.				Tangent					
D	GL	559	131.000	Single	60lb A.S.				Tangent					
D	GL	559	136.000	Single	60lb A.S.				Tangent					
D	GL	559	141.000	Single	60lb A.S.				Tangent				Excessive Creep as per CETS - Right Rail	
D	GL	559	143.000	Single	60lb A.S.				Tangent					
E	WL	356	108.000	Single										
E	WL	356	110.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 109.961km and 110.461km
E	WL	356	112.000	Single	41KG				Tangent					
E	WL	356	114.000	Single	41KG				Tangent					
E	WL	356	115.900	Single	41KG				Tangent					
E	WL	356	118.000	Single	41KG				Tangent					
E	WL	356	120.000	Single	41KG				Tangent					
E	WL	356	122.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 121.971km and 122.471km
E	WL	356	124.000	Single	41KG				Tangent					
E	WL	356	126.000	Single	41KG				Tangent					
E	WL	356	127.600	Down	41KG				Tangent					
E	WL	356	127.600	Up	41KG				Tangent					
E	WL	356	130.000	Single	41KG				Tangent					
E	WL	356	132.000	Single	41KG				Tangent					
E	WL	356	134.000	Single	41KG				Tangent				Excessive Creep as	

													per CETS - Right Rail	
E	WL	356	136.000	Single	41KG				Tangent					
E	WL	356	138.000	Single	41KG				Tangent					
E	WL	356	140.000	Single	41KG				Tangent					
E	WL	356	142.000	Single	41KG				Tangent					
E	WL	356	144.000	Single	41KG				Tangent					
E	WL	356	146.000	Single	41KG				Tangent					
E	WL	356	148.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	356	150.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	356	152.000	Single	41KG				Tangent					
E	WL	356	154.000	Single	41KG				Tangent					
E	WL	356	156.000	Single	41KG				Tangent					
E	WL	356	158.000	Single	41KG				Tangent					
E	WL	356	159.920	Single	41KG				Tangent					
E	WL	356	161.000	Single	41KG				Tangent				Non Recovering Creep	
E	WL	356	163.750	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
E	WL	353	43.900	Single	41KG				Tangent				Insufficient Data	
E	WL	354	45.010	Single	41KG				Tangent					
E	WL	354	47.002	Single	41KG				Tangent					
E	WL	354	49.000	Up	41KG				Tangent					
E	WL	354	49.000	Down	41KG				Tangent					
E	WL	354	51.000	Single	41KG				Tangent					
E	WL	354	53.000	Single	41KG				Tangent					
E	WL	354	55.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	354	57.000	Up	80lb R				Tangent					
E	WL	354	57.000	Down	80lb R				Tangent					

E	WL	354	59.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	354	61.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	354	63.000	Single	41KG				Tangent				Excessive Creep as per CETS	Close proximity to Fixed Track Structure
E	WL	354	65.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	354	67.110	Up	41KG				Tangent					
E	WL	354	67.110	Down	41KG				Tangent					
E	WL	354	69.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	354	71.000	Single	41KG				Tangent					
E	WL	354	73.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	354	75.000	Single	41KG				Tangent					
E	WL	354	77.000	Single	41KG				Tangent					
E	WL	354	79.000	Single	41KG				Tangent				Non Recovering Creep	
E	WL	354	81.000	Single	41KG				Tangent				Excessive Creep as per CETS	Close proximity to Fixed Track Structure
E	WL	355	85.000	Single										
E	WL	355	87.000	Single	41KG				Tangent					
E	WL	355	89.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	355	91.000	Single	41KG				Tangent					
E	WL	355	93.000	Single	41KG				Tangent				'Diverging' Rails	
E	WL	355	95.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	355	97.000	Single	41KG				Tangent					
E	WL	355	99.000	Single	41KG				Tangent				Excessive Creep as per CETS	Close proximity to Fixed Track Structure
E	WL	355	101.000	Single	41KG				Tangent					
E	WL	355	103.000	Single	41KG				Tangent				Excessive Creep as	

													per CETS	
E	WL	355	105.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	355	107.000	Down	41KG				Tangent				Insufficient Data	
E	WL	355	107.000	Up	41KG				Tangent				Insufficient Data	
E	WL	463	83.900	Single	41KG				Tangent					
E	WL	563	166.000	Single	41KG				371	L	60			
E	WL	563	168.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	563	170.000	Single	41KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 169.961km and 170.461km
E	WL	563	172.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	563	174.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	Close proximity to Fixed Track Structure
E	WL	563	176.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	563	178.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	563	180.000	Single	41KG				Tangent					
E	WL	563	182.000	Single	41KG				Tangent					
E	WL	563	184.000	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	563	186.000	Single	41KG				Tangent					
E	WL	563	188.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	563	190.000	Single	41KG				Tangent					
E	WL	563	192.000	Single	41KG				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 191.851km and 192.351km

E	WL	563	194.000	Down	41KG				Tangent					
E	WL	563	194.000	Up	41KG				Tangent					
E	WL	563	196.000	Single	41KG				Tangent					
E	WL	563	198.000	Single	41KG				Tangent					
E	WL	563	200.000	Single	41KG				Tangent					
E	WL	563	202.000	Single	41KG				Tangent					
E	WL	563	204.000	Single	41KG				1200	L	80			
E	WL	563	206.000	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	563	208.000	Single	41KG				Tangent				Non Recovering Creep	Possible high stress area. Stress test between 207.68km and 208.18km
E	WL	565	208.400	Single									Non Recovering Creep	
E	WL	565	213.400	Single	41KG				Tangent					
E	WL	565	218.400	Single	41KG				Tangent				'Diverging' Rails	
E	WL	565	223.400	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	565	228.400	Single	41KG				Tangent				Excessive Creep as per CETS	
E	WL	565	233.400	Single	41KG				Tangent					
E	WL	565	238.400	Single	41KG				Tangent					
E	WL	565	243.400	Single	41KG				Tangent					
E	WL	565	248.400	Single	41KG				500		70		Excessive Creep as per CETS	
E	WL	565	253.400	Single	41KG				Tangent				Non Recovering Creep	Close proximity to Fixed Track Structure
E	WL	565	258.400	Single	41KG				Tangent				Excessive Creep as per CETS - Right Rail	
E	WL	565	263.400	Single	41KG				Tangent				Excessive Creep as per CETS - Left Rail	
E	WL	565	268.400	Single	41KG				3145		70			
E	WL	565	273.400	Single	41KG				Tangent				Excessive Creep as per CETS	

F	WL	565	278.400	Single	41KG				Tangent					
F	WL	565	283.400	Single	41KG				Tangent					
F	WL	565	288.400	Single	41KG				Tangent					
F	WL	565	293.400	Single	41KG				Tangent					
F	WL	565	298.400	Single	41KG				Tangent					
F	WL	565	303.400	Single	41KG				Tangent				Insufficient Data	
F	WL	565	308.400	Single	41KG				Tangent					
F	WL	565	313.400	Single	41KG				Tangent					
F	WL	565	318.400	Single	41KG				Tangent					
F	WL	565	323.400	Single	41KG				Tangent					
F	WL	565	328.400	Single	41KG				Tangent				Non Recovering Creep	
F	WL	565	333.600	Single	41KG				375		60			
F	WL	565	338.400	Single	41KG				Tangent					
F	WL	565	343.400	Single	41KG				Tangent					
F	WL	565	348.500	Single	41KG				Tangent					
F	WL	567	351.200	Single										
F	WL	567	361.200	Single	41KG				Tangent				'Diverging' Rails	
F	WL	567	371.200	Single	41KG				Tangent				Excessive Creep as per CETS	
F	WL	567	381.200	Single	41KG				Tangent					
F	WL	567	391.200	Single	41KG				Tangent					
F	WL	567	401.200	Single	60lb A.S				Tangent					
F	WL	567	411.200	Single	60lb A.S				Tangent				Non Recovering Creep	Possible high stress area. Stress test between 410.891km and 411.391km
F	WL	567	421.200	Single	41KG				Tangent					
F	WL	567	431.200	Single	31KG				Tangent					
F	WL	567	441.200	Single	41KG				Tangent				'Diverging' Rails	Possible high stress area. Stress test between 441.167km and 441.667km
F	WL	567	451.200	Single	31KG				1000		70		Non Recovering Creep	Close proximity to Fixed Track Structure

F	WL	567	461.200	Single	60lb R				Tangent				Non Recovering Creep	
F	WL	567	471.200	Single	60lb R				Tangent				Non Recovering Creep	
F	WL	567	481.200	Single	60lb R				Tangent				Non Recovering Creep	
F	WL	568	491.200	Single	60lb R				Tangent					
F	WL	568	501.200	Single	60lb R				1600		70		Non Recovering Creep	
F	WL	568	511.200	Single	60lb R				Tangent					
F	WL	568	521.200	Single	60lb A.S				Tangent					
F	WL	568	531.200	Single	60lb A.S				Tangent				Non Recovering Creep	
F	WL	568	541.200	Single	60lb A.S				Tangent				Non Recovering Creep	
F	WL	568	551.200	Single	60lb A.S				Tangent					
F	WL	568	561.200	Single	60lb A.S				Tangent					
F	WL	568	571.000	Single	60lb A				Tangent					
F	WL	568	581.000	Single	60lb R				Tangent					
F	WL	568	591.000	Single	60lb R				Tangent					
F	WL	568	601.000	Single	61lb				Tangent					
F	WL	568	611.000	Single	60lb A.S				Tangent				Non Recovering Creep	
G	GW	716	0.000	Single									Insufficient Data	
G	GW	716	10.500	Single	42lb				Tangent				Insufficient Data	
G	GW	716	19.800	Single	42lb				Tangent				Insufficient Data	
G	GW	716	30.370	Single	42lb				Tangent				Insufficient Data	
G	GW	716	40.000	Single	42lb				Tangent				Excessive Creep as per CETS - Right Rail	Possible high stress area. Stress test between 39.75km and 40.25km
G	GW	716	50.000	Single	42lb				400		60		Insufficient Data	
G	GW	716	60.000	Single	42lb				1600		60		Insufficient Data	

G	GW	716	70.000	Single	41KG				Tangent				Insufficient Data	
G	GW	716	80.500	Single									Insufficient Data	
G	GW	717	90.100	Single	42lb				Tangent				Insufficient Data	
G	GW	717	100.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	110.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	120.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	130.500	Single	42lb				Tangent				Insufficient Data	
G	GW	717	140.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	149.950	Single	42lb				Tangent				Excessive Creep as per CETS	Possible high stress area. Stress test between 149.841km and 150.341km
G	GW	717	160.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	170.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	180.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	190.000	Single	42lb				Tangent				Insufficient Data	
G	GW	717	200.000	Single	61lb				Tangent				Insufficient Data	