

# Welded Track Stability Analysis

ETM-06-09

## Applicability

ARTC Network Wide
SMS

## Publication Requirement

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## 1 Introduction

### 1.1 Purpose

The purpose of this procedure is to specify and describe requirements for carrying out Welded Track Stability Analysis (WTSA).

### 1.2 Scope

The procedures are applicable to timber sleepered CWR and LWR in main lines.

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*Note:* For the purposes of this Procedure, timber sleepered track includes track with:

- Interspersed sleeper types;
  - Steel or composite sleepers in a face;
  - Concrete sleepers in a face with an overall length of less than 300m; or
  - Any curve not completely sleepered in concrete.
- 

Locations where WTSA is required are identified in ETM-06-08 Managing Track Stability.

### 1.3 Document Owner

The Manager Standards is the Document Owner and is the initial point of contact for all queries relating to this procedure.

### 1.4 Reference Documents

This procedure is to be read in conjunction with the following document:

- ETM-06-08 Managing Track Stability

## 1.5 Definitions

The following terms and acronyms are used within this document:

Term or acronym	Description
Alignment index	The ratio of curve radius to length of curve (both in metres).
Anchor point	A section of track where all sleepers are required to be fully anchored, or fastened with <i>resilient fastenings</i> .
Buckle	A buckle (also known as a misalignment) occurs when the <i>compression</i> generated in the rail exceeds the ability of the track structure to hold itself in place and the track is displaced laterally. Lateral displacement of track in high temperature shall be treated as a buckle.
Bunching point	A section of track where <i>stress free temperature</i> may reduce due to an accumulation of rail resulting from <i>creep</i> , including on the approaches to <i>fixed points</i> , bottoms of gradients, signals where trains regularly stop, train braking zones, or where there is a change in track type (e.g. non-resilient to <i>resilient fastenings</i> ).
Compression	The compressive (squeezing) force generated in <i>CWR</i> when rail temperature increases above the <i>stress free temperature</i> , and the rail cannot expand.
Creep	Longitudinal movement of rail (or rail plus sleepers) over time, resulting in changes to <i>stress free temperature</i> .
CWR (Continuously Welded Rail)	Rail lengths welded end to end into strings greater than 400m without rail joints.
Fixed point	A section of track, such as through a turnout or road crossing, which offers greater resistance to longitudinal rail movement than elsewhere.
GT	Gross tonnes of rail traffic.
High temperature	The temperature at which lateral track stability may be affected due to existing track deficiencies and/or maintenance activities and/or construction activities. On a well maintained track these are air temperatures above design SFT or rail temp above 60°C. These temperatures may trigger requirements for speed restrictions and/or track inspections.  History and condition of the track should be considered when nominating the temperature.
LWR (Long Welded Rail)	Rail lengths welded end to end into lengths between 55m and 400m.
Misalignment	See <i>buckle</i> .
Net tangent creep	The amount and direction of <i>creep</i> into or out of a section of track, calculated as the difference between the <i>creep</i> measured at each end.
Pull-apart	A rail break and contraction of rail ends, when in tension during cold weather.
Pull-in	Lateral track movement towards the centre of a curve, resulting from <i>tension</i> in the rails.
Resilient fastenings	Fastenings which exert a toe load on the rail foot, inhibiting <i>creep</i> .

Term or acronym	Description
Special location	For the purposes of this procedure, a location which has an increased risk of track instability.
Stress free	Rail which has no axial thermal forces, it is neither in <i>compression</i> nor in <i>tension</i> .
Stress free temperature (SFT)	The temperature at which the rail in <i>CWR</i> is <i>stress free</i> .  If the rail were to be cut, the gap created would remain constant. It would neither close nor would it widen unless the rail temperature was to change.
Stressing	The process of adjusting <i>CWR</i> to the correct <i>stress free temperature</i> .
Tension	The tensile (pulling) force generated in <i>CWR</i> when rail temperature decreases below the <i>stress free temperature</i> and the rail cannot contract.
Track Condition Index (TCI)	A numerical value reflecting the quality of track geometry.
TrackStab	Software application for <i>WTSA</i> .
Track Stability Management Plan (TSMP)	A document which specifies the required preparation and practices for management of track lateral stability during an annual hot weather period – refer ETM-06-08 Managing Track Stability.
Welded rail	Rail which is either <i>CWR</i> or <i>LWR</i> .
WTSA	Welded Track Stability Analysis.

## 2 General

### 2.1 Application

Timber sleepere track is to be examined and analysed in accordance with this Procedure where specified in ETM-06-08 Managing Track Stability.

### 2.2 Welded Track Stability Analysis

WTSA considers both buckling force and buckling resistance, to produce an integrated assessment of track stability. The examination and calculations are necessary to identify locations of potential track misalignment or pull-apart, and to allow corrective work to be undertaken.

The WTSA process of deducing SFT for CWR from creep relies on the following assumptions:

- The rails were correctly stressed when welded to CWR.
- The creep monuments were installed when the rails were correctly stressed to design SFT.
- All short rail replacement or rail defect removal has been correctly undertaken.
- Lateral monuments for curves were installed when the rails were correctly stressed and the curve was on the correct alignment.

It should be noted that if a buckle occurs that is not predicted by WTSA, then the assumptions are shown to be not correct. The rails should be restressed and the monuments reset to zero. For curves, the curves need to be on the correct alignment and the lateral monuments reset as appropriate.

### 2.3 Timing

Where required as specified, field examinations and calculations for WTSA, comprising the detailed inspection of track stability, are to be carried out between July and October each year.

Where necessary, an additional examination may be undertaken in summer/autumn, to identify potential pull-aparts and for planning future track works.



## 2.4 Basis for Assessment

Field examinations are to be undertaken and welded rail track stability calculated as specified in Table 1.

Track	Basis for Calculation
LWR with rail lengths not greater than 220m, and with no or partial resilient fastenings (not more than 1 in 3).	As for LWR (refer section 6).
LWR with rail lengths greater than 220m, and with no or partial resilient fastenings (not more than 1 in 3).	Respond as for a priority 1 non-conformance – refer section 3.3.
LWR with resilient fastenings (more than 1 in 3), installed and monitored in the same way as CWR i.e. adjusted, creep pegs installed, alignment known.	As for CWR – refer section 5.
LWR with resilient fastenings (more than 1 in 3), not installed and monitored in the same way as CWR i.e. not adjusted, no creep pegs installed, or alignment unknown.	Refer section 5.2.
CWR which is adjusted has creep pegs installed, and alignment is known.	As for CWR (refer section 5).
CWR which is not adjusted has no creep pegs installed, or alignment is unknown.	Refer section 5.2.
Track sections less than 500m long	Refer section 13.

**Table 1 – Basis for calculation**

## 2.5 Progress Reporting

Weekly Reports detailing progress in measurement, analysis of track and correction of WTSA priorities are to be faxed or emailed to the Team Manager by 12 noon each Wednesday for the preceding week (Sunday to Saturday). The first report is due on the first Wednesday in September.

It is essential that reports are timely, accurate and complete.

## 2.6 Use of Stress Free Temperature Measurement in Conjunction with WTSA

Stress free temperature measurements may be used in conjunction with WTSA:

- As part of the response to WTSA stability losses requiring intervention
- Where there have been indications of lateral instability or creep occurring, but this is not indicated in the stability loss calculated from WTSA
- At locations where the continuity of creep measurements has been lost
- Where curve alignment measurements are unreliable or not possible
- Where buckles have occurred at locations not predicted by WTSA.

### 3 Summary of WTSA Process

#### 3.1 Field Examination & Analysis

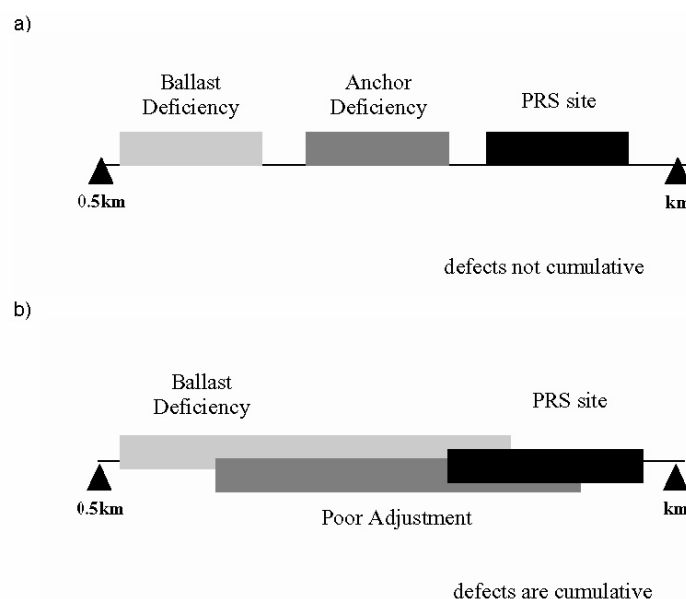
Applicable welded track is to be examined and analysed in accordance with these instructions.

Analysis calculations may be carried out manually, by spreadsheet, or by using the TrackStab application.

#### 3.2 Secondary Analysis

The initial analysis accumulates the loss of stability due to all aspects which may occur over 500m of track. If the calculated final stability loss is 40% or greater, rectification may be required, so the section should be further inspected/reviewed to:

- 1 Confirm the accuracy of the input data.
- 2 Assess the cumulative effects within the 500m section. Some defects occur at different points within the 500 m such that their effects are not cumulative as assumed in the analysis, as illustrated in Figure 1. Where appropriate, the resulting stability loss may be amended accordingly.



**Figure 1 – Non-cumulative and cumulative defects**

- 3 Re-evaluate the effect of track disturbances. Reference Table 11 - Effect of Tonnage on Track Disturbance provides a comparison of reduction in track stability loss due to traffic tonnage. The original assessment is time based and therefore general, but the influence of tonnage is significant, so should be assessed for each priority location.
- 4 Re-calculate the location factor (refer section 11.11), reassessing all contributing factors.
- 5 Where there is an indication that the track adjustment varies significantly over the 500m section, an analysis should be carried out over a shorter length (the worst section) using the methods in section 13.
- 6 Determine a revised final stability loss.

### 3.3 Responses

Following determination of a revised final stability loss, the location is to be actioned as shown in Table 2

Revised Final Stability Loss	WTSA Priority	Action
40% – 55%	2	Implement programmed attention or evasive action.  Apply speed restriction when ambient temperature exceeds 30°C.
>55%	1	Implement immediate attention or evasive action. Treat as special location until rectified.  Apply speed restriction when ambient temperature exceeds 25°C.

**Table 2 – Responses to calculated loss of stability**

On CWR, action may include verification of stress free temperature by measurement (refer ETM-06-08 Managing Track Stability).

### 3.4 Loss of Adjustment Control

Any area where adjustment control has been lost, so is being dealt with in accordance with the provisions of section 5.2, and has other stability problems such as ballast deficiency, poor ballast condition or recent disturbance, the repair or protection requirement must be treated with additional urgency.

### 3.5 Control of Correction Process

When WTSA priorities are corrected, the stability loss must be recalculated to ensure the priority has been reduced below WTSA Priority 1 level (preferably below WTSA Priority 2 level to avoid having a priority again the following year).

For corrected locations, there must be a signed off record showing the work carried out and the revised stability loss at below WTSA Priority 1 level.

## **4 Field Examination**

### **4.1 Track Sections**

Field examinations are to be carried out on 500m sections of track, between kilometre and half-kilometre pegs.

### **4.2 Recording**

Inspection details are to be recorded on:

- Form ETM0609F-01 WTSA Data Collection (CWR & LWR) or
- Form ETM0609F-02 WTSA Data Collection (JWR).

Alternatively, the WTSA field sheets generated by the Access Database "TrackStab Field Sheets" may be used providing the minimum information in forms ETM0609F-01 and ETM0609F-02 is included.

## 5 Measurement of CWR

### 5.1 Introduction

The adjustment of CWR is to be assessed from recordings of two main indicators:

- Measurement of rail creep at each kilometre and half-kilometre peg
- Measurement of track alignment on curves, compared to survey information.

### 5.2 Where Rail Adjustment Cannot be Assessed with Confidence

Measurement of rail adjustment on CWR is only appropriate where creep marks or alignment monuments were installed or reset at the time of adjustment. Where rail adjustment cannot be assessed with confidence:

- Apply the adjustment specified in Reference Table 10 - Influence of Non Standard or Special Track Conditions, or
- Implement an alternative to WTSA, assessing buckling force by measuring stress free temperature, and identifying and correcting buckling resistance issues in accordance with ETM-06-08 Managing Track Stability.

### 5.3 Measurement of Rail Creep

- 1 Locate the creep control reference points established on both sides of the track at the kilometre and 0.5 kilometre pegs.
- 2 Locate the punch marks on the outside heads of both rails.
- 3 Using creep measuring equipment, record the amount of rail creep for each rail on the appropriate form. This measurement is to be taken at each kilometre and half-kilometre peg over the CWR section. Always fill out the form in the down direction, i.e. with the zero kilometre end at the top of the page.
- 4 On the recording sheet, indicate any rail movement with an arrow pointing up the page if the creep is toward the zero kilometre, and down the page if the creep is away from the zero kilometre.

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*Note: Creep towards the zero kilometre is negative; creep away from the zero kilometre is positive.*

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## 5.4 Measurement of Track Alignment

Track alignment is to be recorded at intervals not exceeding 50m, on curves as detailed in Table 3.

Curve radius	Measurements to be recorded
Greater than 610 metres	Measure if the curve has a history of pulling in, or is considered to be at risk of pulling in.
Greater than 410 metres – 610 metres	Measure all curves, except those with demonstrable stability.
410 metres or less	Measure all curves

**Table 3 – Measurement of track alignment on curves**

Curves to be measured are to be listed in the Track Stability Management Plan.

Record the distance between the track and the reference point on the appropriate form. If the survey alignment figures are known, the difference in the two readings (the "alignment error") can also be entered on the form as a positive number if the curve has moved further from its centre (pushed out), or as a negative number if the curve has moved closer to its centre (pulled in).

Some track has deliberately been continuously welded "off design line". If this is the case and the "off line" position at time of welding is known and documented then it can be considered as an "interim design" and is acceptable.

Where, for any reason, the alignment cannot be established, this must be noted on the form.

## 6 Measurement of LWR

### 6.1 Introduction

This section applies to LWR with rail lengths up to 220m. LWR with rail lengths greater than 220m is to be dealt with in accordance with section 5.2.

### 6.2 Measurements

The rail temperature is to be measured at each 500m (kilometre and half-kilometre pegs) along the track. The temperature reading and kilometrage are to be recorded on the form.

More than one temperature reading location may be required if part of the rail is shaded or in a cutting, to give an average temperature for the rail length.

Gaps are to be measured at all rail joints, including mechanical insulated joints (end post not to be counted as part of the gap). Measurements and kilometrage are to be recorded on the form for the up and down rails separately for later analysis. Glued insulated joints and joints within a turnout are not included.

### 6.3 Rail Joint Gap Measurement Problems

Problems often arise in the measurement of rail gaps, which can, if left uncorrected, give wrong assessments. To minimise these problems the following procedures should be used:

#### **Suitable Temperatures**

In general, 25°C – 35°C is the most suitable range for gap measurements. This is based on the normal temperature range of theoretically correct gap measurements, which should vary between 0mm and 12mm.

#### **Large Gaps (i.e. in excess of 20 mm)**

Gap gauges go up to 20mm and bent bolts in joint can increase the size of the gap. If gaps are larger than 20mm, re-measure the full 500m section at a higher rail temperature, when the rail gap has reduced by at least 2mm from the original reading.

#### **Zero Gaps**

Re-measure the full 500m section at a lower rail temperature, at which a minimum gap of 2mm occurs. If, for a rail temperature which is 10°C cooler than the original, no gap has occurred, action should be taken to locally adjust and record measurements. This will correct local rail compression which could otherwise result in a misalignment.

#### **Frozen Joints**

A visual inspection run should be undertaken prior to gap measurement to ensure joints are working. Following the visual inspection undertake minor maintenance as required. Otherwise, if a frozen joint is suspected, rail gap measurement is to be repeated at different temperatures to assess joint movement.

#### **Locked Up Stresses**

During visual inspections while carrying out WTSA measurements, make notes in the remarks column where sleeper are skewing, localised ballast is being pushed by sleepers, etc.

## 7 Examination of Anchors & Resilient Fastenings

### 7.1 Introduction

Field examinations are to include examination of anchors and/or resilient fastenings.

### 7.2 Rail Anchors

The anchor inspection should identify locations where:

- Anchors do not meet the standard pattern
- Anchors are not correctly fitted tight up against the sides of sleepers
- There is evidence to indicate rails have "crept" through the anchors - (look for marks on the rail flange indicating movement; anchors on one side of sleeper all drifted away from the sleeper edge; skewed sleepers; wide/tight rail joints)
- Anchor effectiveness is reduced - check by removing a few anchors and testing their spring action by driving them back on - anchors which require little or no effort to replace have lost their spring and are ineffective
- Anchor points - such as each side of a turnout - are inadequately anchored.

### 7.3 Resilient Fastenings

Where resilient fastenings are used, look for evidence of rail creep through the sleepers - look for marks on the rail flange indicating movement.

### 7.4 Recording

Inspection results are recorded for each 500m. If the anchoring and fastenings for the 500m section are satisfactory, the "OK" column on the manual form is to be ticked, or the Yes/No answered on the computer form. If anchors or resilient fastenings are not working properly, the percentage ineffective is to be assessed.

If any deficiencies are identified, the worst example for the 500m section is recorded in the respective column on the manual form, or the Yes/No and Remarks columns of the computer form completed, using Table 4 as a guide.

Type of anchor	Condition
Fair type anchor	Good
	Incorrect pattern
	Creep indications
	Ineffective/missing
Resilient fastening	Good
	20% ineffective

**Table 4 – Guide to anchoring deficiencies**



## 8 Examination of Ballast Profile

### 8.1 Introduction

Field examinations are to include examination of ballast.

It is necessary to identify locations where:

- Ballast deficiencies exist, or
- Where track ballast is contaminated by mud or debris.

### 8.2 Recording

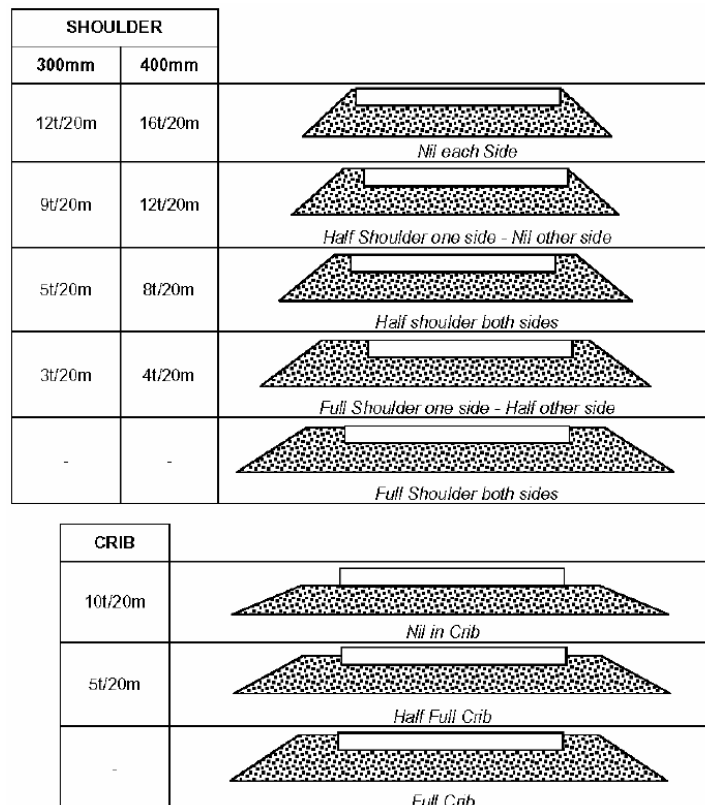
Any deficiency must be recorded on the form, showing crib or shoulder deficiencies in tonnes per 20m. For shoulder ballast deficiencies on curves, indicate whether the deficiency is on the high or low rail by writing H or L next to the tonnage figure e.g. 5 t/20 m(H).

Guidelines for estimating deficiency quantities are given in Figure 2. The requirements of ARTC Code of Practice Section 4 - Ballast should also be followed.

Assessment of ballast crib deficiencies in steel sleepered areas is to include an allowance for ballast deficiencies in the sleeper pods. Estimate additional ballast required to fill pods and add this figure to the estimated crib deficiency to give a total crib deficiency each 20m.

The worst result for the 500m is to be recorded, as this represents the weakest point for the section.

During the inspection, all areas of foul ballast, poor formation, or pumping joints are to be noted on the inspection form.



**Figure 2 – Guidelines for estimating ballast deficiency**

## **9 Misalignment Triggers**

### **9.1 Field Examinations**

Field examinations are to include identification of misalignment trigger points.

Misalignment trigger points include discrete locations such as:

- Straight closures in curves
- Bad weld alignment
- Bridge ends
- Underline crossings.

Misalignment trigger points may not show up as priorities in the WTSA over 500m, but must be noted on the measurement form.

## 10 Evaluation of Bunching Points

### 10.1 Introduction

All bunching points must be the subject of an additional assessment to review the likely impact on track adjustment. If no assessment is carried out track adjustment must be calculated assuming that incoming rail creep is confined to the track between the creep point and the bunching point.

### 10.2 Examination

Is the bunching point really a location where steel has been bunching? Factors to be considered include:

- Creep into the 500m section is close to creep out of the section
- Creep in the section has been stable for at least 3 years, or has reduced in that time
- Single line track with no particular reason to bunch as traffic is similar in both directions
- Are there indications on sleepers/fastenings that steel has been passing through the bunching point?

If it can be established that the location is not actually causing steel to bunch then the bunching point adjustment calculation is not required. Alternatively, if only some of the steel is creeping through the bunching point, a reduced level of creep can be used in the analysis.

## 11 Analysis of CWR

### 11.1 Process

WTSA uses information gathered as part of the field examination, plus available data on major track works, to predict the stability of track under high temperature conditions.

The field information is used to calculate the percentage of "track stability loss" for each 500m section of welded rail track. Special procedures are included for adjustment analysis of sections less than 500m (section 13).

### 11.2 Tangent Creep

#### Net Tangent Creep

From the recorded measurements of rail creep, calculate the net tangent creep. This result is calculated by comparing the amount and direction of the creep at either end of the 500m track section being analysed.

The analysis assumes the rails have been correctly installed and maintained.

If the result means additional rail has moved into the section then stress produced is compression (-).

If the result means that rail has moved out of the section then the stress produced is tension (+).

#### Example 1:

km peg	Creep – 10 mm )	Creep direction
½ km peg	Creep – 25 mm )	–25– (–10) = –15 mm
		Additional rail in section
		Net tangent creep = –15 mm

#### Example 2:

km peg	– 10 mm )	Creep direction
½ km peg	+ 25 mm )	+25– (–10) = +35 mm
		Less rail in section
		Net tangent creep = +35 mm

---

*Note: Creep towards the zero kilometre is negative while creep away from the zero kilometre is positive.*

---

#### Stress Free Temperature Error

Using Reference Table 2 - CWR Tangent Creep Analysis, read the equivalent stress free temperature error for the 500m section due to the amount of net tangent creep.

#### Example:

Net tangent creep = -15mm

From Reference Table 2 - CWR Tangent Creep Analysis, stress free temperature error

= -3°C.

---

*Note: When the net tangent creep is negative (-), the stress free temperature error is also negative (-) i.e. the stress free temperature of the rail has been lowered. When the net tangent creep is positive (+), the stress free temperature error is positive (+) i.e. the stress free temperature has been raised.*

---

## 11.3 Curve Pull-in

### Introduction

For each curve in the 500m section where alignment was measured, determine the stress free temperature error due to curve pull-in, as set out below.

### Alignment Index

Calculate the alignment index for each curve or portion of curve in the 500m section:

$$\text{Curve Alignment Index} = \frac{\text{Radius}}{\text{Length of curve in 500m section}}$$

These indices can be calculated initially and entered on the field recording sheets for the section.

### Stress Free Temperature Error

Calculate the stress free temperature error from the effect of movement of the curve in the 500m section using Reference Table 3 - CWR Curve Pull-in Analysis.

*Example:*

Curve 300m long, Radius 900m

$$\text{Curve Alignment Index} = \frac{900}{300} = 3$$

Average Alignment Error = -40mm

(Where alignment error is taken over the worst 100m, being that which is the greatest negative or least positive alignment error.)

From Reference Table 3 - CWR Curve Pull-in Analysis:

Stress free temperature error = -3°C for 500m section.

### Multiple Curves

For more than one curve or portions of curves in the 500m section, add the stress free temperature error results for each curve (or portion thereof), to give the total stress free temperature error due to curve pull-in for the 500m section.

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*Note: Use zero stress free temperature error for curves which are not required to be measured. Apply Reference Table 10 - Influence of Non Standard or Special Track Conditions to curves which are required to be measured but for which alignment details are not known.*

---

## 11.4 Loss of Track Stability Due to Stress Free Temperature Error

### Total Stress Free Temperature Error

For each 500m, and for each rail separately, calculate the total stress free temperature error.

$$\begin{aligned} \text{Total stress free temperature error} = & \text{ stress free temperature error due to net tangent creep} \\ & + \text{ stress free temperature error due to curve pull-in} \end{aligned}$$

### Loss of Track Stability

- 1 For each 500m calculate the Total Rail Temperature Error:

$$\begin{aligned} \text{Total rail temperature error} = & \text{ Longitudinal creep (tangent) temperature error} \\ & + \text{ lateral movement (curve creep) temperature error} \end{aligned}$$

- 2 Using Reference Table 4 - Loss of track stability (% of total stability) for CWR, obtain the loss of track stability for the total stress free temperature error.

*Example:*

$$\begin{aligned} \text{Total Stress Free Temperature Error} = & \text{ Tangent Temperature Error} + \\ & \text{ Curve Temperature Error} \\ & = -3^{\circ}\text{C} + -3^{\circ}\text{C} \\ & = -6^{\circ}\text{C} \end{aligned}$$

From Reference Table 4 - Loss of track stability (% of total stability), loss of track stability is 15%.

This process is repeated separately for the up and down rails, giving two separate results.

The total or combined track stability loss due to rail adjustment in the 500m section is the sum of the losses of track stability for each rail.

The result should be recorded as a % stability loss.

## 11.5 Missing Pegs or Monuments

If there are no creep pegs, or the alignment details are not known for any particular 500m section, then a combined track stability loss as detailed in Reference Table 10 - Influence of Non Standard or Special Track Conditions is to be assumed for the 500m section.

## 11.6 Anchors & Resilient Fastenings

From the information recorded in accordance with section 7, use Reference Table 5 - Influence of Anchor Conditions to determine the stability loss from the recorded field examination information.

Record the worst result for each 500m section as representative of the weakest point in the section.

## 11.7 Ballast

From the information recorded in accordance with Part II section 7.6, use Reference Table 6 - Influence of Ballast Deficiencies to determine the stability loss from the recorded field examination information.

Record the worst result for the 500m section, as representative of the weakest point in the section. The result should be the sum of the crib result and the shoulder result.

If any areas have been noted as having foul ballast, poor formation pumping joints, etc, a loss of track stability as specified in Reference Table 10 - Influence of Non Standard or Special Track Conditions is to be added to the ballast deficiencies result.

## 11.8 Track Disturbances

Reference Table 7 - Influence of Major Track Disturbance indicates the loss of track stability for major track disturbances. Depending upon the timing of major works and the type of work, variations to the impact on track stability will occur. There is a "look-ahead" period in the assessment, which is carried out from July to October each year to ensure that account is taken of works scheduled for the summer ahead. These are more significant than those during the past months even though the critical situation has not yet occurred.

Reference Table 8 - Summer Updating Analysis is used to update the analysis during the summer period, when the effect of Track Disturbance is reduced as time passes.

The type, extent and timing of the major work activity should be plotted on ETM0609F-01WTSA Data Collection (CWR and LWR) or ETM0609F-02WTSA Data Collection (JWR).

Using Reference Table 7 - Influence of Major Track Disturbance, an appropriate Track Stability Loss can be determined, and again the worst situation for the 500m section should be applied. Different activities are not additive.

### *Example:*

If ballast cleaning is set for next March (28% result) and surfacing in September (24% result) the loss of Stability would be the worst, i.e. 28% loss of stability (not 52%).

The use of a ballast stabilising machine in conjunction with resurfacing works provides an immediate improvement in track stability. Reference Table 7 - Influence of Major Track Disturbance and Reference Table 8 - Summer Updating Analysis indicate the percentage stability loss to be added when a Ballast Stabilising Machine is used.

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*Note: Because of the restrictions placed on the use of the ballast stabilising machine in some locations, some track which has been resurfaced may not have been stabilised. If non stabilised track occurs in a 500m section then it must be separately noted and the maximum disturbance value used.*

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Additional precautions should be taken to protect the worksite following track disturbance, as specified in ETM-06-08 Managing Track Stability.

Areas subject to ongoing disturbance (e.g. mudholes or pumping joints) are to be dealt with as shown in Reference Table 10 - Influence of Non Standard or Special Track Conditions.

## 11.9 Track Condition

The general condition of track can be measured by the TCI data provided by the AK Car. Poor sleeper condition, formation problems, etc., as well as causing deterioration to track geometry and TCI can also cause the track to lose lateral stability. The deteriorated track conditions often provide the "trigger" mechanism for a misalignment.

Reference Table 9 - Influence of General Track Condition indicates the loss of track stability for track condition. The worst TCI for each 500m section, excluding turnout assessments, should be used as the basis for determining the stability loss, and the result recorded or entered directly into the computer.

## 11.10 Preliminary Result

The addition of individual results will give a preliminary assessment of track stability loss due to:

Down rail adjustment	%
Up rail adjustment	%
Anchors	%
Ballast deficiencies	%
Track disturbance	%
Track condition	%
<b>Preliminary Stability Assessment</b>	<b>%</b>

## 11.11 Location Factors

It is recognised that each 500m of track has its own unique characteristics. The features of the 500m section will affect the track stability beyond those described above and the preliminary stability assessment must be adjusted accordingly.

A location factor must be determined for each 500m section adding factors selected from Table 5.

Feature	Location factor component	
Curvature (radius)	0 – 400 m	0.20
	400 – 800 m	0.12
	800 – 1600 m	0.07
	1600 m +	0.00
Grade	> 1 in 60	0.05
	1 in 60 – 1 in 120	0.02
	< 1 in 120	0.00
Bidirectional working	Yes	0.00
	No	0.02
Braking zone	Heavy	0.05
	Steady	0.02
Bunching points in section e.g. turnouts, level crossings, fastening type changeover, bridges, etc.		0.10
Sum of relevant components		
Location Factor = 1.0 + Sum of relevant components		

**Table 5 – Location factors**

There will be different location factors for each 500m and they will be in the range 1.00 to 1.42.



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*Note: Location factors will generally remain constant year after year and can be calculated once and included on the form, or entered into TrackStab as a fixed entry. The factors need only be altered if there is a significant change. Location factors must however be reviewed annually.*

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### **11.12 Bunching Points**

Where the 500m section contains a bunching point and the field examination indicates that bunching is occurring, the calculation should be for a shorter length, as detailed in section 13, assuming that the incoming steel is confined to between the creep point and the bunching point.

The minimum length to be used is 165m. If the adjusted length is less than 165m, use 165m. If greater than 165m, use the actual length. This is because where the track length is short; the measurement accuracy can have a misleading effect on the adjustment error calculated.

### **11.13 Special Conditions**

The special conditions detailed in Reference Table 10 - Influence of Non Standard or Special Track Conditions are to be checked, and adjustments applied as specified.

### **11.14 Final Result**

Final Stability Assessment = Preliminary Stability Assessment x Location Factor

Adjusted if required by Reference Table 10 - Influence of Non Standard or Special Track Conditions.

The final stability assessment is expressed as a percentage stability loss.

### **11.15 Actions**

Refer section 3.3.

## 12 Analysis of LWR

### 12.1 Introduction

The analysis of rail gaps is based on the measurements of joint gaps and rail temperature, for each separate 500m section of track.

### 12.2 Average Rail Length

From the number of rail gaps in the 500m section calculate the average length of rail for that section.

*Example:*

For 5 rail gaps - Average rail length is 100m

For 4 rail gaps - Average rail length is 125m

Calculate the average rail gap for the 500m section by totalling the length of all gaps and dividing by the number of rail gaps in that section.

*Example:*

For 4 gaps with total gap measuring 40mm - the average rail gap is 10mm

For 10 gaps with total gap measuring 36mm - the average rail gap is 3.6mm

### 12.3 Theoretical Measured Temperature

Using Reference Table 1 - Long Welded Rail - Gap Analysis, determine from the average rail length and average rail gap what the theoretical measured temperature for that 500m section should have been.

*Example:*

Average rail length = 125m

Average gap = 10mm

From Reference Table 1, theoretical measured temperature is 32°C

### 12.4 Stress free temperature error

The stress free temperature error for the 500m section will be the difference between the rail temperature (as measured) and the theoretical measured temperature from Reference Table 1 - Long Welded Rail - Gap Analysis.

Stress free temperature error = actual measured temperature - theoretical measured temperature

If the stress free temperature error is a minus number then the effective stress free temperature for the rail has been reduced. In other words, there is likely to be an excess of steel. The stress free temperature error is a suitable means of assessing the adjustment of sections of LWR track.

*Example:*

Actual measured rail temp = 28°C

Theoretical measured temperature = 32°C

Stress free temperature error = 28-32 = -4°C

Effective stress free temperature = 35-4 = 31°C

(35°C is the design stress free temperature at which the average rail gap is 6mm)

## 12.5 Loss of Track Stability due to Rail Adjustment

Using the column in Reference Table 4 - Loss of track stability (% of total stability) for LWR, determine the applicable loss of track stability from the stress free temperature error. Record this figure as the result for the 500m section in question.

*Example:*

Stress free temperature error = -4°C

Loss of track stability = 13%

The process is to be repeated separately for the up and down rails. This will give two separate results. These results should be recorded.

## 12.6 Frozen Joints

The comments column of the recording sheet should be checked to ensure that there were no frozen joints or other irregularities. The correct adjustment cannot be calculated if there were any:

- Frozen joints
- Joints with a zero gap reading
- Gap readings which show a joint is fully open and pulling on the bolts.

In such cases, a loss of Track Stability for each affected rail in the 500m section as indicated in Reference Table 10 - Influence of Non Standard or Special Track Conditions is to be used.

## 12.7 Other Stability Losses

Other stability losses should be assessed, and the final stability loss calculated, in accordance with the procedures for CWR, as detailed in sections 11.6 - 11.14.

## 12.8 Actions

Refer section 3.3.

## 13 Analysis of Track Lengths less than 500 metres

### 13.1 General

A method has been developed which will allow an assessment of track of length less than 500m. A calculation is available to determine the stress free temperature error for both LWR and CWR track of any length. All the other processes in WTSA remain the same.

### 13.2 Application

The method is for a manual assessment. It is appropriate to assess anomalous sections i.e. where there is a section which has an adjustment which is uncharacteristic of the average result for the normal 500m section.

*Examples:*

- All joints closed at one end of a 500m section
- Where creep into a section is confined to a smaller part of the section by turnouts or more creep resistant track structure e.g. dogspike track running into resilient fastening track
- Where track is totally confined by fixed points and the adjustment is different to the rest of the 500m.

### 13.3 Overview

The method is intended to provide a formal analysis method, using the principles embodied in WTSA.

One difference in this method is the allowance for statistical variation when analysing LWR over a smaller length (i.e. a smaller effective sample). No allowance for statistical variation has been included for CWR track.

### 13.4 Calculation of Stability Loss Due to Rail Adjustment for CWR

For use in section 11

#### Tangent Creep

The stress free temperature error due to tangent creep may be calculated for any rail length by the following formula:

$$E_t = C_t * 85.5 / L$$

where

L = length of rail (m)

E<sub>t</sub> = stress free temperature error (°C) due to tangent creep

(-ve means too much steel)

C<sub>t</sub> = net tangent creep (mm)

(-ve means net creep into section)

Coefficient of linear expansion used = 1.17E-5 mm/mm/degree

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*Note* If small lengths are to be analysed, the accuracy of creep measurements needs to be very good, otherwise the validity of the calculation is overwhelmed by the errors in measurement.

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### Curve Pull-in

The stress free temperature error due to curve pull-in may be calculated for any rail length by the following formula

$$E_c = A \cdot 85.5 \cdot L_c / (L \cdot R)$$

where

$E_c$  = stress free temperature error (°C) due to curve creep

(-ve = too much steel)

$A$  = average alignment error (mm)

(pull-in is considered negative)

$L_c$  = length of curve (m) (must be less than  $L$ )

$L$  = length of section to be analysed (m)

$R$  = radius (m)

Coefficient of linear expansion used =  $1.17E-5$  mm/mm/degree

### Loss of Track Stability

The total stress free temperature error is determined as in Part II section 8.2.3, using the errors for tangent creep and curve pull-in derived above.

The calculation of stability loss for rail adjustment can then be determined for each rail.

## 13.5 Calculation of Stability Loss Due to Rail Adjustment for LWR

For use in section 12.

The stress free temperature error may be calculated for any rail length by the following formula.

$$E = T_a - 35 + 85.5 \cdot (G - 6 \cdot N) / L$$

where

$L$  = length of rail (m)

$E$  = stress free temperature error (°C)

(-ve means too much steel)

$T_a$  = measured temperature (°C)

$G$  = total gap (i.e. sum of gaps) (mm)

$N$  = number of gaps

Coefficient of linear expansion used =  $1.17E-5$  mm/mm/degree

In addition, because of the inherent statistical variations involved in using distances shorter than 500m, the following factor can be used to reduce the apparent excess steel.

- for 250m or less: 1.25°C per rail
- for 500m or more: nil

## Analysis of Track Lengths less than 500 metres

- for 250m to 500m: a linear interpolation i.e.  $(500-L)/200$

*Example:*

For a length of 300m under consideration, with gaps 5mm, 10mm, 5mm on one rail, at a temperature of 30°C:

$$\begin{aligned}
 L &= 300 \\
 T_a &= 30 \\
 G &= 5+10+5 = 20 \\
 N &= 3 \text{ gaps} \\
 \text{hence } E &= 30-35+85.5*(20-3*6)/300 \\
 &= -5+85.5*2/300 \\
 &= -5+0.6 \\
 &= -4.4
 \end{aligned}$$

Now for 300m, the statistical variation factor =  $(500-300)/200 = 1.0$

Hence the modified stress free temperature error =  $-4.4+1.0 = -3.4$

The calculation of stability loss for rail adjustment can then be determined for each rail from section 12.5

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*Note: This process is only valid where the criteria specified in section 2.4 apply.*

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## 13.6 Final Stability Assessment

The remaining WTSA process is unchanged from that in sections 11.6 to 11.15.

## 14 Reference Tables

### 14.1 Reference Table 1 - Long Welded Rail - Gap Analysis

Theoretical measured temperature (°C)

Average rail length (m)	No. of gaps per 500 m	Average rail gap (mm)												
		2	3	4	5	6	7	8	9	10	12	15	20	25
33	(15)	44	42	41	38	35	32	29	27	25	20	8	n.a.	n.a.
36	(14)	43	42	40	37	35	33	30	27	25	20	10	n.a.	n.a.
38	(13)	43	41	40	37	35	33	30	28	26	21	13	n.a.	n.a.
42	(12)	42	41	40	37	35	33	30	29	27	22	16	n.a.	n.a.
45	(11)	42	41	39	37	35	33	31	29	27	24	18	n.a.	n.a.
50	(10)	42	40	39	37	35	33	31	30	28	25	19	n.a.	n.a.
56	(9)	41	40	38	36	35	34	32	30	29	26	21	14	n.a.
63	(8)	40	39	38	36	35	34	32	30	30	27	23	16	9
71	(7)	39	38	37	36	35	34	33	31	30	28	24	18	12
83	(6)	39	38	37	36	35	34	33	32	31	29	26	21	16
100	(5)	38	37	36	36	35	34	34	33	31	30	27	23	19
125	(4)	37	37	36	36	35	34	34	33	32	31	29	26	22
167	(3)	37	37	36	36	35	34	34	33	33	32	30	28	25

## 14.2 Reference Table 2 - CWR Tangent Creep Analysis

Tangent creep - stress free temperature error (°C)

Tangent creep (mm)	Stress free temperature error (°C) for 500 m section
5	1
10	2
15	3
20	4
25	4
30	5
35	6
40	7
45	8
50	9
55	10
60	11
65	12
70	13
75	14
80	14
85	15
90	16
95	17
100	18



**14.3 Reference Table 3 - CWR Curve Pull-in Analysis**

Alignment error - stress free temperature error (oC)

Curve alignment index	Average alignment error (pull-in) (mm)								
	15	25	50	75	100	125	150	175	200
0.6	4	7	14	21	29	36	43	50	57
0.8	3	5	11	16	21	21	32	37	43
1.0	3	4	9	13	17	21	26	30	34
1.2	2	4	7	11	14	18	21	25	29
1.4	2	3	6	9	12	15	18	21	24
1.6	2	3	5	8	11	13	16	19	21
1.8	1	2	5	7	10	12	14	17	19
2.0	1	2	4	6	9	11	13	15	17
2.2	1	2	4	6	8	10	12	14	16
2.4	1	2	4	5	7	9	11	12	
2.6	1	2	3	5	7	8	10	12	13
2.8	1	2	3	5	6	8	9	11	12
3.0	1	2	3	4	6	7	9	10	11
3.5	1	1	2	4	5	5	7	9	11
4.0	1	1	2	3	4	5	7	8	9
4.5	1	1	2	3	4	4	5	7	8
5.0	0	1	2	2	3	4	5	6	7
6.0	0	1	1	2	3	3	4	5	6
7.0	0	1	1	2	2	2	3	3	4
8.0	0	0	1	1	2	2	2	3	4
9.0	0	0	1	1	2	2	2	3	4
10.0	0	0	1	1	2	2	2	3	3
11.0	0	0	1	1	2	2	2	2	3
12.0	0	0	1	1	2	2	2	2	2
13.0	0	0	1	1	2	2	2	2	2
14.0	0	0	1	1	1	1	2	2	2
15.0	0	0	1	1	1	1	2	2	2
16.0	0	0	1	1	1	1	2	2	2
17.0	0	0	1	1	1	1	2	2	2
18.0	0	0	0	1	1	1	1	2	2

**14.4 Reference Table 4 - Loss of track stability (% of total stability)**

(Based on single rail only)

Stress free temperature error	LWR	CWR
-1	3	2
-2	7	5
-3	10	8
-4	13	10
-5	17	13
-6	20	15
-7	23	18
-8	27	20
-9	30	23
-10	33	25
-11	37	28
-12	40	30
-13	43	33
-14	47	35
-15	50	38
-16	53	40
-17	57	43
-18	60	45
-19	63	48
-20	67	50
-21	70	53
-22	73	55
-23	77	58
-24	80	60
-25	84	63
All positive values	0	0

**14.5 Reference Table 5 - Influence of Anchor Conditions**

Loss of track stability (% of total stability)

Type of anchor	Condition	Loss of stability
Resilient Fastening	Good	0%
	20% Ineffective	5%
Fair Type Anchor	Good	2%
	Ineffective / Missing	8%

**14.6 Reference Table 6 - Influence of Ballast Deficiencies**

Loss of track stability (% of total stability)

Ballast required (tonnes/20 m)	% on shoulder	% in crib
1	5	7
2	10	14
3	14	19
4	17	24
5	19	27
6	20	29
7	20	30
8+	20	30

**14.7 Reference Table 7 - Influence of Major Track Disturbance**

Loss of track stability (% of total stability) for the following summer

April analysis	August analysis	Manual resleeper	Surfacing ballast stab		Tie & Surf ballast stab		Ballast cleaning	
			W/out	With	W/out	With	W/out	With
Last Jan	Last Jan	0	0	0	0	0	0	0
Last Feb	Last Feb	0	0	0	0	0	0	0
Last March	Last March	0	0	0	0	0	0	0
April	Last April	0	0	0	0	0	0	0
Next May	Last May	0	9	0	10	0	14	11
Next June	Last June	0	15	3	17	3	22	15
Next July	Last July	0	20	14	22	14	27	20
Next Aug	August	11	22	14	26	14	28	20
Next Sept	Next Sept	17	24	14	26	14	28	20
Next Oct	Next Oct	20	24	14	26	14	28	20
Next Nov	Next Nov	20	24	14	26	14	28	20
Next Dec	Next Dec	20	24	14	26	14	28	20
Next Jan	Next Jan	20	24	14	26	14	28	20
Next Feb	Next Feb	20	24	14	26	14	28	20
Next March	Next March	20	24	14	26	14	28	20

*Notes: Manual Resleepering - track disturbance occurs due to partial resleepering involving manual processes e.g. boodling, beater packing*

*Mechanised timber resleepering and concrete resleepering are included in the tie and surfacing category. Steel sleepers are not included. This work generally involves a greater amount of disturbance to sleepers being replaced and also the adjacent sleepers.*

*Reconditioning, underline crossings by excavation, and sledding are to be treated similarly to ballast cleaning.*

**14.8 Reference Table 8 - Summer Updating Analysis**

Influence of major track disturbance

Loss of Track Stability (% of total stability)

Months since work performed	Manual resleeper	Surfacing + ballast stabilisation		Tie & surfacing + ballast stabilisation		Ballast cleaning	
		W/out	With	W/out	With	W/out	With
Over 6	0	0	0	0	0	0	0
5 to 6	0	9	0	10	0	14	11
4 to 5	0	15	0	17	0	22	15
3 to 4	0	20	0	22	0	27	20
2 to 3	11	22	0	26	0	28	20
1 to 2	17	24	3	26	3	28	20
0 to 1	20	24	14	26	14	28	20
Any future work planned	20	24	14	26	14	28	20

**14.9 Reference Table 9 - Influence of General Track Condition**

Loss of Track Stability (% of total stability)

TCI	Loss of track stability
Up to 45	0
46 to 48	1
49 to 51	2
52 to 54	3
55 to 56	4
57 to 58	5
59	6
60 to 62	7
63 to 66	8
67 to 73	9
74 and over	10

**14.10 Reference Table 10 - Influence of Non Standard or Special Track Conditions**

	<b>Non Standard or Special Track Condition</b>	<b>Stability Loss</b>
1	Frozen joints , zero gaps, gaps fully open & pulling on bolts	10% Each Rail
2	Long welded rail on resilient fastenings - more than 1 in 3 sleepers resilient fastened	10% Each Rail
3	No creep pegs	* Calculate using 20mm tangent creep on each rail for the tangent creep component of adjustment
4	Alignment details for CWR not known	Calculate using -50mm average alignment error for curve pull-in component of adjustment
5a	Foul ballast, pumping joints, poor formation	10% total is the minimum that is to be used for track disturbance
5b	Rounded, disturbed or pulverised ballast, including disturbed ballast associated with steel sleepers	10% stability to be added to preliminary result
5c	Transom top steel underbridges without expansion switches and with span 40m or greater and with elastic fastenings	10% stability to be added to preliminary result
5d	Elbows or sharp misalignment in the rail	10% stability to be added to preliminary result
5e	Rail corrugations causing vibration of track and/or causing degraded ballast sufficient to result in track disturbance	10% stability to be added to preliminary result
5f	Severe rail corrugations, causing major disturbance	Add an additional 10% to the final stability loss

\* Whilst 20mm is the default assumed tangent creep, a level in keeping with historic creep rates is preferable where this is known. This should include consideration of the length of time since creep control was lost. (e.g. 3 years at an average of 5mm per year would give 15mm)

**14.11 Reference Table 11 - Effect of Tonnage on Track Disturbance**

Tonnage (000 GT)	Manual resleeper	Surfacing + ballast stabilisation		Tie & surfacing + ballast stabilisation		Ballast cleaning	
		W/out	With	W/out	With	W/out	With
0	20	24	14	26	14	28	20
125	11	14	5	15	5	20	14
500	6	8	3	8	3	11	8
1000	2	3	3	3	3	3	3
2000	0	1	1	1	1	1	1
3000	0	0	0	0	0	0	0

15 Summary Diagram

The WTSA process is summarised in Figure 3.

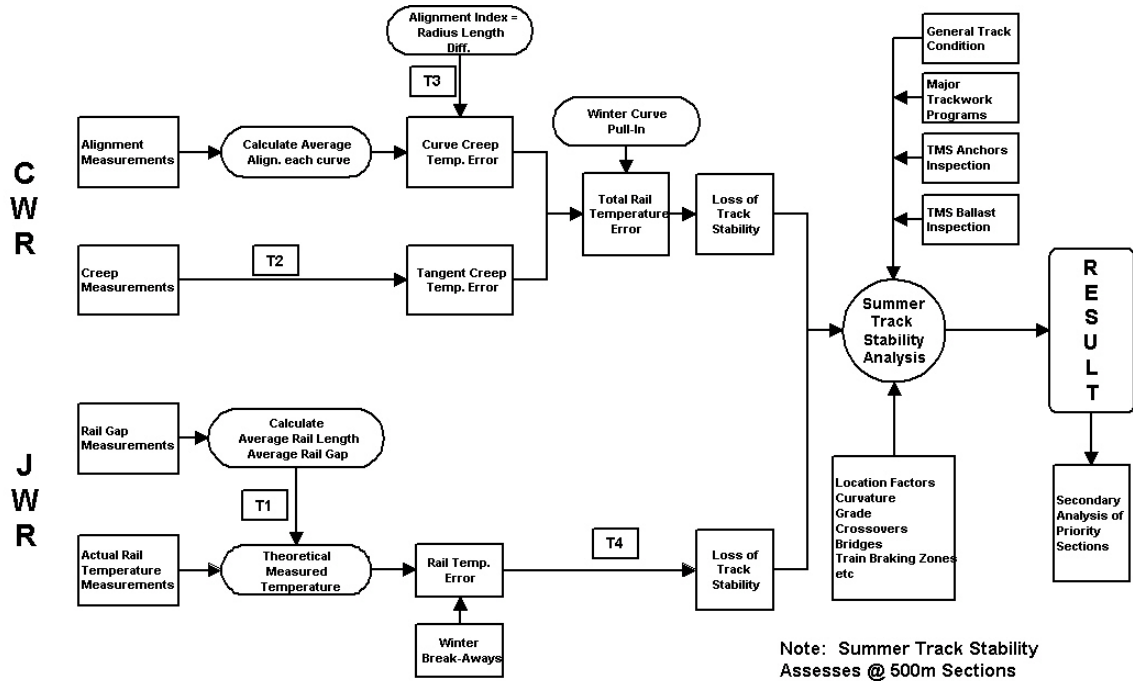


Figure 3 - Diagram summarising WTSA process