Division / Business Unit: Safety & Systems
Function: Track & Cvil
Document Type: Procedure

Rail Profiling

ETP-01-01

Applicability

ARTC Network Wide

SMS

Publication Requirement

Internal / External

Primary Source

ETM-01-02

Document Status

Version #	Date Reviewed	Prepared by	Reviewed by	Endorsed	Approved
2.0	30 Sep 24	Rail Maintenance Engineer	Standards	Principal Track Standards Engineer	Manager Engineering Services 01/10/2024

Amendment Record

Amendment Version #	Date Reviewed	Clause	Description of Amendment
2.0	30 Sep 24		Document renumbered from ETM-01-02. Update is for a low rail profile for curves of radii less than 900 metres within the Hunter Valley network.

Table of Contents

1 Introduction

1.1 Purpose

The purpose of this Procedure is to guide the profiling planning process and specify requirements for work undertaken to profile in service rail.

1.2 Scope

This Procedure provides:

- Background information and guidance on rail management in terms of rail profiling
- Basic requirements and processes for rail profiling
- Quality standards to be achieved during profiling.
- This Procedure applies to:
- ARTC leased and owned tracks.
- ARTC Track and Civil staff and contractors.

Profiling can be achieved by grinding or by milling. The predominant process used is grinding.

1.3 Document Owner

The Manager Engineering Services is the document owner and is the initial point of contact for all queries relating to this Procedure.

1.4 Responsibilities

ARTC Track and Civil staff and contractors are responsible for adoption of the Procedure.

1.5 Parent Procedure

The following document supports this Procedure: Section 1 Rail

1.6 Definitions

Terms and acronyms used within this document include:

TERM OR ACRONYM	DESCRIPTION
ARTC	Australian Rail Track Corporation Ltd.
ARTC Project Manager	A person who has formally been allocated maintenance delivery responsibility for a particular area or region at engineer level.
ARTC Profiling manager	An ARTC Manager with responsibilities for profiling, or a delegated representative. Nominated from each Business Unit's Asset Management team. To be allocated engineering authority with respect to rail profiling management, the ARTC Profiling Manager should have suitable experience in rail management. Such personnel should also have demonstrated competency in the assessment of rail conditions and suitable remedial measures, as contained in ARTC standards, procedures and guidelines.

TERM OR ACRONYM	DESCRIPTION
As-rolled rail	Rail that is not treated to increase head hardness as part of the manufacturing process (also known as standard carbon rail).
Cant bar	A flat bar section that sits over the rails to provide a measure of the actual rail cant when taking rail profiles manually.
Checking locations	Specific points marked on the rail, within a track segment, where the achievement of the defined rail profile and/or metal removal is checked and monitored.
Contact band	The contact position of the wheels on the rail as evidenced by the shiny worn surface. This generally applies to contact occurring on the running surface of the rail, but in the high rails of sharper curves the contact band extends into the gauge corner region and face (refer to Figure 1, Figure 2 and Figure 3).
Contractor	The organisation conducting rail profiling.
Corrective profiling	Profiling to remove specific defects in the rail. Such defects may occur over a relatively long track section (e.g.: rail corrugations or extensive rolling contact fatigue), or over relatively short track sections (e.g.: wheel burns, squats or isolated rolling contact fatigue defects).
Field side	The side of the rail opposite the gauge face (refer to Figure 1).
Field side relief	Clearance between the wheel profile and the rail profile to reduce wheel rail contact on the head of the rail on the far field side (refer to Figure 1).
Gauge bar	A rod or bar section which sits between and normal to the rails to provide a superelevated reference for the application of the template.
Gauge corner	The top corner of the rail above the gauge face (refer to Figure 1).
Gauge face	The zone of the rail head facing the inside of the track. In the tighter curves the gauge face may be worn due to contact with wheel flanges.
Gauge corner relief	Clearance between the wheel profile and the rail profile to reduce wheel rail contact in the gauge corner region (refer to Figure 1).
Head-hardened rail	Rail that is specially treated during the manufacturing process to increase hardness of the rail head.
Heavy Haul lines	Lines carrying greater than 25 MGT per year with a permitted axle load greater than 25 tonnes, including Islington Junction – Narrabri and Muswellbrook – Ulan.
MGT	Million gross tonnes of rail traffic.
Minimum metal removal	Generally, a specified depth of the minimum metal to be removed from the contact band. Usually determined by measurements taken before and after profiling.
New rail profiling	Profiling of rails that have been in track for less than 5 – 10 MGT.
Plain track	All track, excluding turnouts and the rail cant adjustment zone before and after turnouts.
Preventive (cyclic) profiling	Profiling carried out on regular cycles for the purpose of maintaining the rail profiles, preventing/inhibiting the growth of defects, and maintaining the surface condition of the rail (particularly in terms of corrugations and local vertical irregularities), with typically a minimum metal removal of 0.2 mm from the rail contact surface each cycle.

TERM OR ACRONYM	DESCRIPTION
Profiling Supervisor	The person representing the Contractor who is responsible for the rail profiling operation.
R_A	Arithmetic average of the rail surface roughness profile.
Rail profiling template	A template used to fit over the head of the rail to show the relationship of the profiled rail to the defined profile.
RCF	Rolling Contact Fatigue, rail defect cracks in the contact zone.
Relief	Provision of a clearance between the wheel profile and the rail profile (see field side relief and gauge corner relief).
Running surface	The zone on top of the rail head which generally contacts the wheel tread (refer to Figure 1). In the high rails of sharper curves, the wheel/rail contact extends into the gauge corner region (Figure 2).
Skipping	An intermittent, sometimes cyclic, variation in the depth of metal removed during profiling along the gauge corner of the rail.
TAL	Tonnes Axle Load, designated limits for vehicle loads limits and operating for each track as per Route Access Standards
TP	Tangent point – the start or end of a curve or tangent.
Track Segment	A section of track in which the rail is profiled to a uniform profile, e.g.: a curve from the start TP to the end TP, or a tangent from the start TP to the end TP, or the midpoint of a short (< 200 m) tangent separating two curves.
Transitional profiling	Profiling carried out over several cycles to move from a corrective to a preventative profiling regime.
Undercut	A portion of a rail profile where relief has been provided and the wheel is unlikely to make contact.
Vehicle mounted measuring system	A system mounted on the rail profiling unit or auxiliary vehicle that can measure the rail head profiles, metal removal and/or surface characteristics.
Wheel hollowing	Deviation from a new wheel profile as a result of wear in the central part of the wheel tread.

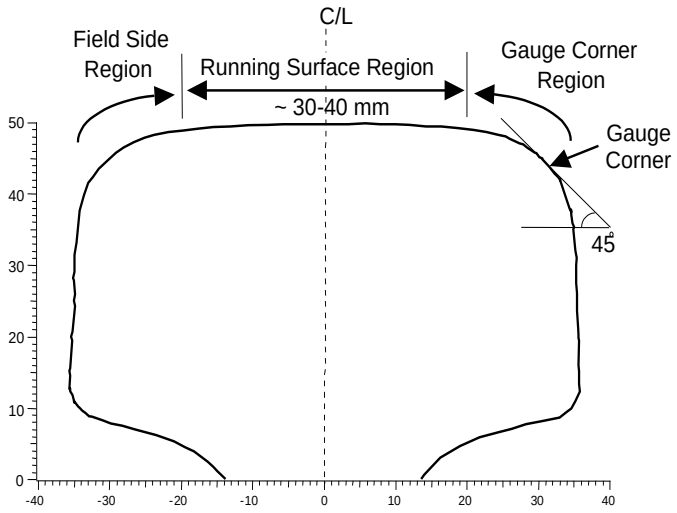


Figure 1 – Regions in rail head

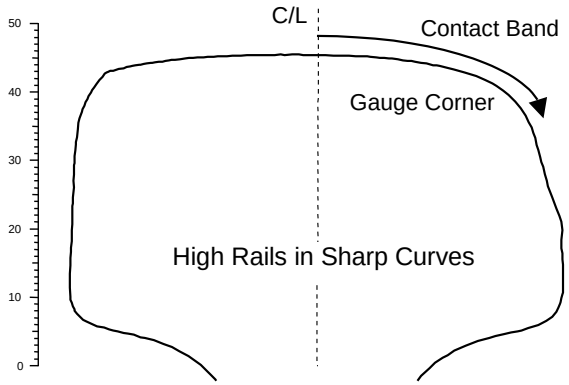


Figure 2 – Rail contact band: high rails in sharp curves

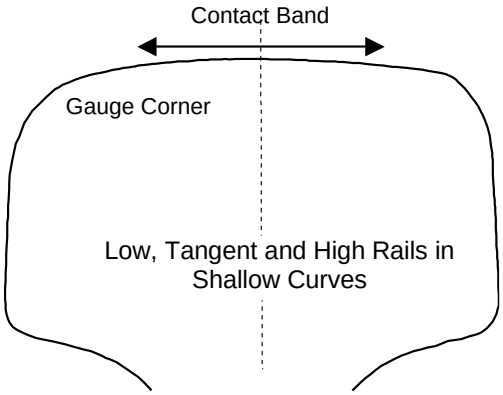


Figure 3 – Rail contact band: tangent track, low rails in curves, and high rails in shallow curves

2 Background

2.1 Types of Rail Profiling

There are two recognised methodologies of rail profiling, between these lies a wide variable range of intermediate strategies;

- **Preventative profiling** (preferred) – Profiling at regular intervals (cycles) based on usage and degradation rates, typically using light cuts with minimal metal removal per cycles. Strategy based on cost and risk optimisation for maximum rail life and minimal condition failures.
- **Transitional profiling** involves a progressive range of condition states somewhere between the corrective profiling and preventative profiling regimes. A state of constant adjustments or controlled balance.
- **Corrective profiling** – generally considered the least desirable approach, applied where the other two methods have failed. Heavier/deeper metal removal often done reactively to remove failed rail surface.

The types of equipment used for profiling are:

- Grinding - is the predominant method of profiling and is used for both corrective and preventative work.
- Milling - Milling is most suited to removing significant amounts of steel in corrective profiling, and generally in locations where fire risks are elevated or where the grinder cannot access the full rail head e.g. level crossings, transom bridges, dual gauge tracks.

2.2 Objectives

The principal objective of rail profiling is to remove the fatigued layers of metal due to wheel contact stresses. As a parallel goal the process aims to progressively establish rail profile shapes that improve wheel/rail interface:

- Lowering contact stress (increase patch area) to reduce surface defects
- Reduce the risk of unstable vehicle performance (hunting conicity)
- Minimising longitudinal rail impacts into the track structure to protect all components and the geometry
- Reduce rail and wheel wear by better steering at the wheel/rail interface (conicity)
- Increasing rail life, by optimising all the above, at the lowest overall metal removal rate achievable (carefully control of the combined profiling and wheel contact wear)

Other objectives include:

- Rectifying or controlling existing rail surface defects, thus reducing the risk of rail failures and track deterioration.
- Controlling rail surface condition so that defects such as rolling contact fatigue do not shield or prevent ultrasonic testing of rail.
- Extending weld life by smoothing of HAZ and other failures
- Improving contact for signalling systems
- Reducing wheel rail noise (roughness and/or flanging and squeal)

2.3 Additional Requirements

All rail profiling work must be conducted in accordance with:

- Health and safety requirements
- ARTC environmental licenses
- Applicable legislation
- Relevant safe working requirements
- Applicable Australian Standards and ARTC Standards, including operations and rolling stock/plant.
- Suitable road-rail firefighting chase vehicles must accompany rail grinding. A risk assessment should be undertaken to determine fire control requirements for rail milling.

3 Rail Profiles

3.1 Background

Required rail profiles have been determined for tangent track and for curved track (including for high and low rails). The same basic shapes apply to all rail sizes and types.

The rail profiles are designed to suit wheel profiles in both the new and worn conditions (within prescribed wear tolerances). As part of the design, the width and location position of the contact band is determined.

For Heavy Haul operations there are additional modified profiles specified for optional use.

These heavy haul profiles are designed to enhance wheel contact and rail life in regions using predominantly WPR2000 wheel profiles and largely 30 TAL traffic.

The profiles are also designated their own criteria for cycle strategy and track segment definitions.

For clarity, the existing freight ≤25TAL profiles in Table 1 are still feasible for use in Heavy Haul lines, and vice versa the heavy haul profiles would be feasible for freight track usage and ANZR1 wheels. The differences between the suites of rail shapes are marginal and are designed for fine-tuning superior reliability performance under 30 TAL i.e. moderately low risk if interchanged in any circumstances.

The naming convention for these profiles aligns with their major usage in the Hunter Valley Coal network, hence the prefix “HV”, however these profiles would be applicable to any tracks running 30 TAL and WPR2000-type wheel shapes

3.2 Profile Definitions (≤ 25TAL freight only)

Profiles to be used in tracks with ≤25TAL are specified in Table . Full details of each profile design are given in Appendix A.

GENERAL FREIGHT TRACK SITUATION (WITH ≤25TAL)		ARTC TEMPLATE
Preferred Profiles	Tangent track and curves with radius > 900 m	TGT
	Curved track low rails ≤ 900 m radius	L2
	Curved track high rails ≤ 900 m radius	H2
Profiles listed below only applied in special circumstances		
Tangent track and curves with radius > 900 m, additional field and gauge side relief. Consider for tight gauge and areas affected by hunting.		TGT1
Curved track low rails ≤ 900 m radius as part of a transitional profiling strategy		L1
Curved track low rails ≤ 900 m radius, with additional field and gauge side relief. Consider for curves with track gauge >1445mm		L3
Curved track high rails ≤ 900 m radius, with additional field side relief		H2R
Curved track high rails ≤ 900 m radius, transitional, exhibiting severe RCF defects in the gauge corner region		H3

Table 1 – Profile templates for ≤25TAL tracks

Figure 4 provides an illustration of the freight profiles in relation to new 60 kg rail.

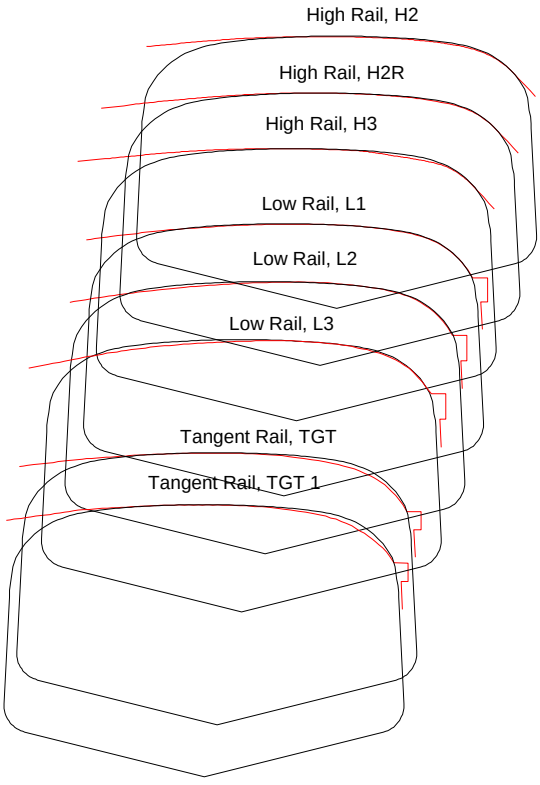


Figure 4 – New 60 kg rails with profiles (rails shown in a vertical position)

3.2.1 High Rails

H2 profile exhibits a minor undercut in the gauge corner region relative to new rail. This is to establish a relatively conformal contact with the wheel profiles, reducing the contact stresses in this region.

H3 profile exhibits an additional undercut in the gauge corner region with the aim of reducing the wheel contacts in this region.

H2R profile exhibits additional field side relief. It is implemented where excessive wheel hollowing is a problem.

Profile TGT may also be used for the high rails in very sharp curves (radius < 300 m) and low operating speed (< 25 km/h)

3.2.2 Low rails

The L1 and L2 profiles have similar gauge corner region details, which exhibit very minor undercuts relative to the new rails. The aim is to centralise the wheel/rail contact on the running surface.

L1 profile is applied only as part of a transitional profiling strategy towards the L2 profile, to reduce the field side profiling effort required.

L2 profile has more field side relief than L1, to prevent contact in this region with the more hollowed wheels present in freight and coal traffic.

L3 profile has additional field and gauge side relief and is implemented where wheel hollowing is severe. It should be considered for wide gauge >1445mm

3.2.3 Rails on tangents

The TGT profile exhibits significant undercut in the gauge corner region, to ensure that wheel/rail contact is made near the centre of the running surface. This enhances vehicle stability at higher operating speeds.

The gauge corner undercut is increased further with the TGT1 profile, which is implemented to reduce or eliminate plastic flow (mushrooming) in this region. It should be considered for areas of tight gauge or with a presence of hunting.

3.3 Profile Definitions (>25TAL Heavy Haul)

Profiles to be used in tracks with >25TAL are specified in *Table 2*. Full details of each profile design are given in Appendix B.

HEAVY HAUL TRACK SITUATION (WITH >25TAL)		**TEMPLATE**
Preferred Profiles	Tangent track and curves with radius > 900 m	HVTGT
	Curved track low rails ≤ 900 m radius	HVLR
	Curved track high rails ≤ 900 m radius	HVHR

Table 2 – Profile templates for >25TAL tracks

3.4 Profile Measurement

The measurement of profiles and tolerances before, during and after profiling is to be conducted by the Contractor, preferably using an electronic profile measuring system.

However, contact systems such as templates may be used by the ARTC Profiling Manager, or by the Contractor, as a means of conducting post-profiling quality assurance assessments.

The specified tolerances in clause 8.5 apply to both non-contact and contact measuring systems.

4 Profiling Works: Strategy & Requirements

4.1 General

Profiling strategy comprises:

- Highly desirable requirements for profiling new rail, and other rail with altered orientation
- Guidelines for preventive profiling
- Guidelines for corrective profiling.

Where targeted profiling strategies have been developed for specific lines or regions, these will take precedence over the requirements and guidelines contained in this Procedure. Such alternative strategies must be approved by the appropriate ARTC Profiling Manager or authorised representative.

The strategy guidelines for preventive profiling provide an indication of the minimum rail profiling requirements. During initial establishment of preventative cycles, additional profiling may be necessary to rectify defective track sections.

4.2 Profiling Method

The method of profiling (grinding or milling) should take into consideration:

- Cost efficiency for the metal removal required and total scope size being planned in km
- Track access; stabling, road access if road/rail equipment.
- Fire risks at various times of the year and locations.
- Environmental risks in sensitive locations

4.3 Profiling of New or Reoriented Rail

4.3.1 Heavy haul lines >25 TAL

On Heavy Haul lines, new rails placed in track as part of re-railing or turnout replacement should be profiled (this does not strictly apply to closures for replacement of defects). Profiling should ideally be carried out within 5 MGT, or within 20% of the profiling cycle specified for preventive profiling, whichever gives the longer interval.

Profiling should be undertaken even if the re-railing occurs in only part of a curve or section.

4.3.2 Freight lines ≤ 25 TAL

On lines with general freight traffic, the new rails should be profiled within 10 MGT after installation, or at the latest no later than the next profiling cycle.

Special care is required in sections within which partial re-railing has occurred between profiling cycles. In these sections, new rails will require some additional initial profiling prior to the final profiling applied to the whole section.

4.3.3 Altered rail orientation

In addition, special profiling is required when the rail orientation is substantially altered. In such cases the profiling should be applied within 5 MGT, or within 20% of the profiling cycle specified for preventive profiling, whichever gives the longer interval. Applicable situations include:

- Change of sleeper type
- Cascading or transposing of rail (Must be profiled within 5 MGT)

4.4 Preventive Profiling

Guidelines for preventive rail profiling cycles are shown in;

- Table 3 - General Freight, vehicles ≤ 25 TAL (passenger, intermodal, bulk goods)
- Table 3Table – Heavy Haul, vehicles > 25 TAL (typically only coal or mixed)

CURVATURE OF TRACK SEGMENT (RADIUS)	**NOMINAL PERIODS BETWEEN PROFILING CYCLES; (FOR FREIGHT TRACKS WITH ≤25 TAL)**	
Curves ≤ R450 m	Standard Carbon & Head-hardened rail	10 MGT
Curves >R450 m ≤ R900 m	Standard Carbon & Head-hardened rail	20 MGT
Tangent & curves > R900 m	Head-hardened rail	20 MGT
	Standard Carbon rail	60 MGT

Table 3 – General Freight Cycle Guidelines for preventative profiling

Notes:

For tracks operating with a significant proportion of bulk goods trains > 23 TAL (enough MGT to initiate accelerated rail failure modes), and for Standard Carbon rail only, the cycles may need to be modified 20-30% shorter than Table 4

All Head hardened rails installed in light-moderate loaded tracks (MGT and/or TAL) are at risk of developing squat defects. In the absence of any detailed engineering study, the default grind cycles on these cases should not extend beyond 20MGT, particularly on tangent tracks. The risk of squats is greatly increased where light passenger (self-propelled) traffic operates. The risk is greatest on tangents and wider curves above radius R500m, however the transitions of very tight curves can also be prone to squats if not ground regularly.

CURVATURE OF TRACK SEGMENT (RADIUS)	NOMINAL PERIODS BETWEEN PROFILING CYCLES; (FOR HEAVY HAUL TRACKS WITH >25 TAL)		
	TARGET CYCLE (MGT)	CYCLE EXTENSION TOLERANCE	MAXIMUM CYCLE (MGT)
Curves ≤ R600 m	18 MGT	+15%	= 20.7 MGT
Curves >R600 m ≤ R1200 m	36 MGT	+20%	= 43.2 MGT
Tangent & curves > R1200 m	54 MGT	+20%	= 64.8 MGT

Table 4 – Heavy Haul Cycle Guidelines for preventative profiling

Notes

Tangent track cycles may be extended a further 10% in low traction areas if extended cycle degradation rates are trialled and found acceptable.

The cycles above apply to track built and maintained to Heavy Haul design standards and assume the use of Head Hardened rail with 30 TAL, standard carbon rail under Heavy Haul would require cycles closer to Table 3 for General Freight above.

All Head hardened rails installed in Heavy Haul tracks are at much reduced risk of developing squat defects (due to heavy wear and grinding practises). The risk of squats is however still greatly increased where mixed coal at lower MGT and light passenger (self-propelled) traffic operates. The risk is greatest on tangents and wider curves above radius 500 m, however the transitions of very tight curves can also be prone to squats if not ground regularly

4.4.1 Profiling cycles guidance;

A general guide to allowable cycle tolerance is an extension of around 20%. This is however significantly influenced by the annual works program and the following factors: most common but not limited to;

- Geography – logistics of travel distance, fire seasonal risks,
- Track access – possession availability in schedules and length of access time per shift, project clashes
- Profiling contractor capacity – machines and resources are generally limited in availability and scheduling to some extent
- Rail life – remaining life of rail before rerail at certain sites i.e. defer final cycles
- Rail conditions – rail ages/types and train types (including all wheel and load variables) environmental factors (friction)

Target cycles should not be extended to the maximum for repeated cycles unless fully trialled or monitored and proved acceptable for unique track conditions. The nominal profiling periods between each profiling in Table 3 and 2A are to be achieved at least on average. If necessary, individual track segment cycles may be adjusted to suit circumstances. Noting that an alternative method is to adjust the depth of metal removal on the extended cycle to compensate: this is effectively a ‘permanent transitional’ strategy.

Early/shorter cycles e.g. -20% tolerance obviously have no benefits and increase rail wear and costs, they are allowable where it suits scheduling and cycle alignment in a track segment. In practise there is no % limit on shorter cycles (a business decision not a standards requirement). Where unique location adverse wheel/rail contact conditions exist, the profiling cycles in Table 3 and 2A may not be suitable (cycles need to be shorter) for some track sections. Such sections should be reported, monitored, and if necessary, adjusted to a different cycle category.

- As an example, rails subjected to higher tractive efforts may exhibit more rapid deterioration rates, thus requiring more frequent profiling. Another example may be mixed train types and speeds that do not suit the track superelevation and hence damage the high or low rails more quickly.
- Again, there is an option here to increase the number of passes or metal removal per cycle to achieve the same outcome as changing the cycle length, these are rail strategy decisions managed for each location.

Where curves (compound) have multiple radii in one continuous section, the full curve or track section should be profiled according to the cycle associated with the smallest radius, provided this radius comprises at least 20% of the total curve length or track section.

4.5 Minimum Metal Removal for Preventive Profiling

When the rails are profiled under preventive profiling regime, a minimum amount of metal should be removed. The following guidance is given only as a reference for typical profiling results, the depth of 0.2mm is not an exact value for all locations and cases and should be viewed as a nominal target. The true metal removal requirement for any given location is determined by the depth at which fatigued surface metal has occurred, this is damaged (fatigued and brittle) metal that is not being worn away naturally before cracks could grow uncontrolled between profiling cycles.

In conjunction with restoration of the rail profile to the designed template as specified in Table , a preventative cycle should aim for a minimum of 0.2 mm of metal to be removed from the contact band. (This does not apply to the gauge face of the high rails (at an angle >50° to the vertical), where gauge face wear has been occurring.)

In sharper curves (with radii up to 900 m), the minimum metal removal of 0.2 mm should generally be achieved each profiling cycle. However, in shallower curves and tangent track the metal removal may be reduced if the track sections are profiled more frequently than the applied cycles, provided an acceptable metal removal is achieved within the cycles.

Metal removal requirements of rails within a preventive profiling regime should be less than about 18 - 20 mm^2. Rails having greater metal removal requirements may be treated as out of preventative cycle.

Some corrective profiling on standard carbon rails may aim to focus all profiling effort onto the movement of the template lug. This is a specialised method to reduce hunting on high speed long tangents where the rail has deformed to a flat (potentially lipped) shape which needs maximum gauge corner metal removal. To achieve this method the depth of cut target 0.2mm may need to be ignored in the contact zone, but only if the rail has no signs of long-term fatigue i.e. in a balanced state of natural wear removing fatigue.

4.6 Corrective Profiling – General

A requirement to apply corrective profiling will require the removal of a considerable amount of metal (greater than preventative), primarily from the running surface of the rail along a length of track.

Corrective profiling shall be completed by implementation of the relevant rail profiles as specified in the relevant Table or Table 2 above, which shall conform with all the standards applied to normal preventive profiling.

The only exception is when the rail profiles before profiling are significantly different to the required profiles, due to excessive gauge corner and/or field side relief applied during previous profiling cycles. In such cases, the rail profiles can be treated as transitional. A relaxation of the required tolerances outside the contact band may be applied at the discretion of the ARTC Profiling Manager.

Special corrective profiling requirements apply for the treatment of various rail defect conditions, such as:

- Corrugations
- RCF defects (gauge corner and running surface checking and spalling)
- Rail plastic flow (mushrooming)
- Squats and other thermal/mechanical defects
- Wheel burns
- Cyclic rail wear, due to rolling stock hunting, or grinder skipping.

Such conditions will require separate assessment and must be dealt with on a case by case basis. The more serious defects will have been identified by track inspection processes, and suitable remedial measures planned.

Lesser conditions that are uncovered during pre-profiling inspections may be dealt with in association with the normal profiling operation. If this cannot be done economically, the work should be rescheduled for special treatment later.

Localised defects such as wheel burns, dipped welds or squat defects may be more effectively treated by other means, such as weld repairs or straightening. Such treatments are preferably applied prior to profiling, to achieve a better final finish.

Where considerable profiling effort is required to achieve full correction to profile, or to remove long wavelength corrugations, transition strategies need to be considered. Such strategies must involve the correction of the problem over time, such that each profiling cycle brings about a progressive improvement. Appropriate expert advice should be sought for the development of such strategies.

4.7 Corrective Profiling – Process

The ARTC Profiling Manager is to specify the metal removal requirements for corrective profiling. These requirements arise primarily because of rolling contact fatigue defects present in rails that have not been cyclic profiled.

Rolling contact fatigue defects may inhibit the routine ultrasonic inspection of the rails, particularly if located in the gauge corner region (gauge corner checking) or running surface region (running surface checking or flaking).

Complete removal of the severe gauge corner or running surface checking defects is not recommended. This requires considerable metal removal and rail profiling effort. It also removes at least some of the protective work hardened steel from the rail surface.

The recommended process to be implemented in cases of severe defects is to:

- Remove a minimum of 0.2 mm and usually more than 0.4 – 0.5 mm, but generally no more than 0.8 mm (subject to approval from the ARTC Profiling Manager) from all contact surfaces including the gauge region.
- Ensure that checking/spalling have been removed from the running surface above the rail web, and preferably from 20 – 25 mm from the gauge corner towards the field side. This is to ensure that the rails are capable of satisfactory ultrasonic testing. Some gauge corner checking defects may be left on the rails.
- Establish the recommended profiles, and where the gauge corner is affected by severe checking defects, implement the H3 template on the high rails to reduce the gauge corner contact for a limited time. Profiling facet limits must still be observed within the gauge corner relieved zone.

In track sections over which this process has been implemented, the additional gauge corner relief will be able to be reduced in following profiling cycles to within the normal limits specified for the H2 profile.

Note: This process should not be required where the rails have been subjected to several preventive profiling cycles.

4.8 Minimum Metal Removal for Corrective or Transitional Profiling

The ARTC Profiling Manager, in consultation with the Contractor, will specify the metal removal requirements for corrective or transitional profiling of transverse profiles.

This may also allow some gauge corner or running surface cracking/checking defects to remain in track after profiling as illustrated in Figure 7.

The recommended rail profiles must always be achieved, notwithstanding the metal removal requirements.

In the case of high rails exhibiting gauge corner RCF defects up to a moderate classification (refer Figure 5), the H2 template should be applied to the high rails, while for severe gauge corner RCF defects (refer Figure 6) the H3 template may be applied.

Figure 5 – Example of gauge corner checking defects left in the high rails after transitional profiling (arrow points to the gauge corner)

Figure 6 – Example of severe gauge corner RCF on high rails that may require application of the H3 profile

4.9 Rail with Plastic Flow Lips

Some rails may exhibit plastic flow lips, which may increase the difficulty of matching templates with locating lugs to the rails.

For templates for the low rails on curves and for tangents, the distance of the lug from the gauge face after profiling must be no greater than the distance before profiling

The distance between the lug and the gauge face of the rail should be reduced by at least 50% during each profiling cycle, with the final target to be less than 0.5 mm once in a preventative regime.

Figure 7 illustrates rails in tangent track before and after profiling with the templates containing the locating lug, showing the acceptable reductions obtained between the lug and the rail gauge face.

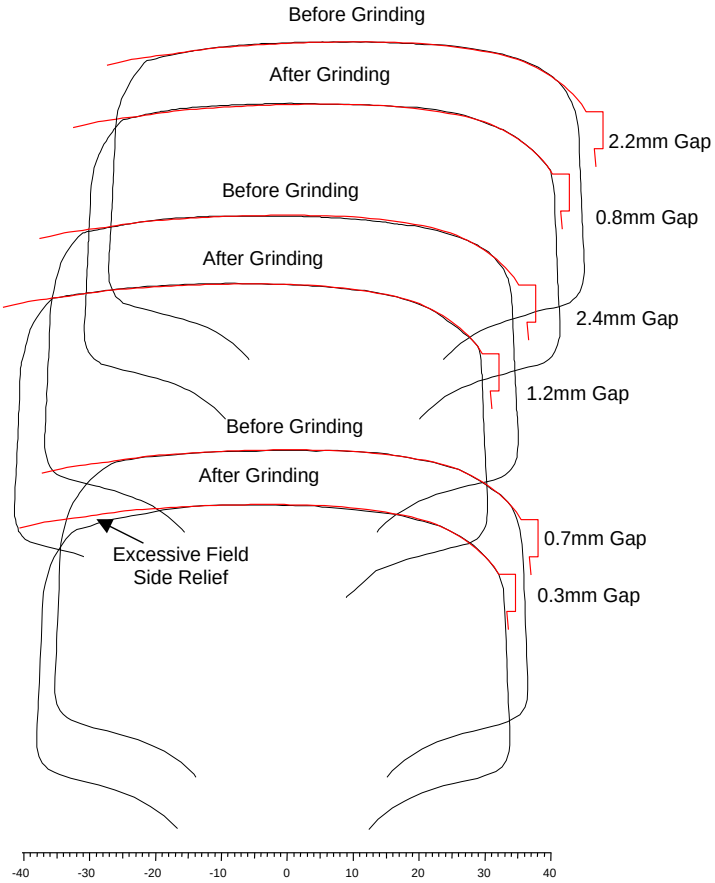


Figure 7 – Examples of rails in tangent track before and after profiling and tangent template (TGT1) with positioning lug

4.10 Rails with Excessive Relief

When the rail profiles before profiling are significantly different to the required profiles, due to excessive gauge corner or field side relief applied during previous profiling cycles (refer to Figure 7 above and Figure 8 below), the rails can be treated as being in a transitional regime.

To reduce the number of profiling passes that may be required a relaxation of the required tolerances outside the contact band may be applied at the discretion of the ARTC Profiling Manager:

The profiling applied during each cycle must reduce the maximum deviation of the rail profile relative to the template outside the contact band by at least 0.3 mm.

A minimum metal removal of 0.2 mm should still be achieved within the contact band. Required tolerances within the contact band remain unchanged.

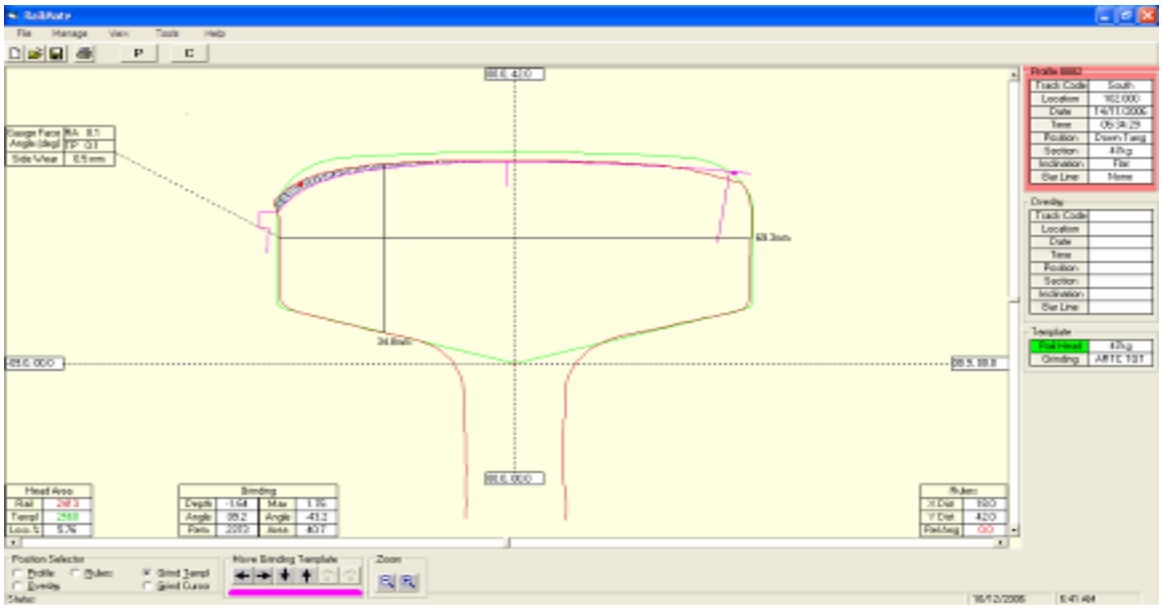


Figure 8 – Example of metal removal requirements and acceptable tolerances in a 47 kg rail on tangent track exhibiting excessive field side relief

4.11 Applying Additional Gauge Corner Relief

Gauge corner relief is normally designed into the rail profile templates. However, where the high rails exhibit moderate to severe gauge corner RCF defects, the use of additional gauge corner relief can extend rail life and ensure that the ultrasonic testing of rails is not inhibited.

If additional gauge corner relief is required due to severe RCF damage in the gauge region of high rails, as illustrated in Figure 9, gauge corner relief should be applied to control such damage. Complete removal of the severe gauge corner checking defects is **not** recommended as it requires considerable metal removal and hence rail profiling effort and it removes protective work hardened material from the surface.

Gauge corner relief can be achieved by the ARTC Profiling Manager directing the application of the H3 template (refer to Table and Appendix A), as part of a transitional profiling strategy.

When applying the H3 template, the specified profiling facet limits must still be observed, together with the specified tolerances to the template.

Uncontrolled excessive gauge corner undercutting leads to two-point wheel/rail contact conditions in sharper curves, as illustrated in Figure 10 and Figure 11. In most cases this is not desired.

Figure 9 – Severe gauge corner RCF defects on high rails requiring application of the H3 profile

Figure 10 – Unacceptable gauge corner undercutting on high rail in sharp curve (arrow points to gauge corner)

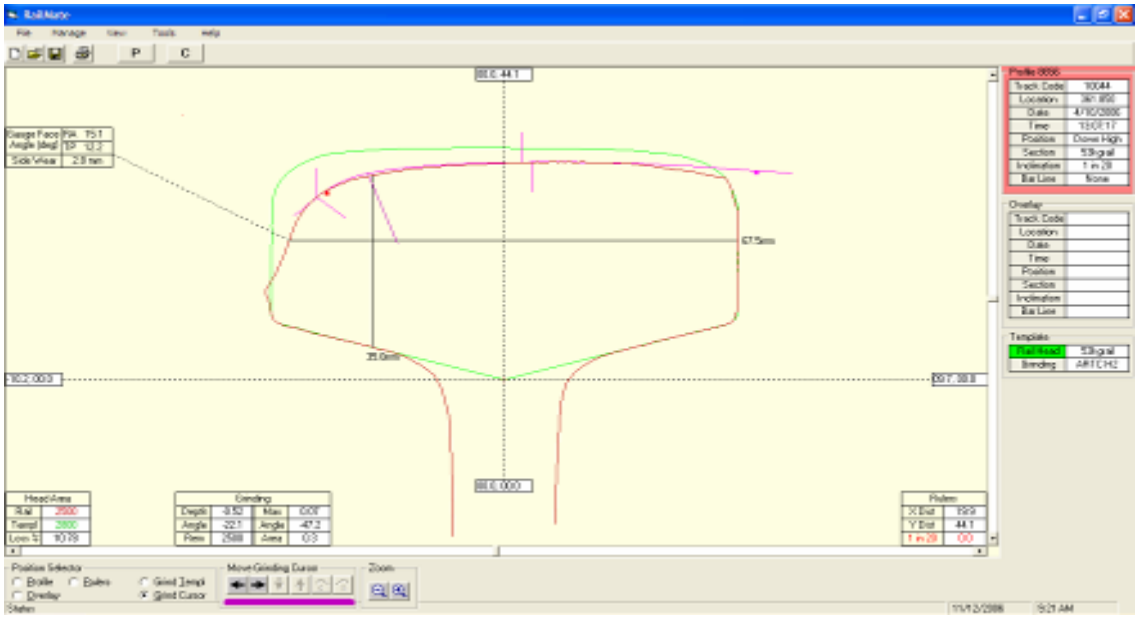


Figure 11 – Unacceptable gauge corner undercutting on high rail in sharp curve

4.12 Applying Additional Field Side Relief

Field side relief is normally designed into the rail profile templates. However, if after the application of normal templates there is still evidence a well-developed contact band extending towards the field side of the rail head, additional field side relief needs to be applied.

Field side relief is intended to ensure that minimum wheel contact occurs in the field side region, i.e. within about 15 mm from the field side rail face.

In curves where the L1 profile has been used, the L2 profile should be implemented in the low rails, as the L1 profile exhibits less field side relief.

If further field side relief is required, the ARTC Profiling Manager may specify the application of profiles L3, TGT1 or ARTC H2R (refer to Figure 12, Figure 13 and Figure 14).

Implementation of the alternative profiles will require further metal removal, and possibly additional profiling passes. It will be the responsibility of the Contractor to advise the ARTC Profiling Manager of this aspect.

The additional field side relief must not extend into the contact zone, and profiling facet limits must still be observed within the field-relieved zone.

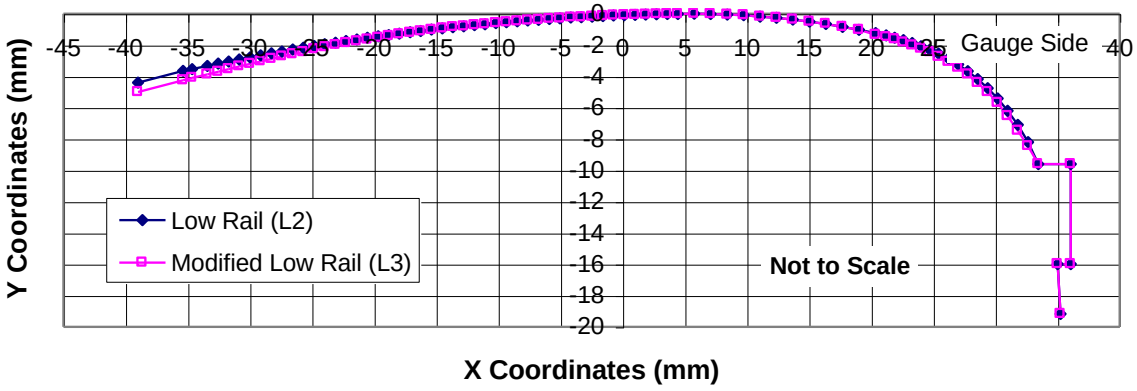


Figure 12 – Comparison of L2 and L3 templates, showing additional field side relief in the latter (rails with 0° cant)

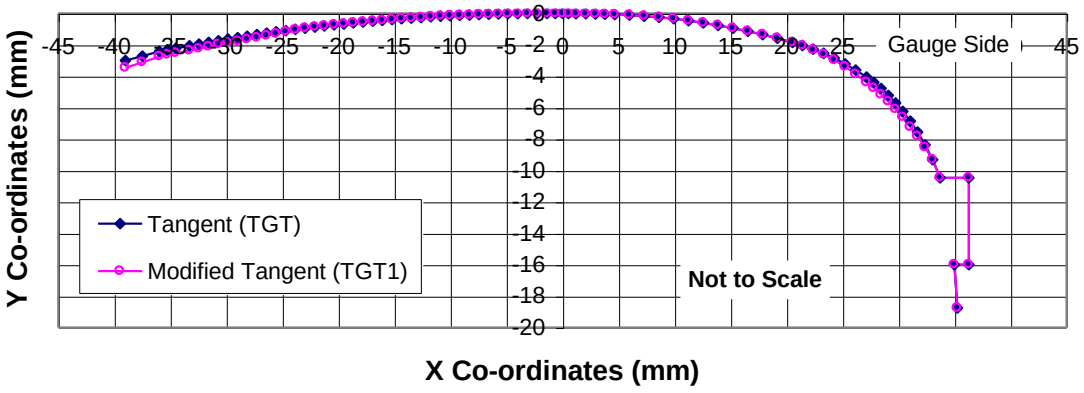


Figure 13 – Comparison of TGT and TGT1 templates, showing additional field (and gauge) side relief in the latter (rails with 0° cant)

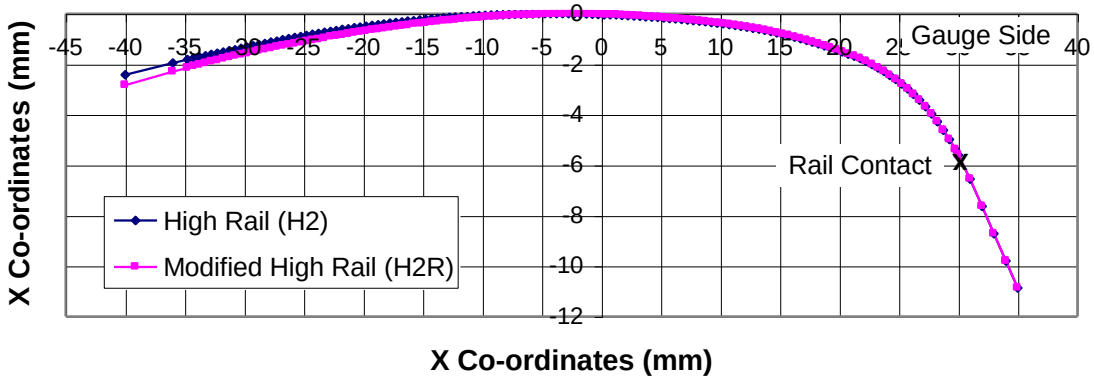


Figure 14 – Comparison of H2 and H2R templates, showing additional field side relief in the latter (rails with 0° cant)

5 Profile Measurement Methods

5.1 Steel Templates

5.1.1 General

Details of templates are specified in Appendices A and B.

Templates used for tangent track and low rails on curves contain positioning lugs, as illustrated in Figure 15. The purpose of these lugs is to provide a referencing point for the template relative to the centreline of the rail.

Note: The locating lug may not make contact on the gauge face, even on new rails. This is due to rail manufacturing tolerances.

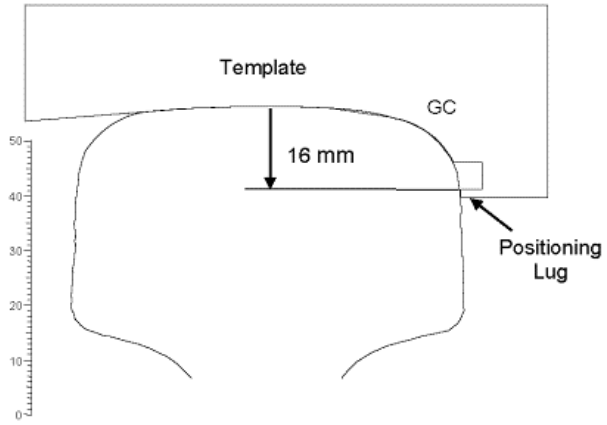


Figure 15 – Template and positioning lug (rail shown in a vertical position)

5.1.2 Template Fabrication

Templates are to be constructed of hardened steel (or a product of equivalent or superior strength, wear resistance, dimensional stability and durability), to a tolerance of ± 0.025 mm at the profile surfaces.

Tolerances at the fixing points for connection to the gauge bar must be adequate, to ensure that the overall superelevated profile tolerances are not compromised.

The template name, date of manufacture and designed contact band details are to be permanently scribed on the face of the template. The template is to be manufactured with the 1 in 20 (2.86°) rail cant included, as shown in the details given in Appendices A and B

5.1.3 Gauge Bars

A gauge bar is to be used with the template. The gauge bar provides fixing holes that are to match those on the template. The gauge bar is to provide a reference to the other rail to give a superelevated reference plane for the application of the template to within ± 0.2°

The gauge bar is to be made of mild steel, aluminium or other product of equivalent or superior rigidity, dimensional stability and durability. The gauge bar must be insulated so that there is no electrical contact between the rails during its application.

Figure 16 shows a typical gauge bar used to hold a single profile template and applied for quality assurance purposes during or after rail profiling.

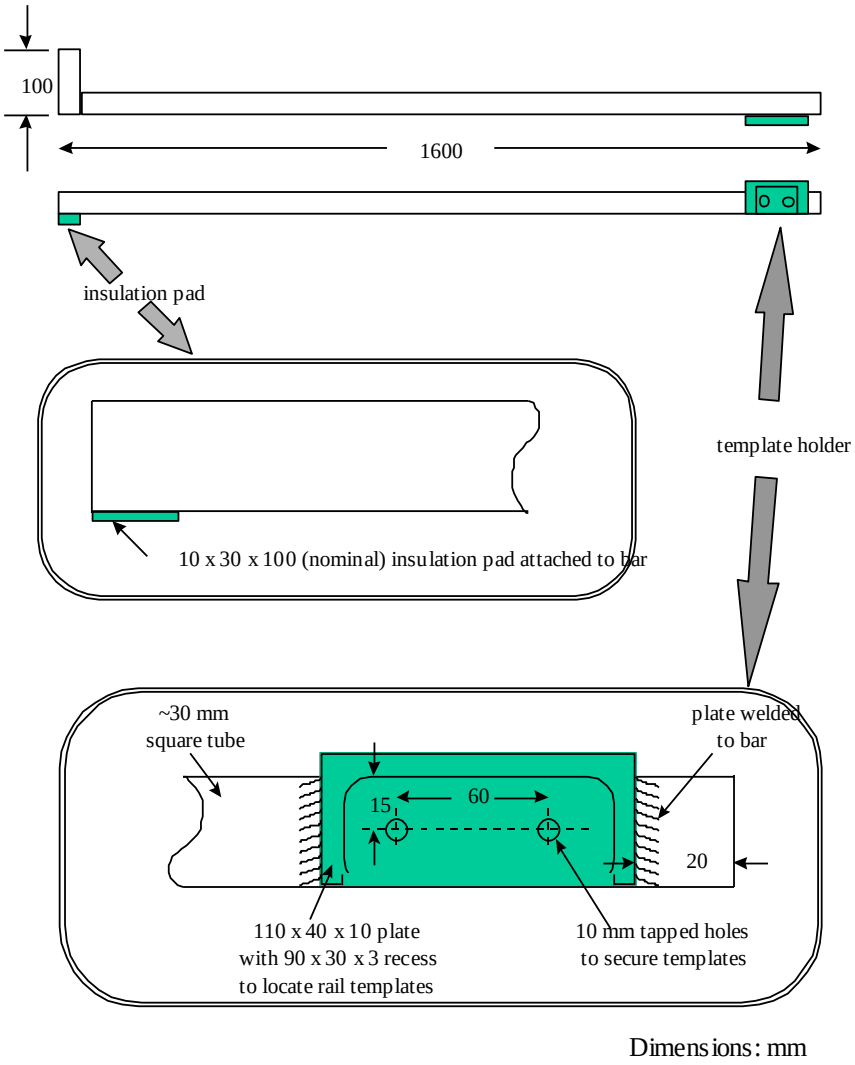


Figure 16 – Gauge bar for single template

5.1.4 Template Placement

The rail template is to be secured to the gauge bar.

With the non-template end of the gauge bar resting on the opposite rail, the template is to be placed onto the rail to be checked and moved down and across to maximise the contact of the template onto the rail.

In all cases, the rail contact point, as illustrated in Appendices A and B, must make contact on the rail gauge face. The contact point generally occurs at an angle of 50°±1° to the vertical for high leg rails and 65°±1° for the low leg rails and for rails on tangents.

Where the template is provided with a gauge positioning lug (for low rails and rails on tangents), the lug must be pushed towards the gauge face of the rail.

For the high rail templates without lugs, the template must make contact on the gauge region of the rail at the start of the template runoff (the rail contact point), as illustrated in Appendices A and B. The runoff is not part of the profile.

Note: It is important that no excessive force is placed on the template or gauge bar. This may lead to distortion, or to accelerated wear.

5.1.5 Template and Gauge Bar Calibration

Template calibration must be checked at initial fabrication and at six-monthly intervals thereafter. The template must be accurate within ±0.025 mm at manufacture and thereafter within ±0.05 mm of the design shape.

Calibration shall be carried out with the template fitted to the gauge bar, or with a suitably designed calibration block that will allow the proper alignment and matching of the template and the block. If a calibration block is used, it must be within ±0.025 mm of the design geometry.

To ensure that the gauge bar has not been deformed, it shall also be checked against a straight-edge at monthly intervals. The gauge bar must be within the original specification of ± 0.2° (i.e. a deviation of less than 2.6 mm from a 1.5 m straight edge).

5.1.6 Calibration of Other Equipment

Any other equipment (including electronic measuring devices and vehicle mounted systems) used for the application of or verification of templates, rail profiles, or surface characteristics must meet equivalent calibration requirements.

Calibration of measuring systems shall be the responsibility of the Contractor and in accordance with a quality plan.

5.2 Vehicle Mounted Measuring Systems

5.2.1 General

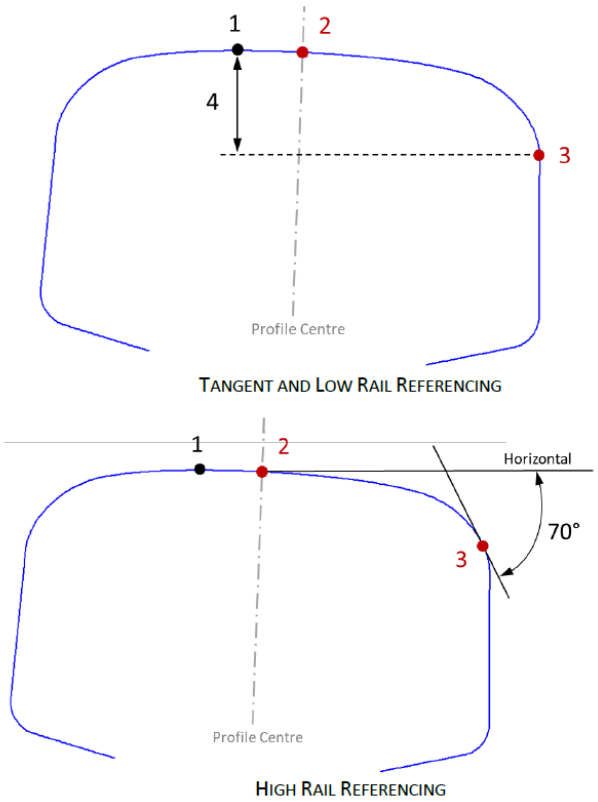
A vehicle mounted system for monitoring rail profiles before, during and after profiling, based on non-contact measuring systems, should be supplied and applied by the Contractor.

A vehicle mounted measuring system must have a proven accuracy and repeatability of better than ± 0.13 mm. Accuracy is to be checked by the Contractor at intervals not exceeding 3 months.

Tolerances specified for profiling work apply equally to manual measurements and to the vehicle mounted measurement system.

5.2.2 Alignment of Rail Profile

The following illustrations indicate how the profiles are referenced for alignment with the rail, showing the two main applications for; high rails, and for low rails & tangents.



1: Top of Template

2: Crown Ref. Point

3: Gauge Ref. Point

4: Depth below Top of Template

Figure 17 – Reference points on rail profiles

Further detail for each profile type as applied to each track segment, is given below for track types Freight and Heavy Haul.

5.2.2.1 Freight Profiles ≤25 TAL

When using a non-contact measuring system, the acquired rail profile can be aligned to the centre reference point of the template, i.e. the (0, 0) point, and to:

CURVATURE OF TRACK SEGMENT(S) (RADIUS)	PROFILE APPLIED	GAUGE REFERENCE POINT
Curves ≤ 900m	H2, H2R and H3	-70º ±1º (approx. 7.5-7.6mm from top of template)
Low rails (all radii) & Tangents	L1, L2, L3 and TGT, TGT1	-16 mm
High rails, curves >900m with side wear present & Tangents	TGT, TGT1	-70º

Table 5 – Reference Points for Freight Profiles ≤25 TAL

5.2.2.2 Heavy Haul Profiles >25 TAL

When using a non-contact measuring system, the acquired rail profile can be aligned to the centre reference point of the template, i.e. the (0.0, 0.0) point, and to the gauge reference points (both points as defined coordinates in Appendix B):

CURVATURE OF TRACK SEGMENT(S) (RADIUS)	PROFILE APPLIED	GAUGE REFERENCE POINT
High Rail Curves ≤ 900m	HVHR	-70º
Low Rail Curves (all radii) & Tangents	HVLRT, HVTGT	-16 mm
High rails, curves >900m with side wear present & Tangents	HVTGT	-70º

Table 6 – Reference Points for Heavy Haul Profiles >25 TAL

6 Preparation for Profiling

6.1 Track segmentation: Identification for planning and work recorded

In the process of profiling, the track is broken up into segments. Each segment must be assessed separately by the Contractor. Segments are designed to align with the adopted preventative cycle strategy described in 4.4 above, noting the difference for General Freight curve segment radii and those used for Heavy Haul (guidance below 8.4 and 8.5 only refers to General Freight radii)

Each segment should have a consistent rail surface shape and condition. A segment cannot be longer than a whole curve, although individual curves can be broken up if required, depending on the curve length.

However, each curve must be fully profiled between the tangent points. It is not permissible to profile only a portion of a curve unless the profiling is required to remove specific defects.

Some track sections may require special consideration in relation to the templates to be adopted, e.g. when two curved track sections are joined by a relatively short tangent (less than 200 m but generally less than 100 m).

In such cases, the middle tangent segment should be treated the same as the adjoining curves.

If short curved sections (less than 80 m) are separated by tangent sections, they should be treated the same as the adjoining longer tangent segments.

6.2 Determination of Work Scope Locations

Specific locations for profiling work should be determined from:

- Rail condition data (from track geometry recordings or manual inspections).
    - Corrugation test measurement of rail surface roughness. Generally sourced from a rail test measurement vehicle or manually measured sources e.g. CAT, electronic straightedges.
    - Rail head profile inspection and measurement
    - Rail surface conditions; cracks and defects such as RCF, squats, wheel burns, weld HAZ or batter.

- The nominated cycle strategies as described above in section 7 Profiling Strategy & Requirements
- Determinations should encompass:
- Start and finish kilometrages
- Templates to be applied to each segment, as defined in 8.3
- For each segment, the number of planned passes, considering;
    - Special corrective goals or conditions to be addressed e.g. corrugations
    - May include guidance on amount of metal removal (depth of cuts)
    - Noting that enough metal must be removed to achieve reprofiling objectives, however excess metal removal is expensive in terms rail head life loss and wasted machine capacity.
    - Also noting that numerically odd pass plans e.g. 1,3,5,7 are more efficient in normal profiling operations, minimising ‘dead’ passes.

6.3 Track Geometry

Profiling should be conducted on track that has good top and line, preferably recently after the track has been surfaced.

6.4 Removal and Replacement of Obstructions

All track obstructions that prevent profiling within a section shall be removed before profiling, and replaced within 2-3 days after profiling, in accordance with the requirements specified by the ARTC Project Manager. Obstructions typically include;

- high ballast – long areas should be removed from plans and rescheduled, short lengths must be removed prior to profiling.
- Lubricators – to be removed in all locations where rail condition will be negatively affected under the cycle strategy in place.
- Level crossing plates
- wayside monitoring devices

The amount of obstruction allowable near the rail head may vary depending on the characteristics of the profiling machine being used (milling is usually clear of all obstructions). This should be confirmed prior to the inspection being carried out.

6.5 Application of Profiles

6.5.1 General

This section describes aspects to be taken into consideration during detailed profile application planning for specific sites.

6.5.2 Application of Locating Lugs

The ARTC Profiling Manager should specify the application requirements for the template locating lug on low rails in curves, and on tangents. These requirements may take the form of a strategy to bring the template into conformance over successive profiling cycles.

Any excessive plastic flow of the rail in the gauge corner region progressively removed at a rate that exceeds the rate of growth of the flow (using a strategy of cycles and metal removal that brings the lug closer to the head until acceptable). This management task for maintaining good profile lateral lug location is critical to ensure high-speed hunting does not occur on tracks.

6.5.3 Sharp Curves <Radius 900m

The L2 and H2 templates are the standard rail templates to be used on curved tracks <R900m with either ANZR1 and/or WPR2000 wheel profiles in operation, the exception being Heavy Haul which uses the HVLR and HVHR as nominal standard profiles. The following is recommended where rail conditions vary and may require special profile management;

- If the rail in a sharp curve has never been profiled (or not profiled for some considerable time), application of the low rail template may require substantial metal removal. In such cases, the application of the L1 or HVLRT template may be considered, as part of a transitional profiling strategy.
- If damaging field side wheel contacts still occur with the L2 and H2 templates, consideration should be given to the application of the L3 or H2R templates. This decision should also consider the populations of wheel hollowing data sourced from Wayside systems as evidence.
- The ARTC Profiling Manager may also approve application of the H3 high rail template in sharper curves on Freight tracks in which the high rails exhibit severe gauge corner RCF defects, as part of a transitional profiling strategy.

6.5.4 Shallow Curves >Radius 900m and Tangent Track

The TGT template is the standard rail template to be used on tangent tracks >R900m with either ANZR1 and/or WPR2000 wheel profiles in operation, the exception being Heavy Haul where the HVTGT is standard. The following is recommended where rail conditions vary and may require special profile management;

- The ARTC Profiling Manager may also approve application of the TGT template to curves of radius down to 800 m, after an assessment of the particulars of the location, rail performance in terms of wheel flanging, and the operational requirements.
- If the rails exhibit plastic flow in the gauge corner region which is adversely affecting track gauge, consideration should be given to application of the TGT1 template, as part of a transitional profiling strategy. Such a strategy should also be considered if wheel hollowing is causing problems or if hunting is occurring.

6.6 Transition profiling

Where considerable profiling effort is required to achieve full correction to profile, or to remove long wavelength corrugations or severe RCF defects, the ARTC Profiling Manager may approve transition profiling.

Transition profiling must involve the correction of the problem over time, such that each profiling cycle brings about a progressive improvement. However, in all such cases the appropriate rail profile must be established, within the specified tolerance limits.

Transition-type strategies can also be applied to locations where the preventative cycles are not achievable. This simply involves a strategic combination of both a longer cycle and a deeper cut for increased metal removal.

6.7 Rail Condition Monitoring

The ARTC Profiling Manager is responsible for monitoring rail condition. Basic rail inspection is to be carried out as part of the track examination system.

- Prior to profiling the rail condition at targeted locations should be assessed visually, by a suitably qualified person. This assessment will assist in determining any specific requirements for the profiling operation.
- Spot checks are also to be carried out of the rail profiling efficiency and the continued effective functioning of the profiles in terms of the contact bands evident and any other rail surface anomalies. These checks will form part of the auditing process.
- Variations to the designed contacts are to be investigated, and if required adjustments made to the templates used or profiling strategies. Spot-checking may be carried out on at least 5% to 10% of profiling locations as a follow up to the profiling operation.
- In addition, a visual inspection may be carried out, if deemed necessary, on all profiled track at about 60% – 70% of the way through the planned profiling interval.
- Where inspections identify any unusual deterioration conditions these are to be recorded in the asset management system and an appropriate response determined. Additional inspections should be scheduled for such locations.

6.8 Periodic Reviews

The ARTC Profiling Manager is to conduct annual reviews of the effectiveness of the rail profiling programme, to assess whether the original purpose for profiling has been achieved. Factors to be considered include:

- Rail corrugation recordings
- Rolling contact fatigue issues, testability issues with ultrasonics
- Effect on track component life, rail fastenings, rail seat pads in concrete sleepers, and sleeper deterioration affected by poor rail surface
- Broken rail history and recent trends
- Fouled ballast or mud holes at rail surface irregularities or rail corrugations
- Tamping cycles being negatively affected by rail impacts
- Evidence of vehicle hunting.

7 Profiling Operations

7.1 Profiling Equipment

The rail profiling unit shall comply with local environmental requirements for maximum noise and dust levels.

7.2 Profiling Supervision Competency

Profiling supervision must be undertaken by personnel who have demonstrated the following competencies:

- Use of rail condition and rail profiling terminology
- Use of rail grinding or rail milling for rail profiling and defect correction, as applicable
- Inspection of rail surface condition and identification of common rail defect conditions
- Inspection of contact bands on rail arising from wheel contacts
- Assessment of completed profiling work
- Compilation of detailed records relevant to on-board operations
- Experience in the operation of rail profiling and rail condition assessment for not less than three months (this can be under the supervision of more experienced personnel).

Profiling supervisors and personnel nominated by the Contractor shall undergo a suitable training course with appropriate accreditation to obtain competency.

Profiling supervisors and personnel nominated by the Contractor shall also receive appropriate training in fire risk management.

7.3 Track Certification

Following profiling works, an appropriately qualified person shall certify the track safe for passage of trains.

7.4 Contractor Records

The profiling Contractor should maintain records for preventive, transitional or corrective rail profiling as follows:

- Profiling machine utilised
- Date of profiling and inspection
- Location of profiling carried out (start and end points), to closest 10 m
- Location of checking points, to closest 5 m
- Profiling template(s) used
- Finished (work completed satisfactorily) and pass track kilometres profiled within 20 m
- Location of any section within a track segment that has not been profiled and the reason (e.g. high ballast, crossing, etc).
- Minimum metal removal at the rail centre line, to the closest 0.05 mm and the overall metal removal area.

- Deviations of the rail profile from the template
- Rail surface roughness achieved after profiling
- Residual rail corrugations after profiling
- Cyclic rail wear after profiling, including any visual indications of skipping or any other surface irregularity
- Number of profiling passes applied to each rail
- Profiling efficiency of machine, i.e. number of profiling motors working
- Details of any condition from pre-profiling inspection or any other specific inspections of rail condition
- Details of the rail contact band assessments carried out immediately after profiling
- Details of any non-conformances in the profiling process or standard of completion

The information is to be available in daily form within 24 hours of the end of each shift.

It will be the responsibility of the ARTC Profiling Manager to ensure that the information has been appropriately collected and recorded.

8 Monitoring and Control

8.1 Checking Locations

Locations in each segment are to be nominated as checking locations. Checking locations are to be used for the ongoing profiling programme.

Checking locations are to be positioned towards the centre of each segment to be profiled, but not at rail closures or anomalous profile conditions. The rail web and foot is to be clearly paint-marked on both the field and gauge sides and its location recorded.

An equivalent procedure may be adopted that will allow the checking location to be accurately defined.

For preventative or transitional profiling, each checking location will represent a track segment generally no longer than:

- 500 m in curved track with radii up to 900 m
- 1000 m in tangent track and shallower curves.

For corrective profiling or for removal of defects, each checking location will represent a track segment generally no longer than 300 m.

The length of the track segments may be increased at the discretion of the ARTC Profiling Manager.

8.2 Checking Operations

The achievement of profiling tolerances, metal removal and surface roughness must be checked on completion of the profiling work and prior to the running of trains.

Checking locations must be examined for:

- Profile
- Metal removal
- Surface roughness
- Short and long pitch corrugations.

The remainder of the rail is to be checked to ensure that the specified defect removal requirements and surface condition have been achieved.

The Contractor will take the necessary measurements after the completion of profiling on at least one track segment profiled in each profiling shift or day, or at the discretion of the ARTC Profiling Manager.

8.3 Checking Methodology

The vehicle mounted rail profile measuring system (or equivalent) is to record profile deviations from the template and metal removals at the checking locations.

If it is considered that vehicle mounted non-contact systems do not have the required accuracy to measure metal removal, the Contractor shall use a mechanical system (such as Railmate or MiniProf to measure both the metal removal at the rail centre line and the overall metal removal area.

The required contact band width on the running surface (indicated in Appendices A and B 1) is to be checked by:

- Painting the running surface of the rails at the checking locations
- Inspection after a minimum of at least 3 or 4 trains, but preferably after several days of operations.
- A preliminary check of the running band by the Contractor can be conducted using the contacts achieved by the wheels on the profiling machine. Any abnormal observations (i.e. when the actual contact band is outside the recommended limits) are to be:
- Reported by the Contractor to the ARTC Profiling Manager during the auditing process
- Recorded by the ARTC Profiling Manager
- Monitored for possible future action.

8.4 Measurement of Metal Removed

Rail profile measurement devices are to be used at a checking location or locations to measure the metal removal achieved by the profiling at the centre of the running surface. This will require taking rail profiles both before and after profiling.

Subject to the proven accuracy and repeatability obtained (preferably better than $\pm$ 0.05 mm), suitable procedures will involve the use of:

- A portable rail profile measuring system such as Railmate, MiniProf or other device capable of achieving an accuracy and repeatability of better than $\pm$ 0.05 mm.

- Non-contact systems if new technology can be proven accurate within the required tolerances
- Portable systems are likely to be applied during the quality assurance or auditing process.

8.5 Tolerance to Profile (Template and Electronic methods)

In design terms, the desirable maximum deviations from the defined profiles, and their respective contact bands (shown in Appendices A and B) and should be targeted to achieve:

- +0.00 mm or -0.25 mm within the contact band
- +0.00 mm or -0.40 mm outside the contact band

8.5.1 Template Tolerance to Profile

The rail is to be profiled so that the profile matches the nominated template.

When applying templates, the tolerance is to be checked by measuring the visible gap between the rail and the template using a feeler gauge which is no more than 3 – 4 mm wide at the end.

The maximum allowable gaps between the rail profile and the template (refer to Appendices A and B for contact band definitions) are shown in Table 7:

BAR GAUGE/ TEMPLATE	FIELD	CONTACT BAND (CROWN)	GAUGE
Tolerance (mm)	-0.4	-0.2	-0.3
Measurement outcome	0.45 mm no-go feeler gauge must not pass between the template and the profiled rail head outside the contact bands (minimum and maximum) covered by the template in the: Gauge corner and field side regions, where templates for the low rails on curves and for tangents have been used Field side region where the high rail templates have been used. The field side region extends to 5 mm from the field side corner	0.25 mm no-go feeler gauge must not pass between the template and the profiled rail head on the contact band of the template. This includes the gauge corner region in the case of high rail templates	0.35 mm no-go feeler gauge must not pass between the template and the profiled rail head outside the contact bands (minimum and maximum) covered by the template. This applies where templates for the low rails on curves and for tangents have been used

Table 7 – Bar Gauge (Template) allowable gaps for measurement

To provide appropriate referencing for the measurements, the templates shall incorporate scribe marks indicating the position of the contact bands and the respective contact angles.

8.5.2 Electronic Tolerance to Profile

The electronic profile measuring systems (mainly vehicle mounted) are to be used in a manner like manual template measurements, i.e. at specific checking locations. Where agreed with the ARTC Profiling manager, the following tolerance may be applied to better suit current technology limitations of system accuracy;

- +0.15 mm or -0.25 mm within the contact band
- +0.15 mm or -0.40 mm outside the contact band.

8.6 Surface Finish

8.6.1 Facets

The profiling process leaves visible facets on the head of the rail and gauge face. These facets must be controlled if excessive contact stress points are to be avoided. The maximum facet width shall be:

- 6 mm in the gauge corner region (refer to Figure 1)
- 10 mm elsewhere on the profiled surface.

In locations using special alloyed rails (high strength and hardness steel) it may be necessary to limit facets to 6mm due to high stress where corners do not deform and smooth. The ARTC Profiling Manager will nominate such locations as required.

If the number of passes planned is unable to meet the requirement for facets (in addition to all other profiling requirements) the contractor shall report the issue to the ARTC Profiling Manager. If planning allows an extra pass to achieve facet removal, a suitable (settings to smooth the surface only, not re-shape) profiling pass shall be applied in track sections to cross cut facets and improve the surface finish of the contact band.

8.6.2 Other Surface Irregularities

The ARTC Profiling Manager will specify the requirements for removal of isolated defects identified prior to profiling (such as corrugations, dipped or peaked welds, or wheel burns). These may not be able to be removed efficiently by the profiling process and do not necessarily have to be removed in one profiling cycle.

Other than for the nominated isolated defects, longitudinal rail surface defects such as corrugations must be removed. The overall surface finish must also meet the following minimum standards:

- No sharp ridges, especially at the interface of profiling facets
- No excessive gouging on the rail surface or sharp profiling marks, as shown in Figure 18
- No indentations in the rail
- No cyclic profiling marks, as illustrated in Figure 19
- No continuous indication of overheating (bluing) of the rail surface
- No rougher than an average of 10 µm RA if within 5 km of any dwellings, or 15 µm RA elsewhere.

Note: A poor quality surface roughness will increase rail noise and may accelerate the future development of rail surface defects.

Figure 18 – Unacceptable severe profiling scratches

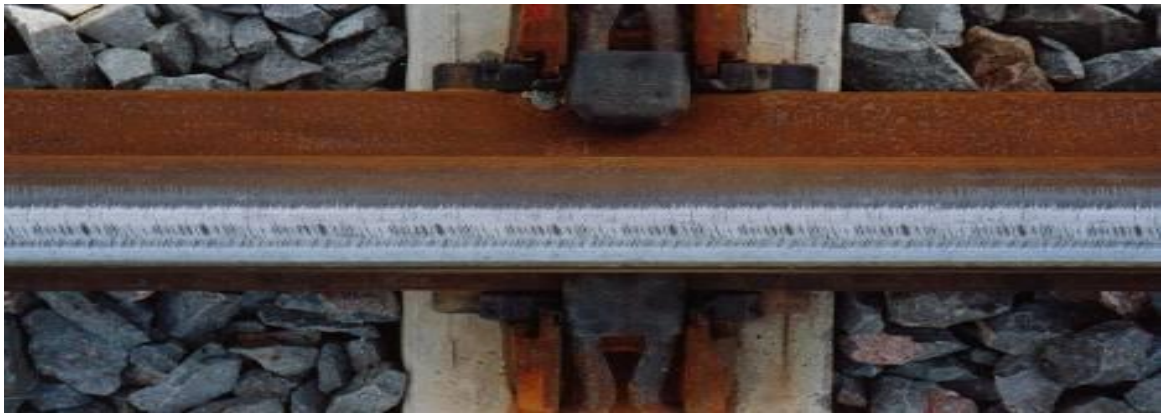


Figure 19 – Unacceptable cyclic profiling scratches

8.6.3 Measurement of Surface Roughness

Surface roughness of the profiled rail shall be measured by the Contractor, within at least one track segment profiled in each profiling shift or day. Surface roughness shall be determined by a roughness measuring system (as typically illustrated in Figure 20), or equivalent, using a measurement travel of 25 mm.

Surface roughness measurements shall be taken on both rails at or near the checking locations and will consist of at least three longitudinal traverses taken on each rail at the rail centre line and 10 – 15 mm on each side of the centre.

Figure 20 – Typical surface roughness measurement system

8.7 Longitudinal Rail Profile

8.7.1 Assessment of Corrugations

Assessment of corrugations shall generally be conducted by the Contractor on both rails at the checking location, on at least one track segment profiled in each profiling shift or day.

However, additional measurements may be conducted at any location within a profiled section when visual examination indicates the presence of cyclic irregularities after profiling.

8.7.2 Short Pitch Corrugations

Short pitch surface irregularities (30 – 150 mm in wavelength), which could be introduced by the profiling process (refer to Figure 19), shall be removed so that:

- The remaining cyclic average longitudinal unevenness along the rail running surface (peak to peak) is less than 15 μm
- The remaining longitudinal unevenness along the rail running surface is less than 0.10 mm
- When measured at the centre of the running surface over any 1 m length (excluding welds), using a suitable measuring system. The measuring system would generally be laser based (as illustrated in Figure 21).

Figure 21 – Measurement of short pitch corrugations

8.7.3 Special Treatment for Long Wave Corrugations and Peaked Welds

On some tracks, particularly where laid with 47 kg rail manufactured at Port Kembla, the combination of axle load and speed have produced long wave corrugations.

Typically, these have a pitch of about 0.8 m to 1.5 m, and an amplitude of up to about 1 mm peak to peak. Special profiling procedures will be required to correct these rails to achieve the parameters specified in Table 2 below.

Note: It is important that rectification is managed so as not to produce widely varying hardness profiles e.g. by profiling too deep into the work hardened section of the head.

8.7.4 Finished Longitudinal Profiles

The longitudinal profile shall be processed to provide a filtered profile within each of the wavelength ranges given in Table 8. The cut-off wavelengths for each wavelength range and the length of the corresponding window within which the pertinent moving average is to be calculated are also given in Table 8.

The percentages of any site in which the moving average RMS amplitudes exceed the values specified in Table 9 shall be calculated. These percentages shall not exceed the limits given in Table 10 for the specified rail type specified.

WAVELENGTH RANGE (MM)	**10 – 30**	**30 – 100**	**100 – 300**	**300 – 1000**	**1000 – 1500**
Window Length (m)	0.15	0.5	1.5	5	15

Table 8 – Parameters for calculation of RMS

Limit of moving average of RMS amplitude (mm)	0.004	0.004	0.012	0.040	0.040

Table 9 – Moving average RMS limit

ALL RAIL SECTIONS ≥53 KG	5%	5%	5%	10%	NO REQUIREMENT
<53 kg rail	5%	5%	5%	10%	10%

Table 10 – Maximum allowable percentage exceedance

8.7.5 Demonstration of Compliance

To demonstrate compliance, one of the following methods (or equivalent) is to be used:

1. An accelerometer or a mechanically based hand operated system such as a corrugation analysis trolley. Both rails in at least 5% of the track profiled per shift are to be measured.
2. An accelerometer, mechanical or noncontact-based system incorporated on the rail profiling unit or auxiliary vehicle. Both rails in at least 10% of the track profiled per shift or day are to be measured.

Measurements should be taken immediately after profiling and must be completed within two days.

8.8 Cyclic Profiling Defects on Gauge Corners (skipping)

8.8.1 General

Some sections of track (mainly shallow curves and tangents) may contain indications of a cyclic gauge region wear pattern that has been produced by wheelset or bogie hunting, or by unsatisfactory profiling practices (known as skipping). The condition is illustrated in Figure 22.

Such wear patterns require special procedures for monitoring and control.

Figure 22 – Cyclic wear (skipping) induced by rail profiling

8.8.2 Prevention

In sections of track that have no prior indications of cyclic wear on the gauge corner, the rail profiling operation shall not result in conditions which may induce any form of cyclic wear, in the form of skipping.

8.8.3 Monitoring & Assessment

To ensure that the profiling operation does not introduce any cyclic skipping wear on the rails, the Contractor is to measure the deviation of the rail profile from the template at an angle of 0⁀ – 50° from the vertical towards the gauge corner region. Measurements are to be made after completion of at least one track segment profiled each profiling shift or day, or as directed by the ARTC representative.

Where possible, the track segment shall be either a shallow curve or a tangent section. Both rails are to be measured, excluding any rail closures that may be present within the track segment.

To quantify skipping:

- Rail profiles are to be measured every 0.5 m for 200 m

- For each measured profile, the variation from the appropriate template is to be calculated at 1° intervals from 0° – 50° (measured from the track plane)
- For each profile the maximum variation is determined
- The standard deviation is to be calculated for a moving window 20 m in length for the 200 m section.
- The mean of the standard deviation is calculated over the 200 m length.

8.8.4 Acceptance Standard

For any 200 m length the mean of the standard deviation shall be less than 0.2 mm.

8.8.5 Alternative Quality Assurance Procedures

The Contractor may recommend an alternate quality assurance procedure for ensuring that no skipping wear is introduced on the rails. Such a procedure must incorporate the acceptance standard.

8.8.6 Extension of Measurement Interval

Once confidence is established in relation to the performance of the Contractor in relation to skipping wear, the detailed measurements may be extended to once every 5 – 7 days, or as directed by the ARTC representative.

8.8.7 Alternative Procedures

The Contractor may recommend an alternative quality assurance procedure for ensuring that no skipping wear is introduced on the rails. The alternative procedure must ensure that specified profile deviations are not exceeded.

8.8.8 ARTC Assessments

The ARTC Profiling Manager is to assess and record the following items, for quality assurance purposes, as part of the auditing process:

- Profile deviations
- Metal removal
- Surface roughness
- Contact band width
- Corrugations.

Assessments are to be conducted within one or two days after rail profiling.

Note: When taking rail profiles with MiniProf or Railmate systems the cant bar must be used at all times, to allow compensation for any deviations from the design rail cant of 1:20.

8.8.9 Field Audits

Field audits of profiling operations by competent personnel should be conducted at regular intervals, which would range from about 2 – 4 weeks in the Hunter Valley, where profiling is conducted more regularly, to 8 – 12 weeks in other regions, where profiling is conducted less regularly.

9 Detailed Performance Assessment

9.1 Average Profile Deviations (including Metal Removal)

Average profile deviations shall be assessed at the checking location in at least one track segment profiled in each profiling shift or day.

The average profile deviations from the template shall be determined:

- Within 5 mm segments across the rail surface
- Including the gauge corner and face regions up to an angle of 50° to the vertical for the high rails and 65° to the vertical for templates for the low rails on curves and for tangents.
- In conjunction with the assessment of average profile deviations, the average metal removal is also to be measured within each 5 mm segment. This will require rail profile measurements to be taken both before and after profiling.

At least 5 segments shall represent the region within the contact band and 4 segments the region outside the contact band.

9.2 Presentation of Data

The deviations shall be presented graphically, as illustrated (example only – limits may vary) schematically in Figure 23 for tangents, low and high rails in shallow curves, and in Figure 24 for high rails in sharper curves.

Note: For the rails in sharper curves, the contact zone extends from the gauge corner region towards the centre line of the rail.

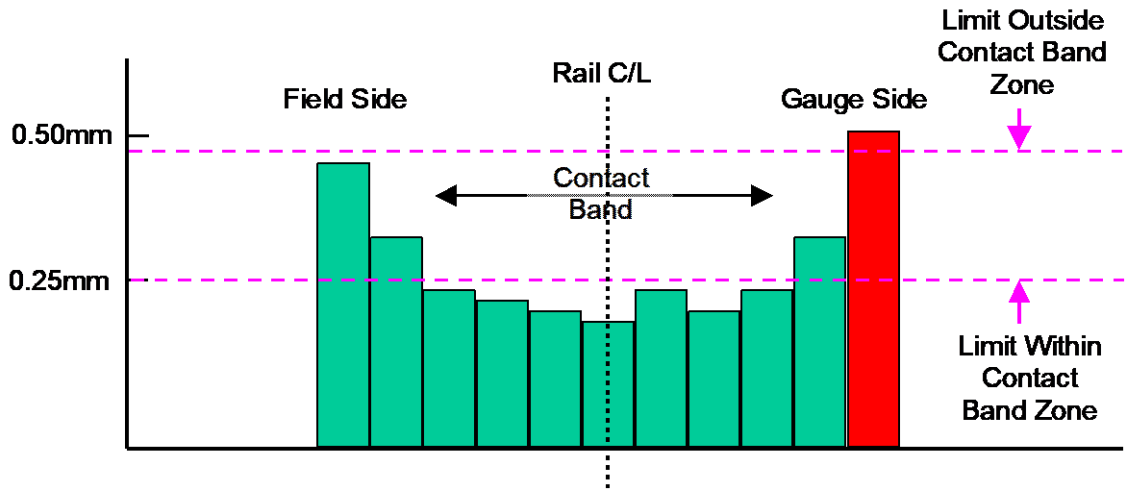


Figure 23 – Graphical output of profile deviations from template for tangents, low and high rails in shallower curves (red indicates outside the specified limits)

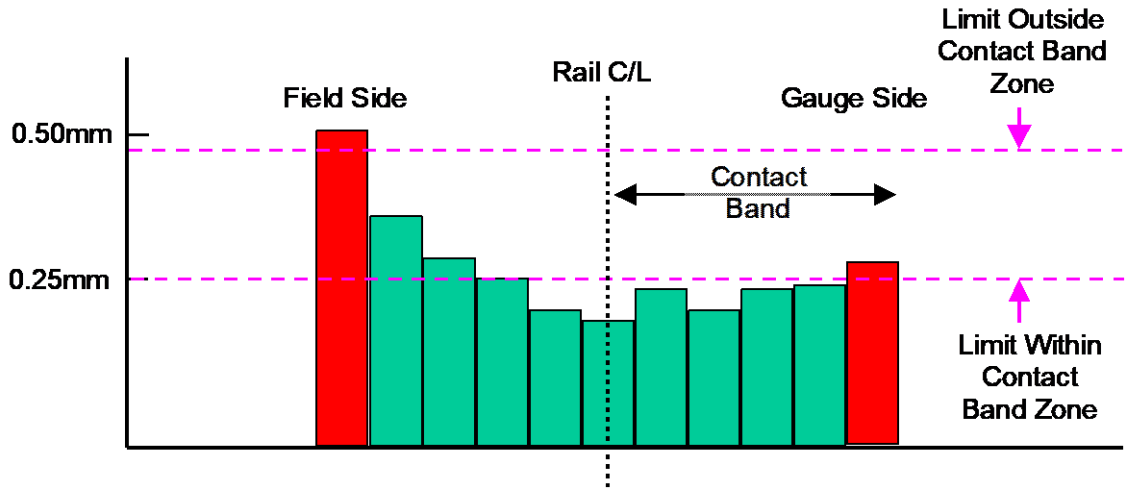


Figure 24 – Graphical output of profile deviations from template for high rails in sharper curves (red indicates outside the specified limits)

9.3 Statistical Analysis

Within 12 months of the start of a profiling contract, and following appropriate field profiling and assessment trials, additional and more detailed rail profile measurements after profiling are to be taken using a vehicle mounted system on at least one-track segment profiled in each profiling shift or day.

The measurements are to be taken at 20 – 25 m intervals along the track segment. The profile deviation values as illustrated in Figure 23 and Figure 24 are then to be used to determine and meet maximum allowable deviations from the applicable templates.

Within the contact zones (refer to Appendices A and B and to Figure 23 or Figure 24):

- 90% of values must be less than 0.25 mm
- 95% of values must be less than 0.30 mm
- 98% of values must be less than 0.35 mm

Outside the contact zones (refer to Appendices A and B and to Figure 23 or Figure 24):

- 90% of values must be less than 0.45 mm
- 95% of values must be less than 0.50 mm
- 98% of values must be less than 0.55 mm

Excessive exceedance that may occur at rail irregularities such as welds and closures will be ignored in the statistical analysis.

The detailed measurements are in addition to the profile measurements taken at the checking locations in all other track segments, which will follow the same tolerance levels as specified for the gauge bar.

10 Rail Profiling for Points & Crossings: Additional Requirements

10.1 Scope: Points & Crossings Profiling

This portion of the standard addresses only the considerations for Points (turnouts) & Crossings profiling where these are different to the requirements of any sections above that covers plain track profiling. All requirement for plain track grinding shall be followed as a minimum and then additional variations applied for Points and Crossings as outlined below.

10.2 Profile Definitions: Points & Crossings Profiling

The points and crossings are to have a single profile applied to all areas (turnout road and straight road), the profile is the same for Freight tracks and Heavy Haul tracks;

- HVTO Profile is to be used in all tracks
- Full detail of these profile design is given in Appendix B.

10.3 Profiling new rail: Points & Crossings Profiling

New turnouts ideally have the correct profiles installed during manufacture (most cost-effective method), however if the new equipment has not been profiled before installation the following applies (whichever is the larger);

- Following installation, any new turnouts should be profile ground within 5 MGT for all rail types,
- or within 20% of the profiling cycle for preventive profiling detailed in Technical Maintenance Plans.

10.4 Guidelines for Preventive Profiling: Points & Crossings

The recommended guidelines for preventive rail profiling should be more stringently followed than the requirements for the main line due to the high cost and risks associated with their function.

Turnout road cycles should be applied as given in Table 1 below, noting only tonnages on the turnout road apply to Table 11, and the cycles apply to all rail types.

TURNOUT TYPE	TARGET CYCLE (MGT)
1:8.25	10 MGT
1:10.5 and 1:12	15 MGT
1:15 or higher	25 MGT

Table 11: Guidelines for Preventive Profiling Turnout Road

Notes

To allow for track possession and profiling irregularities an extension of up to +20% of the recommended cycle tonnages given in Table 11 is applicable. The nominal profiling period however will generally be maintained.

Due to adverse wheel/rail contact conditions, the profiling determined might not be adequate for some track sections. Such sections should be reported, monitored and if necessary, adjusted to a shorter cycle. An example could be rails subjected to higher

tractive efforts which may exhibit higher deterioration rates and hence would require more frequent profiling.

The nominal preventative profiling period between profiles should be achieved at least on average. If necessary individual cycles may be adjusted to suit unique circumstances but generally within the maximum allowable periods.

Generally, the practise of profiling the turnout road (curve) of the turnout at every alternate cycle of the main road (straight) of the turnout, will easily maintain the MGT cycles suggested above (due to the much lower usage of the turnout loop/track in most cases, compared to the mainline). This is acceptable to ensure maximum turnout life through better overall performance of the rail, noting that this curve profiling should be at minimum metal removal to ensure wear rates are not accelerated.

10.5 Tolerance to Template: Points & Crossings Profiling

All Rail template tolerance requirements outlined within this document are to be used for turnouts except on the following:

- All flow on the gauge side of rails is to be removed.
- The lug on the template does not have to fit snug against the gauge face of the rail if the ground rail profile is no more than 2 mm from the edge of the template. There is no requirement to reduce this distance by profiling.

10.6 Allowance for Rail Rotation: Points & Crossings Profiling

Rails exhibit different rotation characteristics under traffic which depend on the rail size, the traffic type, the sleeper and fastening type and the track curvature. Such rail rotation should be accounted for when applying a template during rail profiling.

The rotation under load can be determined by measurement or assessment for each section of track.

The ARTC Profiling Manager may determine the rotation required (normally to the nearest degree, the default value is zero).

10.7 Profiling Operation: Points & Crossings

The initial profiling of turnouts shall be conducted on the through road and continued beyond the points and crossing for 15-20 m or as required to overlap with the Main Line profiling. Subsequent profiling of the turnout road shall finish at the end of the switch, to avoid additional profiling of the rails on the through road. Profiling of the turnout road should continue beyond the crossing for 15 to 20m or as required to complete a full crossover.

When profiling is conducted on a turnout and/or crossing all possible parts of that turnout and/or crossing shall be ground (including switches, closure and stock rails).

- This will require the resetting of switches during the profiling operation. (Signalling and other support requirements for this must be in place for restoration of the work).
- Standard profiling passes can be applied up to 0.5 m from the nose of the crossings and up to 1 m from the tip of the switches.
- Special care must be taken with the profiling applied within these distances to ensure that excessive metal is not removed.

- For those parts that can still be ground, this will usually entail the application of only a limited number of profiling passes (2-3) to clean up the gauge corner region and reduce the plastic flow lipping (refer to Figure 25 and Figure 26).
- Some areas of the turnout may not be able to be ground by current on-track profiling machines (normally the tip of the switches and the crossing nose).
- In these cases, suitable hand-held profiling devices should be used to cover the missed areas. Refer to relevant ARTC standards for hand-profiling guidance.
- They also may also be used to profile any anomalies on the gauge face of the rail (such as rail flow), which similarly have been missed by the on-track profiling machines. See Figure 25 showing profiling in the vicinity of crossings.

Figure 25 Acceptable Profiling Finish at Switch and Stock Rails

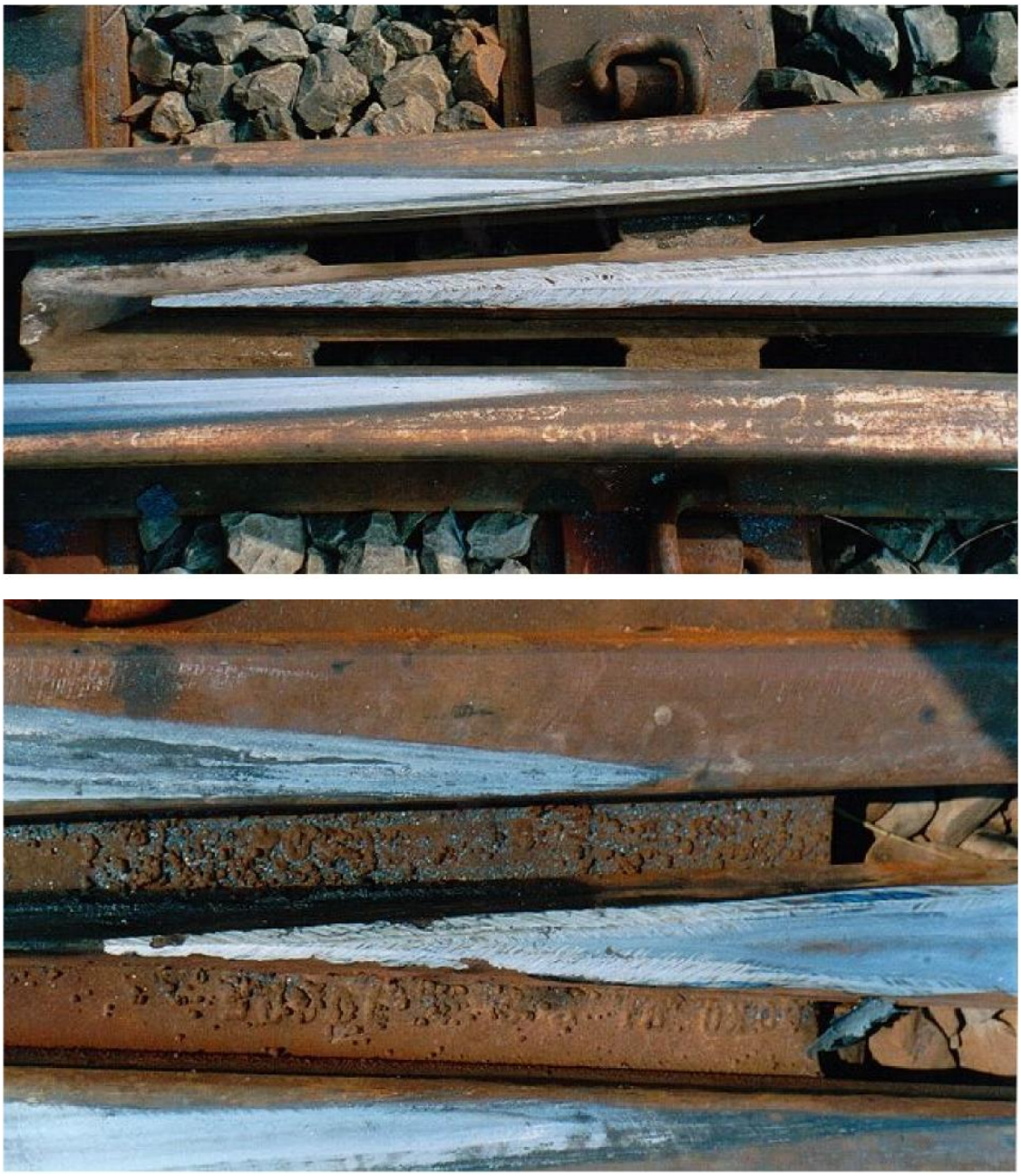


Figure 26 Acceptable Profiling Near the Nose of V Crossings

10.8 Monitoring and Control: Points & Crossings Profiling

10.8.1 Inspection: Points & Crossings Profiling

The achievement of profiling tolerances and metal removal must be checked on completion of the profiling work and prior to the running of trains. Checking locations must be examined for profile and metal removal and the remainder of the turnout checked visually to ensure that the specified defect removal requirements and surface condition have been achieved.

Close visual examination is to be carried out at crossings and switches and stock rails.

At the completion of profiling the chair plates must be washed using pressurised water to remove most of the profiling particles/dust.

Profiles are to be checked at all turnouts at the following locations - switches, stock rails, crossings and in the approximate middle of the turnout. No paint-marking of checking locations is required.

The required contact band width on the running surface shall be checked by painting the running surface of the rails at the checking locations following profiling, and inspection after at least 3 or 4 trains. Any abnormal observations (i.e. when the actual contact band is outside the recommended limits) are to be noted and reported to ARTC for monitoring for possible future action.

10.8.2 Contractor Records: Points & Crossings Profiling

The technical details for either preventive or corrective rail profiling, the following need to be recorded in an electronic database;

- Profiling machine utilised
- Date of profiling and inspection
- Location of turnout on which profiling was carried out specifying from and to km, description of the turnout (e.g. cross-over, diamond, catchpoints) and the points number(s).
- Effective track kilometres ground (work completed satisfactorily) counting both the mainline and turnout road.
- Profiling template(s) used
- Finished (work completed satisfactorily) and number of locations profiled.
- Location of any section within a track segment that has not been profiled and the reason (e.g. high ballast, crossing, etc).
- Minimum metal removal depth at the rail centre line, to the closest 0.05 mm and the overall metal removal area.
- Deviations of the rail profile from the template
- Rail surface roughness achieved after profiling
- Number of profiling passes applied to each rail
- Profiling efficiency of machine, i.e. number of profiling motors working
- Details of any condition from pre-profiling inspection or any other specific inspections of rail condition
- Details of the rail contact band assessments carried out immediately after profiling
- Details of any non-conformances in the profiling process or standard of completion
- The information is to be available in daily form within 24 hours of the end of each shift.

It will be the responsibility of the ARTC Profiling Manager to ensure that the information has been appropriately collected and recorded.

Appendix A – General Freight ≤25 TAL Rail Profiles

Main Templates

Figure A1: ARTC TGT Template for tangent track and curves with radii >900m, with lug

Figure A2: ARTC L1 Template for low rails in curved track with radii ≤900m, applied in transitional profiling, with lug

Figure A3: ARTC H2 Template for high rails in curved track with radii ≤900m, without lug

Figure A4: ARTC L2 Template for low rails in curved track with radii ≤900m, with lug

Special Templates

Figure A5: ARTC H3 Template for high rails in curved track with radii ≤900m exhibiting moderate/severe RCF defects, without lug

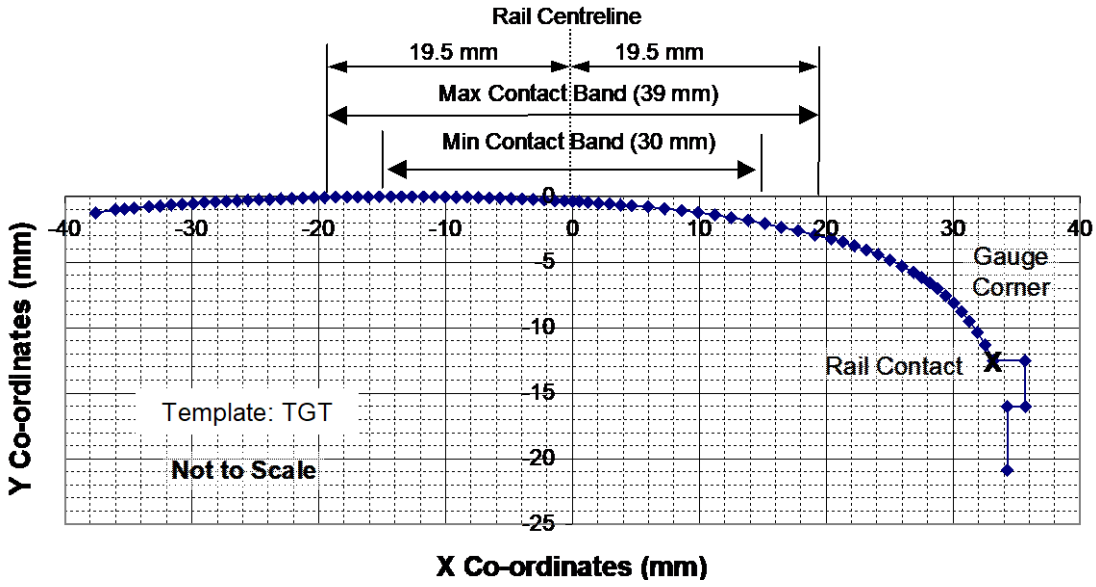
Figure A6: ARTC L3 Template for low rails in curved track with radii ≤900m requiring additional field/gauge side relief, with lug

Figure A7: ARTC TGT1 Template for tangent track and curves with radii >900m requiring additional field/gauge side relief, with lug

Figure A8: ARTC H2R Template for high rails in curved track with radii ≤900m requiring additional field side relief

Note: All profiles have been specified for rails with a cant adjustment of 1:20 (2.86°).

Figure A1: ARTC TGT – Template for tangent track and curves with radii >900m, with lug

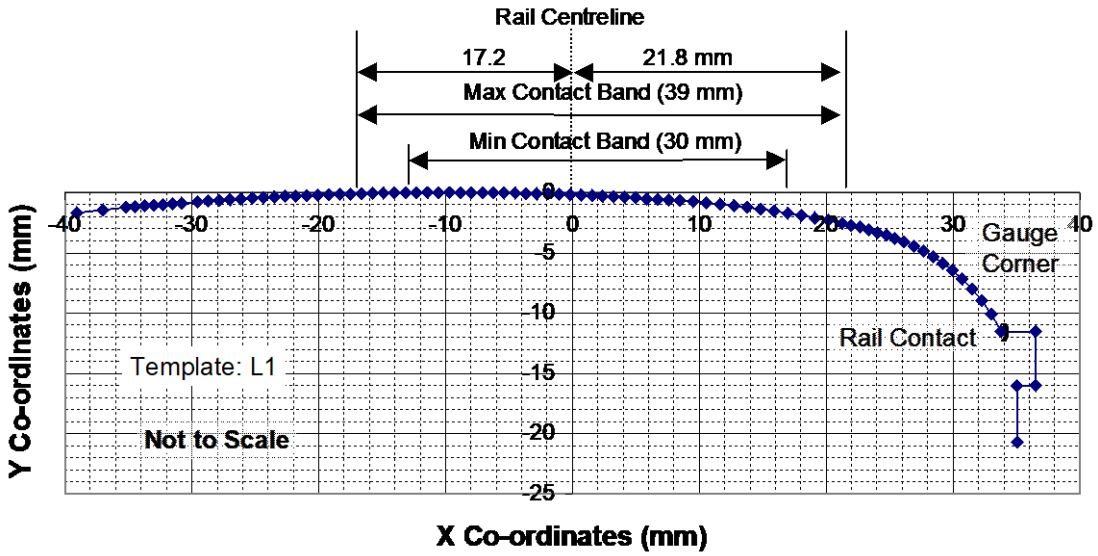


X Coordinates of Contact Band

Min Contact Band	Max Contact Band
+15	+19.5
-15	-19.5

TGT – Template for tangent track and curves with radii >900m, with lug							
X	Y	X	Y	X	Y	X	Y
-39.10	-1.44	-19.53	-0.07	-1.39	-0.31	21.29	-3.49
-37.59	-1.23	-18.67	-0.06	-0.63	-0.35	22.23	-3.76
-36.05	-1.00	-17.79	-0.04	0.00	-0.38	23.16	-4.08
-35.31	-0.94	-16.93	-0.02	0.54	-0.41	24.10	-4.44
-34.58	-0.87	-16.07	-0.02	1.21	-0.45	25.03	-4.84
-33.35	-0.78	-15.21	-0.01	2.07	-0.50	25.97	-5.29
-32.49	-0.71	-14.35	0.00	2.94	-0.56	26.90	-5.79
-31.62	-0.65	-13.48	-0.01	3.79	-0.62	27.53	-6.16
-30.76	-0.58	-12.62	-0.01	4.66	-0.68	28.16	-6.58
-29.89	-0.53	-11.76	-0.01	5.97	-0.79	28.78	-7.04
-29.03	-0.47	-10.88	-0.02	7.28	-0.91	29.41	-7.56
-28.17	-0.42	-10.02	-0.03	8.60	-1.06	30.03	-8.13
-27.30	-0.38	-9.16	-0.04	9.91	-1.21	30.66	-8.78
-26.44	-0.33	-8.29	-0.07	11.22	-1.40	31.28	-9.51
-25.58	-0.28	-7.43	-0.08	12.53	-1.61	31.90	-10.35
-24.71	-0.25	-6.57	-0.10	13.85	-1.83	32.53	-11.34
-23.85	-0.21	-5.70	-0.13	15.15	-2.08	33.16	-12.53
-22.98	-0.17	-4.84	-0.16	16.46	-2.34	35.70	-12.53
-22.12	-0.15	-3.98	-0.19	17.78	-2.62	35.70	-16.00
-21.25	-0.12	-3.12	-0.22	19.09	-2.92	34.26	-16.00
-20.39	-0.09	-2.25	-0.27	20.40	-3.25	34.26	-20.87

Figure A2: ARTC L1 - Template for low rails in curved track with radii ≤900m, applied in transitional profiling, with lug

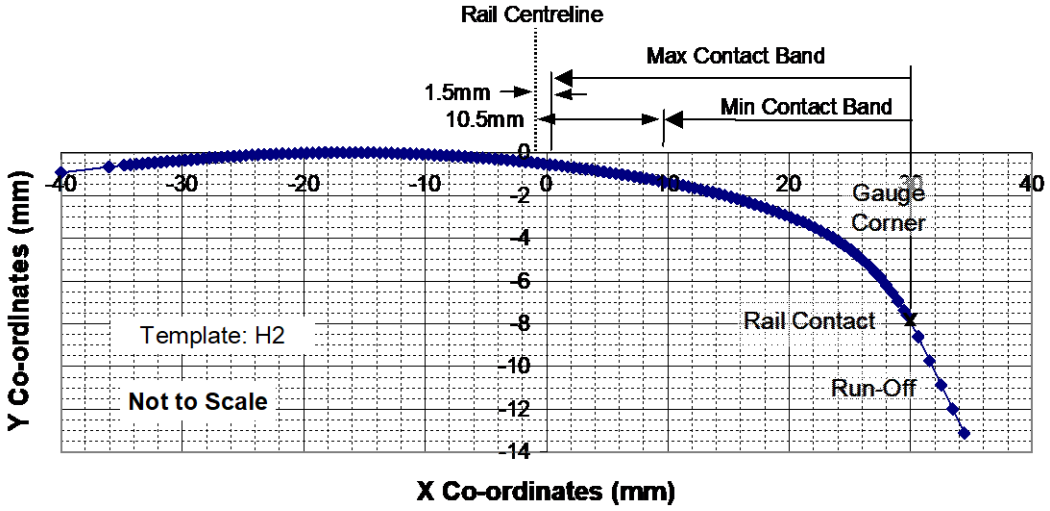


X Coordinates of Contact Band

Min Contact Band	Max Contact Band
-12.7	-17.2
17.3	21.8

L1 - Template for low rails in curved track with radii ≤900m, transitional profiling, with lug							
X	Y	X	Y	X	Y	X	Y
-39.10	-1.69	-18.34	-0.13	0.66	-0.21	21.95	-2.71
-37.00	-1.45	-17.48	-0.11	1.53	-0.26	22.65	-2.87
-35.20	-1.23	-16.62	-0.08	2.39	-0.30	23.34	-3.07
-34.46	-1.17	-15.75	-0.06	3.25	-0.34	24.04	-3.29
-33.74	-1.11	-14.89	-0.05	4.11	-0.39	24.73	-3.53
-33.00	-1.04	-14.03	-0.03	4.98	-0.44	25.43	-3.79
-32.27	-0.99	-13.16	-0.01	5.84	-0.49	26.13	-4.08
-31.54	-0.93	-12.30	-0.01	6.71	-0.55	26.89	-4.44
-30.80	-0.86	-11.44	0.01	7.57	-0.61	27.66	-4.85
-29.58	-0.77	-10.57	0.01	8.44	-0.67	28.43	-5.31
-28.71	-0.70	-9.70	0.00	9.50	-0.75	29.19	-5.85
-27.85	-0.64	-8.84	0.00	10.57	-0.85	29.95	-6.47
-26.98	-0.57	-7.98	0.00	11.64	-0.96	30.72	-7.17
-26.12	-0.52	-7.11	-0.01	12.70	-1.08	31.49	-7.99
-25.26	-0.46	-6.25	-0.02	13.78	-1.22	32.25	-8.94
-24.39	-0.41	-5.39	-0.03	14.84	-1.37	33.02	-10.08
-23.53	-0.37	-4.52	-0.05	15.91	-1.54	33.79	-11.52
-22.67	-0.32	-3.66	-0.07	16.97	-1.71	36.52	-11.52
-21.80	-0.27	-2.80	-0.09	18.05	-1.89	36.52	-16.00
-20.94	-0.24	-1.93	-0.12	19.11	-2.10	35.03	-16.00
-20.08	-0.20	-1.07	-0.15	20.18	-2.32	35.04	-20.72
-19.21	-0.16	-0.20	-0.18	21.25	-2.54		

Figure A3: ARTC H2 - Template for high rails in curved track with radii ≤900m, without lug



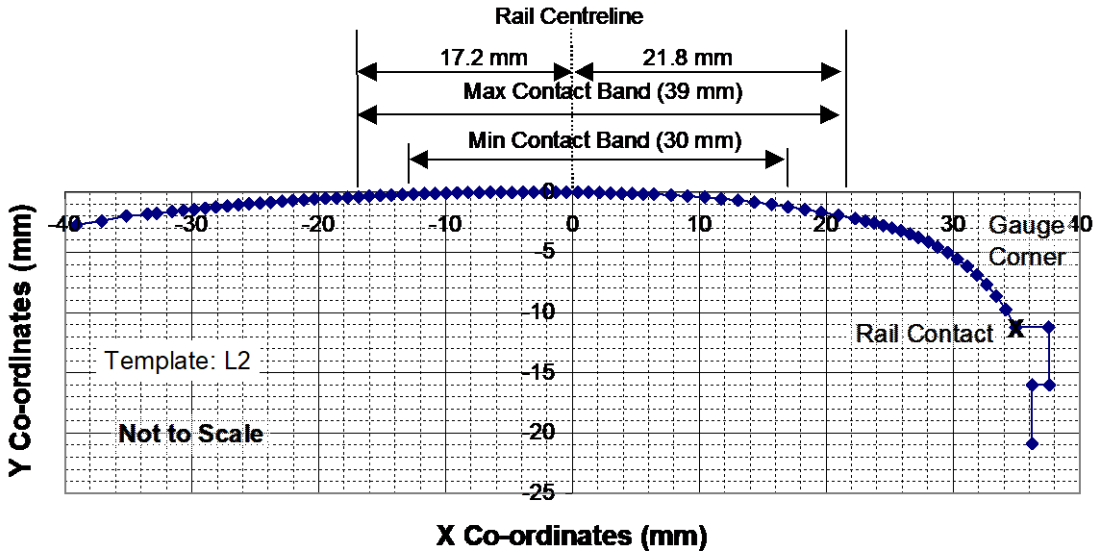
X Coordinates of Contact Band

Min Contact Band	Max Contact Band
+ 9.5 to rail contact point on gauge side (at 50°)	+ 1.0 to rail contact point on gauge side (at 50°)

ARTC H2 - Template for high rails in curved track with radii ≤900m, without lug

X	Y	X	Y	X	Y	X	Y
-40.00	-0.94	-18.25	-0.01	-0.75	-0.49	16.68	-2.33
-36.06	-0.67	-17.75	0.00	-0.26	-0.52	17.17	-2.43
-34.80	-0.59	-17.25	0.00	0.24	-0.56	17.67	-2.52
-34.30	-0.57	-16.75	0.00	0.74	-0.58	18.16	-2.62
-33.80	-0.54	-16.25	0.00	1.24	-0.62	18.66	-2.71
-33.30	-0.52	-15.75	0.00	1.74	-0.66	19.15	-2.82
-32.79	-0.49	-15.25	0.00	2.24	-0.70	19.65	-2.92
-32.29	-0.47	-14.75	0.00	2.74	-0.73	20.14	-3.03
-31.79	-0.44	-14.25	-0.01	3.24	-0.77	20.64	-3.14
-31.29	-0.42	-13.75	-0.01	3.73	-0.81	21.14	-3.25
-30.79	-0.40	-13.25	-0.02	4.23	-0.86	21.63	-3.37
-30.29	-0.38	-12.75	-0.02	4.73	-0.89	22.12	-3.50
-29.78	-0.35	-12.25	-0.04	5.23	-0.94	22.62	-3.66
-29.28	-0.33	-11.75	-0.04	5.73	-0.98	23.11	-3.81
-28.78	-0.30	-11.25	-0.06	6.23	-1.03	23.60	-3.98
-28.28	-0.28	-10.75	-0.06	6.73	-1.07	24.09	-4.16
-27.78	-0.25	-10.25	-0.08	7.22	-1.12	24.58	-4.35
-27.28	-0.24	-9.75	-0.09	7.72	-1.16	25.07	-4.55
-26.77	-0.21	-9.25	-0.11	8.22	-1.22	25.56	-4.77
-26.27	-0.19	-8.75	-0.12	8.72	-1.26	26.05	-5.01
-25.77	-0.17	-8.25	-0.14	9.22	-1.32	26.54	-5.27
-25.27	-0.16	-7.75	-0.15	9.71	-1.37	27.03	-5.55
-24.77	-0.13	-7.25	-0.17	10.21	-1.42	27.51	-5.86
-24.27	-0.12	-6.75	-0.19	10.71	-1.47	28.00	-6.19
-23.76	-0.10	-6.25	-0.21	11.21	-1.54	28.48	-6.56
-23.26	-0.09	-5.75	-0.23	11.71	-1.59	28.96	-6.95
-22.76	-0.08	-5.25	-0.25	12.20	-1.66	29.44	-7.37
-22.26	-0.07	-4.75	-0.27	12.70	-1.72	29.68	-7.60
-21.76	-0.05	-4.25	-0.30	13.20	-1.79	30.63	-8.61
-21.26	-0.05	-3.75	-0.32	13.70	-1.85	31.57	-9.73
-20.76	-0.03	-3.25	-0.34	14.19	-1.93	32.52	-10.86
-20.26	-0.03	-2.75	-0.37	14.69	-2.00	33.46	-11.99
-19.76	-0.02	-2.25	-0.40	15.19	-2.09	34.41	-13.11
-19.25	-0.02	-1.75	-0.43	15.68	-2.16		
-18.75	-0.01	-1.25	-0.45	16.18	-2.25		

Figure A4: ARTC L2 - Template for low rails in curved track with radii ≤900m, with lug



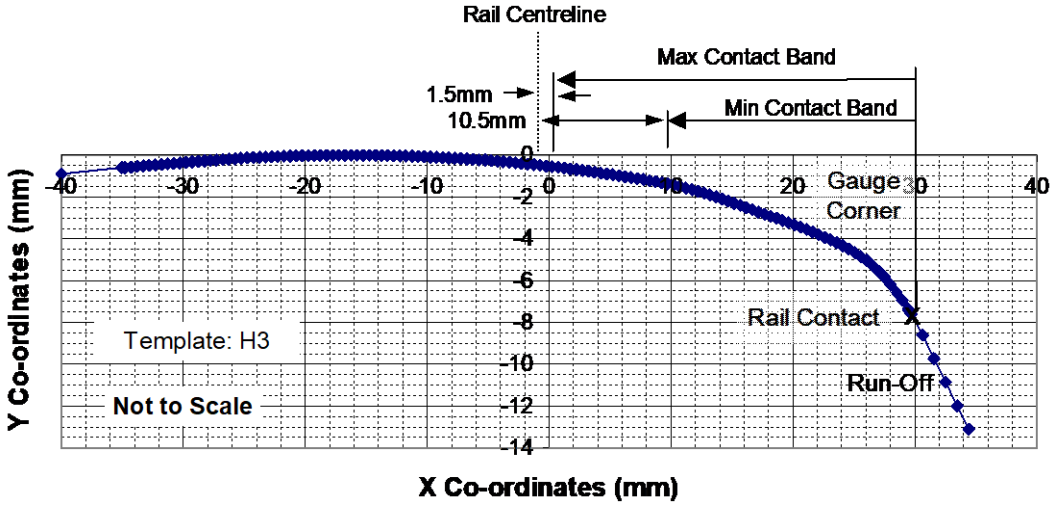
X Coordinates of Contact Band

Min Contact Band	Max Contact Band
-12.7	-17.2
17.3	21.8

ARTC L2 - Template for low rails in curved track with radii ≤900m, with lug

X	Y	X	Y	X	Y	X	Y
-39.10	-2.74	-17.72	-0.43	0.40	-0.03	23.79	-2.58
-37.10	-2.38	-16.87	-0.38	1.26	-0.04	24.50	-2.78
-35.15	-2.01	-16.00	-0.33	2.13	-0.06	25.19	-2.99
-33.50	-1.84	-15.14	-0.29	2.99	-0.08	25.88	-3.23
-32.77	-1.76	-14.28	-0.25	3.85	-0.10	26.58	-3.49
-31.54	-1.62	-13.41	-0.21	4.72	-0.13	27.27	-3.78
-30.67	-1.52	-12.54	-0.17	5.58	-0.16	28.04	-4.13
-29.81	-1.42	-11.68	-0.15	6.44	-0.19	28.80	-4.54
-28.95	-1.34	-10.82	-0.12	7.76	-0.25	29.57	-5.01
-28.08	-1.25	-9.95	-0.09	9.08	-0.33	30.33	-5.55
-27.22	-1.16	-9.09	-0.08	10.40	-0.43	31.10	-6.17
-26.35	-1.08	-8.23	-0.05	11.72	-0.55	31.87	-6.87
-25.50	-1.00	-7.37	-0.04	13.03	-0.69	32.64	-7.69
-24.63	-0.92	-6.51	-0.03	14.36	-0.85	33.40	-8.64
-23.77	-0.86	-5.64	-0.02	15.67	-1.02	34.17	-9.78
-22.90	-0.78	-4.77	-0.01	16.99	-1.22	34.94	-11.22
-22.04	-0.71	-3.91	0.00	18.31	-1.44	37.54	-11.23
-21.18	-0.65	-3.05	-0.01	19.63	-1.68	37.59	-16.00
-20.31	-0.59	-2.19	0.00	20.95	-1.94	36.25	-16.00
-19.45	-0.53	-1.33	-0.01	22.27	-2.21	36.25	-20.87
-18.58	-0.47	-0.46	-0.02	23.10	-2.41		

Figure A5: ARTC H3 Template, high rail curves with radii ≤900m exhibiting moderate/severe RCF defects, without lug



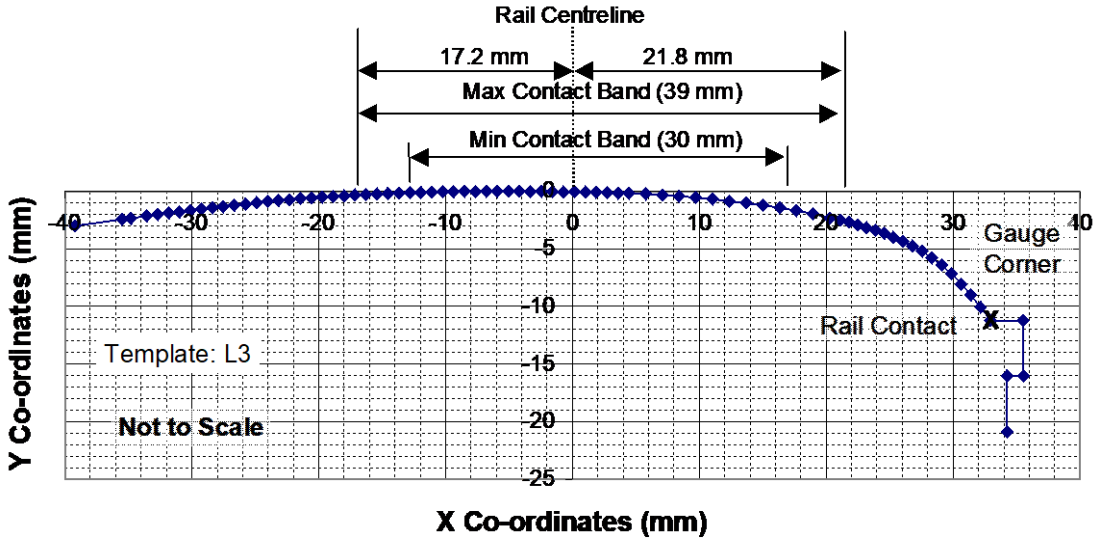
X Coordinates of Contact Band

Min Contact Band	Max Contact Band
+ 9.5 to rail contact point on gauge side (at 50)	+ 1.0 to rail contact point on gauge side (at 50)

ARTC H3 Template, high rail curves with radii ≤900m exhibiting moderate/severe RCF defects, without lug

X	Y	X	Y	X	Y	X	Y
-40.00	-0.89	-18.25	-0.01	-0.75	-0.49	16.66	-2.62
-35.05	-0.60	-17.75	0.00	-0.26	-0.52	17.16	-2.72
-34.80	-0.59	-17.25	0.00	0.24	-0.56	17.65	-2.82
-34.30	-0.57	-16.75	0.00	0.74	-0.58	18.15	-2.92
-33.80	-0.54	-16.25	0.00	1.24	-0.62	18.64	-3.02
-33.30	-0.52	-15.75	0.00	1.74	-0.66	19.14	-3.13
-32.79	-0.49	-15.25	0.00	2.24	-0.70	19.63	-3.23
-32.29	-0.47	-14.75	0.00	2.74	-0.73	20.13	-3.34
-31.79	-0.44	-14.25	-0.01	3.24	-0.77	20.62	-3.45
-31.29	-0.42	-13.75	-0.01	3.73	-0.81	21.12	-3.56
-30.79	-0.40	-13.25	-0.02	4.23	-0.86	21.61	-3.68
-30.29	-0.38	-12.75	-0.02	4.73	-0.89	22.11	-3.80
-29.78	-0.35	-12.25	-0.04	5.23	-0.94	22.60	-3.93
-29.28	-0.33	-11.75	-0.04	5.73	-0.98	23.10	-4.05
-28.78	-0.30	-11.25	-0.06	6.23	-1.03	23.59	-4.19
-28.28	-0.28	-10.75	-0.06	6.73	-1.07	24.08	-4.32
-27.78	-0.25	-10.25	-0.08	7.22	-1.12	24.58	-4.49
-27.28	-0.24	-9.75	-0.09	7.72	-1.16	25.07	-4.66
-26.77	-0.21	-9.25	-0.11	8.22	-1.22	25.56	-4.85
-26.27	-0.19	-8.75	-0.12	8.72	-1.26	26.05	-5.03
-25.77	-0.17	-8.25	-0.14	9.22	-1.32	26.54	-5.29
-25.27	-0.16	-7.75	-0.15	9.71	-1.37	27.03	-5.55
-24.77	-0.13	-7.25	-0.17	10.21	-1.42	27.51	-5.86
-24.27	-0.12	-6.75	-0.19	10.71	-1.49	28.00	-6.19
-23.76	-0.10	-6.25	-0.21	11.21	-1.57	28.48	-6.56
-23.26	-0.09	-5.75	-0.23	11.70	-1.65	28.96	-6.95
-22.76	-0.08	-5.25	-0.25	12.20	-1.72	29.44	-7.37
-22.26	-0.07	-4.75	-0.27	12.70	-1.80	29.68	-7.60
-21.76	-0.05	-4.25	-0.30	13.19	-1.89	30.63	-8.61
-21.26	-0.05	-3.75	-0.32	13.69	-1.99	31.57	-9.73
-20.76	-0.03	-3.25	-0.34	14.18	-2.09	32.52	-10.86
-20.26	-0.03	-2.75	-0.37	14.68	-2.19	33.46	-11.99
-19.76	-0.02	-2.25	-0.40	15.18	-2.29	34.41	-13.11
-19.25	-0.02	-1.75	-0.43	15.67	-2.40		
-18.75	-0.01	-1.25	-0.45	16.17	-2.51		

Figure A6: ARTC L3 - Template for low rails in curved track with radii ≤900m requiring additional field/gauge side relief, with lug

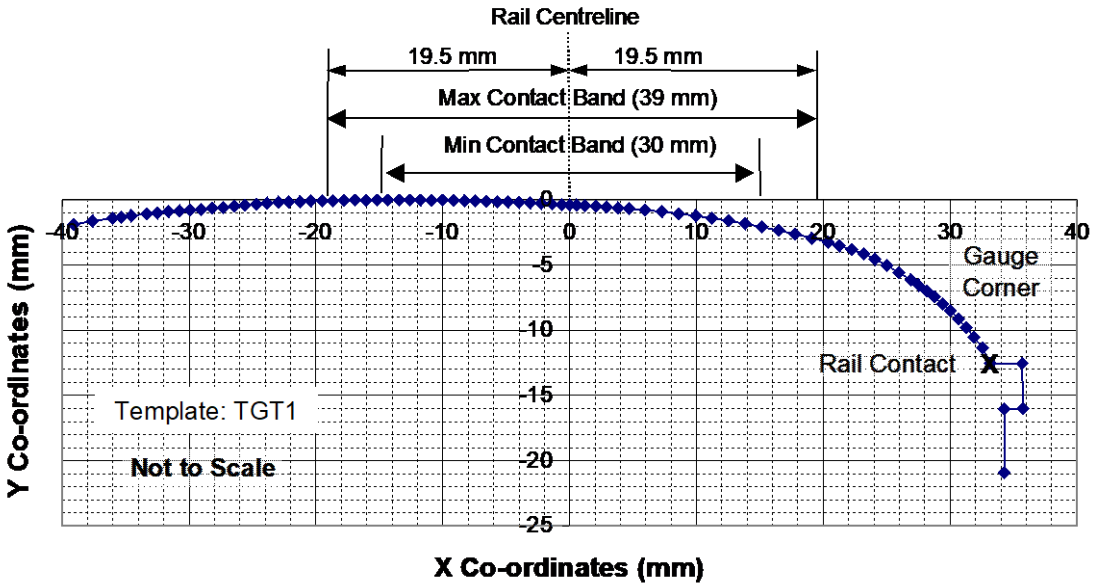


X Coordinates of Contact Band

Min Contact Band	Max Contact Band
-12.7	-17.2
17.3	21.8

L3 – Template, low rail in curves radii ≤900m requiring additional field/gauge side relief, with lug							
X	Y	X	Y	X	Y	X	Y
-39.20	-3.01	-18.87	-0.44	-1.60	-0.03	21.10	-2.51
-35.53	-2.44	-18.00	-0.37	-0.74	-0.04	21.79	-2.68
-34.79	-2.33	-17.14	-0.32	0.14	-0.06	22.49	-2.93
-33.56	-2.16	-16.28	-0.27	1.00	-0.08	23.18	-3.14
-32.69	-2.03	-15.41	-0.22	1.86	-0.10	23.88	-3.38
-31.83	-1.90	-14.54	-0.17	2.73	-0.13	24.58	-3.64
-30.97	-1.79	-13.68	-0.15	3.58	-0.16	25.26	-3.98
-30.10	-1.67	-12.81	-0.12	4.44	-0.19	26.03	-4.33
-29.24	-1.55	-11.95	-0.09	5.76	-0.25	26.79	-4.74
-28.37	-1.44	-11.09	-0.08	7.08	-0.33	27.56	-5.21
-27.51	-1.33	-10.23	-0.05	8.41	-0.43	28.32	-5.80
-26.65	-1.22	-9.37	-0.04	9.72	-0.55	29.09	-6.42
-25.78	-1.13	-8.50	-0.03	11.04	-0.69	29.86	-7.15
-24.91	-0.99	-7.64	-0.02	12.36	-0.85	30.63	-8.03
-24.05	-0.89	-6.77	-0.01	13.67	-1.02	31.39	-9.01
-23.18	-0.81	-5.91	-0.01	15.00	-1.22	32.16	-10.04
-22.32	-0.73	-5.05	-0.01	16.32	-1.44	32.94	-11.22
-21.45	-0.65	-4.19	0.00	17.64	-1.68	35.55	-11.22
-20.59	-0.57	-3.33	-0.01	18.95	-1.94	35.55	-16.00
-19.72	-0.51	-2.46	-0.02	20.27	-2.31	34.25	-16.00
						34.25	-20.87

Figure A7: ARTC TGT1 - Template for tangent track and curves with radii >900m requiring additional field/gauge side relief, with lug

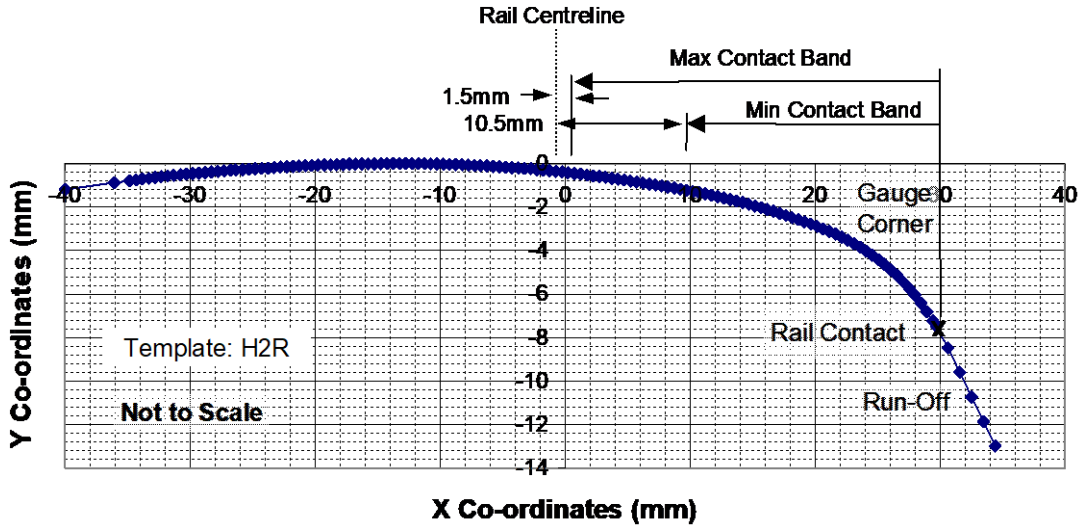


X Coordinates of Contact Band

Min Contact Band	Max Contact Band
+15	+19.5
-15	-19.5

X	Y	X	Y	X	Y	X	Y
-39.12	-1.89	-19.53	-0.07	-1.39	-0.31	21.29	-3.51
-37.61	-1.62	-18.67	-0.06	-0.63	-0.35	22.23	-3.81
-36.06	-1.40	-17.79	-0.04	0.00	-0.38	23.16	-4.15
-35.33	-1.32	-16.93	-0.02	0.54	-0.41	24.09	-4.55
-34.59	-1.23	-16.07	-0.02	1.21	-0.45	25.02	-5.02
-33.37	-1.08	-15.21	-0.01	2.07	-0.50	25.95	-5.56
-32.50	-1.01	-14.35	0.00	2.94	-0.56	26.89	-6.12
-31.64	-0.91	-13.48	-0.01	3.79	-0.62	27.51	-6.53
-30.77	-0.83	-12.62	-0.01	4.66	-0.68	28.14	-6.97
-29.91	-0.78	-11.76	-0.01	5.97	-0.79	28.76	-7.44
-29.04	-0.71	-10.88	-0.02	7.28	-0.91	29.39	-7.97
-28.18	-0.62	-10.02	-0.03	8.60	-1.06	30.01	-8.50
-27.31	-0.56	-9.16	-0.04	9.91	-1.21	30.64	-9.15
-26.45	-0.48	-8.29	-0.07	11.22	-1.40	31.27	-9.78
-25.58	-0.40	-7.43	-0.08	12.53	-1.61	31.89	-10.51
-24.72	-0.33	-6.57	-0.10	13.85	-1.83	32.53	-11.34
-23.85	-0.23	-5.70	-0.13	15.15	-2.08	33.16	-12.53
-22.98	-0.17	-4.84	-0.16	16.46	-2.34	35.70	-12.54
-22.12	-0.15	-3.98	-0.19	17.78	-2.62	35.72	-16.00
-21.25	-0.12	-3.12	-0.22	19.09	-2.92	34.26	-16.00
-20.39	-0.09	-2.25	-0.27	20.40	-3.25	34.26	-20.87

Figure A8: ARTC H2R - Template for high rails in curved track with radii ≤900m requiring additional field side relief



X Coordinates of Contact Band

Min Contact Band	Max Contact Band
+ 9.5 to rail contact point on gauge side (at 50°)	+ 1.0 to rail contact point on gauge side (at 50°)

X	Y	X	Y	X	Y	X	Y
-40.00	-1.20	-18.26	-0.05	-0.75	-0.35	16.68	-2.19
-36.07	-0.87	-17.76	-0.05	-0.25	-0.39	17.18	-2.29
-34.81	-0.79	-17.25	-0.03	0.25	-0.42	17.67	-2.38
-34.31	-0.75	-16.75	-0.03	0.75	-0.45	18.17	-2.48
-33.81	-0.71	-16.25	-0.02	1.25	-0.48	18.66	-2.57
-33.31	-0.68	-15.75	-0.01	1.74	-0.53	19.16	-2.68
-32.80	-0.64	-15.25	-0.01	2.24	-0.56	19.65	-2.78
-32.30	-0.61	-14.75	-0.01	2.74	-0.60	20.15	-2.89
-31.80	-0.57	-14.25	0.00	3.24	-0.63	20.64	-3.00
-31.30	-0.54	-13.75	0.00	3.74	-0.68	21.14	-3.11
-30.80	-0.52	-13.25	0.00	4.24	-0.72	21.63	-3.23
-30.29	-0.49	-12.75	0.00	4.74	-0.76	22.13	-3.37
-29.79	-0.46	-12.25	-0.01	5.23	-0.80	22.62	-3.52
-29.29	-0.44	-11.75	0.00	5.73	-0.85	23.11	-3.68
-28.79	-0.41	-11.25	0.00	6.23	-0.89	23.61	-3.84
-28.29	-0.38	-10.75	-0.02	6.73	-0.94	24.10	-4.03
-27.78	-0.36	-10.25	-0.03	7.23	-0.98	24.59	-4.21
-27.28	-0.33	-9.74	-0.03	7.73	-1.03	25.08	-4.42
-26.78	-0.31	-9.24	-0.03	8.22	-1.08	25.57	-4.63
-26.34	-0.30	-8.74	-0.04	8.72	-1.13	26.06	-4.88
-25.78	-0.28	-8.24	-0.05	9.22	-1.18	26.55	-5.13
-25.28	-0.26	-7.74	-0.07	9.72	-1.24	27.03	-5.42
-24.77	-0.24	-7.24	-0.08	10.22	-1.28	27.52	-5.72
-24.27	-0.22	-6.74	-0.10	10.72	-1.34	28.00	-6.05
-23.77	-0.20	-6.25	-0.12	11.21	-1.40	28.48	-6.42
-23.27	-0.19	-5.75	-0.14	11.71	-1.46	28.96	-6.81
-22.77	-0.16	-5.25	-0.15	12.21	-1.52	29.44	-7.24
-22.27	-0.15	-4.75	-0.17	12.71	-1.59	29.68	-7.46
-21.77	-0.13	-4.25	-0.18	13.20	-1.65	30.63	-8.47
-21.26	-0.11	-3.75	-0.20	13.70	-1.72	31.58	-9.60
-20.76	-0.10	-3.25	-0.22	14.20	-1.79	32.52	-10.73
-20.26	-0.09	-2.75	-0.23	14.69	-1.87	33.47	-11.85
-19.76	-0.08	-2.25	-0.27	15.19	-1.95	34.41	-12.97
-19.26	-0.06	-1.75	-0.29	15.69	-2.02		
-18.76	-0.06	-1.25	-0.32	16.18	-2.11		

Appendix B – Heavy Haul>25 TAL Rail Profiles

Main Templates

Figure B1: HVTGT Template for tangent track and curves with radii >900m, with lug

Figure B2: HVLR Template for low rails in curved track with radii ≤900m, with lug

Figure B3: HVHR Template for high rails in curved track with radii ≤900m, without lug

Special Templates

Figure B4: HVLRT Template for low rails in curved track with radii ≤900m, applied in transitional profiling, with lug

Figure B5: HVTO Turnouts

Note: All profiles have been specified for rails with a cant adjustment of 1:20 (2.86°).

Figure B1: HVTGT - Template for tangent track and curves with radii >900m, with lug

X	Y	X	Y	X	Y	X	Y	X	Y
-39.12	-1.50	-20.55	0.35	-2.06	0.11	16.49	-1.95	32.28	-10.69
-38.87	-1.47	-20.30	0.36	-1.81	0.09	16.74	-2.00	32.42	-10.89
-38.63	-1.43	-20.05	0.36	-1.56	0.08	16.98	-2.05	32.47	-10.97
-38.38	-1.40	-19.80	0.37	-1.31	0.07	17.23	-2.10	32.60	-11.18
-38.13	-1.36	-19.55	0.37	-1.06	0.06	17.47	-2.16	32.73	-11.39
-37.88	-1.33	-19.30	0.38	-0.81	0.04	17.72	-2.21	32.86	-11.61
-37.63	-1.29	-19.05	0.38	-0.56	0.03	17.96	-2.26	32.98	-11.83
-37.39	-1.26	-18.80	0.39	-0.31	0.02	18.20	-2.32	33.09	-12.05
-37.14	-1.22	-18.55	0.39	-0.06	0.00	18.45	-2.38	33.20	-12.28
-36.89	-1.19	-18.30	0.40	0.00	0.00	18.69	-2.43	33.30	-12.50
-36.64	-1.15	-18.05	0.40	0.19	-0.01	18.93	-2.49	33.40	-12.73
-36.40	-1.12	-17.80	0.40	0.44	-0.02	19.18	-2.55	33.49	-12.97
-36.15	-1.09	-17.55	0.41	0.69	-0.04	19.42	-2.61	33.52	-13.06
-35.90	-1.05	-17.30	0.41	0.94	-0.05	19.66	-2.67	33.57	-13.20
-35.65	-1.02	-17.05	0.41	1.19	-0.07	19.91	-2.73	33.65	-13.44
-35.41	-0.99	-16.80	0.41	1.44	-0.08	20.00	-2.75	33.73	-13.68
-35.16	-0.96	-16.55	0.42	1.69	-0.10	20.25	-2.81	33.79	-13.92
-34.91	-0.92	-16.30	0.42	1.94	-0.11	20.49	-2.88	33.85	-14.16
-34.66	-0.89	-16.05	0.42	2.19	-0.13	20.73	-2.94	33.91	-14.41
-34.41	-0.86	-15.80	0.42	2.44	-0.15	20.97	-3.01	33.96	-14.65
-34.17	-0.83	-15.55	0.42	2.69	-0.16	21.21	-3.09	34.00	-14.90
-33.92	-0.80	-15.30	0.42	2.94	-0.18	21.45	-3.16	34.04	-15.14
-33.67	-0.77	-15.05	0.42	3.18	-0.19	21.68	-3.24	34.07	-15.39
-33.42	-0.73	-14.87	0.42	3.43	-0.21	21.92	-3.32	34.09	-15.58
-33.17	-0.70	-14.80	0.42	3.68	-0.23	22.16	-3.40	34.09	-15.64
-32.93	-0.67	-14.55	0.42	3.93	-0.24	22.39	-3.49	34.11	-15.89
-32.68	-0.64	-14.30	0.42	4.18	-0.26	22.62	-3.58	34.11	-15.98
-32.43	-0.61	-14.05	0.42	4.43	-0.28	22.86	-3.67	34.13	-16.23
-32.18	-0.58	-13.80	0.42	4.62	-0.29	23.09	-3.76	34.14	-16.48
-31.93	-0.55	-13.55	0.42	4.87	-0.31	23.32	-3.86	34.14	-16.73
-31.68	-0.52	-13.30	0.42	5.12	-0.33	23.55	-3.95	34.15	-16.98
-31.44	-0.49	-13.05	0.42	5.37	-0.35	23.78	-4.05	34.15	-17.23
-31.19	-0.46	-12.80	0.41	5.62	-0.37	24.01	-4.16	34.16	-17.48
-30.94	-0.43	-12.55	0.41	5.86	-0.39	24.23	-4.26	34.16	-17.72
-30.69	-0.41	-12.55	0.41	6.11	-0.41	24.46	-4.37	34.16	-17.97
-30.44	-0.38	-12.30	0.41	6.36	-0.44	24.68	-4.48	34.16	-18.22
-30.19	-0.35	-12.05	0.41	6.61	-0.46	24.91	-4.59	34.16	-18.47
-29.95	-0.32	-11.80	0.40	6.86	-0.48	25.13	-4.71	34.16	-18.72
-29.70	-0.29	-11.55	0.40	7.11	-0.51	25.35	-4.83	34.16	-18.97
-29.45	-0.26	-11.30	0.40	7.36	-0.53	25.57	-4.95	34.16	-19.22
-29.20	-0.24	-11.05	0.39	7.61	-0.56	25.79	-5.07	34.16	-19.47
-28.95	-0.21	-10.80	0.39	7.85	-0.58	26.00	-5.20	34.16	-19.72
-28.70	-0.18	-10.55	0.38	8.10	-0.61	26.22	-5.32	34.16	-19.97
-28.46	-0.16	-10.30	0.38	8.35	-0.64	26.43	-5.45	34.16	-20.22
-28.21	-0.13	-10.05	0.37	8.60	-0.67	26.64	-5.58	34.16	-20.47
-27.96	-0.10	-9.80	0.37	8.85	-0.70	26.86	-5.72	34.16	-20.58
-27.71	-0.08	-9.55	0.36	9.10	-0.73	27.06	-5.85		
-27.46	-0.05	-9.30	0.36	9.34	-0.76	27.27	-5.99		
-27.45	-0.05	-9.05	0.35	9.59	-0.79	27.48	-6.13		
-27.21	-0.02	-8.80	0.35	9.84	-0.82	27.68	-6.28		
-26.96	0.00	-8.55	0.34	10.09	-0.85	27.89	-6.42		
-26.71	0.03	-8.30	0.33	10.34	-0.89	28.09	-6.57		
-26.46	0.05	-8.05	0.33	10.58	-0.92	28.29	-6.72		
-26.21	0.07	-7.80	0.32	10.83	-0.96	28.49	-6.87		
-25.96	0.09	-7.55	0.31	11.08	-0.99	28.68	-7.03		
-25.71	0.11	-7.30	0.31	11.33	-1.03	28.88	-7.18		
-25.46	0.13	-7.05	0.30	11.57	-1.07	29.07	-7.34		
-25.21	0.15	-6.80	0.29	11.82	-1.10	29.27	-7.50		
-24.96	0.17	-6.55	0.28	12.07	-1.14	29.46	-7.66		
-24.71	0.18	-6.30	0.28	12.31	-1.18	29.64	-7.83		
-24.47	0.20	-6.05	0.27	12.56	-1.22	29.83	-7.99		
-24.22	0.21	-5.80	0.26	12.81	-1.26	30.01	-8.16		
-23.97	0.23	-5.55	0.25	13.05	-1.30	30.20	-8.33		
-23.72	0.24	-5.30	0.24	13.30	-1.34	30.38	-8.51		
-23.47	0.25	-5.05	0.23	13.55	-1.39	30.56	-8.68		
-23.22	0.27	-4.80	0.22	13.79	-1.43	30.73	-8.86		
-22.97	0.28	-4.55	0.21	14.04	-1.47	30.91	-9.04		
-22.72	0.29	-4.30	0.20	14.29	-1.52	31.01	-9.14		
-22.55	0.29	-4.05	0.19	14.53	-1.56	31.18	-9.32		
-22.30	0.30	-3.81	0.18	14.78	-1.61	31.35	-9.51		
-22.05	0.31	-3.56	0.17	15.02	-1.65	31.51	-9.70		
-21.80	0.32	-3.31	0.16	15.27	-1.70	31.58	-9.78		
-21.55	0.32	-3.06	0.15	15.51	-1.75	31.67	-9.89		
-21.30	0.33	-2.81	0.14	15.76	-1.80	31.83	-10.08		
-21.05	0.34	-2.56	0.13	16.00	-1.85	31.98	-10.28		
-20.80	0.34	-2.31	0.12	16.25	-1.90	32.13	-10.48		

Figure B2: HVLR - Template for low rails in curved track with radii ≤900m, without lug

X	Y	X	Y	X	Y	X	Y	X	Y
-40.53	-2.70	-21.26	-0.05	-2.20	0.08	17.15	-1.31		
-40.28	-2.66	-21.01	-0.03	-1.95	0.07	17.39	-1.35		
-40.03	-2.62	-20.76	-0.01	-1.70	0.06	17.64	-1.39		
-39.79	-2.57	-20.51	0.01	-1.45	0.05	17.89	-1.43		
-39.54	-2.53	-20.26	0.03	-1.21	0.05	18.13	-1.48		
-39.30	-2.49	-20.01	0.05	-0.96	0.04	18.38	-1.52		
-39.05	-2.44	-19.76	0.07	-0.71	0.03	18.62	-1.57		
-38.80	-2.40	-19.51	0.09	-0.46	0.02	18.87	-1.62		
-38.56	-2.35	-19.26	0.11	-0.21	0.01	19.11	-1.68		
-38.31	-2.31	-19.01	0.12	0.00	0.00	19.35	-1.73		
-38.06	-2.27	-18.76	0.13	0.25	-0.01	19.60	-1.79		
-37.82	-2.22	-18.52	0.15	0.50	-0.02	19.84	-1.85		
-37.57	-2.18	-18.27	0.16	0.75	-0.03	20.08	-1.91		
-37.33	-2.14	-18.02	0.17	1.00	-0.04	20.33	-1.97		
-37.08	-2.09	-17.77	0.18	1.25	-0.05	20.57	-2.04		
-36.83	-2.05	-17.52	0.18	1.50	-0.06	20.81	-2.11		
-36.59	-2.01	-17.27	0.19	1.75	-0.07	21.05	-2.18		
-36.34	-1.96	-17.02	0.20	2.00	-0.09	21.29	-2.25		
-36.10	-1.92	-16.99	0.20	2.25	-0.10	21.53	-2.32		
-35.85	-1.88	-16.74	0.20	2.50	-0.11	21.76	-2.40		
-35.60	-1.83	-16.49	0.20	2.75	-0.12	22.00	-2.48		
-35.36	-1.79	-16.24	0.21	3.00	-0.13	22.24	-2.55		
-35.11	-1.75	-15.99	0.21	3.25	-0.15	22.48	-2.64		
-34.86	-1.70	-15.74	0.21	3.50	-0.16	22.71	-2.72		
-34.62	-1.66	-15.49	0.22	3.75	-0.17	22.95	-2.80		
-34.41	-1.62	-15.24	0.22	4.00	-0.19	23.18	-2.89		
-34.16	-1.59	-14.99	0.22	4.25	-0.20	23.41	-2.98		
-33.91	-1.55	-14.74	0.23	4.49	-0.21	23.65	-3.07		
-33.67	-1.52	-14.49	0.23	4.74	-0.23	23.88	-3.17		
-33.42	-1.48	-14.24	0.23	4.99	-0.24	24.11	-3.26		
-33.17	-1.45	-13.99	0.23	5.24	-0.26	24.34	-3.36		
-32.92	-1.41	-13.74	0.23	5.49	-0.27	24.57	-3.46		
-32.68	-1.38	-13.49	0.23	5.74	-0.28	24.80	-3.56		
-32.43	-1.35	-13.24	0.24	5.99	-0.30	25.03	-3.66		
-32.18	-1.31	-12.99	0.24	6.24	-0.31	25.25	-3.77		
-31.93	-1.28	-12.74	0.24	6.49	-0.33	25.48	-3.87		
-31.69	-1.24	-12.49	0.24	6.74	-0.34	25.70	-3.98		
-31.44	-1.21	-12.24	0.24	6.99	-0.36	25.93	-4.09		
-31.19	-1.17	-11.99	0.24	7.24	-0.38	26.15	-4.20	32.93	-10.53
-30.94	-1.14	-11.95	0.24	7.49	-0.39	26.37	-4.32	33.04	-10.76
-30.70	-1.10	-11.70	0.24	7.74	-0.41	26.60	-4.43	33.14	-10.98
-30.45	-1.07	-11.45	0.24	7.99	-0.43	26.82	-4.55	33.24	-11.21
-30.20	-1.03	-11.20	0.24	8.24	-0.44	27.04	-4.67	33.34	-11.45
-29.95	-1.00	-10.95	0.24	8.49	-0.46	27.25	-4.79	33.42	-11.68
-29.71	-0.96	-10.70	0.24	8.74	-0.48	27.47	-4.91	33.51	-11.92
-29.46	-0.93	-10.45	0.23	8.99	-0.49	27.69	-5.04	33.58	-12.15
-29.21	-0.89	-10.20	0.23	9.24	-0.51	27.90	-5.17	33.65	-12.39
-28.96	-0.86	-9.95	0.23	9.48	-0.53	28.12	-5.29	33.72	-12.64
-28.72	-0.82	-9.70	0.23	9.73	-0.55	28.33	-5.43	33.77	-12.88
-28.47	-0.79	-9.45	0.23	9.98	-0.56	28.35	-5.43	33.83	-13.12
-28.22	-0.75	-9.20	0.23	10.23	-0.58	28.56	-5.57	33.87	-13.37
-27.97	-0.72	-8.95	0.22	10.48	-0.60	28.76	-5.71	33.91	-13.62
-27.73	-0.68	-8.70	0.22	10.73	-0.62	28.97	-5.85	33.95	-13.86
-27.48	-0.65	-8.45	0.22	10.98	-0.64	29.17	-6.00	33.97	-14.05
-27.23	-0.61	-8.20	0.21	11.23	-0.66	29.37	-6.15	33.99	-14.29
-26.98	-0.58	-7.95	0.21	11.47	-0.68	29.56	-6.31	34.02	-14.54
-26.74	-0.55	-7.70	0.21	11.71	-0.70	29.75	-6.48	34.04	-14.79
-26.49	-0.51	-7.45	0.20	11.96	-0.72	29.93	-6.65	34.06	-15.04
-26.24	-0.49	-7.20	0.20	12.21	-0.74	29.93	-6.65	34.08	-15.29
-25.99	-0.47	-6.95	0.20	12.46	-0.76	30.11	-6.82	34.09	-15.54
-25.74	-0.44	-6.70	0.19	12.71	-0.78	30.29	-7.00	34.10	-15.76
-25.49	-0.42	-6.45	0.19	12.96	-0.81	30.47	-7.18	34.12	-16.01
-25.24	-0.40	-6.20	0.18	13.21	-0.83	30.64	-7.36	34.13	-16.26
-24.99	-0.38	-5.95	0.18	13.46	-0.86	30.81	-7.54	34.14	-16.51
-24.74	-0.36	-5.70	0.17	13.71	-0.88	30.98	-7.73	34.15	-16.76
-24.50	-0.34	-5.45	0.17	13.95	-0.91	31.14	-7.92	34.15	-17.01
-24.25	-0.31	-5.20	0.16	14.20	-0.93	31.30	-8.11	34.16	-17.26
-24.00	-0.29	-4.95	0.16	14.45	-0.96	31.46	-8.30	34.16	-17.51
-23.75	-0.27	-4.70	0.15	14.70	-0.99	31.61	-8.50	34.16	-17.69
-23.50	-0.25	-4.45	0.14	14.95	-1.02	31.76	-8.70	34.16	-17.94
-23.25	-0.23	-4.20	0.14	15.20	-1.05	31.91	-8.90	34.16	-18.19
-23.00	-0.21	-3.95	0.13	15.45	-1.08	32.05	-9.10	34.16	-18.44
-22.75	-0.18	-3.70	0.12	15.69	-1.11	32.19	-9.31	34.16	-18.69
-22.50	-0.16	-3.45	0.12	15.94	-1.14	32.33	-9.52	34.16	-18.94
-22.25	-0.14	-3.20	0.11	16.19	-1.17	32.47	-9.73	34.16	-19.19
-22.00	-0.12	-2.95	0.10	16.44	-1.21	32.56	-9.88	34.16	-19.44
-21.76	-0.10	-2.70	0.10	16.65	-1.23	32.69	-10.09	34.16	-19.69
-21.51	-0.07	-2.45	0.09	16.90	-1.27	32.81	-10.31	34.16	-19.76

Figure B3: HVHR - Template for high rails in curved track with radii ≤900m, without lug

X	Y	X	Y	X	Y	X	Y	X	Y
-39.33	-0.84	-20.36	0.26	-1.56	0.09	16.52	-1.76	32.22	-10.02
-39.08	-0.82	-20.11	0.26	-1.31	0.07	16.77	-1.80	32.35	-10.23
-38.83	-0.79	-19.86	0.27	-1.06	0.06	17.01	-1.85	32.48	-10.44
-38.58	-0.77	-19.61	0.27	-0.81	0.05	17.26	-1.90	32.61	-10.65
-38.33	-0.75	-19.36	0.28	-0.56	0.03	17.50	-1.95	32.74	-10.87
-38.08	-0.73	-19.11	0.28	-0.31	0.02	17.75	-2.01	32.85	-11.07
-37.83	-0.71	-18.86	0.29	-0.06	0.00	17.99	-2.06	32.97	-11.29
-37.58	-0.69	-18.61	0.30	0.00	0.00	18.23	-2.11	33.08	-11.51
-37.33	-0.67	-18.36	0.30	0.19	-0.01	18.48	-2.17	33.19	-11.74
-37.08	-0.65	-18.11	0.31	0.44	-0.03	18.72	-2.23	33.29	-11.97
-36.83	-0.63	-17.86	0.31	0.69	-0.04	18.96	-2.28	33.38	-12.20
-36.59	-0.60	-17.61	0.31	0.94	-0.06	19.21	-2.34	33.47	-12.43
-36.34	-0.59	-17.36	0.32	1.19	-0.07	19.45	-2.41	33.49	-12.47
-36.09	-0.57	-17.11	0.32	1.44	-0.09	19.69	-2.47	33.57	-12.70
-35.84	-0.55	-16.86	0.33	1.69	-0.11	19.93	-2.53	33.66	-12.94
-35.59	-0.53	-16.61	0.33	1.94	-0.12	20.17	-2.59	33.74	-13.17
-35.34	-0.51	-16.36	0.33	2.18	-0.14	20.42	-2.66	33.83	-13.41
-35.09	-0.49	-16.11	0.34	2.43	-0.16	20.66	-2.73	33.91	-13.64
-34.84	-0.47	-15.86	0.34	2.68	-0.17	20.90	-2.80	34.00	-13.88
-34.59	-0.45	-15.61	0.34	2.93	-0.19	21.14	-2.86	34.09	-14.11
-34.34	-0.43	-15.36	0.34	3.18	-0.21	21.38	-2.93	34.17	-14.35
-34.09	-0.42	-15.11	0.35	3.43	-0.23	21.62	-3.01	34.26	-14.58
-33.84	-0.40	-14.86	0.35	3.68	-0.25	21.86	-3.08	34.34	-14.82
-33.59	-0.38	-14.61	0.35	3.93	-0.27	22.09	-3.15	34.43	-15.05
-33.34	-0.36	-14.36	0.35	4.18	-0.29	22.33	-3.23	34.51	-15.29
-33.09	-0.35	-14.11	0.35	4.43	-0.31	22.57	-3.30	34.60	-15.52
-32.85	-0.33	-13.86	0.35	4.68	-0.33	22.81	-3.38	34.68	-15.76
-32.60	-0.31	-13.61	0.35	4.93	-0.35	22.91	-3.42	34.77	-15.99
-32.35	-0.30	-13.55	0.35	5.18	-0.37	23.15	-3.50	34.85	-16.23
-32.10	-0.28	-13.30	0.36	5.43	-0.39	23.38	-3.58	34.94	-16.46
-31.85	-0.26	-13.05	0.36	5.67	-0.41	23.59	-3.65	35.03	-16.70
-31.60	-0.25	-12.80	0.36	5.92	-0.43	23.62	-3.66	35.11	-16.93
-31.35	-0.23	-12.55	0.36	6.17	-0.45	23.85	-3.75	35.20	-17.17
-31.10	-0.22	-12.26	0.36	6.42	-0.47	24.09	-3.84	35.28	-17.40
-30.85	-0.20	-12.05	0.36	6.67	-0.50	24.32	-3.93	35.37	-17.64
-30.60	-0.19	-11.80	0.36	6.92	-0.52	24.55	-4.02	35.40	-17.73
-30.35	-0.17	-11.55	0.36	7.17	-0.54	24.78	-4.12		
-30.10	-0.16	-11.30	0.36	7.42	-0.57	25.01	-4.22		
-29.85	-0.14	-11.05	0.35	7.67	-0.59	25.24	-4.32		
-29.60	-0.13	-10.80	0.35	7.92	-0.61	25.47	-4.42		
-29.35	-0.11	-10.55	0.35	8.16	-0.64	25.69	-4.53		
-29.10	-0.10	-10.30	0.35	8.41	-0.66	25.92	-4.64		
-28.85	-0.09	-10.05	0.35	8.66	-0.69	26.14	-4.75		
-28.60	-0.07	-9.80	0.34	8.91	-0.71	26.37	-4.86		
-28.35	-0.06	-9.55	0.34	9.16	-0.74	26.59	-4.97		
-28.10	-0.05	-9.30	0.34	9.41	-0.76	26.71	-5.04		
-27.85	-0.03	-9.05	0.33	9.66	-0.79	26.93	-5.16		
-27.60	-0.02	-8.80	0.33	9.81	-0.80	27.15	-5.28		
-27.35	-0.01	-8.55	0.33	10.06	-0.83	27.37	-5.40		
-27.11	0.00	-8.30	0.32	10.31	-0.86	27.58	-5.53		
-26.86	0.02	-8.05	0.32	10.56	-0.89	27.79	-5.67		
-26.61	0.03	-7.80	0.31	10.80	-0.91	28.00	-5.80		
-26.36	0.04	-7.55	0.31	11.05	-0.94	28.21	-5.94		
-26.11	0.05	-7.30	0.30	11.30	-0.97	28.41	-6.09		
-25.86	0.06	-7.05	0.29	11.55	-1.00	28.62	-6.23		
-25.61	0.07	-6.80	0.29	11.80	-1.03	28.82	-6.38		
-25.36	0.08	-6.55	0.28	12.04	-1.07	29.01	-6.54		
-25.11	0.09	-6.30	0.27	12.29	-1.10	29.21	-6.69		
-24.86	0.11	-6.05	0.27	12.54	-1.13	29.40	-6.85		
-24.61	0.12	-5.80	0.26	12.79	-1.16	29.59	-7.02		
-24.36	0.13	-5.55	0.25	13.04	-1.20	29.78	-7.18		
-24.11	0.13	-5.31	0.24	13.28	-1.23	29.96	-7.35		
-23.86	0.14	-5.06	0.23	13.53	-1.27	30.14	-7.52		
-23.61	0.15	-4.81	0.23	13.78	-1.30	30.32	-7.70		
-23.36	0.16	-4.56	0.22	14.03	-1.34	30.50	-7.88		
-23.11	0.17	-4.31	0.21	14.27	-1.38	30.67	-8.06		
-22.86	0.18	-4.06	0.20	14.52	-1.42	30.84	-8.24		
-22.61	0.19	-3.81	0.19	14.77	-1.45	31.00	-8.43		
-22.36	0.20	-3.56	0.18	15.01	-1.49	31.17	-8.62		
-22.11	0.20	-3.31	0.17	15.04	-1.50	31.20	-8.66		
-21.86	0.21	-3.06	0.16	15.29	-1.54	31.33	-8.81		
-21.61	0.22	-2.81	0.15	15.54	-1.58	31.48	-9.01		
-21.36	0.23	-2.56	0.13	15.78	-1.62	31.64	-9.20		
-21.11	0.23	-2.31	0.12	15.85	-1.63	31.79	-9.40		
-20.86	0.24	-2.06	0.11	16.03	-1.67	31.93	-9.61		
-20.61	0.25	-1.81	0.10	16.27	-1.71	32.08	-9.81		

Figure B4: HVTO

X	Y	X	Y	X	Y	X	Y	X	Y
-39.12	-1.50	-20.55	0.35	-2.06	0.11	16.49	-1.95	32.37	-10.85
-38.87	-1.47	-20.30	0.36	-1.81	0.09	16.74	-2.00	32.50	-11.07
-38.63	-1.43	-20.05	0.36	-1.56	0.08	16.98	-2.05	32.62	-11.29
-38.38	-1.40	-19.80	0.37	-1.31	0.07	17.23	-2.10	32.73	-11.51
-38.13	-1.36	-19.55	0.37	-1.06	0.06	17.47	-2.16	32.85	-11.73
-37.88	-1.33	-19.30	0.38	-0.81	0.04	17.72	-2.21	32.95	-11.96
-37.63	-1.29	-19.05	0.38	-0.56	0.03	17.96	-2.26	33.06	-12.18
-37.39	-1.26	-18.80	0.39	-0.31	0.02	18.20	-2.32	33.15	-12.41
-37.14	-1.22	-18.55	0.39	-0.06	0.00	18.45	-2.38	33.25	-12.65
-36.89	-1.19	-18.30	0.40	0.00	0.00	18.68	-2.43	33.34	-12.88
-36.64	-1.15	-18.05	0.40	0.19	-0.01	18.92	-2.49	33.37	-12.97
-36.40	-1.12	-17.80	0.40	0.44	-0.02	19.17	-2.55	33.46	-13.21
-36.15	-1.09	-17.55	0.41	0.69	-0.04	19.41	-2.61	33.54	-13.44
-35.90	-1.05	-17.30	0.41	0.94	-0.05	19.65	-2.67	33.63	-13.68
-35.65	-1.02	-17.05	0.41	1.19	-0.07	19.89	-2.74	33.71	-13.91
-35.41	-0.99	-16.80	0.41	1.44	-0.08	20.13	-2.81	33.80	-14.15
-35.16	-0.96	-16.55	0.42	1.69	-0.10	20.37	-2.88	33.88	-14.38
-34.91	-0.92	-16.30	0.42	1.94	-0.11	20.61	-2.95	33.97	-14.62
-34.66	-0.89	-16.05	0.42	2.19	-0.13	20.85	-3.02	34.06	-14.85
-34.41	-0.86	-15.80	0.42	2.44	-0.15	21.09	-3.10	34.14	-15.09
-34.17	-0.83	-15.55	0.42	2.69	-0.16	21.33	-3.18	34.23	-15.32
-33.92	-0.80	-15.30	0.42	2.94	-0.18	21.56	-3.26	34.31	-15.56
-33.67	-0.77	-15.05	0.42	3.18	-0.19	21.80	-3.34	34.40	-15.79
-33.42	-0.73	-14.87	0.42	3.43	-0.21	22.03	-3.42	34.48	-16.02
-33.17	-0.70	-14.80	0.42	3.68	-0.23	22.27	-3.51	34.57	-16.26
-32.93	-0.67	-14.55	0.42	3.93	-0.24	22.50	-3.60	34.65	-16.49
-32.68	-0.64	-14.30	0.42	4.18	-0.26	22.74	-3.69	34.74	-16.73
-32.43	-0.61	-14.05	0.42	4.43	-0.28	22.97	-3.78	34.82	-16.96
-32.18	-0.58	-13.80	0.42	4.62	-0.29	23.20	-3.87	34.91	-17.20
-31.93	-0.55	-13.55	0.42	4.87	-0.31	23.43	-3.97	35.00	-17.43
-31.68	-0.52	-13.30	0.42	5.12	-0.33	23.66	-4.07	35.08	-17.67
-31.44	-0.49	-13.05	0.42	5.37	-0.35	23.89	-4.17	35.10	-17.72
-31.19	-0.46	-12.80	0.41	5.62	-0.37	24.12	-4.27		
-30.94	-0.43	-12.55	0.41	5.86	-0.39	24.35	-4.37		
-30.69	-0.41	-12.55	0.41	6.11	-0.41	24.57	-4.48		
-30.44	-0.38	-12.30	0.41	6.36	-0.44	24.80	-4.58		
-30.19	-0.35	-12.05	0.41	6.61	-0.46	25.03	-4.69		
-29.95	-0.32	-11.80	0.40	6.86	-0.48	25.25	-4.80		
-29.70	-0.29	-11.55	0.40	7.11	-0.51	25.47	-4.91		
-29.45	-0.26	-11.30	0.40	7.36	-0.53	25.69	-5.03		
-29.20	-0.24	-11.05	0.39	7.61	-0.56	25.92	-5.15		
-28.95	-0.21	-10.80	0.39	7.85	-0.58	26.14	-5.26		
-28.70	-0.18	-10.55	0.38	8.10	-0.61	26.36	-5.38		
-28.46	-0.16	-10.30	0.38	8.35	-0.64	26.57	-5.51		
-28.21	-0.13	-10.05	0.37	8.60	-0.67	26.79	-5.63		
-27.96	-0.10	-9.80	0.37	8.85	-0.70	27.01	-5.75		
-27.71	-0.08	-9.55	0.36	9.10	-0.73	27.22	-5.88		
-27.46	-0.05	-9.30	0.36	9.34	-0.76	27.44	-6.01		
-27.45	-0.05	-9.05	0.35	9.59	-0.79	27.65	-6.14		
-27.21	-0.02	-8.80	0.35	9.84	-0.82	27.86	-6.27		
-26.96	0.00	-8.55	0.34	10.09	-0.85	28.07	-6.41		
-26.71	0.03	-8.30	0.33	10.34	-0.89	28.28	-6.54		
-26.46	0.05	-8.05	0.33	10.58	-0.92	28.48	-6.68		
-26.21	0.07	-7.80	0.32	10.83	-0.96	28.69	-6.82		
-25.96	0.09	-7.55	0.31	11.08	-0.99	28.89	-6.97		
-25.71	0.11	-7.30	0.31	11.33	-1.03	29.09	-7.12		
-25.46	0.13	-7.05	0.30	11.57	-1.07	29.29	-7.27		
-25.21	0.15	-6.80	0.29	11.82	-1.10	29.48	-7.43		
-24.96	0.17	-6.55	0.28	12.07	-1.14	29.67	-7.59		
-24.71	0.18	-6.30	0.28	12.31	-1.18	29.86	-7.76		
-24.47	0.20	-6.05	0.27	12.56	-1.22	30.04	-7.93		
-24.22	0.21	-5.80	0.26	12.81	-1.26	30.22	-8.10		
-23.97	0.23	-5.55	0.25	13.05	-1.30	30.40	-8.28		
-23.72	0.24	-5.30	0.24	13.30	-1.34	30.57	-8.46		
-23.47	0.25	-5.05	0.23	13.55	-1.39	30.74	-8.64		
-23.22	0.27	-4.80	0.22	13.79	-1.43	30.91	-8.83		
-22.97	0.28	-4.55	0.21	14.04	-1.47	31.08	-9.02		
-22.72	0.29	-4.30	0.20	14.29	-1.52	31.11	-9.06		
-22.55	0.29	-4.05	0.19	14.53	-1.56	31.24	-9.21		
-22.30	0.30	-3.81	0.18	14.78	-1.61	31.39	-9.40		
-22.05	0.31	-3.56	0.17	15.02	-1.65	31.54	-9.60		
-21.80	0.32	-3.31	0.16	15.27	-1.70	31.69	-9.80		
-21.55	0.32	-3.06	0.15	15.51	-1.75	31.84	-10.01		
-21.30	0.33	-2.81	0.14	15.76	-1.80	31.98	-10.21		
-21.05	0.34	-2.56	0.13	16.00	-1.85	32.11	-10.42		
-20.80	0.34	-2.31	0.12	16.25	-1.90	32.25	-10.63		